PortRail Simulon Model Train Controller

PID684SV Operator and Reference Manual

March 2006

Contents

1 Introduction

Thank you for purchasing the PID684SV "Simulon" Model Railway Controller. The controller is the product of a two-year, hardware and software development program to produce a controller to satisfy the most demanding model train perfectionist. Features include:

- Precise speed control delivered by full "Proportional-Integral-Differential" feedback regulation of engine RPM (engine back EMF);
- Analog Waveform Drive to give the precise control of digital PWM with the gentle action of traditional, fully-analog drive voltage, to guarantee that delicate locomotives are not overheated;
- Shunt (center-off) and Cruise (anticlockwise off) modes to suit layout and operator needs;
- Factory presets of control algorithm coefficients, inertia, braking strength, auto-stop distance, timeout interval, and motor heating estimation constants for Z, N, HO, O and G scales;
- Adjustable simulated inertia, and an override switch to disable inertia for setting up;
- Different acceleration and coasting deceleration rates when using simulated inertia;
- Momentary-action braking when using simulated inertia, for realistic driving;
- Interlock against reversing at speed;
- Adjustable braking capability with simulated inertia;
- Timeout mode ("dead man switch") to halt unattended trains;
- Station stopping with constant-distance pull-up ("ABS");
- Automatic station stops with and without reversing, for automation of layouts;
- Indication of peak or average load current, engine RPM, instantaneous thrust, or engine temperature;
- Full overload protection.

Section 2 describes how to use the controller. If you have never used a PortRail controller before, this tells you what you need to know to start. Other sections go into detail about how to use various special functions, how to wire the controller up, and how it works.

2 Using the Controller

The controller has a THROTTLE knob, a THROTTLE switch, a DIRECTION switch, a switch to turn INERTIA on and off, and some indicators. The controller can operate in "shunt" mode, where the knob is a center-off control that is turned one way to make the train go backwards and the other way for forwards. It can also operate in "cruise mode", where the throttle knob sets speed and the reversing switch sets direction.

The train is started by switching the THROTTLE switch to the accelerate position and turning up the throttle. The train is stopped by paddling the THROTTLE switch to the brake position. The brake position is sprung, so that when the switch is released the brakes are released, and the train coasts. The train can be driven simply by moving the switch between the accelerate, coast and brake positions as required, leaving the throttle knob at a suitable thrust level. The train can also be controlled by adjusting the THROTTLE knob, but the effect is more gentle, like driving a car without pressing the brake pedal.

When first turned on, the tri-colour indicator flashes yellow quickly for about two seconds while the controller boots. The controller then loads the same settings that were in effect when it was last turned off.

After the two seconds starting up, or if the controller is left unattended for half an hour, the controller goes into its "standby" or "dead-man" mode. This is signalled by a slow, even (1 half-second flash per second) yellow 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 brake or the speed knob will reset the controller into its "active" mode and allow the locomotive to be driven. 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.

Applying power with the knob fully anticlockwise causes the controller to operate in Cruise mode. Applying power with the knob turned up more than about 30 degrees causes the controller to enter Shunt mode. This startup decision works quite well, since the control is most usually left in the "off" position, and this is near full anticlockwise if the control is "zero-off" mode, and it is uaually turned through half the travel if it has been in "center-off" mode. In normal usage the initial standby is not even noticed.

The LED shows a "heartbeat" signal, consisting of a one-sixteenth second green flash every second in Cruise mode, and two one-sixteenth second flashes close together every second in Shunt mode.[1] In Shunt mode, the full-speed available from the controller is somewhat lower than that available in Cruise mode. This makes for smoother action of the control knob, and is convenient as high speed is not usually required when shunting.

When INERTIA is on, the brake switch causes the train to slow down more quickly, just as pressing the brake pedal in a car slows it down more quickly that simply removing your foot from the accelerator. There is an INERTIA switch that allows you to turn the simulated inertia off and on. The simulated INERTIA makes for more realistic operation. However, it can be annoying if you only want to set things up on the layout, so it can be

---

[1] Think of the two flashes as suggesting that the knob can be turned to either the left or the right. This mnemonic helps you remember the meaning of the heartbeat.

temporarily bypassed by switching INERTIA off. With INERTIA off, the train immediately obeys the controls, rising as quickly as possible to the speed set by the knob, and stopping immediately if the THROTTLE switch is moved out of the accelerate position, and reversing immediately if the reverse switch is toggled.

In Cruise mode the DIRECTION switch selects forward or reverse direction. In Shunt mode, the DIRECTION switch changes the sense of the knob: If you want a clockwise twist to make the train go forward but the track is wired so that it goes backwards, change the position of the DIRECTION switch and the sense will be inverted. The DIRECTION LED indicates the actual polarity delivered to the track. It is useful for indicating exactly when the train reverses direction, since inertia can delay a reversal of direction for some time after the user reverses the thrust.

One final indicator is of great interest. Different models of Simulon Controllers have either an LED indicator or a panel meter. This indicator can display a range of interesting values. It will display the engine "RPM" (actually calibrated in units of back-EMF potential), the average or peak load current, the percentage of full thrust that the controller is applying at any moment, or an estimate of the engine temperature. On models without the panel meter the brightness of the LED is the indication. The value to be displayed is selected in the set sequence.

If the brake switch is held down for 2 seconds with INERTIA off, a special setting function is activated, rather like setting the time on a digital wristwatch. This allows the user to adjust many parameters of the controller, including what the meter/indicator itself displays. The process is described in detail in section 3.

2.1 Factory Reset of Coefficients

The factory reset state is invoked by holding down the brake while applying power. If the brake lever is depressed at the end of the initial, 2-second startup period, a factory predetermined set of coefficient values are used to overwrite the working set.

The position of the knob when the factory preset is invoked selects one of a number of different sets of coefficients. If the knob is fully anticlockwise, a set of coefficients most suitable for the smallest scale of train (Z-scale) are selected. If the knob is fully clockwise, a set of coefficients most suitable for the largest scale of train (G-scale or 1-scale) are selected. In between these extremes are three other regions that select sets suitable for N, HO or O scale; for example, if the knob is positioned mid-way between its two extremes of travel, pointing straight up, the HO set is selected.

This function is useful if you have been adjusting the coefficients to see their effects, and you want to return to a known, modest feel of operation, or if you intend to use the controller alternately with layouts of different scales.

3 Adjusting the Controller Settings

The most pleasing operation is obtained from your controller if you adjust the setting coefficients to suit your scale of locomotives and your own personal taste. For example, operation with a large layout benefits from greater simulated inertia, so that trains decelerate more realistically, whereas a short shunting layout or one that is "compressed" demands little inertia, because trains do not travel very far and there is not space for a graceful deceleration into each station.

Changed coefficients are stored in non-volatile memory and will thus remain in place when you turn the power off. This section explains how to set the coefficients, and some rules of thumb for choosing the values themselves.

Nevertheless, some users will be quite happy to use the factory preset values. In this case there is no need to read this section, or to ever adjust the coefficients. Should you ever wish to customize your controller, you can always come back and read this section later!

Assuming you want to try adjusting some of them, there are ten things you can set that control the feel and action of the controller:

1. The proportional control coefficient, K_p, that adjusts the strength with which the controller holds constant the speed of the locomotive; this is the first of three so-called "control coefficients" that are available for setting. Most users will not need to change K_p. Section 3.1 describes the process of tuning K_p, K_i, and K_d in some detail.

2. The integral control coefficient, K_i. This coefficient sets the degree of speed control in the case of grades and increasing load on the locomotive; this is the second of three so-called "control coefficients" that are available for setting. Most users will not need to change K_i. Section 3.1 describes the process of tuning K_p, K_i, and K_d in some detail.

3. The differential control coefficient, K_d, that alters the smoothness of the speed control; this is the third of three so-called "control coefficients" that are available for setting. Section 3.1 goes into guidelines for setting these three coefficients in great detail.

4. The inertia constant, K_j, that sets how long it takes the locomotive to come up to speed and to slow down when coasting to a halt. The knob roughly varies K_j so as to cause a train to take anywhere from 0.1 seconds to 30 seconds to coast to a standstill.

5. The braking constant, K_b, that sets how rapidly the train comes to a halt when the brake button is depressed. The value of K_b controls how much faster the brake is able to slow down a train compared to allowing it to coast to a standstill; with the knob set all the way up to maximum, the brake will stop the train in half the time it would take to coast to a stop. A realistic operating feel comes when it is set somewhere between one-half and one-quarter of full scale.

6. The stopping coefficient, K_s, that sets the distance the train will travel after the autostop signal occurs (typically the distance to the station from the position of the local block detector). The autostop or stationing function operates something like the ABS in a car, computing an optimum amount of braking effort to exactly position a train in a station or siding. Section 4 describes the use and setting of this function in detail.

7. The halt coefficient, K_h, sets the period of time that a train remains stationary after an autostop. The knob sets the interval from 10 seconds to three and a half minutes.

8. The timeout duration, K_t, is the period of inactivity before the controller goes to "stand by" and automatically stops the train. If the controls are not touched for a time, the controller assumes the train has been forgotten, and automatically halts its motion. This is the delay on the so-called "dead-man switch". It can be set from 1 minute to 200 minutes (over 3 hours).

9. The meter function. This selects whether the meter displays
   - Engne "RPM", scaled from the back EMF of the motor, 0-18V;
   - Peak load current, on a scale of 0–5A;
   - Average load current, on a scale of 0–1.5A;
   - The power fraction (% of the controller's maximum power);
   - The estimated engine temperature, on an approximate scale of 0–150C (40–300F).

10. The motor size coefficient, K_{th}, that determines how large and how well-cooled is the locomotive's motor(s), for purposes of estimating its temperature. Roughly, this coefficient changes the effective motor size from that of a tiny pager motor to a can motor 4cm (1.5") in diameter.

The sequence to set these is started by switching off inertia, and holding the brake on for 3 seconds (three heartbeat flashes). The controller then allows each of the things listed above to be set via the knob, in turn. Momentarily pressing the brake advances from one item to another, until the last press saves the new values to non-volatile memory and returns the controller to normal operation[2]. While setting, the previously-selected speed setting remains in force, so that you may have a train running, and observe the effects of changes immediately. Also, the current value of the parameter is displayed on the indicator or multifunction meter, in place of whatever is normally displayed.

The INERTIA switch can be switched back to restore inertia once setting has started, it is not required to be off to advance the set function.

Suppose you wish to change the inertia from its default value to a lesser degree, so that the controller can be used on a small shunting yard. The sequence goes like this: Switch off inertia; hold the brake on for three heartbeats; release the brake, observe single yellow

---

[2] The save to permanent memory only occurs on the last button press of the sequence. Thus, if you feel that you have messed up the setting sequence, removing power before you finish cancels the changes.

dashes; press the brake three times, observe four yellow dashes; observe the meter and adjust the knob which will snap to reflect the knob position; leave the knob at about the 9 O'Clock position; press the brake seven more times; restore inertia. Now you can test the new value.

In general, a full setting sequence might go like this: Switch off inertia; hold the brake on for three heartbeats; release the brake, observe single yellow dashes; restore inertia. The controller is in "set K_p mode". This is signalled by the indicator LED giving single yellow dashes: one yellow blink 187ms long every 1 second. This appears a bit like the Cruise heartbeat signal, but is clearly a dash (187ms) rather than a dot (65ms), and it is yellow rather than green. The value of K_p is shown on the multifunction indicator—if you have a panel meter it is shown explicitly, if there is a single LED, its brightness gives a rough estimate of the current value, and the knob will set the exact value if you wish to change it. The maximum value corresponds to the control turned up to full speed, fully clockwise, the minimum or zero to the full counter-clockwise position. Using the clockface analogy 7 O'clock is the zero position and 5 O'clock the full up 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 if you make no adjustment while at this stage.

If you elect to change K_p, adjust the knob. The indicator may suddenly change its display, as the position of the pot replaces the old value of K_p as soon as you move the knob. Observe that your knob position is tracked by the meter needle or the LED brightness, showing the new value of K_p.

When satisfied with the K_p setting, press the button again. The controller will advance to setting K_i, the integral coefficient. The signal becomes two yellow dashes of 187ms duration, spaced 65ms, every second, a dash-dash pattern. The meter snaps to show the current value of K_i. Again adjust the control if you wish to change K_i, make no adjustment to leave it unaltered. For an explanation of how to select good values for these control coefficients, refer to section 3.1.

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

When satisfied with the K_d setting, press the button again. This time the controller will set the amount of simulated inertia, K_j. A small K_j value means that the train will come up to speed as quickly as possible, and a large value of K_j means thatthe train will pick up speed and slow down very slowly as you change the speed setting. Usually a small value is required on small layouts or for a controller used in a shunting yard. Relatively uncompressed layouts suit a large inertia value. When finished setting K_j, press the button again.

This completes the setting of the "yellow" group of coefficients. The indicator now returns to a single-dash pattern, but in green. The controller is ready to set K_b, the braking coefficient. A small value of K_b means that the brake button will have very great effect. A larger value means that the brakes will seem to work very weakly. Too small a value makes the train stop quite quickly—unrealistically so, if desired.

Bear in mind that the braking interacts with the inertia; if you have virtually no inertia, there will be little point in braking at all, so this setting becomes unimportant, since the train will stop almost at once when the speed knob is turned down anyway. The braking always acts more forcefully than the acceleration. The value of K_b controls how much more forcefully.

In general, a middle value of K_b around one third of the way up makes for pleasant operation, requiring a little skill on the part of the driver, and being more scale-realistic. A useful rule of thumb on model railways is to allow the brake to stop the train in about its own length.

Pressing the brake again moves to setting K_s, the stopping distance for the autostop function. The signal becomes two green dashes of 187ms duration, spaced 65ms, every second, a dash-dash pattern. Again adjust the control if you wish to change the value. Use of the autostop function is described in detail in section 4. K_s sets the distance that the train travels once a station or siding stop is requested. This value usually needs to be set for any given layout.

The next press advances to the third value in the "green group", the timeout interval, K_t. The signal becomes three green dashes of 187ms duration, spaced 65ms, every second. This is the duration before the "dead man" circuit shuts off the train. A counter counts minutes; it is reset every time the knob or brake is touched. If it counts the preset number of minutes, the train is slowed to a halt until the knob or brake are touched, at which point it resumes where it was left off. The control can set from 1 to 200 minutes (a little less than 3 and one-half hours) delay. The factory default is about 30 minutes, or half an hour. If you have children who may use the layout, a short time of 5 minutes can preserve locomotive life. If you are a shopkeeper with a display layout, a couple of hours allows for long display followed by controlled shutoff after you leave.

Next comes the final value in the "green group", the duration of an autostop or station stop, K_h. The signal becomes four green dashes of 187ms duration, spaced 65ms, every second. The control can set from 10 to 210 seconds, up to about 3.5 minutes. This is another of those values that should be set to suit the layout: Short times suit small layouts, long times suit large layouts.

Pressing the brake again allows the meter function to be set. The indication becomes a single dash, but this time in red. There are two items in the "red group". The multifunction meter can display several different things, as listed above. If you adjust the knob at this stage notice that the meter needle or LED brightness steps across only 5 different values, changing in visible steps. These correspond to displaying, in normal operation, the "engine RPM" (or the motor back EMF), the peak current drawn by the motor, the average current, the percentage of full thrust (similar to the duty cycle in a PWM controller, but not so linear), or an estimate of the temperature of the armature. This last is discussed in more detail in section 3.2.

Once you have selected what you want to see on the meter in normal operation, pressing the brake advances the set function to the next parameter, K_{th}. The indication becomes two red dashes.

The controller knows the amount of power that it delivers to the motor. It is thus able to estimate the temperature of the motor, provided it knows how massive is the armature and how easily it is able to dissipate heat. This coefficient is used to tell the controller how massive a motor is inside the model. A low value is appropriate for small engines such a Z-scale, while a large value is appropriate for large motors in G or O-scale models. If in doubt about these parameters, it is typically quite satisfactory to use the factory default values for any given scale. See section 3.2 for a more detailed explanation of how to set this value if you are interested in protecting a particular valuable model.

Press the brake again. This time the controller returns to normal operation, the signal to the heartbeat, and the changed values are written to non-volatile memory.

3.1 Adjusting PID Coefficients

The highest possible performance is obtained from any controller if the P-I-D coefficients exactly suit your scale of locomotive, or more exactly the size and cooling of the motor. There are three coefficients that control the precision and smoothness of the motor control: The constant of proportionality, K_p, the integral constant, K_i, the differential constant, K_d. 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, giving rules of thumb for choosing the values themselves.

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 important fact is that if you turn the values of both K_i and K_d down to zero and the value of K_p to a small value, you have exactly what is in virtually all other controllers, simple proportional feedback. Quite often only a small setting for both of these will give a lot of improvement and if not perfect, it is certainly better than most controllers. If in doubt, set both to 10% or less of full value and you will be safe!

If you want to do some serious “fiddling” with the values, you should first switch inertia off, so that it does not make it hard to observe the effect of changes to the PID coefficients. Next, be fearless, because if you get in a mess you can always do a “factory reset” to get back to a good starting point. (See section 2.1.)

One thing to realise is that there is a great deal of interaction between the four values that the controller allows you to set. It is best to get each right in turn, but you may have to iterate a little. Start by setting $K_i = 0$, $K_d = 0$, and getting K_p about right first as described below, then adjust K_i until you are satisfied, then K_d, and if necessary repeat the three steps. Finally, set the inertia to suit your layout, not your locomotive. After a little 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 brake, apply power, and wait until the flashing falls to the slow rate to indicate timeout. Now you have modest values in place. Switch off inertia.

Press and hold the brake down to enter set mode. Press the brake again, observe the two-dash signal, reduce the knob to zero (turning it up first if necessary), to set the "I" term to zero. Press again, observe three dashes, re-zero to set the "D" term to zero. Now press the brake eight more times, and you should be out of set mode, observing the heartbeat signal.

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 a modest speed. Press and hold the brake down to enter set mode again. You should see that the indictar LED swaps from a "dot" flash to a single "dash" flash once per second in yellow. Adjust the control. You are changing the "P" term. You should find that turning it down stops the locomotive and turning 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 brake until you leave set mode, and be done with tuning!

However, at this point trains still slow down or speed up quickly on grades. If you want some improvement, let us carry on. Press the brake again, and observe that the LED now shows two "dashes". We are now adjusting the Integral Coefficient or "I" term, 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 changes, for instance climbing or collecting wagons while shunting. If you were *very* observant and your test track has a steep grade, you might see the train slow a bit as it climbed when K_i is set low, but this change will be minimized as K_i is increased. This would be more pronounced if it carried carriages. Wheel slip probably means the change will never disappear completely, but as with the "P" term there is a point in setting the "I" term above which the effect reduces no more. This is a little like old-fashioned car cruise controls that regulated engine RPM rather than road speed, which is what this controller is doing. 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 "I" control setting, your loco will in all possibility start to move in jerks. This means 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. It is usually worse with lighter loads, zero wagons in tow. That is why we recommended tuning with the locomotive by itself, but with a grade (as steep as possible) to expose the effects of varying load.

Done with K_i, press the brake again. Now you will see three "dashes" on the indicator LED, and the "D" coefficient value on the meter. If this is your second time through these steps, you might want to exit here, 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.

Locomotives with flywheels and heavy cast chassis do not normally require any differential compensation. This setting is probably best ignored and K_d left at zero in this case.

When you are satisfied with the PID settings, switch inertia back on, and adjust the inertia to suit your layout. This setting should be purely to taste. It is easy to set it too high, and get a train that starts very slowly, stops slowly, and is hard to shunt. One-third to one-half of full adjustment is recommended unless you have a huge layout.

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 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.

3.2 Adjusting the Motor Coefficient, K_m

The PID684SV controller continually tries to estimate the temperature of the armature of the locomotive's motor. Should the estimate exceed about 140C (about 280F) the controller will lock the controls and stop the train. This is mainly intended as a mechanism to prevent harm if a locomotive becomes jammed while unattended, since the controller will apply full power in an attempt to maintain the set speed, and this will rapidly overheat a motor that is unable to turn.

The smaller the value of K_{th}, the faster the motor heats up with a given power delivered, and the hotter the engine gets. Thus, K_{th} effectively sets the size of the motor. With the knob set to its lowest position, the controller believes that the locomotive is very small indeed, much smaller than Z-scale, while the full position corresponds to a motor that is quite hefty, 4cm in diameter and 8cm long. This allows the controller to work with custom miniature motors as small as pager motors or motors in large locomotives.

4 Automation of Layouts

The conroller can accept an "autostop" signal. This is typically a logic signal from a block detector on the approach to a station. The purpose is to enable automatic stopping at a station, or stopping with reversal at a terminus or siding.

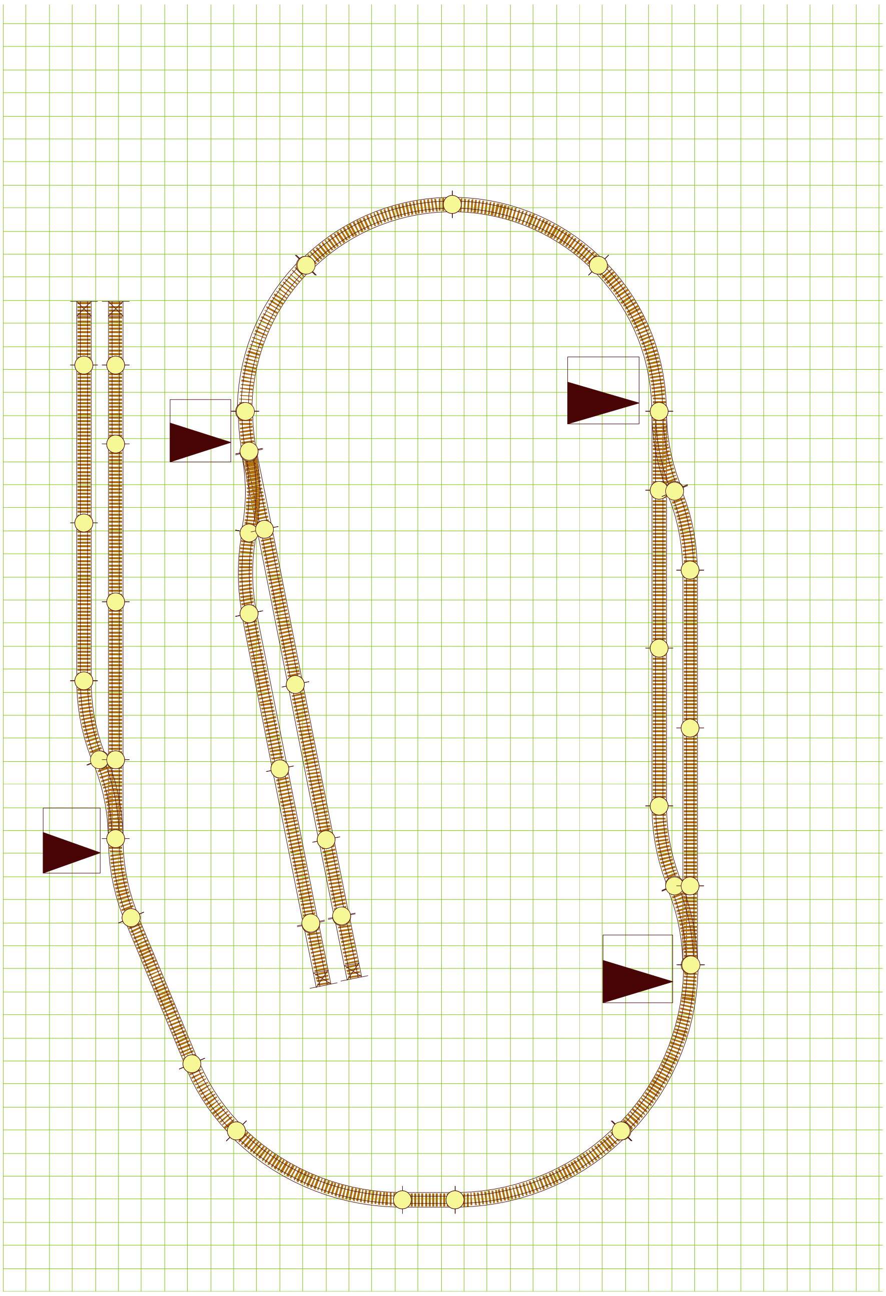
When the signal is received, the controller shows a fast-flashing indication on the indicator LED, and the train is decelerated to a halt for a number of seconds. This stationing duration is set and stored in the controller's non-volatile memory. The controller attempts to apply brakes to the correct extent to bring the train to a stop the same distance from the block detector irrespective of the speed when the block is entered. This distance is also set and stored in the controller's non-volatile memory.

Of course, there are limits to the ability of the autostop mechanism. If the train's speed is so low and the stopping distance K_s so large that the train coasts to a halt too soon without any braking (easily the case if there is very little inertia set by K_j), the autostop will miss. It will miss if the train is travelling very fast and the distance is set to a small value. However, within physical limits, the autostop is a good autopilot.

The signal required is a connection from the autostop input to ground. The autostop cannot be retriggered for 12 seconds after the train restarts. This is to prevent the rear of a long consist from retriggering the block detector if the stop distance is less than the length of the train, or a train reversing out of a siding and triggering a second stop.

If the autostop function is to be disabled, the connection to the autostop input must be broken by a switch. I.e., the controller always responds to an autostop request.

The diagram below shows an example of a layout that demonstrates the use of block detectors with the controller. To automate this layout, four block detectors could be placed as indicated by the triangles. The detectors at either end of the passing loop would be wired to signal a stop without reverse; the detectors near either end would be wired to signal a stop with reverse. The directions for wiring the block detectors to the controller are given in section B.



To initiate an automatic stop, the stationing input must be connected to ground. The stationing input normally floats to +5V, through an impedance of 10kΩ. Grounding this input, or at least pulling the line to less than 1V, triggers a station stop.

To trigger a station stop and have the train reverse, two conditions must be met. First the controller must be in Shunt mode. Secondly, the station input must be connected to ground directly. If the station signal line is connected to ground through a 10kΩ resistor, rather than directly, the train will not reverse in the stop even in SHUNT mode.

In the layout above, the block detectors at either end of the layout would be wired to trigger reverse, while the center ones would trigger a simple stop without reverse.

5 Summary of Indicator Signals

These are the indications that can appear on the LED, and their meanings.

Cruise Heartbeat This is a single short blink every second. This is the normal healthy indication in Cruise mode. Knob operates anticlockwise-off, and the train is put into and out of reverse by means of the DIRECTION switch alone.

Shunt Heartbeat This is two short blinks every second, a “blip-blip-pause” sequence. This is the normal healthy indication in Shunt mode. Knob operates center-off.

Boot Indication When first turned on, the light flashes yellow very quickly, about 15 times per second for around 2 seconds. This tells you that the controller has passed self-test. If this sequence occurs, you know that the power has just been applied.

Time Out This is slow even yellow flashes, half-second on, half-second off. This occurs after boot, and after a preset period of inactivity (default being 30 minutes). It is the “dead-man” indication. Either adjusting the knob by more than 5 degrees or pressing the button cancels this mode.

Maxed Out This is a condition where the indicator stays red for almost all the time, only blinking off for a one-sixteenth of a second every second. It indicates that the controller cannot achieve the speed requested, you have reached the limit of the power supply. This usually occurs when the speed knob is adjusted all the way up.

Open Circuit This is a sequence of four short red flashes repeating every second. It occurs if the locomotive is off the track or a connection is broken between the controller and the track.

Overload This is a sequence similar to “Maxed Out”, but with three short dark blinks per second amid a red indication. It means that the controller was asked to deliver too much current. This may happen when there is a short circuit, or if you have too many locomotives on the track for the rated controller current (1.2A). This is a latching condition that switches off the power to the rails to protect train and controller, and is reset by pressing the button.

Stationing This is a continuous series of short blinks in green. It shows while the train has been halted by the autostop function.

1-dash This is a single long blink (one-quarter seconds long) every second, a sort of “dash-pause-dash-pause” sequence. If yellow, it indicates that the controller is in set-up mode, and the knob may be turned to set the proportional strength of feedback. When the button is next pressed the set will advance to the next step (2-dash, yellow). If the knob was not adjusted by at least 5 degrees, the feedback strength will not be changed, irrespective of the position of the knob. If green, it indicates that braking strength is being set. If red, the meter readout is to be set.

2-dash This is two long blinks (one-quarter seconds long each) every second, separated by one-quarter second, a sort of “dash-dash-pause” sequence. It means the controller is in set-up mode. If yellow, the knob may be turned to set the integral term, K_i. If green, stopping distance, K_s, is being set. If red, motor size coefficient, K_{th}, is being set. When the button is next pressed the set will advance to the next step (3-dash). If the knob is not adjusted by at least 5 degrees, no change occurs.

3-dash This is three long blinks (one-quarter seconds long each) every second, separated by one-quarter second gaps, "dash-dash-dash-pause". If yellow, the knob may be turned to set the differential control coefficient, K_d. If green, the station halt duration, K_h, is being set.

4-dash This is continuous dashes, "dash-dash-dash-dash...". If the indicator is yellow, the knob may be turned to set the constant of inertia, K_j, to be applied to the model. If green, the timeout (dead-man) duration, K_t, is being set.

This table is a quick reference for setting. To enter set mode, switch inertia off, and press the brake for three flashes of the heartbeat signal.

Color	Pattern	Function
YELLOW	dash	setting Proportional Term (Kp)
YELLOW	dash-dash	setting Integral Term (Ki)
YELLOW	dash-dash-dash	setting Differential Term (Kd)
YELLOW	dash-dash-dash-dash	setting Inertia Term (Kj)
GREEN	dash	setting Braking constant (Kb)
GREEN	dash-dash	setting Station-stop distance (Ks)
GREEN	dash-dash-dash	setting Timeout interval in minutes (Kt)
GREEN	dash-dash-dash-dash	setting Station Halt interval in seconds (Kh)
RED	dash	setting Meter readout (Km)
RED	dash-dash	setting Rth (Z,N,HO,O/G) (Kth)

A 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 friction and wheel slippage, yet vastly more stiction, and very little immunity to small pieces of dirt on the track, etc. Feedback controllers, and particularly the PWM type, 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 digital feedback system such as the P275S or the P684S can do wonders. The difference (apart from the complexity) between digital and analog controllers lies in the precision with which the feedback can regulate the speed, and the range of responses to measured conditions. For example, the P684S can adjust the motor power from about 1% to 100% of available power without any help from the driver, if this is required to keep a train climbing a grade steadily, yet it will switch the power off completely if there is a short or open circuit or the dead-man function trips. The same power control is used to simulate the acceleration, coasting and braking as felt on a heavy locomotive.

A.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 much 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 4 volts applied. If a PWM controller applies 15 volts peak, it will run a duty cycle of between 20% and 75%, worsening losses by anything from one 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: It can be no worse than running at a large fraction of full speed for the same amount of time.

However, 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 (such as eddy-currents in the armature metal). Together with a PWM signal, these decrease efficiency and cause heating of the motor. Worse, cooling is usually greater when the engine RPM is high, but PWM losses are greater at low speed. This makes for the unintuitive case that burnout is more likely at *low* speed with PWM drive.

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. This is roughly like trying to run your dc model with half of the energy applied as ac power instead! 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 (18 degrees F) 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 38C/100F. (Luke warm is 38C or 100F, the limit of what you can touch comfortably is in the region of 55C or 130F.) The armature temperature could be much higher, perhaps 80C/175F, 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 lifespan considerations promoted the inclusion of the timeout or “dead man” function, and the development of Analog Waveform Drive or “AWD”.

A.2 Analog Waveform Drive (“AWD”)

Analog Waveform Drive is a method of dynamically shaping the waveform delivered to the locomotive so as to eliminate the high-frequency losses that increase heating at low speeds. A hardware circuit slew limits the voltage applied to the tracks, to guarantee that no operating condition of the computer can stress the motor’s armature.

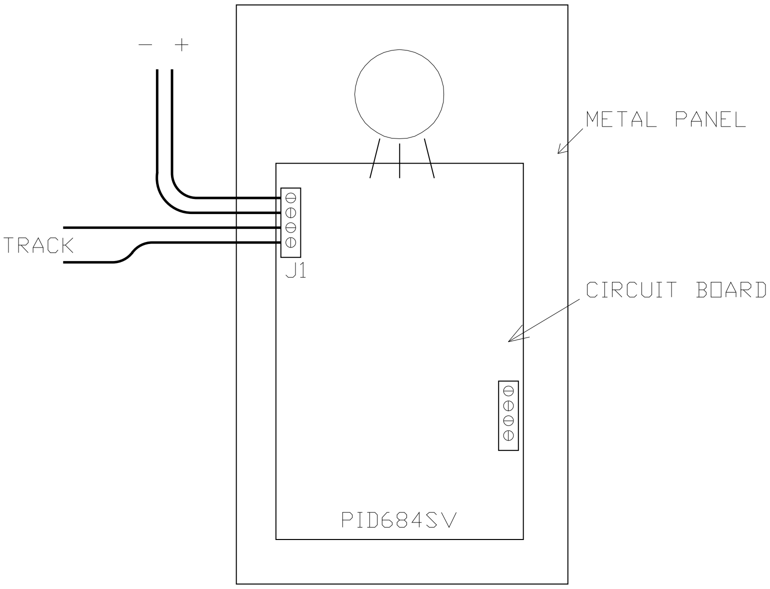
In the low-power situation where a Pulse-Width-Modulation (PWM) controller would deliver a short, but full-amplitude pulse, the AWD circuit produces a wide triangular waveform of lower amplitude. In this regime, the waveform is amplitude modulated. At medium power, AWD delivers a full-amplitude waveform, but the rise times are kept long, decreasing efficiency but keeping the wasted power in the controller, rather than in the locomotive. At full power AWD delivers a flat-topped, full-amplitude signal with occasional triangular zeroes to allow the motor back-EMF to be measured.

B Wiring Up the Controller

If you have a controller card, you will need to wire it up to your layout. This section describes how to wire up the controller when it is purchased unenclosed.

B.1 Power and Track Wiring

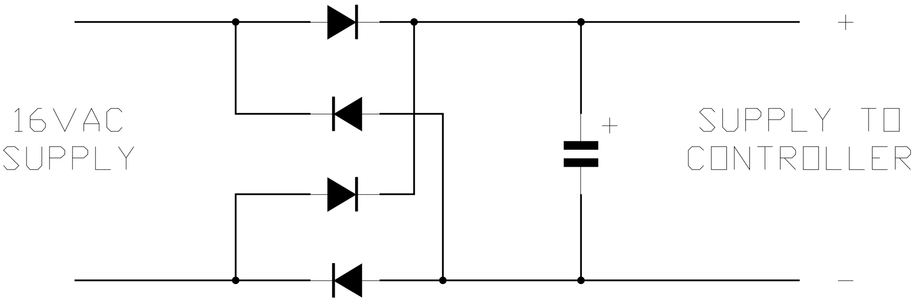
To use the controller, 4 basic connections must be made to the controller PCB. These supply dc power to the controller, and carry current to the track. The connections are made via screw terminal blocks on the printed circuit board (PCB). The power and track connections are made at the J1 terminal block. The picture below shows the terminals that are used for power and connection to the track, viewed from behind the panel:



The controller requires 8–24 volts dc to function properly. Reverse power connection will not harm the controller, but it will not boot or operate if the supply polarity is wrong.

In order to provide a full 10V equivalent average supply for Z-scale locomotives, a supply voltage of 12V or more is required. The recommended supply is +18V at 25W. This can be provided from an open-frame switchmode power supply or a conventional transformer, rectifier and filter capacitor circuit, or from a plugpack power supply. An example of a switching regulator of 18V output is the a Phihong PSA25L 18V 25W open frame switching power supply.

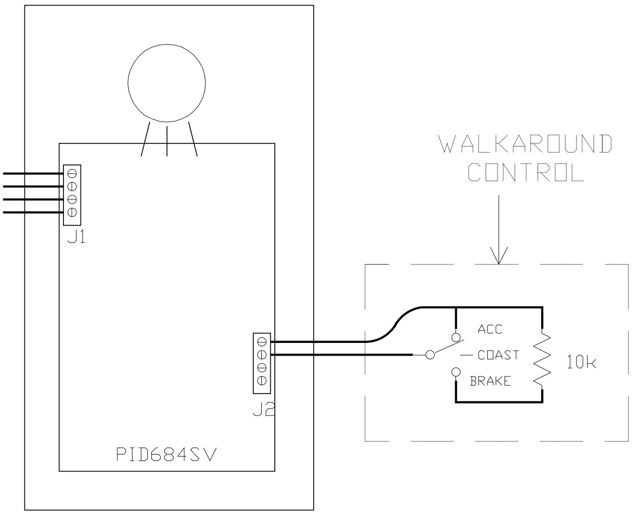
The controller will also operate with a rectified transformer output, provided a filter capacitor of adequate value is connected across the supply. The circuit below can be used to provide a supply from the accessories output available from many model train controllers. The diodes should be 1A rectifiers such as 1N4004. The capacitor should have a value of 4700μF or more.



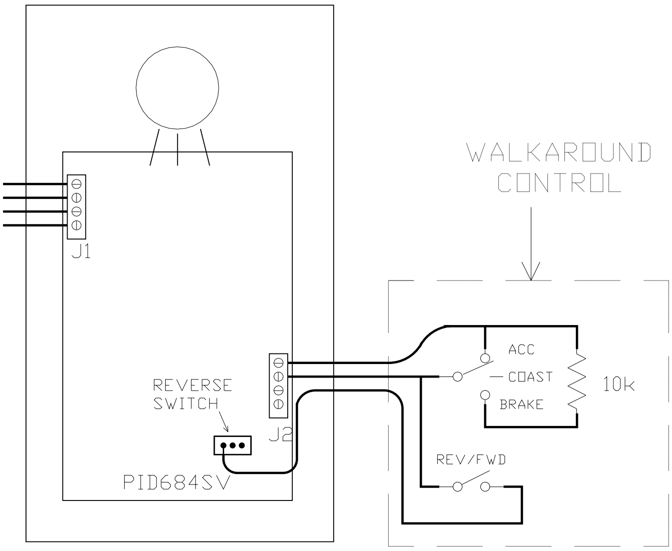
B.2 Walkaround Control

Many enthusiasts like to have a “walkaround” controller, a sort of remote control on a cable. This PID684SV supports a very compact walkaround control. Only two wires are required to connect a control that has a second THRUST switch. If the THRUST switch on the controller is left in the "coast" position, the remote THRUST switch can be used to control a train. A third wire is required to implement reversing from the walkaround controller.

The diagram below shown the terminals and wiring required to implement the walkaround controller. A resistor of 10,000Ω is required. Any switch or pair of switches can be used. A C&K 7107 is a suitable single switch.



Reversing can be wired into a walkaround controller, but this requires some electronic knowledge, and should only be undertaken by someone with experience soldering. A walkaround controller with reversing requires a ground connection and a connection in parallel with the reversing switch of the main controller:

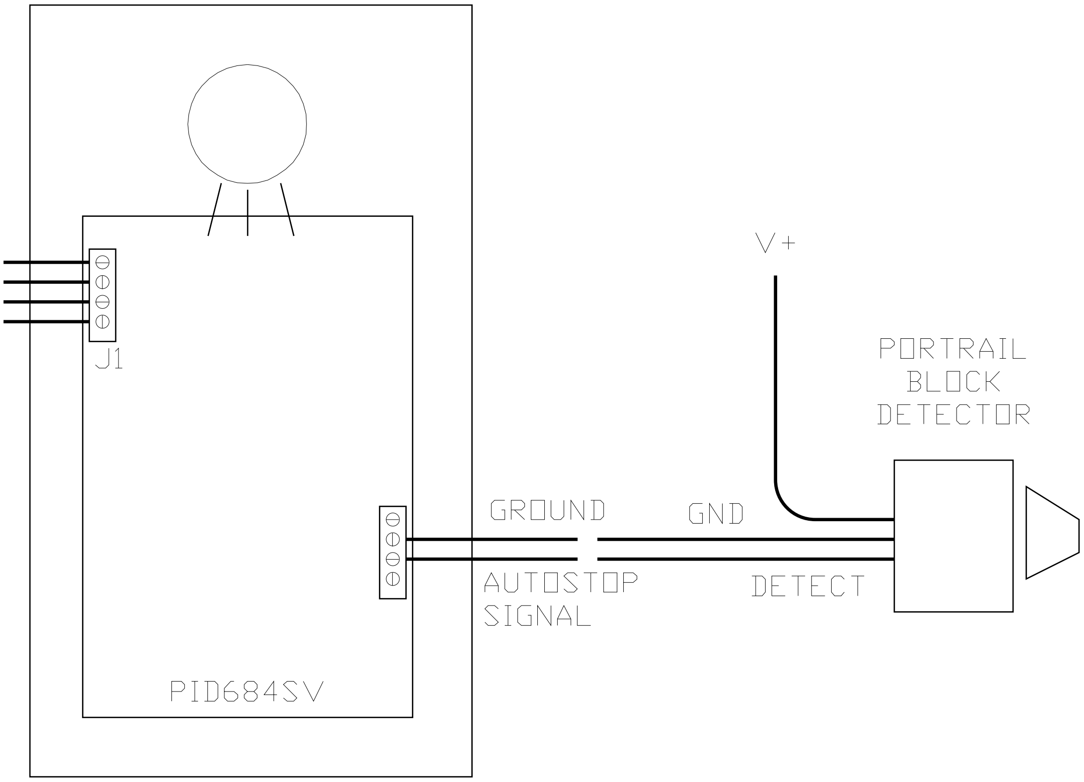


The reverse control wire must be connected to the reverse switch terminal that is situated farthest from the J2 terminal block, as shown in the drawing above.

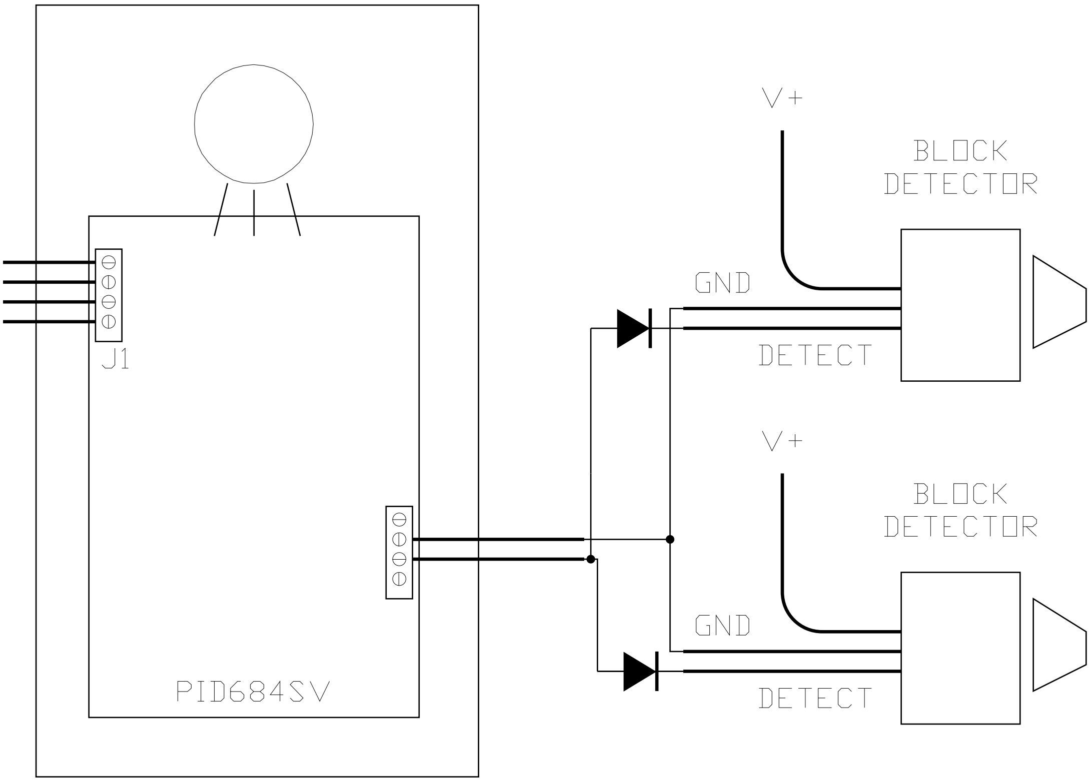
B.3 Wiring Up for Station and Siding Stops

A unique capability of the controller is to automate halts at stations and terminus sidings, as described in section 4. In this section we describe how to wire up Portrail block detectors to the controller to enable stops with and without reversing.

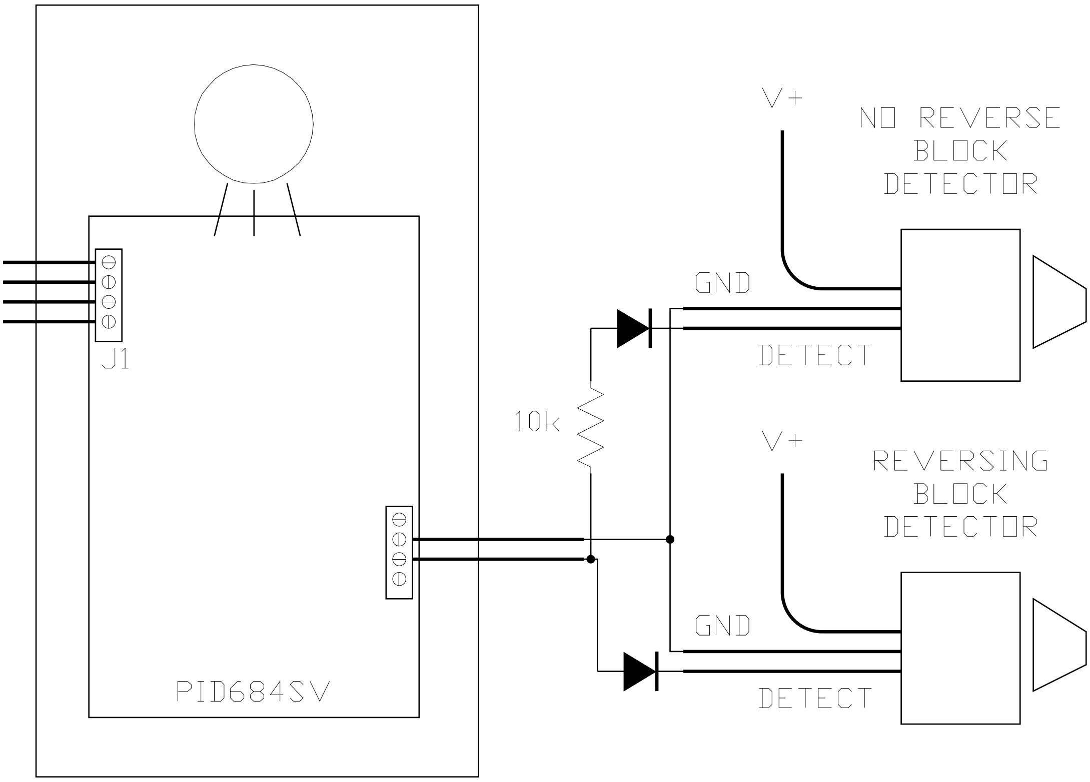
In the diagram below, a block detector is shown wired to the controller so that a station stop will be triggered whenever a train is detected by the block detector.



It is possible to connect any number of block detectors in parallel using the arrangement below. The block detectors connect their DETECT lines to ground when they sense a train. When the STATION line in the controller is pulled low, the controller pulls up the train in the prescribed distance. In these circuits, the train will reverse if the controller is in SHUNT mode, but not if the controller is in CRUISE mode.

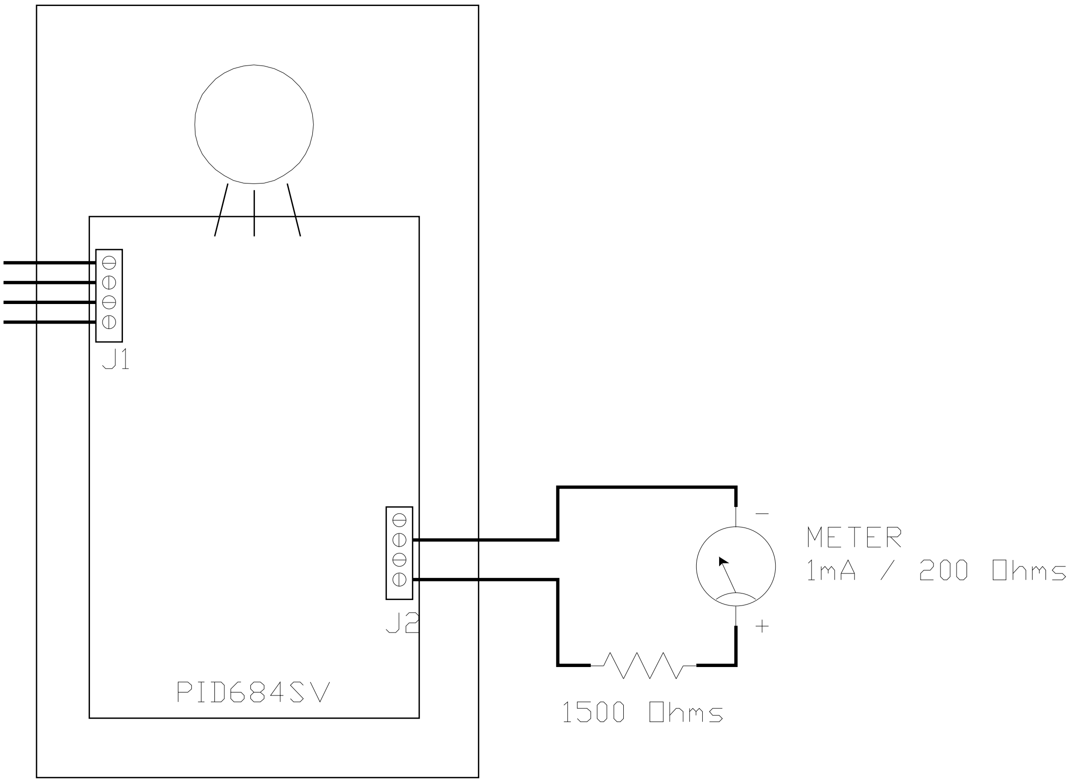


If a 10kΩ resistor is wired in series with the block detector line, the reverse-if-SHUNT function is disabled. In this way, it is possible to arrange for reversing to occur only at certain places in the layout, but not in others. In the curcuit below, the train will reverse for one detector but not for the other, provided it is in SHUNT mode. It will not reverse for either block detector if it is in CRUISE mode.



B.4 Wiring a Panel Meter

The P684 will drive a 1mA panel meter with various signals descibed below. The panel meter is connected between the meter and ground connections of J2. These may be identified from the overlay diagram in section C or by the letters 'M' and 'G' on the underside of the PCB. The meter positive connection goes to the 'M' terminal, the negative to ground.



The meter displays the current delivered to the train by default. However, it can be set to display other useful values. (See section 3 for instructions on setting the meter readout function.) The other values are the peak load current, the fraction of full power that is delivered to the motor (a measure of how hard the controller is working), the measured motor back-EMF (the measure of motor RPM) and the current estimate of the armature temperature (the equivalent of the temperture gauge in a car, but for an electric motor).

C Technical and Service Information

C.1 Specifications

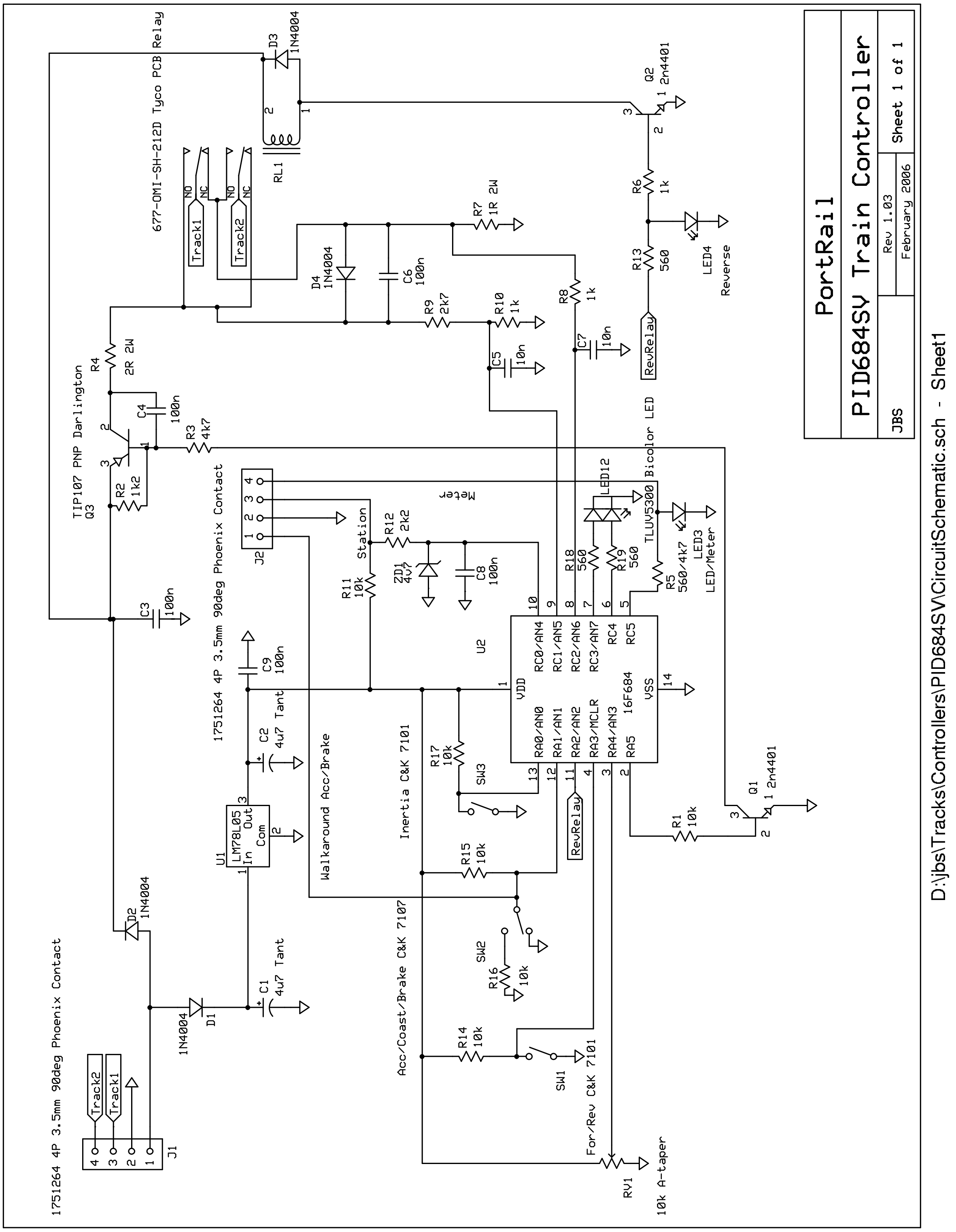
C.1.1 Electronic Circuit Board/Panel Controller

Operating supply Voltage	8–24 Volts dc
Safe supply Voltage	-100–+35 Volts dc
Recommended supply, Z-scale	12 Volts dc
Recommended supply, N-scale	15 Volts dc
Recommended supply, HO-scale & above	18 Volts dc
Load current rating	1.2A average, ≈5A peak
Average current protection	in software, latching, 1.2A
Timeout period	1–205 minutes (3h 25m)
Back EMF sampling frequency	≈125 Hz
Autostop signal	≈1mA to ground (<1V)
Autostop and reverse signal	≈10kΩ to ground
Multifunction meter	motor EMF, current, % thrust, motor temperature

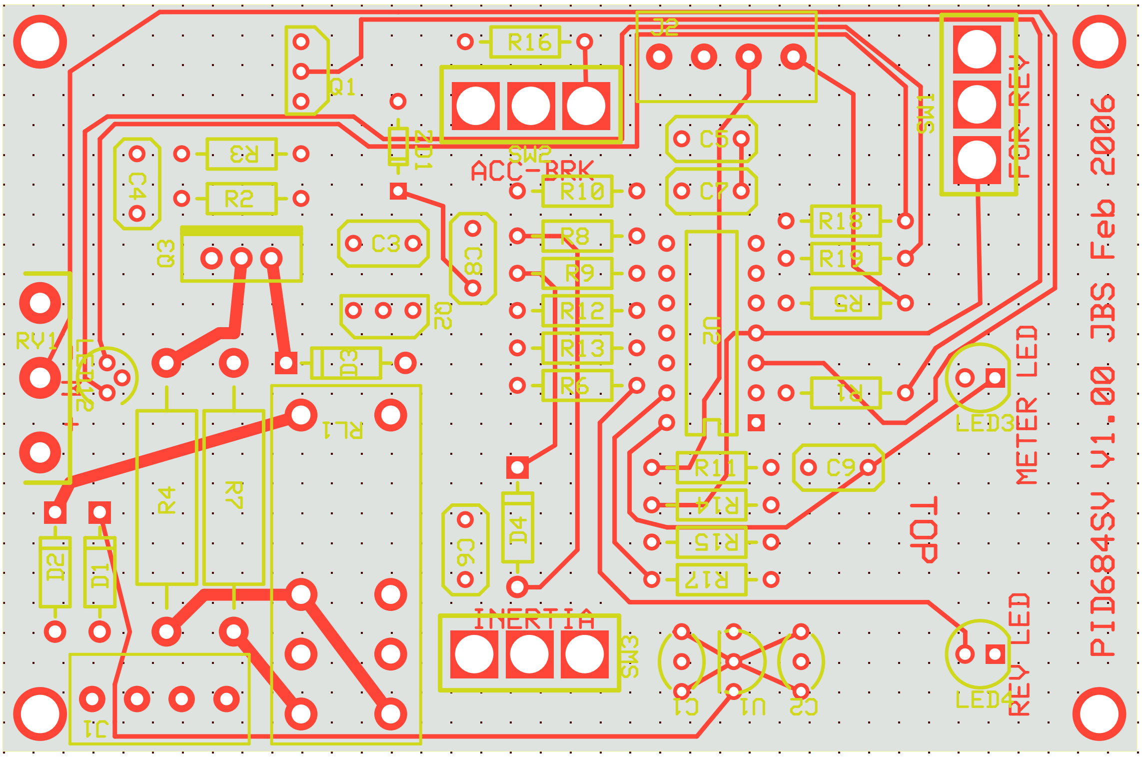
C.1.2 Assembled Controller

Supply Voltage	90–255 Vac, 48-62Hz
Input power connection	IEC mains cable
Output connection	Screw terminals/banana sockets
Power consumption (max)	25W
Indicators	Status signal LED, Reverse, Multifunction meter
Controls	Accelerate/Coast/Brake, Inertia Off, Direction, Throttle, Autostop

C.2 Circuit Diagram



C.3 PCB overlay



D:\jbs\Tracks\Controllers\PID684SV\PCBlayout.pcb (Silkscreen, Top layer)