NMRA



ELECTRONICS TIPS, TRICKS, AND LESSONS LEARNED

A retired electrical engineer's advice
and information for non-engineers

by Jeff Witt

Introduction

This clinic will attempt to:

- De-mystify electronics concepts
- Provide practical and useful practices, and dispel bad practices
- Demonstrate applications the author has implemented
- Provide several circuit examples that highlight the concepts introduced
- Give information on component selection

Electrical Basics – DON'T PANIC

Ohm's Law is simple! We will use this later...

- V the voltage across two nets/pins
- I the current through a net/component
- R the resistance of a component
- P the power dissipated by a component

Various forms:

$V = I \times R$ $I = V / R$ $R = V / I$

$P = I \times I \times R$ $P = V \times V / R$ **$P = V \times I$** ***

Given any two of V, I and R, you can calculate the third.

****** Also note that P = V x I applies to ALL components, not just resistors!***

LEDs

This topic is limited to discrete LEDs, not strip lighting or RGB applications.

Some LED properties:

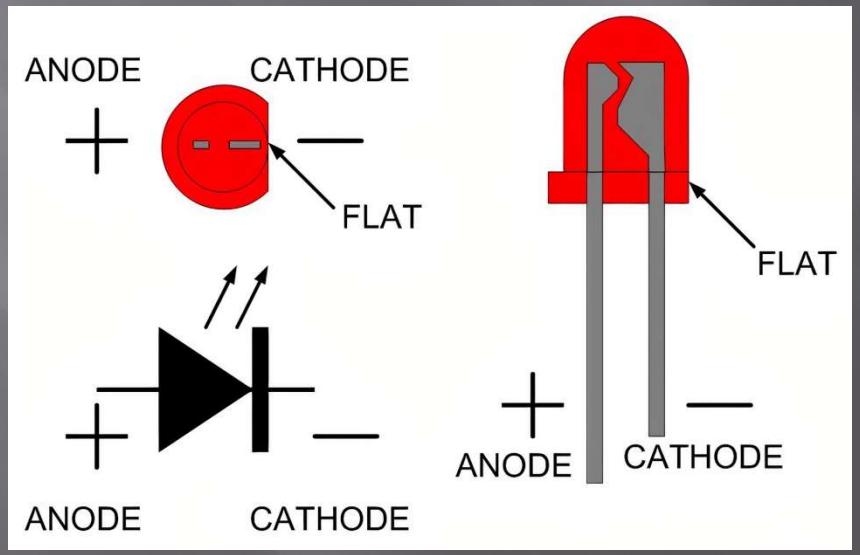
- They are diodes, so have a polarity
- They are ***CURRENT*** devices
- They dissipate power
- They have a variable forward voltage drop $\mathbf{V_F}$
- Different colors have different $\mathbf{V_F}$
- ***They can be destroyed or have a greatly shortened life due to misuse***

LEDs (cont.)

For the following discussion, I will be using datasheets from **Vishay** (corporate HQ in Malvern on Rt. 30 !!) for their family of 3mm discrete LEDs.

Polarity is indicated by the lead length and/or flat:

- **Anode (+)**: The positive side, the longer leg
- **Cathode (-)**: The negative side, flat casing edge



LEDs (cont.)

The forward voltage drop (V_F) varies with LED color, the current, and the "batch" of the LED. Some nominal voltages can be seen in the datasheet chart:

Note that the voltage variation spec V_F is defined at a *FIXED* 20mA current!

PARTS TABLE

PART	COLOR	LUMINOUS INTENSITY (mcd)			at I_F (mA)	WAVELENGTH (nm)			at I_F (mA)	FORWARD VOLTAGE (V)			at I_F (mA)	TECHNOLOGY
		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		
TLHR4600	Red	1	4	-	10	612	-	625	10	-	2	3	20	GaAsP on GaP
TLHR4605	Red	2.5	6	-	10	612	-	625	10	-	2	3	20	GaAsP on GaP
TLHR4605-MS12Z	Red	2.5	6	-	10	612	-	625	10	-	2	3	20	GaAsP on GaP
TLHY4600	Yellow	0.63	3.5	-	10	581	-	594	10	-	2.4	3	20	GaAsP on GaP
TLHY4605	Yellow	2.5	5	-	10	581	-	594	10	-	2.4	3	20	GaAsP on GaP
TLHY4605-MS12Z	Yellow	2.5	5	-	10	581	-	594	10	-	2.4	3	20	GaAsP on GaP
TLHG4600	Green	1	4	-	10	562	-	575	10	-	2.4	3	20	GaP on GaP
TLHG4605	Green	4	6	-	10	562	-	575	10	-	2.4	3	20	GaP on GaP
TLHG4605-MS21Z	Green	4	6	-	10	562	-	575	10	-	2.4	3	20	GaP on GaP

PARTS TABLE

PART	COLOR	LUMINOUS INTENSITY (mcd)			at I_F (mA)	COORDINATE (x, y)			at I_F (mA)	FORWARD VOLTAGE (V)			at I_F (mA)	TECHNOLOGY
		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		
VLHW5100	White	5600	-	11 200	20	-	0.33, 0.33	-	20	2.8	-	3.6	20	InGaN and converter

This is important to determine both the dropping resistor and the power dissipation!!!

LEDs (cont.)

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified) TLHR460., TLHY460., TLHG460.				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
Reverse voltage		V_R	6	V
DC forward current	$T_{amb} \leq 60$ °C	I_F	30	mA
Surge forward current	$t_p \leq 10$ µs	I_{FSM}	1	A
Power dissipation	$T_{amb} \leq 60$ °C	P_V	100	mW
Junction temperature		T_j	100	°C
Operating temperature range		T_{amb}	-20 to +100	°C
Storage temperature range		T_{stg}	-55 to +100	°C
Soldering temperature	t ≤ 5 s, 2 mm from body	T_{sd}	260	°C
Thermal resistance junction to ambient		R_{thJA}	400	K/W

Absolute maximum concerns:

1 – **Reverse Voltage** (6v, but most LEDs are 5v)

Although the LED is a diode, the reverse voltage MUST be limited. A simple silicon diode (or another LED) can be connected in "reverse parallel" across the LED to meet this spec.

I had a failure in a dwarf signal LED when I accidentally ignored this specification!

LEDs (cont.)

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TLHR460., TLHY460., TLHG460.

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Thermal resistance junction to ambient		R_{thJA}	400	K/W

Absolute maximum concerns:

2 – **DC forward current maximum** - this is kind of obvious, but my point here is that you should stay far away from this limit, as component variations create a lot of "slop" around your calculated values.

I shoot for 10mA for almost all LEDs, half the typical maximum of 20mA

LEDs (cont.)

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Absolute maximum concerns:

3 – **Power dissipation** – per Ohms law, the power dissipation is V x I. For example, a white LED at 10ma *could* dissipate 3.6v x 10mA = 36 mW, about a third of the limit. Double the current doubles that.

This is usually not a problem (more later...); note that LED V_F has a negative temperature coefficient; as temp increases, V_F drops, current increases, temp increases...

LEDs (cont.)

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Thermal resistance junction to ambient		R_{thJA}	400	K/W

Absolute maximum concerns:

4 – **Thermal resistance** – this defines how the heat generated by the power dissipation (*in free air*) raises the LED's junction temperature; using the previous example:

36 mW x 400 K/W = 14.4 ˚K = 58 ˚F above ambient

At a 70 ˚F room temp, the junction temp is 128 ˚F (53.3 ˚C)

Again, this is usually not an issue but an enclosed LED can get quite warm or even hot.

LEDs – Common Mistake 1

Do not use a voltage source to directly drive an LED. This article is posted on the NMRA website on the NMRA@Home page:

Voltage Regulators for Scenic LED Lighting

Featured in the Division Business Car Column appearing in the August 2022 issue of NMRA Magazine.



As we use more and more LEDs in our model railroad scenes, there has to be better options than using resistors. Mark Couvillion has come to the rescue with an article in the 100% NMRA Member San Jacinto Model Railroad Club of Houston, Texas newsletter, *The Derail*. His article discusses the use of small adjustable voltage regulators.

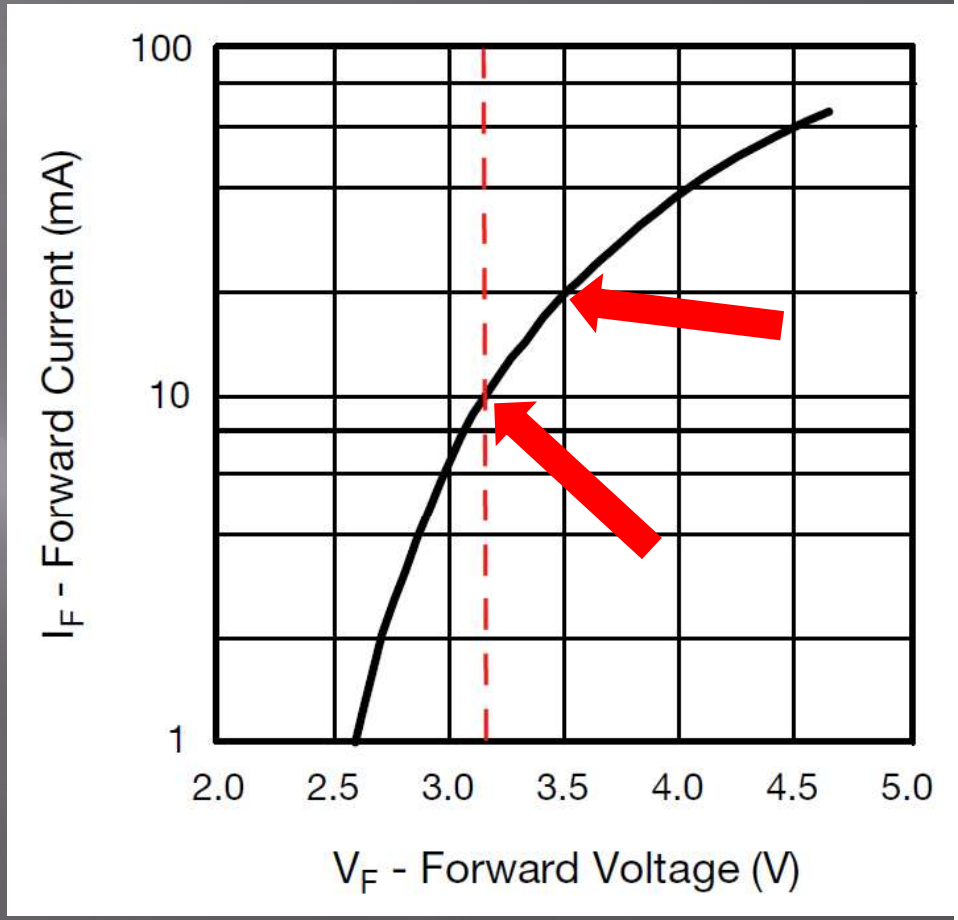
Click for related article

Even though the regulator can be adjusted in 0.1v steps, it is still a <u>really bad idea</u>...

LEDs – Common Mistake 1 (cont.)

The current drawn is VERY sensitive to the voltage applied. For example, from the white LED datasheet, a typical voltage for a 10mA current is 3.2v.

At 3.5v, the current **DOUBLES** to 20mA, or a **100%** increase for a **10%** voltage increase !!!!!



Note:
The X axis (voltage) is linear scale
The Y axix (current) is LOG scale

LEDs – Common Mistake 1 (cont.)

- Using this regulator to adjust brightness gives a VERY coarse adjustment, and risks over-current
- Driving multiple LEDs can be problematic, as variations exist (even in LEDs from the same "batch") that can affect brightness and reliability

The article asserts that both these problems are actually benefits.

The main reason given for this using approach?

"...hooking up a dropping resistor to each and every LED is extremely time consuming and tedious."

But it's not nearly as time consuming and tedious as replacing the failed or blown LEDs in your locos, structures and light fixtures!!!

LEDs – Common Mistake 2

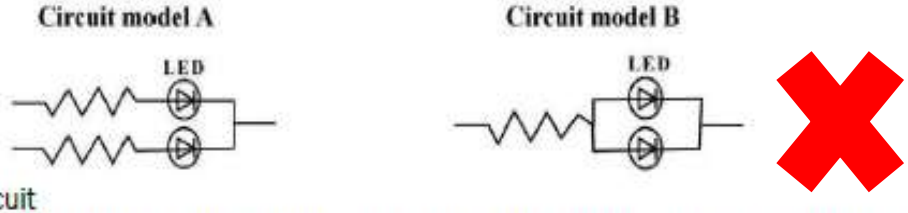
- **Do NOT parallel two LEDs with one shared dropping resistor.**

If the two LEDs are not identical, there will be "current hogging". The same voltage appears on both LEDs, so the current drawn be each can vary significantly, resulting in different brightness and possibly even damage. As the LEDs "age", the brightness can shift over time – what initially was acceptable can become unacceptable over time.

The following is from an LED datasheet:

6. Drive Method

An LED is a current-operated device. In order to ensure intensity uniformity on multiple LEDs connected in parallel in an application, it is recommended that a current limiting resistor be incorporated in the drive circuit, in series with each LED as shown in Circuit A below.



(A) Recommended circuit

(B) The brightness of each LED might appear different due to the differences in the I-V characteristics of those LEDs.

LEDs – Common Mistake 2 (cont.)

A common response:

"I've done that and never had a problem."

I made this mistake and learned from it:

I had two green LEDs in a pair of three-aspect dwarf signals in parallel. It worked fine for a while. A couple of years later I noticed one of them wasn't lighting. Some painful under-layout trouble-shooting revealed that the LEDs were both OK. I added a separate resistor for each and everything worked fine again. LEDs can and do "age" with time, especially if they are "on" most of the time (as these green LEDs were).

LEDs – Common Mistake 3

- **Failure to protect an LED against high reverse voltage will <u>eventually</u> lead to LED failure (it could take some time).**

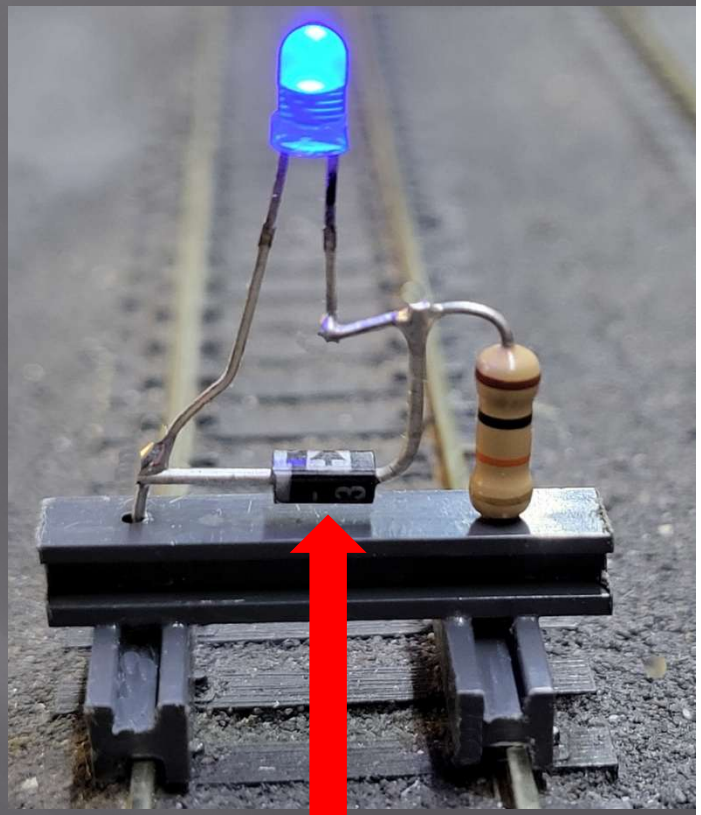
This condition doesn't occur too often, but if you power an LED with DCC track power it is a real concern.

This one was also learned the hard way – again, it was the three-aspect dwarf signals for my double crossover. A yellow LED failed; I added the reverse protection diodes and replaced the dwarf.

LEDs – Common Mistake 3 (cont.)

Another example:

I often operate on Don Bell's excellent railroad. He recently added an MOW train that gets randomly called out. To protect the work area, he built two "warning lights" that get placed on the track around the work area, powered by the DCC track power. **During the FIRST deployment, one of them began flickering and finally went dark!** He has since added reverse protection with a simple diode.



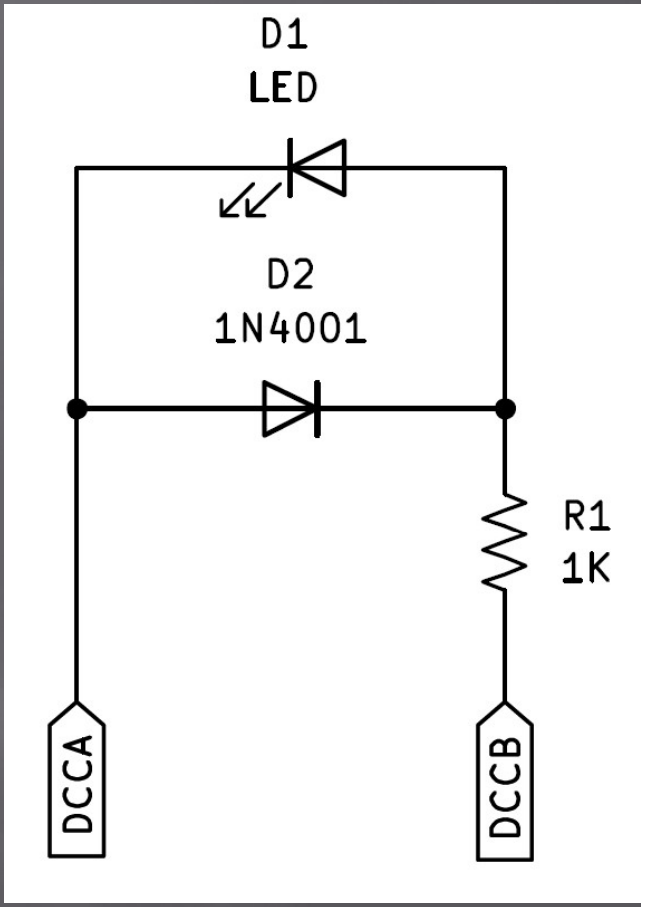
Added reverse protection diode

LEDs – Common Mistake 3 (cont.)

Here's a sample fix (as implemented by Don):

This is a quick and dirty DCC track power indicator. Just place another diode, reversed, across the LED. This limits the reverse voltage to about 0.7 volts, well within spec.

Of course, you could also use another LED rather than a plain diode, and the reverse voltage would be higher but still less than the 5 volt spec.



Note:
All my schematics are made with **Ki-Cad**, a free package that also includes PCB design and layout.

LED Resistor and Voltage Selection

So, by now you probably realize that my recommended application circuit is one LED and a resistor with a DC voltage applied.

So what voltage to use? I'll work a couple of examples, using a white LED and a target 10 mA current, using standard 5% resistor values, but with 1% accuracy.

Depending on the color, batch, temperature, etc. the forward voltage V_F can vary. I will also apply an optimistic +/- 2% accuracy on the voltage supplies.

Resistor and Voltage Selection (cont.)

		Supply Accuracy:	2%	Resistor Accuracy: 1%	I (mA)			(mW)
LED color	Vfwd min	Vfwd max	V	R	max	min	average	Average R Power
red	2.0	3.0	12	2200	4.7	3.9	4.3	41.1
red	2.0	3.0	12	1000	10.3	8.7	9.5	90.4
red	2.0	3.0	5	240	13.0	7.8	10.4	26.2
red	2.0	3.0	5	180	17.4	10.5	13.9	34.9
yellow	2.4	3.0	12	1000	9.9	8.7	9.3	86.6
yellow	2.4	3.0	5	240	11.4	7.8	9.6	22.1
green	2.4	3.0	12	1000	9.9	8.7	9.3	86.6
green	2.4	3.0	5	240	11.4	7.8	9.6	22.1
white	2.8	3.6	12	1000	9.5	8.1	8.8	77.6
white	2.8	3.6	5	180	12.9	7.2	10.0	18.1

Key Notes:

- Using a 12v supply gives much less variation in current, at the expense of more resistor power
- Even so, the resistor power allows 1/8 watt resistors to be used in all cases

Resistor and Voltage Selection (cont.)

Why did I choose 10 mA LED current?

- Many LEDs have a 20mA max spec; half is a very safe value, allows for variations, lower heat, and longer life.
- Today's LEDs are much brighter than those from even 10 years ago; for many applications, you may need to dim the LEDs even further!

Why 2% supply and 1% resistor tolerances?

- Those a reasonable values, and 1% resistors are readily and cheaply available (even on Amazon); the days of "binning" or "tested-in accuracy" are long over.

What about Series LED connections?

This is possible with a 12v supply, but keep in mind that as the resistor value (hence voltage) is reduced, the possible variation range increases rapidly.

Remember, you can always measure the current easily (without breaking the circuit to make a current measurement directly) using Ohm's law by measuring the voltage across the ***resistor***: **I = V / R**

Note that you can't just cut the resistor value in half, as the LED voltage changes very little with current (recall that the current changes a lot with voltage changes).

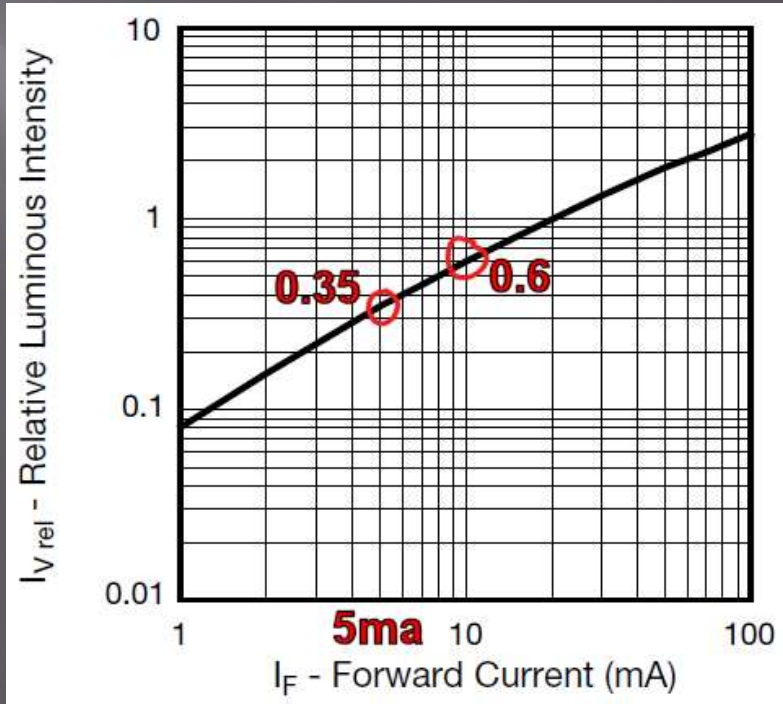
For example, for two white LEDs in series, changing from 1000 to 680 ohms (NOT 500 ohms) gives almost the same 10mA current at 12v.

What about dimming the LED?

Often the LED will be too bright at even 10mA current (shining through structure walls, etc.). Within reason, the LED brightness tracks the current. Also recall that the **LED voltage changes slowly with current**.

Thus, **to a first approximation, doubling the resistor value will result in half the relative brightness** (in this example, from 0.60 to 0.35. Close enough, since the brightness will be judged subjectively.

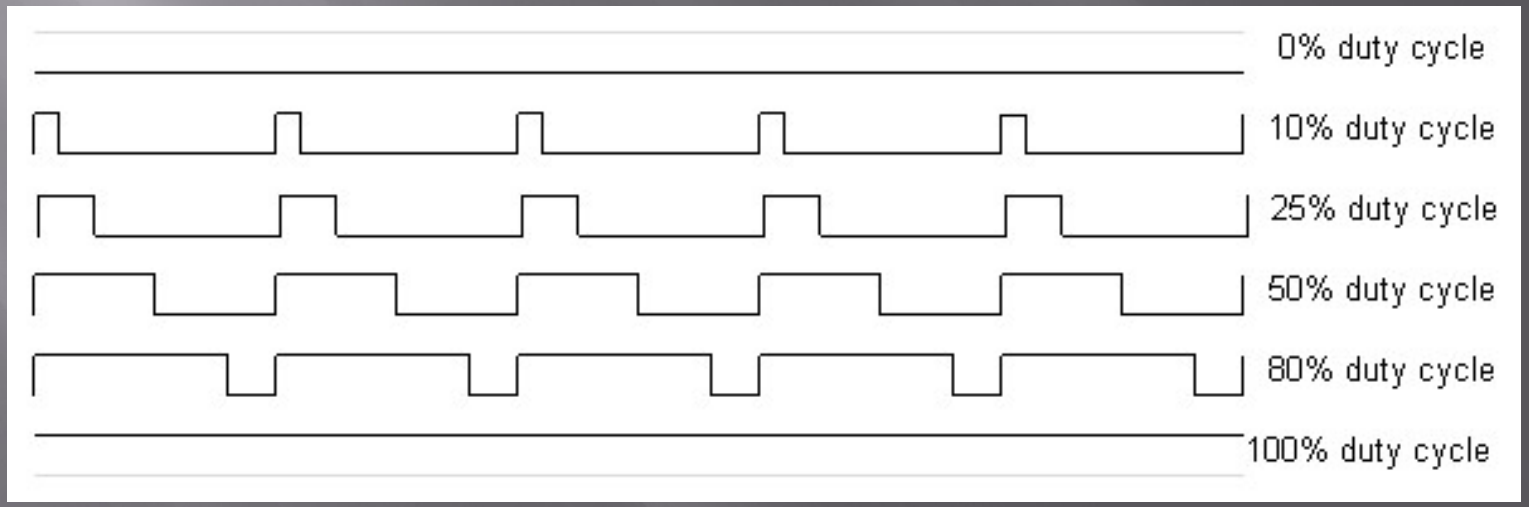
Note:
Both axes are log scale



What about dimming the LED?

Using the current magnitude to control brightness has one drawback: the LED color will change at low current values, which can be especially noticeable with white LEDs.

The best way to dim is to use PWM (**P**ulse **W**idth **M**odulation), but you need a microprocessor for this (DCC decoders use this method). This technique turns the LED on and off very quickly, with the brightness controlled by the ratio of ON to OFF time. The ON time is always at the full current value, so the LED is always the same color.



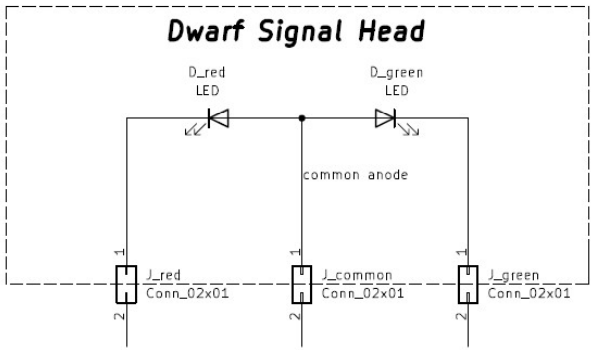
LED Wrap Up! (*Finally!*)

My recommendations for using LEDs for general purpose lighting purposes is:

- Use a 12v supply
- Use a resistor for each LED
- start with a 1K Ohm resistor to give about 10mA; **the current in mA is the voltage across the 1K resistor – no math needed!**
- If polarity can be reversed in a given application, use a parallel reversed diode to limit the reverse voltage

A Bonus Trick

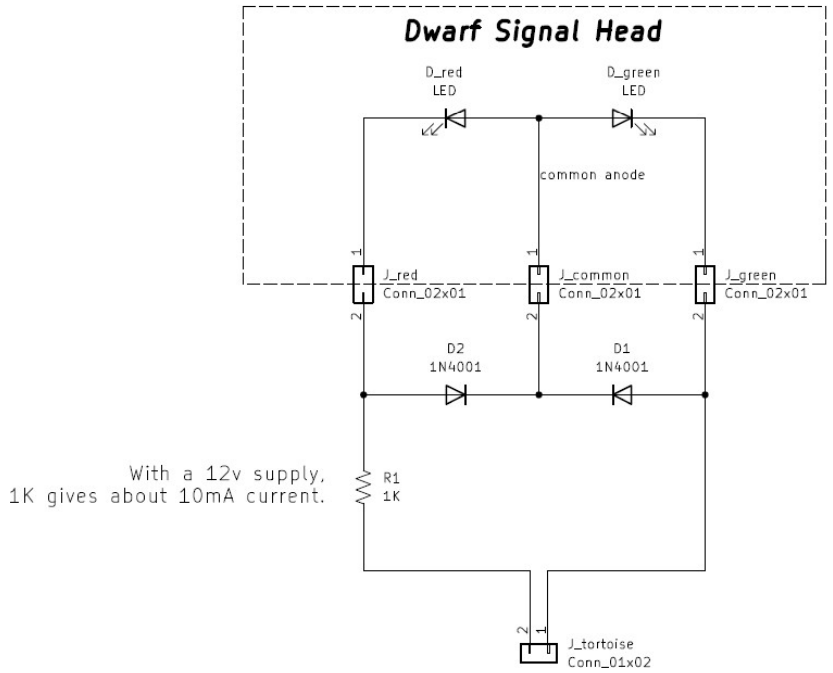
Most pre-assembled dwarf signals are wired common-anode, with three wires. How can you make them work as position indicators with a Tortoise switch motor?



A Bonus Trick

Most pre-assembled dwarf signals are wired common-anode, with three wires. How can you make them work as position indicators with a Tortoise switch motor?

Two diodes and a resistor will do the trick! Just wire this across the Tortoise power pins, testing first to get the correct color aspects (you have a 50% chance!)

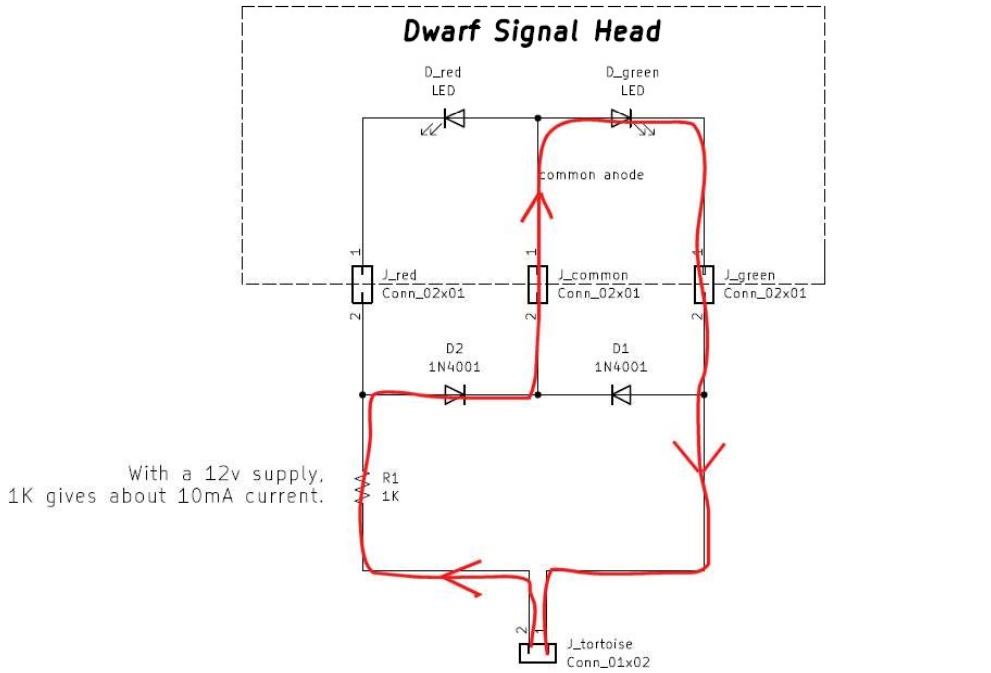


Connect these directly to the Tortoise supply pins.
Pin 1 = 12v, Pin 2 = 0v -> red LED on (through D1)
Pin 1 = 0v, Pin 2 = 12v -> green LED on (through D2)

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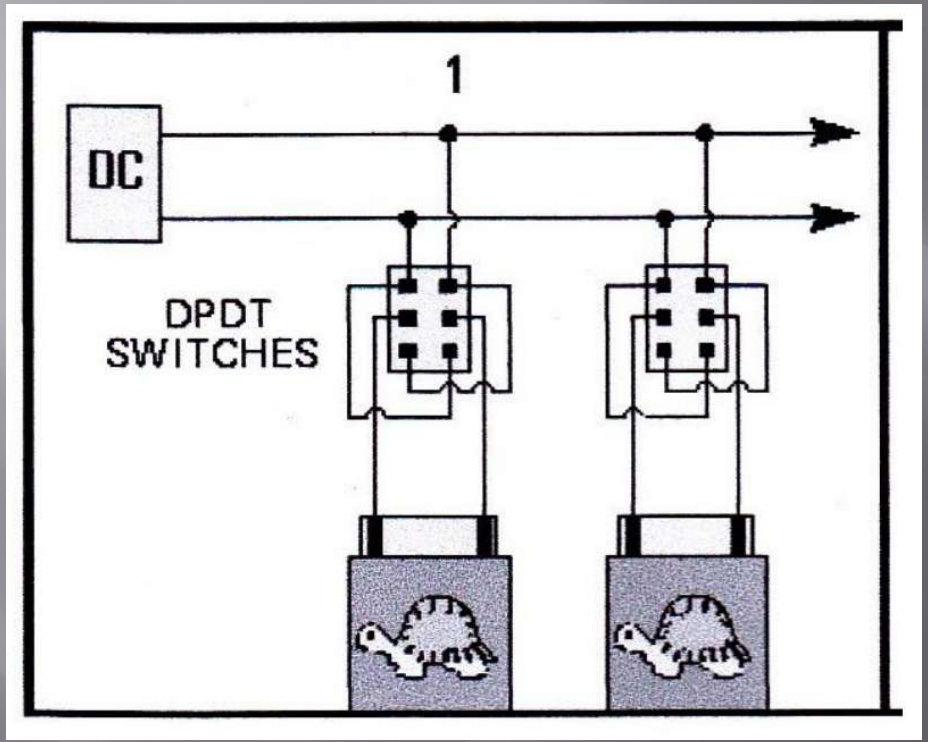
Here's the green LED current path; the red color path is the mirror image.

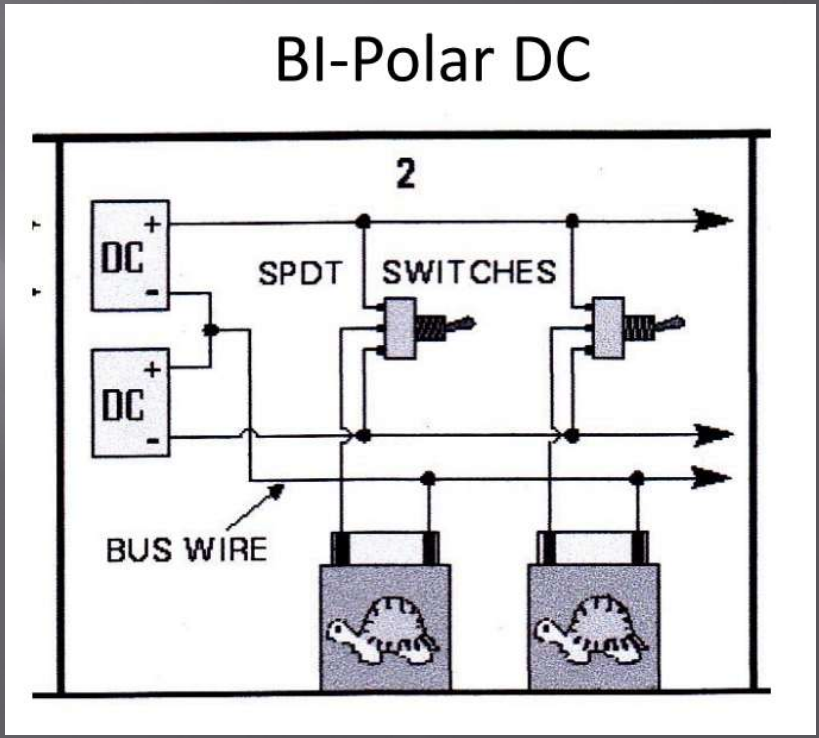


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Speaking of Tortoises… (or down the next rabbit hole)

As per the instruction sheet, two of the ways to wire a Tortoise:





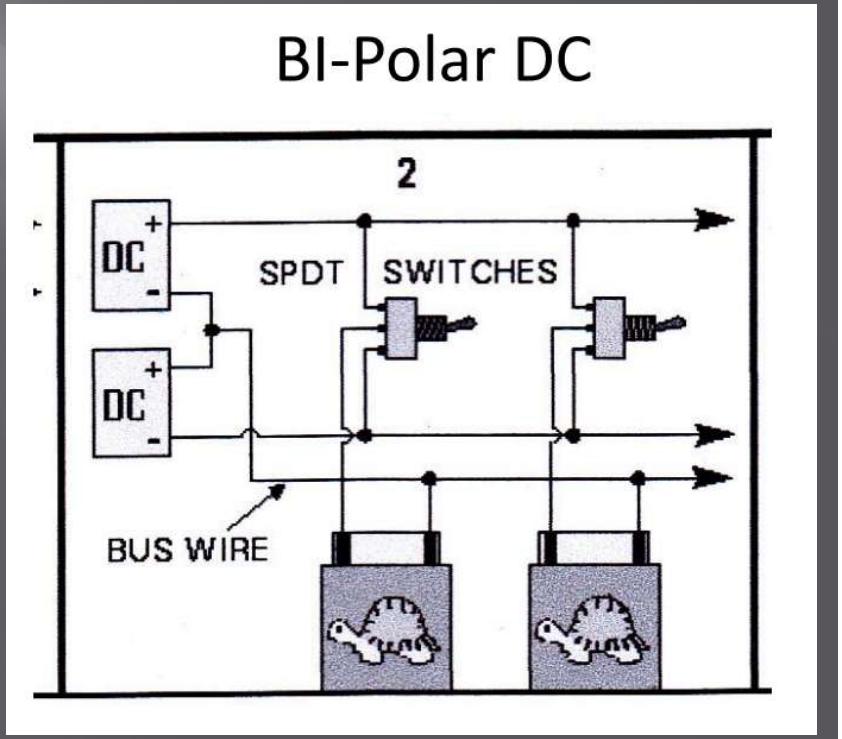
Most people use this method.

Speaking of Tortoises…

I prefer the Bi-Polar method; Tortoise contacts have a propensity for failure, especially if "hot switched". I modify the bi-polar circuit by using DPDT switches, keeping the second pole free for frog power routing in case the Tortoise contacts fail! ***Plus, it's easier to wire the switches.***

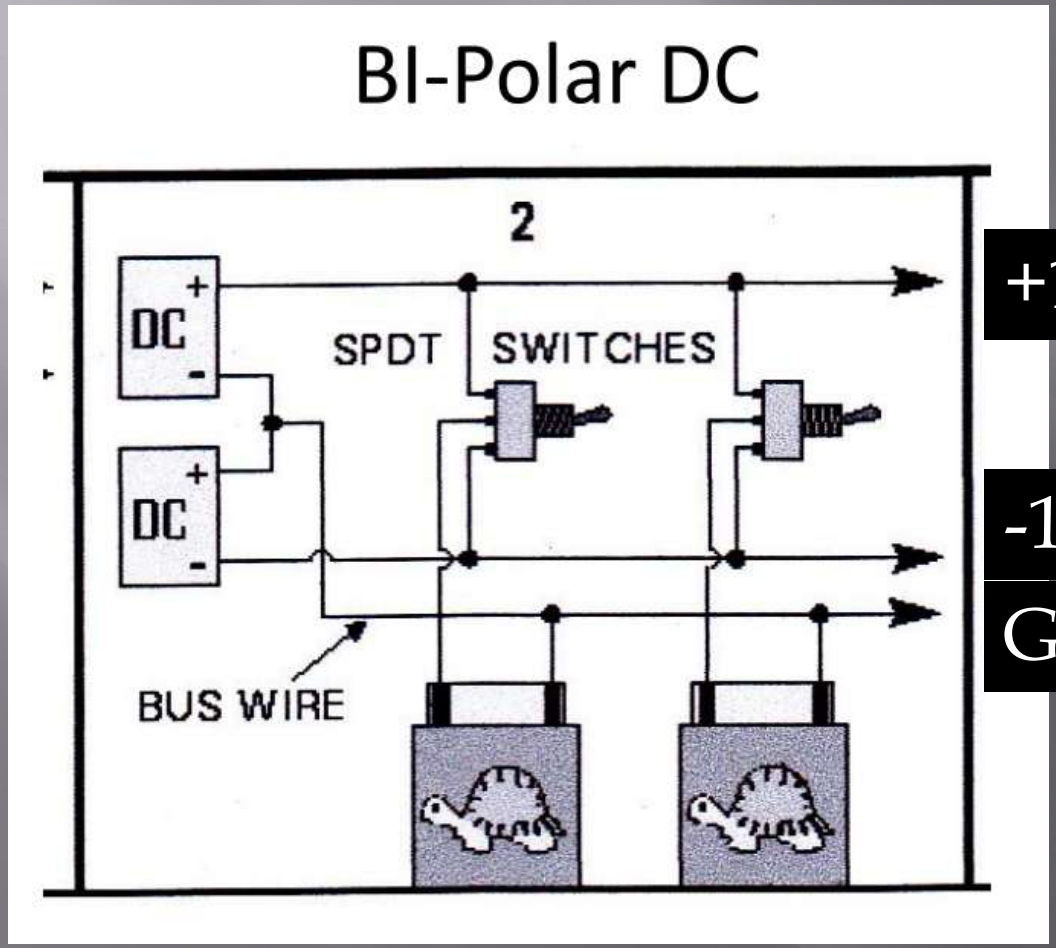
As a bonus, the +/- 12v supply busses double as layout lighting supplies. **CAT-5** wire works great:

- use one pair for the +12v
- use one pair for the -12v
- use **two** pairs for the common/ground



Speaking of Tortoises…

The supplies are just 12v "wall warts", connected just as shown. The common connection becomes "ground".



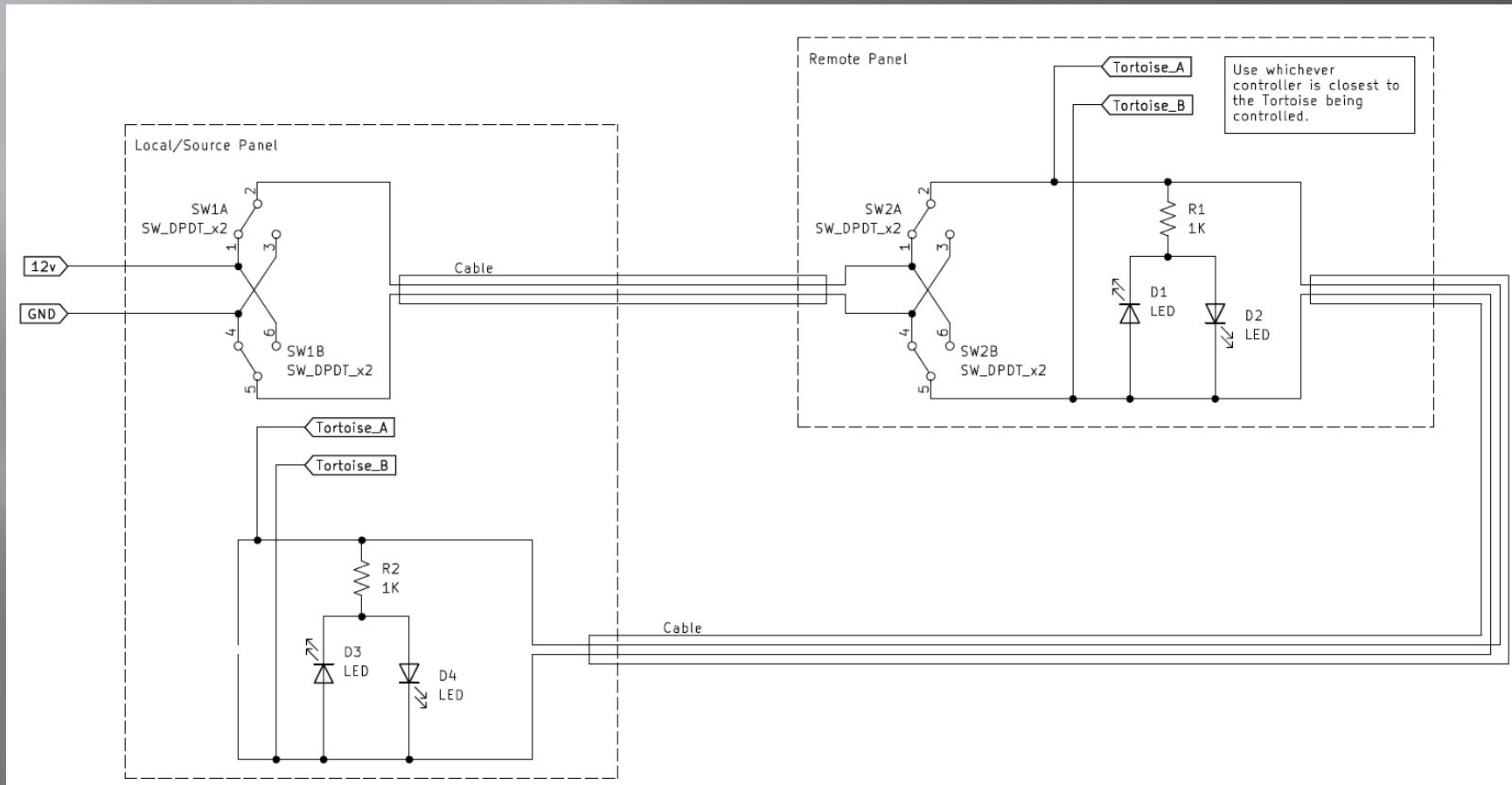
This gives two 12v lighting circuits:

- ❑ +12v to GND
- ❑ GND to -12v

My layout has ~35 Tortoises, many lights, and several other circuits (Arduinos, etc.) powered by the 12v supplies and the total current is less than 1 Amp on either 2 Amp supply.

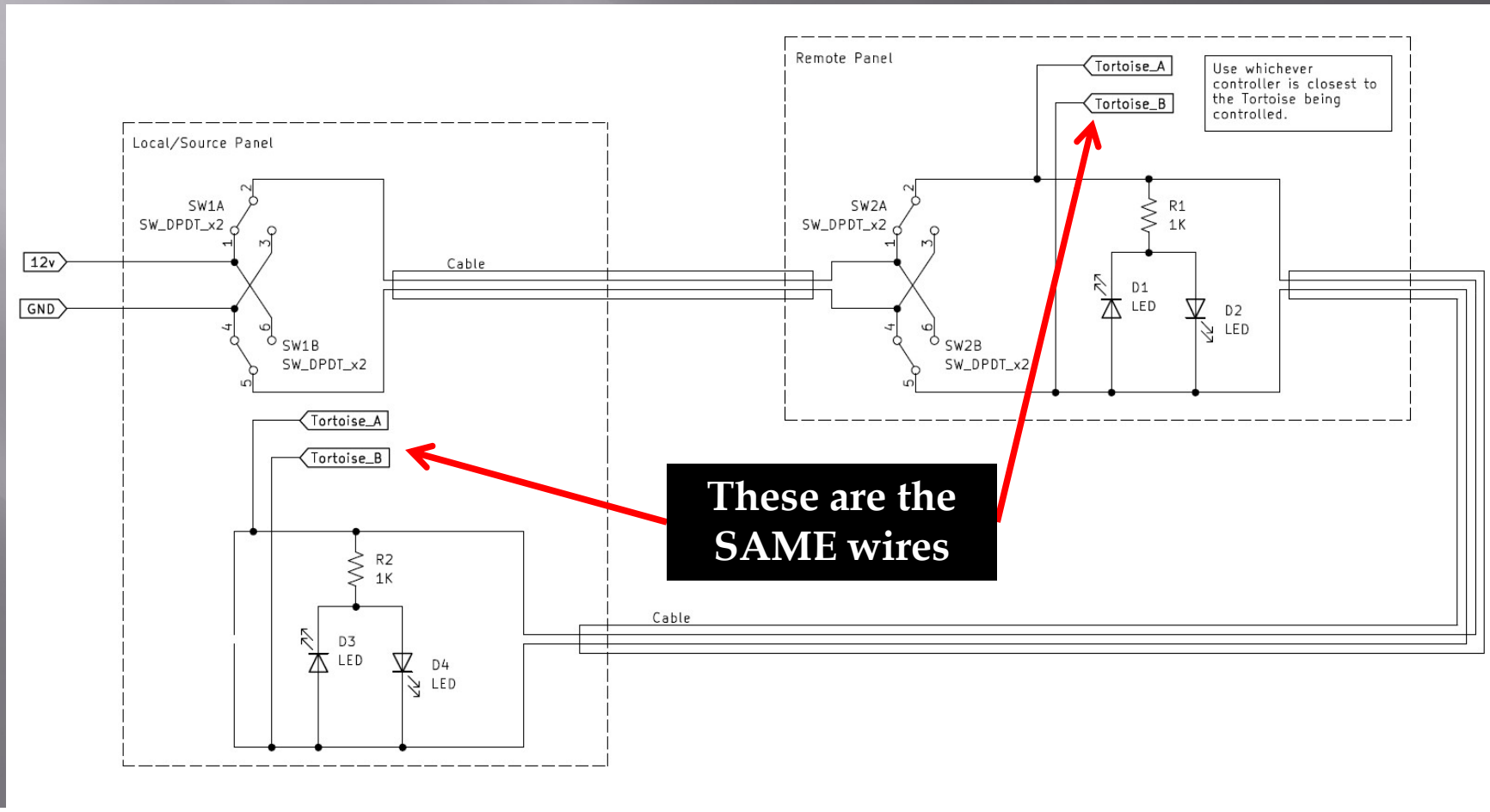
STILL Speaking of Tortoises…

I have two areas on the layout that I wanted to control from ***two different locations*** – the Bi-Polar circuit doesn't work for this! Back to the drawing board:



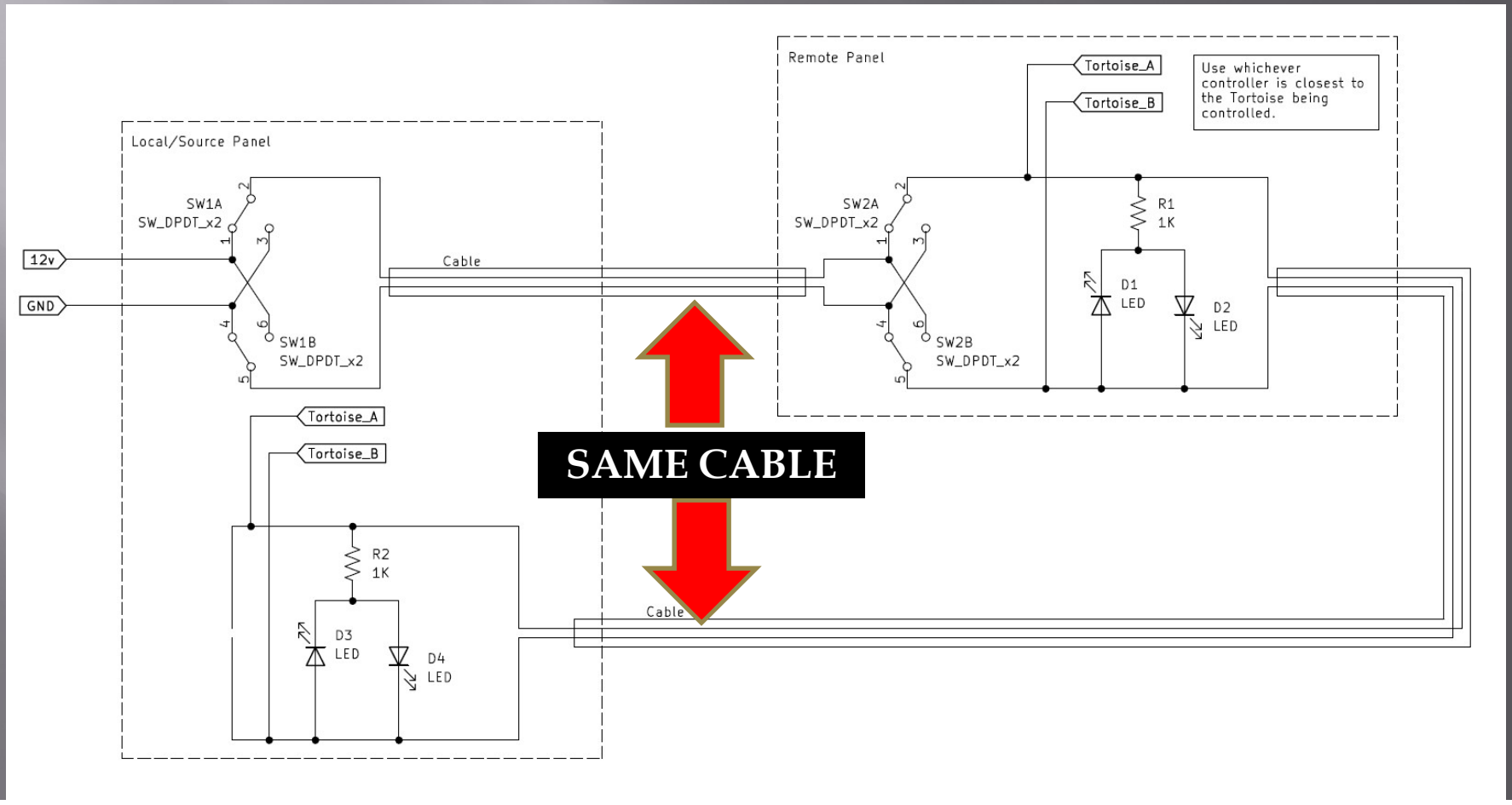
STILL Speaking of Tortoises…

This uses two DPDT switches in series. But, to get the panel LEDs to track at both locations, they must be powered by the same wires that drive the Tortoise, which are the same nets on both panels:



STILL Speaking of Tortoises…

Note again that the Tortoise can be fed from EITHER panel. Also note that **CAT-5** cable is great for wiring this, with each cable (4 pair) supporting two turnouts. The drawing misleadingly shows separate cables.



STILL Speaking of Tortoises…

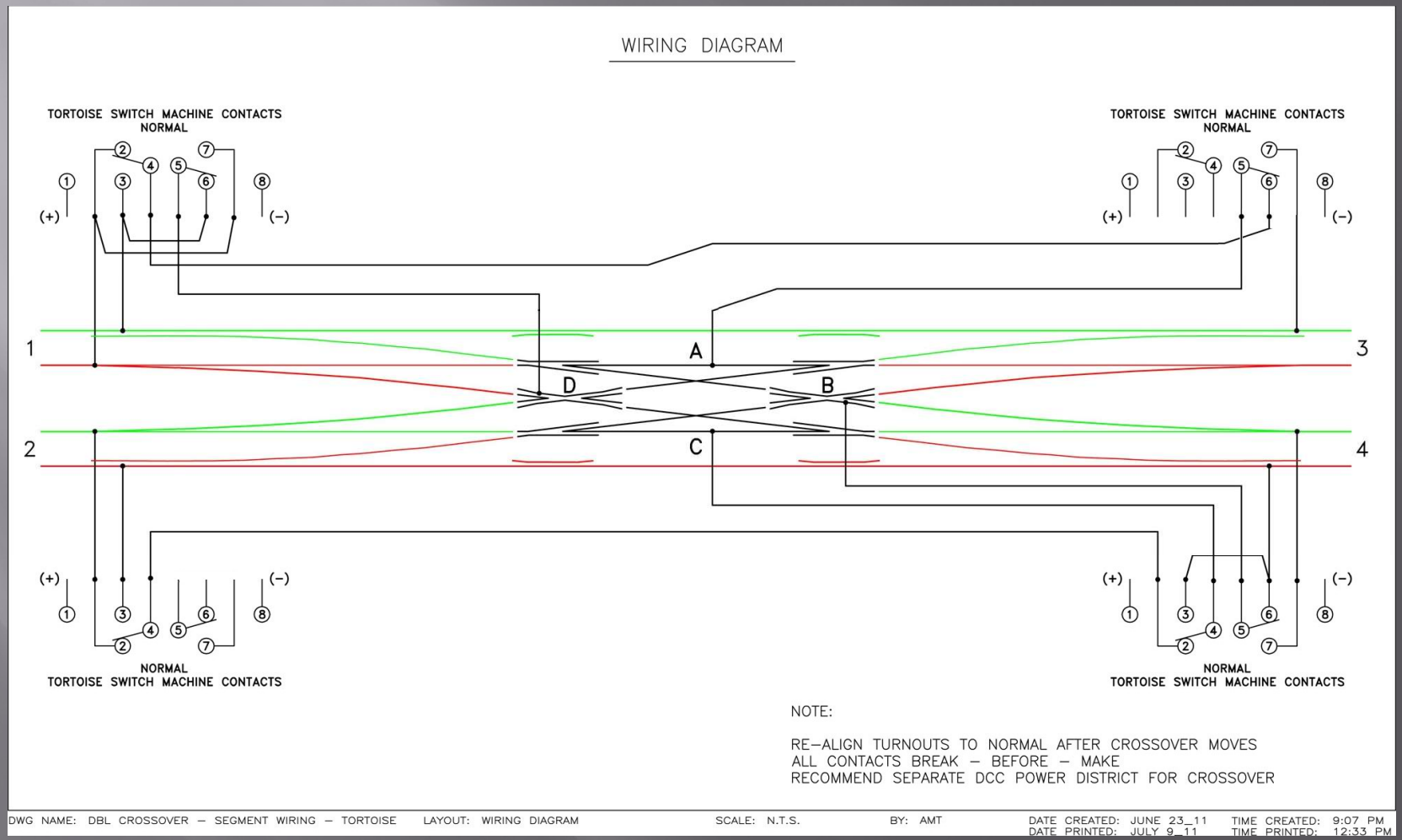
This works great, but it re-exposes one issue – what to do if your Tortoise contacts fail?

- Switch to the other set of contacts, assuming they haven't been used (or they aren't BOTH bad)
- Switch to using a robust 12v automotive relay

The first solution worked for me in one case. But for that trouble-making double crossover, all the contacts were already being used to map polarity for the four "frog" sections!

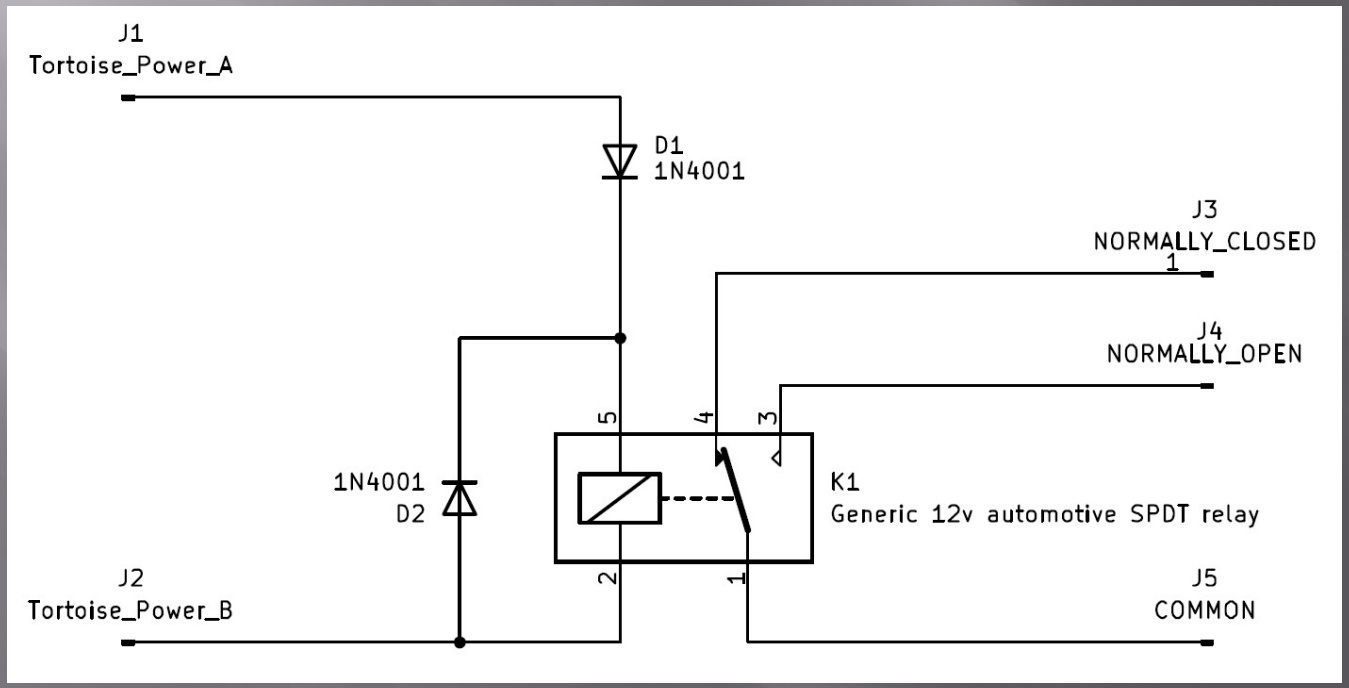
STILL Speaking of Tortoises…

This could almost be a clinic of its own…but to continue…



STILL Speaking of Tortoises…

It's a very simple circuit. The inputs connect to the Tortoise power, which will be either + or – 12v. D1 only activates the relay for one polarity. D2 is the "snubber" diode, which clamps the inductive kickback of the relay coil. The contacts then mimic the original Tortoise contacts.



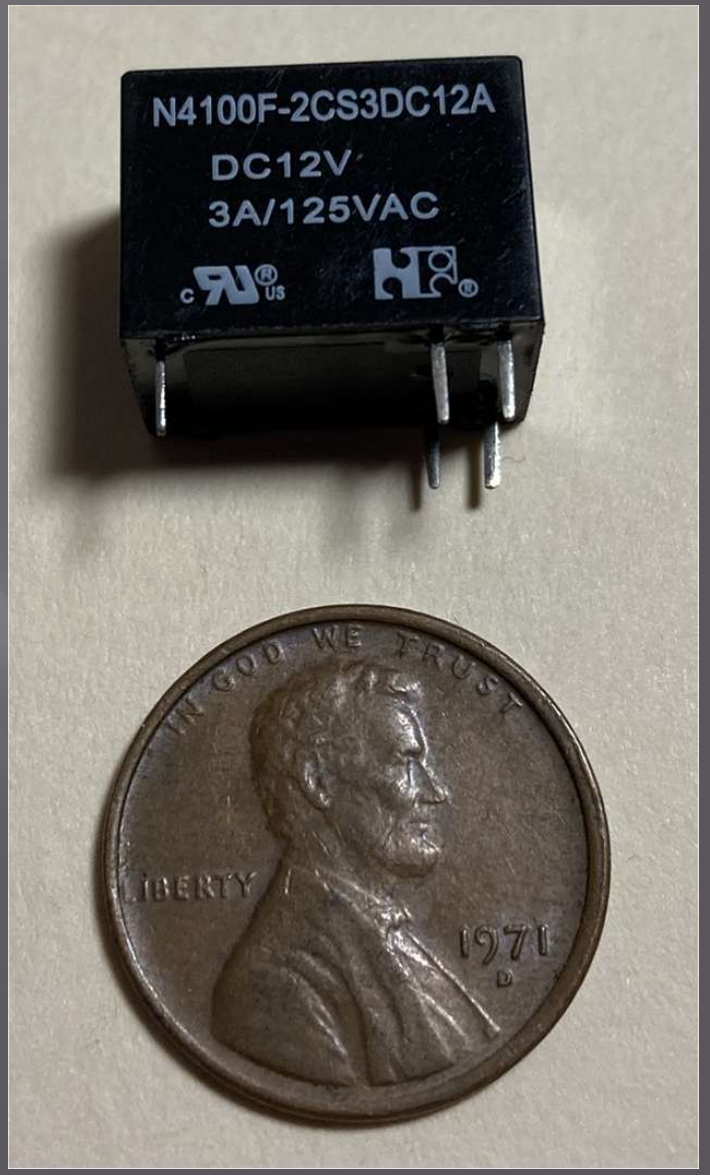
DO NOT OMIT D2 !!!!

STILL Speaking of Tortoises…

Here's a sample relay. They are quite small and handle a lot of current – this particular relay is good for 3 Amps.

The coil resistance is 400 Ohms (a Tortoise is about 600), so it will draw only 30mA at 12v.

There are many varieties, with different pin-outs, etc. but they are all around $1 on Amazon, with free shipping for Prime members.



The next topic – WIRE!

This also could almost be a clinic of its own...but to continue...some basics:

- Wire size, known as "gauge", specifies the cross-section area of the conductor
- The smaller the gauge, the larger the wire
- The same gauge applies to both **solid** and **stranded** wire
- For ***model railroad*** purposes, there is no electrical difference – just physical (flexibility)
- I will concentrate only on copper wire, and only on a few readily available and often used gauges.

WIRE! (cont.)

An internet search readily turns up various charts and data on American wire gauges.

We will focus on:

- 12 & 14 commonly used for DCC bus wiring, and often house wiring
- 24 and 28 commonly used for drops; **CAT-5 wires are 24 gauge**

AWG Gauge*	Area (Circular Mils)	Diameter (mils, 1000th in)	Electrical Resistance (Ohms/1000 ft)		Weight (lb/1000 ft
			at 77 °F (25 °C)	at 149 °F (65 °C)	
12	6530	81	1.62	1.87	19.8
14	4110	64	2.58	2.97	12.4
22	642	25.3	16.5	19	1.94
24	404	20.1	26.2	30.2	1.22
26	254	15.9	41.6	48	0.769
28	160	12.6	66.2	76.4	0.484
30	101	10	105	121	0.304
32	63.2	8	167	193	0.191
34	39.8	6.3	266	307	0.12
36	25	5	423	488	0.076
38	15.7	4	673	776	0.048
40	9.9	3.1	1070	1230	0.02

WIRE! (cont.)

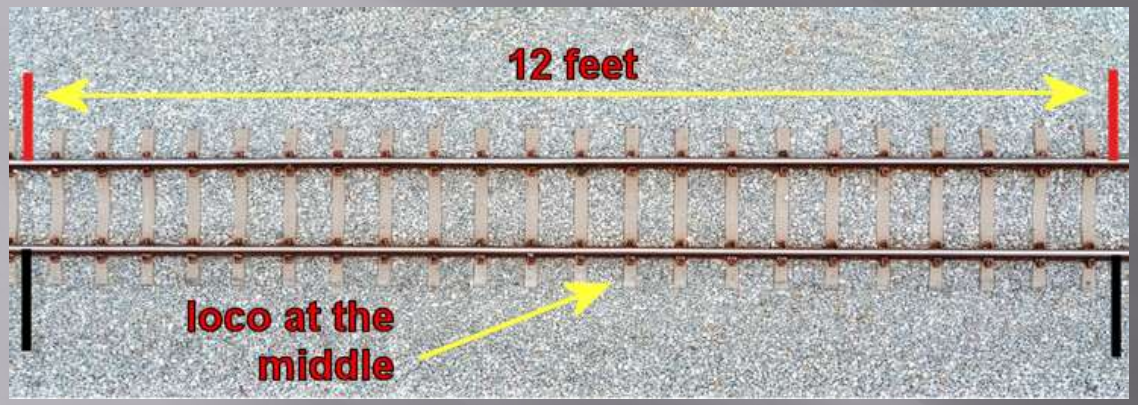
Here's a trimmed down chart. Notice how nickel-silver rail compares to copper wire! It's not a great conductor, but when we throw some numbers on it we'll see that it's not a problem ***in most cases***.

AWG Gauge*	Electrical Resistance *(Ohms/1000 ft)*		Notes
	at *77 °F (25 °C)*	at *149 °F (65 °C)*	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

Let's assume the following:

- A 1.0 Amp load (pessimistic for modern locos)
- 12 feet of code 83 track between drops
- Soldered joints
- Ideal feeders (for now)

WIRE! (cont.)



AWG Gauge*	Electrical Resistance (Ohms/1000 ft)		Notes
	at 77 °F (25 °C)	at 149 °F (65 °C)	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

The voltage drop is:

R_{total} = 26.2/1000 x 6 feet / 2 drops x 2 rails
(ohms/foot) (to drop) (parallel) (A and B)
= **0.1572 Ω**

V_{drop} = I x R = 1 amps x 0.1572 Ω = **0.1572 Volts**

In most cases, this is not a problem...

WIRE! (cont.)

Now, let's consider the DCC bus wiring (ignoring the feeders for now).

AWG Gauge*	Electrical Resistance (Ohms/1000 ft)		Notes
	at 77 °F (25 °C)	at 149 °F (65 °C)	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

Let's assume the following:

- 100 feet total track/bus wire
- A **10.0 Amp load** (1.0 amp locally and 9.0 amps downstream of these feeders)
- The same 12 feet of code 83 track, in the middle of the 100 feet
- 14 gauge bus wire
- Ideal feeders

WIRE! (cont.)

The voltage drop is:

R_{total} = 2.58/1000 x 50 feet x 2 rails
(ohms/foot) (to drop) (A and B)
= **0.258 Ω**

V_{drop} = I x R = 10 amps x 0.258 Ω = **2.58 Volts**

This is a problem!!!

Going to 12 gauge wire reduces the voltage drop to **1.62 volts**. This is probably sufficient. Note that this is an EXTREME case.

AWG Gauge*	Electrical Resistance (Ohms/1000 ft)		Notes
	at 77 °F (25 °C)	at 149 °F (65 °C)	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

WIRE! (cont.)

Now, let's consider the **drops/feeders**.

AWG Gauge*	Electrical Resistance (Ohms/1000 ft)		Notes
	at 77 °F (25 °C)	at 149 °F (65 °C)	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

Let's assume the following:

- A 1.0 Amp load
- The same 12 feet of code 83 track
- 24 gauge feeder wire
- Feeder wires are 1 foot long, rail to bus
- Ideal bus wires

WIRE! (cont.)

The voltage drop is:

R_{total} = 26.2/1000 x 1 feet x 2 rails
(ohms/foot) (to drop) (A and B)
= **0.0524 Ω**

V_{drop} = I x R = 1 amps x 0.0524 Ω = **0.0524 Volts**

This is NOT a problem!!!

Note that this analysis is pessimistic, as it ignores the parallel resistance of the rails which share the current and reduces the load seen by drops.

AWG Gauge*	Electrical Resistance (Ohms/1000 ft)		Notes
	at 77 °F (25 °C)	at 149 °F (65 °C)	
12	1.62	1.87	
14	2.58	2.97	
22	16.5	19	close to NS Code 100 rail
24	26.2	30.2	(CAT5) and close to NS code 83 rail
28	66.2	76.4	

WIRE! - Conclusions

- Your buss wire is the biggest issue; my example was extreme, but 12 gauge is a good choice, although 14 gauge is fine for small layouts or if your total load is low.
- 12 feet of soldered rail is not an issue, as long as the joints are soldered. Every piece of rail NOT soldered should have a feeder in any case, and more drops are better.
- Using 24 gauge for drops/feeder is fine, it is the least significant source of voltage drops in the system.

If in doubt, RUN THE NUMBERS – it's easy!

Capacitor Basics

Capacitor specs:

- Capacitance value and tolerance
- Working voltage
- ESR – equivalent series resistance
- Polarized (electrolytic) or non-polar (large values have polarity)

Capacitor features:

- Are an open circuit to **DC**
- Parallel values add (like series resistors)
- Series values reduce (like parallel resistors) Example: If series caps are equal value, 4 in series has a value of $1/4^{th}$ the individual cap value.

Capacitor Basics (cont.)

Capacitor features:

- Large value caps are NOT effective at high frequencies (high ESR), are usually polarized, and have a relatively loose tolerance, often asymmetrical; Electrolytic capacitors often have a tolerance of -20% and +80%, so they are not normally used where the exact value is important, but a minimum value is.
- Small value caps are needed for high frequency applications, are usually non-polar, and can have very tight tolerance.
- Units can be micro, nano, or pico farads – "Super Caps" can be in farads!!

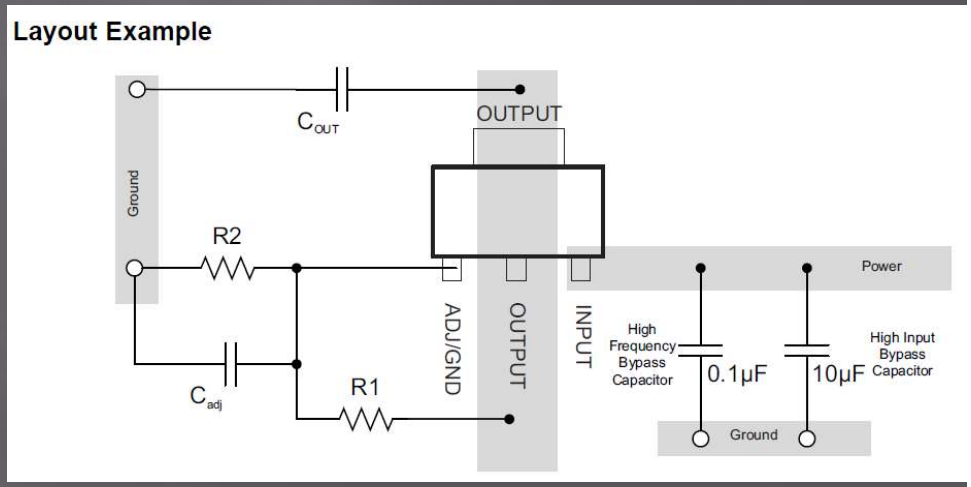
Capacitor Applications

Capacitor uses in model railroading:

- Filtering/decoupling of circuits like regulators, integrated circuit supplies, etc.
- Storage (Stay-Alive)
- Timing circuits (will not be discussed here)

For the first application, due to the frequency response characteristics of various caps, you should always use an electrolytic for low-freq filtering, and add a 0.1uF or 0.01uF in parallel ***very close to the device being decoupled***!

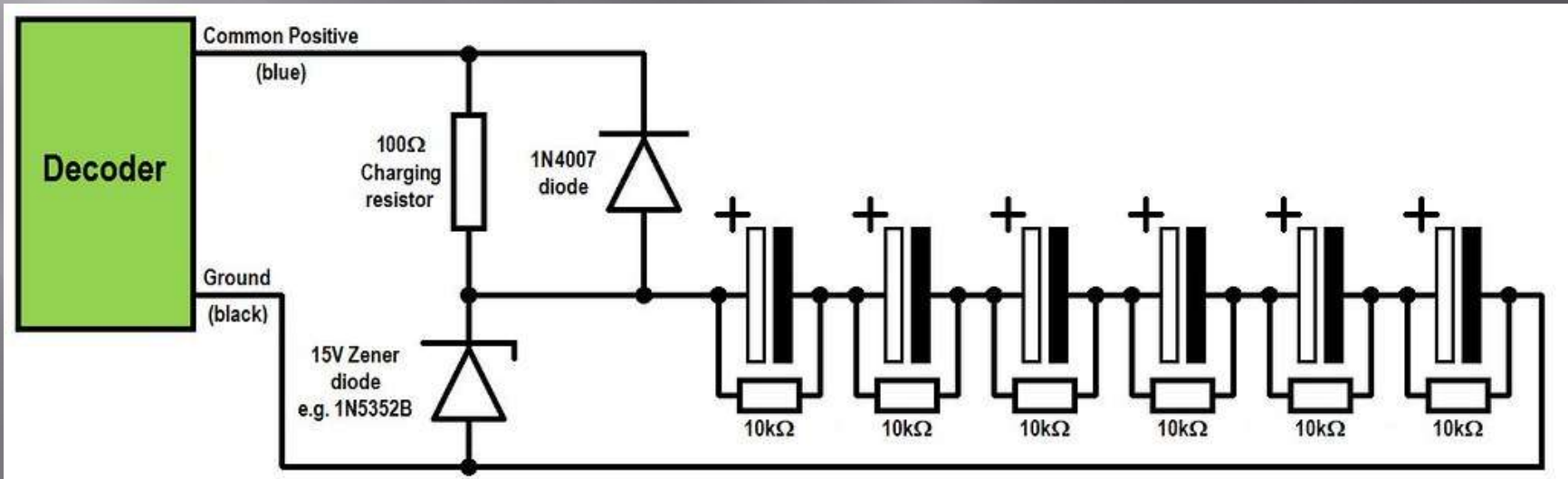
From an LM317 regulator data sheet:



Capacitor Applications (cont.)

Stay alive circuits using "super caps" are a major application. They come in various values. Common voltages are 2.7v and 5.5v. These need to be "stacked" to get to a DCC-safe voltage. Here's a sample schematic, explanation to follow, from:

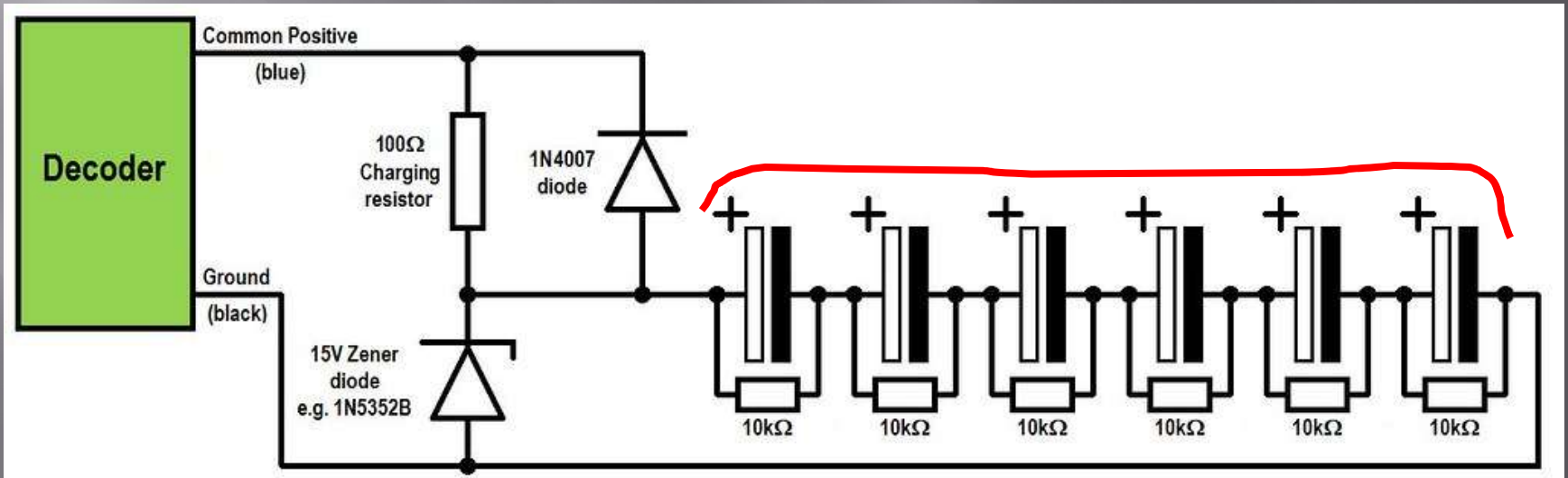
https://www.flickr.com/photos/154160118@N03/45668431465



Six 2.7V super-capacitor stay-alive array wired in series plus protection circuit v2

Capacitor Applications (cont.)

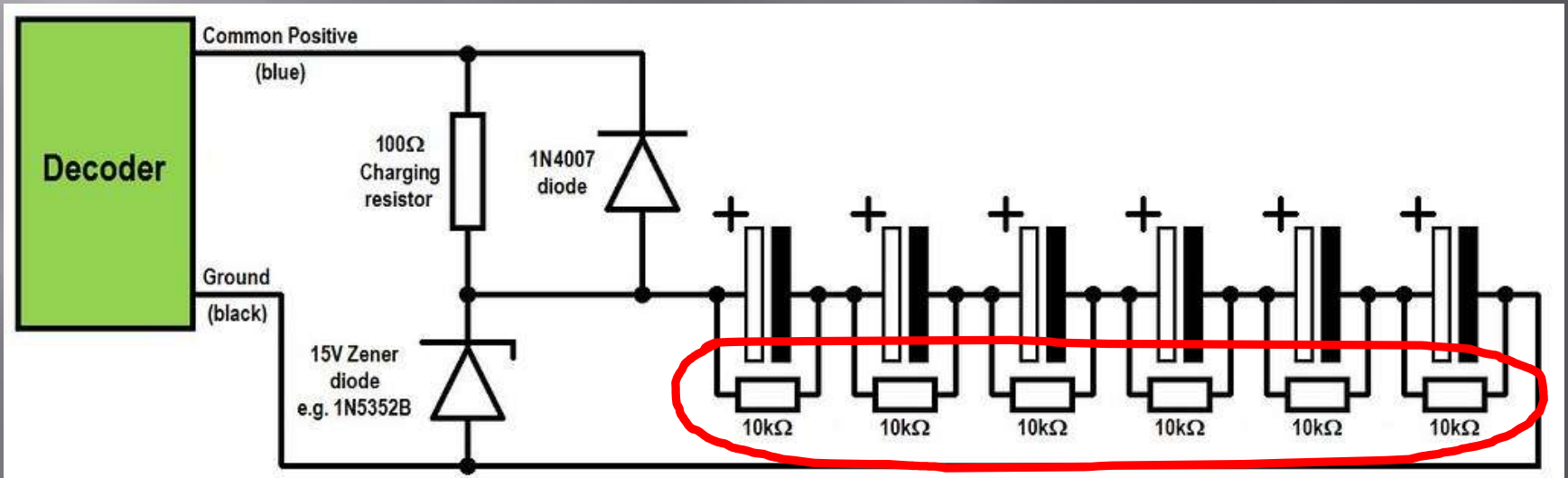
- Why six caps? (6 x 2.7) = 16.2v, which should be safe for most DCC systems/decoders assuming the voltage is evenly divided (more later)...
- Also note that the blue wire from the DCC decoder is the output of a bridge rectifier, so will be about 0.7v below the peak-peak track voltage when under load, but will creep to 0.0v drop as the capacitors charge.



Six 2.7V super-capacitor stay-alive array wired in series plus protection circuit v2

Capacitor Applications (cont.)

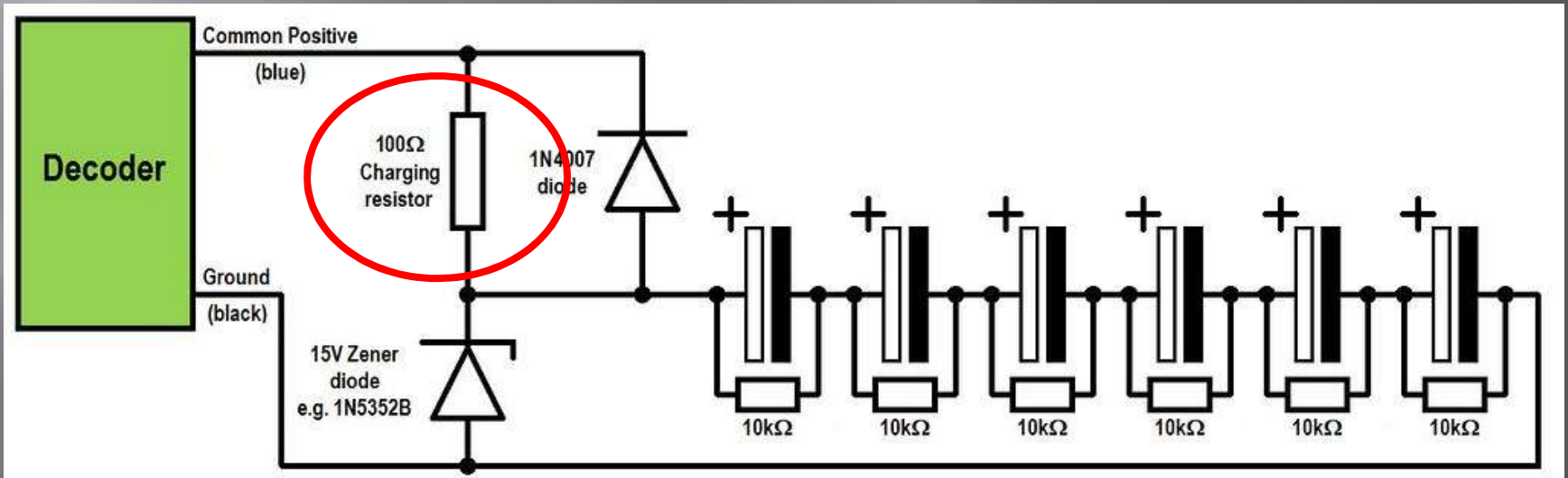
- Why the 10K resistors across each cap?
- Since the cap values can vary +/- 20%, without the resistors, **while charging**, the voltage across each cap will divide proportionately and can vary by 20% as well – the smaller caps will end with a higher voltage!!!
- The resistors provide a DC path that ensures that the final DC voltage on each cap is an equal divide, to the tolerance of the resistors (1% or 5%)



Six 2.7V super-capacitor stay-alive array wired in series plus protection circuit v2

Capacitor Applications (cont.)

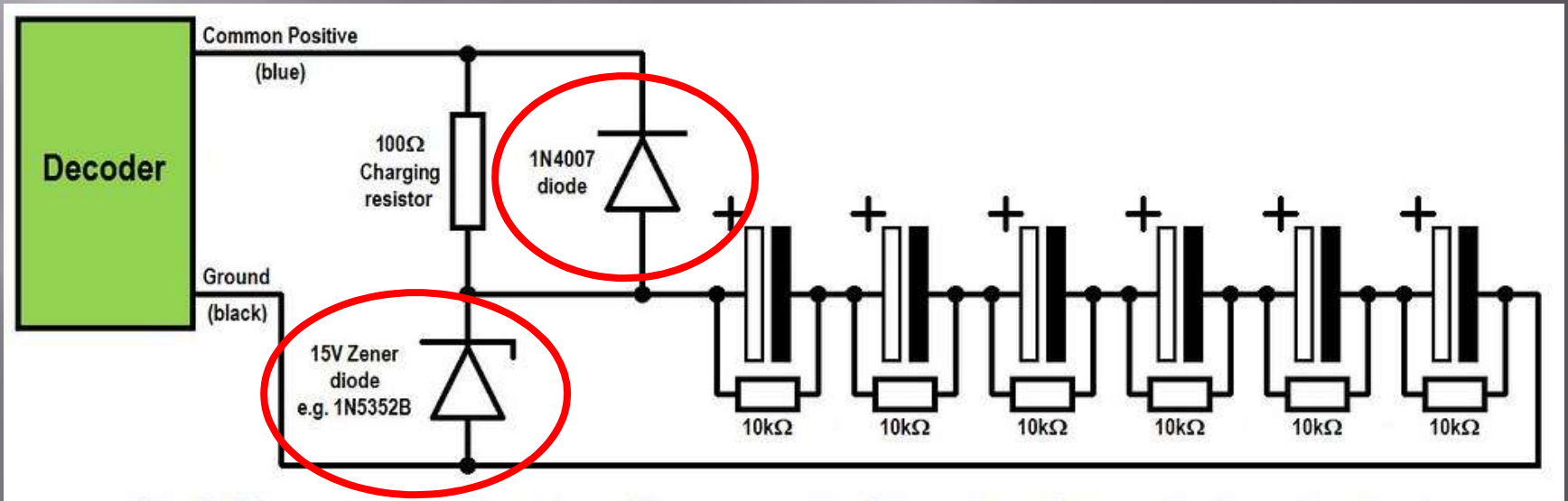
- Why the 100 ohm charging resistor?
- A super cap's rated voltage assumes a limited in-rush current, which, if exceeded, could damage or shorten the life of the cap.
- Additionally, this limits the current that the DCC booster must supply and the decoder must pass, especially an issue on power-up with multiple locos.



Six 2.7V super-capacitor stay-alive array wired in series plus protection circuit v2

Capacitor Applications (cont.)

- The 1N4007 diode is the "stay-alive" path that supplies the decoder when track voltage is interrupted.
- The 15v Zener protects the caps from over-voltage (a Zener diode "breaks down" at a specific reverse voltage, limiting it); this is optional if you know your DCC voltage is limited.

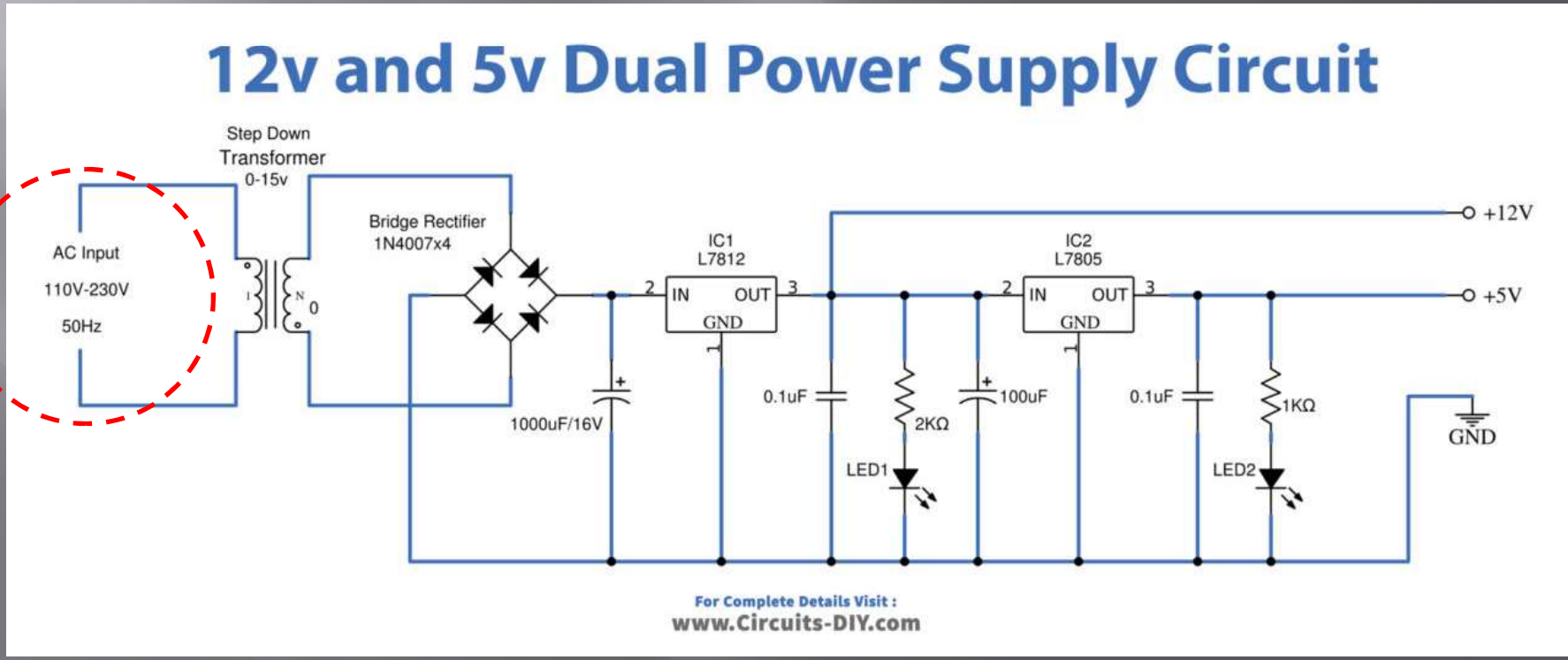


Six 2.7V super-capacitor stay-alive array wired in series plus protection circuit v2



Power Supplies

In the olden days, power supplies involved large transformers, bridge rectifiers, and voltage regulators (with heat sinks), and **LETHAL HIGH VOLTAGE WIRING!!!**



Power Supplies (cont.)

Drawbacks of "traditional" power supplies:

- Wiring the transformer to the dangerous AC line voltage:
  - Adding a on/off switch
  - Adding a fuse
- Size, weight, and cost of a transformer (lots of copper)
- Power dissipation (thus heat). For example:
  - At 2 Amps, the 5v regulator dissipates (2 x (12-5)) = 14 Watts
  - At 7 Amps, the 12v regulator dissipates (7 x (15-12)) = 21 Watts
- Requires a large case/enclosure, maybe a fan
- **Your valuable time to procure everything and then build it**

Power Supplies (cont.)

The answer? Modern switching power supplies!!!

All of the drawbacks mentioned, coupled with the massive growth of household electronics and their need for efficiency have driven this technology to very low prices for the performance achieved!

Even the lowly "wall wart" has evolved, from transformer-based to switching.

Old transformer-based



A couple of these can power all your tortoises and lighting!!



New switcher – 12v @ 1.5A

Power Supplies (cont.)

What about higher power needs?

- DCC booster supplies
- Kadee electro-magnetic uncoupling ramps

The answer is another "commodity" thanks to the computer industry: laptop power supplies!!!



This example includes adjustable output voltage selection.

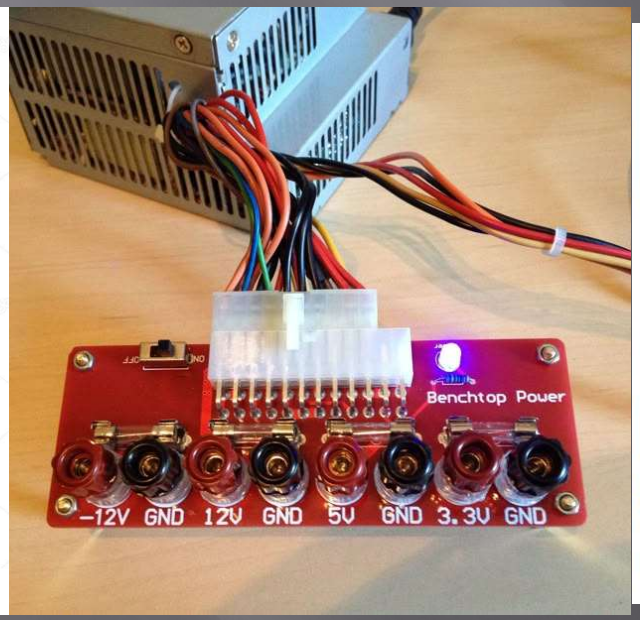
The selection of voltages and currents available will meet almost any need.

Power Supplies (cont.)

Computer power supplies are another option, and can be free if salvaged from an old computer. They provide multiple voltages, and when coupled with one of the many available "breakout boards" are easy to use.

An article on just this solution is in the October 2026 issue of Model Railroader magazine!







24 Step by Step
Build a multi-use power supply

Power Supplies (cont.)

For LED layout lighting, special supplies are available. Keep in mind, with these you still have to deal with hazardous line voltages! **BE CAREFUL!!!**



Power Supplies Summary

Don't build, buy! Advantages:

- Safety!!!! UL listing, short circuit protection, no need to deal with line voltages
- Time; just change (or remove) the output connector or wire to a terminal strip
- Price; these things are cheap compared to legacy supplies.
- Wide selection of voltages and currents available; Amazon, EBay, and many others.

Thanks for your attention!

This presentation (in PDF format) and various support files can be found on the following web page:

https://gdlines.org/NMRA/Electronics_clinic/index.html

Use this QR code:

