Bringing Light to the Little People' or 'Light out of Darkness'

[Included last Month: Prelude to Coach Lighting]

by Phil Spiegelhalter - Solent Area Group

Introduction to this month's Lighting Article:

The article was originally written, a few years ago, to encourage the home-addition of LED lighting to coaches in 00/H0 to G, to replace the short-lived bulbs, which were still prevalent, and particularly, on digital layouts, where the short-life of bulbs becomes very apparent.

The addition of lighting, in general, is worth encouraging because it helps extend the hours an outdoor layout can be appreciated, by extending the 'service' into the late evening hours of weekdays as well as weekends. What can be more enjoyable than relaxing on a warm summer evening by the BBQ, than seeing trains running around an illuminated garden landscape.

Energy saving LED replacements for traditional bulbs are now mandatory for most household uses.
Direct plug-in replacement LED-bulbs are also available for many low-voltage lighting applications.

Ready-made self-adhesive reels or PCB strips of mounted LEDs have become more widely available, at much lower prices per 5m, in yellow, warm & cold whites. Therefore there is less need to design your own circuitry - so treat the examples which follow as a background explanation of the designs. Original and Third Party manufactured Ready-to-Install boards are also available.

The self-adhesive reels/ PCB strips are easy to use ***if*** the specified 12.00V / 24.00V **maximum** specified voltage is kept to. Using an unregulated supply, or 14V for example, can double the current !
[Always use the corresponding 12Vdc or 24Vdc SMPS - regulated power supply for fixed installations]

Also, Train-Tech have introduced (for 00/H0 and N) self-contained Lithium coin cell powered lights which detect movement to turn on and off automatically, and need no additional wiring. Other lighting kits and modules are available.

Bringing Light to the Little People

Replacing Small Bulbs with LEDs in LGB / G-Scale Stock (or 00/H0 etc...)

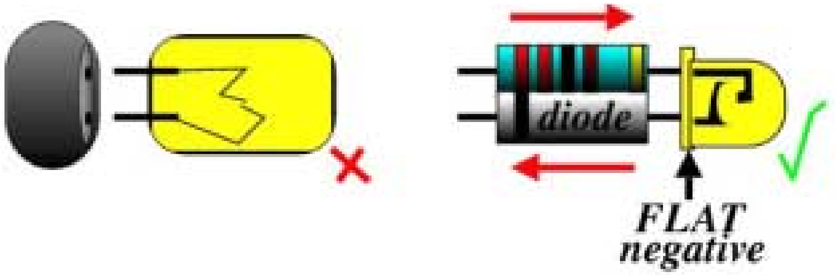
LED = Light Emitting Diode

Why?

Particularly noticeable when you progress to Digital (MTS/DCC or Mfx) is the added benefit of Constant-Brightness or On-Always Lighting in coaches and locomotives etc. The downside is that the bulbs fail more frequently ....because you are using them more!

Options:

Save the environment and Track Current - Change to LEDs E.g. Tail Lights of Post Van: 2 Pin 'plug in lamp' replacement...



A Resistor to limit the current to 20mA or less
A Diode for Protection
An LED for the Light (Any Colour)

An option *in locomotives*, when they are MTS/DCC or Mfx fitted, is to 'turn down' the brightness by giving new values to each output: (by programming the relevant 'CV's - but the numbers used may vary between makes and models of decoder).
This is also effective for when they are then run on an analogue layout.
All the essential, basic features of any make of decoder should be programmable on any programmer.
Programming is very easy when using either the LGB / Massoth - PC Interfaces - on a PC - as it is plain English and Tick boxes.
Free software is also available (such as JMRI) which works with a SPROG - which is a small computer-controlled dcc System.
Sound Decoder manufacturers also offer programming units which can be used to configure or totally re-program their decoders.

What Values? (or WATT values?)

This depends on which bulbs you are replacing, the colour of the LED, and how bright you want it!
In many coaches and locomotives, the bulbs used are only 5V - supplied via a regulator (You may be able to recognise these under Analogue as they come on about the same time as the train moves, and then stay at constant brightness).
In Goods Vans, or Post-Market lighting the lamps may be directly off the track - which is 18-22V dcc.

Remember:

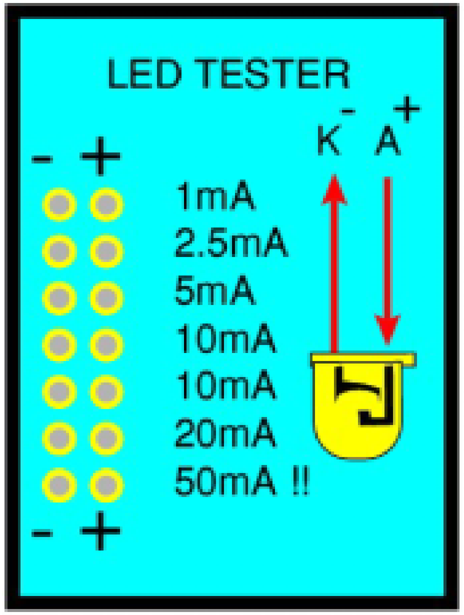
The DEFAULT values on the decoder lighting/function outputs are FULL VOLTAGE and Brightness.
(But if fed via an on-board regulator these will be 5V - so adjust the settings and choose your level)
MTS/DCC or Mfx is a.c. on the track, and many LEDs will FAIL instantly if more than 5V is applied in the wrong polarity.
Flashing LEDs will fail with only 0.5V of the wrong polarity!

Identifying LED Polarity

The 2 Standard Definitions are ' The FLAT SIDE' is the CATHODE (Negative) side (as above). The Longest Leg identifies the Anode (Positive) Side - *but this only works BEFORE you cut it!* With Surface Mount Devices, the identifier may be an angled corner. EYESIGHT can be SAVED in many cases by buying pre-wired LEDs with wires and sometime resistors already fitted. This is particularly true of the smaller sizes of 1mm or less ! Ebay can be a useful source.

LED Tester

A Small LED-Tester is about £8 and allows you to test them safely and also choose what current you want to have - which then chooses what resistor value you'll want (PP3 Battery is Extra). The box contains a PP3 9V Battery, and each contact-pair gives the stated current drive for the LED. It is safe to get it wrong on the low values! So for an unknown LED try it each way in the 5mA or lower contacts first. I have found the Kemo model reliable for all colours of LEDs.



KEMO LED Tester

Calculating the Values

For LGB Assume the maximum possible 24V on track (Theoretically 22V in dcc, 0 - 24Vdc)
An LED 'drops' (uses) 2V if Red//Yellow/Green (approx) A Blue or White LED may drop 5V
(More Energy is required for the Blue and Violet end of the spectrum)

That leaves 22V for the Resistor (for a Red LED) or 19V (say 20V) for a White LED
V= I × R (Voltage = Current × Resistance) 20V = 20mA × 1 k Ohm
S.I. System International unit prefix-multipliers are: m = 1/1000 × k=1000 × **M**=1,000,000 ×
20V = 10mA × 2k Ohm (approx) = my recommendation for G
10V = 10mA × 1k Ohm for Lower DCC/Analogue Voltages (00)
Many LEDs are now 'superbright' and only 5mA is needed!

POWER to all my Friends (and Apologies to Cliff Richard)....

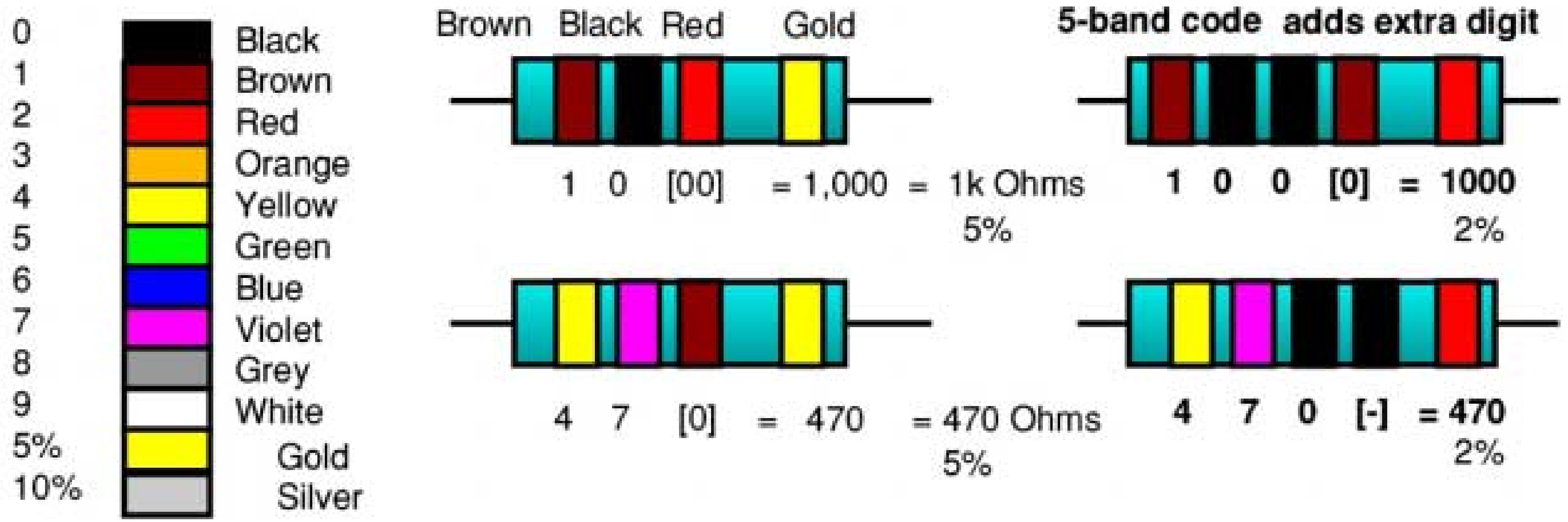
Common 1/4 Watt resistors will suffice for most uses
Power = Current × Voltage P = I × V = 10mA × 20V = 0.010 × 20 = 0.200Watts (¼W resistor pack 480 for £5.49)
However if you want very bright 20mA @20V, then ½ **Watt** Resistors should be used (or 2 parallel ¼W)

It is NOT economic to buy individual resistors - consider your fuel, parking and other costs! The easy way to buy, and have some stock for choice, is to buy a Blister-Pack of ¼W Resistors (Assorted). The Packaging probably has the Colour-Coding of the Resistor explained as well ! Ebay is now also a good source for small quantities.

COLOUR and Preferred E - Values

Traditionally Resistors are marked with Coloured Bands representing the Value (Impedance) in Ohms.
Read the 4 or 5 Bands - with the separated band off to the right (Probably Gold and shows Tolerance)

The first 2 or 3 read as digits, and the next as the number of zeros (Multiplier)
Spectrum is Green and other colours......ROYGBIV Richard Of York Gave Battle In Vain
For Resistors (and some Capacitors) we need 10 digits: therefore 10 colours plus Gold & Silver (& 'body')



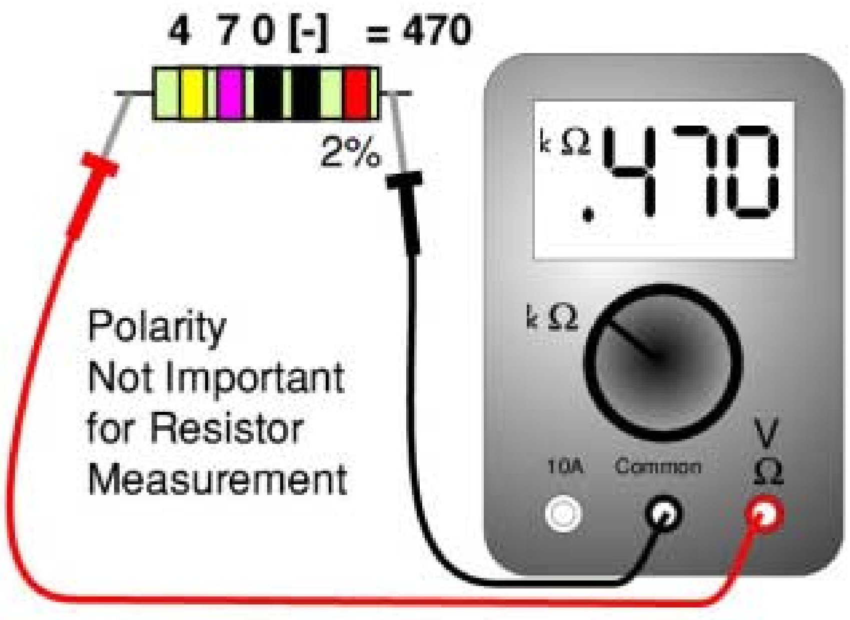
Preferred Values - E-Series are the *equivalent* of the notes making up an octave: a *regular pattern* of steps from 'Middle C' or from 1 for Resistors, to the next decade i.e. 10, 100, 1000 etc
In the 'old days' of 10% Tolerance, only 6 values were needed, with 5%, there are 12 useful values....

1	1.2	1.5	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2	[10] E12 Series (12 values per decade)
10	12	15	18	22	27	33	39	47	56	68	82	[100]
100	120	150	180	220	270	330	390	470	560	680	820	[1000]
1k	1k2	1k5	1k8	2k2	2k7	3k3	3k9	4k7	5k6	6k8	8k2	[10k] (k in place of decimal point)

It is particularly important NOT to misread the 3rd / 4th Multiplier Band as this not part of the E Series !!
Under Artificial Light (especially fluorescent or LED) it *is possible* to confuse some colours - so as a double check, use a Meter:

Multi - Meter - Versatile Indispensable Reliable - Manual or Auto Ranging AC and DC   A.V.O.

If you run a model railway, you SHOULD have a (Digital) Multimeter which will MEASURE the Resistor for you as a double-check, as well as being able to check:
'Continuity', Voltage and Current.

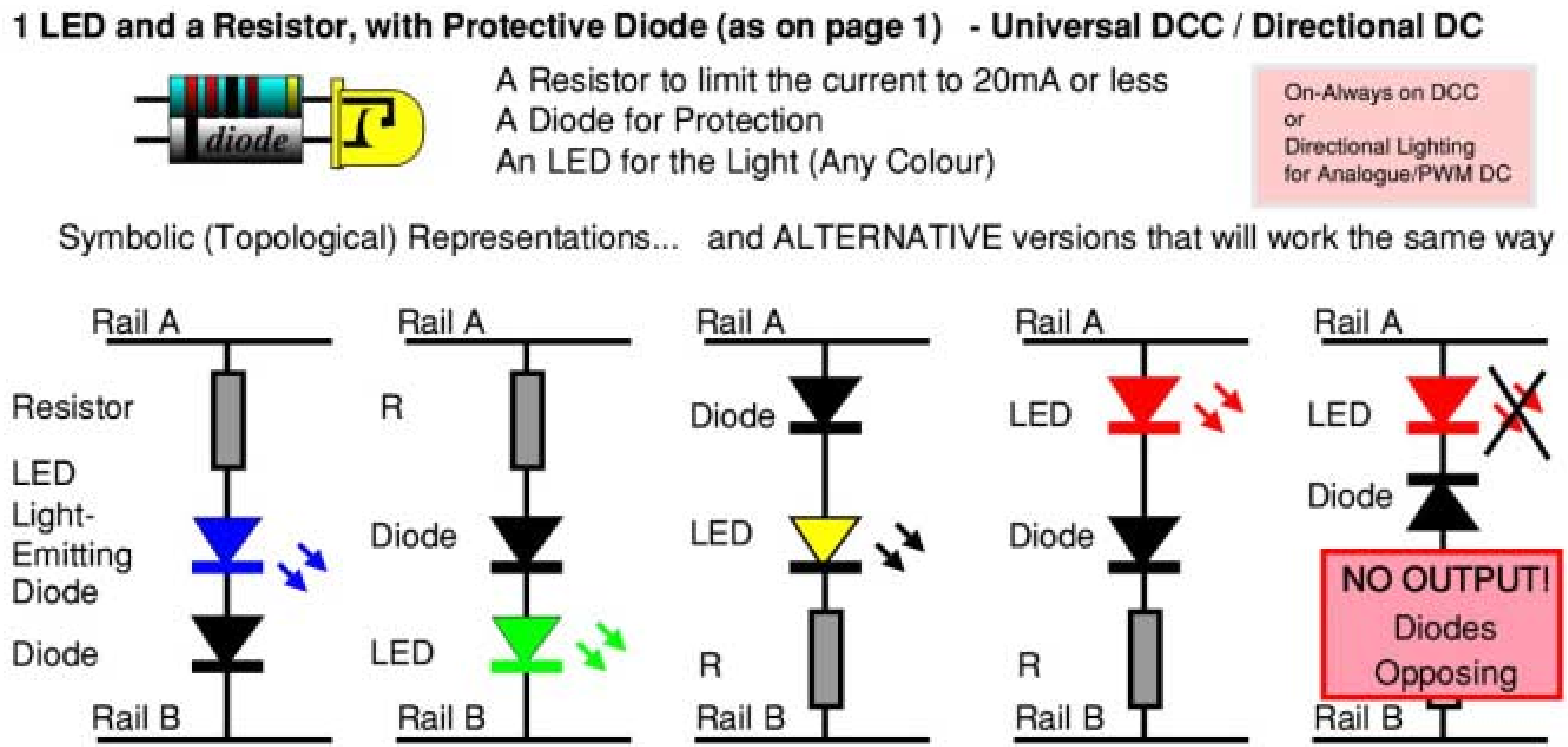


Caution:
INDUCTORS (often near motors) may look like Resistors!

January's Newsletter included a Guide to making a cheap voltage monitor using an Automotive LED Voltmeter Module, and 4 1N4148 diodes, and some wire, for about £5.

Reverse-Failure Protection using a Protective Series Diode

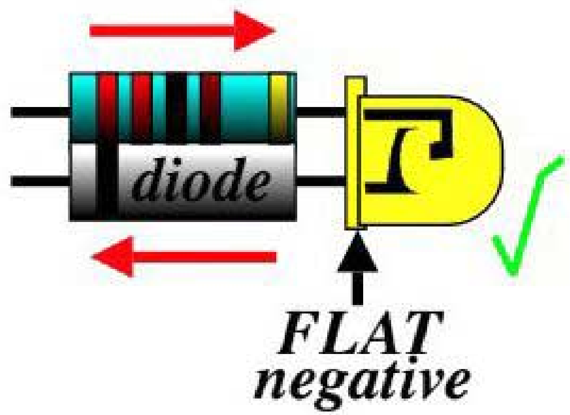
Prevention is Better Than Cure: (Especially when it costs only 1p per 1N4148 diode in bulk). Diodes will start conducting in the 'Reverse' Direction above a certain voltage (the 'Zener Breakdown Voltage'). Some designs such as Zener-Diodes are designed to operate continuously in this way (and provide voltage regulation) However, LEDs will heat rapidly and FAIL if (typically) 5V or more is applied in reverse. Special Flashing ICs built-in to Some LEDs will fail with only 0.5V (a 'diode drop') applied in reverse.



EACH of the different circuits shown, except the last, will light the LED when 'Rail A' is +ve compared to 'Rail B' -ve.
In EACH case, the order of components is NOT important - ONLY the ORIENTATION of the Non-Linear Devices (Resistors, pieces of wire, light bulbs, switches etc are LINEAR and will work 'either way round')

[There is Another Way .... Reverse-Parallel LEDs .... discussed later]

Note: I do not describe either rail as 'Zero volts', as we are ONLY concerned with potential DIFFERENCE.
The standard diode is there to protect the LED from Reverse-Voltage - its cost can be as low as 1p



The Diode used in this 'DCC' circuit only rectifies HALF the waveform - pulsing the LED nearly 10,000times/second (nominally 8,600 Hz)
However, on a DC layout this would become either ON or OFF depending on the track-polarity (direction of travel)

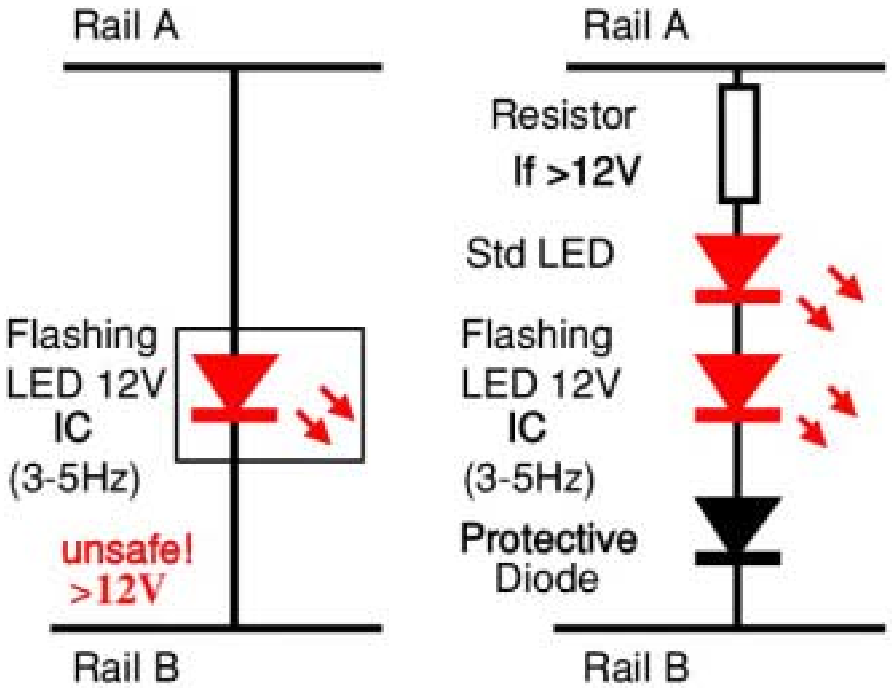
Flashing LED ICs and 12V LEDs

A ready-made LED with in-built flashing circuit does not require an external resistor if used on the stated voltage (usually 12V) The REVERSE voltage accepted is ONLY 0.5V!
A protective diode in series is advised unless the polarity is assured 100%.

Standard LEDs can be added in series which will then flash at the same time.
Add the resistor for higher voltages > 12V + extra LEDs

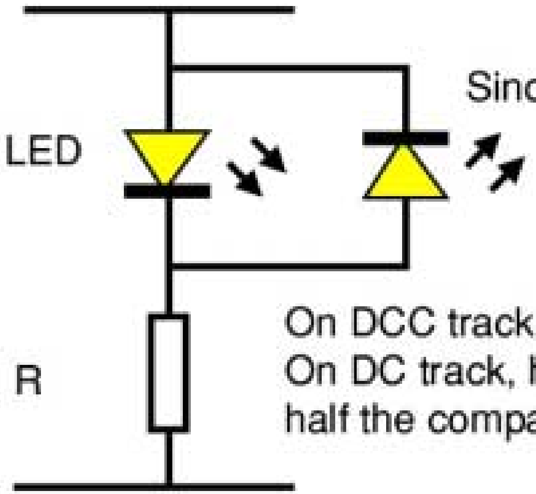
Similarly, LEDs designed to simplify assembly in the Car Industry by having an inbuilt resistor assume 12V for the quoted current, and this will increase rapidly on higher track voltages.

Obviously an additional resistor can be added in series, but it would usually be easier to use a standard LED. Reverse breakdown is normally 5V.



Back to Front / Inverse Parallel LEDs - Inbuilt Reverse Voltage Protection

By preventing the Reverse Voltage from ‘building up’, with a matching parallel LED facing the other way, the LED is protected from such failure.

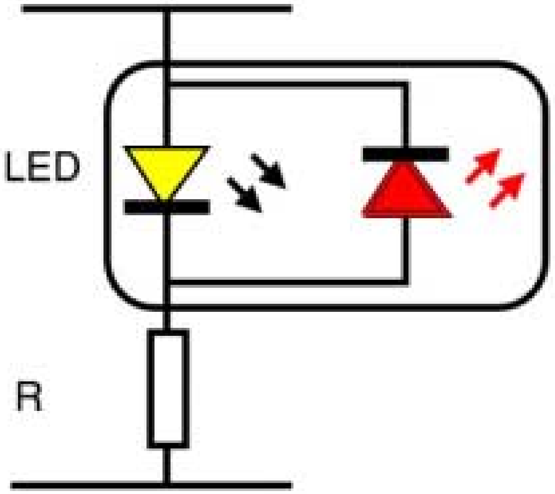


Since each LED Forward-conducts at 2-3V, the voltage never reaches 5V

On DCC track, each LED is on for 50% so could take 'double current' for 1/2 the time
On DC track, half of the lights will come on in each direction - so half brightness or half the compartments lit - with the others lighting when travelling the other way.

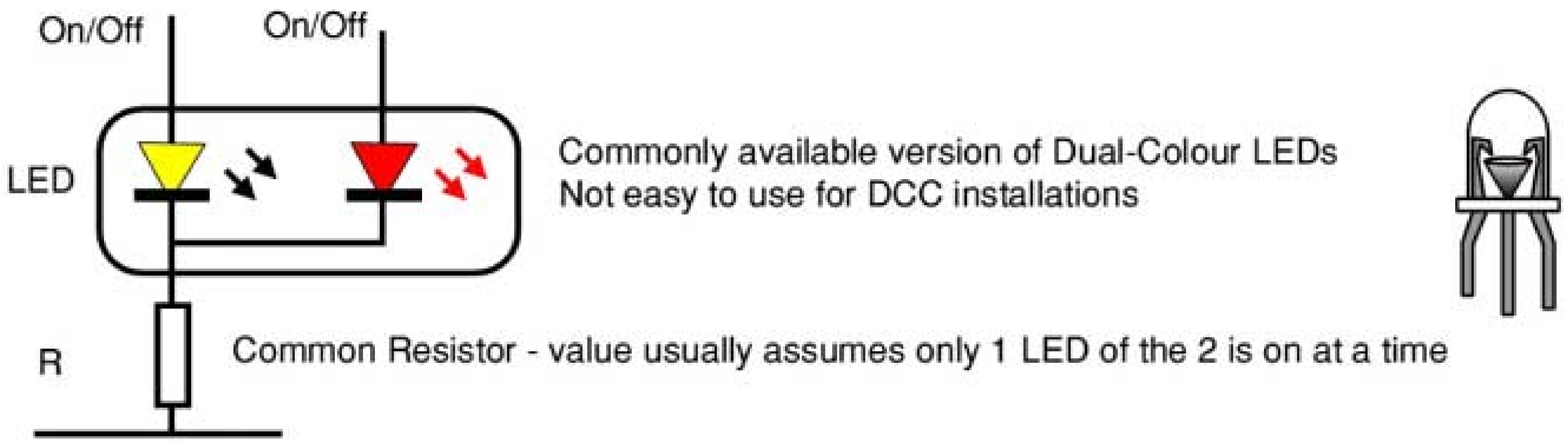
Back to Front / Inverse Parallel LEDs - Bi-directional Lighting in Different Colours e.g. Red / White

Some Manufacturers offer 2-colour LEDs in one package, using just 2 leads - these conduct in opposite directions.

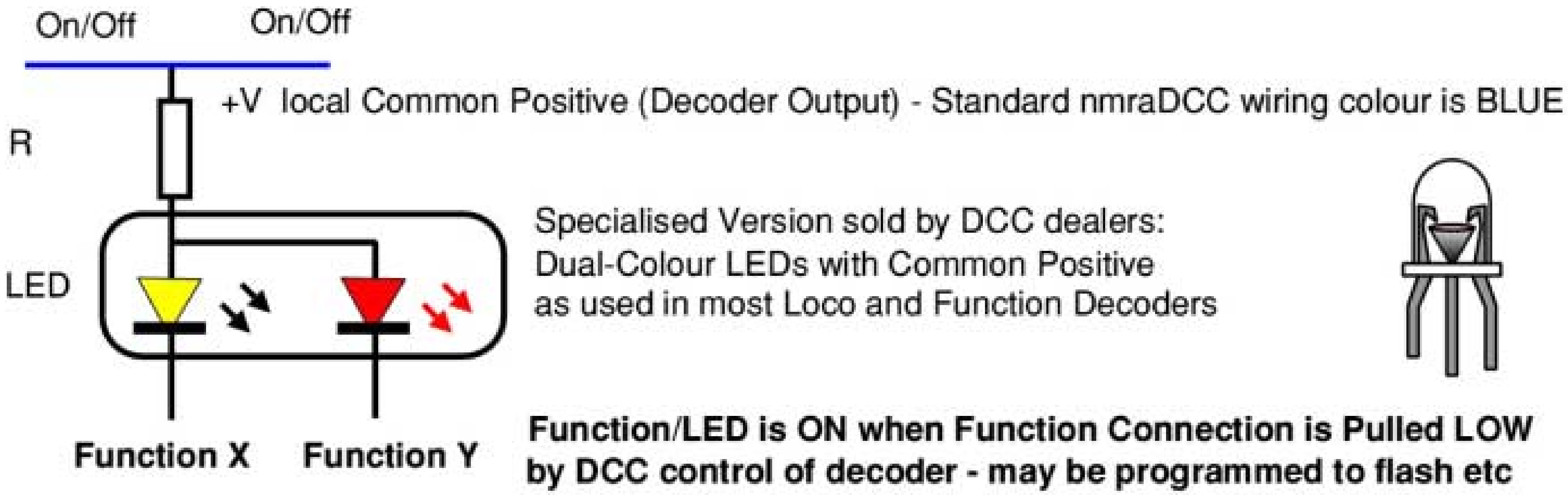


Compact 2-wire connection - but NOT really comptible with DCC
ALTHOUGH they could be used in parallel to the 'Motor' outputs :
However, they would go out when the loco stopped.
This situation ALSO occurs in some pre-fitted models with LEDs

Common Cathode (Negative)- 3-wire Bi-directional Lighting in Different Colours e.g. Red/White

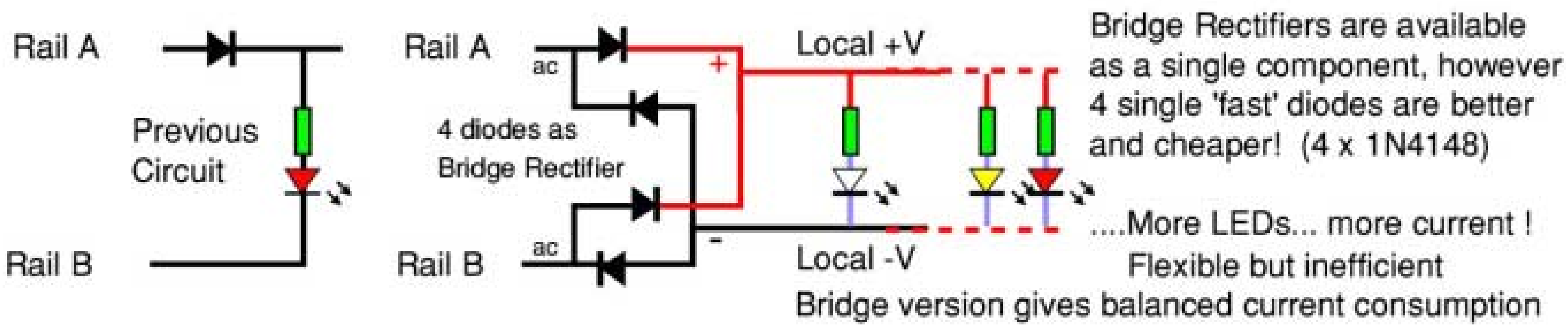


Common Anode (Positive) - 3-wire Bi-directional Lighting in Different Colours e.g. Red /White



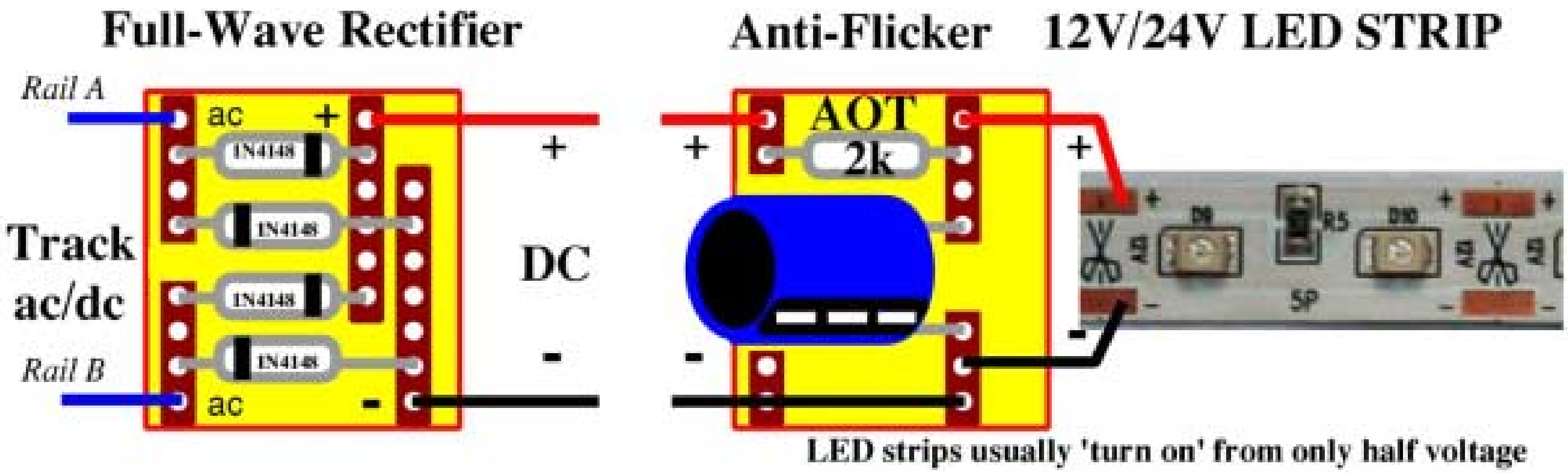
Universal Coach Lighting - ON ALWAYS for both DCC and DC track power *(Given enough Voltage!)*

Modifying the left-circuit to 'Full Wave Rectify' the incoming dcc/dc track voltage (which is what Decoders do)......

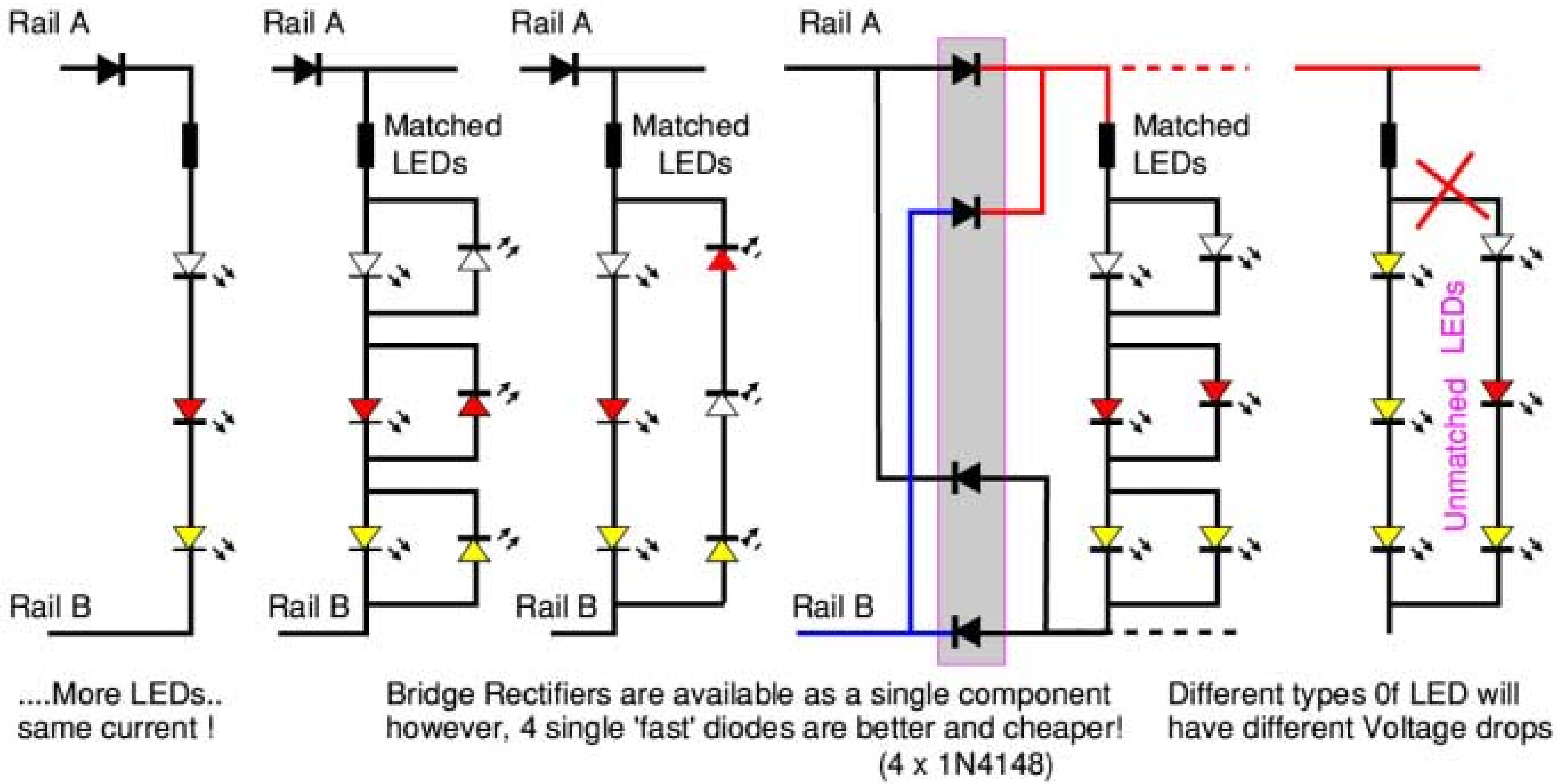


Adjust each individual resistor, as required, to adjust individual LED brightness - ideally suited to mixed colours.
For analogue use, this circuit also brings the lights on at the lowest possible track voltage (3-6V according to colour)
Typically, each LED and resistor will add another 5 - 10 - 20mA of load onto the output and also onto the track.

Full-Wave Rectifier Anti-Flicker 12V/24V LED STRIP



Efficiently using Multiple Identical LEDs ... ideal for DCC layouts



Different Types of LED *can* be mixed in a Daisy-Chain - they will then share the same current
To allow brightness to be controlled independently, requires more resistors: 'AOT': Adjust on Test
If each LED requires the same current, they can be placed in series, with a new, lower value, of resistor

.

The downside of this economy is that a higher voltage must be present before the LEDs will light up.
This is NOT a disadvantage with dcc layouts which have full track voltage at all times. It is with analogue.

How Many in Series? Balancing Energy Efficiency against Over-Voltage Protection

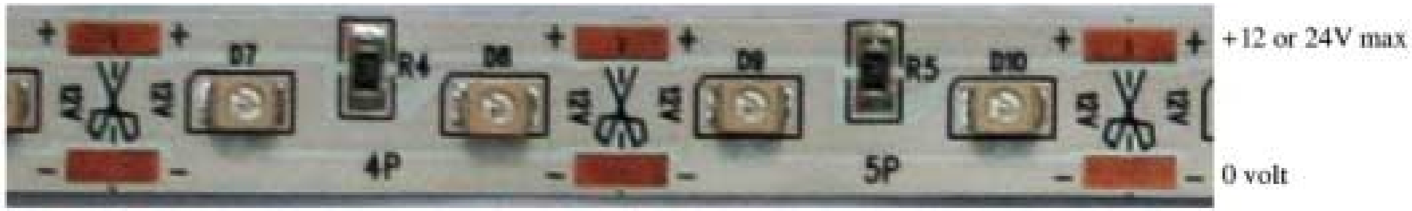
This depends on your track voltage and the type of LED: Red LEDs need the least energy, followed by Yellow and Green with Blue and White LEDs needing most. (Many 'White' LEDs are really Ultra Violet - like Fluorescent Lamps, with added compounds which emit visible light under Ultra-Violet - they do NOT emit a 'continuous spectrum' like a hot-wire bulb)

Important:

You cannot simply add LEDs, without a protective device such as a resistor, to reach the full voltage, as there would be no current limit (for a fraction of a second) until one of the LEDs failed! Diodes/LEDs are NON LINEAR devices.

Pre-Fabricated LED Strips Surface-Mount Resistor and Self-Adhesive Backing

Pre-fabricated LED strips on self-adhesive reels are available for both 12V (12.00V) and 24V (24.00V) in many colours.



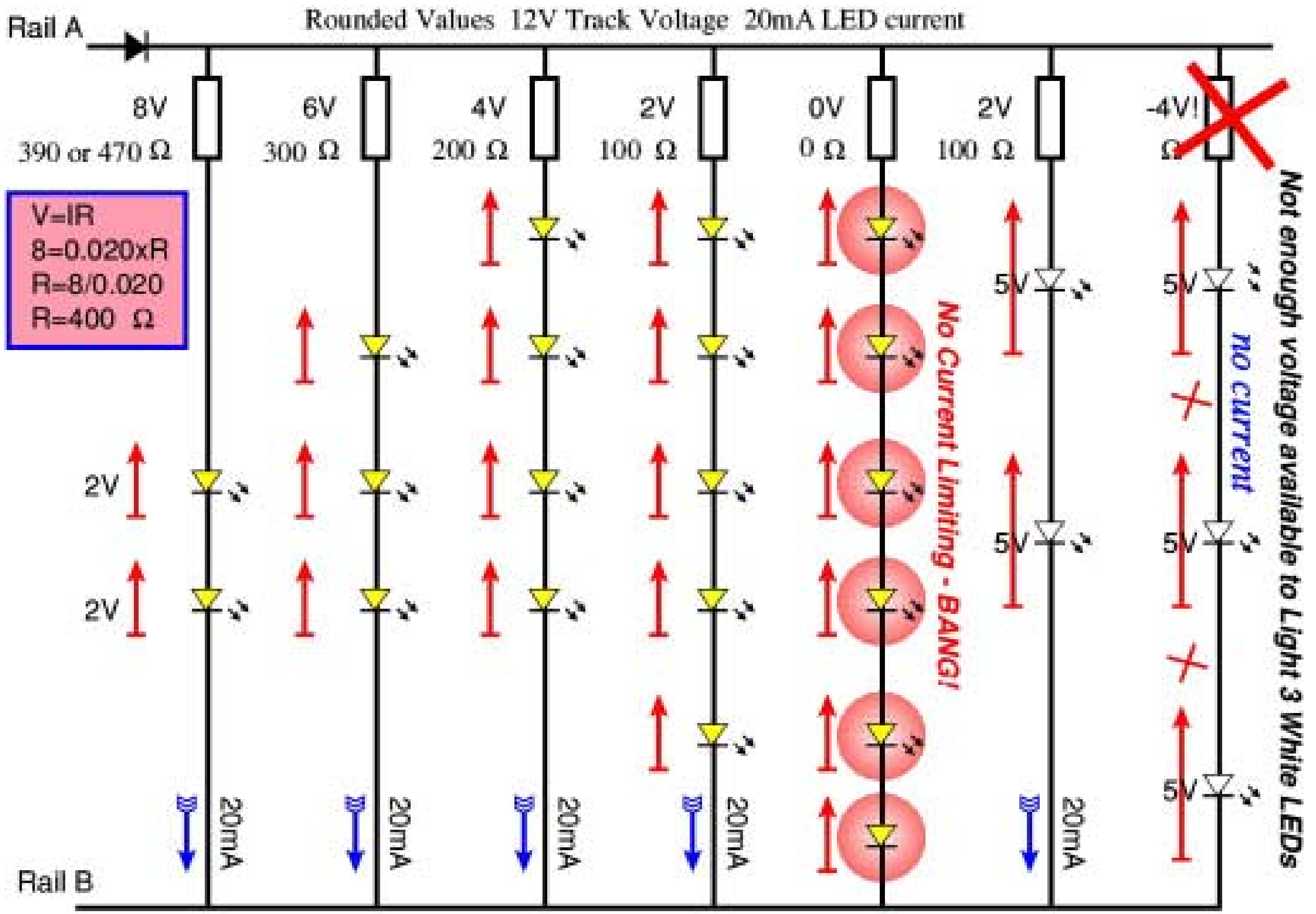
These typically have 2 or 3 LEDs in series with an appropriate resistor. They repeat every 50mm, and the tape can therefore be cut to a suitable length. **Note that increasing the voltage from 12V to 14V doubles the current!! - and they are much warmer!**

If wired into a coach, then a suitable resistor and either diode or bridge rectifier, can be included in the feed wiring connecting to the strip. A capacitor can then be added between the rectification and the LED strip, which will eliminate the flicker caused by intermittent track contacts.

This is similar to the optional 'Stay Alive' circuitry in Loco Decoders - helping to maintain internal power over bad track:
If many coaches are being equipped in this way, then it becomes more important to avoid a sudden current-surge when power is applied - by using the series resistor to reduce the inrush current ... but this then reduces the voltage stored on the capacitors which in turn requires a larger capacitor to provide the same duration of 'dropout' protection.
Commercial solutions are found in factory-fitted coaches from most manufacturers, such as Hornby.

12V Examples

With a 12V supply, you could theoretically use as many as 5 Red LEDs (10V) and a resistor but NOT 6 (12V)
As track voltage can 'dip' at distant places or when an accessory is operated, its advisable not to assume the full voltage is always available, but use fewer LEDs and drop the remaining voltage in the LINEAR resistor.



NOTE: The unit for Resistance is OHMs with the symbol Ω which may misprint on some systems
Therefore R is increasingly used or a Multiplier such as k or M on its own with the Ω assumed

In the examples above, working from left to right: the required Resistor Value was calculated for 20mA (0.020 A)
Since only 'Preferred Values' are usually available, the calculated values (400,200 and need to be substituted with the next available value. Using the next Highest Value errs on the safe side by reducing the current slightly.
For only 10mA current, the resistor values should be doubled (V = I × R where I = 0.010 Amps).
Since the LEDs are Non-Linear, the voltage across them remains almost the same (once conducting) for any current.

4 RED LEDs (2 × 2V drops = 4 V) needs 8 Volts across the Resistor. For 20mA, V = I × R gives R = 400 i.e. 390 / 470 ohm.
For 10mA use R = 800 Ohms which suggests an 820 Ohm Resistor. For 5mA, V = I × R gives R = 1k6 ohms.

Choosing 'Safe Values' taking account of the heat dissipation - even LEDs give out heat!

OO/HO Examples **12V 'nominal' alue, 16V dcc compatible value, 22V maximum 'possible'.**

Bulb lit coaches get noticeably warm in use; Pre-digital designs would only expect to be at 'full voltage' during short high speed runs, and may risk distorting the coach roof if care is not taken. Any bulbs used are 'now' are 16V not 12V. Directional lighting of 'analogue models', when left on continually, may melt or distort their plastic mountings if bulbs.

For a BULB, as the voltage rises, the power increases with the square: P=IV= $V^2 \div R$ 177% @16V and 336% @22V
i.e. 12V bulbs would be at 1.7x their intended Rating @16V, but a possible 336% at the maximum possible track voltage..
16V bulbs would be at their intended Rating @16V, and 1.89x their intended rating at the maximum possible track voltage.

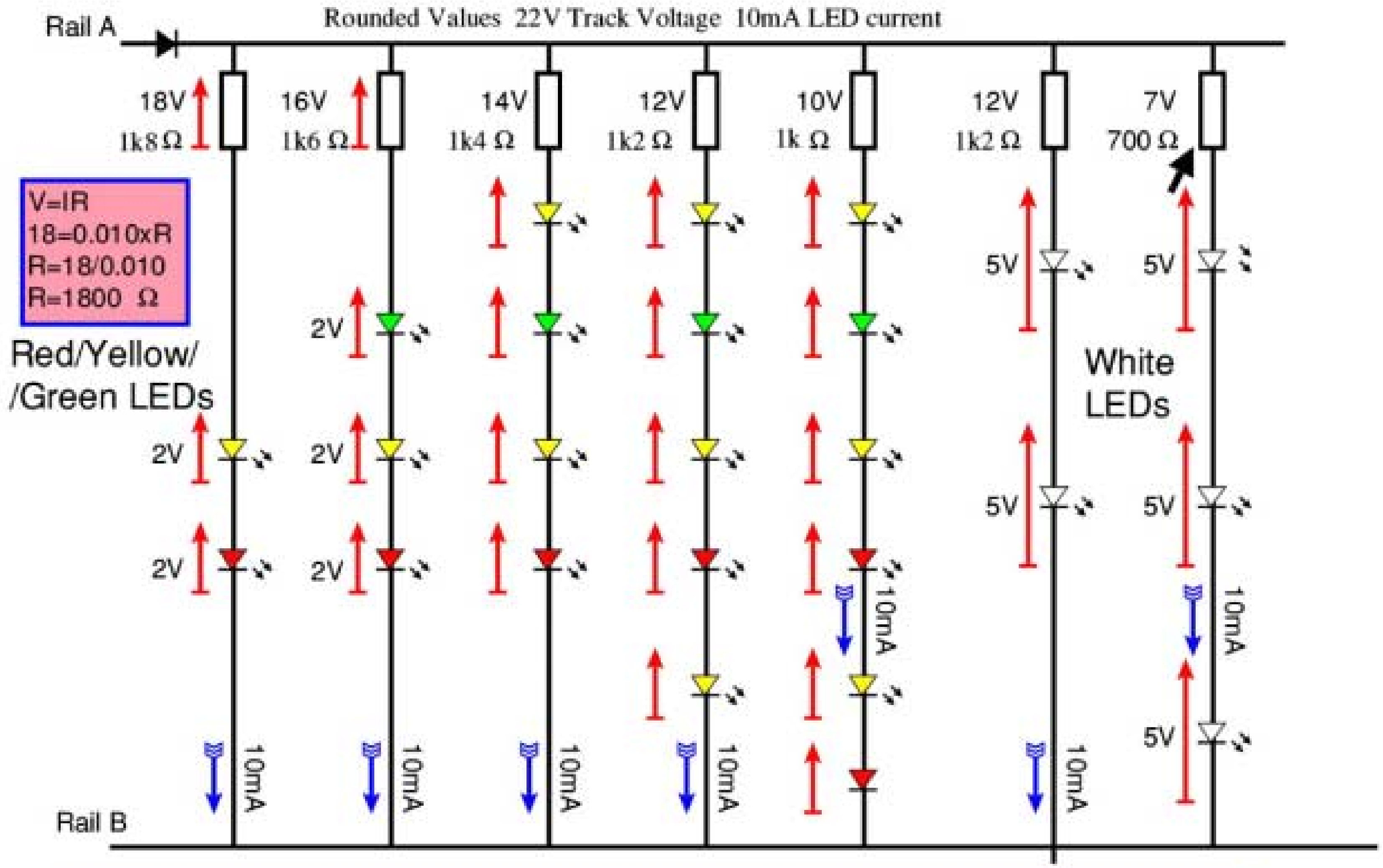
2 Yellow LEDs in Series [4V across LEDs]
12V => 8V across resistor, 16V => 12V across resistor 150%@16V and at 22V => 18V across resistor 225% @22V
and the current also increases proportionally, ***but power with the square:*** *225% @16V and 506% @22V*

3 Yellow LEDs in Series [6V across LEDs]
12V => 6V across resistor, 16V => 10V across resistor 166%@16V and at 22V => 16V across resistor 266% @22V
and the current also increases proportionally, ***but power with the square:*** *400% @16V and 711% @22V*

5 Yellow LEDs in Series [10V across LEDs]
12V => 2V across resistor, 16V => 6V across resistor **300%@16V** and at 22V => 12V across resistor **600% @22V**
and the current also increases proportionally, ***but power with the square:*** *900% @16V and 3600% @22V*

Conversely a severe 50% drop in track voltage, as may occur if a point motor is powered directly from the dcc supply, would cause 3 or more coloured LEDs in series to turn off, but 2 LEDs would only reduce to 5mA from 20mA.

G Scale Examples 22V Maximum Example - but track voltage might drop to or be 16V or less...



To ensure components are within specification, 22V maximum possible voltage is used here, with.2V (or 5V for white) LEDs.
In reality the track voltage may be lower: (LGB Starts sets now using 18Vdc power supplies, we use 16V track voltage indoors).
If too many LEDs are placed in series; with only a small series resistor value, the LEDs may not light, in places around the track.

22V: It is always safest to calculate on the worst case voltage which could cause damage.
[With an ANALOGUE LGB layout, in theory, 24Vdc maximum is possible at full speed! Locos are labelled 0-24Vdc]

With the greater voltage comes more room for manoeuvre in optimising values according to circumstances.
Indoor or Outdoor usage of the Model will also influence the desired lighting level and therefore current required.

Larger LGB Coaches with Factory-fitted lighting usually had a Rectifier, 5V regulator and 5V bulbs. (or now, LEDs)
MTS NMRA dcc specifications ensure the track voltage should never rise above 24-27V maximum,
therefore the following examples look at what happens if, or when, the voltage drops from 22V to 16V or 12V....

Examples Based on 22V: 16V (as with Bruksbanen / new Starter) 12V dip or middle-speed analogue voltage

2 Yellow LEDs 22V => 18V across resistor, 16V => 12V (67%) across resistor, 12V => 8V (44%) across resistor
the current also drops proportionally, and ***power with the square:*** *44% @16V and 19% @12V*

3 Yellow LEDs 22V => 16V across resistor, 16V => 10V (62.5%) across resistor, 12V => 6V (37%) across resistor
the current also drops proportionally, and ***power with the square:*** *39% @16V and 14% @12V*

5 Yellow LEDs 22V => 12V across resistor, 16V => 6V (50%) across resistor, 12V => 2V (16%) across resistor
the current also drops proportionally, and ***power with the square:*** *25% @16V and 2.5% @12V*

or for White/Blue LEDs
1 White LED 22V => 17V across resistor, 16V => 11V (65%) across resistor, 12V => 7V (41%) across resistor
the current also drops proportionally, and ***power with the square:*** *42% @16V and 17% @12V*

2 White LEDs 22V => 12V across resistor, 16V => 6V (50%) across resistor, 12V => 2V (17%) across resistor
the current also drops proportionally, and ***power with the square:*** *17% @16V and <3% @12V*

Summarised in Words:

Below a certain voltage there will be no current flow (from 2-3V for Red to 5V for White) above that the voltage across the LED will hardly change, but the current will increase rapidly. This current also causes energy to be dissipated in the Resistor, which will therefore also give off heat, detectable by touch even at these values! Most Standard LEDs are rated for about 20mA - but modern LEDs are bright enough with only 5-10mA LEDs are often driven by Pulses with a much larger current (perhaps >2Amps) but for only a short time - the average being less than 20mA: frequently used by 'Strobed Displays' and Infra-Red Remotes to save battery life. If used on MTS/dcc/Mfx systems, the Series-examples shown here would be on for 50% of the time thus halving the average current, and therefore, the heating effect.

Caution:

If the current is then set to the 'normal' 20mA using V=IR, when it is also run on an Analogue-dc layout it will either be *always-on* (40mA risking -> **(bang),** or *always-off*, depending on the train's direction. Therefore I prefer to use 10mA as my 'normal current' to avoid having to replace all the LEDs after visiting an analogue layout! Using the inverse-parallel diode arrangement means the resistor is *always* conducting, consuming power, and on Analogue-dc half the lights will be on, or with a diode-bridge, all of them.

Tolerancing

Many layouts used a Transformer to provide the Controller with its Low Operating Voltage. The 'rated' voltage usually applies only when the full current is being taken. e.g. *16Vrms @ 3 Amps*. At other times, the output voltage to the track may be much higher; possibly by 20-50% when no locomotives are running! This effect is *very visible* on *unregulated coach lighting using bulbs*; which will be noticeably brighter and whiter when no trains are moving, and they will have a shorter life to match.

The well known H&M Duette/DC60 etc produce a peak voltage of 26V at 100Hz with 'no load' applied.
Non-electronic controllers are NOT recommended for use, or especially not for use, with DCC fitted locos!

If the track voltage rises then the extra voltage appears only across the resistor. With more LEDs in series, the proportionate increase in voltage across the Resistor increases:.... To counter this problem, a compromise is needed between energy-efficiency *(having as many LEDs as possible in series)* and good low-voltage performance *(Analogue Compatibility and Voltage Dip response)* with regulated brightness. This has been tabulated in the 12V/22V examples.

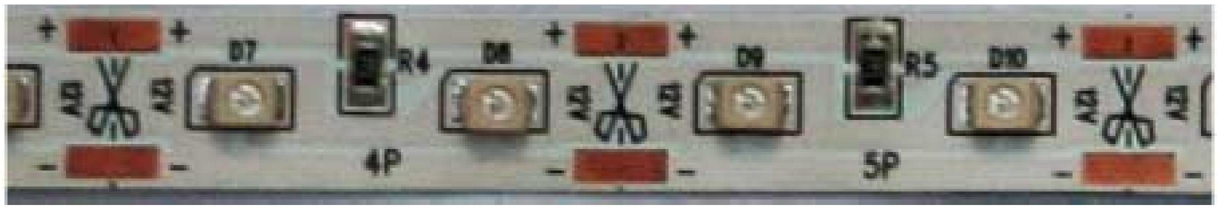
Balanced Power Consumption

Finally, it should be emphasised that it is preferable to try and ‘equalise’ the consumption of power from each half of the dcc signal by not deliberately installing all your LEDs the same way round (in relation to the Track) - remembering that it is normally an ‘AC’ squarewave, with an average value of 0.
ABC Automated braking in dcc uses a *deliberate inequality* in the pulses of each polarity to trigger events such as automatic braking or reduced speed- and this difference of 1.2V is created with just a few diodes. It might take as few as 12 LEDs, all in the same orientation, at 20mA each (¼ Amp) to create this difference on a 5 Amp track supply! (my calculation), Therefore it is best to ‘mix’ both polarities 50:50 within each coach (or lineside lighting if fed from the track dcc).

By using Inverse-Parallel LEDs or full-wave rectifiers this potential problem is avoided completely.
Similarly, LED lighting and other functions **on a Decoder** do not cause a problem because the decoder uses full-wave rectification.
Since each decoder runs its own pulse-width drive for the motor - asynchronously compared to all the other decoders, this tends to balance Motor-Power Consumption, in contrast to the early Zero-1 system which used dedicated ‘data’,‘forward’ and ‘reverse’ time slots; with all the locomotives running in one direction taking their current at the same time!

1N4148 high-speed switching diodes are recommended over 'common' Bridge Rectifiers designed primarily for 50Hz rectification.
Within the total current available, the total consumption of LED lighting will be well below that of the equivalent bulb-based lighting, but it still needs to be considered when assessing overall power provision, as it is likely to increase over the years as you add more and more illuminated coaches; with night-time running no longer ‘in the dark’.

Pre-Fabricated LED Strips Surface-Mount Resistor and Self-Adhesive Backing



E+OE Sources and Examples are only quoted to assist understanding. Product availability and prices are continuously changing. UK Online retailers include Maplin Electronics, CPC (Farnell), RS, Rapid and many resellers of small quantities via Ebay/Amazon/Websites etc. Shopping List (Maplin Electronics) Pack of Resistors E12 Series 1/4 W Eg 480 ‘E3’ (30 of each value) inc 470 1k 2k Order Code N63BH £5.49 Meter - many options £5 - £xxx LED Tester Order Code N71AU £6.99 1N4148 Diodes Order Code QL80B £0.22 each