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

LED = Light Emitting Diode *by Phil Spiegelhalter for members of Solent Group G-Scale*

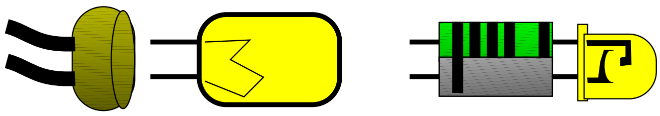
Why?

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

Options:

The simplest option in locomotives, when MTS/DCC controlled is to 'turn down' the brightness by simply giving new values to each output: (also known as 'programming the CVs')
This is very simple when using the LGB-PC Interface - on a PC - as it is plain English and Tick boxes

Alternatively: Save the environment and Track Current - Change to LEDs
Eg 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)

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:

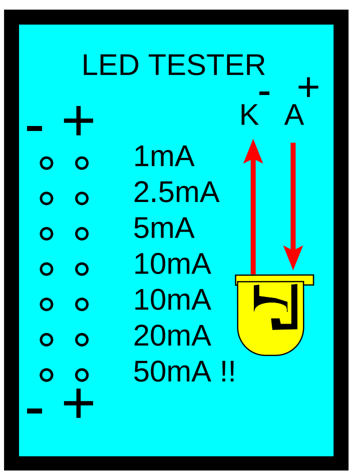
The DEFAULT values on the decoder lighting/function outputs are FULL VOLTAGE and Brightness.
(But if fed via an on-board regulator these will be 5V - so adjust the settings and choose your level)
MTS/DCC is a.c. on the track, and most LEDs will FAIL instantly if more than 5V is applied in the wrong polarity. 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!
My common rule is 'The CUP is the Cathode' - looking inside the LED, when possible, it looks like the CUP-shape of a Satellite Dish, and the Antenna (Feed Horn) is the ANODE (Positive) Side.
However there are some exceptions to these rules!! - read the suppliers catalogue or measure.

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. Its safe to get it wrong on the low values!
So for an unknown LED try it each way in the 5mA or lower contacts.

Calculating the Values

For LGB Assume 24V on track (Theoretically 22V)
An LED 'drops' (uses) 2V if RED/Yellow/Green (approx)
A Blue or White LED may drop 5 V (More Energy required)
That leaves 22V for the Resistor (for a Red LED) or 19V (say 20) for a White LED
V=IR   (Voltage = Current   x   Resistance)
20V =   20mA x 1 k Ohm   SI: m = 1/1000 k=1000 M = 1 000 000
20V =   10mA   x 2k Ohm   (approx) = my recommendation for G
10V =   10mA   x 1k Ohm   for Lower DCC/Analogue Voltages (00)

r

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

Common 1/4 Watt resistors will suffice for most uses

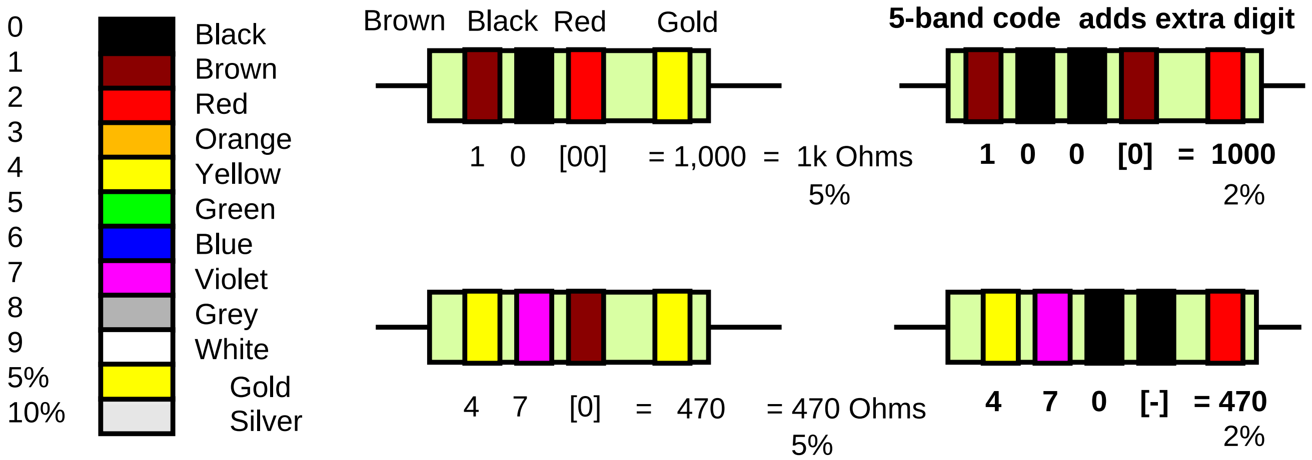
Power = Current x Voltage P=IV = 10mA x 20V = 0.010 x 20 = 0.200 Watts (¼W resistor pack 480 for £5.49)
However if you want very bright 20mA @20V, then ½ Watt Resistors should be used (or 2 parallel ¼W)

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 !

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 ie 10, 100, 1000 etc
In the 'old days' of 10% Tolerance, only 6 values were needed, with 5%, there are 12 useful values....

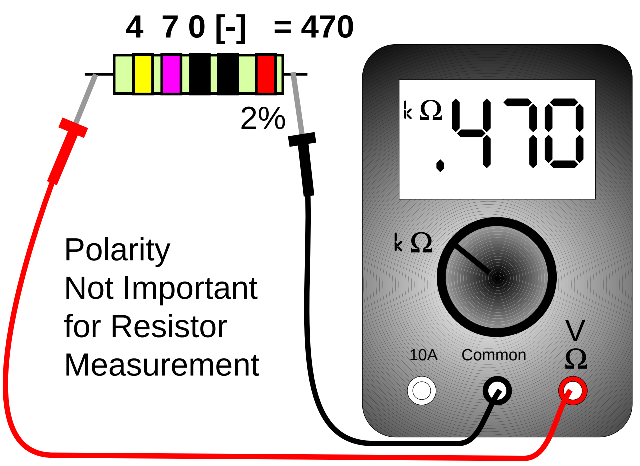
1	1.2	1.5	1.8	2.2	2.7	3.3	3.9	4.7	5.6	6.8	8.2	[10]	E12 Series (12 values per decade)
10	12	15	18	22	27	33	39	47	56	68	82	[100]	
100	120	150	180	220	270	330	390	470	560	680	820	[1000]	
1k	1k2	1k5	1k8	2k2	2k7	3k3	3k9	4k7	5k6	6k8	8k2	[10k]	(k in place of decimal point}

It is particularly important NOT to misread the 3rd/4th Multiplier Band as this *not* part of the E Series !!
Under Artificial Light it CAN be 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 electric motors) may look like Resistors!!



Reverse-Failure Protection using a Protective Series Diode

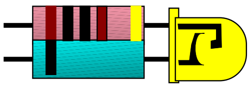
Prevention is Better Than Cure: (Especially when it costs only 1p per 1N4148 diode in bulk)

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.

There is Another Way..... Back to Back LEDs.... discussed later...

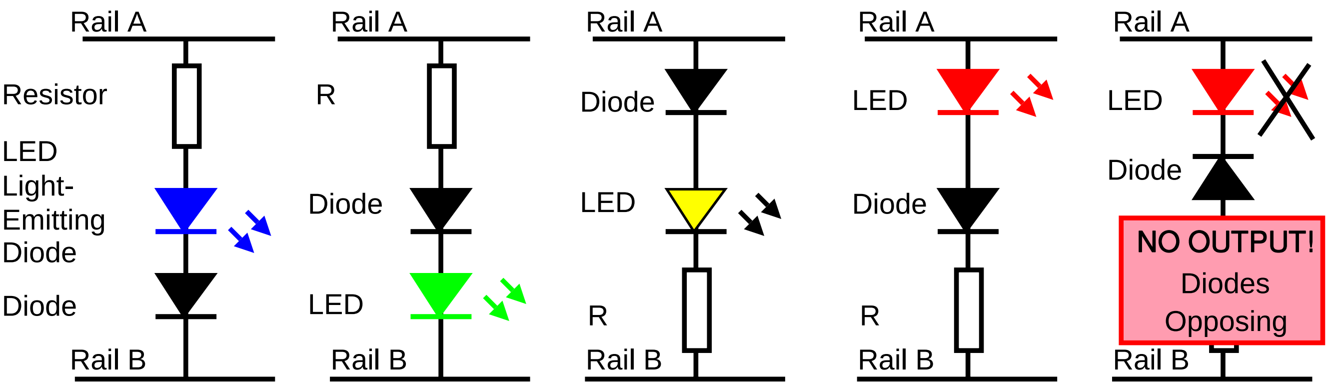
1 LED and a Resistor, with Protective Diode (as on page 1) - Universal DCC / Directional DC



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

On-Always on DCC
or
Directional Lighting
for Analogue/PWM DC

Symbolic (Topological) Representations... and ALTERNATIVE versions that will work the same way



EACH of the different circuits shown above will light the LED when 'Rail A' is +ve compared to 'Rail B' -ve.
In THIS 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')
Note: I do not describe either rail as 'Zero volts, as we are ONLY concerned with potential DIFFERENCE

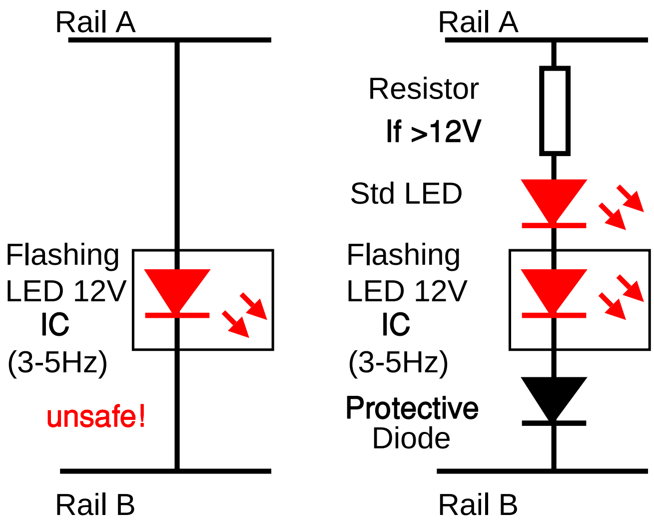
The standard diode is there to protect the LED from Reverse-Voltage - its cost can be as low as 1p

The Diodes used in this 'DCC' circuit only rectified HALF the current - pulsing the LED at 10,000 a second
However, on a DC layout this would become either ON or OFF depending on the track-power polarity

Flashing LED ICs and 12V LEDs

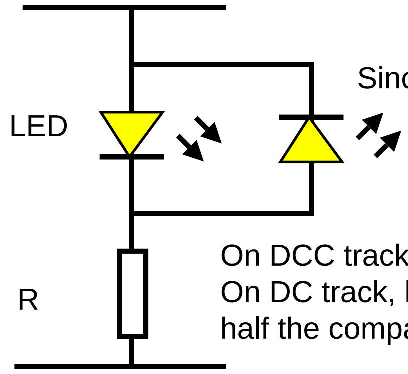
A ready-made LED with in-built flashing circuit does not *require* an external resistor if used on the stated voltage (usually 12V)
The REVERSE voltage accepted is **ONLY 0.5V**!
A protective diode in series is advised unless the polarity is assured 100%. Standard LEDs can be added in series which will ten 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 Back LEDs - Inbuilt Reverse Voltage Protection - Designs for dcc AND dc lighting

BY preventing the Reverse Voltage from 'building up', with a parallel LED facing the other way, the LED is protected from such failure.

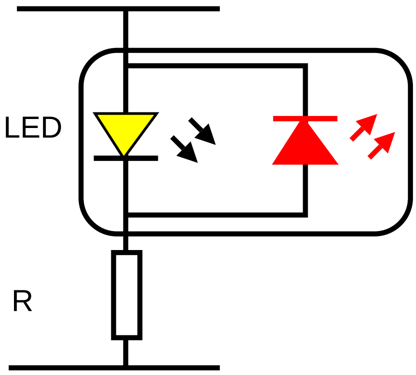


Since each LED Forward-conducts at 2-3V, the voltage never reaches 5V

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 brigtness or half the compartments lit - with the others lighting when travelling the other way.

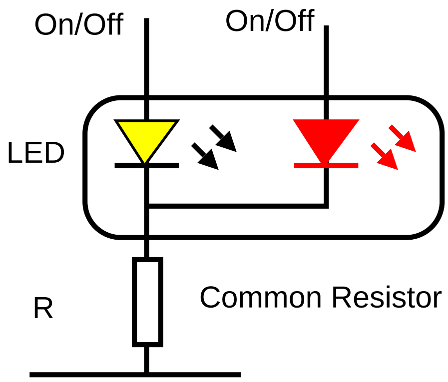
Back to Back LEDs - Bi-directional Lighting in Different Colours eg Red / White

Some Manufacturers offer 2-colour LEDs in one package, using just 2 leads - these are Back to back



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

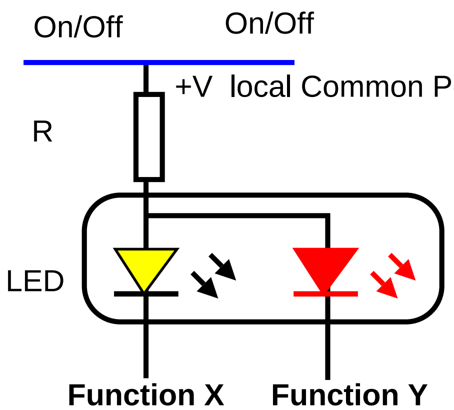
Common Cathode (Negative)- 3-wire Bi-directional Lighting in Different Colours eg Red/White



Commonly available version of Dual-Colour LEDs
Not easy to use for DCC installations

Common Resistor - value usually assumes only 1 LED of the 2 is on at a time

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



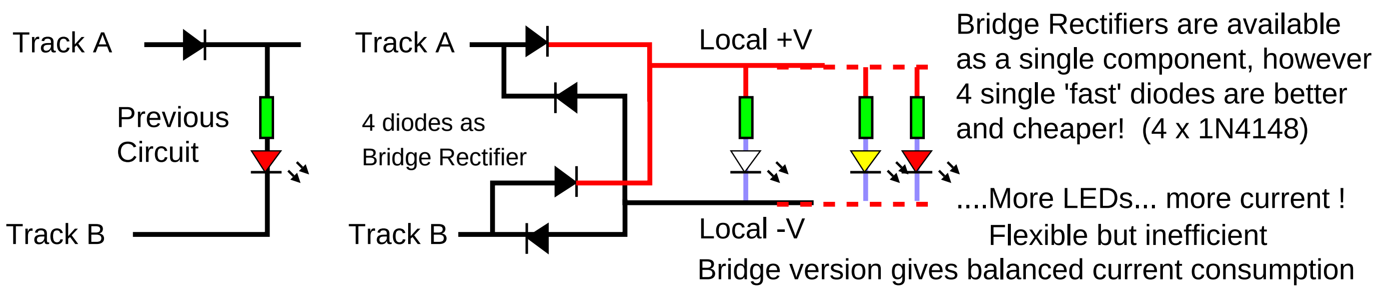
+V local Common Positive (Decoder Output) - Standard nmraDCC wiring colour is BLUE

Specialised Version sold by DCC dealers of Dual-Colour LEDs
Easy to use for DCC installations

Function/LED is ON when Function Connection is Pulled LOW by DCC control of decoder - may be programmed to flash etc

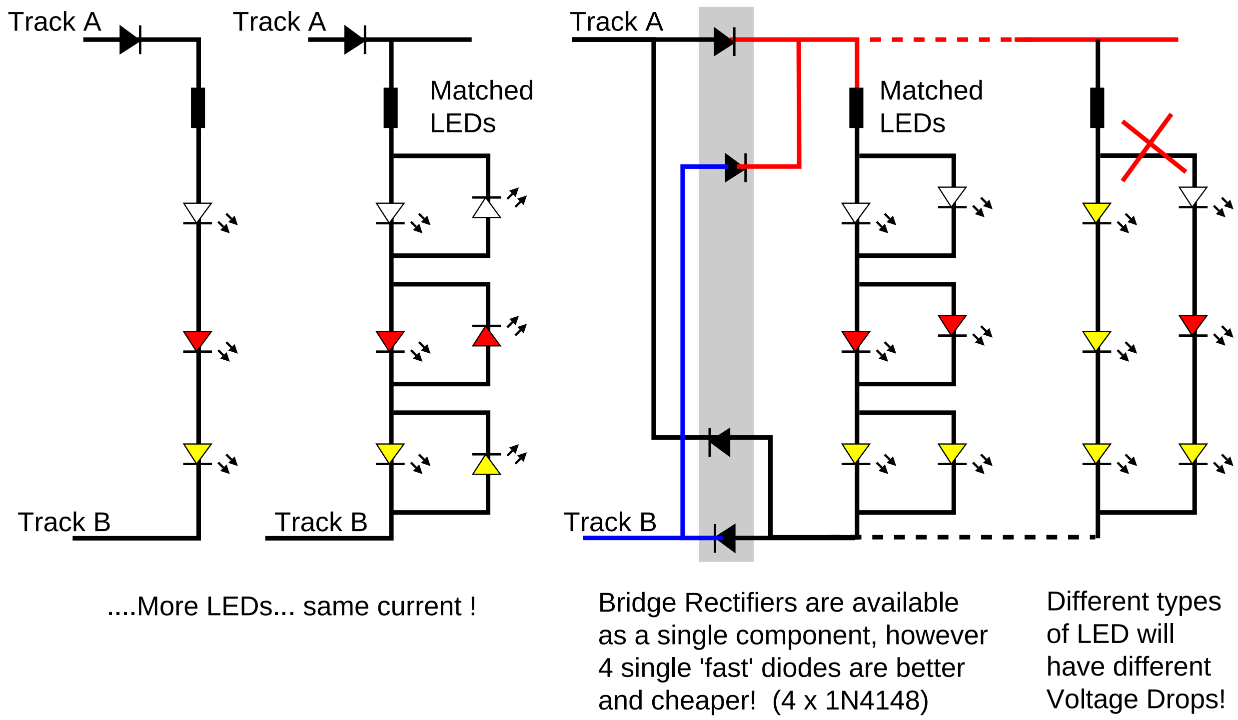
Universal Coach Lighting - ON ALWAYS for both DCC and DC track power *(Given enough Voltage!)*

Modify the Circuit above 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 10-20mA of load onto the output and also onto the track.

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 independantly, 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

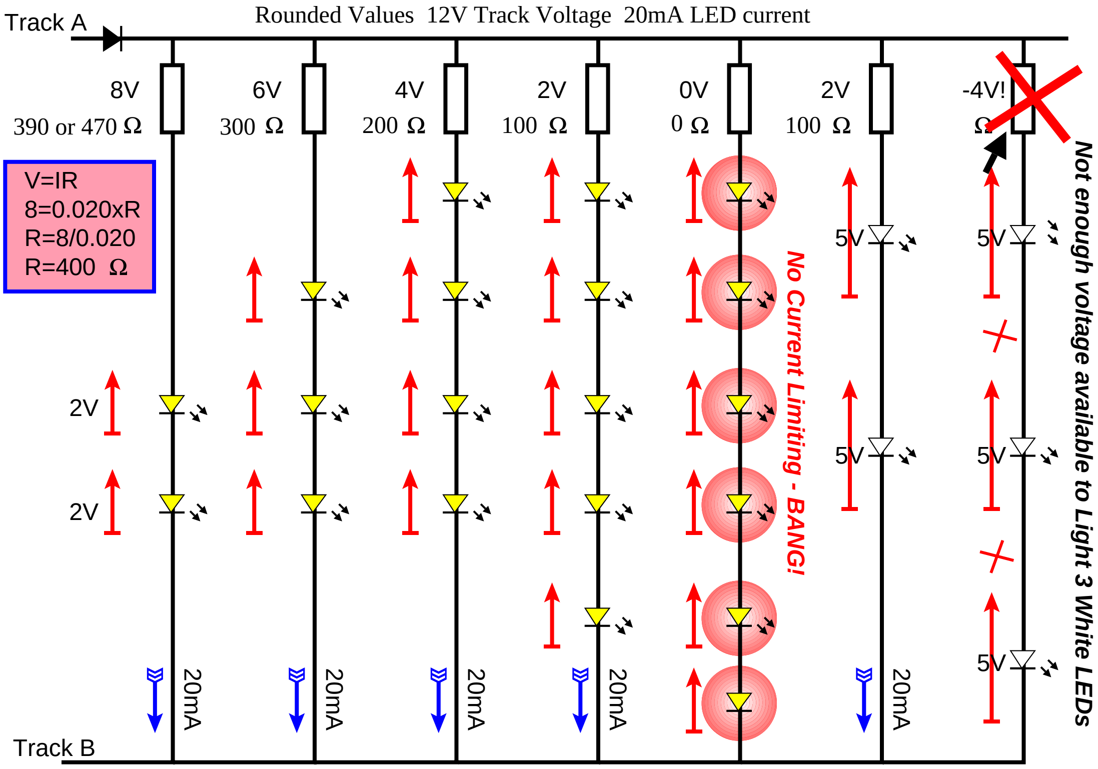
Red LEDs need the least energy, followed by Yellow and Green with Blue and White LEDs needing most.
(‘White’ LEDs are really UltraViolet - like Fluorescent Lamps, with added compounds which emit visible light under Ultra-Violet - they do NOT emit a ‘continuous spectrum’ like a hot-wire bulb)

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.

12V Example

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 is calculated for 20mA (0.020 A)
Since only 'Preferred Values' are usually available, the calculated values (400**Ω**,200**Ω**, 100**Ω**, 0**Ω** and 100**Ω**) need to be substituted with the next available value. Using the next Highest Value will err on the safe side by reducing the current slightly. For only 10mA current, the resistor values should be doubled (V=IR where I = 0.010 A)
Since the LEDs are Non-Linear, the voltage across them remains almost the same (once conducting) for any current.

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

OO/HO Examples __**12V, 16V and 21 (measured voltage with no train running, and 230V:16Vac transformer)**__
Bulb lit coaches (Bulbs now rated for 16Vac/dc for dcc compatibility) - [previously 12V]) => 21V (31%) / [175%]
and the current increases proportionally , but power with the square... $P=IV = V^2 \div R$ *(171%) and [306%]*
(i.e. 16V bulbs would be at 1.7x their intended Rating but 12V bulbs would be at 3x their intended power)

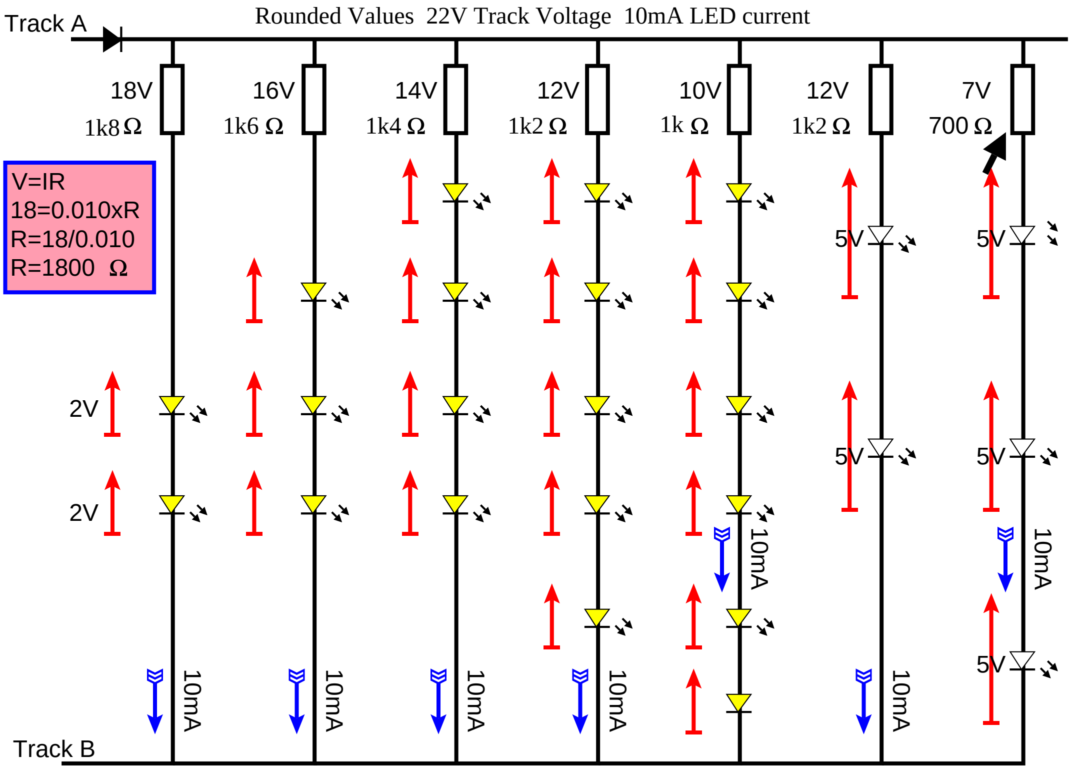
2 Yellow LEDs 12V => 8V across resistor , 16V => 12V across resistor (150%) and 21V => 17V (212%)
and the current also increases proportionally , but power with the square... (225%) and (449%)

3 Yellow LEDs 12V => 6V across resistor , 16V => 12V across resistor (200%) and 21V => 15V (250%)
and the current also increases proportionally , but power with the square... (400%) and (625%)

5 Yellow LEDs 12V => 2V across resistor , 16V => 6V across resistor **(300%)** and 21V => 19V **(950%)**
*and the current also increases proportionally , but power with the square... (900%) and **(902500%)***

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 Example



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

For G-Scale's 22V we could try using 8 LEDs in Series (=> 16-18V), but it may be better to limit it to 6 (=>12V) because 2V is a rounded figure, and may be as high as 3V for some types with 10V across the resistor.
For White and Blue LEDs assume 5V per LED - therefore a maximum of 2 in series for 00/H0 dcc and 3 for G dcc.

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 have a Rectifier, 5V regulator and 5V bulbs.
MTS NMRA dcc specifications ensure the track voltage should never rise above 24-27V maximum, therefore the following examples look at voltage drops...

Examples: Based on 22V 16V (Bruksbanen) and 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%) and (19%)

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%) and (14%)

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%) and (2.5%)

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%) and (17%)

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%) and (<3%)

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 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 'average' 20mA using V=IR, when it is also to run on an Analogue-dc layout it will either be *always-on* (40mA average **->** **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 *back-to-back* diode arrangement means the resistor is always conducting, and even on Analogue-dc half the lights will be on, or with a *diode-bridge*, all of them.

Tolerancing

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

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 between energy-efficiency (having as many LEDs as possible in series) and both 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 around (in relation to the Track) - remembering that it is normally an 'AC' squarewave, with an average value of 0.

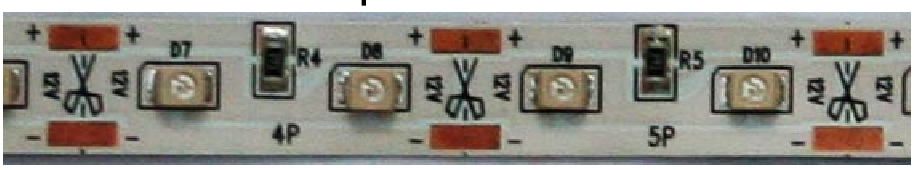
Recent developments in dcc use a *deliberate inequality* in the peak amplitude of the pulses in each polarity to trigger events such as automatic braking - and this difference of 1.2V is created with just a few diodes.
It might take as few as 12 single LED coach lights, all in the same orientation, at 20mA each (1/4 Amp) to create this difference on a 5 Amp track supply!(my calculation), Therefore it is best to 'mix' both polarities 50:50 within a coach.

By using Back-to-Back LEDs or full-wave rectifiers this potential problem is avoided completely. Therefore LED lighting and other functions on a Decoder do not cause a problem because they are already full-wave rectified.
Since each decoder runs its own pulse-width drive for the motor - asynchronously compared to all the other decoders, this tends to balance Motive 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 current at the same time!

1N4148 *high-speed switching* diodes are recommended over 'Ready-made' Bridge Rectifiers which are designed primarily for 50Hz rectification, and may distort the dcc waveform as a result. 1N4148's are also much cheaper!

Within the total current available, the total consumption of LED lighting will be well below that of the 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 [Kingbright]



+12 V max
(For G: 2 x 2 back to back with diodes)
0 volt

LEDs may be bought cheaply as Christmas Lights and Solar Light Strings are ideal for G-Scale Garden Buildings.

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
Digital Multimeter - various options   £5 - £xxx   LED Tester   Order Code N71AU   £6.99   1N4148 Diodes Order Code QL80B £0.22 each

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