Electrical Systems for Private Car Owners

By ERIC WILDE

This article discusses many of the aspects of electrical systems found on railroad cars. It deals with upgrading older electrical systems, how to build modern electrical systems and covers much of the basic principals used in design and construction of electrical systems. It should prove useful to private car owners who wish to work on their own cars or who need to supervise the work done for them by electrical contractors.

The support systems found on old railway cars are like a monument to human ingenuity. If somebody had a bright idea once, you can bet that it's riding around the rails in railway car somewhere. Kitchens had coal stoves and propane burners. Air conditioners were operated by steam, ice or were driven by mechanical drives. Heat was usually steam, the supply of steam being abundant in the days of the steam locomotive. Electrical systems relied on a couple of tons of batteries and axle driven generators. The voltages of these systems varied, with 32, 64 and 110 being common. When it came time to plug into the wayside power, it wasn't unusual to find an arrangement whereby a 240 volt motor drove the axle generator as if the car was moving.

While all of these systems invariably prove fascinating from the engineering history perspective, their reliability and maintainability suffers today. These two goals (reliable and maintainable systems) are the primary reason that all of the systems on modern railway rolling stock have evolved to use electrically driven and operated, standard, off-the-shelf components. The railroads truly believe that they **can** live better electrically.

As private car owners, we are faced with making a decision. Should my car be a rolling industrial museum or should I upgrade it to incorporate all of the latest technology? For most of us, the answer is "upgrade". This being a case, it is essential that one have a thorough understanding of modern electrical gear because it is literally found everywhere on the car. The heat, lighting and air conditioning is electric or electrically driven. Compressed air is generated by the electric compressor which is used to pressurize the water system and the hot water is made by an electric hot water heater. The whole car is controlled by electrical circuits which are its nerves.

Having a good electrician around when you are working on your car is a necessity. If you want an analogy, the car is quite similar to a small to medium-sized industrial facility. Most of these places have a full-time electrician on staff and you should too. At the very least, you should understand the rudiments of electrical systems so that you can understand what the heck the guy is saying to you when you talk to him.

What We Use Electricity For

To put it very simply, we use electricity to give us motion (motors, solenoids, etc.), make light and heat (these two are directly related because the act of heating something causes it to radiate light) and control things. There are other applications for electricity but they mostly don't concern us. All the rest of the electrical gear that you'll meet is mainly involved with moving electricity around.

To further refine things, electrical systems can be grouped into two categories: "Just Kidding Around" and "Power". In actuality, Power can be split into "Power" and "BIG

Eric Wilde is a software engineer by profession and a railroad car rebuilder by avocation. He has extensive knowledge about railroad car rebuilding gained over twenty years of restoration and rebuilding of streetcars and railway equipment. His current project is the upgrading of a 1950's Pullman-built sleeping car to current Amtrak standards.

POWER" (a.k.a. "Distribution", like the way power companies do it) but we needn't worry about the latter. Power systems are any systems where there is some serious voltage and/or current involved. Just what you'd expect to find on a railroad car.

Now, Power circuits are quite a bit like other kinds of electrical circuits. After all, the laws of physics don't change just because the voltage or current goes up. However, Power is like good drugs. The drugs work great. Too bad the side effects can kill you. The same with Power. If you aren't careful, the side effects, which are negligible at low-power, can kill you.

Let's look at a relay and a contractor, for example. They both work the same: apply power to the coil and contacts close, juice flows and you're in business. Remove the coil power and the contacts open breaking the flow of juice. Cool! Only one problem. At 100A and 480V, when the contacts open an arc starts and it can easily, if not extinguished, burn up the contacts (just like arc welding). That's why some contactors have arc chutes to help blow out the arc. The same thing with motors. As they get bigger, one must make changes to allow for getting the heat out, keeping the losses low, reducing weight, etc.

So, while things are familiar to those of us who know basic electricity, they are also different. And speaking of different, there are two different classes of electrician. Those who do residential work and those who do industrial work. Here the differences are less discrete but present, nonetheless. Suffice to say, residential electricians will not feel comfortable working on a railroad car. If you must hire someone, I think you can figure out what to do.

Three Phase Power

One of the major differences between residential and industrial systems is three phase power. Residential systems are single phase and industrial are usually three phase. Consequently, an industrial electrician must understand three phase power (residential electricians are also lousy plumbers but that's another story). Since Amtrak supplies your car with electricity in the form of three phase power which must be consumed in a balanced fashion, many of the systems on your car will need to use three phase power which means that you need to understand it too.

Three phase power is actually really neat stuff because to use it, you get to use vectors (heavy groan from the reader). I mean, where else, besides figuring out slings for lifting heavy stuff, does the average guy get to use vectors? Just think of the prestige.

OK, so nobody's interested in learning vector arithmetic. I don't blame you. Luckily, you can put three phase power to work and still remain blissfully ignorant of vectors. Just remember that, if you want to impress the heck out of your friends at a cocktail party, show them how you

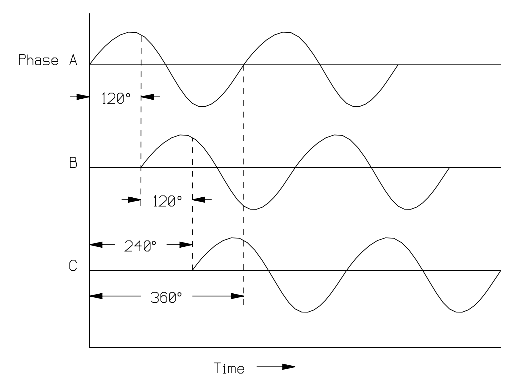

Figure 1 - Three Phase Waveforms

did the power factor calculations for your car's air conditioner motor.

In a nutshell, here's what three phase power is all about.

In a single phase system like your house, the power comes in one wire and goes out the other. The current, which alternates 60 times per second (at least here in North America) flows in one loop or circuit.

A long time ago, somebody had the clever idea to use three circuits instead of one. The electricity would flow out one wire and back on another (one circuit) but there would be three distinct circuits in a complete system. That's not the clever part, however. The clever part is that they decided to **combine** the three circuits into one so that, instead of using six pieces of wire, they'd only use three.

"How can this be," you ask? The idea was to delay the alternating current waveform in each circuit by a tiny bit with respect to the other waveforms of the circuits that it shares. In this manner the waveforms wouldn't cancel each other out. If we look at the typically generated sinusoidal, AC waveform and call one cycle 360 degrees then the delay chosen was 120 degrees (see Figure 1). Each circuit or current path was called a phase. Without getting into vectors and waveform manipulation, that's about all there is to it. Trust me. It works like a champ!

Why bother with three phase power when single phase power works just fine? Besides giving employment to a whole bunch of electrical engineers, there's one simple reason: you can push more power through one pound of copper using three phase power than you can with single phase. Everything is smaller, lighter and cheaper. Not too shabby! So, get used to it. Three phase power is here to stay.

Delta and Wye

Three phase power comes in two flavors: delta and wye.

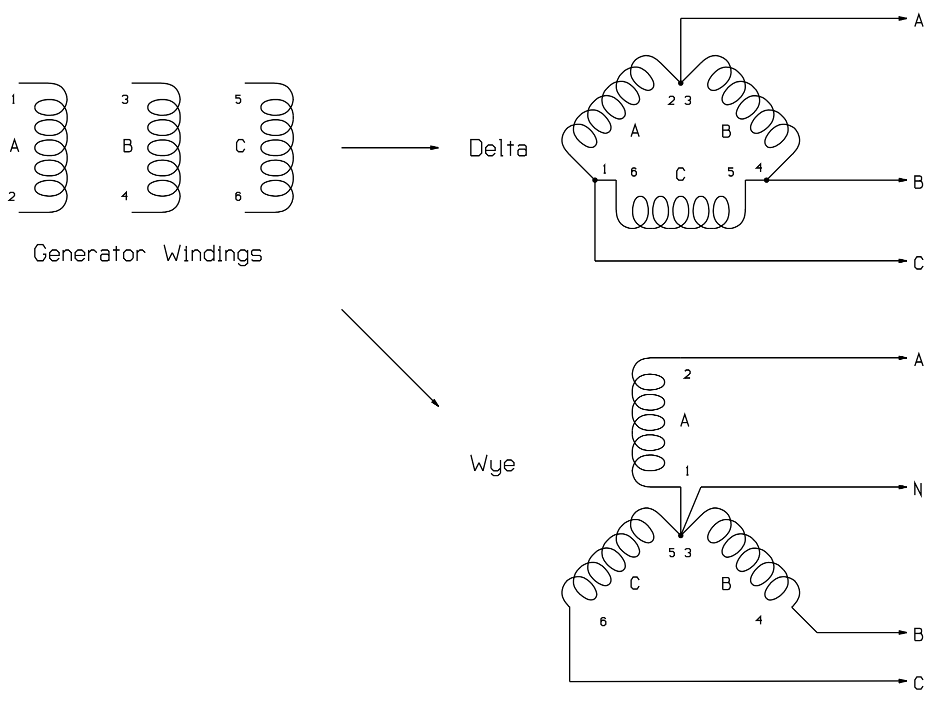

Figure 2: Connecting Windings as Delta or Wye

Imagine that you want to generate alternating current in three separate circuits and that you want the waveforms to be synchronized such that the waveform in circuit A (three phase circuits have each of the three phases labeled A, B and C by convention) leads the waveform in circuit B by 120° and so on. You could build three single phase generators and synchronize them somehow so that the waveforms were all lined up as required. This plan probably wouldn't work. You could build three single phase generators on a common shaft so that they were synchronized by virtue of their bond to the shaft. This plan works but there's a better one. You could build a generator with three sets of windings. Each set of windings could be offset around the perimeter of the generator by 120°. As the armature rotated it would induce a current first in the A winding then 120° later in the B winding followed by 120° later in the C winding. Now **that's** a plan! Three separate sinusoidal waveforms, offset in time from one another by 120°. Sound familiar?

The only thing left to decide is how to connect those windings together. That's where Delta and Wye come in.

Looking at Figure 2, we see generator with three windings. The arrows show the two ways of connecting the windings to yield either a Delta or Wye configuration. The configurations are thusly named because one looks like a Δ (delta) and the other looks like a **Y** (wye).

The two configurations are sometimes referred to as three phase, three wire (Delta) and three phase, four wire (Wye). Delta is usually employed in transmission because it uses less copper. Wye is usually employed at the end point because the fourth wire, called a neutral, can be grounded for safety reasons and because there are two voltages available (in Delta, the voltage between A/B, B/C or C/A is equal to the voltage generated [e.g. 240V or 480V] while in Wye the voltage between A/B, B/C or C/A is 1.7 times the voltage generated [e.g. 208V] while the voltage between A/N, B/N or C/N is equal to the voltage generated [e.g. 120V]). To convert from Delta to Wye and vice versa requires a transformer. Conversion is usually handled at the same time as step down of voltage from transmission to consumption levels but it need not be.

On a railway car, you'll find both configurations (unless you live in Australia). Power from the Amtrak is 480V Delta. The older wayside power connections are 240V Delta. At least some portion of the system is Wye to give 120V with grounded neutral for outlets (hair dryers, razors, etc.) and lighting.

Practical Implications

As I mentioned earlier, one of the practical implications of three phase power is that the wire size is smaller than that required for single phase. Combine that with the much higher voltages used in today's systems and you find that you're using a lot less copper than was used in the old days (Table 1 lists the sizes and ampacities of copper conductors). Battery cables were frequently 300 or 350 MCM, quite a hefty size, whereas today 4/0 is as large as it gets. This means that, not only will your car weigh a lot less when you're done but you may end up with a whole lot of nearly empty conduit as well. Too bad you can't rent it out.

Size	Conductor Temperature Rating		
AWG or kcmil	60° C (Note 1)	75° C (Note 2)	90° C (Note 3)
18	—	—	14
16	—	—	18
14	20	20	25
12	25	25	30
10	30	35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	110
2	95	115	130
1	110	130	150
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260
250	215	255	290
300	240	285	320
350	260	310	350
Ambient Temp ° C	For ambient temperatures other than 30° C, multiply the ampacities above by these correction factors		
21-25	1.08	1.05	1.04
26-30	1.00	1.00	1.00
31-35	0.91	0.94	0.96
36-40	0.82	0.88	0.91
41-45	0.71	0.82	0.87
46-50	0.58	0.75	0.82
51-55	0.41	0.67	0.76

Note 1:Wire types TW, UF.
Note 2:Wire types FEPW, RH, RHW, THHW, THW, THWN, XHHW, USE, ZW.
Note 3:Wire types TA, TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2.
Note 4:If the conduit has more than three conductors, adjust the allowable ampacities (after any temperature correction) as shown below:

4-6 wires	80%	7-9 wires	70%
10-20 wires	50%	21-30 wires	45%
31-40 wires	40%	41-50 wires	35%

Note 5:In general, the Neutral Conductor is not counted, if present, for the purposes of adjusting ampacities as shown in Note 4.

Table 1: Wire Sizes and Ampacities For Copper Conductors (From NEC Table 310-16)

Speaking of conduit fill, there is one important fact to consider when you are pulling new wire into the conduit. In any AC system, three phase or otherwise, any circular metal object through which an AC carrying conductor passes will have a current induced in it. Since the object is circular, the induced current will flow around and around in it and the object will get hot. This is known as inductive heating and it is a problem specific only to AC systems. The old DC systems found in many cars did not experience this problem because DC doesn't induce any current in surrounding objects.

Fortunately, there is a simple solution to the problem of inductive heating. The wires feeding a circuit and returning from it must pass through all metal objects together. In a single phase circuit, the hot and neutral must pass through the same conduit, holes, circular clips, etc. In a three phase circuit, all three or four wires of the circuit must pass through the same conduit, holes, etc. This way, the induced currents are canceled out by the returning induced currents and there is no heating. Unfortunately, the old DC wiring may not be suitable because there was no need to follow this rule. The wiring may need to be replaced even if it is in top condition. No more running one wire through one conduit and the other back through another.

Another consideration to take into account in three phase, four wire circuits is the sizing of the neutral conductor. This conductor only needs to carry the unbalanced current in the circuit. Since this is the case, if you balance the loads on the circuit carefully, you can frequently reduce the size of the neutral conductor accordingly. This practice is contrary to what you may be used to a single phase circuits (e.g. house wiring) where the neutral must frequently carry the sum of the currents. Of course, if you don't maintain phase balance (see "Load Calculation") then all bets are off.

Power Factor

When you are paying for power by the KWh, it pays to be cheap. This is the reason that you may hear talk about power factor. Power factor is a nasty effect peculiar to reactive and inductive AC systems. In a nutshell, it means that you don't get to use what you pay for. Since nobody seems inclined to hook up a watt/hour meter to your car, its best that you forget about it — that is, unless you want to play with vectors.

Load Calculation

In a three phase system, all of the loads attached to each phase should add up the same. The reason is because balance is good (haven't you been listening to those new-agers talk about balance and harmony all these years — turns out they were right about something). When it comes time to do your power budget (see "The Power Budget"), things had better balance.

Normally, if you're hooking up a three phase device (like a motor), it will draw current evenly from all three phases. If you are constructing or purchasing a big heater (e.g. ceiling heat) it can be designed for three phase by using three heating elements (or six, or nine, ...) of equal value and connecting one (or two, or three, ...) across each phase. In either of these two cases, balance will be maintained.

A problem arises when single phase loads, such as a fractional horsepower motor, lights, small heaters, etc., are connected to a three phase system (a single phase load may be connected across any two phases [A/B, B/C or C/A] or between any one phase and neutral in a four wire system). This will yield a phase imbalance, which is bad. The phase imbalance will be on the two phases that the load is connected to (three wire system) or on the single phase and neutral that the load is connected to (four wire system).

To adjust the imbalance, you add another single phase load of equal proportions to another phase (four wire system) or pair of phases (three wire system). Then you add a third single phase load of equal proportions to the remaining phase or pair of phases. The loads can be different (e.g. motors, heaters, lights) and can be made up of a number of smaller loads. It's no big deal really. It's analogous to balancing the three kid's trust funds — you give one 1240 shares of Exxon, the second gets 1150 shares of GM and the third gets 1000 shares of Coke. Everybody is happy (i.e. as of Aug 7, 1998 [pre-plunge] they each get $80K — hopefully, this makes them happy).

The day may come when you can't make the loads be exactly equal on each phase. So, what do you do then? If this happens on a three wire system, the current drawn from each conductor A, B and C must be determined from the individual loads connected to A/B, B/C and C/A using vector arithmetic (**Oh, No!**). If this happens on a four wire system, the load on each phase between its conductor and neutral is connected to this phase on the B-axis. Now, take a piece of paper or other suitable straight edge and line it up so that it passes through the two dots. Transfer the two dots to the piece of paper.

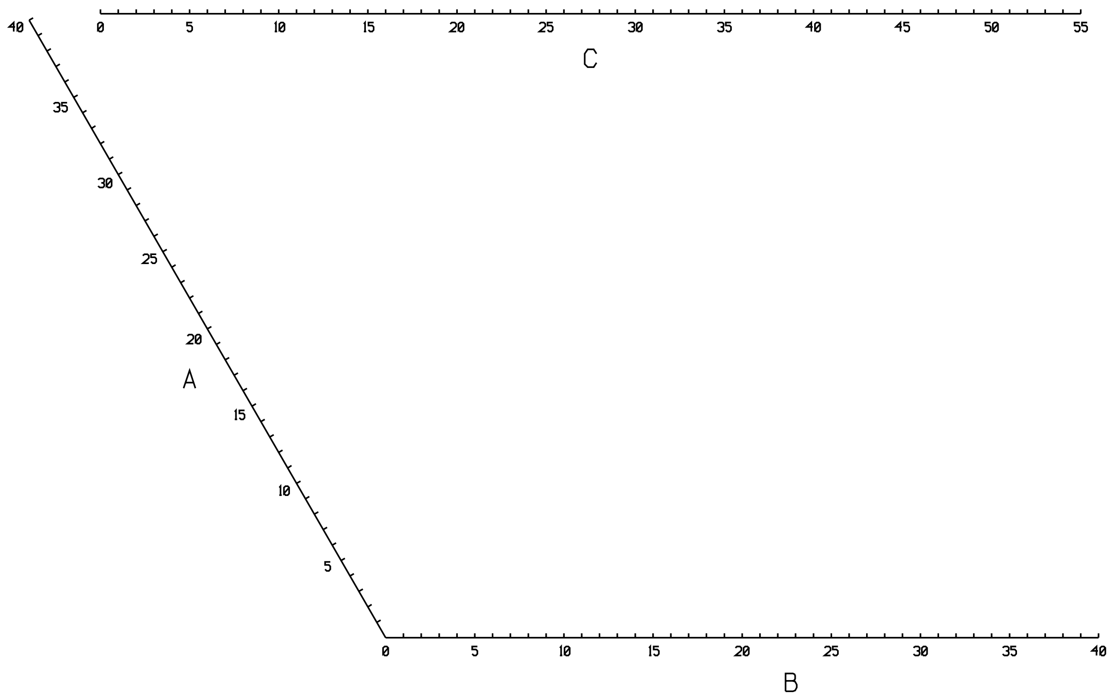

Figure 3: Three Phase Calculator

exactly the load connected to the phase. The peak neutral current is calculated from the currents drawn from conductors A, B and C using, guess what, vector arithmetic.

Don’t panic! I know what you thinking: "He said we wouldn’t need to use vectors". And you won't (or at least you won't know you’re using them). This won't hurt a bit. By doing a little judicious punting, you can avoid using vectors and take care of all of the unbalanced phase load calculations you’ll ever run into.

Just scope out Figure 3. In it you will find a handy, dandy three phase calculator. It can be used to determine the unbalanced current flowing in any of the three phases of a Delta connected circuit. To use it, mark the current drawn by one of the single phase loads, connected to the phase of interest, with a dot on the A-axis. Mark the current from the other single phase load that is Finally, lift the paper and move it to the C-axis, lining it up so that one end is on 0. Wherever the other dot falls is the current flowing in that phase. Simple! To find the currents in the other two phases, just repeat this procedure for each of them.

As a little practice, let's try to calculate the current in each phase of a Delta system that has three single phase loads of 10A, 12A and 11A, connected to A/B, B/C and C/A respectively. Start out by putting a dot on the A-axis at 10. Another dot is placed on the B-axis at 11 (the load on **A**/B is 10A and the load on C/**A** is 11A). Read off the value 18 on the C-axis. This is the current in phase A. Do the same for phase B (10A, 12A, result 19A) and phase C (12A, 11A, result 19.8A).

To calculate the unbalanced load current in the neutral conductor of a three phase, four wire system, you really do have to use vectors. But this is where the judicious punting comes in. You only need to calculate this unbalanced current if you want to reduce the size of the neutral conductor. Otherwise, if you are willing to use a neutral conductor equal to the size of the conductors chosen for A, B and C, no calculations are necessary. So, it may be worthwhile to do just that and skip the vector arithmetic. After all, how much does a few pounds of copper cost? And how much does a college degree in mathematics cost? I rest my case.

Plumbing

Now that we understand everything that there is to know about three phase power, let's start hooking things up. Hold it! Not so fast. First we need to learn about plumbing.

"Plumbing," you say?

Yes, plumbing. Much of the wire in your car lives inside pipe called conduit or electrical metallic tubing (a.k.a. EMT). As a general rule of thumb, you will use conduit underneath the car (where it is exposed) and EMT inside the car (enclosed in walls, ceilings, etc.). What wire doesn't live inside pipe lives inside boxes connected to the pipe, called junction or pull boxes. Before you can lay in any wire, you have to put the plumbing in place.

Conduit resembles threaded water or gas pipe (black iron) except that it is galvanized. Otherwise, you cut it with a pipe cutter, ream out the ends with a reamer and thread it with a pipe threader just like you would gas or water pipe. You'll also need a chain vise or tri-stand to hold it while you work on it. In a deviation from water or gas piping, the conduit is bent with a hydraulic bender and a set of bending shoes to yield gentle sweeps through which the wire can be pulled. If you don't have such a bender, pre-fabricated sweeps can be purchased in 45° and 90° configurations.

When you purchase conduit, it comes threaded on both ends and one straight coupling is supplied. If you need more couplings, they can be bought separately. The conduit is assembled, one length to the next, by threading it into the coupling and tightening it with a pipe wrench. For a watertight joint, use a little plumber's pipe dope on the threads.

Conduit is attached to boxes by removing a knockout (on those boxes that have them) or drilling an appropriately sized hole with a hole saw (an electrician's hole saw kit can be purchased that has all the good sizes). A nut is threaded onto the conduit and then its end is pushed through the hole. A second nut is threaded on and tightened with pliers, a screwdriver and hammer or whatever else works. Finally, it is **very important** that a plastic bushing be added to the protruding conduit end to eliminate chafing of the wires.

If you plan the conduit assembly sequence correctly, all you'll need are conduit couplings and boxes. However, sometimes it is impossible to assemble the conduit in-place because you can't swing the pieces being threaded together. In this case, a part much like a pipe union, called an Ericson, can be used. Treat Ericsons like gold — they cost as much — using them sparingly and only where necessary (the true mark of a pro is when you look at his work, you can't figure out how he put it together with no Ericsons).

Also available are a series of right angle connectors that can be used to turn a corner at 90° (instead of a sweep) in a tight squeeze. These are called els and they come in three forms LL, LR and LB. Tees can be had too. All of these "conduit bodies" have a gasketed cover plate on one side (left, right or back for LL, LR and LB and on the back for tee) so that the wire can be pulled in. A straight conduit body is made to provide a pull point in straight pipe. The LL, LR and LB each have a long side and short side so that they may be oriented as required to fit into a tight space.

As you lay in the conduit or EMT, be sure to provide enough pull points to allow you to get the wire in. A run of pipe with more than a couple of 90° bends will be difficult to pull. Try to put a box or conduit body in the middle of the pipe run to ease your task. If necessary, you can pull wire into tough conduit runs using a comealong but it's better not to have to.

Its easy to forget that conduit plus copper wire weighs a lot because you tend to put it in a little bit at a time. Failure to remember this fact can lead to the whole lot coming crashing down. You wouldn't want this to happen at track speed so make sure you really bolt it down. I use homemade clips made out of 1" x 1/8" steel strip which I attach to the structural members (the conduit is wrapped with a piece of thick tar paper to prevent rattling in the clip). Or, you can attach a piece of Unistrut to the frame and clip the conduit in place with Unistrut clips. Whatever you use, just be sure everything is solid.

It doesn't hurt to reiterate at this point that you should take great care to remove all razor blades (i.e. sharp edges) from the interior of all pipe, boxes, etc. It is especially important, given the amount of vibration present on a railway car, to do this so that the wire won't chafe and wear through. A good test is to run your finger over all edges where the wire could rub. Once you slice the tip of your finger open a few times, you'll learn to remove the burrs properly.

EMT is like conduit in some respects (you install it pretty much the same way) but it has a much thinner wall and is easier to cut and bend — you can cut it with a hack saw or plumbers pipe cutter. Pay particular attention to burr removal with EMT.

The sizes are the same as conduit (all sizes are nominal inside diameters). Fittings should be the compression type since the set screw type are apt to rattle loose. Note that a fitting is required at each end of the EMT where it enters a box. The box connectors are connected using a single nut and bushing. The nut can be tightened in the same manner as with conduit.

Bending EMT is a lot easier than bending conduit and it can be done by hand using a bender commonly called a Gardner bender (invented by Bill Gardner's pappy). Smaller conduit sizes can also be bent with this type of bender (a 3/4" EMT bender will bend 1/2" conduit) but this is too much like work for me.

As a last resort, one can use small amounts of a product called Liquid Tite (Amtrak says that no more than 18" of Liquid Tite should be used at any one place). This product is essentially a flexible metal tube covered by a tough, plastic, outer skin. It can be bent to fit into tight spots and is good for isolating vibration from resiliently mounted motors.

Liquid Tite has its own special fittings which are of the compression type but which come with gaskets so that the joints are liquid tight. Fittings are available in straight and right angle configurations. The Liquid Tite may be joined to the end of a piece of conduit with a Liquid Tite fitting and a conduit coupling.

The choice of the size of conduit or EMT to use (provided you are not reusing existing pipe)

Size	1/2"	3/4"	1"	1-1/4	1-1/2	2"	2-1/2	3"
THHN								
14	13	24	39	69	94	154		
12	10	18	29	51	70	114	164	
10	6	11	18	32	44	73	104	160
8	3	5	9	16	22	36	51	79
6	1	4	6	11	15	26	37	57
4	1	2	4	7	9	16	22	35
3	1	1	3	6	8	13	19	29
2	1	1	3	5	7	11	16	25
1		1	1	3	5	8	12	18
1/0		1	1	3	4	7	10	15
2/0		1	1	2	3	6	8	13
3/0		1	1	1	3	5	7	11
4/0		1	1	1	2	4	6	9
TW								
14	9	15	25	44	60	99	142	
12	7	12	19	35	47	78	111	171
10	5	9	15	26	36	60	85	131
8	2	4	7	12	17	28	40	62

Table 2: Number of Wires Allowed in Conduit (From NEC Table 3A/B, Chapter 9)

is based on the size and number of wires that the pipe is to carry. For conductors of equal size, you can use Table 2. For conductors of differing sizes, you must first get the area of the conduit from Table 3 and then work out the areas of all the wire from Table 4. Based on the allowable fill percentage (Table 3), you can calculate whether the conduit will carry all of the wire.

Now might be a good time to mention the National Electrical Code (NEC). Although railway equipment slips through the cracks of governance and is not covered by the NEC, it still contains a wealth of useful, well thought out information. You should obtain a copy of the NEC from the NFPA and use it in your work. The complete tables of wire size and conduit fill are found therein along with much other valuable information.

Boxes

Boxes or junction boxes are where all of the splicing and cross connecting of wiring takes place. In addition, they are often used as hubs to distribute wires from a single, large conduit into a number of smaller conduits feeding numerous devices at a convenient point, say in the roof or under the floor, far from the electrical locker (the source of all electrons). Occasionally, a box may be provided to facilitate pulling although a conduit body would serve equally well.

Size	Internal Diameter	Area - Square Inches Total	2 Wire 31%	Over 2 40%	1 Wire 53%
1/2"	.622"	.30	.09	.12	.16
3/4"	.824"	.53	.16	.21	.28
1"	1.049"	.86	.27	.34	.46
1-1/4"	1.380"	1.50	.47	.60	.80
1-1/2"	1.610"	2.04	.63	.82	1.08
2"	2.067"	3.36	1.04	1.34	1.78
2-1/2"	2.469"	4.79	1.48	1.92	2.54
3"	3.068"	7.38	2.26	2.95	3.91

Table 3: Conduit Area and Allowable Fill
(From NEC Table 4, Chapter 9)

Boxes may be purchased prefabricated (Hoffman, Weigman, etc.) or may be made up in the shop. Common construction materials are epoxy coated mild steel, galvanized steel and stainless steel (required for Amtrak's control and power boxes). Aluminum may be used for interior boxes. Sixteen gauge sheet is good for general fabrication but eighteen gauge may serve for smaller or inside boxes. Large boxes may be better able to stand up when made of fourteen gauge.

Interior boxes may be spot welded or assembled with pop rivets and can have a plain sheet metal cover. Exterior boxes should be all welded to make them watertight and they should have gasketed covers (see the article, "How to Fabricate Weatherproof Boxes" for more details). As a general rule, bigger is better because there never seems to be enough room inside. Also, try to locate boxes in convenient locations as you will need to get at them and work inside them from time to time.

Holes in boxes can be punched with a Greenlee punch (makes a neat hole) or drilled with a hole saw (crude but effective). Basically, you can make a hole wherever you need it but you should use common sense and leave room for nuts. Outside, boxes can be sealed around conduit entrances with caulking to make them waterproof.

Wire Selection

All wiring on railway equipment must be done with stranded wire, the reason being to prevent its breaking from flexing and vibration. Another reason for using stranded wire is that it is a whole heck of a lot easier to pull in than solid wire — why work hard when you don't have to?

The types of insulation vary (old wiring was rubber and jute covered, for example) with the types THHN and TW being the most common. Both of these types are suitable and they have temperature ratings of 90° C or 105° C so they can be wired to almost all fixtures. The THHN has an outer sheath of nylon to reduce pulling friction and is commonly available in smaller sizes (#14 - #10) at building supply stores. Larger sizes of THHN come in basic black and must be purchased from an electrical distributor (measure how much you need first as it is cut to

Size	Types TF, TW Diam. In.	Types TF, TW Area Sq. In.	Types TFN, THHN Diam. In.	Types TFN, THHN Area Sq. In.
18	.106	.0088	.089	.0062
16	.118	.0109	.100	.0079
14	.131	.0135	.105	.0087
12	.148	.0172	.122	.0117
10	.168	.0222	.153	.0184
8	.245	.0471	.218	.0373
6	.323	.0819	.257	.0519
4	.372	.1087	.328	.0845
3	.401	.1263	.356	.0995
2	.433	.1473	.388	.1182
1	.508	.2027	.450	.1590
1/0	.549	.2367	.491	.1893
2/0	.595	.2781	.537	.2265
3/0	.647	.3288	.588	.2715
4/0	.705	.3904	.646	.3278

Table 4: Wire Cross Sectional Area
(From NEC Table 5, Chapter 9)

length). TW is commonly available from places such as Waytek and may be known as UL 1015.

Special circumstances may require different types of insulation (e.g. Hypalon in high-temperature locations or cross linked polyethylene [XLPE] under the car). Amtrak uses XLPE for all their wiring because they like the flame propagation characteristics of the insulation and the strand counts are high which renders the wire extra flexible and they require XLPE for **any** in-car 480V wiring.

There are other types of wire that may be used on a railway car other than single conductor stranded. Multiconductor wire is called cable. It typically comes with two to four conductors bundled inside a protective outer sheath. The most commonly used cables are SO, SJO and G or W. Companies like Carol Cable have extensive catalogs of these types of cables. Even hard to find cables such as the heavy, four conductor cable used for standby power connection can be found in the Carol Cable catalog.

If you are able to separate low voltage (less than 50 volts) wiring from high voltage wiring in separate conduit and boxes, you can use wire and cable meant for low voltage use (e.g. computer cable, etc.). Otherwise, wire that shares the same conduit or boxes with high voltage wiring (often unavoidable on a railway car) must have insulation whose dielectric strength (insulation value) matches or exceeds the highest voltage wiring. This usually means that you simply use the same wire for low voltage wiring that you use for all of the other wiring (THHN and TW are good for 600V, for example).

Wire Marking

Electrical wiring is usually color-coded with a specific color assigned to each wire function (see Table 5). Some of the wire colors are accepted standards while others are more discretionary. It's a good idea, however, to decide on a color scheme and stick with it throughout the car. That way, wherever you are in the car, you'll know immediately what a particular wire does. In addition, using the accepted standards will allow anyone else who works on the car to know, at a glance, what something does.

Color	Usage
Commonly Accepted Standard	
Black	120V line, 240V line 1, 3 phase A
White	120V or 120/208V grounded neutral, 3-phase C (when using multiconductor cable) although should be taped some other color (I prefer blue)
Red	240V line 2, 3 phase B
Green or Green/Yellow Striped	Ground
Suggestions	
Orange	Switched circuits
Brown	
Yellow	Control wiring
Violet	
Blue	3 phase C

Table 5: Wire Color Code

On top of a standardized color scheme, each wire should be marked at each end and at any intermediate points, where a connection will be made to it, with a wire label that is unique to that wire. There are literally thousands of pieces of wire in a railway car and without a comprehensive wire marking scheme to identify each one, you are in deep poo poo. Wire labels can be applied by writing on a piece of tape with an indelible marker or professional wire markers (my preference) can be used. Professional wire markers are of the write-on type (one step up from writing on tape), pressure sensitive type (such as Brady) plastic clip on type or the latest computer-generated shrink tubing type. The type that you use is mainly a personal preference. I, myself, use both the write-on and pressure sensitive types.

Whatever type of markers you use, decide on a wire code (Chart 1 shows an example of the one that I use) and assign a unique wire label to each piece of wire. Write each label down along with a description of the wire's function and other related information (e.g. color, size, conduit route, applicable drawing, etc.) and put them in a table in alphabetical or numerical order (a personal computer and some kind of database software are invaluable here). Use these labels in any circuit drawings that you create as well.

The wire code consists of three characters followed by two or more alphanumerics as follows:

T S L [C] {/|blank} W

Wire identifier. Indicates the wire within the circuit. This identifier is indicative of what the wire actually does:

L1, L2 - The line or lines of a two-wire circuit.
N - The neutral (120/208V only) of a two- or three-wire circuit.
S1, S2, ... - A switched line or lines.
P (plus), M (minus), P1, P2, ... - DC lines.
A, B, C - The three phases of a delta- or wye-connected device.
1, 2, 3, ... - Numbers (as required), typically in a control circuit.

Circuit number. If there are several circuits with the same prefix, a number may be appended to differentiate them. Acceptable numbers begin with "1" (usually starting at the A-end or left side of the car) and increase monotonically by 1 (towards the opposite end or side of the car). Other rules for the assignment of numbers are acceptable, providing unique circuit numbers are maintained.

Location that the circuit feeds. Select one from the following list:

B -	Bedroom	L -	Lounge
C -	Ceiling	M -	Markers
D -	Door	R -	Roomette
E -	Electrical Locker	S -	Section
F -	Floor	U -	Underfloor
H -	Hallway	V -	Vestibule
K -	Kitchen	W -	Washroom

Secondary type of circuit. Select one of the following:

A -	Annunciator	M -	Motor
B -	Blower	P -	Primary
C -	Control	S -	Secondary
E -	Emergency	W -	Water
I -	Information (radio, etc.)		

Type of circuit. Select one from the list below:

A -	Airconditioning	L -	Lighting
B -	Built-in device (e.g. a refrigerator)	M -	Power mains
G -	Generator	P -	Power-limited
H -	Heating	R -	Receptacle

Chart 1: Sample Wire Code

While you are at it, label everything else too (see Table 6) — conduit, junction boxes, transformers, motors, contactors, etc. Tables of all of a car's conduit, junction boxes and labeled components have proved useful to me. I have conduit drawings that have each conduit labeled and I include the route of each wire through the conduit in the wire's table entry. Anal-retentive? You bet! Ever have problems figuring out what something does or where it goes? Nope, never!

Pulling The Wire In

Once all of the pipe and all of the boxes are in place and bolted down, you are faced with pulling the wire in. If you have designed the conduit well and haven't put in too many bends or too long a run between boxes, you won't have any problems. This ideal situation isn't always the case in the real world so here are a few tricks of the trade to help you pull wire like a pro.

Label	Function
Conduit	
CA	Conduit at A-end of car
CB	Conduit at B-end of car
CU	Conduit underneath car
Junction Boxes	
JA	Boxes at A-End of car
JB	Boxes at B-End of car
JU	Boxes underneath car
Components	
C	Filter capacitor
CB	Circuit breaker
CT	Contactor (high current)
D	Rectifier diode
F	Fuse
H	Heater
M	Motor
P	Pilot light
PH	Phase failure relay
R	Resistor
RY	Relay
SW	Switch
T	Transformer
TD	Time delay relay

Table 6: Suggested Conduit/Box/Component Labels

Incidentally, we are often faced with removing old wire from existing conduit first before we can pull in new wire. Frequently, this proves to be a rotten job. The old wire is typically rubber or jute covered with rubber being the worst. As the rubber insulation was heated by the current flowing through the wires over the years, it literally vulcanized itself to the conduit walls. Breaking this stuff loose without breaking the wire (especially the smaller sizes) is often a tricky proposition. So, first a few tips that even the pros might not be familiar with.

Always start with the jute covered wire. Although pulling jute is messy (the outer covering disintegrates and black snow falls all over), it breaks loose very easily. Starting with jute allows you to reduce the number of wires in the pipe, thereby rendering the rest easier to pull.

Once all of the jute is out, try pulling the rubber covered wire. If it snaps off, you may have to pull it in a bunch. By the way, always pull wire straight in and straight out of the conduit. Even if it hangs loosely over a bushing, the slight bend can generate enormous friction. Having a helper push or feed the wire from the other end helps immensely.

Pulling wire in a bunch is time-consuming but usually always works. To do this, strip off eight to ten inches of insulation from every wire. Divide each wire's strands evenly into two groups. Thread one group of strands through the hook of your comealong (the cable end) from right to left. Thread the other group of strands through the hook the opposite way from left to right. Now, double both groups back and wrap them around the wire, one group clockwise and the other counter clockwise. Repeat this procedure for every piece of wire. Try to make them all come out even so that tension will be applied evenly. Lastly, tape the whole lot into a nice bundle.

You are now ready to pull the whole mess of wires out. Attach the comealong to a solid pull point and ratchet it up until it is good and tight. If you're lucky, everything will move. If not, proceed to the next step (a helper is useful here). Wherever you can get at the conduit, use a large ball peen hammer and beat the crap out of it, especially the curves. Work starting at the comealong and away towards the other end. Go back and tighten up the comealong or tighten it continuously as you beat on the conduit, if there's two of you. If this doesn't get things moving (it will), "You're outta luck, buddy"! You'll need to disassemble the conduit.

Large diameter wire (#4 and up) can be pulled in/out with a device that resembles the Chinese finger pull that you indubitably played with as a child. This device is made of steel wire and is frequently called a Kellem. Several sizes are available and they should be spliced onto about 50 ft. of 1/2" nylon rope. The Kellem can be slipped over a piece of wire (or several pieces of wire, taped into a bundle) and the rope attached to the comealong. Once again, after the comealong is tightened up, beating on the pipe often helps to get things moving.

One very important thing to remember is to always, always pull a piece of pull cord into the conduit on the end of an old piece of wire before you pull the last piece out. Trust me on this one. If you don't, you're going to be real mad at yourself one day.

Pull cord can be as simple as a role of thin nylon cord (50-100 lb. test). For ten bucks you can get as much as you'll ever need. I stuff a piece into every conduit and just leave it there. It's not hurting anything and you never know when you might need it.

What about if you installed some new conduit or, heaven forbid, were hapless enough to pull everything out of an old piece of conduit? What then? You have several options.

The easiest is to use a fish tape (although why it's called a fish tape, I'll never know— I've never caught any fish with it). A fish tape is a flexible, spring steel wire, flat in cross-section, about 3/16" x 3/32" in size. It comes reeled up in a plastic reel that allows it to be unreeled and fed into a pipe as necessary. The end is bent into a long thin loop to reduce the chances of snagging and allow a cord or wire to be attached to it (I braze the loop to the tape and file it smooth so that it can't get caught on withdrawal [a trick that I learned from bitter experience]). The fish tape is shoved down the pipe until it comes out at the far end. A piece of pull cord or the wires to be pulled are attached to the loop and taped up. When the fish tape is withdrawn, the pull cord or wires are in place.

Your second option is the vacuum cleaner method. To use this method, you need some very light string (I use sewing thread) and a projectile (I use a plastic bag, the kind that you put your fruit in at the grocery store). You also need a good, strong vacuum cleaner such as a Shop Vac.

Go to the far end of the conduit run and stick the vacuum nozzle in the end of the pipe. Stuff a rag around it or tape it in place so that it seals at least halfway decently. Turn on the vacuum and return to the other end of the conduit. Tie the bag to the thread, insert it into the pipe and let her rip. It takes about 10 seconds and it's all over. Return to the other end, turn off the vacuum and carefully remove it from the end of the conduit.

Now that the thread is in place, attach a piece of pull cord and carefully pull it in. If you need it, pull in a heavier piece of cord (I use 1/8" nylon in the tough pipe runs because you can really reef on it). By the way, it's a good idea to calibrate the cord by marking it with bands every five feet (one band at 5, two at 10, three at 15, ...) using a marking pen. This way, you'll know how much wire to buy when purchasing the big stuff and avoid buying too much (you can't take it back for a refund).

Unfortunately, the last option for getting the wire in, when all else fails, is to start taking things apart until you can pull in a pull cord. A similar option was presented in the paragraphs above about removing wire but in neither case is this my most favorite choice.

Wire is pulled into the conduit by attaching it to the end of the pull cord. This is usually done by taping the cord to the wire (doubling the cord up and back along the wire as you tape can help to prevent slippage). Small gauge wires (e.g. #14 or #16) can be pulled over short distances, a few at a time, with the smallest pull cord. Heavier wire (e.g. #12, #10 or #8) or longer runs require heavier cord (e.g. 1/8" nylon). Above this gauge, I usually use the 1/2" rope with a Kellem and comealong. The heavier wire is frequently being used in a three phase circuit and all three pieces may be pulled at once with the comealong. Tape the three wires together for about 18" to make a nice, neat bundle. Slip the Kellem over the bundle, tape it up to reduce friction and commence heaving.

Amazingly enough, there is a huge amount of friction between the smooth plastic outer covering of the wire and smooth metal inside of the conduit or EMT, not to mention the effects of kinks or trying to pull the wire over a bushing at a 90° angle. Consequently, pulling wire can be a strenuous job. To make life easier, get yourself some pulling soap. Have your helper squirt some onto a rag and wrap this rag around the wire so that it gets smeared with soap as you pull it in. At the same time, the helper can make sure that the wire is going in straight. Ahhh! Much better.

The last word on wire pulling is marking tape. You may recall from "Wire Selection" that heavy gauge wire is like Model A Fords. You can have any color you want as long as it's black. But wire color is used as an indicator of a wire's function so it is often important to have different colors of wire available. This is where marking tape comes in. This tape comes in the whole rainbow of colors and is used to mark black wire (as well as other colored wire), during and after pulling, as to its function.

It is a good idea to keep a couple of rolls of the popular colors (see "Wire Marking") of marking tape on hand at all times to mark wire as is pulled in and/or as it is hooked up. For pulling, a temporary marker of a couple of wraps around the wire of the right color will do. For permanent marking, neatly wrap about six inches of wire, near the end, with tape, in a spiral fashion, so that is easy to see at a glance what the marking color is.

Reusing Existing Wire

While I am not a big advocate of reusing existing wire, it is possible to do so. On the other hand, often the function of the wire in a particular piece of conduit will change with the switch to three phase AC power from DC (e.g. there isn't much call for 350MCM battery cables, one per conduit, in the new scheme of things). This will mean that new wire must be pulled in.

If the existing circuits can be reused (lighting circuits are one example of the type of circuit that might be reused), the wire should be checked to ensure that it is OK and that it can stand the new, probably higher, voltage that will be used. A good indication of the fitness of old wire is its dielectric strength. One way to measure dielectric strength is with a megger.

Essentially, a megger is a device for generating a high voltage. This high voltage is applied to the wire under test and a measure of the amount of leakage is taken. The leakage is directly related to the dielectric strength of the wire's insulation. A high value for the dielectric strength (low leakage) indicates a good piece of wire.

There are some safety issues to be considered when using a megger, all stemming from the fact that, to test insulation dielectric strength, a high voltage is used. First, all of the devices connected to circuits that share conduit, boxes, etc. with the wire under test must be disconnected. It is obvious why the devices on the circuit under test should be disconnected but not so obvious why other devices on other circuits must also be disconnected. The reason is that, should the insulation on the circuit under test break down, other circuits near it could become charged with a high voltage. Second, use extreme caution when conducting the test to ensure that you and anybody else doesn't come in contact with the circuits under test during testing. Doing so could prove to be the last mistake you'd ever make.

Finally, one last word about using a megger. You should be prepared to replace any piece of wire that turns out to be bad. The reason that I make this patently obvious statement is that, sometimes, a piece of wire that is perfectly good but in marginal health will become sick after the test. This is because the high voltage of the megger can punch through marginal insulation and render it ineffective. Thus, the act of testing the wire guarantees that you will have to replace it.

Connectors and Splices

As you go about the business of pulling wire into conduit and boxes to implement the various circuits required on your railway car, you will need to join the wire together to make splices, branches and so on. There are a number of methods that can be used. Also, when a wire arrives at the device it is to supply or the one it is being fed from, it must be terminated and connected properly. There are several methods to accomplish this.

When splicing one or more wires together, the method used depends, to a certain extent, on conductor size. Smaller conductors (say up to #10) can be soldered. Larger conductors can be joined using split bolts. And, all sizes of conductors can be joined with crimp connectors.

Soldering is becoming something of a lost art. Many electricians prefer to use crimp connectors everywhere because they are fast and, with the proper ratchet-release crimpers, a high quality connection is virtually ensured every time. However, should you wish to become an artist, here are some tips on soldering.

First, I should say that a properly made solder joint is better than a crimped joint any day. Anyone who says differently is just having you on. I've taken apart 50 year old joints on railway equipment that look like they were made yesterday. A mechanical joint just ain't going to do that. After all, a soldered joint is first a mechanical joint and then it's filled with solder. It's like wearing a belt and suspenders too. No worries about oxidation or flexing or anything else. But, the key is "properly made". A poorly made solder joint will not perform any better than what you'd expect from something poor (i.e. it will perform badly). This is the main problem with soldering. It takes time and practice to do it properly.

To begin a soldered joint with two pieces of wire, strip back about 1-1/2" of insulation on each one. Lay the stripped ends over each other at about 45° and 1/2" from the insulation (i.e. approximately 1" of the end sticks out). Wrap one end around the other piece of wire, two or three wraps. Now, wrap the other end around its piece of wire. The joint should look like Figure 4A. It is called a Western Union splice because it was used on the railroad telegraph lines by Western Union. How fitting. You can pull on it but it shouldn't come apart even with no solder.

To splice a piece of wire to a second piece of wire that is just passing through, it isn't necessary to cut the second wire. Simply shave about 1-1/4" of its installation off with a knife (shave it off the same way that you would sharpen a pencil) being careful not to nick any of the strands. Strip about 2" of installation off of the first wire and then wrap it around the second wire four or five times, as shown in Figure 4B, to make a running splice.

If you're dealing with more than a couple of wires, double them up. Strip an extra amount of insulation off the wires to be doubled and twist them together to make a bigger wire. Then, proceed as described above. This works with up to four wires for the Western Union splice (two and two) or three wires for the running splice (one through and two spliced). To splice more wires in a running splice, you can strip more insulation off the through wire and bring in two wires from the left and right sides.

Figure 4: Soldered Wire Splices

However you splice the wires, you should be able to give them a good, solid pull without them coming apart before soldering. If you can't do this, strip more insulation and redo the joint.

To solder the joint, you need a noncorrosive, electrical flux (sometimes called rosin) and 60/40 solder (oh no, the dreaded lead). Do not use plumber's flux or lead free solder. Also, rosin core solder is a poor substitute for flux. A soldering iron or gun rated at 100 watts or more is a necessity to solder large joints such as we'll be making.

Coat the entire joint with flux (you don't need a lot but everything should be coated). Apply the hot iron to the joint and wait until it is good and hot. Add a little bit of solder to the joint (not the iron). It should get sucked into the wire strands by capillary action. Keep adding a little bit of solder at a time until it flows out and fills the whole joint. This will happen if the joint is really hot. When the joint is filled with solder, keep the heat on it for another 15-20 seconds —

the whole joint should look shiny bright. Remove the heat and allow the joint to cool undisturbed (this is **very** important). When the joint is cool, it should still appear shiny, albeit not as bright. If it is a dull, gray/white color it is a cold joint (i.e. it didn't get enough heat) or you moved it while it was cooling. Reapply the heat until the whole joint melts and let it cool again.

Larger conductors or one large conductor (e.g. three phase 208V neutral) and several smaller conductors can be spliced using split bolts. A split bolt is a copper bolt that is split down the middle. The wires to be spliced are inserted into the split and the nut is tightened down on them creating a tight mechanical and electrical joint. Split bolts come in sizes from #8 up to the largest wire sizes (e.g. 500MCM) so you should be able to find whatever you need.

To splice two conductors with a split bolt, remove enough insulation to allow insertion into the bolt with a little extra on either side. Insert one wire from the left and the second on top of it and from the right. Tighten the nut to the proper torque value. To make a running splice on one conductor (e.g. a neutral), strip its insulation, open the bolt by removing the nut completely and slip it over the wire. Reassemble the bolt, taking care not to cross-thread it (it's very easy to do). Now you can add the other wires from the left and right and tighten the nut to complete to splice.

Soldered joints and splices made with split bolts will need to be taped to insulate them. I use three layers of tape to create a tight, waterproof, abrasion proof cover.

The first layer is rubber splicing tape (sometimes called cold splicing tape), available either in a linerless variety or backed with a thin plastic, peel-away liner (your choice). This tape is stretched when it is applied (up to twice its length) and wrapped evenly all over the joint. A couple of wraps will ensure that all of the interstices are filled and that adequate dielectric strength results (the tape is good for 2000V per wrap). After a few days, the rubber will weld itself together into a uniform, unbroken, impervious layer that you won't be able to take apart except with explosives.

By the way, when taping a joint, start in the middle and work your way out to one end, overlapping the tape about 1/4 of its width. When you reach the end, wrap back to the middle and continue to the other end and then back to the middle. Either stop here or apply a second wrap that extends a little past the ends of the first wrap. To wrap a split bolt, start on one conductor near the closed end (bottom) of the bolt and wrap around the bolt in an X pattern (i.e. left/bottom, top/right, left/bottom, top/left, right/bottom, top/left) followed by a couple of turns around the top, followed by a wrap or two from bottom to top, followed by wrapping down one wire and back and then down the other wire and back to the center, ensuring that all voids are filled. The reason for always starting/stopping in the middle is to only leave one loose end of tape and **that** only in an out of the way place.

The second layer is one or two wraps of friction tape, a cloth tape impregnated with bitumen (the stuff that you used to wrap your hockey sticks with, if you're a Canuck and the pond was frozen nine months of the year). The friction tape is a protective layer to hold the rubber tape in place and keep it from being chaffed or otherwise damaged.

I like to add a third layer of a good vinyl electrical tape such as 3M 33 or 88. This helps keep the friction tape in place and gives the exterior one more layer of protection against moisture. I've seen lots of those famous, 50 year old joints just wrapped with rubber and friction tape and they were in fine shape so I guess you could skip this layer but, on the other hand, **neatness counts**.

Many electrical devices come with terminals that are known as pressure wire. These terminals are formed from a rectangular box, open on two ends. The box is slipped over the device terminal and a set screw is threaded into one side of it, opposite the terminal. The terminal usually has serrations in it to grip the wire. To wire one of these terminals, strip the wire's insulation enough so that the bare conductor will go all the way into the box, loosen the screw and slip the wire into the box on top of the serrated side of the terminal. Tighten the set screw to the specified torque.

Devices that use pressure wire terminals include circuit breakers, contactors, heaters, terminal blocks and many others. If the wire size is above #8, pressure wire will be common.

Last in the line of connection methods are the crimp connectors. Crimp connectors come in about half a million varieties and all sizes from tiny to huge. They come in insulated and uninsulated types with the insulated being color-coded based on the wire size that they accept. See Table 7 for some of the common ones.

For use on railway equipment, the most popular connectors are ring terminals and butt splices. Although they should be avoided where possible, Sta-kon or push-on type terminals are becoming ubiquitous on most electrical equipment and so they must be used in these places. Insulated connectors should be used exclusively and they should be of the double crimp type that grips both the wire and its insulation.

While fork or spade type and hook type connectors are available that slide over screw terminals without removing the screw, these should be avoided because they may vibrate loose. Rather, ring connectors that encircle the terminal screw are preferable. Vibration is also the reason to avoid Sta-kon terminals, if possible.

Ring connectors should be sized according to the screw size of the terminal that they will be attached to. This size is referred to as the stud size and it usually varies in direct proportion to the wire size. Thus, as a general rule of thumb, connectors for #16 wire should be sized for a #6 or #8 screw, #14 and #12 wire for a #8 or #10 screw, #10 wire for a #10 screw, #8 and #6 wire for a 1/4" screw and so on.

As I mentioned above, Sta-kon connectors are becoming quite popular so it is likely that you'll run into them on at least a few devices. Because you probably can't avoid their use, you should have some connectors in the common sizes on hand. Since these terminals are typically used for low current and control wiring, the range of wire sizes you'll likely need is #16-12. The two most common terminal sizes are .187" and .250". If you avoid applying and removing the connector multiple times, you shouldn't have any problems with it vibrating loose.

Description	Size/Stud		Remarks	Waytek Part
Butt Splice	#22-18	Red	Nylon, double crimp.	30780
	#16-14	Blue	Used to splice two wires	31780
	#12-10	Yellow	together.	32780
Ring Terminal	#22-18/8	Red	Nylon, double crimp.	30702
	#22-18/10	Red	Control wiring.	30703
	#16-14/8	Blue	Nylon, double crimp.	31702
	#16-14/10	Blue	Power wiring.	31703
	#12-10/10	Yellow		32702
	#12-10 / 1/4"	Yellow		32703
Push-on (Sta-kon), female	#22-18/.187"	Red	Nylon, double crimp.	30716
	#22-18/.250"	Red	Control wiring.	30711
	#16-14/.187"	Blue	Nylon, double crimp.	31716
	#16-14/.250"	Blue	Power wiring.	31711
	#12-10/.250"	Yellow		32711
Pigtail	#22-16		Nylon.	37021
	#14-12		Wiring lamps and switches.	37020
Bullets, male	#22-18/.180"	Red	Nylon, double crimp.	30767
	#16-14/.180"	Blue	Connecting removable items.	31767
Bullets, female	#22-18/.180"	Red	One male and one female	30766
	#16-14/.180"	Blue	required for each wire.	31766
Eyelets	1/0 / 1/2"		Plated, heavy duty.	36523
	4/0 / 1/2"		Main trainline wiring.	36553

Table 7: Common Crimp Connectors

The proper application of crimp connectors depends entirely on a good crimp. While it is possible to crimp these connectors with a cheap crimping tool from the automotive supply store or Home Depot, it isn't recommended. Rather, you should use a ratchet crimping tool with the proper size dies for the connector (this is especially important for the double crimp type connectors). The ratchet guarantees a good crimp every time because the tool will not release until you've squeezed it hard enough.

The large lugs, such as those used on 4/0 trainline wire, must be crimped by a heavy-duty crimper with the correct dies for the lug. Two kinds are available: a compound lever, manual crimper; and a hydraulic crimper. Amtrak requires the use of a hydraulic crimper on all trainline connectors on the theory that it isn't possible to get a consistent crimp with the manual crimper. Hydraulic crimpers are pretty expensive to buy so renting or borrowing one, when it comes time to make the few crimps required on the trainline, makes sense.

Wiring Devices

On railway equipment, you will find a number of general-purpose wiring devices such as switches, lamp sockets and outlets. These devices probably haven't changed much in the fifty years since your car was built.

The lamp sockets are still exactly the same. DC lamps were made with the same bases as AC lamps so that they could screw into regular sockets. Consequently, railway equipment builders used regular, off-the-shelf lamp sockets which were typically rated for at least 250V and 100W. If an inspection of the socket reveals it to be in good shape, it will serve admirably in a 120V lighting circuit and may be reused. Conversely, it should be possible to find replacements for any worn out sockets because many of the old designs are still in use.

Fluorescent lamp fixtures still use the same sockets and other items like starters. Once again, the ratings on existing parts should be perfectly adequate for continued use today. And, starters are still made the same way so they should be obtainable. Ballasts are another thing. Most of the ballasts you'll find on old railway equipment are burnout cases. Or, if they're not burnt out, they'll probably be leaking tar (old ballasts were potted with tar) or some other nasty staff. Best two consign these suckers to a landfill somewhere and replace them with something a tad newer.

Old-style outlets are usually of the two-blade, non-polarized type. Furthermore, the ground fault interrupter is a pretty recent idea although one that definitely has its place on rebuilt railway cars (many outlets are located in bedrooms and roomettes right next to the sink — water and electricity, an unbeatable combination). Regardless of the fact that most old-style outlets are quite capable of carrying modern loads, their lack of safety features means that they should take the ride along with the fluorescent light ballasts to the landfill.

If possible, try to fit a new GFCI outlet into the old outlet location. Usually, it can be done although sometimes it's tricky. If this won't work, a GFCI breaker at the panel is the next best thing. Bearing in mind that the primary use of an outlet in bedrooms and roomettes nowadays is to run a 1500W hair dryer, one should wire each outlet on a separate circuit too.

Switches are frequently the kind of switches found on electronic equipment instead of those used for house/commercial wiring. Replacements are found at electronics suppliers rather than electrical distributors. If your car was a DC car, the existing switches on it are more than adequate to handle the requirements of the new, AC system. The reason for this is because a DC arc is much more difficult to extinguish than an AC arc. When a switch is opened, an arc forms between the contacts and so DC switches must be correspondingly heavier to prevent their burning up when switched off. On the other hand, switches are prone to wear out from use so you might wish to replace them anyway.

When you purchase wiring devices, try to make sure that they have either screw terminals or pigtails. All of the devices mentioned above are available in one or the other of these configurations. This will allow you to connect the devices with either ring crimp, butt splice or pigtail connectors. Then, whatever method you use, the effects of vibration will be minimized.

Transformers

AC power is converted from one voltage to another by a device called a transformer. Why would you want to convert voltages from one to another and not just use one voltage for everything? That's a good question! Next question, please.

KVA Rating	Load Current at Rated Line Voltage		
	120V	240V	480V
Single Phase Transformers			
0.25	2.08	1.04	0.52
0.5	4.16	2.08	1.04
0.75	6.24	3.12	1.56
1.0	8.33	4.16	2.08
1.5	12.5	6.24	3.12
2.0	16.66	8.33	4.16
3.0	25	12.5	6.1
4.0	33.2	16.6	8.3
5.0	41	21	10.4
7.5	62	31	15.6
10.0	83	42	21
15.0	124	62	31
20.0	166	83	42
25.0	208	104	52
Three Phase Transformers			
3.0	14.4	7.2	3.6
6.0	28.8	14.4	7.2
9.0	43.2	21.6	10.8
12.0	57.8	28.9	14.5
15.0	72	36	18
22.5	108.4	54.2	27.1
30.0	144	72	36
45.0	216	108	54
60.0	288	144	72
75.0	360	180	90

Table 8: Transformer Ratings

If you're building railway equipment for use in Australia, that's exactly what you do. In North America we are stuck with some legacy voltages so voltage conversion is necessary. At the very least, you'll need to convert the 480V supplied by Amtrak to 120/208V for use by outlets and lighting circuits. You can wire the rest of your car at 480V or you may want to support the older 240V standby power. Although scarcer these days, this type of power may still be available. This implies conversion from 240V to 480V or 480V to 240V (whichever way you choose to wire your car). Also note that 240V devices such as heaters tend to be more readily available so you should take this into account.

As noted in the preceding paragraph, voltage conversion is going to be necessary one way or another. If you haven't picked a common voltage for your car (choose either 240V or 480V), now's the time to do it. After you've decided on that, you'll know what kind of voltage conversion you will need to make (e.g. 480/240V, 480 Delta / 120/208V Wye, etc.).

The next thing to do is figure out how much power you'll be converting. Transformers are rated in KVA. KVA are like kilowatts (i.e. voltage times current) except that, if you have a lot of motors, you need to multiply the transformer's KVA rating by .8 to get kW. For three phase transformers (see Table 8), the KVA rating is based on the highest current (if unequal) in the three phases (another reason to balance things so that you don't pay for capacity that you don't use).

Incidentally, a three phase transformer is just three transformers wound on a common core. This is merely done for convenience sake (to reduce the amount of iron required). There is no requirement electrically for the windings to share the core. Three single phase transformers can be connected (see Figure 5) in Delta or Wye configuration, if necessary. Often, there isn't enough room under a railway car to use a three phase transformer so three single phase transformers (which are individually smaller) can be used instead.

Transformers consist mainly of two things: copper; and iron. In large proportions. This implies that you need mucho big steel to hold them up, since they are mucho heavy (a single phase, 25KVA transformer may weigh upwards of 250 pounds). To mount transformers (usually under the car), you need an appropriate open space with some heavy cross-members that you can weld to. If there aren't any, add one or two as necessary. The preferred mounting for transformers (all heavy equipment, for that matter) is a U-shaped cradle. The cradle is fabricated (out of angle iron [2-1/2" or 3" x 1/4" equal leg angle works well] or square tube [2", schedule 120 works well]) in such a manner as to allow the transformers to sit on top of the horizontal portion of the U. The transformers are bolted down with the bolts pointing downwards.

Transformers come in two forms: dry location, ventilated; and potted. For wet locations, the ventilated transformers can be ordered with rain shields that can be placed over the vents. Unfortunately, this scheme probably won't work on a railway car where water could be splashed or blown into the vents. Potted transformers are filled completely with a high temperature potting compound that renders the core and windings impervious to water. This type of transformer is more suitable for use on railway equipment.

The last thing to consider when selecting transformers is their temperature rating. It is often hot underneath a railway car and transformers generate their own heat too. Thus, the transformers should first, be located somewhere where there is good airflow and second, have the highest temperature rating available. Fortunately, because they **are** potted, the potted transformers have a high temperature rating thereby making them doubly suitable for use on railway equipment.

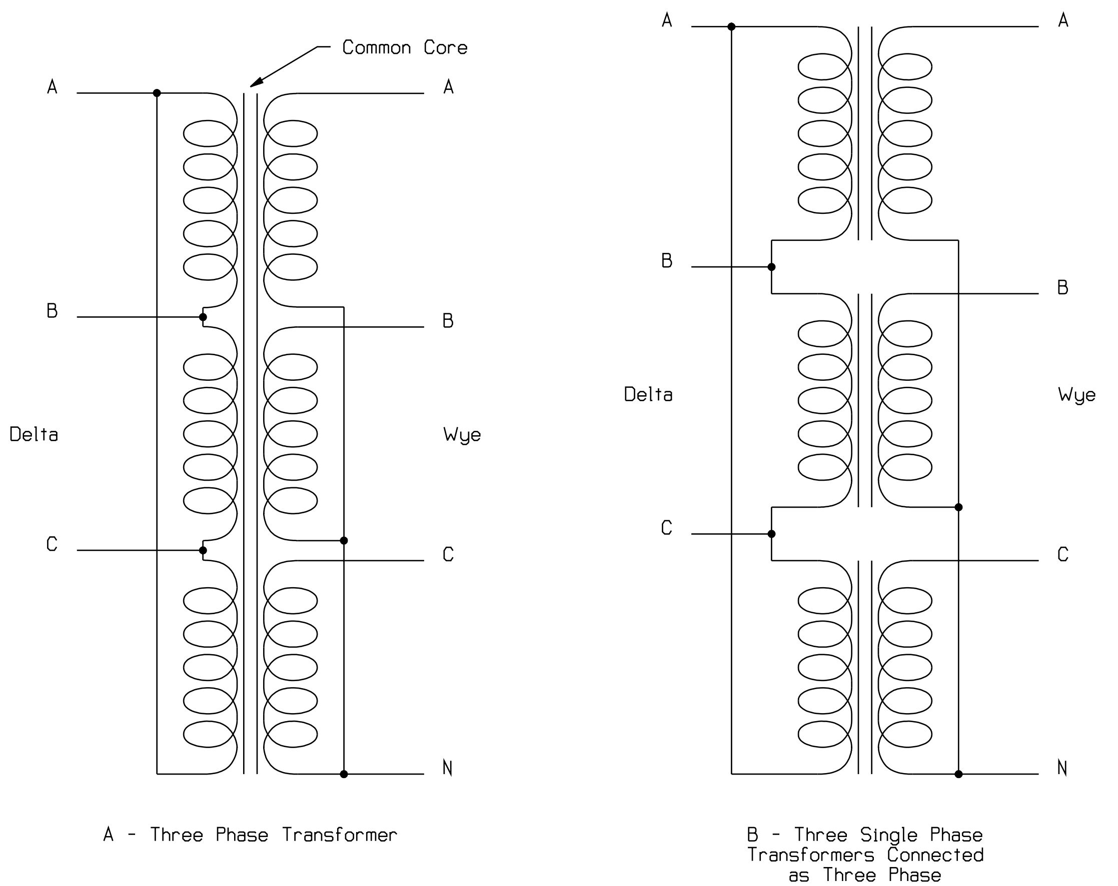

Figure 5: Connecting Transformers

Motors

Other than solenoids, motors are likely to be the sole source of electrically generated motion on a railway car. Motors are used to power pumps, compressors, blowers, fans and airconditioners so it is important that we understand and are comfortable with motors.

Motors are usually divided into two categories: big iron (e.g. the ones with a lift ring on them); and fractional horsepower. The division is usually made at around 1 HP with the 1 HP and sometimes 1-1/2 HP motors being crossover types that can go either way. For our applications (i.e. where three phase power is readily available), the big iron is three phase while the fractional horsepower motors are single phase. Smaller three phase motors such as half horsepower are available but aren't too common.

Single phase motors come as PSC, centrifugal start and capacitor start types. PSC motors, which have a permanently connected starting winding and a starting capacitor, tend to have pretty wimpy starting torque and are useless except for light, aluminum bladed fans. They are typically found driving airconditioner condenser fans. Centrifugal start motors have a starting winding that is connected through a centrifugally actuated switch. When the motor gets up to speed, a throwout bearing actuates the switch which disconnects the starting winding leaving only the running winding to carry the load. Starting torque is good but the switch is a maintenance item. Capacitor start motors use a large capacitor to kick the motor off to a good start. Starting torque is high so this type of motor should be considered for squirrel cage blowers (which have a lot of inertia and, hence, starting resistance), pumps, etc.

Very small horsepower motors come in universal and synchronous varieties. The synchronous variety is like the larger PSC motor but without the starting winding. Needless to say, it has very little starting torque. It does have the property of always staying synchronized with the line frequency, however, so it can be used to drive clocks or timers that keep very accurate time. A universal motor is like the one on your electric drill, having a wound armature as well as a wound field. The armature is powered by a commutator and a set of brushes, which are prone to wear out. Both these motors are commonly used to power fans. The universal motor is frequently used where speed control is desired because it's speed may be varied easily by a simple voltage control (all other AC motors must have their speed varied by frequency control). Reversing a universal motor is trivial too so one may be used where this feature is important.

The fractional horsepower motors have starting windings to keep their running current low. The motor is started with low resistance windings that provide lots of torque to overcome friction and inertia and get things moving. Once the motor is running, the friction becomes negligible as does the inertia and the starting winding can be cut out to reduce the current by switching to a high resistance running winding. Larger motors don't need a running winding because they rely on an effect called back EMF to reduce running current.

Three phase motors come in two varieties: synchronous; and squirrel cage. Synchronous motors are pretty rare so you are unlikely to see them. They have a wound rotor, slip rings and a DC exciter, all of which make them complicated. Their primary benefit is their ability to vary their power factor and so they become important in large sizes where power factor correction can yield savings of big bucks. Squirrel cage motors are really it. They are about as simple as it gets, having no moving parts except the rotor. They have high starting torque, are robust and easy to connect. They come in three speeds (3600, 1800 and 1200 RPM here in North America). What more can I say?

Most AC motors come with multiple windings. The reasons for this are: to allow for multiple voltages (e.g. 120/240V or 240/480V); to permit selection of shaft rotation direction; and to facilitate changing of rotational speed without the need to change frequency. The function of a motor's windings is indicated on its nameplate and the windings should be connected accordingly.

In a nutshell, connection of motor windings works as follows. To change the voltage, windings are split in two. To select the high voltage, the two windings are connected in series. To select the low voltage, windings are connected in parallel. To change the speed of a motor (on single phase motors), windings are grouped in pairs, one pair for 3600 RPM, two for 1800 RPM and three for 1200 RPM. To select the speed, a set of windings is chosen (i.e. the one group, the two group, the three group). To change the direction of a motor, the order in which the windings are energized is changed. On a single phase motor, winding A is placed before winding B or vice versa to reverse it. On a three phase motor, nothing need be done to the motor windings. Instead, any **two** phases are reversed (e.g. ABC becomes BAC) to reverse the motor.

Note that, in the preceding paragraphs, motor speeds were given as 3600, 1800 or 1200 RPM. This is the product of the AC line frequency (60 Hz) times the number of seconds in a minute (60) divided by the number of winding pairs (1, 2 or 3). In actuality, motors don't usually (except for true synchronous motors) run at this synch speed. Instead, there must be some slip between the rotating magnetic field and the rotor so that a current will be induced in the rotor which will in turn generate its magnetic field. Slip usually yields motor rotational speeds of 3520, 1760 and 1180 RPM.

Starters

Fractional horsepower motors are often connected directly to the line through a switch (often called a manual starter) or relay. Their relatively low starting current makes this possible. On top of that, these motors are protected from overload by a built-in, automatic thermal protector (these motors are shown as "auto" in motor selection tables) which shuts the motor down, should its winding temperature rise too high.

Larger motors and three phase motors typically draw more current and/or do not have any thermal overload protection (shown as "none" in motor selection tables). It is not possible to control these motors with a simple relay and also some kind of external overload protection must also be provided. This is the job of a motor starter (often called a magnetic starter).

Starters are composed of a contactor section and an overload section. The contactor is rated by the range of currents that it can handle (see Table 9). Typically, railway car equipment will use the NEMA 00, 0 and 1 sizes. The contactor will have a main set of contacts for carrying the motor current and possibly one or two auxiliary contacts. The auxiliary contacts are often used to implement a latch circuit so that standard start/stop push button stations can be used to start/stop the motor. Another use for the auxiliary contacts is remote indication of contact closure (e.g. so that you can tell from inside the car when a device has power). If more than one set of auxiliary contacts is required, most starters provide for additional contact blocks to be installed on them.

The overload section must provide some method of measuring the motor current and tripping when it is out of bounds. Motors draw a high starting current for a short time and then the current settles down to the normal running current. After that, a very large overcurrent for a short time or a small overcurrent for an extended time signals a fault. How is this set of rules implemented?

A motor starter's overload section consists of a set of control contacts (inserted into the contactor's control circuit), equipped with a manual overload reset button and connected to a current sensor. The current sensor has a set of thermally responsive current sensing elements, one for each line to the motor. These sensing elements are either bimetallic strips or melting alloy slugs. This kind of sensing element is unaffected by short current spikes (starting current) but will react to very high overcurrents to or small overcurrents that exist for long periods (the heat will build up slowly and eventually trip the sensor).

NEMA Size	Current Rating	Motor Volts	Max HP
00	9	208	1-1/2
		240	1-1/2
		480	2
0	18	208	3
		240	3
		480	5
1	27	208	7-1/2
		240	7-1/2
		480	10

Table 9: Motor Starters

Motor starters are sold with no current sensing elements (usually called heaters). You select a set of heaters (two for single phase motors, three for three phase motors) from a chart provided by the starter manufacturer based on the motor's running current. Heaters are made with a relatively small current range so that they may effectively protect the specific motor for which they are selected.

Starters are available in two types: enclosed; and open. An enclosed starter comes in its own box. An open starter is just the starter, no sheet metal. I find the latter type to be most useful as I am usually including them in the control box of the equipment that I build.

Contactors

Contactors are the big brothers of the relay. Their function is the same: to open/close a set of contacts based on a control signal. The only difference is that the contacts on a contactor are meant to handle much heavier currents than those handled by a relay. Contactors typically handle currents in the range of 30 to nearly a thousand amperes. Above that and we're into the realm of BIG POWER.

On a railway car, contactors are mainly used to operate heaters but you may use two or three large contactors to implement automatic power selection from the two or three sources of power available to the car (trainline, generator and possibly standby). In this application, a power selection control circuit decides which source of power to choose from and closes one contactor which then connects the car to the power source. The selection circuit should be interlocked so that only one contactor can ever be closed at any one time and you may wish to include a phase failure relay and time delay relay (to prevent immediate connection to a possibly uncertain power source) in the circuit too.

Amtrak requires a contactor and time delay relay in the trainline power tap with the pickup time randomized based on the car number (to prevent a huge instantaneous load from being applied to the trainline when the power comes on, which would be the case if all cars began using power immediately) so you will have at least one contactor on board for the purposes of connecting power to the car. For a modest incremental cost, it is possible to have contactors on all sources of power and, hence, automatic power selection.

Circuit Breakers

If anything goes wrong with the circuits in your railway car, it is possible that some serious arc welding could take place. This is because there is more than ample current available from the trainline to fry even the heaviest wiring (some locomotives are capable of supplying 700KW into the trainline which translates into more than 1400A at 480V).

Given the very real possibility for a meltdown, it is very important to adequately protect your car and all of the circuits in it. This is the function of circuit breakers and fuses. To protect the wiring and, to a lesser extent, the devices connected to the wires when (**not** if) an overload occurs.

Circuit breakers are constructed from a switching section and a current sensing section. The current sensing section has one or more sensing elements inserted in series with the load so that they can measure the current being supplied to it. If the current exceeds the limit of the circuit breaker, the switching section is made to disconnect the load. Typical sensing elements are thermal or magnetic.

The switching section must be capable of opening and disconnecting the load under less than ideal circumstances. For example, let's imagine that you just laid your best screwdriver across two terminals in a 100A circuit. Your best screwdriver is bound to be able to draw way more than 100A — a couple of thousand at least before it melts. Now, the circuit breaker must still be able to open and remove the load even though the instantaneous current is 2000A. This is known as the interrupting current or AIC. So, circuit breakers are rated with two ratings, the trip current (the current at which point the breaker decides an overload is taking place) and the interrupting current (the maximum current flow that can be interrupted). Amtrak requires that circuit breakers which have interrupting current ratings of 10,000 AIC be used.

Circuit breakers are applied to each circuit that must be protected at the initial feed point of the circuit because the circuit breaker is meant to protect the wire as well as the devices in the circuit. All of the wire in the circuit must be sized according to the circuit breaker's trip current. The breaker should be selected according to the current requirements of the device or devices in the circuit (see Table 10).

The various circuits of a railway car form an inverted tree. The trainline is the root of the tree, feeding into the main panel. From there, circuits lead to the high voltage devices. At least one circuit feeds a set of step-down transformers that supply 120/208V for lighting and small appliances. Each of these circuits must have, in order of decreasing trip current, a main breaker, high voltage breakers (including one for the step-down transformers) and 120/208V breakers.

It is acceptable, in the case of infrequently switched devices, to use the circuit breaker as an on/off switch. However, for devices that are turned on/off several times a day, you may want to provide a separate switch to avoid wearing the out the relatively expensive circuit breaker.

Amtrak requires that you use a Westinghouse FDB or EHD circuit breaker such as a FDB-3150 for the main 480V breaker (no substitutions). Also, any 480V circuits must be supplied by Westinghouse EHD breakers. If your car is wired for 240V, however, you can use whatever breakers you choose.

Fuses

Fuses can be used instead of circuit breakers and, in fact, they quite frequently were in older railway equipment. Fuses operate on a very simple principle, that of the fusible link. A piece of metal that is designed to melt, when a certain current flows through it, is placed in the circuit to be protected. When an overcurrent occurs, the link melts and the circuit is broken. This always works. Sometimes the fuse blows up when the interrupted current is too high but the circuit still opens. I suppose you can say that this is the principal advantage to fuses. That and they're cheap.

Device to be protected		Inverse Time Breaker	Fuse	Time Delay Fuse
Motors				
Single phase, all types, no code letter		250%	300%	175%
Three phase, squirrel cage, no code letter		250%	300%	175%
Single phase, all types and three phase, squirrel cage,	Letter A	150%	150%	150%
	Letter B-E	200%	250%	175%
	Letter F-V	250%	300%	175%
Airconditioning Compressors				
For any compressor that starts on 15 or 20A, 120V		15/20A	15/20A	15/20A
For any compressor that starts on 15A, 240V		15A	15A	15A
All others, use		175%	175%	175%
Unless compressor won't start, then use		225%	225%	225%
Transformers (primary overcurrent protection)				
Less than 9A primary current		167%	167%	167%
Greater than 9A primary current		125%	125%	125%
Lighting, Outlets and Other Branch Circuits				
Circuit conductor size	#14	15A	15A	15A
	#12	20A	20A	20A
	#10	30A	30A	30A

Note 1: It is difficult to summarize all of the rules for overcurrent protection in a single table. The NEC sections 310-16, 430-31 thru 430-44, 440-21, 440-22 and 450-3 contain more information and should be consulted before making a definitive decision on overcurrent protection

Note 2: To select an overcurrent protection device, use the load current of the equipment to be protected. If a fixed current rating is shown, use that. If a percentage is shown, the maximum current rating of the overcurrent device shall not exceed this percentage of the load current.

Note 3: Overcurrent devices are available in fixed sizes. In general, pick the next lower sized overcurrent device than the one calculated from the percentage. If the equipment will not operate with this overcurrent device, it is usually permissible to pick the next size up.

Table 10: Summary of Overcurrent Protection

The principal disadvantage to fuses is that the link melts. You must either replace the whole fuse (in the case of the smaller amperage fuses) or open up the cartridge and replace the link (in the case of the larger ones). In either case, a supply of spares must be kept on hand and this can be a pain.

Breaker Panels

Any sensible, new installation of a railway car electrical system will be based on circuit breakers. This being the case, we should discuss breaker panels.

First, however, circuit breakers can be brought as individual, stand-alone units (molded case) and you may wish to use these type for your main breakers (480V trainline, 240V standby and generator). These units are simply bolted to something solid (e.g. a sheet of 1/16" or 1/8" mild steel) and wired up. They can be placed wherever is necessary (although I recommend placing all breakers inside the car in an accessible location). They should either be covered with a protective panel that allows them to be operated without removing the panel or placed inside a lockable electrical locker or box so that only knowledgeable, authorized personnel can get at them.

For the main breakers, a method of locking them open is required. I use a bar that slides into position above the handle and can be padlocked in place or a sheet of steel that covers the whole breaker but has a hole in it for the handle and that padlocks it in place. In either case, the breaker cannot be turned on when it is locked. This allows someone to work on the car's electrical system without the danger of some well-intentioned person accidentally turning the power on while they are doing so. Adding a tag that says "Do Not Operate" gives an extra measure of safety.

Distribution of power is best accomplished with a breaker panel or distribution panel. These consist of a set of busbars (heavy, current carrying, copper or aluminum bars) that are fed by the main breaker. Along the busbars, positions are provided where circuit breakers can be inserted so that they attach to the busbars and tap into the current flowing through them (for use on railway equipment, bolt-on circuit breakers should always be used). The breaker current is chosen to meet the requirements of the circuit to be supplied and the circuit is wired to the breaker.

Two types of distribution panels are available: those with main breakers and those without (called main lugs). They are rated for their total current carrying capacity. You'll probably want 200-250A for the high voltage panel and 100A for the 120/208V panel. Both of these panels should be three phase. They can be bought without a box or enclosure, since they will be built into the electrical locker.

The size of the breaker or distribution panels is given in breaker slots or sometimes inches. Each pole on a circuit breaker consumes one slot or so many inches (although some single phase circuit breakers are built to consume only one slot but switch two poles). A single pole breaker uses one slot, a two pole breaker uses two slots and a three pole breaker uses three.

Panels are made in various sizes. You should know ahead of time roughly how many circuits you will need on your car and purchase panels of adequate size. I found that a 240V panel that is sized at 45" and that holds 10 3-pole breakers along with a 30-circuit 120/208V panel works on a car with 16 beds, a kitchen, a washer/drier, air conditioning, ceiling and floor heat and freeze protection (in short, the works) so this combination of panels (see below) may work for you too.

Power distribution on your car can probably be divided into two parts. The higher voltage power (either 240V or 480V) will probably be three phase, delta. Distribution of this power should be through a large, industrial-style panel (e.g. Square D HCN2365-2N). One breaker on this panel should feed a set of transformers that step the voltage down to 120/208V and change the configuration to three phase wye.

The lower voltage (i.e. 120/208V) is fed to a second panel which can be of lesser size and capacity (e.g. Square D NQOD430L100CU). The neutral in the wye side of the circuit can be grounded (so that GFCI breakers and other safety features will work). The breakers in this panel will typically be single pole, low current (e.g. 15A or 20A) and will feed lighting circuits or appliance outlets. Two pole breakers can be used for things like duplex, kitchen outlets but 208V devices should be eschewed in favor of 240V or

480V devices connected to the high voltage panel.

The low voltage panel is usually constructed so that a circuit breaker may be placed in any position and it will be connected to one of the three phases, depending on its position. So, the top position connects to phase A, the next to B, the next to C and so on with the cycle repeating on down line (breaker slots always come in multiples of three and panels have two sides so they are made with 6, 12, 18, 24, 30, 36 and 42 slots). Bear the allocation of slots in mind as you install circuits so that the load is balanced. Any unused slots are filled by a blanking plate on the panel's cover so all slots need not be used.

The high voltage panel is constructed so that a breaker in any position can connect to any phase or phases, rather than the position determining which phases are used. In the case of a three pole breaker, this is obvious. In the case of two or one pole breakers (the latter is used on wye configurations only), you must purchase the proper breaker based on which phases you want to connect to. Usually, the breaker part number will have a suffix such as "AB" to denote which phases it connects to. Bear this in mind when purchasing two pole breakers and always try to keep the load balanced (see "Load Calculation"). As with the other panel, blank spots are filled with a cover blanking plate.

Heating

One of the main uses of electricity on a railroad car is heating, both space heating and water heating. Space heating is usually broken in two, forming separate systems for ceiling and floor heat.

Ceiling heat usually consists of a large heating coil (15-24kW) placed in the plenum of the air conditioning system right after the evaporator. This coil is capable of tampering the car's air (say by raising its temperature to 70-80°F) and carrying a large part of the heating load. The exit temperature of the air is set fairly low so that it feels cool to the passengers. They can then adjust their room temperature with individual floor heat controls and for those who wish, the room can be set at a relatively low temperature while still getting airflow.

Originally, ceiling heat coils were steam heat exchangers. If you have hot water heat on your car, you can reuse this heat exchanger. Otherwise, you'll need to replace it with an electric heater. I prefer to use a heater made up of finned strip heaters which can be assembled in groups of three to give a large, three phase heater (I use 21 Vulcan 900W heaters to give an 18.9kW heater — see the article, "Replacing Steam Ceiling Heat Coils"). You may be able to use a commercial heater but most of these consist of nichrome wire strung on ceramic supports and I worry about the effects of vibration on the open wire (especially when it's hot and prone to sag).

I don't know about you but the thought of a heater glowing red hot at 900-1000°F up in the ceiling of my car while I'm snoozing at night makes me nervous. Call me a wimp, if you like, I don't care. I think it's important to have a few safety interlocks in place to avoid the possibility of a disaster (like a dust fire in your air conditioning plenum). I use a differential air pressure switch, with the sensing tube placed in the plenum, to give a positive indication of air flow, an automatic limit thermostat set at 160-180°F and a manual reset limit thermostat set at 200°F (a belt and suspenders too). All of these safety devices are wired in series with the heating contactor and supplied from the blower motor's power circuit (see Figure 6). In this manner, there's no heat if the blower has no power or if there's no air flow or the temperature of the air leaving the heater is too high.

As I said above, the temperature of the air supplied by the ceiling heater is kept fairly low. Control of the air's temperature can be effected by a remote bulb thermostat (e.g. Honeywell T6031A) placed in the plenum. A point approximately 1/2 to 2/3 the length of the car away from the heating coil is an ideal location for this thermostat. If a remote bulb thermostat is used, the sensing element can be placed in the center of the plenum where the air stream can impinge upon it and the control may be located in an out of the way but nonetheless conveniently reached spot so that adjustments are relatively easy to make. I've found that setting this thermostat somewhere in the 70°F to 80°F range works well.

While the ceiling heat takes the edge off the cold air and maintains the car at a reasonable, albeit cool, temperature (say 60°F), the floor heat makes up the difference and allows the occupants of individual areas and compartments to adjust the temperature to their liking. Also, in times of extreme outside ambient temperature dips, the floor heat will save your butt and keep the car warm.

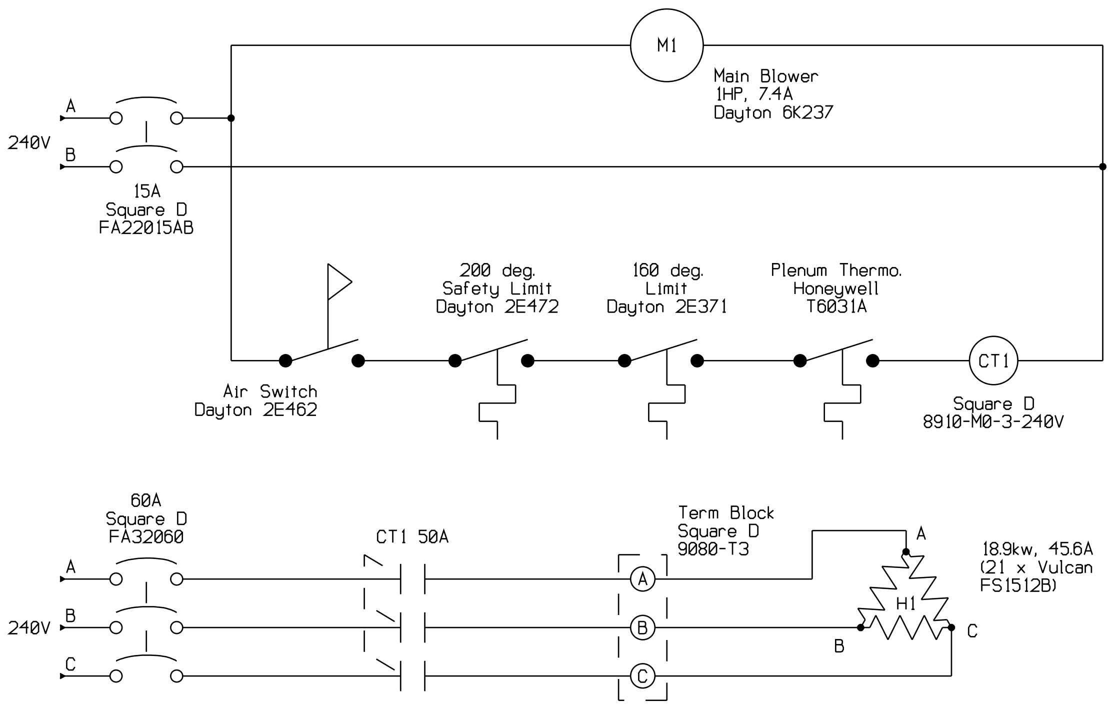

Figure 6: Ceiling Heat Circuit

The amount of ceiling heat should be in the vicinity of 20kW and the floor heat should be a likewise amount. A total of 40-45kW of heat is more than adequate with the lower value probably being acceptable for a private car that is kept mostly buttoned up and that doesn't experience the loading/unloading of an Amtrak short haul coach.

Given that you need to sprinkle about 20-25kW of floor heat around, how do you do it? You might try: 500-750W in each roomette; 1-1.5kW in a bedroom; 3-4kW in a small lounge or 5-6kW in a large lounge; 500-750W in a bathroom/shower; 2-3kW in a side hallway; and 1kW in the hallway near the vestibule. Kitchens, being places where you toil over an open fire, may not need any heat. However you decide to do it, try to spread the heaters out so that they are distributed evenly. This translates to about 1kW of heaters for every 4ft. of car length. Also, don't forget to balance the loads as you connect them up.

The type of heaters to use are up to you. Via Rail (an acknowledged expert in car heating) uses Vulcan strip heaters with a low wattage density. Lots of people like oil filled heaters such as Intertherm. Personally, I use industry standard finned heaters (such as Qmark) — a little judicious trimming of the sheet metal plus a few pieces of copper wire wrapped around the heating element and tied to the surrounding shell to prevent vibration and, hey, presto, you've got a nice little heater that'll pop right into the spot occupied by a former steam heat coil. The benefits of using the industry standard heaters are that they are readily available, in a variety of wattages and parts can be found in almost any town.

Controls for floor heat should be located in each individual area. If you are rebuilding a car, you can often locate your controls where Mr. Pullman or Mr. Budd put them. As a matter of fact, if you want, you can even reuse these controls. Here's how to do it.

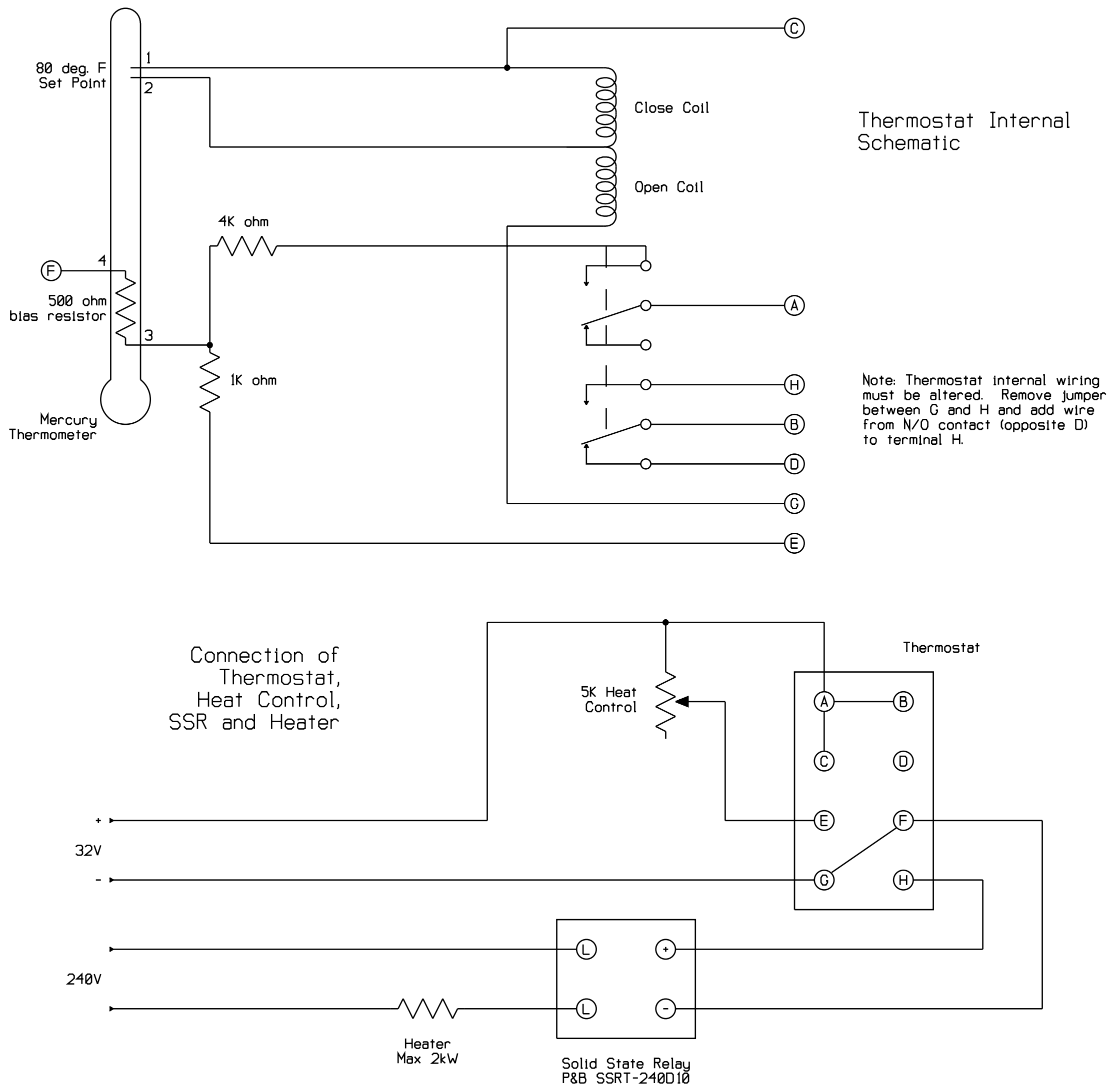

Figure 7: Using a Vapor Thermostat for Modern Heat Control

Original floor heat controls usually had a wall mounted thermostat located slightly above floor level and on the opposite wall from the heater. Temperature selection was provided by a dial on the thermostat or a remotely-located knob. Control of steam flow was by a radiator-mounted solenoid valve. This whole arrangement was powered by the car's batteries.

You can keep the thermostat and dispense with the solenoid valve. You will need to build or buy a DC power supply that matches your car's original battery voltage and provides a reasonable amount of current (e.g. I use a 4A, 32V power supply on my 32V car). Regulation is more important than filtering as some ripple will be quite acceptable. However, if you want a very good power supply, one with excellent regulation and very little ripple, one that is robust and easy to build, in short, one that looks very much like a battery, you can build the one shown in the section on DC power supplies. This power supply can be used power all of the thermostats on a typical car, including a sleeping car which has 15 or 16.

The typical car thermostat (e.g. Vapor) has a relay in it with a set of low current contacts, ample for switching the 10 or 20 watts (i.e. 0.5A to 1A at 32V) drawn by a solenoid valve but inadequate for switching the higher currents, never mind voltages, associated with electric resistance heating. You could interpose another set of contacts, in the form of a small contactor, in between the thermostat and heater but this is not the best solution. In my opinion, a solid-state relay is.

A solid-state relay is a modern device that is just the ticket for this application. There are two types, SCR and Triac, either of which can be used (SCR types tend to be somewhat cheaper). What a solid-state relay is an opto-isolator that drives a current switch (the SCR or Triac), attached to a heat sink and all encapsulated in a plastic package. What a solid-state relay looks like to you is a device, with four terminals, that you bolt to the wall near the heater. One pair of terminals, the power side, is wired in series with the heater (be sure to get an SSR that can handle the heater's voltage and current rating) while the other pair, the control side, is connected to the thermostat (the built-in opto-isolator keeps the two sides, power and control, isolated up to several thousand volts). The control side of most SSRs is rated at up to 32V so there's no need for a current limiting resistor but, if need be, one can be added for higher voltages (e.g. 64V).

It's that simple (see Figure 7). When the thermostat switches on, the SSR will switch the heater on, silently, and nobody will even know the difference (except for the missing hiss of steam). The car will look just like it did when it rolled out of Red Lion, PA.

Water Heaters

Hot water heaters are readily available in large and small sizes (e.g. 40 gallons and 15 gallons). The large size heaters are made for 240V operation and the smaller ones are made for 120V operation. Three phase units are not common.

Fortunately, two problems can be solved at once. The first is space. The second is balancing the three phase load. The solution to both is to use three small heaters (three 15 gallon heaters can be fitted easily underneath a car in a single row or in a cluster) to provide the capacity of one large heater. The piping must be done carefully to ensure that the end-to-end pressure drop from inlet to outlet is equal for all three water heaters (this will ensure that one heater doesn't hog all of the load and thereby defeat the purpose of having three). Otherwise, the use of three heaters is straightforward.

As I said, the heating elements of small water heaters are usually 120V. You can easily replace the 120V element with a 240V element for a lot less money than buying the same water heater set up for 240V operation (ain't life strange). Then, the three heaters are wired up to make a 240V Delta heater. A good heating element size to use is 2-3kW giving a total of 6-9kW for a 45 gallon water heater. Recovery time (i.e. the time that it takes for the water heater to bring the water back up to operating temperature after all of the hot water is used up) will be quite rapid with this arrangement.

Pipe Tracing

Much of a railway car's water piping, as well as the water tanks themselves, is found beneath the car. In this location, it is exposed in the wintertime to cold temperatures well below freezing. Especially when the car is moving and wind wipe is removing any heat rapidly, the probability of something freezing is one.

To combat this problem, one uses tracing. Tracing simply encloses all pipes and tanks that are likely to freeze inside of suitable insulation (often called lagging, this insulation consists of an insulating layer [Halstead and Rubatex make a rubber-like insulation that is quite good] covered with a protective metal or plastic jacket). Inside the insulation, right next to the pipe or tank, is a heat source which keeps it from freezing.

In oil refineries, where tracing is used extensively, a small steam line (steam being plentiful) is run alongside each pipe. An alternative to this would be a pipe loop containing circulating hot water/anti-freeze. You might see a system like this for heating tanks (a loop of 1" copper pipe circles the tank inside the jacket or is even inside the tank itself) or pipe trenches on railway cars. Originally, steam was used but you can reuse the pipes by connecting them to an electric circulation heater and circulating pump and filling the loop with water/anti-freeze.

By far the most common method of tracing on railway cars is heat tape. Heat tape consists of two parallel wires with a conductive plastic core in between. When power is applied to the wires, a small current flows through the plastic core and makes heat. This heat, which is uniformly generated along the entire length of the tape, keeps the traced object from freezing.

Typically, heat tape comes in two ratings: 3W per foot; and 6W per foot. The rating to be used is chosen based on the size of the object to be traced (3W per foot is good for up to 2" pipe). You should consult the supplier of the heat tape to determine which rating is appropriate for your application.

Heat tape can be applied directly to the object to be traced, including plastic pipe. The plastic core is designed so that, as the heat rises, the resistance rises proportionally. This has the effect of limiting hot spots and causing the tape to shut down completely when the ambient temperature is high enough (i.e. above freezing). Thus, heat tape can be left powered up continuously.

Several types of heat tape and operating voltages are also available. Usually, one picks 120V or 240V, depending on the car's system voltage. As for the type to choose, heat tape is supplied with a plastic jacket (for dry locations only), with a metal braid over the plastic jacket (also for dry locations) and with two plastic jackets, one under and one over a metal braid (for wet locations). The third kind is, in my opinion, the only kind to use. At the very least, the second kind may be used but avoid the first. There have been some reports of the first kind catching fire after an impact and burning along the length of the pipe underneath the insulation. Not a pleasant thought! Heat tape with metal braid should be grounded and fed by a GFCI breaker or outlet to protect against his eventuality.

Heat tape can be applied to anything that needs it. This can include plastic pipe (as I said earlier) but you may also want to consider applying it to air regulators and valves, since water that condenses out of the compressed air can cause them to freeze. The heat tape manufacturer (Raychem and Chromalox are two) will supply you with instructions on the proper application of the tape. They can also supply you with terminator and splice kits. Once the heat tape is applied, it is insulated along with the pipe, tank or valve.

One more method to consider for heating tanks is the cartridge heater. These heaters (Vulcan or Chromalox make a variety) can be screwed into a standard pipe flange that is welded into the tank (they can be purchased with stainless-steel outer cladding so that they're compatible with whatever the tank holds). Placing one or a few (three can be wired up three phase) along the bottom of a tank can supply enough heat to ensure that the entire contents don't freeze. Just be careful to provide some kind of shut off mechanism (e.g. an integral thermostat) so that the heater won't overheat if the tank's contents are drained.

Lighting and Outlets

Assuming that you installed a set of 120/208V, Wye-connected transformers and a breaker panel, you can assign a number of circuits to lighting and outlets. Try to break things into logical groups of related lights and related outlets.

As I previously mentioned, in bedrooms and roomettes, I like to feed each outlet from its own circuit breaker and ensure that they are all GFCI protected. This will allow more than one of your guests to dry their hair or iron their clothes without any embarrassments. For purposes of the power budget, I assume that only three outlets will be in use (15A), one on each phase, at any one time. How convenient! This might not actually be true but circuits of this type are known as "demand" circuits, meaning that the load fluctuates on demand. What the true load will be at any one time is anybody's guess. My guess is 15A x 3 on A/B/C.

You can wire all the lighting in a single area up to one circuit. For example, all the roomettes on the left side of the car, all those on the right, the left side lounge lights, the right side, the kitchen, a bathroom and shower and so on. You get the idea. Most of the light fixtures (e.g. small wattage fluorescents and incandescents) used on a railway car draw very little current so you can hook up a whole bunch of them on a 15A circuit fed with #14 wire. Think about how you might use the lights on a circuit and group them so that those that might all be off at once (e.g. vestibule lines) are on the same circuit. In this manner, by flipping off one breaker, you can kill them all.

Many of the light fixtures on a railway car have an additional lamp in them which is part of the car’s emergency lighting system. These emergency lamps fulfill the requirement that every enclosed space must have an emergency light along with a reasonable number of emergency lights in the open spaces.

The emergency lighting must be supplied by batteries which can keep it running when the power is lost (see "Batteries" and "Emergency Lighting"). To implement this function, you must wire each emergency-lamp-equipped fixture with a separate emergency lighting circuit. Because this circuit is low voltage DC, heavier wire should be used (I use #12 or #10) to carry the correspondingly higher current.

The original emergency lighting in railway cars used small incandescent lamps rated at the car’s battery voltage. I like ease of maintenance so I convert everything to use automotive lamps (#1156). These bulbs run at 12V (you can **always** find 12V batteries everywhere) and the bulbs themselves are ubiquitous so you will even be able to find some when you are laying over in East Nowhere. One or a couple of these bulbs in each fixture will provide ample light for emergency purposes.

Other 120V Devices

The most common voltage for many electrical devices in North America is 120V. Things such as refrigerators, dishwashers, small fans (e.g. room circulators) and the ever-present Mr. Coffee are readily and sometimes only available in 120V. You may wish to wire these appliances on separate circuits (each will typically have its own outlet except perhaps the fans) or string a few together on one. If you have a kitchen, be sure to provide at least two outlets on separate circuits so that two high-wattage appliances (e.g. toaster and waffle iron) can be plugged in at once. A separate circuit for the microwave oven and the dishwasher is probably a good idea too.

Although refrigerators and freezers are typically built-in on railway equipment, the compressors used by them are often small, packaged units consisting of a compressor, condenser, condenser fan and receiver. The whole package is known as a condensing unit and they are typically 1/4, 1/3 or 1/2 HP units made for 120V operation. A 20A circuit will feed two 1/3 HP units, one high-temp for the refrigerator and one low-temp for the freezer.

Another appliance that you might have on board is a washer/drier. The washer presents no problem as it runs off of 120V. The drier, however, expects 240V for the heating element but 120V for the motor and timer. You could replace both of these items but this is tedious (another option is to purchase a European washer/drier that is built for 240V operation). It is fairly easy to open up the drier and split out the heating coil so that only it requires 240V. Then the drier can be fed with both 240V and 120V (the 120V can be supplied by a small transformer [e.g. I used a 1.8KVA transformer to supply the washer/drier] so that one circuit breaker isolates the entire appliance — an important safety consideration) and it will work with a minimum of modification.

Controls

Much of the equipment on a railway car is set up for automatic operation so that no manual intervention is required in the course of normal operation. This is desirable since it is often the case that the car is placed in the hands of inexperienced personnel, say on a charter. In addition, protection (above and beyond that provided by circuit breakers) of the car's electrical circuits is desirable too.

It is important to install reliable and robust controls and protection devices at all times so that the requirements of safe, reliable operation are met. So, let's discuss some of the controls that you'll likely meet on railway equipment.

Phase Failure Relays

When using three phase power, there's always the possibility that one phase could be lost (e.g. on a fused circuit, a single fuse could open) or the voltage on one phase could be severely reduced (e.g. a large single phase load is suddenly added upstream). This is the worst kind of situation because a three phase motor will often keep running or maybe stall but continue to consume power. In either case, it will soon go up in smoke. Another problem, inherent in the fact that the car plugs into standby power, like a giant appliance, is the possibility that one phase could be reversed on some installations. This situation would cause all of the motors to run backwards — fans would suck instead of blow and the oil pump on some airconditioning compressors would cease to pump oil, to mention just a couple of things — not a happy state of affairs.

Luckily, there is a simple control that can effectively guard against all of these occurrences. It is called a phase failure relay. Its function is to monitor all three phases of any circuit that it is connected to and look for no or under-voltage on one or more phases as well as any phase reversal. It also implements a small on-delay to protect against short-term fluctuations (i.e. the relay won't switch on until it is **sure** that the power is good).

The contacts of the phase failure relay can be inserted into the control circuit of the power contactor so that, when the power is bad, power to the whole car will be removed. One phase failure relay can protect the car from all of its power sources but I prefer to use three (one for the trainline, standby and generator feeds). This allows them to be included in the automatic power selection circuit so that it can pick a power feed only when its power is good.

Timers

A number of the automated functions on a railway car require that time delays be used to implement sequencing, etc. Some examples include: pickup delay for the car's trainline contactor to implement the random delay based on car number, as mandated by Amtrak; air conditioning and refrigeration compressor shutdown lockout to prevent possibly severe damage due to short cycling when the temperature set point is near the ambient; delay, for automatic power selection, in selecting a power source to ensure that the power is **really** good and not just fluctuating; and open time delay for door engines.

Many types of time delay relays are available which can be used to provide the various timing functions required: delay on make; delay on break; recycle; one shot; etc. They also come in electro-mechanical and solid-state (either pure or hybrid with a solid-state timer driving a relay) varieties.

You can choose a specific relay for the job (ICM makes a low-cost line of specific duty timing relays, as does Time Mark) or a general-purpose timing relay can be adapted to the job (an electronics distributor such as Allied carries many kinds of timing relays by Omron, P&B, etc.).

I prefer to use a single, general-purpose timing relay, that is switch selectable to one of eight different timing functions and that has a large delay range (from a few tenths of a second to 1000 seconds), for all my timing needs (P&B CNS-35-92). This relay operates on any voltage from 24V AC/DC to 240V AC — truly a universal timing relay. The reasoning behind this is that, should a critical timing relay fail, I'll have a few spares hanging around in less critical applications (e.g. door engines) that I can rob to get things going again.

Relays

Low current/low voltage switching operations (usually up to 10A and 240V) are often performed by relays. There are many places in railway equipment controls where a relay may need to be used. Areas such as automatic power selection, heating and cooling, refrigeration and on-board power generation are a few of the more common ones. Frequently, control voltages of 24V or 48V are used to operate relays which then switch higher voltages.

As with the timing relay, it is wise to pick one or two standard types and then use them throughout for the same reason as mentioned above. I like to use an octal base, socketed, enclosed relay of the DPDT type (e.g. the 24V P&B KRPA-11AG-24 or the 240V Omron MK2P-S-AC240). These relays plug into a socket that can be pre-wired before they are plugged in (this also makes swapping easy). The relay itself is enclosed in a plastic case that excludes dust and dirt. The DPDT contacts are usually all that most circuits require.

Relays can be located in control boxes, as necessary or a single shelf or rack can be located in the electrical locker to hold them all, including the phase failure and timing relays. This arrangement makes wiring somewhat easier but locating the relays where needed is also more convenient in some instances. I try to group things logically so that, for example, all of the air conditioning relays are located in the air conditioning control box (which is next to the compressor so that it can also contain the pressure switches and motor starter) while general-purpose control relays such as those used in the automatic power selection circuit are located in the electrical locker.

Control Voltage

As I mentioned above, control circuitry is often implemented using a low voltage such as 24V or 48V. One reason for this is that it provides a modicum of safety — anyone who comes in contact with 48V on a control panel is not going to get zapped. Another reason, perhaps more germane to our needs, is that the control circuitry may all be wired at a common voltage, regardless of the voltage that it controls (e.g. power selection circuitry can be wired at 24V despite the fact that it controls both 240V and 480V).

The low voltage (24V is probably more typical) is supplied by a small transformer (usually 50VA or 2A @ 24V) called a control transformer. Several of these transformers may be used, as necessary, and one side of each one's secondary may be wired to a common return to make wiring easier — the common return is routed around to all of the control devices that use this power.

PLCs

Implementation of complex control functions (e.g. loss of trainline power detection, automatic starting of a generator set and switching to generator power) can require a large number of relays and/or timing relays. A better solution may be to use a PLC (Programmable Logic Controller) for this purpose.

PLCs are general-purpose devices that come with a set of inputs and a set of contacts (how many of each are determined by the model purchased). Given a standard ladder diagram (one method of diagramming relay control circuits frequently used by electrical engineers), a program is burned into the PLC such that it mimics exactly the function of the circuit diagrammed. Sensors, etc. are connected to the PLC's inputs and the PLC's contacts give the output of the circuit. A large amount of complex wiring and a fair number of relays can be replaced by a single PLC. Several of today's private cars are successfully using PLCs to implement various and sundry control functions.

There are only a couple of caveats that I can think of associated with using PLCs. One is that you must make sure to use PLCs that are rated for the temperature extremes which a railway car can face. It wouldn't be too swell to arrive in Chicago when it's 20 below and find that the PLC that starts your diesel is suffering brain damage. The other is that I like electromechanical devices because you can observe them in operation, visually. As a matter of fact, you can even push a relay shut with a pencil to convince a balky circuit to come to life.

Sensors

Control systems require input from the various pieces of equipment on the car as well as other measuring devices (e.g. thermostats) so that they can determine the current state of affairs and act upon it. There are a number of sensing devices that you'll often encounter, including: thermostats and temperature senders; pressure switches and senders; airflow switches; revolution counters or tachometers; microswitches; and voltage and current measuring devices. Here is a quick review of where you might expect to find them.

Thermostats control the temperature of air and water in heating and cooling systems. The air conditioning system will have a thermostat to turn on the compressor when the air in the car becomes too hot whereas the heating system will have a thermostat to turn on the heat when the air becomes too cool. A high temperature limit thermostat (located in the plenum just downstream of the heating element) may also be provided to guard against fires. Water heaters have thermostats in them to control the temperature of the heated water.

The types of thermostats that you'll encounter usually have a bimetallic strip which bends, opening and closing contacts as the temperature changes (e.g. water heater snap-disc thermostats are like this) or a sensing tube (either a coil or a remote capillary), connected to a bellows, which contains fluid (often alcohol) that expands/contracts with the changes in temperature (room thermostats are like this).

Railroad specific room thermostats (e.g. Vapor [see Figure 7]) contain a mercury filled thermometer (like the one you put in your mouth) that has a pair of contacts in the mercury column at a single set point (e.g. 80 degrees F). As the mercury rises, the contacts are bridged. Set point adjustments are made by applying current to a bias heater wrapped around the thermometer. It's a clever (and non-obvious) scheme and it is very reliable as well as impervious to vibration. And, speaking of impervious to vibration, the newer room thermostats that employ a thermistor and solid-state circuitry are very good at ignoring vibration so you may wish to replace older thermostats with this type.

Temperature senders are used anywhere that it is desirable to make a continuous temperature measurement. If you have a generator set, the engine is usually instrumented with water and oil temperature senders that send a signal to the water/oil temperature gauges and/or engine over-temp monitor.

Pressure switches measure the pressure of various liquids and gases. They almost universally consist of a sealed diaphragm, one side of which is connected through a tube to the pressurized area to be measured, the other side of which operates a spring loaded switch which is activated/deactivated when the pressure overcomes the spring. Pressure switches are used to control air compressors and air conditioning compressors and to guard against low oil pressure in compressors and engines.

Pressure senders consist of some kind of sensing element (such as a pizzo electric crystal) that generates an analog signal as the pressure varies. The most likely place for them to be used is in a generator set's engine monitoring package where a pressure sender transmits an oil pressure signal to the control panel gauges and/or the engine safety system.

Airflow switches can be used as safety interlocks to ensure that a fan is blowing air before a heating element or air conditioning compressor is turned on (to prevent fires or coil icing, respectively). Two types are available: sail switches; and differential pressure switches. Sail switches consist of a metal sail that pivots and trips a microswitch when flowing air impinges on it. Unfortunately, these switches are susceptible to vibration. The differential pressure switch is preferred on railway equipment because it's sensing technique (it senses the difference in pressure between two measurement points, hence its name) renders it immune to vibration.

Revolution counters or tachometers can be of the optical type (an optical sensor detects a contrasting mark passing by on the spinning object) or proximity type(a magnetic proximity sensor detects a magnetic target attached to the spinning object). Of the two, the magnetic proximity type is oblivious to the dirt and grime found on railway equipment and so may be more useful. Tachometers are frequently added to generator set engines to indicate engine RPMs (e.g. for control of automatic starting).

Microswitches are small, low activation-pressure switches that can be added to any mechanical device to provide positive position indication. As I said, very little pressure on the actuator is required to activate the switch and different models are available that have small, medium and relatively large amounts of actuator travel. Also, models with plungers, levers and rollers (to name a few) are available to act as limit switches, open door/panel detectors and cam followers. Microswitches are likely to be found in door engines, door light circuits, damper position indicators and many other places.

Voltage and current measuring devices usually occur in the form of voltmeters and ammeters on railway equipment. These meters are provided as information-only devices to be used by operators to diagnose problems, etc. Voltmeters are direct measurement devices — they are simply connected to the circuit whose voltage is to be measured. Current meters or ammeters require a series connection with the load that they are measuring or, for high current AC loads (e.g. an entire car), a current transformer.

A current transformer is a toroidal coil wound around an iron core that is shaped like a doughnut. To measure the current flowing through a wire (e.g. the main feed to the car), the wire is run through the center of the current transformer (the doughnut can be slipped over the wire and secured in place with wire ties at a convenient spot). The output of the current transformer is then connected to a 5X ammeter (5X ammeters are specifically meant to be used with current transformers) which will read the current flowing in the wire.

You'll note that, because the current transformer works by measuring the current induced in it by the wire passing through it, it can only be used to measure AC. For high current DC, a **large** shunt is required.

It is fairly common for one ammeter to be installed on a car's control panel and a switch to be used to select which phase (A, B or C) it will measure. This scheme requires three current transformers and a SP3T selector switch (one side of each of the three transformers is tied together — the other three transformer leads are fed to the selector switch). If the three current transformers are placed on the three main feed wires to the car, the car's entire current usage can be measured.

Frequency meters are another display device that are often found on railway equipment, especially considering that one generates power on board. It is important that frequency regulation be maintained so that motors will operate at the correct speed. The use of a frequency meter will allow you to observe how accurately your generator's governor is working.

Control Panels

It is often convenient to group all of the car's controls together in one place. By locating the air conditioning, heating, power generation and selection, air compressor and other controls together in one spot, it is possible to easily observe and control all aspects of a car's state. This is the function of the control panel: to lay out all of the status displays and controls in a logical, easy to use manner (in today's terminology, the user interface).

By putting some thought into how the controls will be used and what information they need to convey, one can arrive at a control panel that is easy to use. Here are some rules of thumb.

Try to group logically related functions together. Locating the controls for air conditioning next to controls for heating allows you to focus your attention on an area of the control panel that controls all related functions (i.e. climate control). Outline grouped controls with a box, if you wish.

Use lines to indicate flow. Arrange controls that work in sequence from left to right (we're used to reading this way). As an example, I built a control panel that showed the three sources of power supplying the car entering from the left. As the eye moves right along a line, it comes to an availability indicator, a phase rotation indicator and then a selector switch. The three sources converge like the tines of a fork on the source selector switch. Emanating figuratively from the right of that switch is the power to the car. From there it continues to the voltage, current and frequency meters. Thus, by sweeping your eyes from left to right, you can take in the status of the three sources of power, determine which is selected and then see what the car is using.

Pilot lights are a cheap indicator of the status of the various devices on the car. They give an on/off status indication which is sufficient for most devices. You should use as many of them as you see fit but especially use pilot lights for all of the equipment that is hung under the car (it is difficult to jump out and run alongside of the car to see if something is working when your going 70). Connect the pilot light to the power feed for the device so that you will always know when it is getting power (alternately, connect it to a set of auxiliary contacts on the motor starter or contactor so that it will indicate that the device at least should be getting power).

Use color and position to convey information. Pick pilot light colors based on their importance (e.g. green means OK, yellow indicates a warning such as second stage heat/cool and red means trouble such as engine overtemp). Position (higher up implies higher importance) of switches, their color and the direction that they point can be chosen to aid in directing the hand to make the right choice, especially in crisis situations (e.g. make sure that the generator set emergency stop button is obvious because, when the flame is shooting out of the alternator, you’ll want to press that button in a hurry without thinking twice).

Incidentally, while we’re on the subject of controls, I’ll just mention a couple of my favorites. For pilot lights, I like a solid-state model (IDI 6091M1-24V) that comes with a nice panel-mount bezel and looks really sharp — available in red, green and yellow. They should last about 50 years. For switches, I like Square D's line of Glove Knob (can be operated by a railroad employee wearing gloves) rotary selectors (Class 9001, Type KS with Knob FB). For panel meters, I like Simpson's 2-1/2" analog meters (Models 1247/1257). I think that analog meters are often easier to read than digital meters and I especially like the ammeters and voltmeters (Parts #02626 and #10018). On the other hand, for frequency meters I prefer a digital meter such as the Datel (Model DMS-20PC-3-FM).

Generators

The fact that a railway car can roam about the nation's railroad system at will, in the consist of passenger or freight trains, necessitates self containment including the capability to generate one's own power. Not knowing where you'll be next or who's going to be pulling you means that you can hardly depend on a reliable source of power. Sure, you can count on Amtrak or your host railroad to supply you with trainline or wayside power **most** of the time but what about those occasions when they don't, for whatever reason? It always seems to be just when you're cooking breakfast or sitting down to eat dinner or when its a hundred and five in the shade.

Since having a generator set is a de facto requirement, all that remains is to select one and hook it up. Selection is up to you but keep in mind that you want reliability in a harsh environment. The location for the generator set is nearly always under the car where it is hot and dusty. Not the best of conditions for an air breathing heat engine. If you want ease of installation and reliability, a company like Stadco deserves your attention. They have lots of experience in the railcar powerplant business. Your local generator distributor may also be able to help you with a new or refurbished unit (something like a used, packaged power rental unit might work well). You'll probably have to do some engineering work to figure out how to hang the sucker, if you take this route.

When selecting a generator set, you'll need to know how much power it will be required to supply. Perhaps you're willing to shed some load when running on the generator but this usually isn't the case. Thus, you should size the alternator (the electricity generation portion of an AC generator set is technically called an alternator) to supply most or all of the car's load (Hint: think in the 40-50 kW range). Also, bear in mind that you want to be a little conservative and allow some room for derating of engine output due to variations in altitude and ambient temperature (e.g. you aren't going to get as much power from the engine in Denver when it's 95° F as you are in Boston when it's 60° F).

One other thing to consider is that alternators are frequently rated in kVA instead of kW. I guess that this is one way for the manufacturers to inflate the output of the alternator (like the way the stereo manufacturers inflate the output of their amplifiers). Of course, if you are supplying a load that has a unity power factor then kVA equals kW but this is hardly ever the case. What we're really interested in is kW so multiply by .8.

Most alternators are what's known as 12-lead reconnectable (three phase but then that goes without saying). What this implies is that the alternator has six windings and that all 12 leads are where you can get at them. By connecting the windings in different configurations, you can get outputs of 240V or 480V Delta as well as 240/416V Wye (which can be tweaked to the standard 277/480V by adjusting the voltage regulator). You should connect the windings as necessary to supply your car's system voltage and wire them up to the generator set circuit breaker and contactor.

AC alternators need a supply of DC (called excitation current) to generate a magnetic field in the rotor. It is this rotating magnetic field that induces AC in the stator. In the old days, a small DC generator was attached to the main shaft and the rotor was supplied with DC from it through slip rings. With the advent of modern, solid-state diodes (that don't mind being whirled around at 1800 rpm) somebody got the bright idea to build an exciter winding as part of the alternator's rotor and rectify the AC induced in it with solid-state diodes (also mounted on the rotor). The resulting DC could be fed directly to the rotor to excite it with no need for slip rings or brushes. One less thing to wear out and compromise reliability on the appropriately named brushless alternator — just what we want on a railway car.

A key feature that you may want to include on your generator set is a heater. A heater is a good idea for any generator set that sits idle for extended periods of time in damp environments. Sound familiar? Essentially, the heater is a low-wattage heating element built in to the stator winding. It is energized whenever the generator set is not running to keep the windings dry and prevent short circuits upon startup.

Generator set controls are broken into three categories. The first, voltage regulation, is an alternator control. The next two, speed control and engine protection, are engine controls. Between the three, you get total control.

Voltage regulation is usually accomplished by a simple, solid-state control. It works by varying the excitation current supplied to the rotor. Recall that the excitation current, in a brushless alternator, is generated in a separate exciter winding mounted on the rotor. The field for the exciter is part of the stator and it is this field's strength that the voltage regulator controls. Increasing it causes more current to be induced in the exciter winding which raises the excitation current in the rotor which increases the strength of the rotating field of the rotor which increases the induced current in the stator and hence the voltage in the stator. Decreasing the exciter's field has the reverse effect.

Pretty simple except for one thing. You can't get there from here. Where does the voltage regulator get the power to run the exciter field windings? Well, it sucks a small amount of the generated power away from the load, rectifies it and applies it to the field. But, here's the problem. How do you do this when there's no power there in first place? Fortunately, the answer is simple. There's enough residual magnetism left in the field pieces to induce enough excitation current to get things rolling — except when there isn't. Usually, the residual magnetism will last for months before it fades away. But, if it does, it must be restored by a process known as flashing (see your alternator users manual for information on how to do this).

The easiest way to afford this problem altogether is to just fire up the generator set every couple of months and make some electricity. This will also get the oil flowing around in the engine and make sure that the injectors (if they are mechanical) don't get stuck. If you run the engine long enough to get hot, you'll also dry it out and you'll know that when you need it, it's going to start and run. All around, it's a good idea.

Although an engine control, the speed control is important from an electrical point of view because the engine speed determines the frequency of the power generated. If the engine doesn't turn at exactly the right speed (probably 1800 rpm), the power generated will not be 60 cycle and all sorts of problems will arise.

Engine speed control is accomplished through the use of a governor. There are two kinds: mechanical; and electrical. The governor maintains engine speed by adjusting the position of the engine fuel rack. This admits more or less fuel as the load on the engine varies, thereby keeping the speed constant.

Mechanical governors use the pressure of a spring to effect control of engine speed. A set of fly-balls are spun by a shaft from the engine. As the speed increases, the centrifugal force acting on the balls tends to make them fly outwards. The spring pressure counteracts this force. When the speed is correct, the spring pressure and ball forces cancel each other out and the fuel rack is held in a constant position. Changes in speed up or down result in appropriate fuel rack changes. Mechanical governors are cheap but their regulation is only mediocre albeit adequate.

Electrical governors measure the actual frequency of the generated power and translate this directly into fuel rack changes, usually through the use of a solenoid. They respond rapidly to load fluctuations and give good regulation. Unfortunately, they aren't cheap.

Engine protection is up to you but will typically include low oil pressure and engine over temperature protection. Sensors for these measurements can feed gauges on the main control panel, so that you can observe engine performance from inside the car, as well as the automatic engine protection package. Detection of measurements outside of an acceptable range, by the protection package, should result in the generator set being automatically shut down.

Control of the generator set can be manual (start/stop push buttons and a manual power selector) or it may be achieved through a complete management package that encompasses automatic starting and stopping incorporated with engine protection to guard against mishaps. For full flexibility, both modes of operation should be available with the choice of which one to use made by a selector switch.

Many generator sets designed for standby power use come with these packages. They monitor for the presence of line power. When it goes away, after a few seconds delay to eliminate spurious starts, the generator set is started. When the power being generated is clean, the load is switched to the generator set. Upon resumption of the line power, the load is switched back after a few seconds delay to ensure that the line power is clean. The generator remains running for a short time, in case the line power drops again and then it is shut down.

It is not necessary to purchase a transfer switch with the management package as the car's main contactors will be used to implement power switching. The management package will, however, need to produce a signal that can be used to switch the contactors.

Other inputs and outputs to look for are power availability detection, engine oil temperature and pressure, water temperature and a tachometer input (for the detection of overcrank [cranking of the engine for too long without starting]). An output that drives the engine shut down solenoid allows the package to kill the engine when required and an output that drives the starter motor allows it to be cranked for starting.

DC Power Supplies

Some of the devices found on a railway car will require low voltage, DC power. One place where this is sure to be the case is the heating controls, if you reuse the existing controls (and there's no reason not to) as mentioned in the section on "Heating". There are many other uses for low-voltage DC so it's a good bet that you'll have one or two DC power supplies to contend with.

The function of a DC power supply is essentially to replace a battery. In an ideal world, its output would look like that of a battery. This is not an ideal world but it is possible to come pretty close to the goal. Your DC power supply will be fed by relatively high-voltage AC so the steps taken in conversion of this power to low-voltage DC are: voltage step down; rectification (conversion from AC to DC): filtration (adjust the rectified DC to be pure like a battery's output); and regulation.

Beginning with the first step of conversion, there are two approaches that are used. One is called linear and the other is called switching. The linear approach is simple in that it uses a big transformer — lots of copper and iron. The switching approach (switchers are found in all of today's personal computers) uses high-voltage switching transistors to generate a high frequency (25-50 kHz) waveform from the line voltage. This high frequency AC is then stepped down with a transformer but the transformer that is employed can be very small and light. Complexity is traded for weight. The choice of which type of power supply to use is yours but I am a big fan of simplicity as well as iron and copper.

Rectification converts the AC power into DC. At the voltages we are concerned with, rectification is universally accomplished via solid-state diodes. Full-wave and half-wave rectification is possible with full-wave being the best (less residual AC waveform remains behind in the rectified DC with full-wave). Full-wave rectification uses four diodes in a configuration called a bridge. Bridge rectifiers are available in a single encapsulated package that contains all four diodes — AC in, DC out.

The output of a bridge rectifier is not pure DC. It contains some vestiges of the original AC waveform called ripple. For many applications, this DC is adequate but for the remainder, the ripple must be removed. This is the reason for filtration. Without getting too involved, filtration is achieved through the use of big capacitors and sometimes inductors (called chokes) which

control voltage and/or current. Low currents (up to 5A) can be supplied by an integrated voltage regulator. Above 5A, a pass transistor is employed.

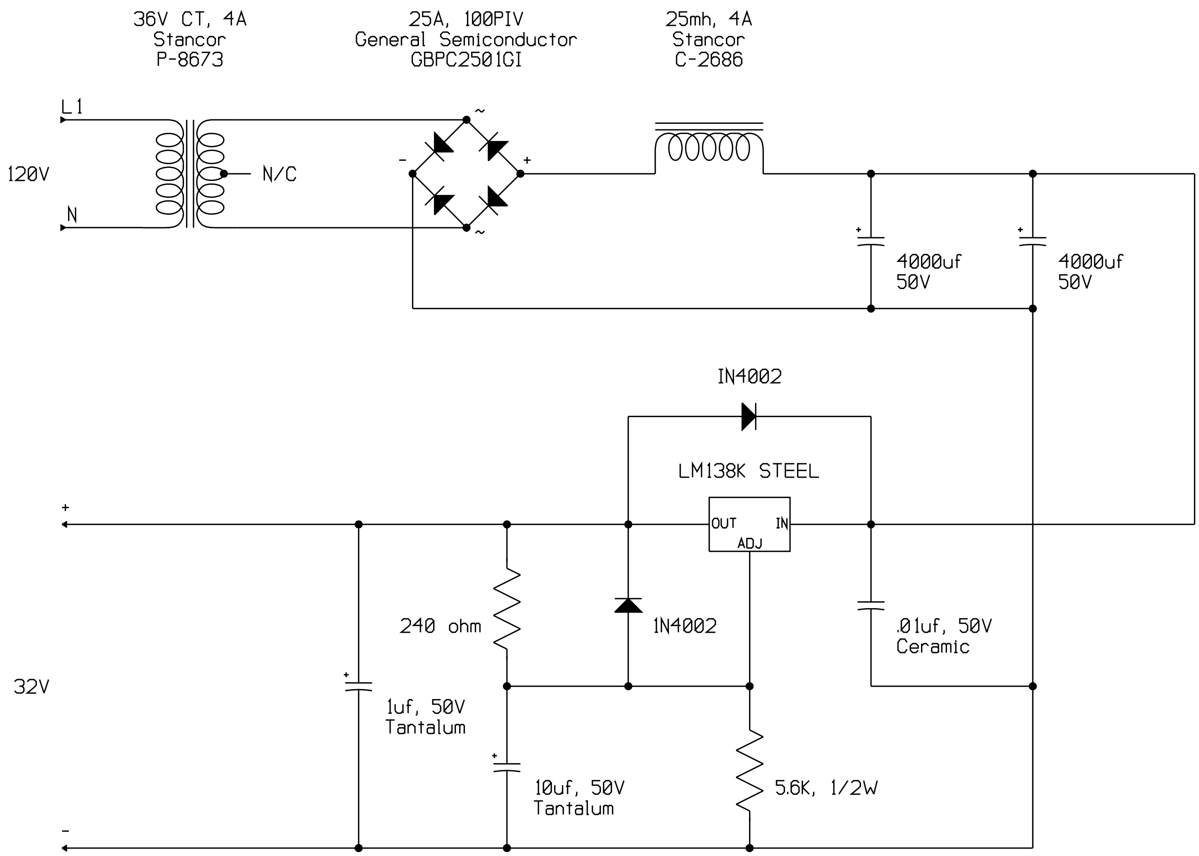

Figure 8: 32V, 4A DC Power Supply

resemble transformers but with only one winding. By adding enough filtration, you can get pretty pure DC out of your power supply.

The last step in the process is regulation. If the load on the power supply is constant, it can be designed to produce exactly the voltage desired without the need for regulation. However, the load is rarely constant so regulation is almost always mandatory. Regulation typically employs a voltage control (called a voltage regulator) and sometimes a heavy-duty current control (called a pass transistor) to

Voltage regulators use a constant voltage reference (settable on some regulators) and a variable current switch. They compare the voltage being supplied to the load with the reference voltage. If it drops below the reference, more current is switched into the load. This increases the voltage to the load. If the load voltage increases, less current is switched into the load which drops its voltage. Add a little hysteresis and, hey, Presto, you have a voltage regulator.

There are literally a ton of books available on power supply design. If you feel like building one yourself, you can scope out one of these books. Figure 8 shows a simple 32V, 4A DC power supply that I use to run all of the legacy thermostats on my car. This power supply puts out 128W (a good size) and the voltage (32V) is a bit higher than usually shown in most books so you may find that this circuit comes in handy.

Batteries

There is the need on railway equipment for a reliable, always present source of power to operate emergency systems (e.g. lighting and marker lights) as well as to bootstrap the power generation process (e.g. to start the generator set). This need is fulfilled by one or more sets of batteries.

Originally, railway cars were supplied with power entirely from a large set of batteries. These batteries were charged when the car was in motion or on standby power by an axle- or motor-driven generator. The batteries were usually nickel/iron and, because of the need to supply the entire car's power requirements, a full set could weigh many tons. Consequently the set of batteries was usually slung beneath the car in one or two battery boxes.

The requirements for batteries today are greatly reduced and can be met by a few hundred pounds of them at most. This being the case, the battery boxes can be emptied out, turned into storage bins and the required batteries placed in one corner of a single battery box.

Batteries have three ratings that you should pay attention to. The first is voltage (the voltage that a battery supplies varies between fully charged and discharged but is usually given as an average or near-charged value). Select a battery that supplies the voltage you need (typical voltages are 6V, 12V and 24V). Actually, batteries only generate between 1.2V and 2V per cell (depending on the type) so the number of cells varies depending on the total battery voltage. In the same manner as the way cells are connected in series within a battery, if you need a voltage other than those commonly available (e.g. 48V), two or more batteries may be connected in series.

The second rating is current. You can only draw current out of a battery so fast before you fry the sucker. So, you should pick a battery that will handle the largest load without buckling the plates or otherwise wrecking the battery. In general, bigger is better. If you can't find something big enough, hooking multiple batteries in parallel increases current.

The third battery rating to consider is ampere/hour rating. A battery will only put out so much juice and then it is discharged. You will need to calculate the expected current drain (see previous paragraph) in addition to how long the load will last (sometimes this is a given, as with Amtrak's two hour emergency lighting requirements). These two numbers are multiplied together to get the ampere/hour rating. As above, the bigger the battery, the better and, also as above, paralleling increases the rating.

Depending on the application (lighting or starting) the latter two ratings are somewhat more or less important. For starting, the amount of current that can be supplied is more important (especially when it's cold out). For lighting, the ampere/hour rating is more important, since the load is fairly constant but can be applied for a long period of time.

A fourth parameter is sometimes given for batteries meant for starting (e.g. automobile batteries). This parameter is called Cold Cranking Amps (CCA) and it is somewhat of a manufactured number. Basically, its goal is to specify how well the battery will crank an engine when it is butt-freezing cold out (the engine oil is very viscous and the battery is cold and feeling tired). Obviously, for starting batteries, the higher this number, the better.

The types of batteries available vary all over the map from the mundane (lead/acid) to the exotic (lithium-ion). Why, you can even get flat batteries made from plastic sheets nowadays! However, in an operation who's motto could best be summarized as, "Boring is best," we don't want to get too creative. Consequently, most railway car needs can best be filled by good, old lead/acid batteries. Never the winners of any beauty contests, they are nonetheless readily available and boringly reliable.

Lead/acid batteries come in two configurations: sealed; and vented. These configurations arise from the fact that hydrogen is generated by charging batteries (bear this in mind if you're still of those unfortunate souls whose life is being shortened by tobacco — don't smoke around batteries or it could be **really** shortened). Some means of releasing the hydrogen must be provided. In vented batteries, the cell caps have a hole. In non-vented batteries, it's done by a trick.

Although the kind of large batteries that can supply the ampere/hour ratings necessary in emergency lighting circuits typically come in ventilated form, you may wish to use non-ventilated ones even though they are harder to get. This will prevent the electrolyte from leaking out when the car flips over on its side in a wreak (what a horrible thought) and prevent the lights from going out just when they're most needed. At the very least, emergency lighting batteries should be securely bolted down to a solid part of the car in a cushioned, protected case. A location inside the car body (so that the batteries won't get ripped off of the underframe by a flying truck) and away from the crumple zone (i.e. the car ends) but in a well-ventilated area so that the explosive hydrogen can't build up would be ideal. Pretty tough list of criteria, huh? Well, do your best. Think disaster!

Batteries used for generator set starting and any other non-emergency lighting uses can certainly be of the ventilated type. They can also be located wherever is convenient (e.g. next to the engine of the generator set) to keep the heavy battery cable length short. After all, in a wreck, when the generator set batteries fly off, this will be the least of your worries.

Battery Chargers

Batteries are seldom, if ever, called upon to supply a constant source of power. Rather, they are meant to kick in at a moment's notice and supply power in a pinch for a short period of time.

Before batteries can be asked to supply power, they must first be charged. Since the batteries must always be ready and can be asked to supply power anytime, they should be constantly charged. The best way to ensure this is to keep them constantly connected to the charger. When this is done, the charger can supply a small charge (called a trickle charge) to keep the batteries constantly topped up (a battery will lose a tiny bit of its charge every hour that it just sits idle due to internal discharge paths). Charging a battery in this manner is called float charging.

After a battery is called upon to supply power, it becomes discharged. To replenish the charge, the charger must supply a heavy charging current called a fast charge. Then, once the battery becomes fully charged, it must automatically switch back to trickle charging. This, strangely enough, is called an automatic charger.

Design of automatic battery chargers is not all that easy. Detecting when the battery reaches its full charge, so that the switch to trickle charging can be made, depends on the type of battery. Some may even require temperature sensors or a special circuit for measuring internal resistance. In any case, be sure to tell the charger manufacturer what type of batteries the charger will be connected to so that they can ensure that it will properly charge them (destruction of the batteries due to improper charging is a very real possibility).

Finally, you must decide whether the charger will remain connected to the batteries while they supply the load. If not, it can be disconnected by a relay. If so, it must be able to cope with high current drain, switching spikes, etc. Let the manufacturer know this fact when you order your battery charger. One manufacturer that produces chargers able to cope with out of the ordinary demands such as remaining connected to the load is Interacter.

The batteries used for generator set starting can be charged by an engine driven alternator, much as an automobile battery is charged. However, the generator set is probably run only infrequently (an automobile, on the other hand, unless it is up on blocks in the front yard, is usually run regularly) so the battery may become discharged in between. I prefer to continuously charge the starting battery via a line-connected charger to avoid this eventuality. This way, it is charging the battery whenever there's power of any kind, including from the generator set, supplied to the car.

Emergency Lighting

We discussed, in the previous section, the types of batteries to use for emergency lighting and mentioned emergency lighting wiring practices in the wiring section. Now, let's talk for a bit about implementing the emergency lighting circuits.

You should put emergency lights in regular fixtures or special fixtures wherever they are necessary and use the wattages necessary to ensure adequate illumination during emergency situations. This means that enough light should be provided to remove an emergency window and crawl out of it when it is pitch black and the car is flipped on its side. Think about it!

The emergency lighting lamps are wired together into one or more circuits and routed to the secure location where the batteries are to be mounted. At this point, all of the circuits, if there are more than one, are connected together into one big circuit and fed through a contactor of adequate current carrying capacity. This contactor should have a coil that is rated for the lighting system voltage. Its normally closed contacts are used to connect the lighting circuits to the battery. Incidentally, don't locate the contactor too close the batteries or contact arcing may result in a hydrogen explosion. The contactor coil is permanently connected to the source of lighting power (through a circuit breaker, of course) so that, when the power is on, the contactor is energized and the emergency lighting circuit is de-energized. When the power fails, the contactor will open which will close the normally open contacts and the lights will come on.

You may wish to add a switch of sufficient current rating, in series with the lighting circuit, so that it can be shut off to avoid draining the batteries when the car is in the yard. On the other hand, this negates the idiot-proof simplicity of the circuit and may mean that somebody forgets to turn the emergency lights on before the car is placed in service. If you add this switch, be sure that you have an iron-clad procedure in place that guarantees that a potentially fatal mistake cannot be made.

Before we move on to the next topic, I'll mention one trick that is used on some equipment to skip the separate emergency lighting circuit and lamps altogether. Instead of having regular and emergency lights, all fixtures employ 120V incandescent bulbs only. The emergency lighting batteries are set at a voltage that is close to this value (e.g. 64V or 72V). Then, when the power fails, the battery voltage is simply applied to all of the regular lighting circuits. Even at reduced voltage, enough light is produced to meet the emergency lighting requirements.

Standby Power

Railway equipment was originally provided with standby power or wayside power by a cable and plug (made by Pyle National). The power that was usually available was 240V three phase Delta at 100A. When traveling on Amtrak nowadays, the standby power is simply provided by plugging a standby power cable into the 480V trainline receptacle. All locations where passenger equipment is likely to be parked on the Amtrak system have these standby power cables provided. Consequently, the need for the traditional 240V standby power receptacle may be obviated. On the other hand, there may be plenty of places still around (my car's home siding for example) where the older form of standby power is provided and, because of this, you may still want to implement this kind of standby power connection.

The older standby power arrangement usually consists of two receptacles, one on each side of the car, so that plugging it in is convenient. The receptacles are located as near to the middle of the car as possible for the same reason.

The two receptacles have their power pins wired together with #1 wire which feeds the standby breaker in the electrical locker. It is a good idea to include in this circuit (before the breaker is OK) a 100A, two pole knife switch that is wired to reverse two phases. This phase reversal switch, which may be located near the receptacles, allows you to reverse the phase rotation that the car sees and, along with a phase failure relay, ensures that your car will always be able to use the standby power that is supplied, whatever it finds.

You will note that the standby receptacle has two contacts in it that are of a lower current carrying capacity (i.e. they are much smaller) and which are jumped by a shorting pin when the standby plug is fully inserted. These contacts should be connected in series with the time delay relay that controls the standby power contactor. The reason for these contacts is to prevent arcing when the plug is inserted or withdrawn under power. The time delay is important because it prevents the standby contactor from bouncing open and closed under power (the resulting arcing shortens the contact life considerably) which is exactly what would happen if these pins were wired directly in series with the contactor's coil. Dirt and/or the insertion angle of the connector can cause the path through the shorted pins to be made and broken repeatedly when the plug is inserted or withdrawn under power.

"When does removal of the plug under power happen," you ask?

"Why, when your favorite railroad moves your car without unplugging it first."

The Trainline

The trainline required for operation on Amtrak consists of two parts: the head end power portion; and the communications and MU control portion. The power conductors of the head end power portion are run the length of the car, exposed except in the vicinity of the trucks, in rubber cleats using heavy, XLPE insulated wire. The trainline complete conductors of the head end power portion and the conductors of the communications and MU control portion are run in separate conduit.

The power portion of the trainline consists of twelve pieces of 4/0 wire, four wires in parallel for each phase. These wires run from the four 480V receptacles and connectors at each end of the car to the center of the car where they are joined at the 480V junction box. The wires are supported at regular intervals by rubber cleats which can support six wires. Two cleats are ganged up to carry twelve wires.

In the vicinity of the trucks, the wires pass through two single 10' lengths of 3" conduit, six wires through each piece or through four single 10' lengths of 2" conduit, three wires through each piece. Typical routing for the power wiring is shown in Figure 9. Be sure that when you route the wires through the conduit you keep them together in three phase groups (e.g. for three inch conduit, route A1, A2, B1, B2, C1 and C2 through one piece and A3, A4, B3, B4, C3 and C4 through the other or for two inch conduit

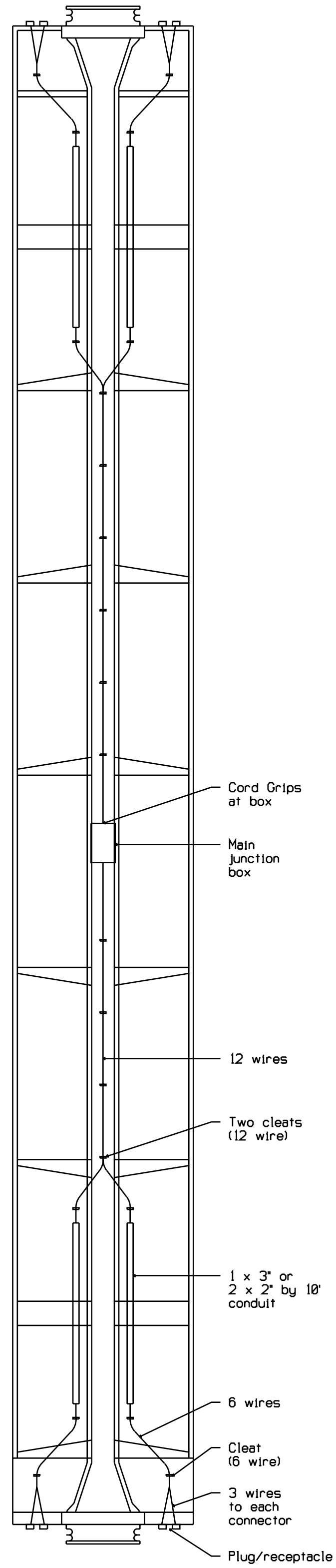

Figure 9: Typical Power Wiring Routing

route A1, B1 and C1 through one piece, A2, B2 and C2 through a second and so on). If you don't do this, the conduit will be heated by inductive heating (see "Practical Implications"). Also, keep the lengths of the wire exactly the same or the variations in their resistance will cause one wire to run hotter than the others.

It should be noted that the power wiring must be exposed or in other words not enclosed in any conduit except over the truck. This is absolutely necessary for it to dissipate heat and maintain its full current rating. This is not to say that you shouldn't try to keep it out of harm's way. The installation on the wire used (Exane) is robust but it still can get nicked by flying rocks. Other than these rules, you can pretty much route the wire wherever it is convenient to do so.

You should follow all of the trainline wiring procedures outlined in the Amtrak HEP book. This book describes the construction of the main junction box, the use of cord grips, connectors and sockets, how to install the 480V and control trainline wiring and gives schematics and other drawings showing much useful information.

After you have installed the power wiring, you will need to tap into it in order to power the car. This is done by running a piece of 1-1/2" conduit from the electrical locker to the main trainline junction box. Three pieces of 1/0 Exane wire are run from the junction box to the trainline circuit breaker. You may prefer to keep his feed short and locate the circuit breaker close to the junction box, say in a raintight box under the car or you may prefer to locate it inside the car (e.g. in the electrical locker) where you can get at it if it trips while the car is moving. Most of the people that I've talked to say that their breaker has never, ever tripped so the point appears to be moot.

After the power leaves the circuit breaker, Amtrak purports not to care too much about what you do (provided you are not wiring up 480V devices) so you can follow sound, albeit standard wiring practices. As mentioned earlier, the NEC contains a wealth of practical, time-honored advice.

The wiring for the trainline complete circuits and the MU and communications circuits must be kept separate. All of this wiring leaves connectors at the end of the car, enters a junction box and then is routed to the other end of the car through conduit. The reason that it must be kept separate, especially the MU circuit, is so that a short in the wiring cannot cause a potentially serious problem (imagine that a short between the MU and the trainline complete wiring, if they were run together, were to apply the emergency brakes on a fast moving train).

One way that the wiring is kept separate is to run it in three separate pieces of conduit. You'll need to run a piece of 1", 1-1/4" and 1-1/2" conduit from one end of the car to the other. In these three conduits you will run the trainline complete circuits, MU control circuits and communications circuits, respectively. These three pieces of conduit fit pretty nicely into the center sill area where the original steam line went. Some short bits of Unistrut can be bolted in place and the conduit clipped to them. Follow the route of the steam line around the trucks and down to the coupler area.

Another way that the wiring is kept separate is to use two junction boxes at either end of the conduit. One box has the trainline complete wiring leading from the 480V receptacles and feeding into it. The 1" conduit runs into this box. The other box has the wiring leading from the communications and MU receptacles and feeding into it. The 1-1/4" and 1-1/2" conduits run into this box. The boxes themselves contain terminal blocks that are used to splice the wires from the connectors with the wires going down the conduit.

The communications and MU receptacles are frequently mounted on a sheet metal wiring trough that is fastened somewhere on or about the car's end sheet (see Amtrak drawing "C-05-7171" for exact placement). The trough is roughly 4"-6" deep by 8" wide and roughly 16"-18" long (two connectors) to 24"-26" long (three connectors). It has a removable cover with cutouts for the connectors, thereby allowing them to be pre-wired, fastened to the cover plate and then bolted onto the trough. The trough continues to a point where a piece of 2" conduit can lead conveniently from its back or bottom to the junction box (snaking this conduit around the cut lever and brake chain can certainly be fun).

Installing the connectors involves attaching a suitable length of wire (called a pigtail) to each pin and making all of the wires from each connector up into a bundle. The two bundles are fed through the appropriate holes in the cover plate, through the trough and down the conduit. Once the connectors are screwed to the cover plate and the cover plate is screwed into place, the pigtails are spliced at the junction box terminals to the wires leading to the other end of the car.

Amtrak allows and even encourages you to tap into the communication line. This is most easily done by running a piece of 1" conduit from the electrical locker to the junction box nearest it. Then, a set of wires feeding the communications equipment is run from the junction box to the electrical locker to tap into the PA1/PA2 (Tape Music 1), PA3/PA4 (Intercom), PA7/PA8 (Tape Music 2) and RA1/RA2 (Radio) channels. A circuit showing how to connect to an amplifier and a switching arrangement that can be used to listen in on the communications channels is shown in Amtrak’s“HEP Conversion For Conventional Cars Manual”.

The Power Budget

When a new private car is first made ready to run on Amtrak, part of the requirements for its initial inspection, prior to its acceptance onto the Amtrak system, is a document that describes all of the electrical loads imposed by the car on the 480V trainline. I call this the power budget because I work it out like an accountant would work out a budget.

The power budget can be shown as a tree diagram, otherwise known as a single line schematic (Amtrak's preferred method), that begins at the trainline (root) and proceeds through the various distribution points to all of the ultimate load points (leaves). Beginning at the leaves, the power consumption of each device is noted. Then, working backward, as the branches join together, the sum of all of the sub-currents is calculated for the joined branch and so on back to the root. When you’re done, you get something that looks like Figure 10.

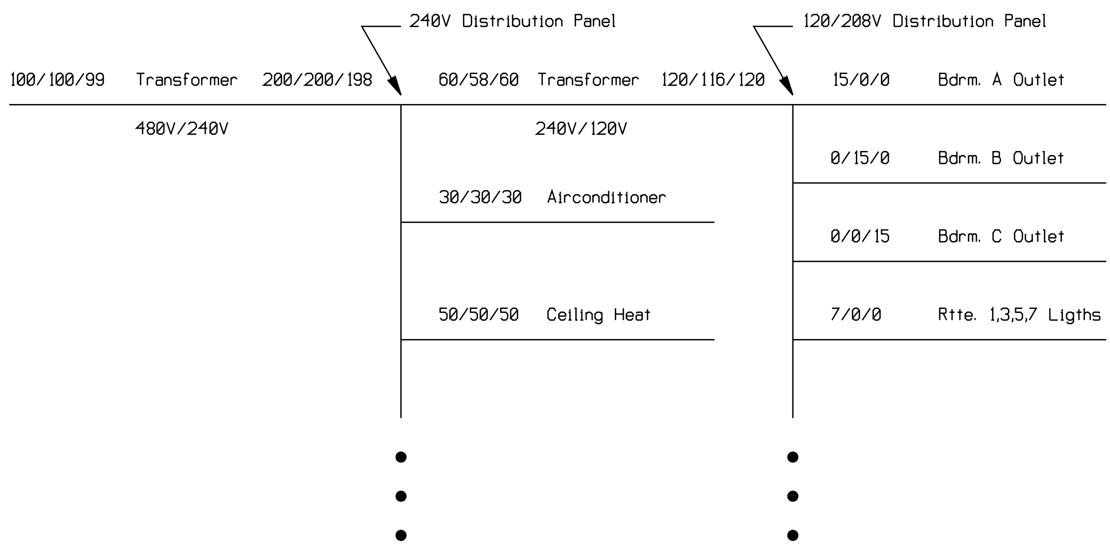

Figure 10: Power Budget Tree Diagram

When the car inspector sees the car, they will use this tree diagram to locate and turn on all of the loads. Then, they will measure the current consumed on each of the three phases of the trainline to determine whether those shown in the tree diagram are accurate. If they aren't, you could be in trouble.

As I alluded to earlier, the reason for doing the power budget is balance. Amtrak wants the load applied to their trainline to balance. This lets them generate the minimum amount of power (unbalanced loads use power based on the highest single phase load, not the average of the three) and save diesel fuel. It also reduces the overall size of the wire used in the trainline. Both of these goals are very desirable and so Amtrak imposes the requirement that the loads on each of the three phases, as measured at the trainline with all of the lights burning, so to speak, must be within 5% of one another.

To ensure that your car's loads meet this requirement, the car inspector measures them, as noted above, and verifies the power budget's accuracy. Meanwhile, the electrical engineer who reviews the power budget checks that the three loads are within 5% of each other.

I find that maintaining the tree diagram required by Amtrak is tedious during the construction phase. Rather than do this, I set up a spreadsheet that looks like the one shown in Chart 2. Then, as I work, I can add, subtract and move things around to balance the load. The spreadsheet instantaneously calculates the three phase load, which is the total of all of the individual loads, and I can easily see what needs to be done to achieve balance. I use one spreadsheet for the 240V or 480V power budget and one for the 120/208V power budget. When I am completely done with construction, then I draw the tree diagram as shown in Figure 10.

Incidentally, although I just work out the three phase loads that result from any single phase loads manually (e.g. Chart 2, CB45/CB49/CB411), using the methods described in "Load Calculation", you could build the arithmetic into your spreadsheet so that it would calculate these loads automatically. You'll

Breaker	Size	Description	A	B	C
CB41	60A	120/208V Main disconnect	28.6	30.6	24.9
CB43	50A	Carrier 06DA818 AC Compressor @ 10.8 KW 26/26/26 2 x 1/2 HP Fan Motors @ 2A 4/4/4	No Increment (less than ceiling heat)		
CB47	20A	Air Compressor @ 3 HP	9.4	9.4	9.4
CB45	15A	Air-conditioning Blowers: 1 HP @ 8.5A 1/4 HP @ 2.5A 11 A/B	42	34.7	55
CB49	40A	Kitchen Stove: 3 KW Oven @ 12.6A 2 x 1.5 KW Elements @ 6.25A 2.5 KW Lg Element @ 10.4A 35.4 A/C			
CB411	30A	Washer/Dryer: 4.6 KW Heating Element @ 19.2A 1/3 HP Motor @ 3.6A 1/2 HP Motor @ 4.9A 27.7 B/C			
CB42	30A	Freeze Protection: 9 KW Circ Heater 21.7/21.7/21.7 1/2 HP Motor 1.9/1.9/1.9	23.6	23.6	23.6
CB44	30A	4 x 750 W Roomette Heaters 4 x 500 W Roomette Heaters 3 x 1 KW Hallway Heaters 2 x 500 W Kickspace	22.4	23.4	21.9
CB46	30A	2 x 1.3 KW Bedroom Heaters 2 x 1 KW Bedroom Heaters 4 x 1 KW Section Heaters 500 W Bathroom Heater	24.6	26.1	16.5
CB48	60A	Ceiling Heater 18.9 KW	45.6	45.6	45.6
CB410	30A	Water Heater 9 KW	21.7	21.7	21.7
			217.9	215.1	218.6

Chart 2: Sample Power Budget Spreadsheet

need to use the built in trigonometric functions and get the formulas from a **real** book on three phase power.

Sources of Supply

Throughout this article, I've mentioned various components and manufacturers names. These have been by way of example and because these are the suppliers and supplies that I use. I know that they work. However, this doesn't mean that they are the only ones that you can or should use.

The electrical business is a huge business and there are a number of major players in it, all of whom make excellent, top-quality equipment. In North America, these major players included General Electric, Westinghouse, Square D and Siemens. All of them make complete lines of distribution equipment, contactors, controls and even motors.

In addition to the really big guys noted above, there are a large number of manufacturers of support equipment such as Appleton, Allen-Bradley, Burndy, Leviton and T&B, just to name a few. They all produce extensive lines of wiring devices, conduit components, contactors and controls.

Than, there are literally thousands of smaller companies that produce useful equipment which can be used on railway cars. Although too numerous to mention, they supply practically everything else (except for a few specialized railway components) that you'll ever need. I've mentioned the names of some that I've found especially useful in Appendix A.

The best way to get all of the equipment that you need is from a local electrical distributor. Pick one or two that are moderate to large in size (these larger establishments tend to handle industrial equipment, while the smaller ones are mostly concerned with residential equipment only) and make friends with the salesmen and counter guys (this isn't always easy, since surliness is often a prerequisite for working at one of these places). When you tell them what you're doing and make it known to them how much dough you'll be leaving behind in their cash register, they'll warm up to you. These guys are your best bet for catalogs, brochures and free information and advice. You can even get much of what you need from places like Grainger or Johnstone Supply. Come to think of it, this might be a bonus when it comes time to replace something in the field, since these guys are located everywhere.

Specialty items, such as railway connectors, can be purchased directly from the manufacturer. Other items, such as meters, pilot lights, controls and small transformers can be gotten from electronics distributors. One national chain is Allied Electronics. Another is Digi-key.

Conclusion

While not the simplest of subjects that you could tackle, railroad electrical systems can be mastered. I hope that this monograph has shed some light (pun intended) on the subject and that it will prove of some use to those involved with these systems. With the right kind of knowledge, we can all understand and better appreciate these systems which are all too often looked upon as voodoo magic.

Appendix A – Contact Information

Advance Transformer Co.: Fluorescent light ballasts - O'Hare Int'l Center, 10275 West Higgins Road, Rosemont, IL, 60018, (800)322-2086, www.advancetransformer.com/default.asp

Allen Bradley (subsidiary of Rockwell International Corporation): IEC line contactors - ab.com/power/mcs

Allied Electronics: Electronics supplies - 7410 Pebble Drive, Fort Worth, TX, 76118, (800)433-5700, www.allied.avenet.com

AMP: Connectors and wire crimpers - (800)722-1111, (800)522-6752, www.amp.com/tooling

Anderson Power Products: Railroad plugs and connectors - 13 Pratts Junction Road, Box 579, Sterling, MA, 01564, (978)422-0010, www.andersonpower.com

Appleton Electric Company: Boxes, conduit bodies and conduit connectors - 7770 North Frontage Road., Skokie, IL, 60077, (847)679-7800, www.appletonelec.com

WH Brady Co.: Wire markers - Box 571, Milwaukee, WI, 53201-0571, (800)541-1686, www.whbrady.com

Burndy (subsidiary of Framatome Connectors International): Split bolts, connectors and wiring supplies - Framatome Connectors USA, 101 East Industrial Park Drive, Manchester, NH, 03108, (603)647-5000, www.fciconnect.com

Carol Cable Company, Inc.: Wire, including heavy cable - 249 Roosevelt Avenue, Pawtucket, RI, 02860, (401)728-7000

Carroll Appliance Service: Replacement parts for electric heating products, appliances and equipment - 3225 Roanoke Road, Kansas City, MO 64111-3722, (800)654-3545, www.carrollparts.com/car3.html

Chromalox: Pipe tracing and strip heaters - Wiegand Industrial Div., Emerson Electric Co., 701 Alpha Dr., Pittsburgh, PA, 15238, (800)443-2640, www.chromaloxheating.com/default.htm

Clements Nationall: Railroad plugs and connectors - 6650 S. Naragansett Avenue, Chicago, IL, 60638, (800)966-0016, www.cadillacproducts.com/trainline

Cole Wire and Cable Co., Inc.: AAR and diesel engine wire - Box 1500, Lincolnshire, IL, 60069-1500, (888)394-1311, www.colewire.thomasregister.com/olc /colewire/producta.htm

Datel, Inc.: Panel meters - 11 Cabot Boulevard, Mansfield, MA, 02048-1151, (800)233-2765, www.datel.com

Digi-Key Corporation: Electronics supplies - 701 Brooks Ave. South, Thief River Falls, MN, 56701-0677, (800)344-4539, www.digi-key.com

Diversified Electronics, Inc.: Phase failure relays - Box 490207, Leesburg, FL, 34749-0207, (800)874-0619, dei-in.com/index.htm

Electro Wire, Inc.: Exane wire - 100 Jytek Dr., Leominster, MA, 01453-5917, (800)224-0912, www.thomasregional.com/ene/electrowire /index.html

W W Grainger: Everything you could possibly want (well, maybe not) - In every city. Find one near you by searching: www.grainger.com

Greenlee Textron, Inc.: All kinds of electrical tools - 4455 Boeing Dr., Rockford, IL, 61109, (800)435-0786, www.greenlee.textron.com/greenlee

Halstead Industries, Inc.: Pipe insulation (used with tracing) - 300 North Greene Street, Suite 1700, Greensboro, NC, 27401, (336)272-1966, www.halstead.com

Hoffman: Electrical enclosures - 900 Ehlen Drive, Anoka, MN, 55303, (612)421-2240 www.hoffmanonline.com

Honeywell: Micro switches, temperature controls and thermostats - (800)537-6945, www.honeywell.com/sensing

ICM Corporation: Time delay relays, phase failure relays and HVAC controls - Box 2819, Syracuse, NY, 13220, (800)365-5525, www.icmcontrols.com

Ideal Industries: Tools including crimpers and wire pulling lubricant - Becker Place, Sycamore, IL, 60178, (800)435-0705, www.idealindustries.com

Interacter: Battery chargers - 290 Pratt Street, Meriden, CT, 06450, (203)630-0199

Johnstone Supply: Appliance parts and heating/cooling supplies - In every city. Find one near you by searching: www.johnstonesupply.com

Leviton Manufacturing Co: Wiring devices - 59-25 Little Neck Parkway, Little Neck, NY, 11362-2591, (800)824-3005, www.leviton.com

Lima Electric Company (subsidiary of Marathon Electric Mfg. Corp.): Generator set alternators - Box 918, Lima, OH, 45802, (715) 675-3311

Marathon Electric Mfg. Corp.: Motors and generator set alternators - 100 East Randolph Street, Box 8003, Wausau, WI, 54401-8003, (715)675-3311, www.marathonelectric.com

National Fire Protection Association: The National Electrical Code - 1 Batterymarch Park, Quincy, MA, 02269, (800)344-3555, catalog.nfpa.org

Omron: Relays and timing relays - Omron Management Center of America, Inc., 1375 East Woodfield Road, Suite

520,Schaumburg, Illinois, 60173, (847)240-5330 www.omron.com

Osram Sylvania: Automotive, minature and sealed beam lamps (e.g. emergency lighting, marker lights); large lamps (e.g. incandescents, fluorescents) - 100 Endicott Street, Danvers, MA, 01923, (978)777-1900, www.sylvania.com

Paladin: Wire crimpers - www.paladin-tools.com/index1.htm

Panduit: Wiring supplies - 17301 S. Ridgeland Ave., Tinley Park,IL, 60477-3091, (888)506-5400, www.panduit.com

Potter & Brumfield (subsidiary of Siemens): Relays and timing relays - www.sec.siemens.com

Power Parts Company: Railroad plugs, connectors, wire and 480V HEP kits - 1325 Pratt Boulevard, Elk Grove Village, IL, 60007-5711, (847)952-8900, www.motivepower.com/power.html

Pyle National: Railroad plugs and connectors - 25325 Joy Boulevard, Mt. Clemens, MI, 48046-2336, (800)511-2414, www.sineco.com

Qmark (subsidiary of Marley Electric Heating): Electric baseboard heaters - 470 Beauty Spot Road East, Bennettsville, SC, 29512, www.marleymeh.com

Raychem Corp.: Pipe tracing - 300 Constitution Drive, Menlo Park, CA, 94025-1164, (800)542-8936, www.raychem.com

Ridge Tool Co.: Plumbing tools - 400 Clark Street, Elyria, OH, 44036, (888)743-4333, www.ridgid.com

Rubatex: Pipe insulation (used with tracing) - 5223 ValleyPark Drive, Roanoke, VA, 24019, (800)782-2839, www.rubatex.thomasregister.com/olc /rubatex/home.htm

Simpson Electric: Panel meters - 853 Dundee Ave., Elgin, IL, 60120, (847)697-2260, www.simpsonelectric.com

Stadco (Stauffer Diesel, Inc.): Generator sets (AAPRCO Trade member) - 46 Pleasant Valley Road, Ephrata, PA, 17522, (717)738-2500

Stancor (subsidiary of White Rogers): Transformers and relays - 131 Godfrey Street, Logansport, IN, 46947

Thomas & Betts: Connectors and wiring devices - 8155 T&B Boulevard, Memphis, TN, 38125, (901)252-8000, www.tnb.com

Time Mark: Time delay relays and phase failure relays - 11440 East Pine Street, Tulsa, OK, 74116, (800)862-2875, www.time-mark.com/main.html

Vulcan Electric Company: Strip heaters, cartridge heaters and thermostats - 100 Mountain View Extension, Kezar Falls, ME, 04047, (800)922-3027, www.vulcanelectric.thomasregister.com/olc /vulcanelectric

Waytek, Inc.: Wiring supplies and wire - Box 690, Chanhassen, MN, 55317-0690, (800)328-2724, www.bioweb.net/prosp/waytek