SIGNAL SYSTEM FOR MODULAR LAYOUTS

By Gregg Fuhriman

The Northern California Free-Mo (NorCalF) and San Luis Obispo Free-Mo (SLO-Mo) HO modular groups strive for realistic, true-to-life modeling on our free-form modules. Many Free-Mo scenes are based on actual locations, including track-side signals. To make our signals behave realistically we've developed a modular, low-cost detection and occupancy system for modular layouts. In its simplest form this system simulates simple Absolute Block Signaling (ABS), without a computer.

Features of the signal system include:

- accommodates reversible nature of Free-Mo modules (wiring permits modules to be oriented either way relative to one another in a layout)
- independent of module placements in a Free-Mo layout (modules can be used anywhere in a layout)
- no customizing or tailoring for each unique layout arrangement
- simple plug-and-run connections at module-to-module joints, just as the other Free-Mo busses have
- required hardware is simple to add to modules
- train detection emulates the prototype, and does not require resistor wheel sets on rolling stock
- flexible component choice allows module builders to select electronics to fit their preferences and budget
- provides a basic foundation for more complex, customized prototype-based signaling implementations

Though some features are unique to the Free-Mo modular format, this system can be used by other modular formats like NMRA or N-Trak, or applied to permanent home or club layouts as a low cost, basic signaling solution. This system is a general foundation for signaling that lends itself to enhancement in a dynamic modular environment.

The system is organized in a layered fashion allowing each module owner to implement only what is required by a particular model scene. And for modules requiring multiple signals and associated wiring, the layered approach allows spreading out wiring tasks and component costs as hobby time and budget allow.

Basic Elements

The wiring of this system is implemented using Category-5 RJ45 components found at computer or electronics stores, as well as Internet outlets. RJ45 is an 8-conductor format commonly used for computer networks like 10/100BaseT Ethernet. The connectors look like chunky phone plugs having eight contacts.

This application uses low cost unshielded cables since track occupancy information is essentially DC (as opposed to the high-speed nature of computer networks which require costly shielded, controlled-impedance cables to maintain data integrity). Don't waste money on expensive cables for this application.

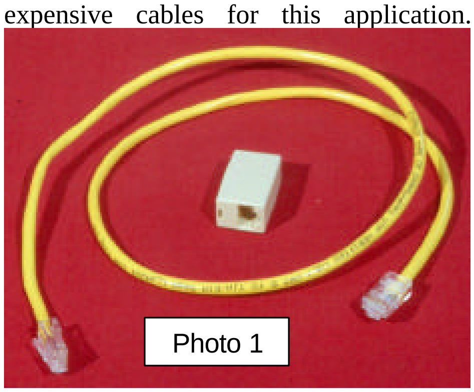


Photo 1

Photo 1 shows a typical cable and in-line coupler. RJ45 cables wired in two configurations are used: "cross-over" and "straight-through" (often labeled "patch").

RJ45 in-line couplers wired as “straight-through” are also used. Ready-made cables are suggested to save time (the connectors are pre-installed, cables are available in a variety of lengths). However it’s possible to make cables by attaching the connectors with a crimping tool designed for RJ45 connectors. Just be careful to get the wire-to-pin connections in the correct order! Figure 1 shows pinouts and wire color-codes for all cable types used in this system.

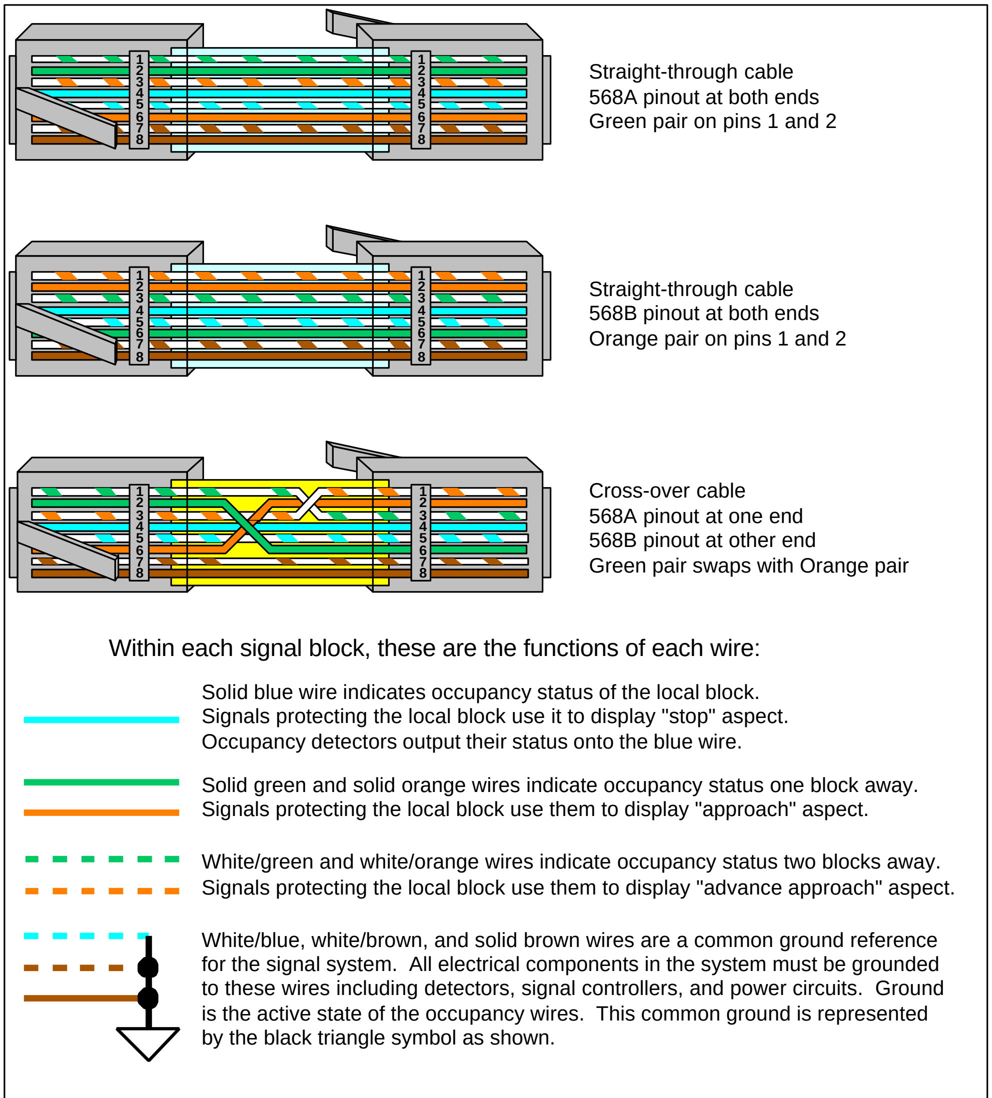


FIGURE 1

Figure 1 shows there are two possible wiring pinouts at cable connectors, called “568A” and “568B” within this article. These names are derived from EIA/TIA industry standards that define these two wiring patterns for Ethernet cables. Note that a cross-over cable always has one 568A pinout and one 568B pinout, so there is only one possible wiring for cross-over cables. However there are two possible wire color arrangements for straight-through cables: one has 568A pinout at both ends, and the second has 568B pinout at both ends. Although 568B straight-through cables are more commonly found commercially, this article explains how to use either type.

Figure 1 reveals how the two cable types differ. Straight-through cables have each of the eight wires connected to the same pin number at both ends. But in a cross-over cable, two of the wire pairs swap pin assignments from one end to the other. Pin pair 1-2 is crossed with pin pair 3-6. The other two pairs (pins 4-5, and pins 7-8) do not cross and connect straight through. How this feature of cross-over cables is used will be explained shortly.

To emphasize where these different cables are used in this system, the drawings in this article show cross-over cables with a yellow background, and straight-through cables with a light blue background. Individual wires are colored to match what is found in actual cables. The eight cable wires are arranged as four pairs: each solid color wire is paired with a white wire with a matching color stripe. Figure 1 lists the functional assignments of the eight wires in this system.

The Occupancy Bus Layer

The most innovative concept of this system is the RJ45 “bus layer” - we’ve dubbed it the Occupancy Bus to differentiate it from the other standard Free-mo wiring busses (Track Bus, LocoNet, and Accessory Bus). The Occupancy Bus is the interconnecting wiring that carries track occupancy status through the layout from detectors to signal controllers. Therefore the bus layer is required for all modules.

This bus gives any one module visibility to occupancy status of five signal blocks plus an electrical reference ground. This is the lowest-cost layer of the system and is the simplest to install. In fact, virtually every NorCalF and SLO-Mo module was outfitted during a weekend setup meet.

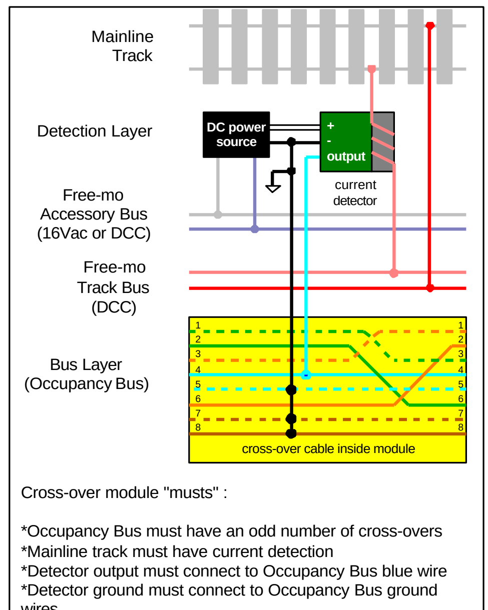
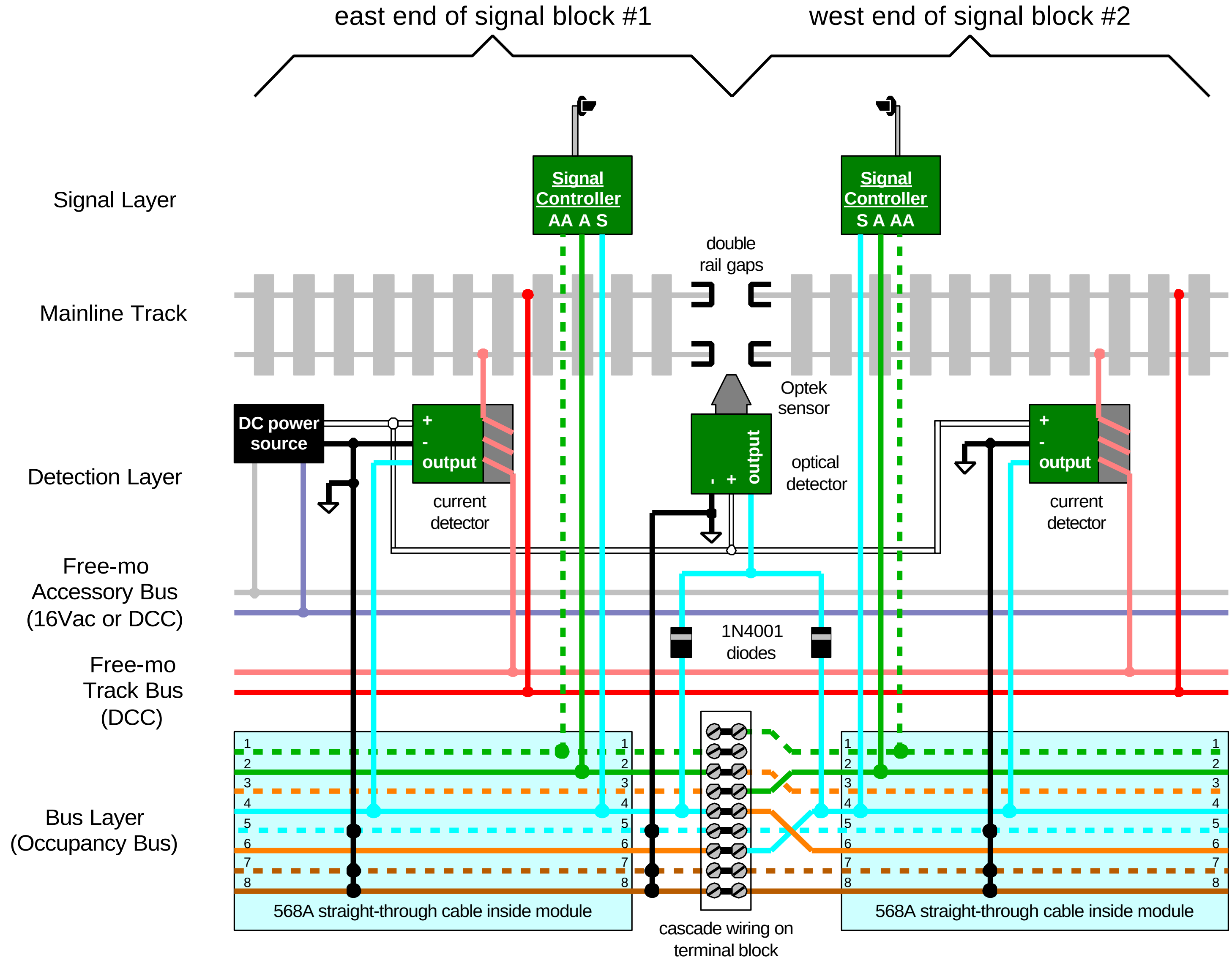


FIGURE 2

There are two types of modules in this system. Figure 2 shows the first type called a “cross-over module”, which is the most common type. Cross-over modules form the central portion of signal blocks, and therefore never have track-side signals.

Each cross-over module has at least one cross-over internally, implemented with an RJ45 cross-over cable. In general, there must be an odd number of cross-overs within each cross-over module (i.e., between its “east” and “west” ends). Note that a cross-over module’s RJ45 cabling



Cascade module "musts" :

*Occupancy Bus must have same pinout on both ends (568A or 568B)
*Cascades must be separated by an odd number of cross-overs
*Mainline track must have current detection
*Signal block boundary must have optical detector
*Optical detector output must pass through diodes to isolate occupancy wires
*Detector outputs must connect to Occupancy Bus blue wires, on corresponding sides of cascade
*Detector grounds must connect to Occupancy Bus ground wires
*Both mainline rails must be gapped at signal block boundary

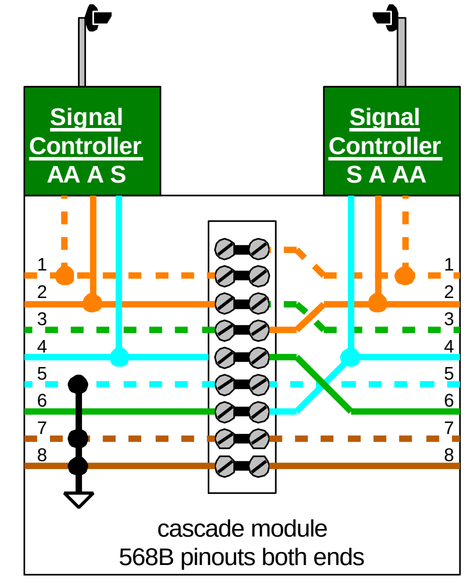
FIGURE 3

will always have a 568A pinout at one end, and a 568B pinout at the other end.

Figure 3 shows the second module type called a "cascade module", which is the less common type. Cascade modules form the boundaries between adjacent signal blocks, and therefore have track-side signals to protect the ends of the signal blocks. Cascades break up the layout's mainline into individual signal blocks – the more cascades there are, the more signal blocks the layout will have. Since cascades appear where signals exist, they are most often built into modules that have passing siding turnouts, junctions where a branchline joins the mainline, or multiple mainlines that cross at grade. However, sometimes there are intermediate signals found along a stretch of single main track – this is an opportunity to add eye-catching working signals to an otherwise simple module.

Within a cascade module the Occupancy Bus has a special wiring arrangement that transfers signal block occupancy status from one wire color to another, "cascading" occupancy information along the layout in both directions.

Note a cascade must be built with straight-through cables, and will always have the same pinout at both ends. Figure 3 shows detailed wiring of a cascade



Detection not shown

FIGURE 4

module using the 568A pinout at both ends. Figure 4 is a simplified diagram showing the key wiring differences when the 568B pinout is used at both ends. The two versions can be mixed randomly throughout a layout.

The wiring pattern of both versions is identical relative to cable pin numbers – the only difference is the wire color codes.

Figure 3 suggests one way to build a cascade: cut a straight-through cable in half and wire the two pieces back together on a terminal strip.

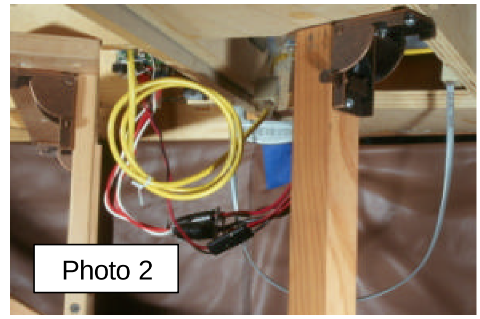
All cascades must be separated by at least one cross-over. In general, there must be an odd number of cross-overs between cascades.

It is possible for a single module to include both cross-over and cascade

elements, and even have multiples of both. An example is the 20-foot long Glen Frazer Free-mo module set featured in the April, May, and August 2003 RailModel Journal. Glen Frazer has two cascades, one at each end of its passing siding. And it has one cross-over, located between the two cascades. Because it is a cascade module, it has the same pinout at both ends.

Straight-through wired in-line couplers make the bus modular for quick connection during layout setup, and ease installation and maintenance within a module. Each module has a coupler near each end. The module's internal cables are permanently plugged into one side of each coupler. These connections do not get plugged or unplugged during layout setup or teardown.

During layout setup, portable "jumper"

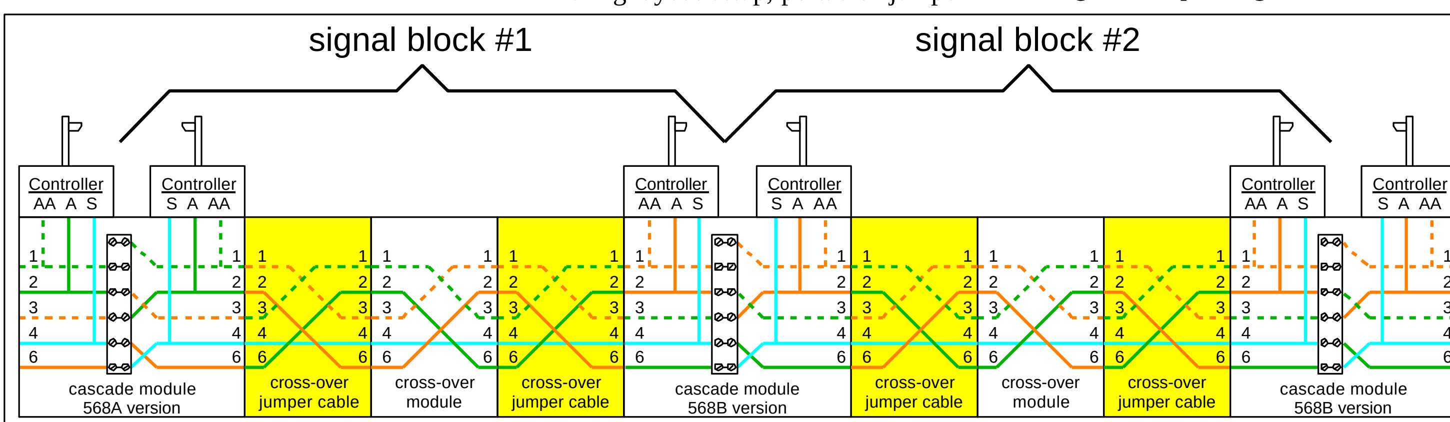


cross-over cables are installed at the joints where modules mate together, to bridge the Occupancy Bus from one module to the next. They are plugged into the open sides of the in-line couplers at module ends as seen in Photo 2. While the jumper cables can be any length, a 3-foot length is typically adequate and is the shortest commonly available off-the-shelf. Longer cables are used as needed to bypass modules not yet outfitted with the bus. Since this bus is not required by Free-Mo standards, it's possible to have modules in a layout that do not include the bus.

Why are cross-overs necessary? They are the solution to the "reversible module" nature of Free-Mo. As listed in Figure 1, the function assignments for the eight wires are carefully chosen to utilize the built-in "reversible" nature of cross-over cables.

Figure 5 shows how cross-over modules and cascade modules are strung together and joined with cross-over cables to form the Occupancy Bus. Note there are always cross-overs between cascades. Recall that in general there must be an odd number of cross-overs between cascades. This requirement is automatically satisfied as long as every cross-over module has an odd number of internal cross-overs, and the jumper cables are all cross-over type.

Figure 5 also reveals how the cascades affect the Occupancy Bus wiring as it runs through multiple signal blocks. The



Ground wires on pins 5, 7, 8 not shown. Cascade versions and cross-over orientations are randomly mixed.

FIGURE 5

significance of this wiring scheme is explained later in this article when the signal layer is discussed.

The Detection Layer

Track occupancy detection is the second layer of the system. Detectors generate "input" to the Occupancy Bus.

One very important aspect of detectors is the nature of their electrical output. Most brands of detectors have an open-collector drive-to-logic-low output, while a few brands have an always-driven or drive-to-logic-high output.

This system <u>requires</u> the open-collector drive-to-low type because it allows multiple detectors to connect directly to the same occupancy wire. This is called a "wired-OR" configuration.

This system has an innovative dual-mode detection using current and optical detector circuits. Each type is discussed in detail, starting with current detectors.

Current detectors activate when electrical current flows in the track, or in this case in the feeder wires to the track. For example, the detector is activated when a powered locomotive is present and its motor is drawing current from the track power supply.

We've determined this system requires <u>every</u> module to have a current detector on its mainline wiring. Therefore the Detection Layer, specifically current detection, is <u>required</u> for all modules. Why? Because Free-mo layouts allow completely flexible module arrangements, the only way to guarantee every segment of the mainline has occupancy detection is to install a current detector in every module. Otherwise it's possible to end up with a segment of track with no occupancy status, due to a series of adjacent modules that don't have detectors.

Figure 2 shows how the current detector is wired in a cross-over module. The current detector is placed on one feeder wire to the mainline track only, so that only trains on the mainline (and not side tracks) affect the Occupancy Bus and signals, just like prototype signal systems. This requires the module's Track Bus and feeder wire structure be designed to cleanly separate mainline and side track connections.

If multiple feeders connect to the same rail of the mainline track, the current detector must be wired in to detect current in any of those feeders. Figure 6 shows

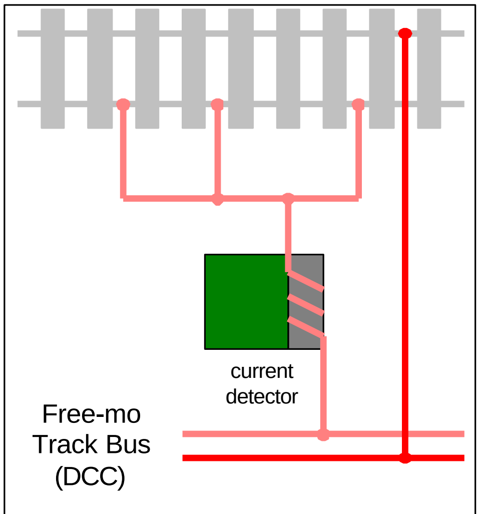


FIGURE 6

one way to do this by tapping into the track power bus at just one point, placing the detector on that tap, and then fanning out feeders to the mainline rails.

Another important note on current detection: only one rail's feeder wire needs to have the detector. In other words, do not run both rail's feeders through a detector. Follow the instructions provided with the specific detector unit you use.

The current detector's output always connects to the blue wire in the Occupancy Bus RJ45 cable to drive "local" occupancy when a train activates it.

We've also determined it is <u>required</u> to gap both track rails between each current detector because the track itself acts as a parallel current path to the Track Bus wires. Without rail gaps between current detectors, a loco drawing current in a given block will cause current to flow in the track (and thus its feeder wires) of unoccupied blocks between it and the track power source (e.g. the DCC booster). This unintended current path can cause detectors to activate on blocks that are not occupied! Gapping the rails stops this unwanted current flowing through the rails and feeder wires, forcing it to flow only through the Track Bus in unoccupied blocks. For Free-mo the rail gaps are simple to implement using insulated joiners on the "fitter" rails between modules.

So far we've used two brands of open-collector drive-to-logic-low current detectors: the BD20 from North Coast Engineering (Photo 3), and the DCC Optimized Detector (DCCOD) from JLC Enterprises (Photo 4). Each has advantages and disadvantages. The BD20 is lower cost and simpler to wire in, but it's not sensitive enough to detect a DCC loco

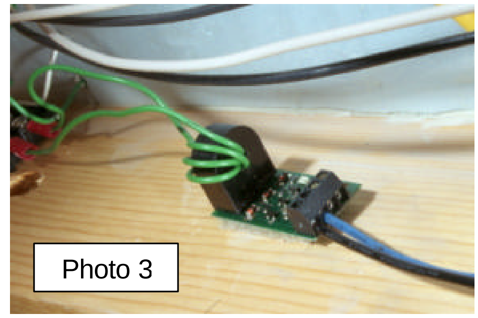


Photo 3

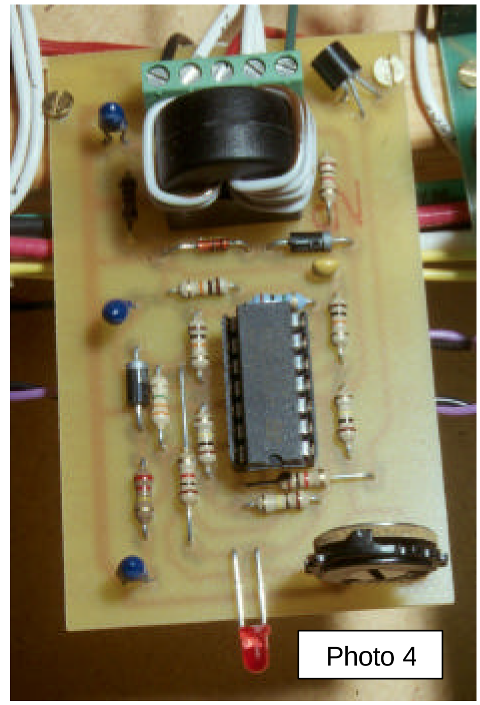


Photo 4

with a high-efficiency can motor that is stopped with no functions activated (e.g. the latest offerings from Atlas). The DCCOD is essentially the opposite: it costs more and requires more wiring, but its sensitivity can be adjusted to detect that stopped high-efficiency DCC loco. We don't recommend one over the other, and there are several other current detectors on the market that should work - we just haven't tried them so can't offer meaningful comments. Try different types in various situations and choose what you like best.

Optical detection is the innovation that allows signals to behave realistically while avoiding the need for resistor-equipped wheel sets on rolling stock, which in turn lowers overall system cost in terms of both time and money. Another advantage is the train cars don't draw track current, preserving it all for driving locomotives.

The optical sensor type we chose emits an infrared light beam upward from track level. When a train is above the sensor, the beam reflects off the bottom of the train and is received by the sensor, activating the detector circuit. Infrared sensors work well

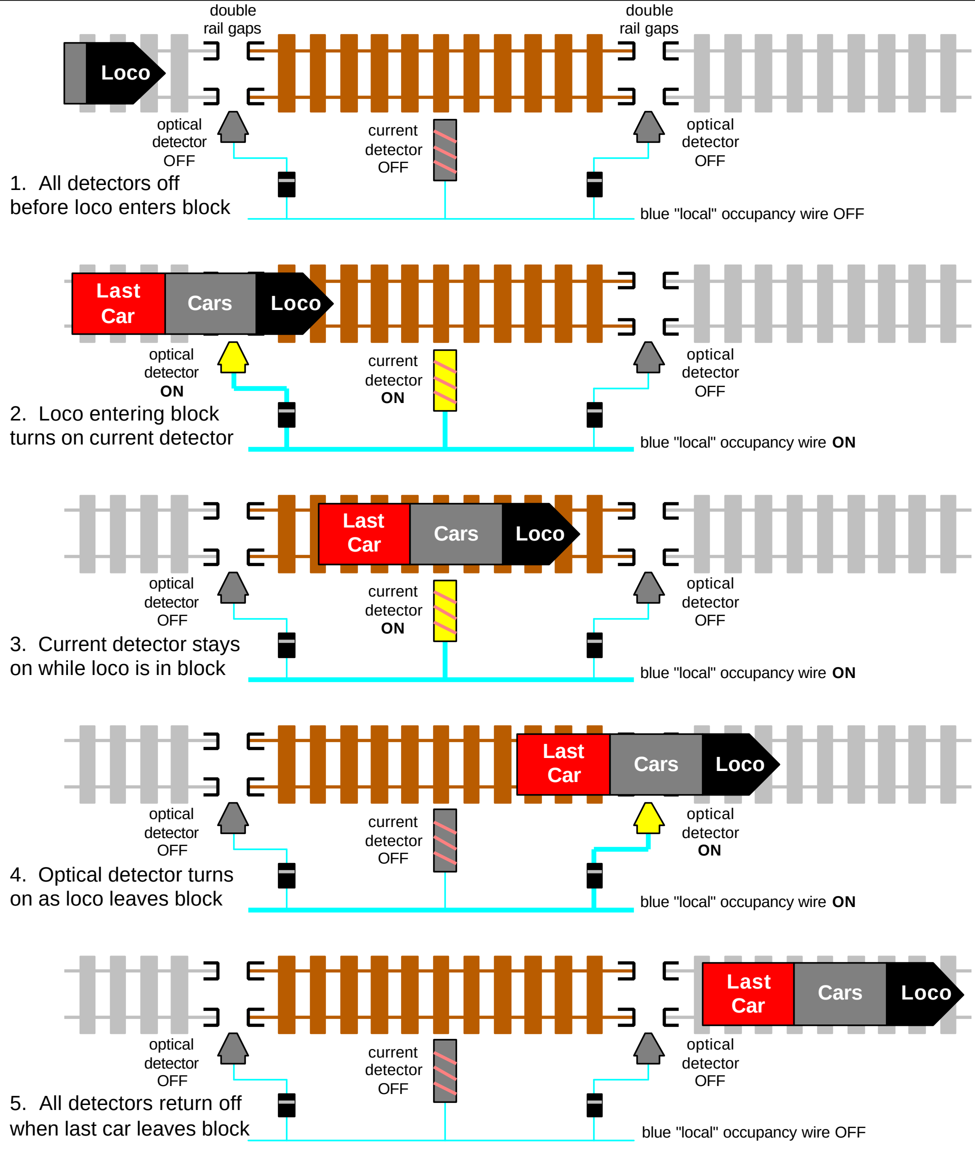


FIGURE 7

at most modular layout venues where poor lighting often causes problems for ambient-light sensors.

Only cascade modules require optical detectors. The optical sensor is placed in the track at the signal block boundary that separates the ends of two sequential signal blocks. Figure 3 shows a cascade module wired for both optical and current detection.

The optical detector output always connects through two parallel 1N4001 diodes to the two blue "local" occupancy wires, one for each signal block at either side of the cascade, as shown in Figure 3. This setup allows a single sensor to indicate occupancy for both adjacent signal blocks; the diodes electrically isolate the two block's "local" occupancy wires from each other (note the two blue wires of the adjacent blocks do <u>not</u> connect to each other). Note the orientation of the diodes – the "banded" ends point toward the detector output.

Before going into detail on the optical detector hardware, Figure 7 shows how the dual-mode detection scheme works. When the head end of a train (the locomotive that is drawing current) crosses a signal block boundary both the current and optical detectors activate in the block the train has just entered. While the train's loco is in the block the current detectors remain active, but turn off when the loco leaves the block at the far end. However, the optical detector at that far end block boundary remains on while the remainder of the train passes by, holding the signal aspects steady until the train's rear end clears the far end of the block. Without the optical detectors, the signal aspects would change as soon as the loco left the block (when the current detectors de-activate), even though the rest of the train is still occupying it – not a realistic behavior. Optical detectors are essential at each signal block boundary so that trackside signals change aspect when the locomotive enters a signal block, and they hold that aspect until the last car exits the signal block just as real signals do – all without a single resistor wheel set required.

Some types of cars might draw track current, such as lighted passenger cars or a caboose with marker lights. If they draw enough current, such cars only help to reinforce the detection scheme by keeping the current detectors active once the locos leave the block. Also, there is no ill effect if cars equipped with resistor wheel sets are indeed present. Again they simply cause the current detectors to remain active after the locos leave the block.

The optical detector circuit we use is the Heathcote Electronics IRDOT-1D (Photo 5). This unit connects to the track-mounted infrared sensor. The IRDOT-1D has a neat built-in delay feature that keeps

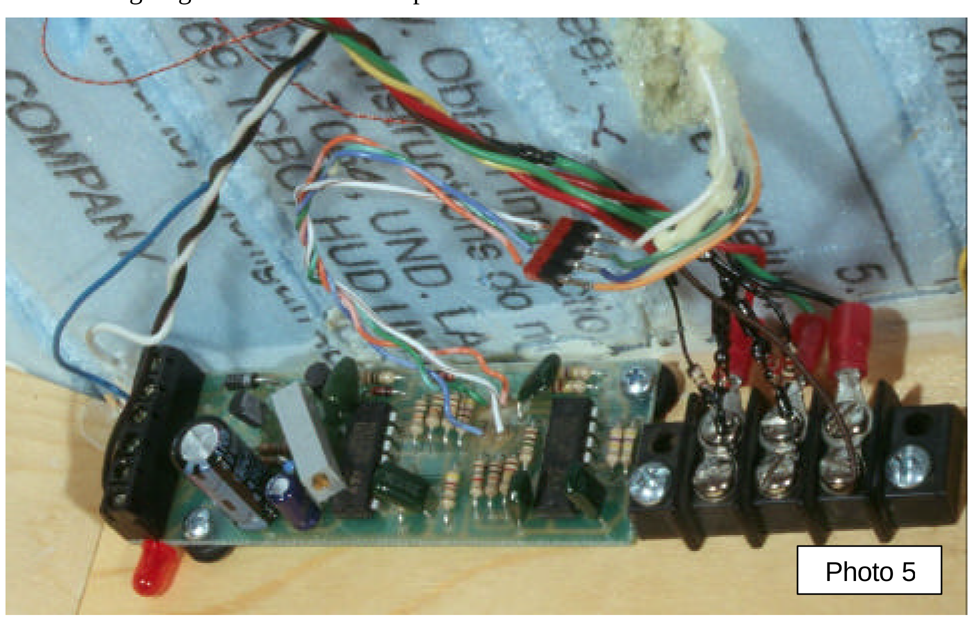


Photo 5

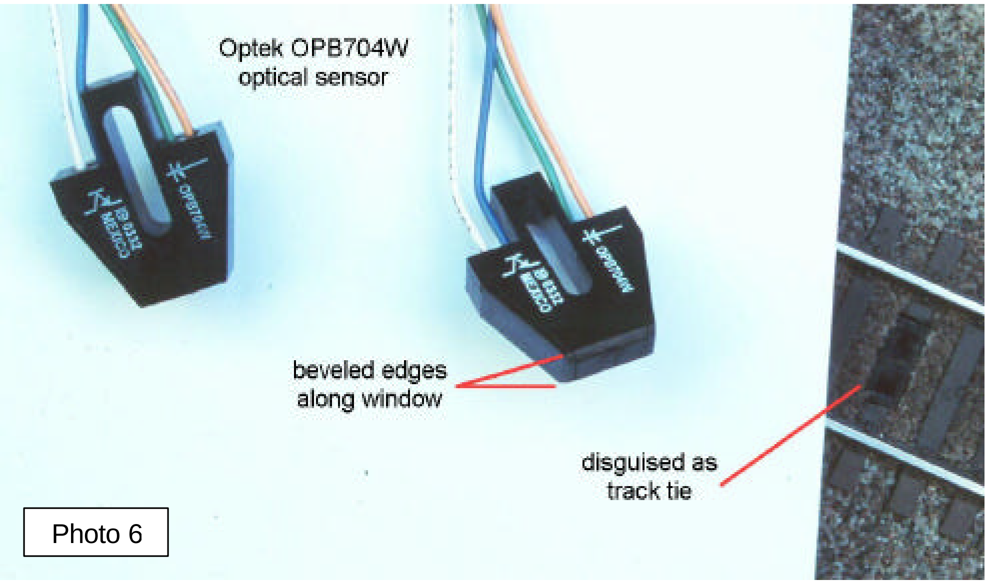


Photo 6

the detector active for about four seconds after the train has passed. This ensures signals do not flicker as a gap between cars passes over the sensor. We feel the four-second delay is too long and modify the unit by replacing one resistor with a potentiometer/resistor combo to make the delay adjustable between two and four seconds.

The IRDOT-1D comes with a two-piece sensor. One piece emits the infrared light upward from the track, the other piece receives the reflected light. The two pieces are intended to mount side-by-side in the track since it's easier to disguise the sensors in the track than it is to hide them in the scenery next to the track. The Heathcote-supplied sensor, however, has some drawbacks. To get the best sensing results, the two pieces must be installed at an optimum angle to each other, something which is difficult to achieve. The supplied two-piece sensor is also susceptible to false triggering under fluorescent lighting or bright sunlight (coming in through a window, for example).

Both problems are solved by replacing the Heathcote-supplied sensor with the Optek OPB704W sensor. This is a single integrated unit with a built-in emitter/receiver angle, and a filter "window" that significantly reduces false triggering. This sensor is a direct replacement for the two-piece sensor described above. Its four wires connect to the IRDOT-1D board as shown in Photo 5. Extend its wires as needed for the particular installation. We also modify this sensor by beveling the housing corners alongside the sensor window, reducing the width of the flat window surface to closely match an HO scale track tie. Warning: do not remove material all the way up to the window sides … leave a little of the black housing!

Photo 6 shows a stock sensor (left), a modified sensor (center) and a finished installation disguised as a track tie (right). For this installation the center portion of a tie was removed, the sensor glued in place flush with the tie top surface (a shot of expanding insulation foam from beneath works great), and the track ballast and weathering touched up. Be sure to temporarily cover the sensor window with a bit of tape during track ballasting and weathering. Again, each signal block boundary requires one optical sensor and its detector circuit.

Both the current and optical detector circuits must be electrically grounded to the three Occupancy Bus ground wires (white/blue, brown, and white/brown as shown in Figures 2 and 3).

Most detector circuits require a power supply. This can come from any convenient source, but the supply's output ground reference (sometimes labeled the "negative" output) must be connected to the Occupancy Bus's three ground wires. The Free-Mo standard specifies an Accessory Bus that carries either DCC or AC power, which is a convenient source for powering detectors. If the detector circuit requires a DC voltage power input, a bridge rectifier and voltage regulator circuit may be used to convert the Accessory Bus DCC or AC voltage to whatever DC voltage the detector requires, as illustrated in Figure 8.

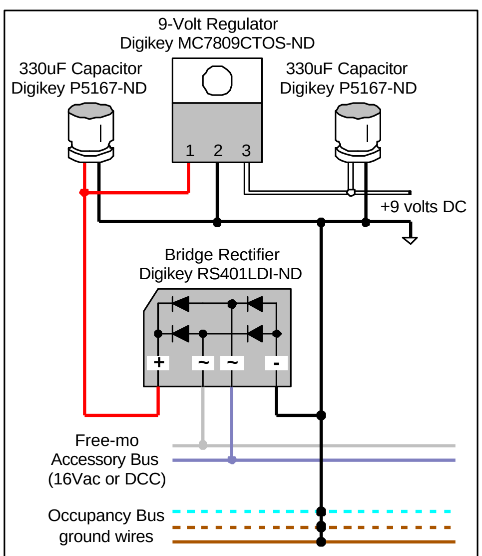


FIGURE 8

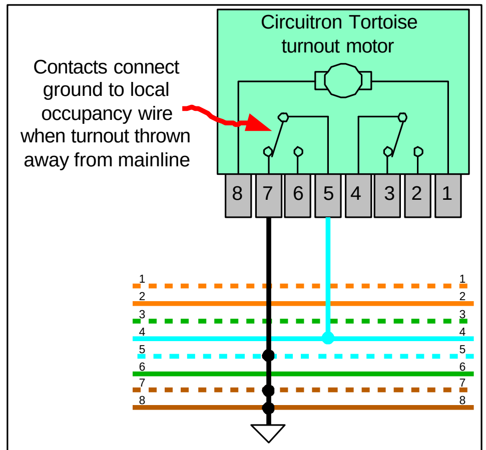


FIGURE 9

Turnouts on the mainline also affect occupancy status. When a mainline turnout is lined away from the mainline, the signals protecting the affected block must indicate occupied status. Most of our modules use Circuitron Tortoise turnout motors with one built-in SPDT switch used for this purpose as shown in Figure 9. One side of the SPDT switch is wired to the Occupancy Bus ground wires while the common contact is wired to the blue "local" occupancy wire. When the turnout is lined against the main, the blue wire is connected to ground through the Tortoise SPDT switch, thus changing the local block status to "occupied". When the turnout is lined for the main, nothing is connected to the blue wire through the open side of the Tortoise SPDT switch, and the local block status is unaffected by the turnout.

Sometimes a turnout must affect more than one occupancy line. In this case use 1N4001 diodes to isolate one occupancy wire from the other. The diode banded ends point toward the switch machine.

Many other brands of turnout controls have accessory contacts, but not all. This is something to consider when selecting turnout control hardware for your module.

The Signal Layer

The signal layer completes the system and consists of the model track-side signals and electronic controllers to drive them. This layer receives occupancy status as “output” from the Occupancy Bus and converts it to signal aspects. It is installed only in modules with track-side signals (cascade modules) and is not necessary for the overall system to function.

The Occupancy Bus can’t be used directly to illuminate signal light bulbs or LEDs. Some form of electronic signal control circuit is required to decode the information on the occupancy wires and adapt it to illuminate the signals.

So far we’ve used the TracTronics AutoBlock (Photo 7), and the Circuitron SD-1 and SD-3. Other brands are available - choose controllers that best fit the needs of the particular signal types you model (e.g. target, tri-color, position-light, semaphore, etc.). Also consider whether the model signals use light bulbs or LEDs when choosing controllers.

Figures 3 and 4 show how signal controllers are wired to the Occupancy Bus around a cascade (both cascade versions are shown). Generic signal controllers are shown with the following letter codes on their inputs:

- S = stop (red)
- A = approach (yellow)
- AA = advance approach (yellow)

The signal controller circuits require a power supply. If a power supply is present for the detectors, hopefully it can also power the controllers (refer to the Detection Layer section above). Remember to tie the power supply’s output reference ground to the three Occupancy Bus ground wires, so all components of the system - detectors, controllers, and power supplies - have a common electrical ground.

The final components are the model track-side signals themselves. Many products are on the market replicating all manner of prototype signals, and discussion of all the variations is beyond the scope of this article. Signals shown in this article are made by Sunrise Enterprises.

The Big Picture

Figure 10 shows how the Occupancy Bus carries track occupancy status through multiple signal blocks to control a sequence of signal aspects.

Consider a snapshot in time when a train occupies Block #3 and its detectors have activated the blue “local” wire of the Occupancy Bus (shown in bold). Starting in Block #3, follow that activated wire in both directions to the signal controllers at each end of Block #3. The signals

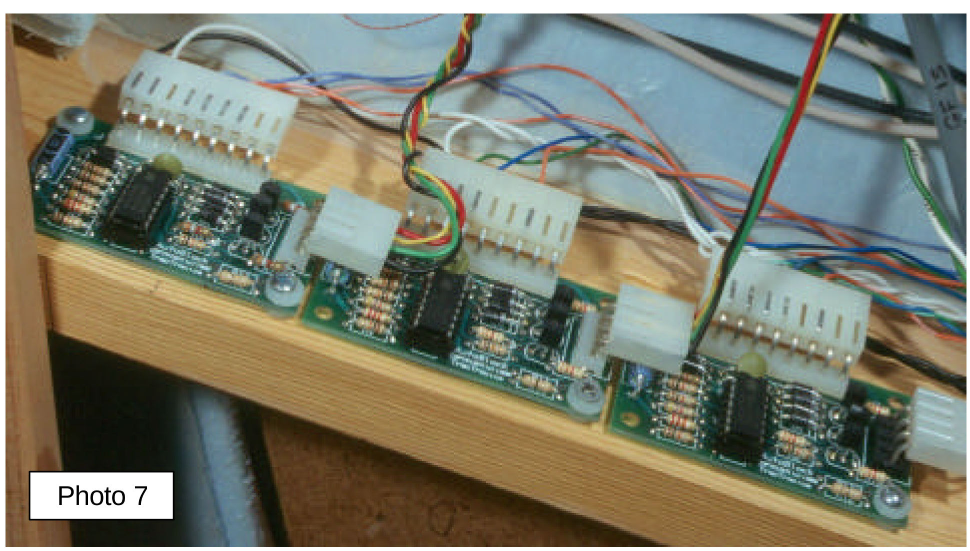


Photo 7

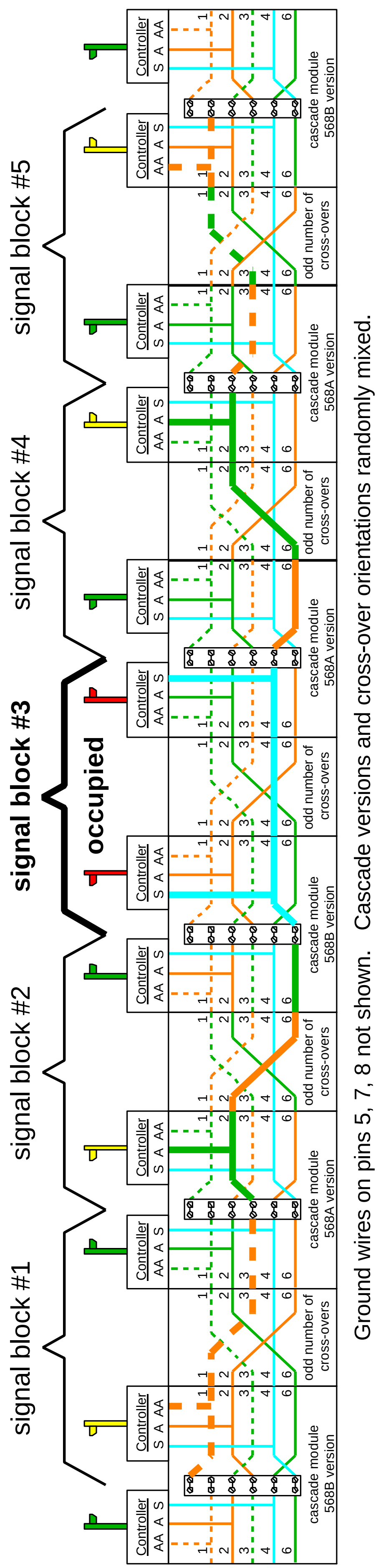


FIGURE 10

protecting - that is, facing outward from the ends of Block #3 display red (stop) because their signal controller "S" inputs are activated.

Continue following the active wire outward through the cascade points - the active wire transfers to a different colored wire as it goes into Blocks #2 and #4. The active wire connects to the "A" input of the signal controllers protecting the far ends of Blocks #2 and #4 (facing away from the train in Block #3), which makes their signals display yellow (approach).

Continue following the active wire outward through the next cascades and into Blocks #1 and #5 where the active wire transfers again. The active wire connects to the "AA" input of the signal controllers protecting the far ends of Blocks #1 and #5 (facing away from the train in Block #3), which makes these signals display advance approach (also shown as yellow in Figure 10). At this point the active wire ends and does not cascade again. Similarly, following any other block's blue wire outward will correctly control the signals protecting that block.

The advance approach aspect is optional in this system. If you don't want to use it, simply don't connect that input to the signal controllers.

Summary

After installing this system in several modules, we realized the wiring effort could be greatly reduced with a small custom printed circuit board. The result is called the Occupancy Bus Utility Board, or OBUB, shown in Photo 8. The OBUB is available from Scale Nature Company. It has several features to simplify installation of this system:

- Off-the-shelf RJ45 cables plug into the RJ45 jacks, eliminating tedious cutting of cables and working with fragile individual bus wires
- The bus lines are routed to screw-terminals for easy wire connection to detectors and signal controllers

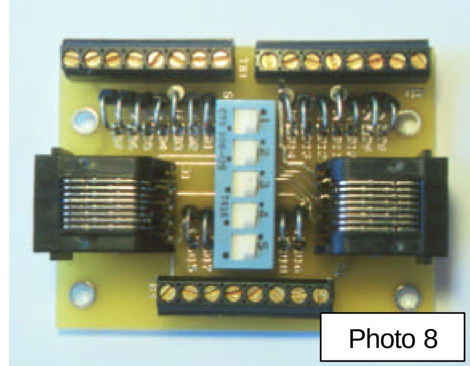
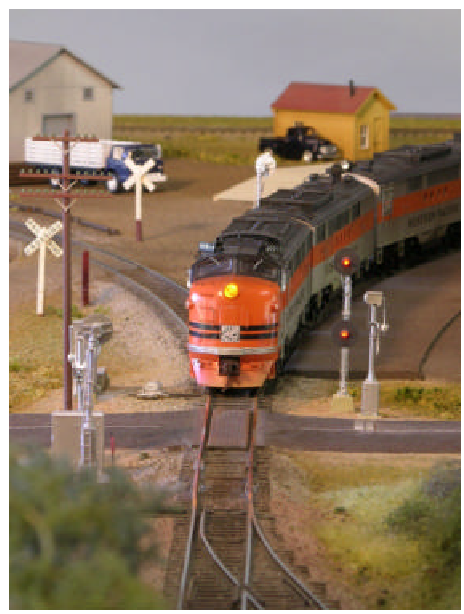


Photo 8

- It is configurable as a cascade, a cross-over, or a straight-through connection between its two RJ45 jacks
- Can be used as a portable cascade, to add signal block boundaries on-the-fly at layout setup time
- Cascade mode can be disabled, to merge two signal blocks into one
- Provides locations for isolation diodes at the detector inputs and signal controller outputs

In conclusion, we hope the ideas here inspire your modular group to add working signals for your layouts. Signals that change aspects as trains roll by are a real eye-catcher, and add realism and fun for both train operators and observers alike!



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