Wiring American Flyer Sectional Track

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1. Introduction

There are many options for routing wire between a transformer and American Flyer sectional track. This document evaluates the impact of wire gauge (AWG) number of connections, and routing of wires to a notional loop consisting of 40 sections of American Flyer sectional track: 12 curve and 28 straight. Seven different cases are examined for six different gauges of wire and 3 different values of track resistance.

In comparing the options, the following metrics were considered:

1. The difference between the highest and lowest resistance of points on the track as measured from the transformer terminal. This difference reflects the variability in speed the engine will experience as it completes a revolution of the track. Experiments conducted on my layout (using a 12B transformer) indicate a difference of 0.5 ohms is barely noticeable at low speeds, but not at high speeds. Allocating half of this resistance difference to each of the two conductors / rails, desirable performance is for each conductor / rail to have a resistance difference of no more than 0.25 ohms. Marginal performance is attributed to a resistance difference of between 0.25 ohms and 0.5 ohms. Undesirable performance is attributed to a resistance difference greater than 0.5 ohms.
2. The average resistance from the sample points to the transformer terminal is not an issue unless it becomes so large that the train engine cannot achieve a reasonable speed when the transformer is at its maximum setting. Subjectively, I determined that the average resistance for each conductor / rail would have to exceed about 0.75 ohms with my 12B transformer before becoming excessive. This only occurs for Case 1, hence average resistance was not used as a discriminator.
3. While cost is always of concern, none of the cases used more than 100 ft, and the cost difference between 100 feet of the smallest (22 AWG) and largest (12 AWG) wire is only on the order of $8 if speaker wire is used. See Table 1 for details.

Table 1: Cost of Cable (as of March 29, 2020)

AWG	length	single conductor stranded	Source	Speaker Wire	Source	ROMEX house wiring	Source
22 AWG	100 ft	$9.95	Jameco	$10.95	Audiopipe - Amazon		
20 AWG	100 ft	$12.95	Jameco	$11.95	Audiopipe - Amazon		
18 AWG	100 ft	$18.95	Jameco	$12.95	Audiopipe - Amazon		
16AWG	100 ft	$20.95	Jameco	$14.95	Audiopipe - Amazon		
14AWG	100 ft			$16.89	Audiopipe - Amazon	$31.57	Home Depot
12AWG	100 ft			$18.95	Audiopipe - Amazon	$48.57	Home Depot

Three different values of track resistance are used because one of the critical factors for track resistance is the degree that the track connectors make good electrical contact. I connected together ten pieces of American Flyer section track without making any special effort to establish a good electrical connection. The resistance of one rail was 0.75 ohms while the other was 1.61 ohms. Based on these measurements, I selected three values of track resistance per section to use in this analysis: 0.025 ohms, 0.075 ohms, and 0.15 ohms. The lower value (0.025 ohms) reflects a value that should be attainable with careful attention to establishing a good electrical connection. The middle value (0.075 ohms) reflects a value attainable with a reasonable effort to establish a good electrical connection, or that value that may happen as the electrical conductivity degrades over time. The higher value (0.15 ohms) reflects a value where little attention has been paid to establishing good electrical conductivity, or where the electrical conductivity has degraded over time.

A desirable configuration achieves the desirable resistance difference for the middle value of track resistance. A highly desirable configuration achieves the desirable resistance difference for the higher value of track resistance.

The resistance per foot of copper wire is listed in Table 2. The source for this data is ASTM B8 and is applicable for 20˚ C (68˚ F) which is a reasonable room temperature for a train layout.

Table 2: Resistance (ohms) per foot of stranded copper wire

12 AWG	14 AWG	16AWG	18AWG	20AWG	22AWG
0.00163	0.00258	0.0041	0.00654	0.0103	0.0164

The voltage drop experienced by an engine will be equal to its current draw (amps) multiplied by twice the resistance of a single rail / wire from the point on the track back to the transformer. The American Flyer Service Manual indicates for steam engines, the maximum current draw at 12 volts a.c. can range from 1.75 to 2.3 amps when pulling 4 box cars. For diesels, the maximum current draw can range from 1.8 to 3.25 amps. For post war American Flyer steam engines, the maximum currents I measured on my collection of engines are between 1.6 and 2.5 amps when pulling 8 freight cars (6 gondolas, 1 box car, 1 TOFC). For a dual motor ALCO, I measured a maximum of 2.5 amps. An American Models Baldwin diesel with a can motor had a maximum current draw of 0.6 amps.

Based on the above, one can probably plan on a maximum current of about 2.5 amps. With a maximum track resistance difference of 0.25 ohms for desirable operation, this translates into a maximum voltage variation of 2 x 0.25 x 2.5 = 1.25 volts.

2. Cases

Figures 1 through 7 depict the seven cases and the resistances for three wire gauges and the three track resistances as calculated at points that are near the local maximum and minimum resistance values. The "Delta R" table provides the differences between the maximum and minimum resistances. Combinations of wire gauge and track resistance that resulted in a desirable "Delta R" of 0.25 ohms or less are highlighted in green. Marginal performance is highlighted in yellow, and Undesirable performance is highlighted in orange.

The data for all six wire gauges are presented in Appendix A.

For cases 1 through 6, the track oval was broken into 8 groups of 5 sections of track. The boundaries between groups are nodes labeled: 10, 12, 20, 23, 30, 34, 40, and 41. The transformer terminal is assigned node 0. Each group of tracks was modeled as a resistor with a label beginning with "RT_" and ending with the labels of the two nodes at its end. In case 7, two of the groups are broken into two subgroups with node 60 midway between nodes 10 and 12, and node 61 midway between nodes 12 and 23. In this case, RT_1060 and RT_6012 replace RT_1012, while RT_1261 and RT_6120 replace RT_1220. The resistances of each track group (including low, medium, and high values) are presented in Table 3.

Table 3: Track group resistance

	sections	Resistance (ohms)		
		L	M	H
RT_1012	5	0.125	0.375	0.75
RT_1220	5	0.125	0.375	0.75
RT_2023	5	0.125	0.375	0.75
RT_2330	5	0.125	0.375	0.75
RT_3034	5	0.125	0.375	0.75
RT_3440	5	0.125	0.375	0.75
RT_4041	5	0.125	0.375	0.75
RT_4110	5	0.125	0.375	0.75
RT_1060	2.5	0.0625	0.1875	0.375
RT_6012	2.5	0.0625	0.1875	0.375
RT_1261	2.5	0.0625	0.1875	0.375
RT_6120	2.5	0.0625	0.1875	0.375

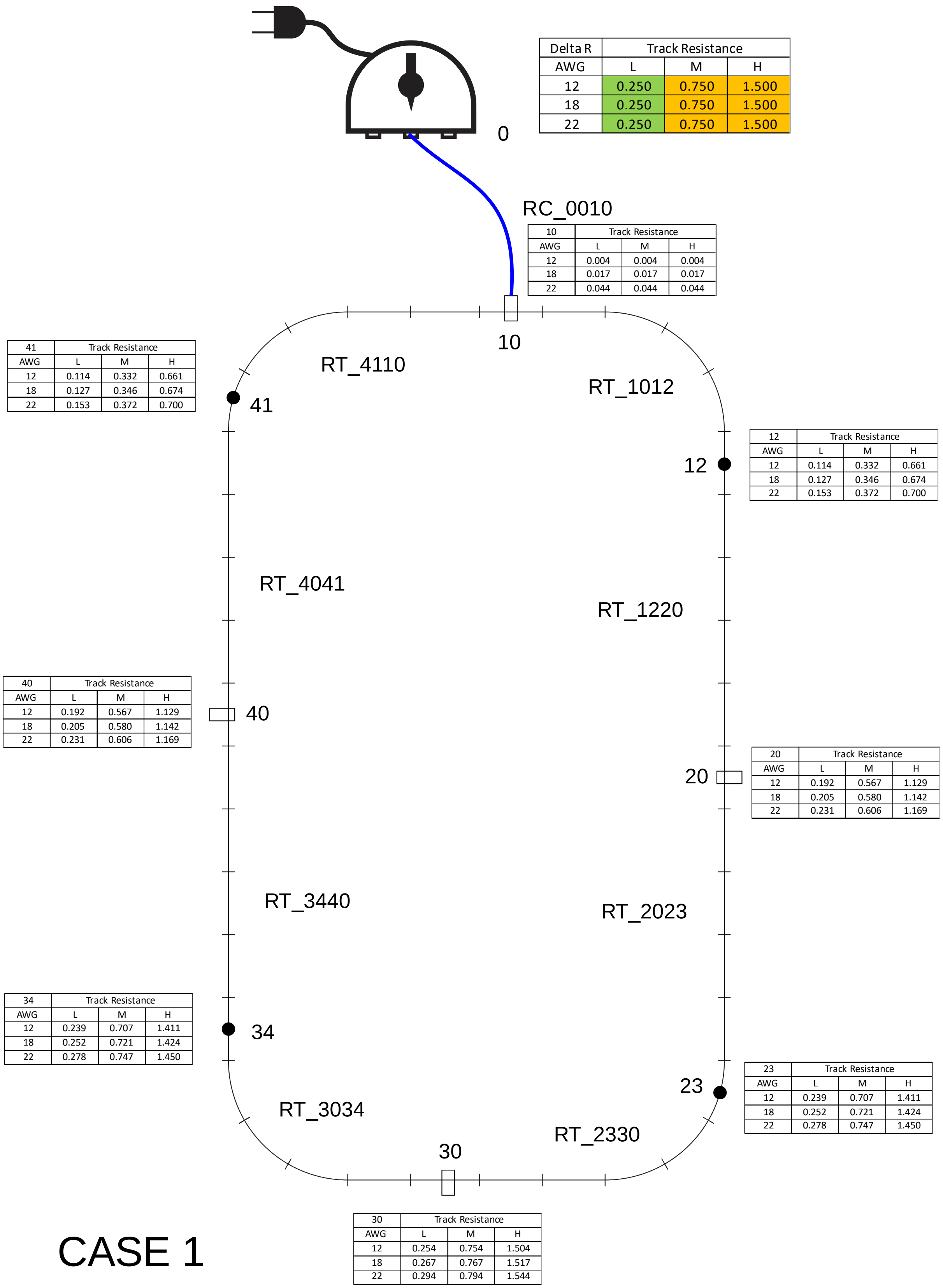
Copper wires are labeled with "RC_" followed by the labels of the nodes they connect. Cases 6 and 7 have an additional node 50 used to connect wires together, but not associated with a track group. Details on all of the wires defined in all seven cases are provided in Table 4. All the wires are not used in any one case. Table 5 indicates which wires (cables) are used in each case and the total length of cable required.

Table 4: Resistance of copper wires (ohms)

Wire	length (in)	12 AWG	14 AWG	16AWG	18AWG	20AWG	22AWG
RC_0010	32	0.0043	0.0069	0.0109	0.0174	0.0275	0.0437
RC_1030	154	0.0209	0.0331	0.0526	0.0839	0.1322	0.2105
RC_1020	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_2030	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_3040	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_4010	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_0020	134	0.0182	0.0288	0.0458	0.0730	0.1150	0.1831
RC_0030	180	0.0245	0.0387	0.0615	0.0981	0.1545	0.2460
RC_0040	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_0050	110	0.0149	0.0237	0.0376	0.0600	0.0944	0.1503
RC_1050	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_2050	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_3050	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_4050	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_1250	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_2350	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_3450	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093
RC_4150	80	0.0109	0.0172	0.0273	0.0436	0.0687	0.1093

Table 5: Cable lengths and association with cases

	Cable (inches)						
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
RC_0010	32	32	32	32	32		
RC_1030		154					
RC_1020			110	110			
RC_2030			110	110			
RC_3040			110	110			
RC_4010				110			
RC_0020					134		
RC_0030					180		
RC_0040					110		
RC_0050						110	110
RC_1050						80	80
RC_2050						80	80
RC_3050						80	80
RC_4050						80	80
RC_1250							80
RC_2350							80
RC_3450							80
RC_4150							80
	Total Cable (inches)						
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
	32	186	362	472	456	430	750



Delta R	Track Resistance		
AWG	L	M	H
12	0.250	0.750	1.500
18	0.250	0.750	1.500
22	0.250	0.750	1.500

10	Track Resistance		
AWG	L	M	H
12	0.004	0.004	0.004
18	0.017	0.017	0.017
22	0.044	0.044	0.044

41	Track Resistance		
AWG	L	M	H
12	0.114	0.332	0.661
18	0.127	0.346	0.674
22	0.153	0.372	0.700

12	Track Resistance		
AWG	L	M	H
12	0.114	0.332	0.661
18	0.127	0.346	0.674
22	0.153	0.372	0.700

40	Track Resistance		
AWG	L	M	H
12	0.192	0.567	1.129
18	0.205	0.580	1.142
22	0.231	0.606	1.169

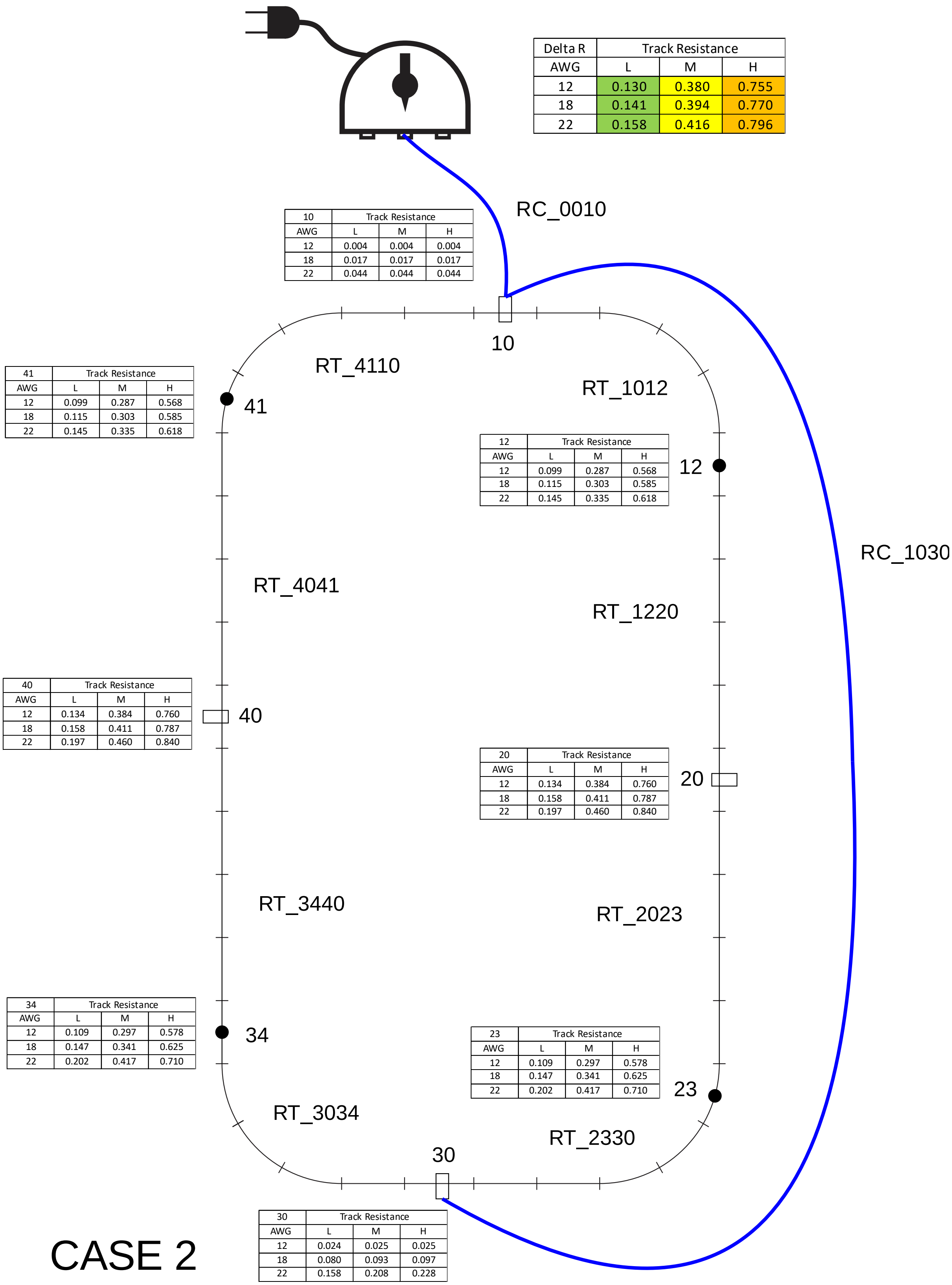
20	Track Resistance		
AWG	L	M	H
12	0.192	0.567	1.129
18	0.205	0.580	1.142
22	0.231	0.606	1.169

34	Track Resistance		
AWG	L	M	H
12	0.239	0.707	1.411
18	0.252	0.721	1.424
22	0.278	0.747	1.450

23	Track Resistance		
AWG	L	M	H
12	0.239	0.707	1.411
18	0.252	0.721	1.424
22	0.278	0.747	1.450

30	Track Resistance		
AWG	L	M	H
12	0.254	0.754	1.504
18	0.267	0.767	1.517
22	0.294	0.794	1.544

Figure 1: Case 1



Delta R	Track Resistance		
AWG	L	M	H
12	0.130	0.380	0.755
18	0.141	0.394	0.770
22	0.158	0.416	0.796

10	Track Resistance		
AWG	L	M	H
12	0.004	0.004	0.004
18	0.017	0.017	0.017
22	0.044	0.044	0.044

41	Track Resistance		
AWG	L	M	H
12	0.099	0.287	0.568
18	0.115	0.303	0.585
22	0.145	0.335	0.618

12	Track Resistance		
AWG	L	M	H
12	0.099	0.287	0.568
18	0.115	0.303	0.585
22	0.145	0.335	0.618

40	Track Resistance		
AWG	L	M	H
12	0.134	0.384	0.760
18	0.158	0.411	0.787
22	0.197	0.460	0.840

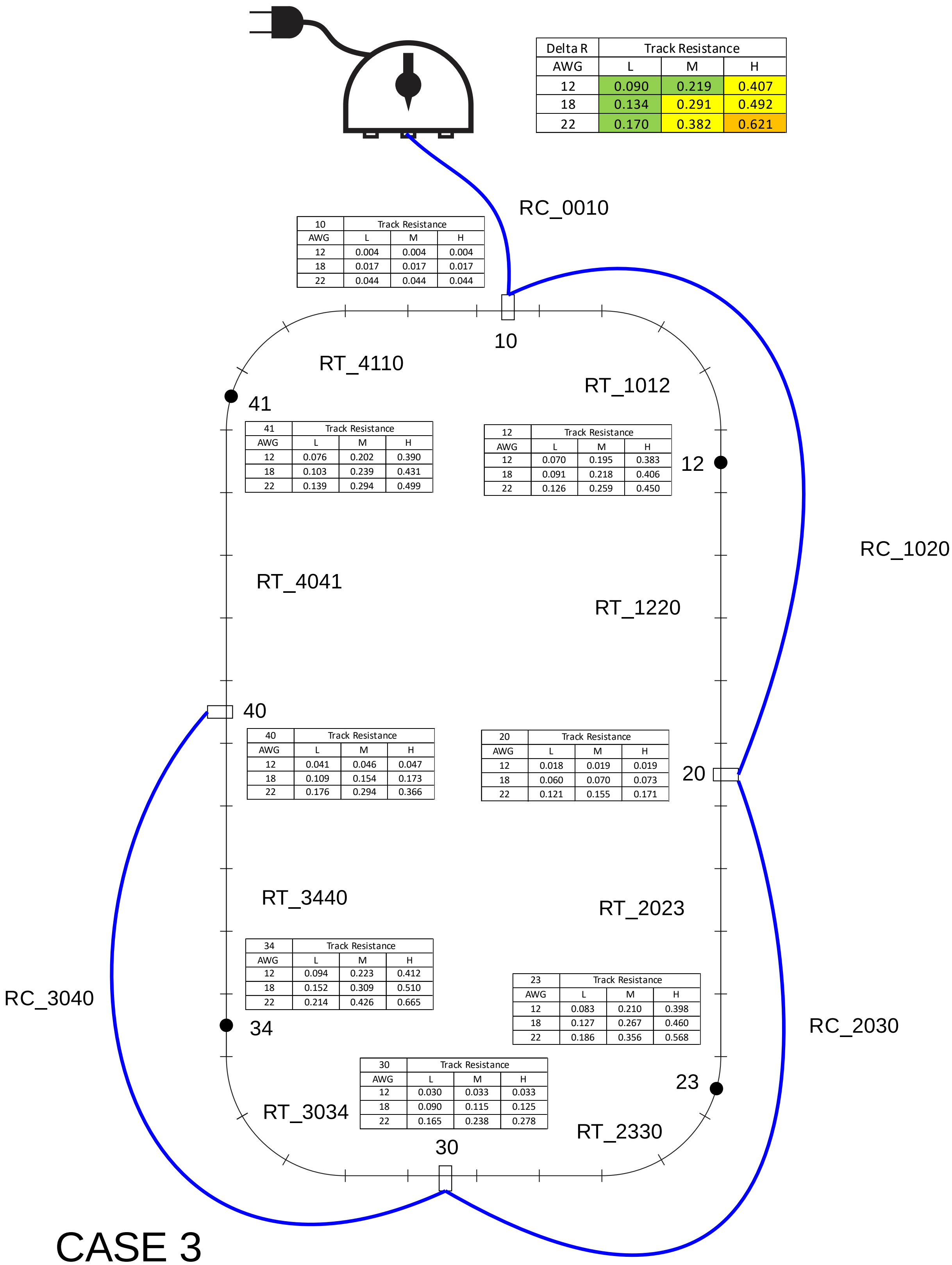
20	Track Resistance		
AWG	L	M	H
12	0.134	0.384	0.760
18	0.158	0.411	0.787
22	0.197	0.460	0.840

34	Track Resistance		
AWG	L	M	H
12	0.109	0.297	0.578
18	0.147	0.341	0.625
22	0.202	0.417	0.710

23	Track Resistance		
AWG	L	M	H
12	0.109	0.297	0.578
18	0.147	0.341	0.625
22	0.202	0.417	0.710

30	Track Resistance		
AWG	L	M	H
12	0.024	0.025	0.025
18	0.080	0.093	0.097
22	0.158	0.208	0.228

Figure 2: Case 2



Delta R	Track Resistance		
AWG	L	M	H
12	0.090	0.219	0.407
18	0.134	0.291	0.492
22	0.170	0.382	0.621

10	Track Resistance		
AWG	L	M	H
12	0.004	0.004	0.004
18	0.017	0.017	0.017
22	0.044	0.044	0.044

41	Track Resistance		
AWG	L	M	H
12	0.076	0.202	0.390
18	0.103	0.239	0.431
22	0.139	0.294	0.499

12	Track Resistance		
AWG	L	M	H
12	0.070	0.195	0.383
18	0.091	0.218	0.406
22	0.126	0.259	0.450

40	Track Resistance		
AWG	L	M	H
12	0.041	0.046	0.047
18	0.109	0.154	0.173
22	0.176	0.294	0.366

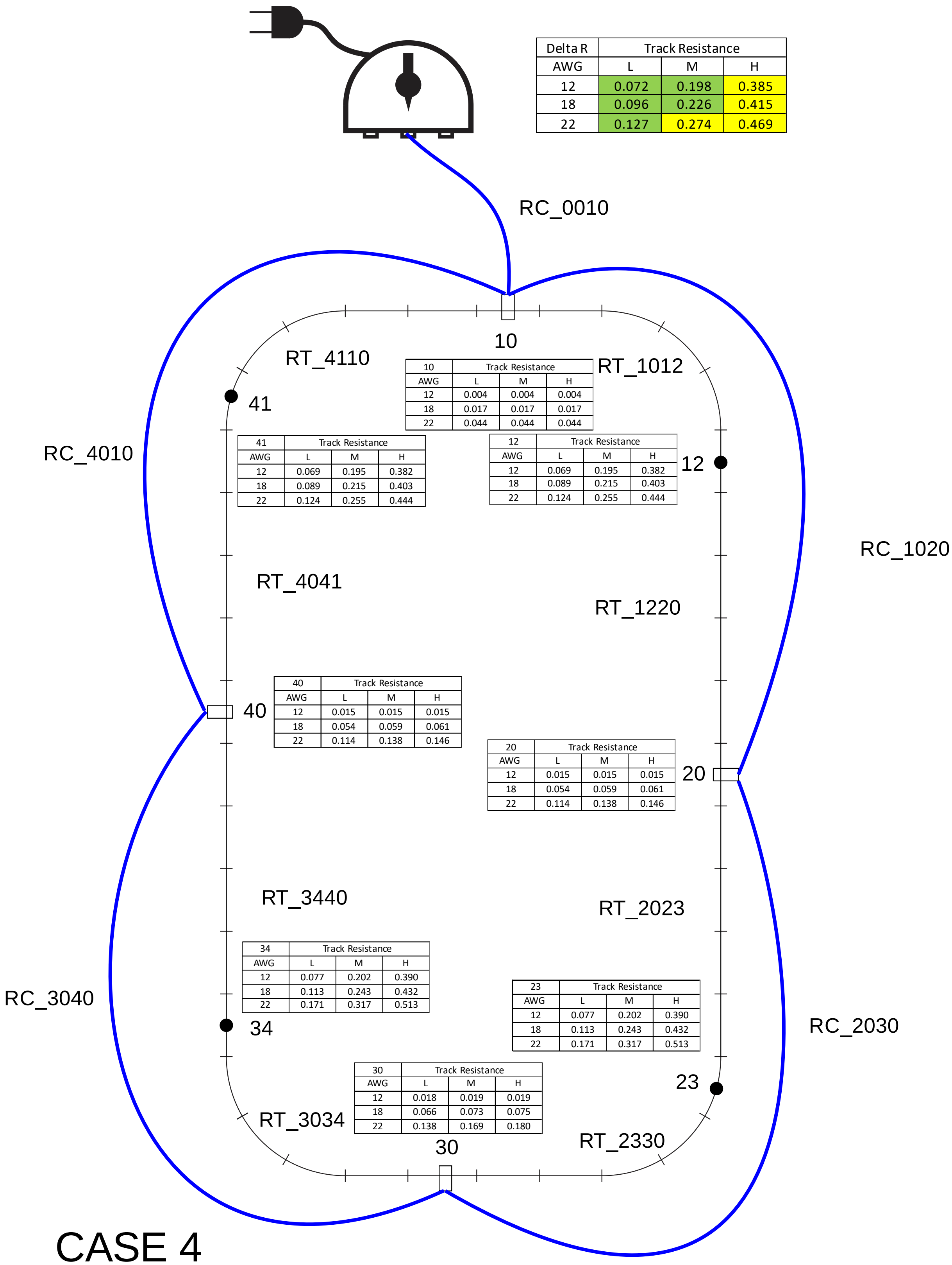
20	Track Resistance		
AWG	L	M	H
12	0.018	0.019	0.019
18	0.060	0.070	0.073
22	0.121	0.155	0.171

34	Track Resistance		
AWG	L	M	H
12	0.094	0.223	0.412
18	0.152	0.309	0.510
22	0.214	0.426	0.665

23	Track Resistance		
AWG	L	M	H
12	0.083	0.210	0.398
18	0.127	0.267	0.460
22	0.186	0.356	0.568

30	Track Resistance		
AWG	L	M	H
12	0.030	0.033	0.033
18	0.090	0.115	0.125
22	0.165	0.238	0.278

Figure 3: Case 3



Delta R	Track Resistance		
AWG	L	M	H
12	0.072	0.198	0.385
18	0.096	0.226	0.415
22	0.127	0.274	0.469

10	Track Resistance		
AWG	L	M	H
12	0.004	0.004	0.004
18	0.017	0.017	0.017
22	0.044	0.044	0.044

41	Track Resistance		
AWG	L	M	H
12	0.069	0.195	0.382
18	0.089	0.215	0.403
22	0.124	0.255	0.444

12	Track Resistance		
AWG	L	M	H
12	0.069	0.195	0.382
18	0.089	0.215	0.403
22	0.124	0.255	0.444

40	Track Resistance		
AWG	L	M	H
12	0.015	0.015	0.015
18	0.054	0.059	0.061
22	0.114	0.138	0.146

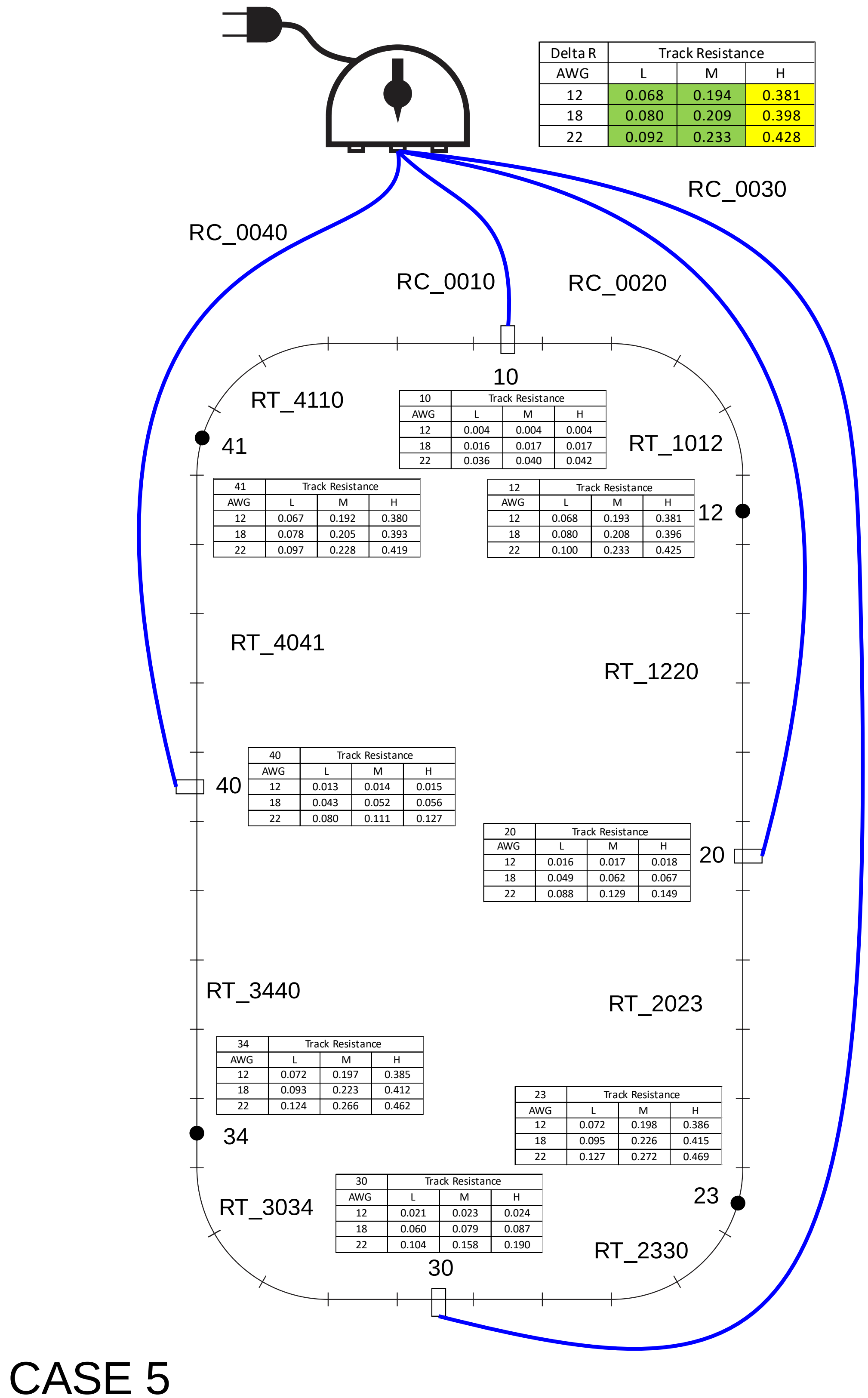
20	Track Resistance		
AWG	L	M	H
12	0.015	0.015	0.015
18	0.054	0.059	0.061
22	0.114	0.138	0.146

34	Track Resistance		
AWG	L	M	H
12	0.077	0.202	0.390
18	0.113	0.243	0.432
22	0.171	0.317	0.513

23	Track Resistance		
AWG	L	M	H
12	0.077	0.202	0.390
18	0.113	0.243	0.432
22	0.171	0.317	0.513

30	Track Resistance		
AWG	L	M	H
12	0.018	0.019	0.019
18	0.066	0.073	0.075
22	0.138	0.169	0.180

Figure 4: Case 4



Delta R	Track Resistance		
AWG	L	M	H
12	0.068	0.194	0.381
18	0.080	0.209	0.398
22	0.092	0.233	0.428

10	Track Resistance		
AWG	L	M	H
12	0.004	0.004	0.004
18	0.016	0.017	0.017
22	0.036	0.040	0.042

41	Track Resistance		
AWG	L	M	H
12	0.067	0.192	0.380
18	0.078	0.205	0.393
22	0.097	0.228	0.419

12	Track Resistance		
AWG	L	M	H
12	0.068	0.193	0.381
18	0.080	0.208	0.396
22	0.100	0.233	0.425

40	Track Resistance		
AWG	L	M	H
12	0.013	0.014	0.015
18	0.043	0.052	0.056
22	0.080	0.111	0.127

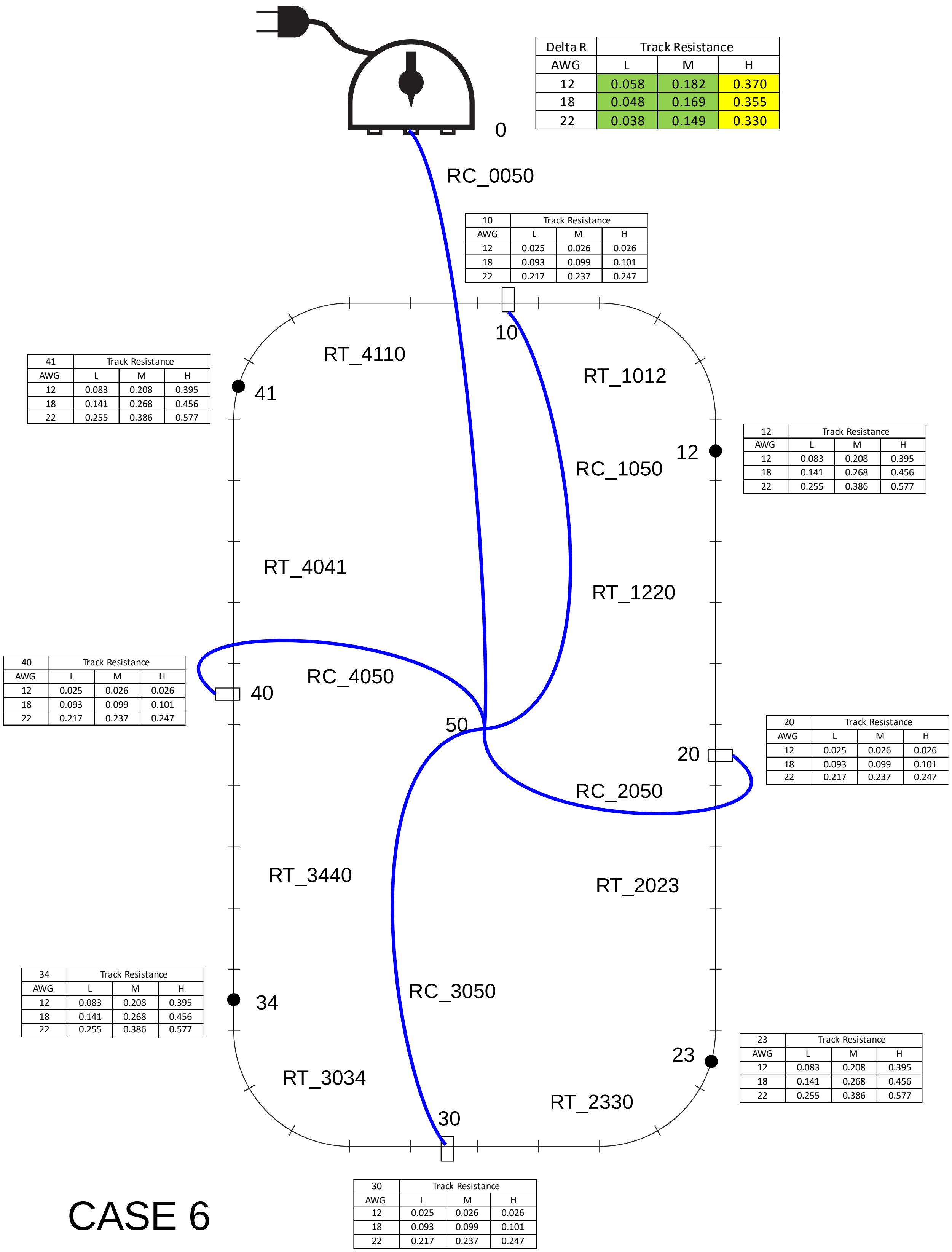
20	Track Resistance		
AWG	L	M	H
12	0.016	0.017	0.018
18	0.049	0.062	0.067
22	0.088	0.129	0.149

34	Track Resistance		
AWG	L	M	H
12	0.072	0.197	0.385
18	0.093	0.223	0.412
22	0.124	0.266	0.462

23	Track Resistance		
AWG	L	M	H
12	0.072	0.198	0.386
18	0.095	0.226	0.415
22	0.127	0.272	0.469

30	Track Resistance		
AWG	L	M	H
12	0.021	0.023	0.024
18	0.060	0.079	0.087
22	0.104	0.158	0.190

Figure 5: Case 5



Delta R	Track Resistance		
AWG	L	M	H
12	0.058	0.182	0.370
18	0.048	0.169	0.355
22	0.038	0.149	0.330

10	Track Resistance		
AWG	L	M	H
12	0.025	0.026	0.026
18	0.093	0.099	0.101
22	0.217	0.237	0.247

41	Track Resistance		
AWG	L	M	H
12	0.083	0.208	0.395
18	0.141	0.268	0.456
22	0.255	0.386	0.577

12	Track Resistance		
AWG	L	M	H
12	0.083	0.208	0.395
18	0.141	0.268	0.456
22	0.255	0.386	0.577

40	Track Resistance		
AWG	L	M	H
12	0.025	0.026	0.026
18	0.093	0.099	0.101
22	0.217	0.237	0.247

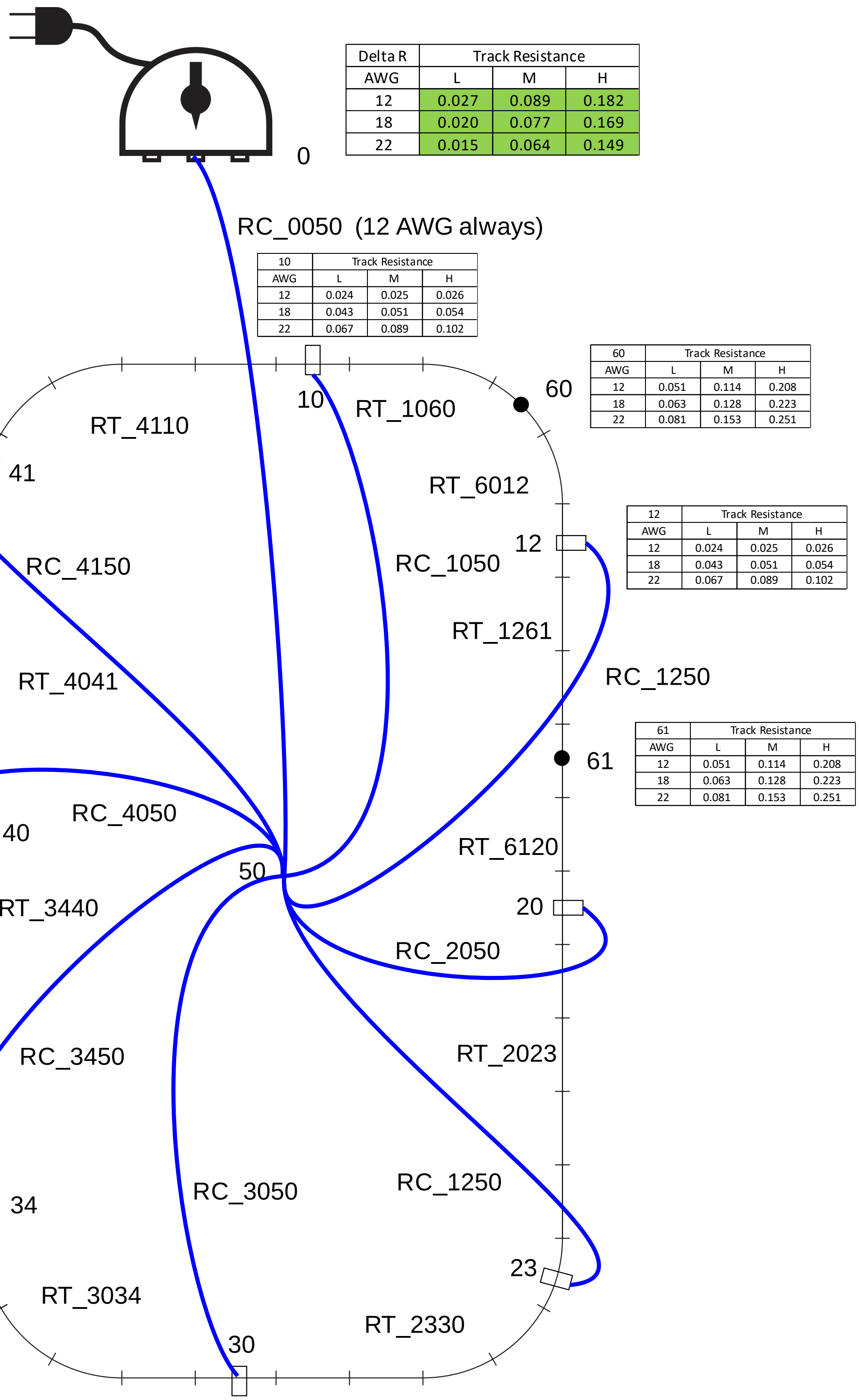
20	Track Resistance		
AWG	L	M	H
12	0.025	0.026	0.026
18	0.093	0.099	0.101
22	0.217	0.237	0.247

34	Track Resistance		
AWG	L	M	H
12	0.083	0.208	0.395
18	0.141	0.268	0.456
22	0.255	0.386	0.577

23	Track Resistance		
AWG	L	M	H
12	0.083	0.208	0.395
18	0.141	0.268	0.456
22	0.255	0.386	0.577

30	Track Resistance		
AWG	L	M	H
12	0.025	0.026	0.026
18	0.093	0.099	0.101
22	0.217	0.237	0.247

Figure 6: Case 6



Delta R	Track Resistance		
AWG	L	M	H
12	0.027	0.089	0.182
18	0.020	0.077	0.169
22	0.015	0.064	0.149

10	Track Resistance		
AWG	L	M	H
12	0.024	0.025	0.026
18	0.043	0.051	0.054
22	0.067	0.089	0.102

60	Track Resistance		
AWG	L	M	H
12	0.051	0.114	0.208
18	0.063	0.128	0.223
22	0.081	0.153	0.251

12	Track Resistance		
AWG	L	M	H
12	0.024	0.025	0.026
18	0.043	0.051	0.054
22	0.067	0.089	0.102

61	Track Resistance		
AWG	L	M	H
12	0.051	0.114	0.208
18	0.063	0.128	0.223
22	0.081	0.153	0.251

CASE 7

Figure 7: Case 7

3. Observations and Recommendations

In examining the "Delta R" tables for all seven cases it is apparent that minimizing track resistance has a greater impact on acceptability than increasing the size (lower AWG) of the copper wire. Similarly, adding more connections to the track (1for Case 1, 2 for Case 2, 4 for Cases 3-6, and 8 for Case 7) has a greater impact than increasing copper wire size. In fact in Case 7, acceptable performance is achieved with the smallest wire (22 AWG).

Based on the results of this analysis, I recommend using a "star" type wiring configuration as depicted in Cases 6 and 7. Key to minimizing the "Delta R" is keeping all of the wires from the common distribution point to the track roughly the same length and the same gauge as well as having track-wire connections no more than 5 track sections apart (as in Case 7). Although of lesser importance, I recommend using 18 AWG wire or larger to reduce the average resistance.

To make it easier to maintain the layout while maintaining a good electrical connection between the wire and track, I recommend soldering the wire directly to the underside of each rail. I recommend soldering about a 9 inch length of 22 AWG wire to the rail. While one would still likely need a high wattage soldering iron (40 watts or more) or a soldering gun, it is easier to solder a 22 AWG wire to a rail than a wire of greater size. Make sure the solder joint area on the track is clean and corrosion free.

Underneath the train table, you can connect the 22 AWG wire to a larger gauge wire using a 2 pole European style terminal block as depicted in Figure 8. The European style terminal blocks usually are purchased with 8 or more poles; but they are easily cut down to size.

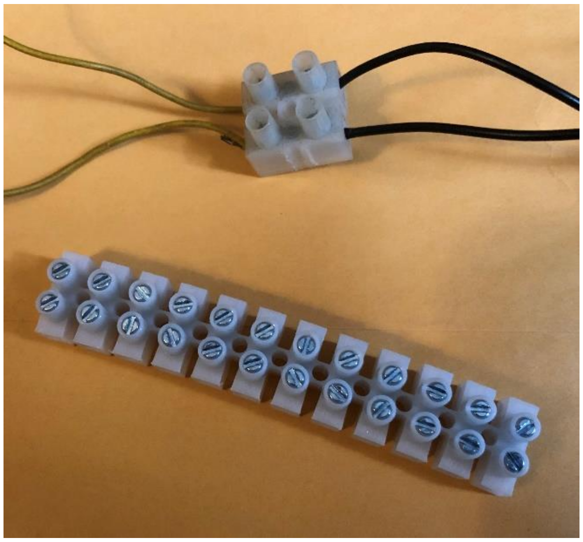


Figure 8: European Style Terminal Blocks

There are many options for the common distribution point. I generally recommend using either the European style Terminal Blocks or a feed through Terminal Block as depicted in Figure 9. You can use one terminal block for each of the two rails. With the feed through Terminal Block, all the terminals can be electrically connected by soldering a bare solid copper wire across all the terminal pole leads; the track and transformer wire are attached using the screws on top. For the European style Terminal Block, you can use solid wire to connect all the terminal poles on one side and connect the track and transformer wire on the other side. There are many other possible solutions that will work just as well.

Figure 9: Terminal Block Examples

Appendix A: Data

			Resistance to transformer (ohms) from Node												
CASE	Track R	AWG	10	12	20	23	30	34	40	41	Average R	Std Deviation	Greatest R	Smallest R	Delta R
1	0.025	12	0.004	0.114	0.192	0.239	0.254	0.239	0.192	0.114	0.168	0.086	0.254	0.004	0.250
1	0.025	14	0.007	0.116	0.194	0.241	0.257	0.241	0.194	0.116	0.171	0.086	0.257	0.007	0.250
1	0.025	16	0.011	0.120	0.198	0.245	0.261	0.245	0.198	0.120	0.175	0.086	0.261	0.011	0.250
1	0.025	18	0.017	0.127	0.205	0.252	0.267	0.252	0.205	0.127	0.182	0.086	0.267	0.017	0.250
1	0.025	20	0.027	0.137	0.215	0.262	0.277	0.262	0.215	0.137	0.192	0.086	0.277	0.027	0.250
1	0.025	22	0.044	0.153	0.231	0.278	0.294	0.278	0.231	0.153	0.208	0.086	0.294	0.044	0.250
1	0.075	12	0.004	0.332	0.567	0.707	0.754	0.707	0.567	0.332	0.497	0.257	0.754	0.004	0.750
1	0.075	14	0.007	0.335	0.569	0.710	0.757	0.710	0.569	0.335	0.499	0.257	0.757	0.007	0.750
1	0.075	16	0.011	0.339	0.573	0.714	0.761	0.714	0.573	0.339	0.503	0.257	0.761	0.011	0.750
1	0.075	18	0.017	0.346	0.580	0.721	0.767	0.721	0.580	0.346	0.510	0.257	0.767	0.017	0.750
1	0.075	20	0.027	0.356	0.590	0.731	0.777	0.731	0.590	0.356	0.520	0.257	0.777	0.027	0.750
1	0.075	22	0.044	0.372	0.606	0.747	0.794	0.747	0.606	0.372	0.536	0.257	0.794	0.044	0.750
1	0.15	12	0.004	0.661	1.129	1.411	1.504	1.411	1.129	0.661	0.989	0.513	1.504	0.004	1.500
1	0.15	14	0.007	0.663	1.132	1.413	1.507	1.413	1.132	0.663	0.991	0.513	1.507	0.007	1.500
1	0.15	16	0.011	0.667	1.136	1.417	1.511	1.417	1.136	0.667	0.995	0.513	1.511	0.011	1.500
1	0.15	18	0.017	0.674	1.142	1.424	1.517	1.424	1.142	0.674	1.002	0.513	1.517	0.017	1.500
1	0.15	20	0.027	0.684	1.152	1.434	1.527	1.434	1.152	0.684	1.012	0.513	1.527	0.027	1.500
1	0.15	22	0.044	0.700	1.169	1.450	1.544	1.450	1.169	0.700	1.028	0.513	1.544	0.044	1.500
2	0.025	12	0.004	0.099	0.134	0.109	0.024	0.109	0.134	0.099	0.089	0.049	0.134	0.004	0.130
2	0.025	14	0.007	0.102	0.139	0.117	0.036	0.117	0.139	0.102	0.095	0.048	0.139	0.007	0.132
2	0.025	16	0.011	0.107	0.147	0.129	0.054	0.129	0.147	0.107	0.104	0.048	0.147	0.011	0.136
2	0.025	18	0.017	0.115	0.158	0.147	0.080	0.147	0.158	0.115	0.117	0.048	0.158	0.017	0.141
2	0.025	20	0.027	0.127	0.174	0.170	0.114	0.170	0.174	0.127	0.135	0.050	0.174	0.027	0.147
2	0.025	22	0.044	0.145	0.197	0.202	0.158	0.202	0.197	0.145	0.161	0.054	0.202	0.044	0.158
2	0.075	12	0.004	0.287	0.384	0.297	0.025	0.297	0.384	0.287	0.246	0.148	0.384	0.004	0.380
2	0.075	14	0.007	0.290	0.390	0.306	0.039	0.306	0.390	0.290	0.252	0.148	0.390	0.007	0.383
2	0.075	16	0.011	0.295	0.398	0.320	0.060	0.320	0.398	0.295	0.262	0.146	0.398	0.011	0.387
2	0.075	18	0.017	0.303	0.411	0.341	0.093	0.341	0.411	0.303	0.278	0.145	0.411	0.017	0.394
2	0.075	20	0.027	0.316	0.431	0.372	0.140	0.372	0.431	0.316	0.300	0.144	0.431	0.027	0.403
2	0.075	22	0.044	0.335	0.460	0.417	0.208	0.417	0.460	0.335	0.335	0.144	0.460	0.044	0.416
2	0.15	12	0.004	0.568	0.760	0.578	0.025	0.578	0.760	0.568	0.480	0.299	0.760	0.004	0.755
2	0.15	14	0.007	0.571	0.765	0.588	0.039	0.588	0.765	0.571	0.487	0.298	0.765	0.007	0.758
2	0.15	16	0.011	0.577	0.774	0.602	0.062	0.602	0.774	0.577	0.497	0.296	0.774	0.011	0.763
2	0.15	18	0.017	0.585	0.787	0.625	0.097	0.625	0.787	0.585	0.514	0.294	0.787	0.017	0.770

			Resistance to transformer (ohms) from Node												
CASE	Track R	AWG	10	12	20	23	30	34	40	41	Average R	Std Deviation	Greatest R	Smallest R	Delta R
2	0.15	20	0.027	0.598	0.808	0.658	0.149	0.658	0.808	0.598	0.538	0.291	0.808	0.027	0.780
2	0.15	22	0.044	0.618	0.840	0.710	0.228	0.710	0.840	0.618	0.576	0.289	0.840	0.044	0.796
3	0.025	12	0.004	0.070	0.018	0.083	0.030	0.094	0.041	0.076	0.052	0.033	0.094	0.004	0.090
3	0.025	14	0.007	0.074	0.027	0.093	0.044	0.109	0.058	0.082	0.062	0.034	0.109	0.007	0.102
3	0.025	16	0.011	0.081	0.041	0.107	0.064	0.128	0.081	0.091	0.075	0.037	0.128	0.011	0.117
3	0.025	18	0.017	0.091	0.060	0.127	0.090	0.152	0.109	0.103	0.094	0.041	0.152	0.017	0.134
3	0.025	20	0.027	0.105	0.086	0.152	0.123	0.180	0.140	0.118	0.116	0.046	0.180	0.027	0.152
3	0.025	22	0.044	0.126	0.121	0.186	0.165	0.214	0.176	0.139	0.146	0.052	0.214	0.044	0.170
3	0.075	12	0.004	0.195	0.019	0.210	0.033	0.223	0.046	0.202	0.116	0.098	0.223	0.004	0.219
3	0.075	14	0.007	0.200	0.029	0.222	0.050	0.242	0.070	0.210	0.129	0.098	0.242	0.007	0.235
3	0.075	16	0.011	0.207	0.045	0.240	0.077	0.270	0.105	0.222	0.147	0.099	0.270	0.011	0.259
3	0.075	18	0.017	0.218	0.070	0.267	0.115	0.309	0.154	0.239	0.174	0.102	0.309	0.017	0.291
3	0.075	20	0.027	0.234	0.104	0.304	0.167	0.360	0.216	0.262	0.209	0.108	0.360	0.027	0.332
3	0.075	22	0.044	0.259	0.155	0.356	0.238	0.426	0.294	0.294	0.258	0.118	0.426	0.044	0.382
3	0.15	12	0.004	0.383	0.019	0.398	0.033	0.412	0.047	0.390	0.211	0.198	0.412	0.004	0.407
3	0.15	14	0.007	0.388	0.030	0.410	0.052	0.432	0.074	0.399	0.224	0.197	0.432	0.007	0.425
3	0.15	16	0.011	0.395	0.047	0.430	0.081	0.463	0.113	0.412	0.244	0.197	0.463	0.011	0.452
3	0.15	18	0.017	0.406	0.073	0.460	0.125	0.510	0.173	0.431	0.274	0.197	0.510	0.017	0.492
3	0.15	20	0.027	0.424	0.112	0.503	0.187	0.574	0.254	0.459	0.318	0.200	0.574	0.027	0.547
3	0.15	22	0.044	0.450	0.171	0.568	0.278	0.665	0.366	0.499	0.380	0.208	0.665	0.044	0.621
4	0.025	12	0.004	0.069	0.015	0.077	0.018	0.077	0.015	0.069	0.043	0.032	0.077	0.004	0.072
4	0.025	14	0.007	0.073	0.023	0.084	0.028	0.084	0.023	0.073	0.050	0.032	0.084	0.007	0.077
4	0.025	16	0.011	0.080	0.035	0.096	0.044	0.096	0.035	0.080	0.060	0.032	0.096	0.011	0.085
4	0.025	18	0.017	0.089	0.054	0.113	0.066	0.113	0.054	0.089	0.074	0.033	0.113	0.017	0.096
4	0.025	20	0.027	0.103	0.079	0.137	0.096	0.137	0.079	0.103	0.095	0.035	0.137	0.027	0.110
4	0.025	22	0.044	0.124	0.114	0.171	0.138	0.171	0.114	0.124	0.125	0.040	0.171	0.044	0.127
4	0.075	12	0.004	0.195	0.015	0.202	0.019	0.202	0.015	0.195	0.106	0.099	0.202	0.004	0.198
4	0.075	14	0.007	0.199	0.024	0.210	0.030	0.210	0.024	0.199	0.113	0.098	0.210	0.007	0.203
4	0.075	16	0.011	0.205	0.038	0.223	0.047	0.223	0.038	0.205	0.124	0.097	0.223	0.011	0.212
4	0.075	18	0.017	0.215	0.059	0.243	0.073	0.243	0.059	0.215	0.141	0.097	0.243	0.017	0.226
4	0.075	20	0.027	0.231	0.090	0.273	0.111	0.273	0.090	0.231	0.166	0.096	0.273	0.027	0.245
4	0.075	22	0.044	0.255	0.138	0.317	0.169	0.317	0.138	0.255	0.204	0.098	0.317	0.044	0.274
4	0.15	12	0.004	0.382	0.015	0.390	0.019	0.390	0.015	0.382	0.200	0.199	0.390	0.004	0.385
4	0.15	14	0.007	0.386	0.024	0.398	0.030	0.398	0.024	0.386	0.207	0.198	0.398	0.007	0.391

			Resistance to transformer (ohms) from Node												
CASE	Track R	AWG	10	12	20	23	30	34	40	41	Average R	Std Deviation	Greatest R	Smallest R	Delta R
4	0.15	16	0.011	0.393	0.038	0.411	0.048	0.411	0.038	0.393	0.218	0.197	0.411	0.011	0.400
4	0.15	18	0.017	0.403	0.061	0.432	0.075	0.432	0.061	0.403	0.236	0.196	0.432	0.017	0.415
4	0.15	20	0.027	0.419	0.094	0.464	0.116	0.464	0.094	0.419	0.262	0.194	0.464	0.027	0.436
4	0.15	22	0.044	0.444	0.146	0.513	0.180	0.513	0.146	0.444	0.304	0.192	0.513	0.044	0.469
5	0.025	12	0.004	0.068	0.016	0.072	0.021	0.072	0.013	0.067	0.042	0.030	0.072	0.004	0.068
5	0.025	14	0.007	0.070	0.024	0.077	0.030	0.076	0.020	0.069	0.047	0.029	0.077	0.007	0.071
5	0.025	16	0.010	0.074	0.034	0.085	0.043	0.083	0.030	0.073	0.054	0.028	0.085	0.010	0.075
5	0.025	18	0.016	0.080	0.049	0.095	0.060	0.093	0.043	0.078	0.064	0.028	0.095	0.016	0.080
5	0.025	20	0.024	0.088	0.066	0.109	0.080	0.106	0.059	0.086	0.077	0.028	0.109	0.024	0.085
5	0.025	22	0.036	0.100	0.088	0.127	0.104	0.124	0.080	0.097	0.095	0.029	0.127	0.036	0.092
5	0.075	12	0.004	0.193	0.017	0.198	0.023	0.197	0.014	0.192	0.105	0.097	0.198	0.004	0.194
5	0.075	14	0.007	0.196	0.027	0.204	0.035	0.202	0.022	0.195	0.111	0.095	0.204	0.007	0.197
5	0.075	16	0.011	0.201	0.041	0.213	0.053	0.211	0.034	0.199	0.120	0.092	0.213	0.011	0.202
5	0.075	18	0.017	0.208	0.062	0.226	0.079	0.223	0.052	0.205	0.134	0.089	0.226	0.017	0.209
5	0.075	20	0.026	0.218	0.090	0.245	0.113	0.241	0.077	0.214	0.153	0.086	0.245	0.026	0.219
5	0.075	22	0.040	0.233	0.129	0.272	0.158	0.266	0.111	0.228	0.180	0.083	0.272	0.040	0.233
5	0.15	12	0.004	0.381	0.018	0.386	0.024	0.385	0.015	0.380	0.199	0.197	0.386	0.004	0.381
5	0.15	14	0.007	0.384	0.028	0.391	0.037	0.390	0.023	0.382	0.205	0.194	0.391	0.007	0.385
5	0.15	16	0.011	0.389	0.043	0.401	0.057	0.399	0.036	0.387	0.215	0.191	0.401	0.011	0.390
5	0.15	18	0.017	0.396	0.067	0.415	0.087	0.412	0.056	0.393	0.231	0.187	0.415	0.017	0.398
5	0.15	20	0.027	0.408	0.100	0.437	0.129	0.432	0.084	0.403	0.253	0.182	0.437	0.027	0.410
5	0.15	22	0.042	0.425	0.149	0.469	0.190	0.462	0.127	0.419	0.285	0.175	0.469	0.042	0.428
6	0.025	12	0.025	0.083	0.025	0.083	0.025	0.083	0.025	0.083	0.054	0.031	0.083	0.025	0.058
6	0.025	14	0.039	0.094	0.039	0.094	0.039	0.094	0.039	0.094	0.067	0.030	0.094	0.039	0.055
6	0.025	16	0.060	0.113	0.060	0.113	0.060	0.113	0.060	0.113	0.086	0.028	0.113	0.060	0.052
6	0.025	18	0.093	0.141	0.093	0.141	0.093	0.141	0.093	0.141	0.117	0.026	0.141	0.093	0.048
6	0.025	20	0.142	0.185	0.142	0.185	0.142	0.185	0.142	0.185	0.164	0.023	0.185	0.142	0.043
6	0.025	22	0.217	0.255	0.217	0.255	0.217	0.255	0.217	0.255	0.236	0.020	0.255	0.217	0.038
6	0.075	12	0.026	0.208	0.026	0.208	0.026	0.208	0.026	0.208	0.117	0.097	0.208	0.026	0.182
6	0.075	14	0.040	0.220	0.040	0.220	0.040	0.220	0.040	0.220	0.130	0.096	0.220	0.040	0.179
6	0.075	16	0.063	0.238	0.063	0.238	0.063	0.238	0.063	0.238	0.151	0.094	0.238	0.063	0.175
6	0.075	18	0.099	0.268	0.099	0.268	0.099	0.268	0.099	0.268	0.184	0.090	0.268	0.099	0.169
6	0.075	20	0.153	0.314	0.153	0.314	0.153	0.314	0.153	0.314	0.233	0.086	0.314	0.153	0.160
6	0.075	22	0.237	0.386	0.237	0.386	0.237	0.386	0.237	0.386	0.312	0.080	0.386	0.237	0.149

			Resistance to transformer (ohms) from Node												
CASE	Track R	AWG	10	12	20	23	30	34	40	41	Average R	Std Deviation	Greatest R	Smallest R	Delta R
6	0.15	12	0.026	0.395	0.026	0.395	0.026	0.395	0.026	0.395	0.210	0.198	0.395	0.026	0.370
6	0.15	14	0.040	0.407	0.040	0.407	0.040	0.407	0.040	0.407	0.224	0.196	0.407	0.040	0.367
6	0.15	16	0.064	0.426	0.064	0.426	0.064	0.426	0.064	0.426	0.245	0.194	0.426	0.064	0.362
6	0.15	18	0.101	0.456	0.101	0.456	0.101	0.456	0.101	0.456	0.279	0.190	0.456	0.101	0.355
6	0.15	20	0.158	0.502	0.158	0.502	0.158	0.502	0.158	0.502	0.330	0.184	0.502	0.158	0.345
6	0.15	22	0.247	0.577	0.247	0.577	0.247	0.577	0.247	0.577	0.412	0.176	0.577	0.247	0.330

CASE 7

Track R	AWG	Resistance to transformer (ohms) from Node 10	60	12	61	Average R	Std Deviation	Greatest R	Smallest R	Delta R
0.025	12	0.024	0.051	0.024	0.051	0.038	0.016	0.051	0.024	0.027
0.025	14	0.029	0.054	0.029	0.054	0.041	0.014	0.054	0.029	0.025
0.025	16	0.035	0.058	0.035	0.058	0.046	0.013	0.058	0.035	0.023
0.025	18	0.043	0.063	0.043	0.063	0.053	0.012	0.063	0.043	0.020
0.025	20	0.053	0.071	0.053	0.071	0.062	0.010	0.071	0.053	0.017
0.025	22	0.067	0.081	0.067	0.081	0.074	0.009	0.081	0.067	0.015
0.075	12	0.025	0.114	0.025	0.114	0.070	0.051	0.114	0.025	0.089
0.075	14	0.031	0.117	0.031	0.117	0.074	0.050	0.117	0.031	0.086
0.075	16	0.039	0.121	0.039	0.121	0.080	0.048	0.121	0.039	0.082
0.075	18	0.051	0.128	0.051	0.128	0.090	0.045	0.128	0.051	0.077
0.075	20	0.067	0.138	0.067	0.138	0.103	0.041	0.138	0.067	0.071
0.075	22	0.089	0.153	0.089	0.153	0.121	0.037	0.153	0.089	0.064
0.15	12	0.026	0.208	0.026	0.208	0.117	0.105	0.208	0.026	0.182
0.15	14	0.031	0.211	0.031	0.211	0.121	0.104	0.211	0.031	0.179
0.15	16	0.040	0.216	0.040	0.216	0.128	0.101	0.216	0.040	0.175
0.15	18	0.054	0.223	0.054	0.223	0.139	0.098	0.223	0.054	0.169
0.15	20	0.074	0.234	0.074	0.234	0.154	0.093	0.234	0.074	0.160
0.15	22	0.102	0.251	0.102	0.251	0.176	0.086	0.251	0.102	0.149

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0. PREAMBLE

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