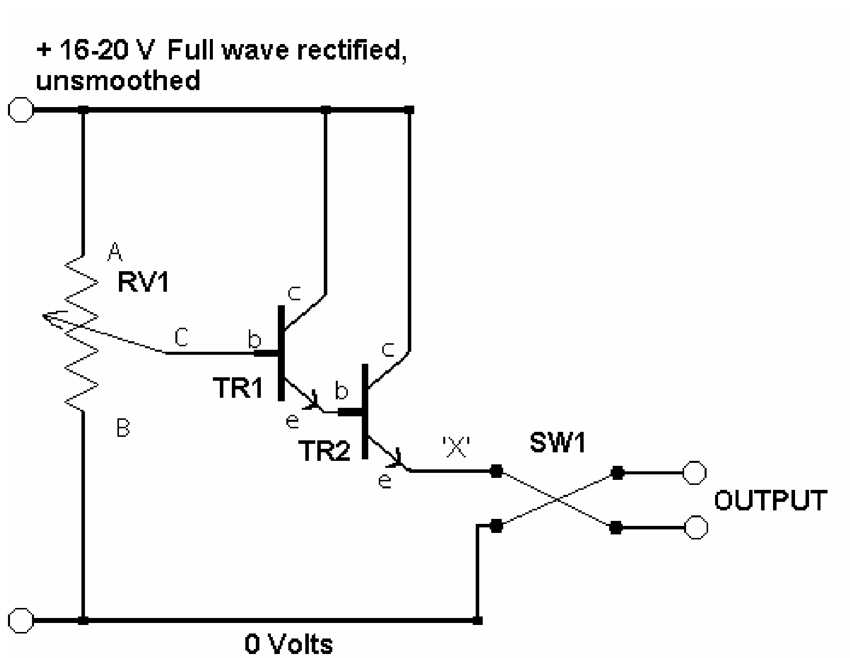
A Simple Controller

How it works

RV1 is a potentiometer, or variable resistor. The one chosen has a resistance of 10 kOhms (ten thousand ohms) between the ends A and B. A small current will always flow through this resistance. At the nominal voltage of 20 volts, this current is only 2 mA (two thousandths of an amp - not enough to light an LED). The third terminal, C, is connected to a slider, which "taps off" a percentage of the resistance. The percentage is proportional to the number of degrees that the knob is turned - when turned through half a turn the resistance tapped is half the full resistance. When used in the form shown, in effect the voltage on the slider is also proportional to the degrees turned. In theory, this voltage could be provided to the locomotive, and speed would be proportional to the position of the slider. However, the resistance left in circuit would prevent enough current being supplied to turn the motor. Hence the transistors.



RV1 - 10 kOhm Linear potentiometer (Speed)
TR1 - BC 547 NPN Transistor
TR2 - TIP31 NPN Power Transistor
SW1 - Double pole changeover switch (forward/reverse)

TR1 is a medium power transistor, with high gain (or current amplification) of 300 - 400 times. The current entering terminal b - the base, is amplified to provide a higher current from terminal e - the emitter. This transistor still cannot handle the currents required by the motor however.

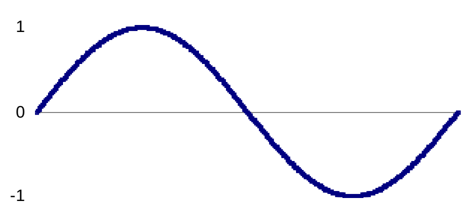
TR2 is a power transistor, capable of several amps. Its gain is about 40 times. This can handle the required motor current. In combination with TR1 the arrangement is described as a Darlington pair. The current drawn by the motor, from TR2's emitter, is reduced by a factor of 12,000 to 16,000 at the base of TR1. This current does not change the voltage set on the slider of RV1 appreciably, so the voltage at 'X' follows the voltage on the slider, and TR2 is described as an emitter follower.

There is a small penalty to pay, in that a voltage drop of 0.6 volts exists between terminals b and e of each transistor. Therefore, the actual voltage delivered to the motor is 1.2 volts less than the slider setting. This reduces the overall maximum voltage available to 20 - 1.2 = 18.8 volts, but since most locomotives will move at a good speed with less than 12 volts, this is not material. The effect also ensures that no voltage will be applied to the motor until the slider voltage is greater than 1.2 volts, and there is therefore a positive "off" position for the speed control.

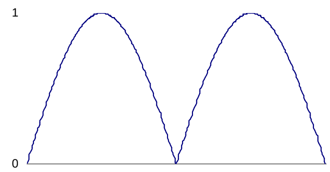
The speed versus voltage characteristics of different locomotives will differ with the motor type and final gearing. However, for any one locomotive, with the speed control set to any position (e.g. a quarter turn) the locomotive will accelerate until the voltage created by the motor (back emf) is equal to the setting voltage less a small voltage due to the current in the motor resistance. If the locomotive meets an additional load (e.g. going uphill) the motor will slow down and the back emf reduce. The voltage at point X does not change, however, so the voltage difference drives additional current through the motor, causing it to speed up until the voltages are balanced again. All this happens of course, faster than can be described. The resulting speed will be slightly lower, since there is an additional voltage drop in the motor due to the additional load, but this drop off will not be too noticeable.

Similarly, if the motor tries to speed up (e.g. going downhill) the motor back emf will increase. This effectively attempts to reduce the voltage drop across the b-e terminals of the transistors, which then reduces the current available from the combination. Therefore, the motor will now slow down until, again, the voltages balance.

If the controller were operated from a perfectly smooth direct current, in theory the motor would run smoothly from very slow speed, up to full speed. However, stickiness in the mechanism, and dirty contacts mean that a higher voltage is needed to start the motor moving, than to continue. So called "pulse controllers" have been produced to give a short, higher voltage pulse with varying "off" periods to overcome this. However, this simple controller makes use of the properties of the transformer/rectifier from which it is powered. The transformer reduces mains voltage to a safe level of about 15 volts. This voltage changes direction from plus to minus at 50 cycles per second (alternating current). This voltage rises from zero in a curve to maximum plus, back to zero, to maximum minus, and back to zero (a sine wave) thus:



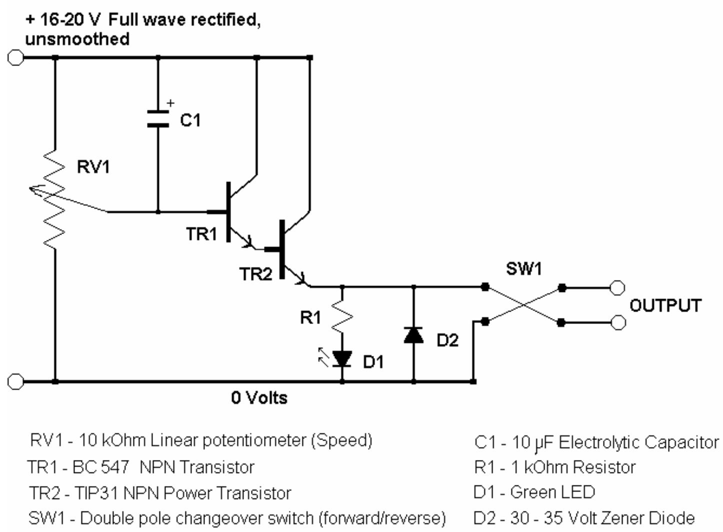
The rectifier takes the negative parts of the cycle, and turns them round to always go positive (full wave rectification):



It will be seen that the voltage appears as a sequence of "peaks". Thus the maximum voltage presented to the motor is higher than the average, which produces the necessary "kick" to get the motor moving, but means the motor speed is controllable.

The switch reverses the power to the track, and therefore the direction of the locomotive.

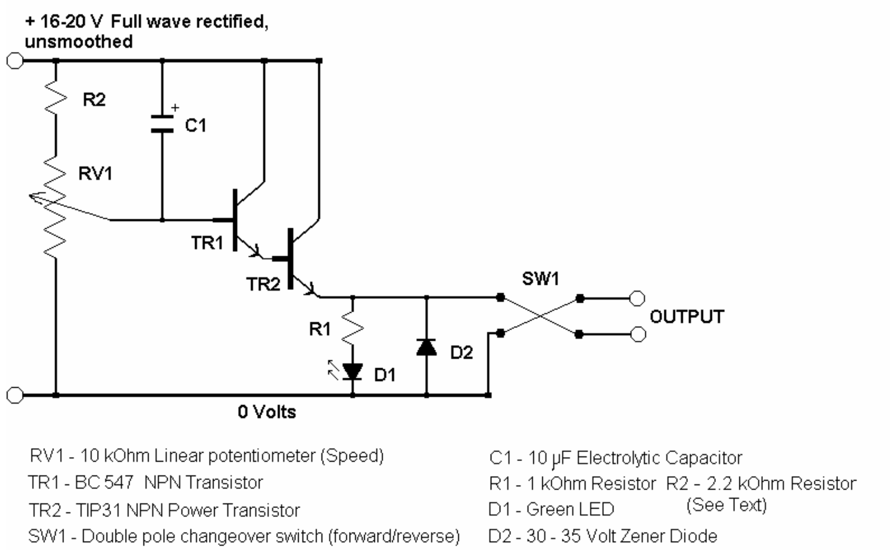
Sophistication



The LED (D1) and resistor (R1) are connected across the output of the transistor. The brightness of the LED increases with voltage, and therefore acts as an indicator that the controller is working.

Diode D2 is an added luxury. When the motor is spinning, occasional dirt on the contacts or track can cause momentary interruptions to the current. This can produce a short spike of high voltage back into the controller. Also, since the controller should be operated from unsmoothed direct current, in theory the current to the motor is cut off momentarily 100 times a second. The motor however continues to spin, and generates its own current, which produces a reverse voltage across the output. These effects may damage the transistors. To some extent, the LED helps to quench the overvoltages, but may itself be damaged. Diode D2 is a zener diode, which will conduct normally in the forward direction, but will not conduct until more than 35 volts appears across the terminals, in the reverse direction. In this application, the diode is reverse biased by the controller voltage. Since the controller will not provide more than 18 - 20 volts, the diode remains non-conducting. As soon as a voltage higher than 35 volts appears on the output, the diode conducts, and shorts this safely away from the controller. Similarly, any reverse voltages will be limited to 0.6 volts by this diode. Having said this, I have operated this type of controller successfully without D2 being fitted.

In its basic form, RV1 as described produces an output voltage proportional to the degree of rotation. As described above, the output voltage is "pulsed" from the supply. Capacitor C1 helps to reduce the time for which the voltage is close to zero, and thus reduces the heating effect in the motor.



The final, optional, component is R2. This is used to reduce the "top speed" of the controller if it is found that use is normally made only of the lower end of RV1. Its value may be found by experimentation, but with the recommended value of RV1 (10,000 ohms) R2 should be from 1000 - 3000 ohms.

Since there is no inbuilt protection against short circuits, the controller should be powered by a transformer with its own overcurrent protection. Alternatively, a suitable 3 Amp fuse should be used in series with the +ve connection to the controller. The Transistor TR2 should handle an overcurrent up to 3 Amps without harm until the fuse operates. In any case, rarely will the controller be set at full volts, and most overcurrents will be less than 1 amp. The output current capacity of the transformer should be chosen to be 1 to 1.5 Amps.

Construction

No layout is given, as in most cases the few components may be assembled using “tag strip”. For example, the Diodes and R1 may be assembled onto the terminals of Switch SW1. Also C1 (and R2) may be soldered to the terminals of RV1. The final version might be built on matrix board. **Note** – Whatever method is chosen, ensure that TR2 is mounted onto a substantial heat sink – either ready made, or a suitable length of aluminium sheet, bent to suit the enclosure. The enclosure may be any suitable plastic box, and I have succeeded in fitting the parts in a tapered box that fits easily in one hand as a “wander” controller.