Further thoughts on train controller design

The ETI-1508 Train Controller (December '82 issue) proved a popular design and occasioned much reader comment. Though seemingly elaborate, many readers said we han't gone far enough! After many months of experience, some improvements suggested themselves (a clever train controller!). Here they are, plus further thoughts on new design possibilities.

OUR LAST train controller project, the ETI-1508, has stirred above-average comment and enthusiasm, it seems. It was a fairly imaginative design (read oddball if you are one of the school that disapproves of radical steps). In a way, the more sceptical people had a point, for there are two drawbacks with the design, one brought on by lack of experience with different train systems on my part, and the other a purely cost-based one. This article talks about the problems, suggests short term measures to improve the situation, discusses the inherent design problems and points the way to the next generation design — work upon which continues.

The first thing to note from reader responses is that many of the heavy enthusiasts are willing to accept rather high component counts, and hence cost. When the '1508 was designed, a lot of attention was paid to keeping the circuit reasonable in size so that beyond the transformer, the cost could be low. True, the hardware was not cheap, especially if you built it entirely from scratch, but it was cheap if you used a cheap box and an existing power supply. I should have spent more time than I did wandering in model shops, because if you look at how much trains cost, controllers aren't big chips. However, remembering my days of cannibalising old equipment and buying AC127s in ones (oops, dated now) we played Scrooge. At this point, it seems fitting to mention the first inescapable design decision on train controllers.

Decisions, decisions

There are two radically separate controller designs. The "1508 epitomises one, and perhaps the Hornby 'Zero-One' the other. The Zero-One places 16 volts ac on the tracks at all times and controls engines (plural), points, signals and all accessories using only the two connections of the track. This it does by sending control signals as well as raw available power down the lines, rather like the SEC controlling off-peak systems with control tones. These are picked up by small switching units in the controlled items which do their stuff, drawing from the rails whatever power is required. This gives ease of wiring and the ability to control several trains separately without isolating track sections.

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In a way, it is quite superior to the '1508 type, which needs on train per circuit and that is all it will handle. However, it sacrifices feedback. This means no 'real train feel', no erratic response to hills, no difficulty in control and no open/short-circuit indication, etc. It is also costly as every item on the system needs an 'implant'; one is likely to pay about $200 for a starting setup, and each new item added demands another 'implant'. It is also a rather cut-and-dried design; there is little room for tinkering and improvement, because of the lack of feedback. So if you want to go that way, we can see the reason. It probably produces the best effect as far as looking is concerned, in that lights are always on and models always moving in a 'controlled' way. There are far fewer wires and fewer things to twiddle. The professional's system it is, in every way.

Jerking off

The '1508 is a sensitive analogue approach, for which we pay in complexity and 'fiddliness'. So, back to its problems. Engine takeoffs are often 'unsmooth' and sometimes need the train to be nudged. If you have the throttle up too far the train can jerk off, entirely ruining realism. If the current rises slowly, the train may never shift without a nudge, or may appear to jam for a while and then, when the power is enough to overcome static friction, it takes off at a pace.

These effects are aggravated by the fact that the unit is regulating current rather than voltage. We found that Hornby trains, which are significantly less smooth than other makes, are particularly susceptable. Airfix or Jouef ones proved quite OK in this regard. Some Hornby pickup systems are virtually the same as they were on their locomotives over twenty years ago! Tradition is nice but often painful. Even Rolls Royce have begun to change their grille design!

A voltage regulation regime gives improvement, but tends to remove the very real (steam era) effect that a locomotive engine develops more power as it speeds up, giving a positive feedback effect, demanding care and concentration from the driver. What is required is voltage regulation in the short term (seconds) and current regulation in the longer term (tens of seconds and up).

The modification shown in Figure 1 can be added quickly to the '1508 and gives this effect. Startup is smoother and far less critical. It has one drawback on the '1508: namely, that the open-circuit sensor uses the fact that there is current drive, and since the current drive is effective only after 5-10 seconds, the o/c light may take up to this long to respond.

In future designs the current sense requirement of the o/c detector can be removed so that the drawback is overcome (at a small cost of increased component count).

The suggested modification requires only three points of connection to the pc board and is thus quickly added in situ, and removed if you do not like it. Startup only requires that you use more throttle than you thought before; the margin for miss-estimation is greatly reduced. In addition, the engine appears to have more inertia when encountering a sudden hill or extra carriages, though the need for attention to the throttle in the long term is still present, which I feel is important.

You may wish to reduce the basic acceleration time constant and the idle-slowdown time constant as well, in order to restore the original feel of inertia, as the circuit here will suggest an increase

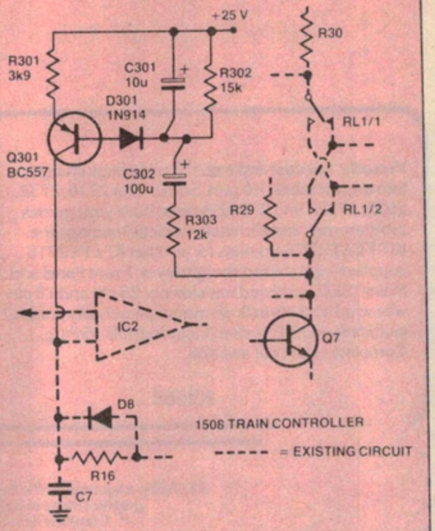
HOW IT WORKS — ETI-1508 MOD.

The function of the modification is to apply feedback to the main regulation amplifier in order to produce output voltage regulation effects for frequencies in the 0.1 Hz region. It achieves this by converting changes in output voltage in this frequency area into current and adding this to the signal presented to the feedback input of the control operational amplifier.

Clearly, Q301 will be turned off in the quiescent dc state by R302. Together, R302, C301, R303 and C302 form a filter which passes frequencies near 0.1 Hz to the base of Q301. When load voltage increases, the voltage at the collector of the output transistor falls with respect to the +25 V rail. This is passed on to the base of Q301 which conducts sourcing current, the amount determined by R301. Thus R301 defines the transconductance of the system at the frequency of peak gain.

Although the whole circuit may have a large ripple component because the +25 volt line has large ripple on it, this is not passed down to the op-amp because of the constant current output characteristic of the transistor.

The sourced current for a rise in load voltage in turn induces the drive to the output of the controller, effectively holding load voltage constant. Owing to the required Vbe drop of Q301 and that of D301 there is a small dead band before which the regulating action occurs, meaning that there is no effect for small signals. This, plus the bandwidth limitation of C301, assists stability and also



reduces the lag before the o/c detector responds. The bandwidth limitation is such that the turn-on pulse is not significantly affected. D301 also protects the transistor b-e junction against reverse biasing when a low load impedance is suddenly added.

Sudden load reductions, as in braking or collecting extra carriages, represent rises in the output transistor collector voltage, which serves only to turn Q301 further off so that its action occurs only at or near acceleration points.

overall. (i.e: reduce R4 and R7 to around half or a little more of the previous values.)

The second half of the problem, the effect of jamming whereby the train does not take off at all without mechanical persuasion, is not solved even by the voltage regulation technique. It was hoped that the initial impulse delivered at the point of accceleration would overcome this to a large extent, which it does, but it still occurs annoyingly often.

The effect occurs because the friction of the gears and engine mechanicals requires more force to be initially applied than is necessary to sustain movement. It is worse in certain designs.* The Hornby wormgear drive is again not the best way to do it. Also, engines with a higher top speed, and hence usually a lower reduction ratio, are worse. Oiling and cleaning are partially effective, but are not cures. It seems as though applying power in pulses is very helpful. this suggests that a switchmode power delivery scheme would be beneficial. I did not use a switchmode supply in the '1508 because, firstly, it did not seem justified as a power economising measure and because it tends to make engines 'sing' at the switch frequency. As the '1508 applies power, albeit a tiny amount, even when at a standstill, the engine would sing even when standing at a station. To apply the technique while avoiding obtrusive noise, excessive component count and disturbance and s/c and o/c detectors, is tricky. I have not solved this stumbling block as yet.

To summarise the needs and changes which should be implemented in a next design: **(1)** The o/c sense will be of an independant type, as is a s/c in the 1508, so that **(2)** one can use voltage regulation for frequencies above about 0.1 Hz and current regulation below this point. (This constrains the gain and configuration of the feedback loop in order to guarantee stability — for example, the drive must not permit the load impedance to affect gain of the final stage, as does the 1508 where it does not matter.**)

(3) The power delivery mechanism should be switchmode, with a frequency and duty cycle optimised for overcoming friction yet minimising noise. The circuit must apply pulses with a rate comparable to the armature time constant in order to exercise maximum force momentarily to overcome static friction, yet be fast enough to give smooth travel at low speed and hopefully be inaudible. It must also respond to input changes faster than the actual inertia of the train permits *it* to respond, and also deliver a current which it is practially possible to average out faster than the train can respond. The latter condition is necessary in order to maintain apparently slothful response in the actual model, despite real world effects like dirty contacts, which are instantaneous. ●

** This may also be due to demagnetisation effects, especially if you have ever made the mistake of dismantling the engine (motor) itself.*

*** This is the limitation of effectiveness of the modification suggested earlier. Any tighter regulation of train voltage at higher frequencies (than the circuit offers) gives rise to oscillation when load impedance rises, disabling the o/c indicator totally. Reduction of the BC557's 3k9 emitter resistor would tighten the regulation, smoothing response further, but permitting instability for large load impedance. Curing that by reducing loop gain bandwidth elsewhere defeats the turnon impulse. That resistor may be selected (1k-10k range) to give best train response for stability.*