Model Electronic Railway Group
TECHNICAL BULLETIN G16/51
Issue 1
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A Computer-controlled Throttle Unit

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This Technical Bulletin is included in the G16/xx series, dedicated to Gordon Hopkins' RPC and allied systems, since it is conceived as a complementary unit to work with, and use elements of, RPC. It is referenced as G16/51 to leave plenty of space for further Bulletins from Gordon....

Introduction

There are many circuits for throttles in the model railway world. Unfortunately the number that are computer controllable are few. I wanted:

- Good slow running
- Minimum component count – for ease of assembly
- Feedback (to reduce slow-down and stalling on curves and slopes)
- Not using Pulse Width Modulation (PWM) (because of the risks of demagnetising small motors)
- Low motor noise (some PWM throttles make the motors vibrate a lot)
- Computer controllable, from the MERG RPC system.

As none of the available commercial units or any of the published circuits met all of the above specification I picked parts out of lots of circuits, and created my own design.

Interface specifications.

• Power requirements	15VAC transformer secondary (one per throttle)
• RPC interface	8 bit port of MERG SRO4 module (refer to TB G16/7) 5V DC regulated supply from SRO4 module 1 relay from MERG DPR module (refer to TB G16/6)
• Output	0-12V RMS DC track supply for Z, N or OO scales (Current depends upon transformer rating and heatsink size) Output compatible with MERG FTC module (current detector) with 1Kohm bypass resistor. (Refer to TB 16/8)

Circuit description (refer to main throttle circuit diagram on page 2)

Slow speed running is achieved using a rectified, but unsmoothed AC signal (from D7 & D8). This gives a peak voltage (and hence torque) much higher than the RMS voltage which determines speed. As the output is unsmoothed, a 15V transformer is required (giving 23V peaks), even for N-scale. The average voltage, and volt drops in the circuit mean that the train will not go into orbit, even at full speed.

The transformer output drives a full-wave rectifier (D1, D2, D7 & D8) to generate the motive power, a separate feed for the amplifiers, and another feed which is the reference signal. The motive power connects only to the main drive transistor, so that the inevitable electrical noise on that circuit will have minimal feedback to the amplifiers. The amplifier supply is generated by pair of diodes (D3, D4) and is smoothed by C1 to produce 23V DC. The reference signal is yet another pair of signal diodes (D5, D6 with R4) to generate a full-wave rectified signal, of 23V peaks.

The computer interface capability comes from using a control voltage which can be generated from any analogue output port, where a zero volt input creates no output, and around 3V input creates full speed. Naturally this control voltage could be generated with a simple potentiometer if a computer interface is not required. The diagram shows the control voltage is generated by half an opto-isolator (IC2), more on this, and how it is driven later. This control voltage is first amplified by IC1a to produce a full 0-23V output (or as close to the supply rails as the amplifiers are capable of driving). This is then added to the reference signal by the resistor network R2 and R5. This control signal thus created is an 11V rectified AC signal, which can be level shifted between the supply lines by changes in the control voltage.

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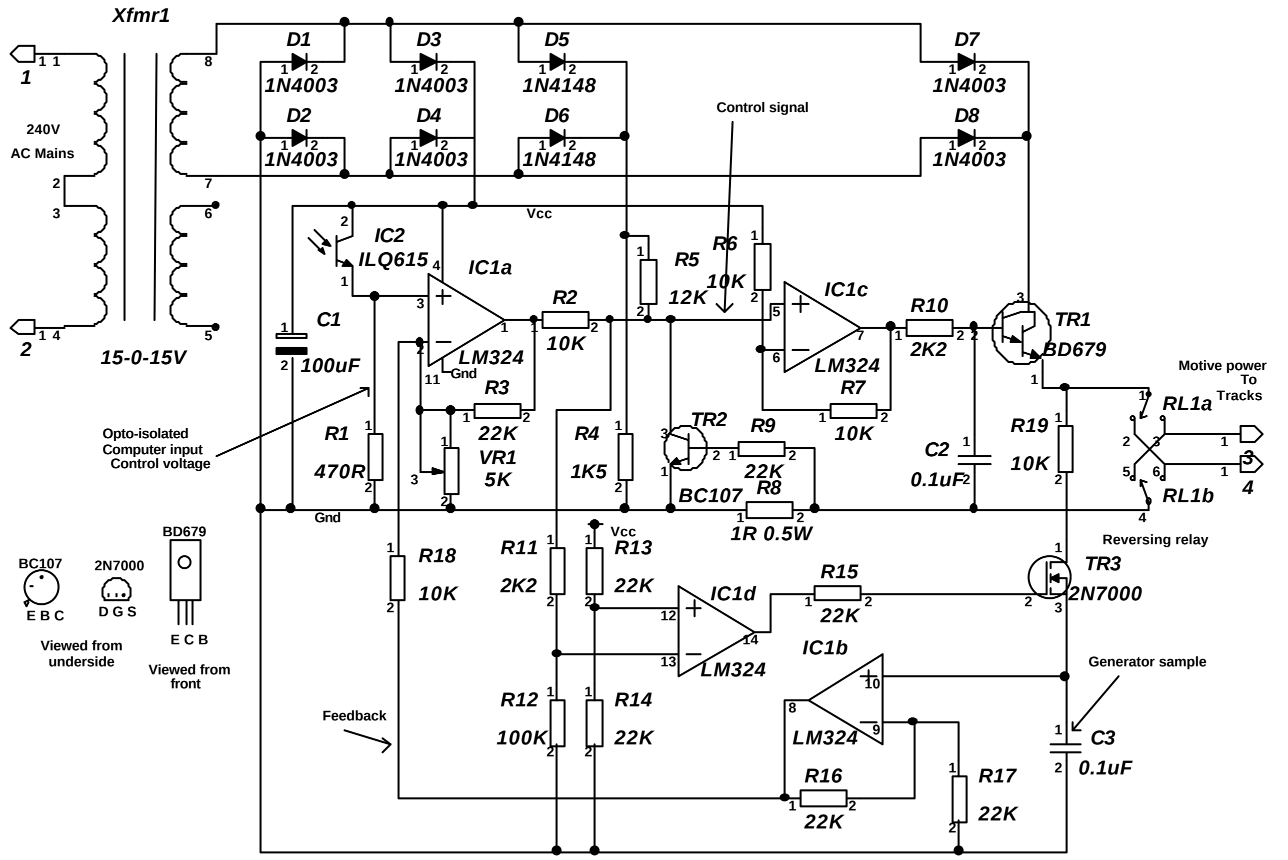
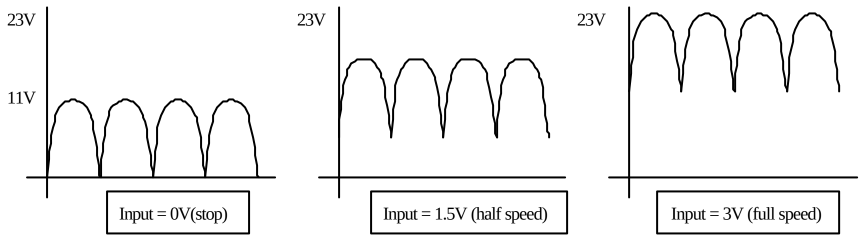
Main throttle circuit diagram

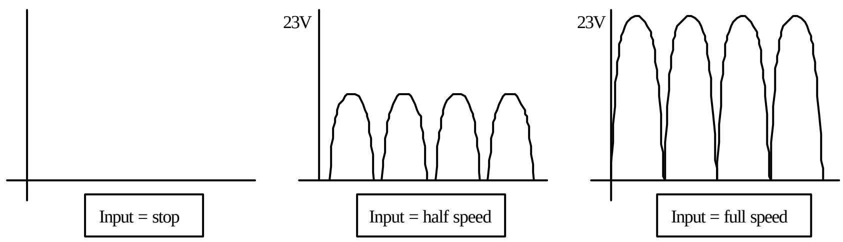


The **control signal** (IC1c – pin 5) looks like this:



This control signal is then fed to the output stage (IC1c) which has a gain of 2, but referenced from the supply, instead of the usual ground. This means that for every volt that the control signal is below Vcc, the drive voltage is two volts below Vcc, defined by R6/R7 (ignoring volt drop in the transistors). Whenever the control voltage is below Vcc/2, output is zero. The amplifier output drives a power Darlington which feeds the track. The network R10 and C3 act as a filter and stop the circuit oscillating. The level of the input control voltage that defines full speed can be adjusted by VR1. If you have several of these throttles connected to a layout in a manner that a train is passed from throttle to throttle then VR1 must be adjusted so that for a normal speed setting, all the throttles produce exactly the same output.

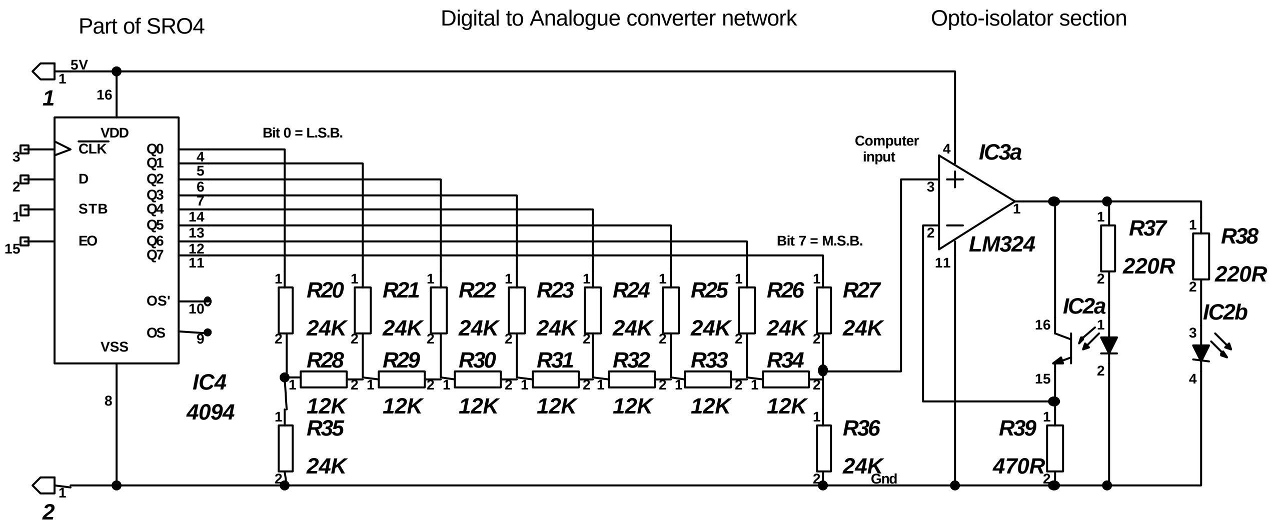
Output waveform



A current limit (R8, TR2) is applied to the output, as normal, which pulls down the control signal, if the output is shorted. The output voltage is then connected to a reversing switch or relay as normal. One relay on a MERG RPC DPR module is ideal for the purpose.

Opto-isolated input stage

It must be noted that once the reversing switch is added to the circuit we have the potential for common earth problems. You cannot common the ground line of several of these circuits because the switch might connect the ground to either the common return, or a track feed, depending upon the direction required. To overcome this problem each throttle must be electrically isolated, except for the common return on the track. This means that each throttle must have its own transformer secondary and an opto-isolated input. The throttle circuit shows a transformer with two independent secondary windings. The second winding could be used for a second throttle. A centre-tapped secondary is not suitable for driving two throttles, as the supply inputs would be tied together.
The input control voltage is generated from a D to A converter attached to an RPC SRO4 module and therefore all inputs start by being referenced from the computer's ground. An opto-isolator must be inserted to avoid the short circuit problems but opto-isolators are not known for having a linear response, and so the following circuit is used to improve linearity (note that IC4 (4094) is part of the SRO4 module):

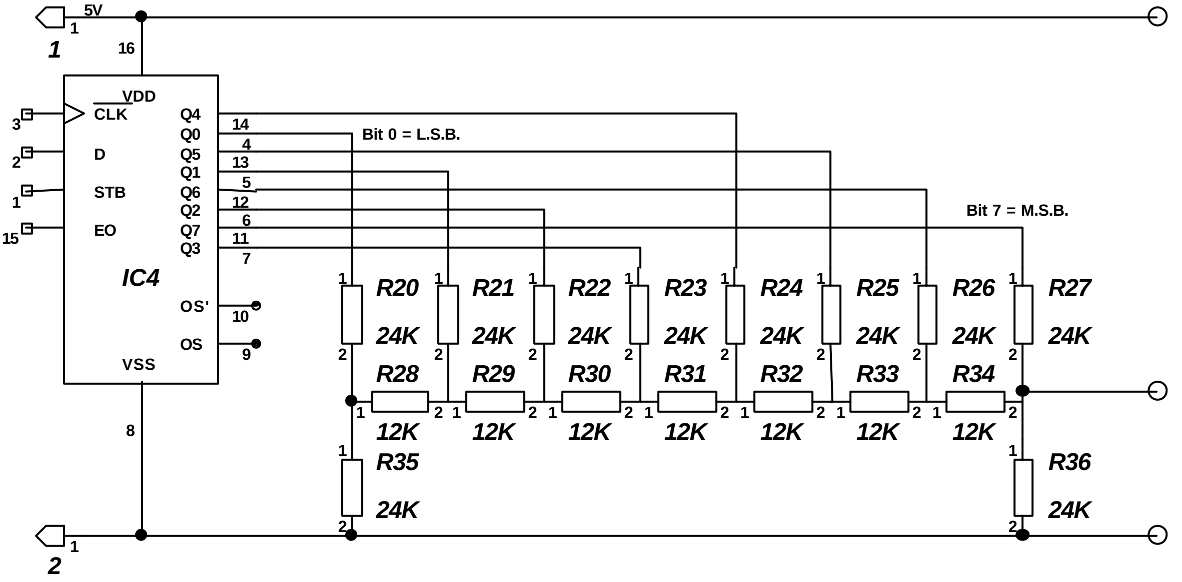


The resistor network R20-R36 is an R-2R network that converts a binary input signal to an analogue output conversion. The network is fed from one of the 4094 chips on an SRO4 module (the ULN2803A chip is not fitted in this instance). The network relies upon the outputs from the 4094 chip swinging reasonably well from supply to ground. As the CMOS chips have a fairly low current drive capability, high value resistors are used. The low current load on the 4094 means that the outputs should swing close to the supply rails. This results in a reasonably linear conversion (plenty accurate enough for our application).

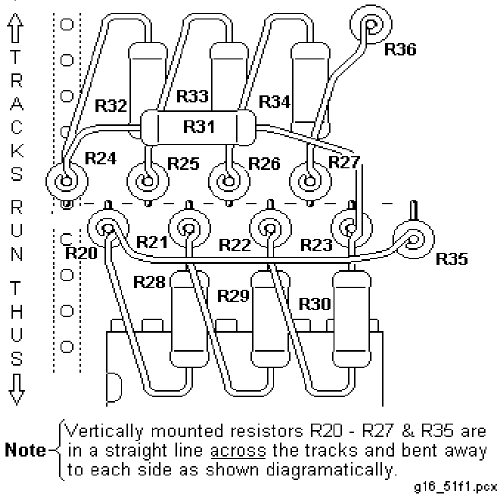
The op-amp (IC3a) ensures that the voltage on R39 is the same as the input from the computer. If the voltage across R39 is lower than the input, then the output of the amplifier will rise (subject to power supply limits), thus increasing the current through both LEDs and increasing the current thought R39 and hence the voltage. The amplifier drives two opto-isolators and we assume they are reasonably well matched so that the current through both phototransistors is similar. The second phototransistor is IC2 on the main throttle circuit. This circuit is fed from the 5V supply on the RPC stack. Only a quarter of an LM324 and half an ILQ615 is used in this circuit and so one LM324 and two ILQ615s can drive four throttles.

The end effect should be that the voltage across R1 on the throttle circuit is equal to the voltage controlled by the computer (IC3a, pin 3), but is electrically isolated from the computer.

The R-2R network can be assembled on the SRO4 module itself, in place of the ULN2803A output drive chip. As the pinout on the SRO4 module is adjusted to simplify the PCB layout, a layout oriented circuit diagram might be as shown on page 4 overleaf.



The sketch to the right suggest how the R - 2R network might be implemented
(based on a colour photo provided by the author. TB. Ed.)



Feedback

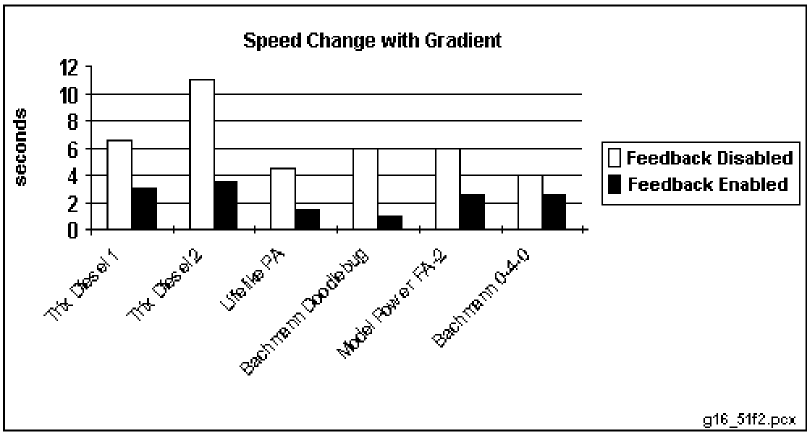
Feedback is handled by sampling the voltage generated by the motor in-between supply pulses. Comparator IC1d (see Main Throttle circuit on page 2) determines when the control signal is below Vcc/2, and hence when the output is turned off (as illustrated in the waveform diagrams above). When the output is off FET TR3 connects the output (which is now the voltage generated by the motor) to capacitor C2. The voltage on this capacitor now measures the speed of the motor, and hence the speed of the train. This feedback signal is amplified by IC1b and used to adjust the input control voltage.

When the feedback is small, the control voltage is increased, thus increasing the power to the train. This means that when the train goes around a corner, or up a gradient the power increases to compensate.

This feedback mechanism will not make all trains go at exactly the same speed for all tracks, but it will reduce the variability enormously.

For example, using a selection of Locos on the flat, or up and down a 1:20 gradient (yes, a quite extreme test, but they weren't pulling anything) the times taken to cover the 1m test track (in seconds) are as shown below. The 'delta' column shows the spread – the difference between the up-hill and downhill times. The spread is in essence a measure of the quality of speed control where the lower the value the better the control. In order to ensure a constant baseline figure, the time to cover the level track with each loco was set as close to 10 seconds as possible.

Loco	Feedback disabled				Feedback enabled			
	Down	Level	Up	Delta	Down	Level	Up	Delta
Trix Diesel 1	6.5	10	13	6.5	8.5	10	11.5	3
Trix Diesel 2	6	9.5	17	11	8.5	10	12	3.5
Lifelike PA	8	10	12.5	4.5	9.5	10	11	1.5
Bachmann Doodlebug	9	10.5	15	6	9.5	10	10.5	1
Model Power FA-2	9	10.5	15	6	8.5	10	11	2.5
Bachmann 0-4-0	7.5	9	12	4.5	8	9.5	10.5	2.5



This chart clearly shows the benefits of using a feedback throttle.

Feedback controllers have a general problem in that most current detectors insert diodes in series with the track feed. This means that a volt or so is subtracted from the motive power voltage, which doesn't matter much, but it is also subtracted from the generated voltage as well.

As the generated voltage is relatively small the diode volt drop has a significant effect on the feedback effect. To address this problem a current detector is required that drops less voltage, especially when measuring the generated voltage. This can be achieved by connecting a 1Kohm resistor across the detector terminals.

Components

Most components are fairly non-critical. Similar substitute components may be used in most cases. The component types shown are simply those in the RS catalogue that were the cheapest.

- TR1 needs a reasonable gain, assume 1mA base current, so a gain of 1000 for 1A output is required.
- Transformer 1 can be any with 15VAC secondary and a current rating sufficient to drive one train.
- TR2 can be any NPN transistor.
- TR3 in an enhancement mode N-type Field Effect Transistor. This means that as the gate voltage is raised above the source (pin 3) it starts to conduct. Any device that conducts with a gate voltage of 3-10V should suffice.
- R9 needs to be rated to suit the current you need. Assume 0.7V during a short circuit, power = V^{2x} I = ½ So a 1A supply needs at least a half-watt resistor (which would get very hot during a short circuit).
- IC2 can be any opto-isolator with a transistor output. A current transfer ratio in the range of 50% to 200% is assumed.
- D1, D2, D7, D8 need to be rated for your current load, so any 1N4000 series diode will suffice up to 1A.
- TR1 requires a heatsink, but with an insulating washer you can put several on a single heatsink (see picture)

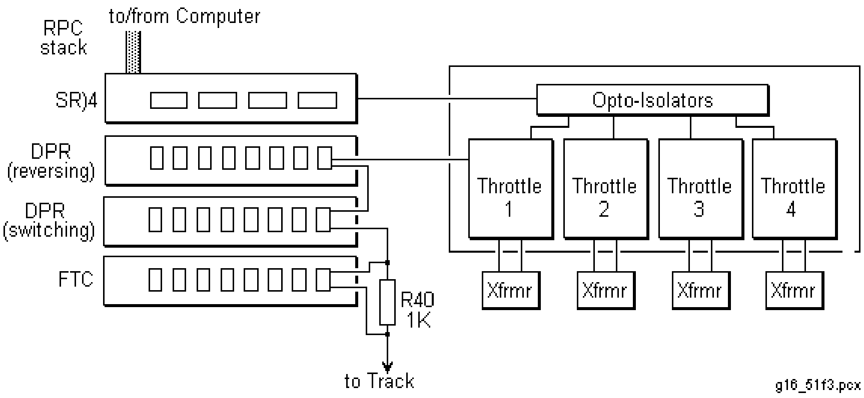
Parts list

IC1	LM324	D1-D4, D7, D8	1N4001
IC2	¼ILQ615	D3, D4	1N4148
IC3	¼ LM324	C1	100uF 35V
IC4	¼ RPC SRO4 module	C2, C3	0.1uF
		Xfmr1	15VAC
TR1	BD679		
TR2	BC107	RL1	DPDT relay from RPC DPR module
TR3	2N7000	Detector	1/8 MERG RPC FTC module
VR1	5K preset		
R1, R39	470R	R10, R11	2K2
R2, R6, R7, R18, R19	10K	R12	100K
R3, R9, R13-R17	22K	R20-R27, R35, R36	24K
R4,	1K5	R37, R38	220R
R5, R28-R34	12K	R40 (across FTC)	1K
R8	1R ½W		

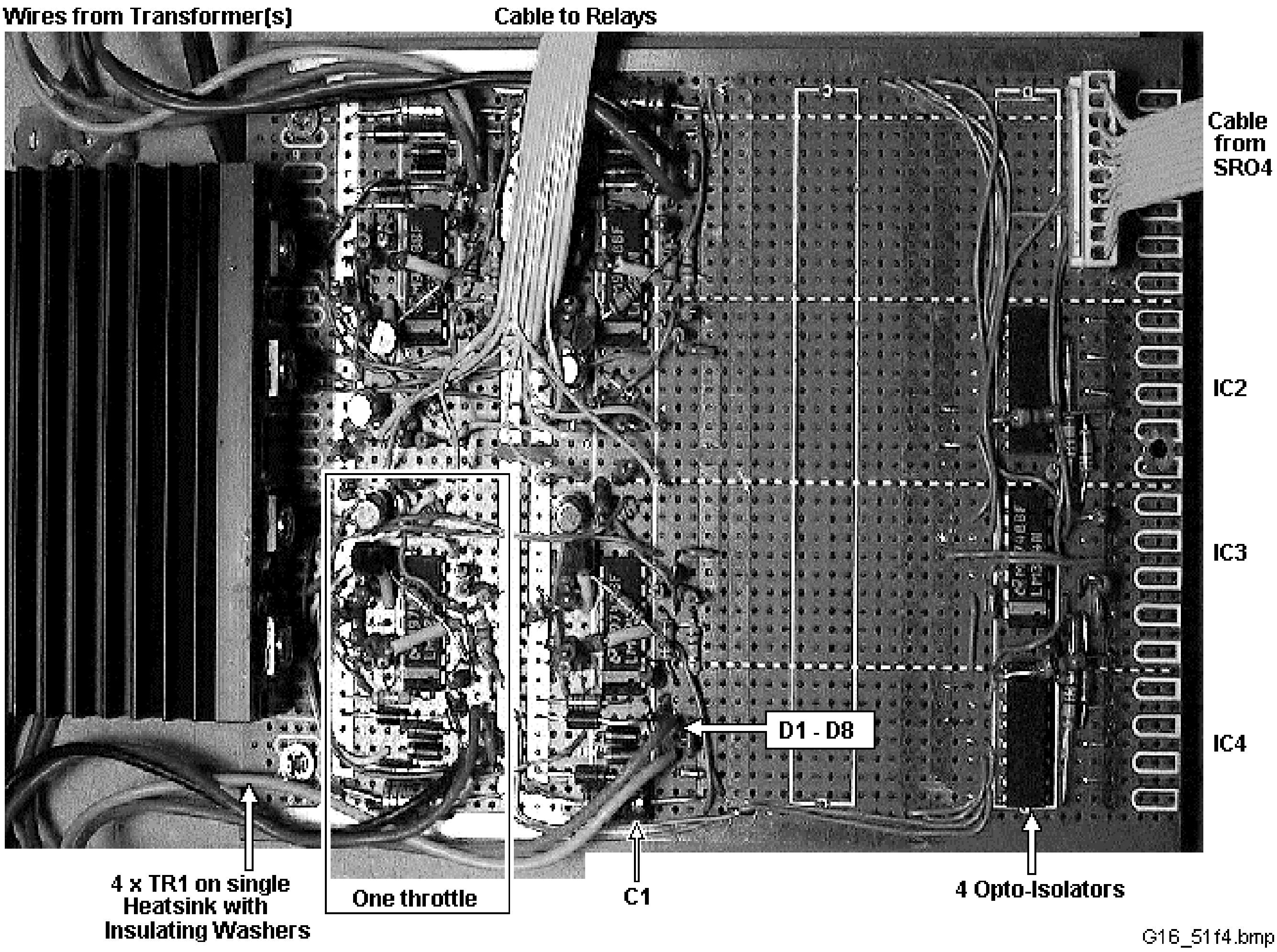
Connecting it all together...

The schematic looks something like this:

(Note: each throttle must have its own transformer, or at least electrically separate low voltage windings.
Using the halves of a centre-tapped secondary is _not_ permissible.)



and here's a picture of the prototype on which this Technical Bulletin is based. It shows four Throttles assembled on one board, with opto-isolators.



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