

# P675S Users Manual

PortRail

November 2005

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# 1 Introduction

Thank you for purchasing the P675S Model Railway Controller. Features of the P675S include:

- Precise speed control delivered by proportional regulation of engine EMF with digital loop stabilisation;
- Shunt (center-off) and Cruise (anticlockwise off) modes to suit layout and operator needs;
- Factory presets of control gain, inertia, braking strength and timeout interval for Z, N, HO, O and G scales;
- Adjustable simulated inertia;
- Coasting deceleration and button-activated braking when using simulated inertia, for realistic driving;
- Reversing at speed is impossible;
- Low cost;
- Adjustable braking capability;
- Operational condition (overload, shunting, etc.) indicated by LED;
- Timeout mode (“dead man switch”) to halt unattended trains;
- Full overload protection.

## 2 Using the Controller

The controller 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 controller has started correctly. The controller then loads the same settings that were in use when it was last used.

After the two seconds starting up, the controller goes into its “standby” mode. This is signalled by a slow (1 half-second flash per second) 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, so that trains can be driven. Starting in standby prevents trains moving as soon as power is applied.

In operation, the knob sets the speed of the train. In “Shunt” mode, the knob operates center-off, and the locomotive travels forward when the knob is turned clockwise, and backwards if it is rotated anti-clockwise. In “Cruise” mode, the knob operates “anticlockwise-off”. At the same time the LED shows a “heartbeat” signal, consisting of

a one-sixteenth second flash every second in Cruise mode, and two one-sixteenth second flashes close together every second in Shunt mode.<sup>1</sup>

The action of both the button and the knob is different in Shunt and Cruise modes. In Shunt mode, the train is stationary when the knob is near the middle of its travel, usually with the pointer on the knob pointing straight up, the “center-off” position. When the knob is turned clockwise the train goes in one direction, when it is turned anticlockwise it goes in the other. This is good for shunting work. When in Cruise mode, the train stops when the knob is turned fully anticlockwise. Turning up the knob makes the train go faster and turning it down makes it go slower. Reverse is selected by pressing the push button *while the train is stationary*.

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.

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 usually turned through half the travel if it has been in “center-off” mode. In normal usage the initial standby is not even noticed.

The press button “applies brakes”. When the controller is set to simulate inertia, the train does not slow down quickly. It speeds up faster than it slows down, corresponding to the driver applying the force of the engine to accelerate the train, but allowing it to coast to a standstill when the throttle is backed off. Pressing the button—simulating the application of brakes—slows down the train much more quickly, as in the case of a real train. This is very useful for controlled and skillful stopping in stations or before buffers in sidings. The knob is returned to the “off” position, and then the button pressed and released as required to bring the train to the correct stopping position.

The button “applies brakes” in both modes, but it engages reverse only in Cruise mode. Remember that the knob deals with reversing in Shunt mode. If pressed when the train is moving, the button will apply brakes, but in Cruise mode if the train is not moving at the moment the button is pressed, it will toggle direction. You can tell if direction is toggled by the click that the relay inside the controller emits.

If pressed for more than 10 seconds continuously the press button activates a special setting function, rather like setting the time on a digital wristwatch. This allows the user to adjust the strength of the speed-control function, the amount of simulated inertia, the strength of the brakes, and the interval of user inactivity required before the controller times out and stops the train. This function is accompanied by special indications on the indicator light, and is described in detail in section 4.

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<sup>1</sup>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.

### 3 Factory Reset of Coefficients

The factory reset state is invoked by holding down the press button while applying power. If the button is depressed at the end of the initial, 2-second startup period, the factory preset 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, 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.

### 4 Adjusting the Controller Coefficients

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 demands little inertia. 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!

There are four coefficients that control the feel and action of the controller:

1. The constant of proportionality,  $K_p$ , that adjusts the strength with which the controller holds constant the speed of the locomotive;
2. 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;
3. The braking constant,  $K_b$ , that sets how rapidly the train comes to a halt when the brake button is depressed; and
4. The timeout duration, or the period of time without the controls being adjusted that must elapse before the controller assumes the train has been forgotten, and automatically halts its motion. (This is the delay on the so-called “dead-man button”.)

The sequence to set these four is started by holding the push button down for a period of more than 10 seconds, more than 10 “heartbeat flashes” of the indicator.

Upon the release of the push button, provided it was held down for ten 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 Cruise 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 not to adjust loco speed, but the value of  $K_p$ . 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.

In many circumstances the controller will operate quite satisfactorily with “typical control”, so the control can be turned to a convenient mid-point of its travel. However, certain light or small models may vibrate or “chatter” or give small starts if the control is set too high. (This is especially so if the track or wheels are dirty.) If this is the case, turn the knob down in “set  $K_p$  mode”. In general, the control will be most smooth when the knob is no higher than it needs to be. 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.

The most convenient way to adjust  $K_p$  is with the train running around a loop of track. Start a locomotive running at a modest speed, then press and hold the button for 10 flashes of the indicator. Release the button and observe the single-dash indication. Now adjust the knob first down (the train will slow below a certain point and eventually stop), then up. You should note that the train does not go any faster when the knob is increased past a certain point, and it may eventually begin to get jerky or chatter. Adjust the knob to the point where speed does not change any more, but before the loco chatters or jerks.

When satisfied with the  $K_p$  setting, press the button again. The controller will advance to setting  $K_j$ , the inertia. The signal becomes two dashes of 187ms duration, spaced 65ms, every second, a dash-dash pattern. Again adjust the control if you wish to change  $K_j$ , make no adjustment to leave it unaltered. 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 that the train will pick up speed and slow down very slowly as you change the speed setting. When finished setting  $K_j$ , press the button again.

Next  $K_b$  will be set. The signal becomes three dashes of 187ms duration, spaced 65ms, every second. A small value of  $K_b$  means that the brake button will have very little effect. A larger value means that the brakes will seem to work very powerfully, stopping the train quite quickly when pressed. In general, a middle value, sufficient to halt the train in three to five seconds makes for pleasant operation, while smaller values that would require 5 to 10 seconds are more scale-realistic.

Finally press the button once again, and you can set the timeout duration. The signal is four dashes of 187ms duration, spaced 65ms, so that it appears as if there are 4 short dark blinks per second. The control can set from 1 to about 200 minutes (a little less than 3 and one-half hours) delay. The factory default is about 30 minutes, or half an hour. If a value of zero is entered—the knob turned fully down—the dead man function

is disabled, and the controller will never time out. Disabling the dead-man button is not recommended, any more than on a real train!

When finished setting the timeout, press the button again. This time the controller returns to normal operation, the signal to the heartbeat.

## 5 Summary of Indicator Signals

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

**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 pressing the button while the train is stationary.

**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 very quickly, about 15 times per second. This tells you that the controller has passed self-test. If this occurs, you know that the power has just been applied.

**Time Out** This is slow even flashes, half-second on, half-second off. This occurs after boot, and after a preset period of inactivity (default being 30 minutes). 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 on 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. When the power supply is correct for the model in question, it means you are at full speed for that model. It will also occur if you try to operate the controller with too low a voltage for the scale of model, for instance if you have a 10V supply and try to run an HO scale model at full speed.

**Overload** This is a sequence similar to “Maxed Out”, but with three short dark blinks per second. 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). The peak current is limited to 6A, and the average current to 1.2A. This condition switches off the power to the rails to protect train and controller, and is reset by pressing the button.

**1-dash** This is a single long blink (one-quarter seconds long) every second, a sort of “dash-pause-dash-pause” sequence. It indicates that the controller is in set-up mode, because the button has been pressed for more than 10 seconds (ten heartbeats). In this mode, the knob may be turned to set the strength of feedback. When the button is next pressed the set will advance to the next step (2-dash). 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.

**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. The controller is in set-up mode and the knob may be turned to set the amount of inertia to be applied to the model. 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”. In this mode, the knob may be turned to set the braking strength. When the button is next pressed the set will advance to the next step (4-dash). If the knob was not adjusted by at least 5 degrees, the braking strength will not be changed, irrespective of the position of the knob.
- 4-dash** This is continuous dashes, “dash-dash-dash-dash...”. In this mode, the knob may be turned to set the time-out interval from 1 minute to over 3 hours. If the knob is adjusted down all the way, timeout is disabled. If the knob is not adjusted the value does not change. Pressing the button ends set-up mode.

## A Connecting the Controller

There are 4 connections to the P675S controller. Two are required to bring DC power. The controller requires 10–18 volts dc to function properly. The two other wires deliver current to the track. All connections are made at a small terminal block. The function of each terminal is indicated on the underside of the PCB if these instructions are lost.

Reverse power connection will not harm the controller, but it will not boot or operate.

### A.1 DC Input Power

The controller expects filtered DC power, but will function to some degree with unfiltered dc power. The LED may indicate “loss of control” if the power supply is not filtered or of too low a voltage for the desired model and speed. If more than a volt or two of ripple appears on the supply, the current overload condition may be triggered. The controller will not be harmed by either reverse polarity or the application of up to 26V, but may not function properly if the supply is less than required for the model or more than 18V. If the voltage is higher than required for the model, for example if it is run on an 18V supply with N-scale locomotives, the action of the control knob may be very sharp, just as it would be if using a normal controller with too high a voltage output, and the locomotive’s motor will be hot in operation.

The controller will work if the supply is not very well filtered, but operation can be less effective or the detection of overloads erratic. The controller is specifically designed to operate in conjunction with a switching regulator of 12 or 15V output,<sup>2</sup> although it will operate equally well with any regulated supply from 10 to 18V.

It will also operate with a rectified transformer output, provided a filter capacitor of adequate value is connected across the supply. A value of 10,000 $\mu$ F is recommended.

### A.2 Output to Rails

The output to the track consists of two wires. These are connected to the same terminal block as receives the input dc power. On the PCB the output connections for the track are labelled “T”.

Since the controller reverses direction itself there is no fixed positive and negative connection. If the sense of the controller is wrong when in Shunt mode (control center-off) the track wires should be reversed.

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<sup>2</sup>For example, Cincon 412-CFM1505S 12V 15W or Phihong PSA25L 15V 25W open frame switching power supplies.

## B 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 controllers 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 driver's 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 P675S 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 P675S 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 acceleration, coasting and braking as felt on a heavy locomotive.

### B.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 3 volts applied. If a PWM controller applies 15 volts, 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 discussed 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.

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 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.

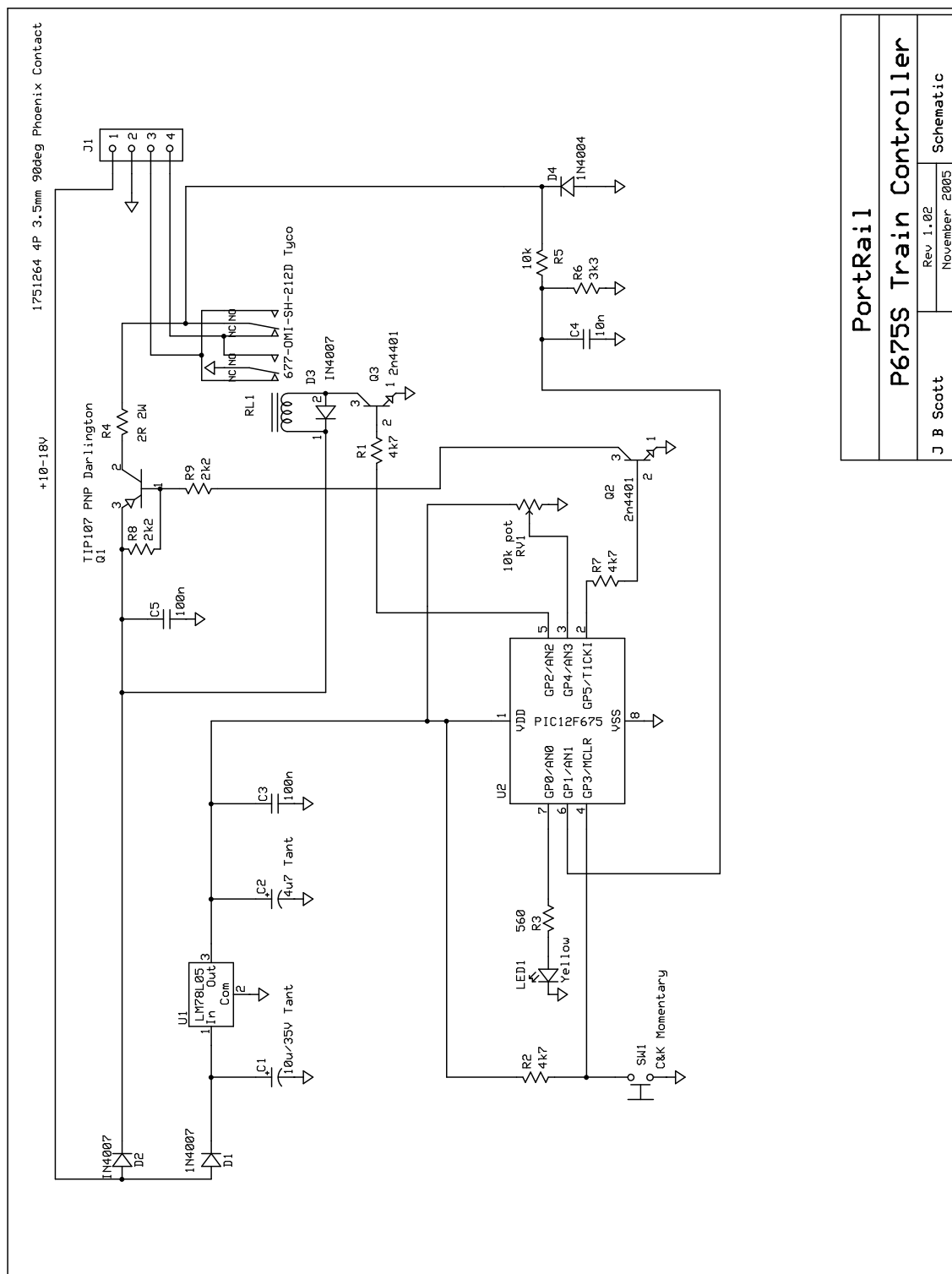
These lifespan considerations promoted the inclusion of the timeout function. The designer of the controller is confident that you will not see reduced lifespan of even Z-scale locomotives if you drive responsibly. For those very concerned with burnout, or if you intend to drive your locomotives for extended periods, a controller such as the P684S offers active control of the pulse output amplitude as well as duration, and continuous estimation of the motor temperature to assist in addressing problems of locomotive operating life.

## C Technical Information

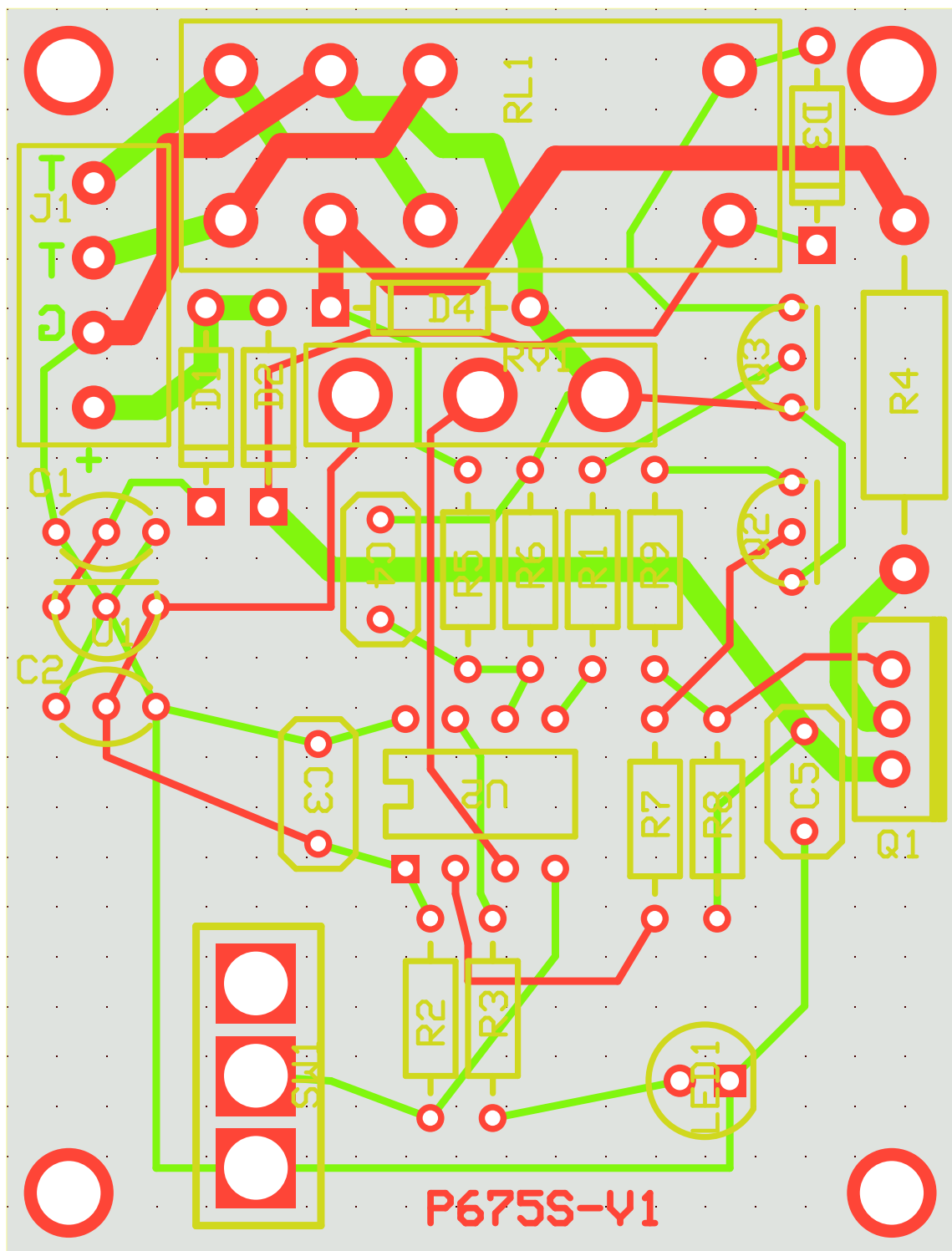
### C.1 Specifications

|                          |                                         |
|--------------------------|-----------------------------------------|
| Operating supply Voltage | 10–18 Volts dc                          |
| Safe supply Voltage      | -100–+26 Volts dc                       |
| Load current capability  | 1.2A average, $\approx$ 6A peak         |
| Pulse duty cycle         | 0–90%                                   |
| Timeout period           | 1–205 minutes (3h 25m)                  |
| Pulse amplitude          | $\approx V_{\text{supply}} - 1\text{V}$ |
| Pulse frequency          | $\approx$ 125 Hz                        |

## C.2 Circuit Diagram

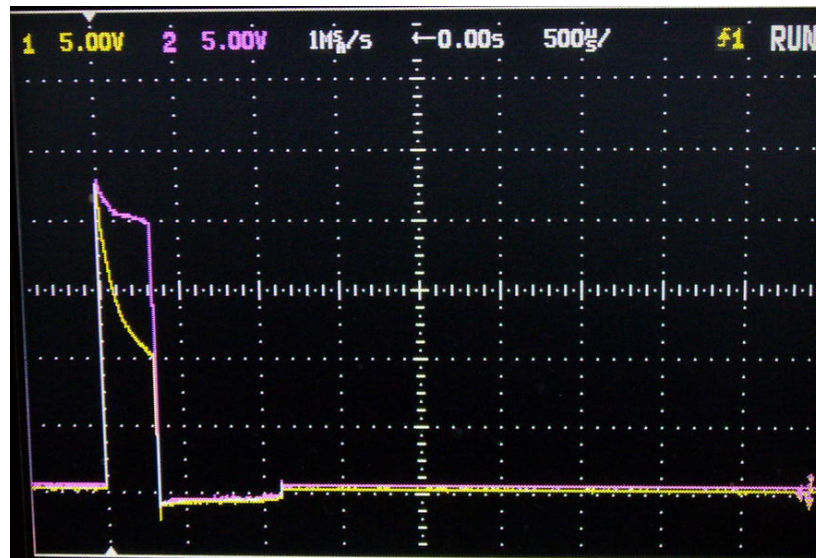


### C.3 PCB overlay

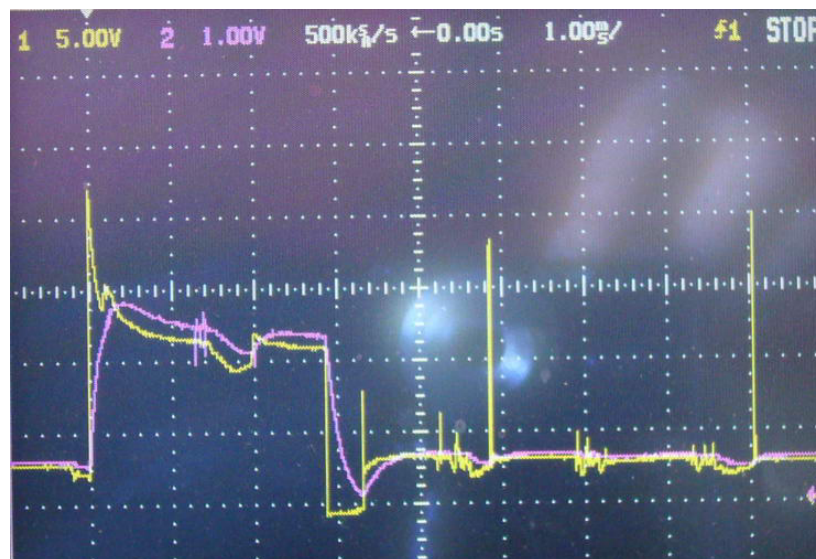


D:\jbs\Tracks\Controllers\P675S\P675S.pcb (Silkscreen, Top layer, Bottom layer)

## C.4 Typical Operating Waveforms



Current overload waveforms (drive and load voltages).



Operating motor and back-EMF ADC input waveforms.