Traffic Signal Controllers

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This Traffic Signal Operations course presents information regarding traffic signal controllers along with information concerning the contents, arrangement, and function of items found inside a typical traffic signal controller cabinet. The material is intended to provide a practical overview of controllers and controller cabinets.

NEMA

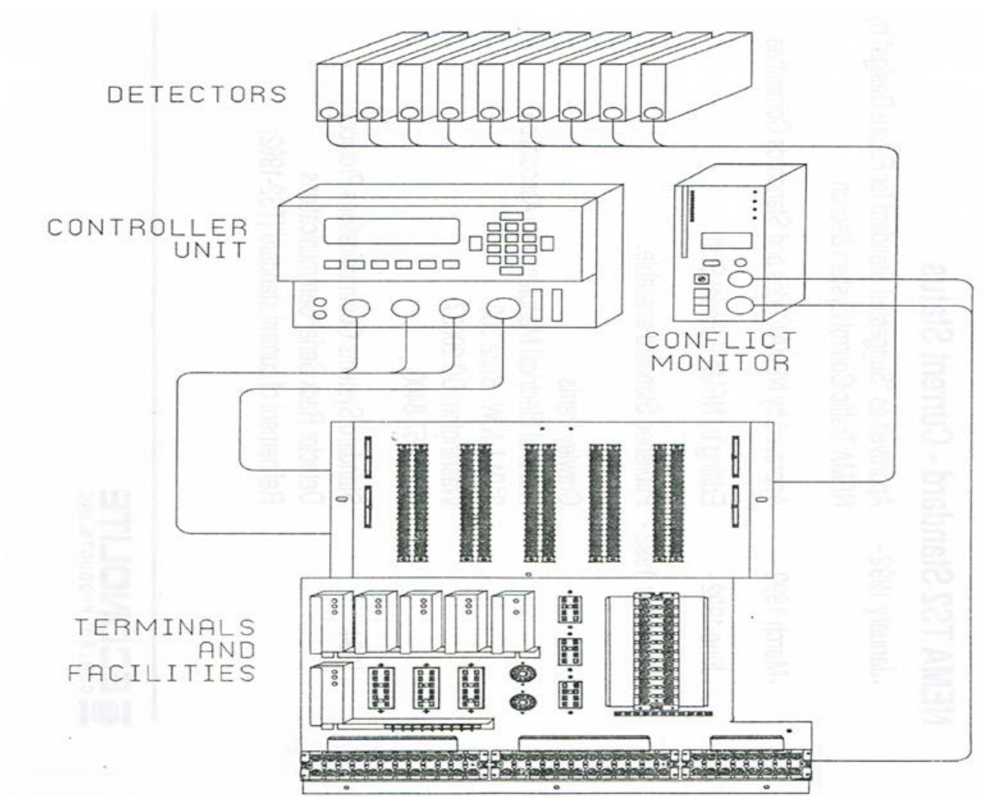
NEMA is an acronym which stands for the National Electrical Manufacturers Association. This group develops standards and conventions for various pieces of traffic signal control equipment, including controllers and cabinets.

The older NEMA standard for traffic signal control equipment is known as the TS-1 standard while the newer standard is known as the TS-2 standard. The first version of the TS-1 standard was introduced in 1975 and the first version of the TS-2 standard was introduced in 1998. Prior to 1975, there was no industry standard for traffic control equipment and no interchangeability amongst controller manufacturers.

THE NEMA TS-1 STANDARD

The last update of the NEMA TS-1 standard for traffic signal control equipment was published in 1989. It is still of interest since much of the traffic signal control equipment that exists along today's streets was installed under, and conforms to, this standard. The TS-1 publication provides standards on a variety of important topics, including:

- Environmental Requirements
- Load Switches
- Conflict Monitors
- Inductive Loop Detectors
- Flashers
- Signal Controllers



TS-1

In a TS-1 configuration the controller is connected to the back panel and other cabinet devices via three MS-type connectors designated A, B, and C with designated pin configurations. A fourth D connector may be added to provide advanced features but a standard pin configuration is not specified by NEMA for this connector; it is manufacturer specific.

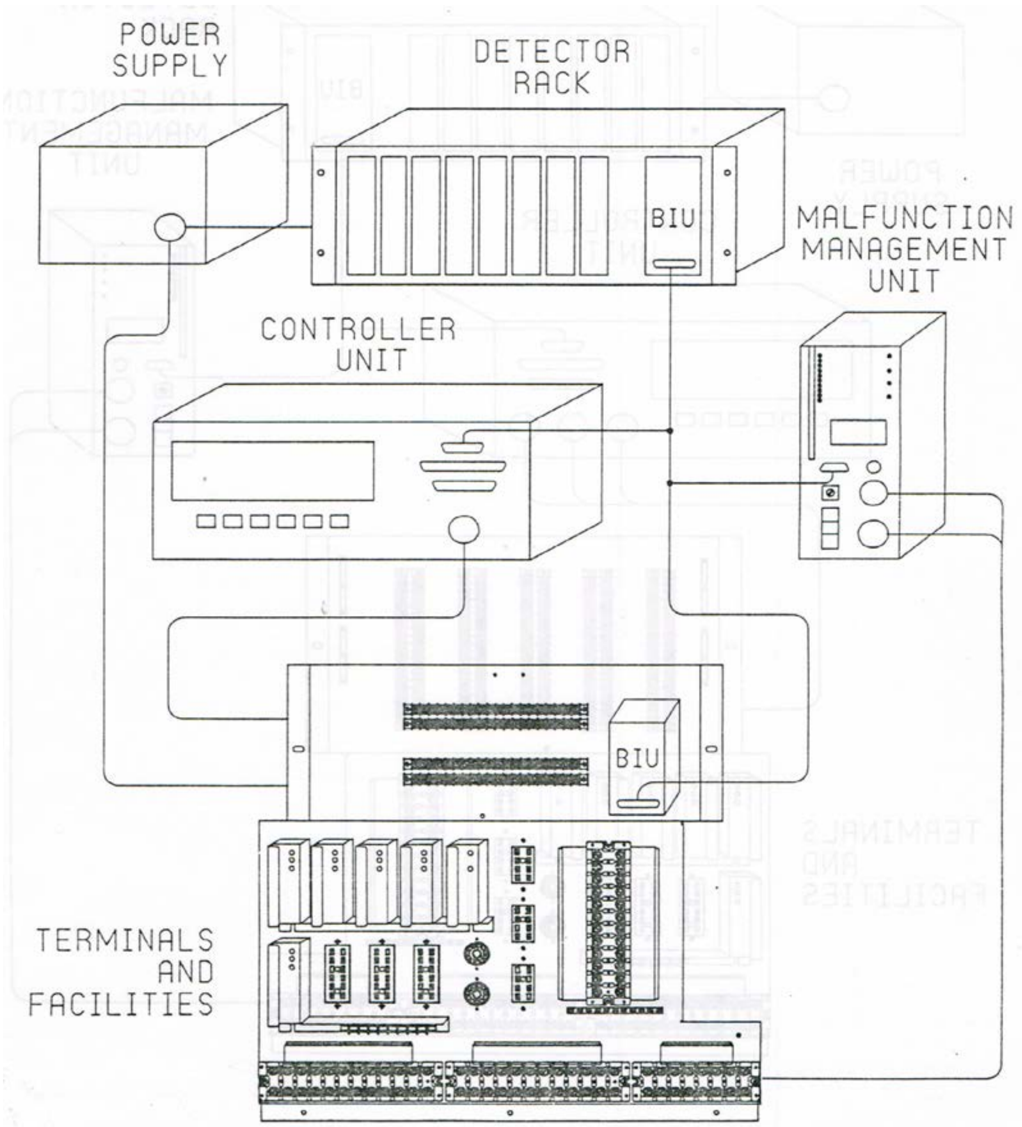
NEMA requires electrical devices used within the controller cabinet to operate properly under adverse environmental conditions, including temperature extremes, shock, vibration, and voltage transients. The extent of the extremes that the equipment must endure, and the specific tests used to verify acceptable performance is spelled-out by NEMA in the TS-1 document.

NEMA requires that the equipment operate properly between -34°C and +74°C, which equates to a Fahrenheit temperature range between -30°F and +165°F. During periods of high ambient temperature with direct sunlight beating down on the cabinet, the temperature inside the cabinet can exceed these temperatures. Consequently, a thermostat-controlled fan and vent assembly are usually needed to circulate air within the cabinet so as to keep the temperature within NEMA limits. During very cold weather, cabinet heaters may be needed to keep the temperature from dropping too low.

THE NEMA TS-2 STANDARD

The last update of the NEMA TS-2 standard for traffic signal control equipment was published in 2003. This standard has many advantages with respect to the older TS-1 standard. These include: a standardized treatment of preemption, coordination, and time-based control functions; a more sophisticated failure detection system; extended detector capabilities; and the routine availability of many advanced controller features.

The TS-2 standard permits two different system configurations. The Type 1 configuration is the most advanced, enjoying all of the capabilities and features of the TS-2 standard, however, having no downward compatibility with existing TS-1 equipment.



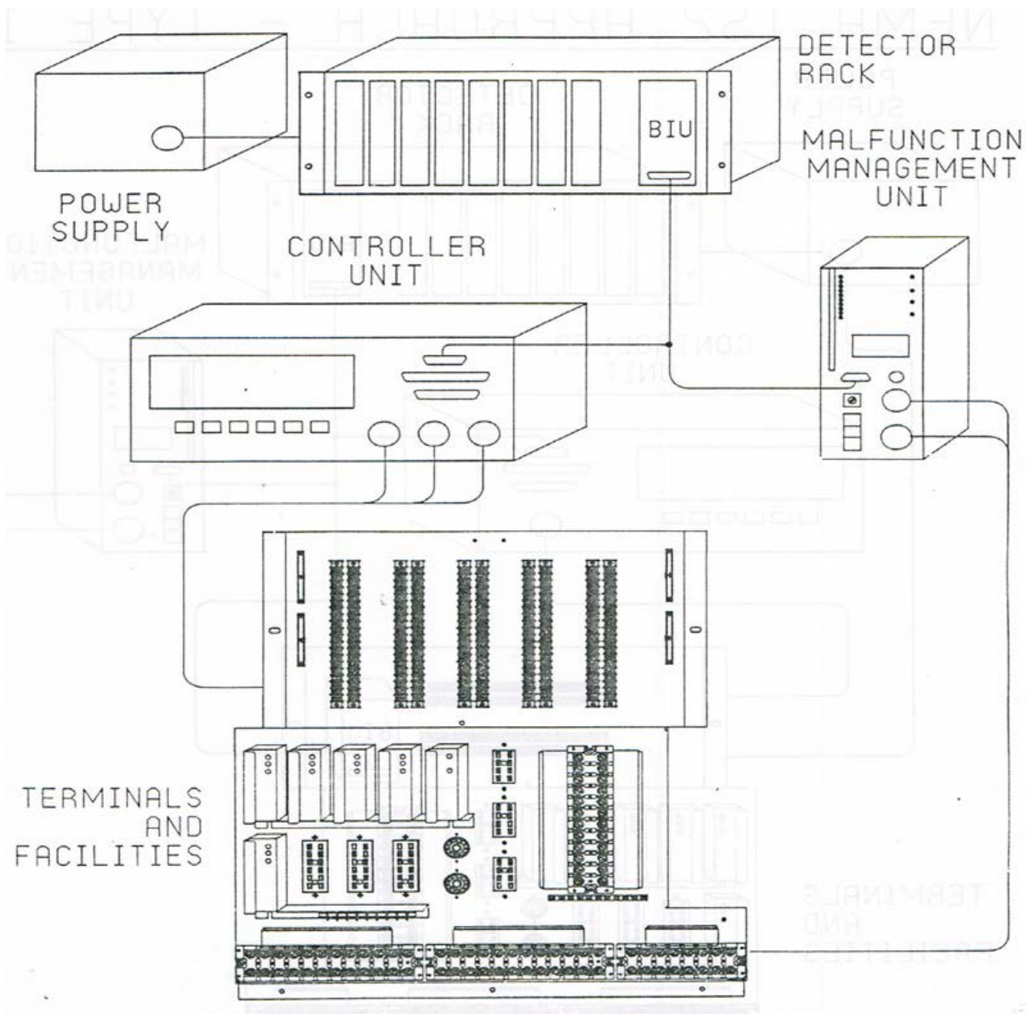
TS-2, Type 1

The Type 1 configuration makes use of three communication ports:

Port 1: a high-speed serial bus for data transfer between all major pieces of equipment in the cabinet
Port 2: a standard RS-232C port
Port 3: a systems communication port for interfacing with a traffic signal control system, such as a closed-loop system

Bus Interface Units (BIU's) are used in the Type 1 configuration to connect various pieces of control equipment (such as the detector rack) to the high-speed data bus. The input/output configuration of the BIU depends on the piece of equipment to which it is attached, and the desired application.

The Type 2 configuration provides downward compatibility with TS-1 cabinets, but has considerably fewer capabilities than the Type 1 configuration. The Type 2 configuration retains the standard A, B, and C, MS-type connectors found in TS-1 installations while adding 24 inputs and 24 outputs for new functions:



TS-2, Type 2

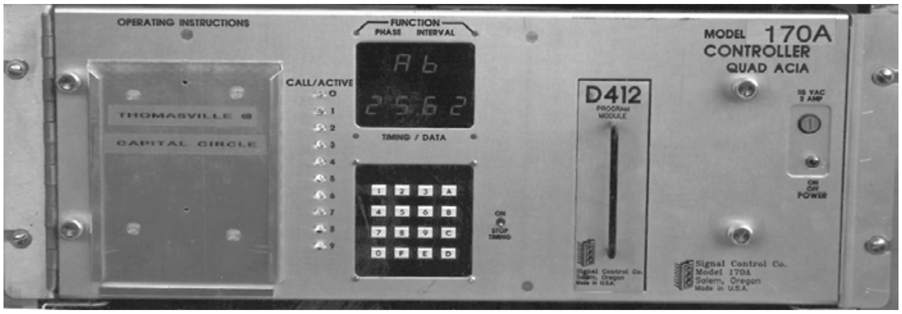
Both the Type 1 and Type 2 configuration make use of a Malfunction Management Unit (MMU) which replaces the TS-1's conflict monitor. The MMU provides the same basic conflict and voltage monitoring functions as a conflict monitor, but with a host of additional features, including:

- cabinet level AC line voltage monitoring
- load switch input/output monitoring
- minimum clearance time monitoring
- automatic diagnostics
- communications capabilities

Both the Type 1 and Type 2 configurations call for the use of rack-mounted detectors. Inductance loop diagnostics for detecting such failures as an open loop, a shorted loop, or an excessive change in inductance, are provided for all detectors. Both the Type 1 and Type 2 configuration also enjoy expanded detector capabilities in comparison to TS-1. This includes auxiliary detector inputs that can be assigned to any phase or function, and up to 8 inputs that can be assigned to system detectors. In addition, each detector input can have delay, extend, or detector switching capabilities activated.

THE TYPE 170 STANDARD

Instead of following the NEMA standard, the States of California and New York developed their own set of controller and cabinet specifications for what are known as Type 170 controllers. Although originating with California and New York, a number of other states and local agencies adopted the Type 170 Standard. Updates to the Type 170 standard produced the 179 controller and eventually the modern model 2070 controller, which is the latest in a line of traffic signal control equipment that falls under the general heading of Type 170.



Type 170

The Type 170 specification results in standardized hardware, which allows a higher degree of equipment interchangeability. In general, equipment from one manufacturer can be mixed-and-matched in a controller cabinet with equipment from other manufacturers, with little or no loss in performance. Since the hardware is standardized, money is saved on spare parts as well as the training of maintenance personnel.

In order to achieve standardization, the 170 Standard is much more detailed than the NEMA standard, providing precise specifications on virtually every item inside the cabinet. The specifications cover a wide range of items, including communication devices, relays, detectors, flashers, preemption devices, and the controller itself. To make the hardware truly interchangeable, this high degree of hardware specification must be provided.

Even though the hardware is standardized, the performance of the control system is kept flexible through the use of customized software. Any party, not just the controller manufacturer, can write software for Type 170 controllers. This allows unique and innovative signal control techniques to be developed by anyone that has the time and initiative to do so.

The controller cabinet for the Type 170 controller is generally taller, with a smaller footprint, than a NEMA cabinet. All of the equipment, including the controller and the detectors, are stacked vertically on top of one another within a 19-inch rack. One interesting feature of most model 170 controller cabinets is that they have a back door to the cabinet as well as a front door. This increases accessibility to the equipment and to the internal cabinet wiring, making repair easier.


DANGER
HIGH
VOLTAGE


STOP
HERE ON
RED
BUS
STOP
DANGER
HIGH
VOLTAGE

A slot within the Type 170 controller is reserved for a standardized Prom Module which contains the software used to control the Type 170 system. The inputs and outputs controlled by this software are highly flexible and logic can be written into the software to control devices other than standard traffic signals. Ramp metering signals, changeable message signs, uniform sprinkler system, can all be controlled using a Type 170 system with the proper software.

In comparison to NEMA, the Type 170 standard has a slightly different temperature requirement for cabinet equipment: between -37°C and +74°C, which equates to a Fahrenheit temperature range between -35°F and +165°F.

The Type 170 specification defines many more standard timing functions than the NEMA standard, including such items as red lock, yellow lock, double entry (also called "dual entry"), lag phases (for lead/lag left turn operation), and so on. In addition, delay and extend features are routinely provided for all detectors.

ADVANCED TRANSPORTATION CONTROLLER

In 2006, a new comprehensive controller standard was finalized that has essentially been embraced by the entire traffic industry - the Advanced Transportation Controller (ATC) standard. This standard includes rack mounted and shelf mounted ATC controllers for compatibility with both NEMA and Type 170 cabinets. The new ATC standard uses an open Linux operating system that encourages the development of advanced transportation applications by third-party software developers. Communication capabilities are provided via two Ethernet ports, one designated for Wide Area Network (WAN) applications and one designated for Local Area Network (LAN) applications. This powerful new controller has virtually unlimited capacity and flexibility for both advanced traffic signal and ITS (Intelligent Transportation System) applications.

The ATC has been designed to operate within a new roadside cabinet that comes in three sizes: the large base-mount model 340 cabinet, the intermediate size base-mount model 342 cabinet, and the small pole-mount model 356 cabinet. However, many of the design choices in the standard reflect the basic requirement that the ATC provides backward interface compatibility with existing cabinets, including NEMA TS1, TS2, Caltrans Model 170, NYDOT Model 179, and 2070 units.

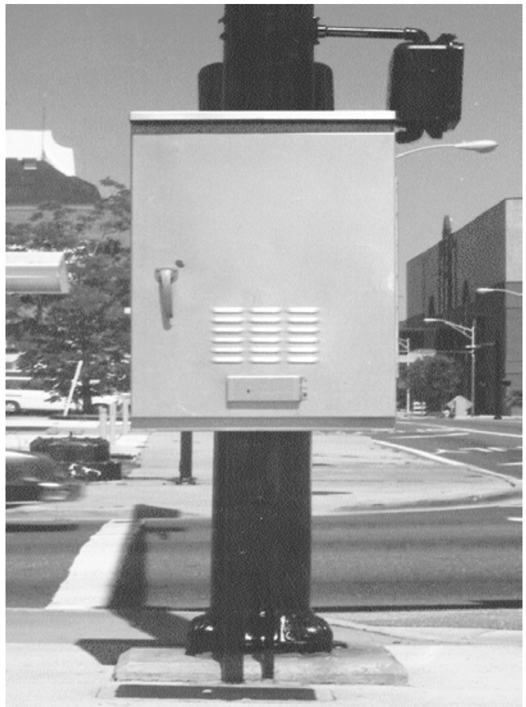
The goal of this new standard is to provide an open architecture design for the next generation of transportation controller applications. The design specified in the ATC standard is based on the concentration of computing power in a single component, the engine board, which is interchangeable with engine boards designed by other manufacturers. The standard provides for both required and optional features, all of which are based on open and common communication protocols.

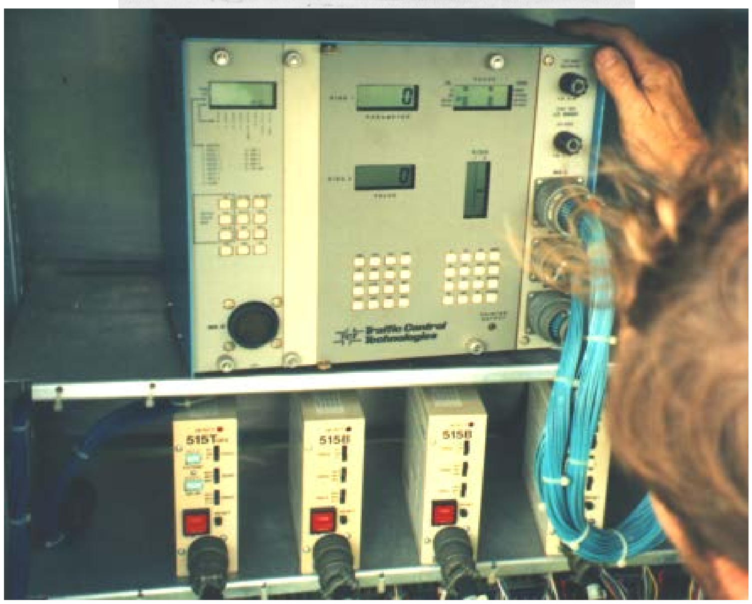
The end result is that the NEMA standard and the Type 170 standard will, over time, slowly but surely give way to the newer, more powerful, and more flexible, ATC standard.

The ATC standard specifies an operating ambient temperature range that matches the Type 170 range, from -37 ˚C to +74 ˚C. It also specifies a storage temperature range, from -45 ˚C to +85 ˚C. In addition, the ATC standard requires that the equipment meet humidity, vibration and shock requirements.

THE CONTROLLER CABINET

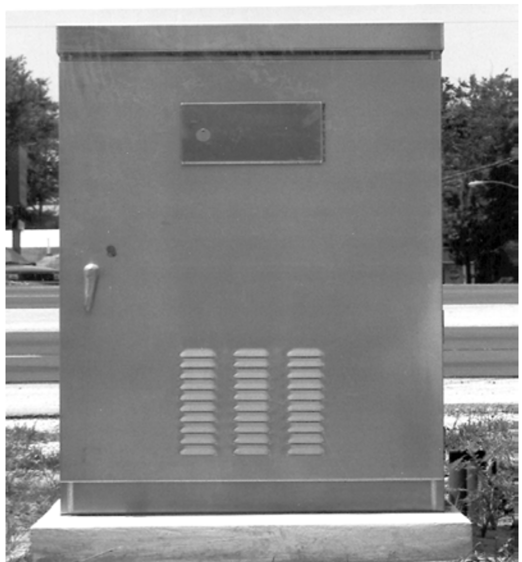
Controller cabinets are generally either pole mounted or ground mounted. Pole-mounted cabinets are typically banded or bolted to the side of a traffic signal support pole.

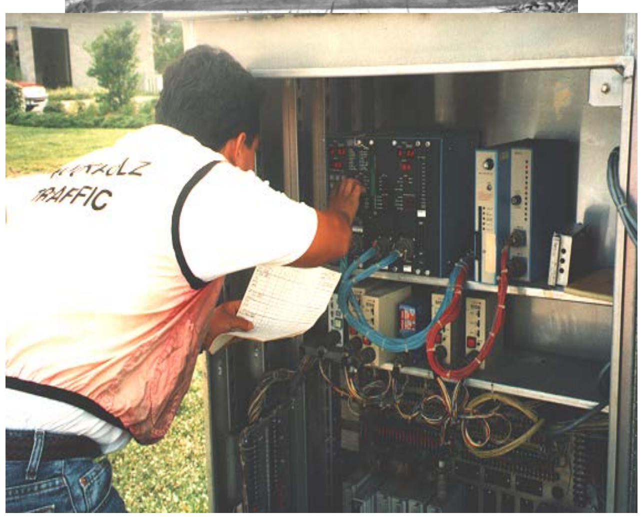




The field wires from a pole-mounted cabinet either run through the back of the cabinet to the center of the hollow support pole to which it is attached, or run through the bottom of the cabinet to steel conduit mounted on the outside of the support pole.

Ground mounted cabinets are typically bolted to a concrete foundation with the heads of the bolts set in the concrete and the cabinet attached to the concrete using a set of washers and nuts.





The field wires from the cabinet run through conduit that is encased in the cabinet foundation. Larger cabinets are typically ground mounted because of their considerable size and weight. Unless extenuating circumstances prevent it, the cabinet door should open away from the intersection. This allows the technician to easily monitor signal head indications and traffic behavior while, at the same time, observing the operation of the controller and detector units located within the cabinet.

Some agencies require that the base of the controller be at the same elevation, or higher, than the road surface. This prevents the controller from being located in a ditch or gully that could make seeing the intersection difficult and that might facilitate water intrusion. Electrical devices and water do not mix. Consequently, the controller cabinet must be sealed to prevent water intrusion. This is done by providing a rubber gasket for the cabinet door and, for base-mounted foundations, by sealing the gap between the cabinet and the concrete base with a silicone sealant.

Circulating air through the controller cabinet is important to keep temperatures to acceptable levels in hot climates. However, doing so can draw dust into the cabinet, and dust can adversely affect electrical components. Consequently, filters must be used at the cabinet air input vents to catch dust particles.

The cabinet cannot be completely sealed from water since air input vents are needed for the air circulation system to work. Consequently, if the cabinet is located close to the road and the door opens toward the road, passing vehicles may splash puddled water through the air input vents and into the cabinet. This is another reason to orient the cabinet so that the door opens away from the intersection.

Controller cabinets come in various sizes**.** Smaller cabinets are used for simple intersections with few phases whereas large cabinets are used for complicated multi-phase intersections. With more phases comes the need for more load switches, more detectors, and larger interface panels, hence the need for a bigger cabinet. Cabinets are typically fitted with a light for night work along with a standard electrical outlet. To save energy and increase bulb life, a door switch is often used to turn off the light when the cabinet door is closed, just like a refrigerator.

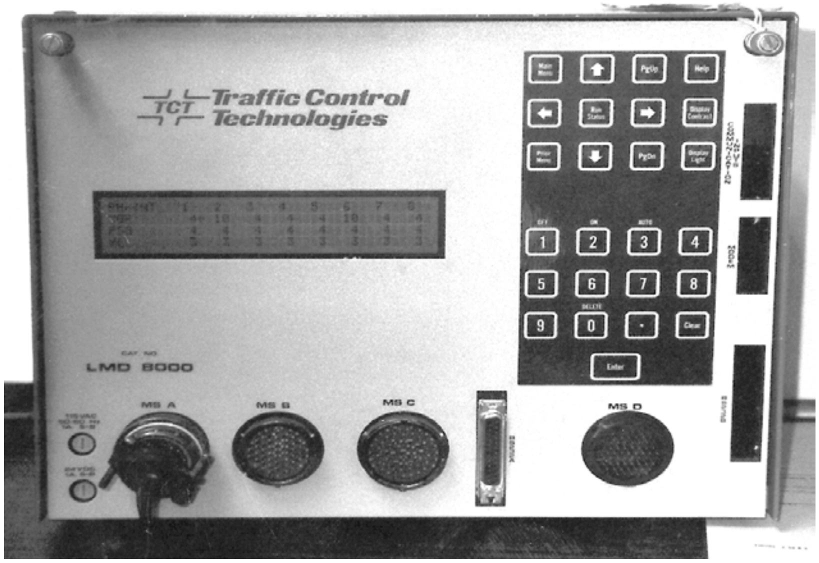
Depending on the type of controller cabinet that is used, the major electrical devices may be either mounted on racks within the cabinet or may just sit on a cabinet shelf. In some instances, both mounting techniques may be used inside a cabinet. For example, it is not uncommon to encounter rack mounted detector amplifiers in the same cabinet with a shelf mounted controller and conflict monitor.

Although controller cabinets may contain a wide variety of electrical devices, the following major items are almost always found:

- Traffic Signal Controller
- Conflict Monitor (or Malfunction Management Unit)
- Detector Amplifiers (also referred to as "Detector Units" or just "Detectors")
- Load Switches (called Switch Packs for Type 170 controllers)
- Electrical Panels

THE TRAFFIC SIGNAL CONTROLLER

The traffic signal controller is the "brain" of the intersection. Modern controllers are capable of fully actuated operation, producing signal timings that vary depending on the level of traffic demand. The controller uses settings that have been programmed inside it, along with the vehicle demand for each phase as presented to it by vehicle detectors, to make decisions on the allocation of green time to the various phases.



The settings in a modern traffic signal controller can be grouped into six timing categories:

- Basic Settings
- Coordinated Settings
- Time-of-Day Settings
- Preemption Settings
- Detector Settings
- Special Settings

Basic settings include controller timings and functions required for isolated (non-coordinated) signal operation (initial, passage, maximum, yellow, all-red, recall, etc.) and rudimentary phase configuration information (phase rotation, start-up phases, flash entry and exit phases, etc).

Coordinated settings include cycle lengths, offsets, split plans, permissive periods, and other information needed to develop coordinated signal operation between signalized intersections.

Time-Of-Day (TOD) settings control the times during which the various coordinated timing plans and special functions (such as low-volume flashing operation) are active. These settings include year plans, week plans, day plans, special day plans, and procedures for switching to and from daylight savings time. The controller's internal clock and date are also set in this section.

Preemption settings are used to dictate the behavior of the traffic signal when a preemption input is received. The type and number of settings that are needed will depend on the kind of preemption that is to be accommodated at the intersection (railroad, emergency vehicle, fire station, or bridge opening) as well as the complexity of the signal. For example, railroad preemption at an eight phase intersection requires a more detailed set of timings than bridge preemption at a two-phase signal.

Detector settings include all settings that affect detection behavior, including detector phase assignments and delay and extend times.

Special settings is a catch-all category that includes seldom-used or sophisticated settings, such as settings to activate diamond interchange operation or signal dimming.

Modern controllers are designed to retain all settings in their memory even when power to the controller is removed, as may happen during a power outage caused by a storm.

Certain manufacturers are now offering battery back-up systems to power the entire intersection when normal power is lost. These units, which attach to the outside of the controller cabinet, can provide supplemental power to the signal for many hours.

With the widespread use of low-power-consuming LED traffic signal displays, and with the increasing power storage capabilities of modern batteries, the capability to run signalized intersections for extended periods of time on batteries alone has been constantly improving. In fact, it is getting to the point where charging these new batteries using solar or wind power is a feasible way to power an entire signalized intersection on a permanent basis; not just as a back-up plan.

In modern controllers, signal timing parameters are programmed into the controller using a keyboard located on the front of the controller, giving rise to the term: "front panel programming". The first wave of controllers with front panel programming capability used numerical codes to represent timing functions, with the codes appearing on the front panel display along with the phase number and the timing entry. For example, the numerical code for the yellow interval in a particular controller might be "3". This code would show-up at some fixed location in the display, along with the phase number (such as 5) and the timing value (such as 4.0). This technique requires the operator to either memorize the codes for each type of controller or to constantly refer to the programming manual.

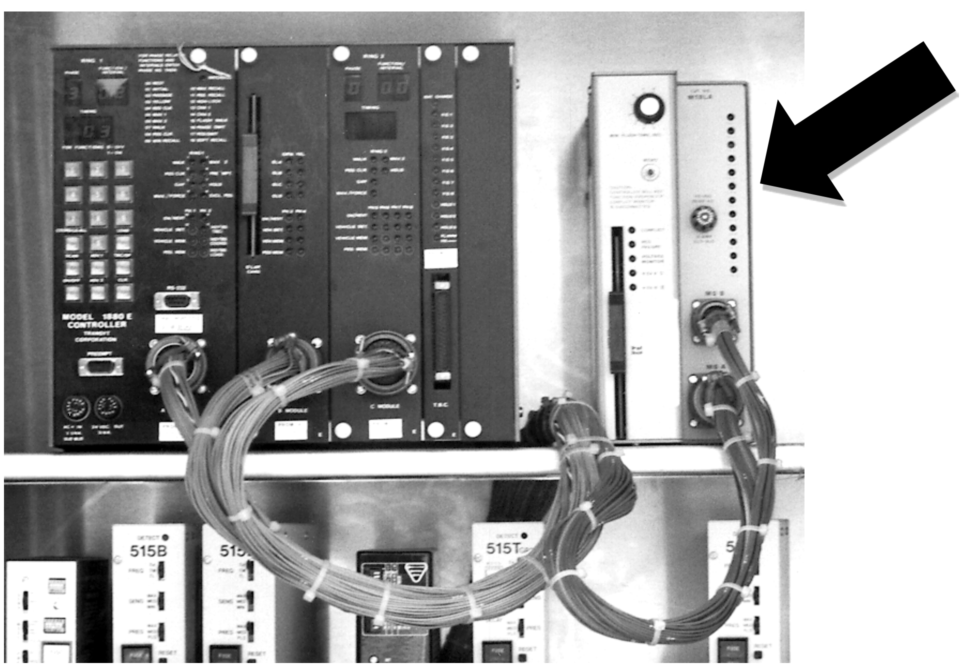
Since about the early 1990's, controllers with front panel programming have used plain English descriptors (either words, phrases, or acronyms) to indicate timing functions.

In addition, a standard computer menu structure (an upside-down tree) is now used to logically organize groups of signal settings. This makes each setting much easier to understand and much easier to locate within the controller. Using plain English and standard menu structures also reduces the need for memorization of codes or constant referral to a manual. Settings in these newer controllers can also be quickly updated using laptop or notebook computers, or via a hand-held PDA (Personal Digital Assistant). And if the intersection is connected to a central control center (thru copper cable, fiber-optic lines, radio modems, or a telephone drop) timings can be downloaded remotely to the controller. The entire data entry process for traffic signal controllers has become much more automated as time has gone by.

THE CONFLICT MONITOR (aka MALFUNCTION MANAGEMENT UNIT)

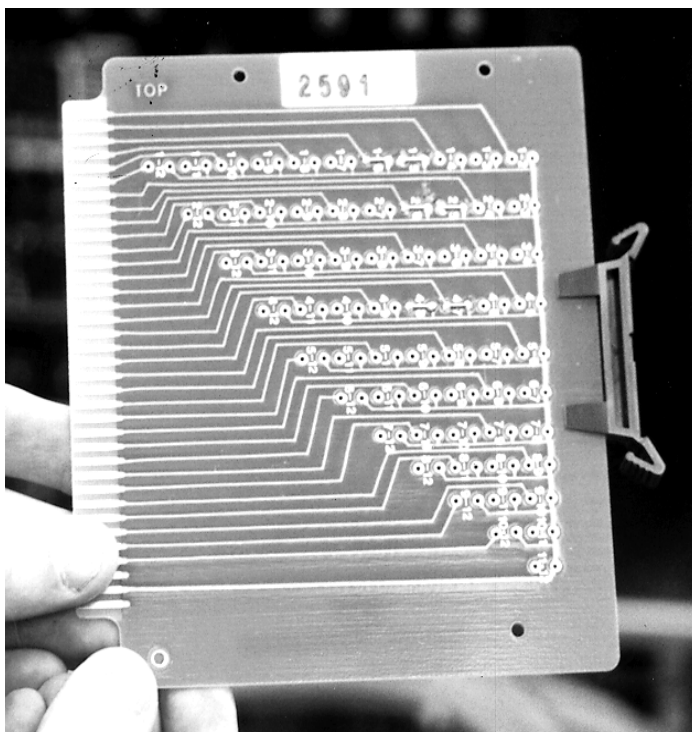
The conflict monitor checks the operation of the traffic signal controller to make sure that an electrical glitch does not create a dangerous situation at the intersection. The conflict monitor has three basic functions:

- To check for the simultaneous activation of conflicting phases;
- To check for the absence of a red indication on a phase that does not have a green, yellow, or walk; and
- To check for insufficient operating voltage (usually due to a power interruption).



If the conflict monitor detects that two conflicting phases (phases that control conflicting vehicle movements) are active at the same time, the monitor will immediately place the intersection into latched flashing operation. A phase is considered to be active if it has either a green, yellow, or walk indication. Latched flashing operation is flashing operation that will continue until the conflict monitor's reset button is activated.

A removable programming card is inserted into the conflict monitor. The configuration of the programming card indicates to the conflict monitor the phase combinations that are non-conflicting and can be active at the same time. After it is configured, the card is inserted into the slot on the front of the conflict monitor.



If the conflict monitor detects that a phase is not active, yet there is no red input to the phase, the monitor will immediately place the intersection into latched flashing operation. It should be emphasized that the conflict monitor checks for absence of red at the field terminals within the cabinet. Consequently, it cannot identify absence of red if it is caused by factors outside the cabinet, such as burnt out bulbs. If this type of monitoring is desired, manufacturers offer sensors which can be used to determine if a signal head bulb has burned-out.

If the conflict monitor detects that the operating voltage of the controller's 24 volt DC supply (which powers peripherals, such as the load switches) has fallen below 18 volts, then the monitor will immediately place the intersection into non-latched flashing operation. If the "voltage monitor output" of the controller is not "true" (low), then improper operating voltages are present within the controller unit. The conflict monitor will detect this and immediately place the intersection into non-latched flashing operation. The monitor will also place the intersection into non-latched flash if its own operating voltage is improper. Having flash operation that is non-latched for low voltage situations allows the intersection to automatically return to normal operation once power to the intersection has been restored and voltages return to normal.

Conflict monitors have front panel indicators which provide information as to the type of failure that sent the intersection into flash (green conflict, absence of red, or low voltage) and the phases that were active when the intersection was sent into flash. This information is very helpful to the repair technician in determining what caused the conflict.

Conflict monitors have a reset switch that, when activated, returns the signal to normal operation.

The reset switch should only be used when the problem which caused the conflict has been identified and corrected, or during conflict monitor testing.

Modern controller cabinets are wired such that the intersection will immediately go to flash if the conflict monitor is disconnected. This safety feature, referred to as cabinet interlock, ensures continual use of the conflict monitor.

DETECTOR UNITS

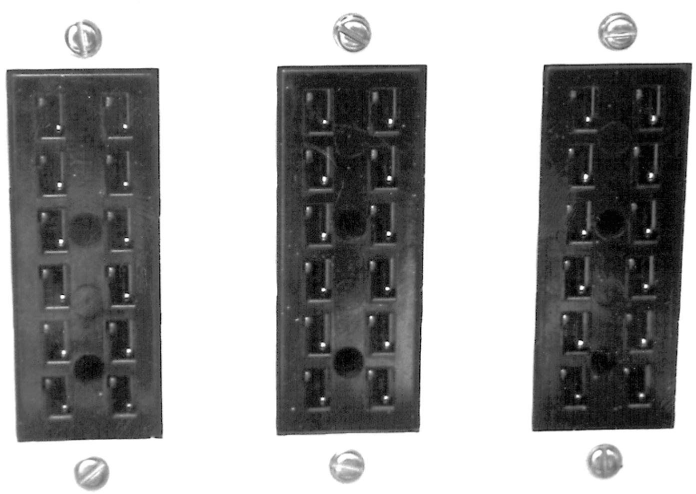
Detector units identify vehicle actuations based on information sent back to the units by their associated field units and pass this information along to the controller for use in timing the intersection.

Detector units are referred to as "detector amplifiers" when they are used with inductance loops, which are the most common field units used for vehicle detection. In addition to identifying vehicle actuations based on information received from the inductance loops, the detector amplifiers also power the inductance loops, resonating them at a selected frequency.

LOAD SWITCHES (SWITCH PACKS)

Load switches (known as switch packs in a model 170 installation) are essentially electrical gating devices that allow the controller logic, which operates in a 24 volt DC system, to direct the 120 volt AC current to the various signal heads.

The load switch has 12 large male connectors that plug into 12-hole sockets located on the back panel of the controller cabinet. These sockets are commonly referred to as the load switch "bays".



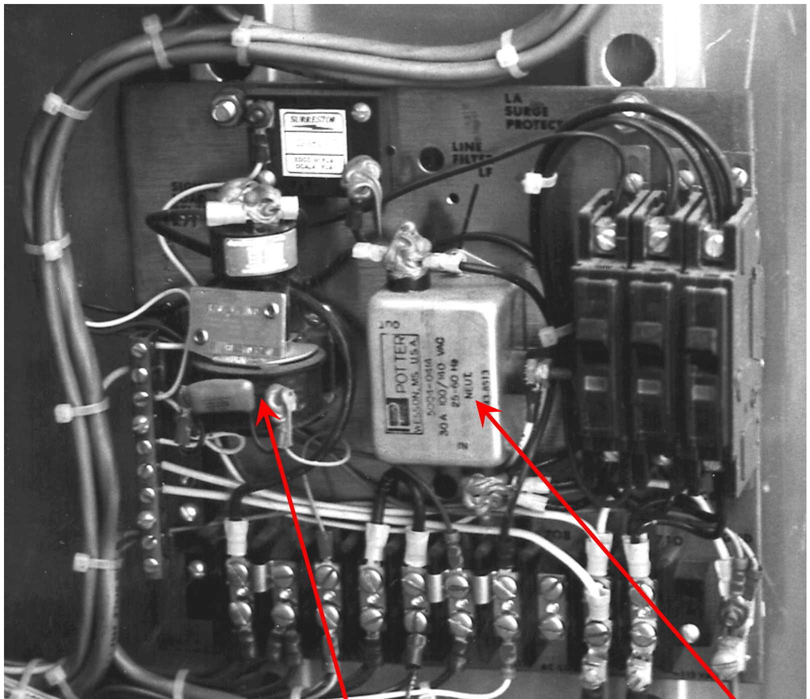
A load switch is required for each signal phase, pedestrian phase, and overlap used at an intersection. Each of the load switches has three indicator lights arranged vertically on the front of the load switch. For load switches that gate current to signal heads, the top light is on when the red indication is active, the middle light is on when the yellow indication is active, and the bottom light is on when the green indication is active. For load switches that gate current to pedestrian heads, the top light is on when the "don't walk" indication is active, the middle light is on when the pedestrian clearance interval (flashing don't walk indication) is active, and the bottom light is on when the "walk" indication is active.

ELECTRICAL PANELS INSIDE THE CONTROLLER CABINET

In addition to these electrical devices, the cabinet also contains a number of electrical interface panels. They are:

- The Power Panel
- The Detector Panel
- The Detector Test Panel
- The Back Panel
- Preemption Panel (Optional)
- The Communications Panel (Optional)

The 120 volt, 60 Hz, single-phase AC+ (Line Side) and AC- (Common or Neutral) power supply lines from the local electric company are attached inside the cabinet at the power panel.

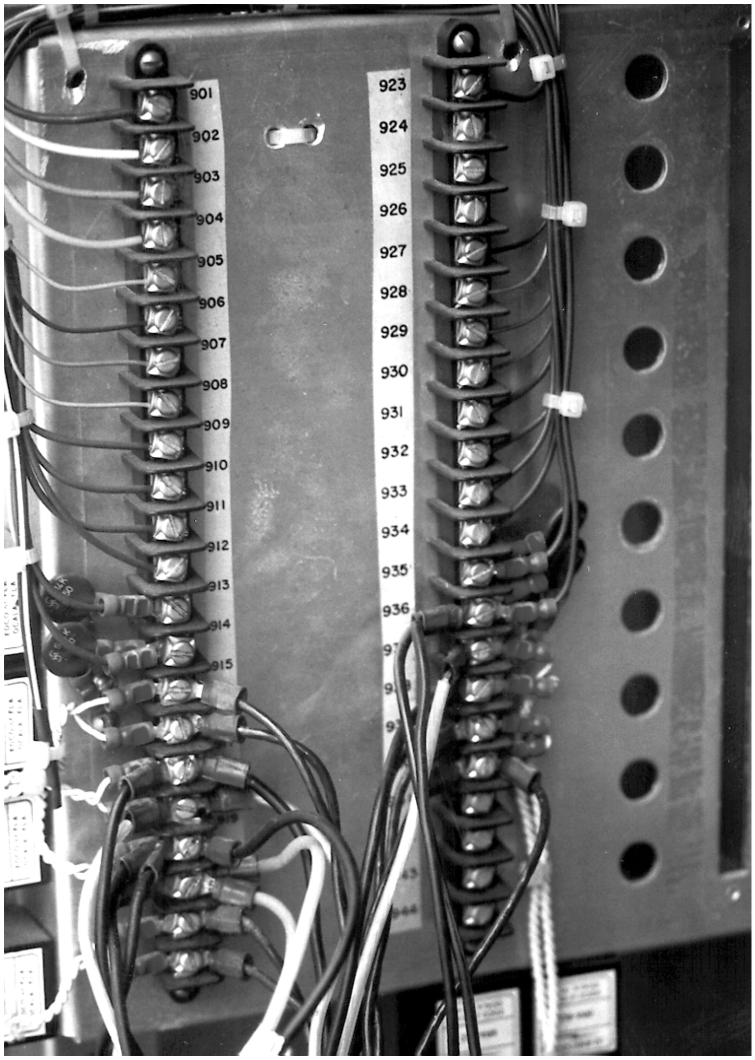


Before being fed to electrical devices within the cabinet, the electricity from the power company is passed through a <u>radio interference suppressor</u> and a <u>surge suppressor</u> that are located on the power panel. Also located on the power panel are a series of circuit-breakers which protect against current overload.

The surge suppressor located on the power panel is designed to intercept transient voltages that could affect signal operation or damage signal equipment, such as those caused by nearby lightning strikes. Depending on the location and intensity of the strike, a surge suppressor may or may not be able to protect the signal against voltage spikes caused by lightning.

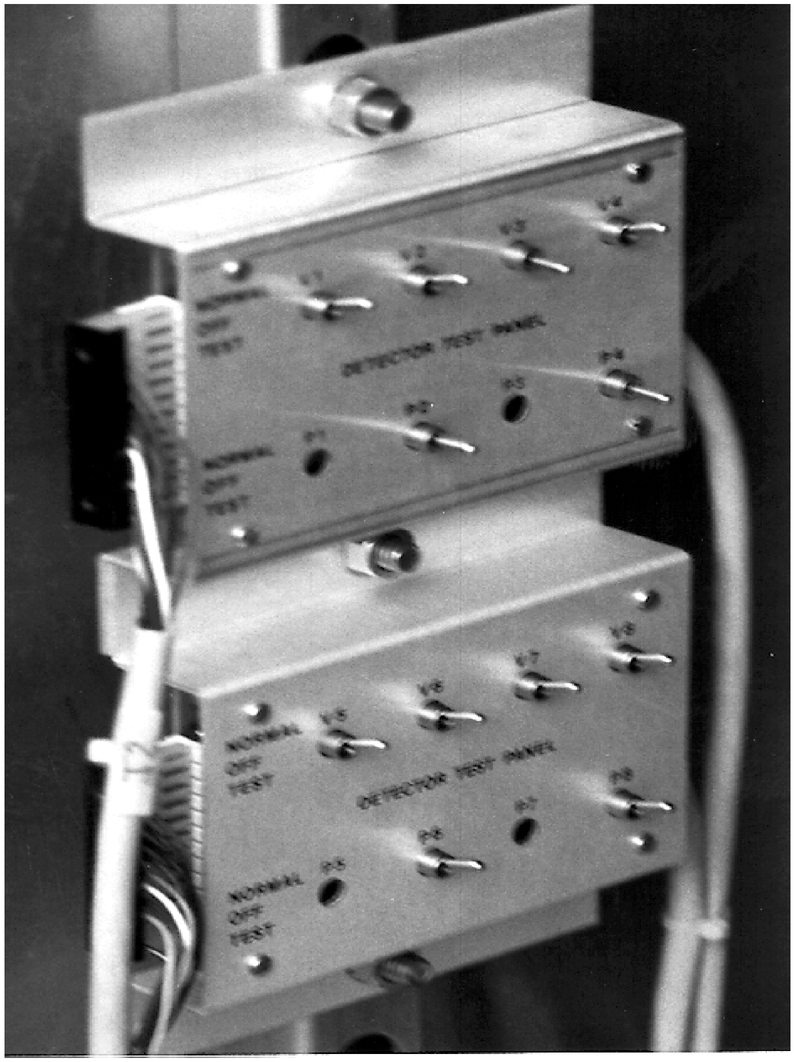
The radio interference suppressor protects the electric company's equipment and items attached to it (televisions, radios, etc.) from interference that might be generated by the traffic signal equipment and fed back through the power lines or radiated into the air.

The detector panel provides the interface between the vehicle detector field units (such as inductance loops) and the detector amplifiers.



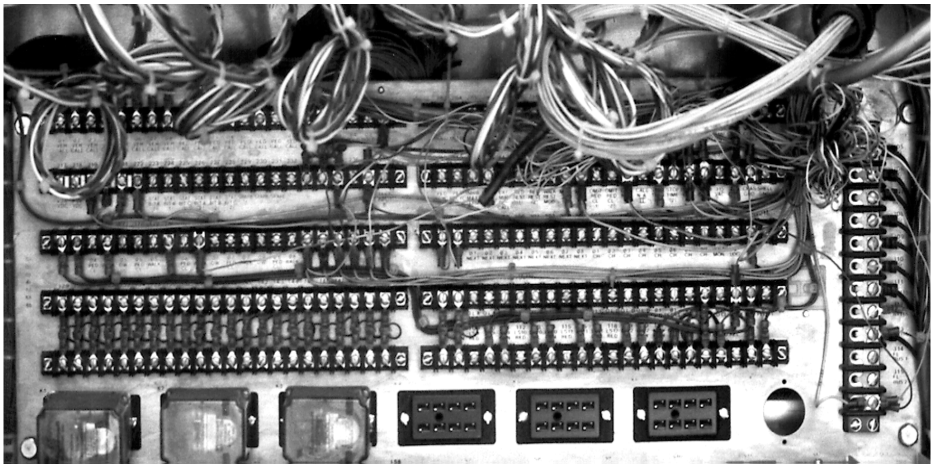
The field wires from the inductance loops are attached to terminals located on the detector panel. In many cabinets, field wires from the pedestrian detectors are also terminated on this panel.

The detector panel is also connected to a detector test panel which has toggle switches (or sometimes push buttons) that can be used to simulate vehicle actuations and test controller operations.



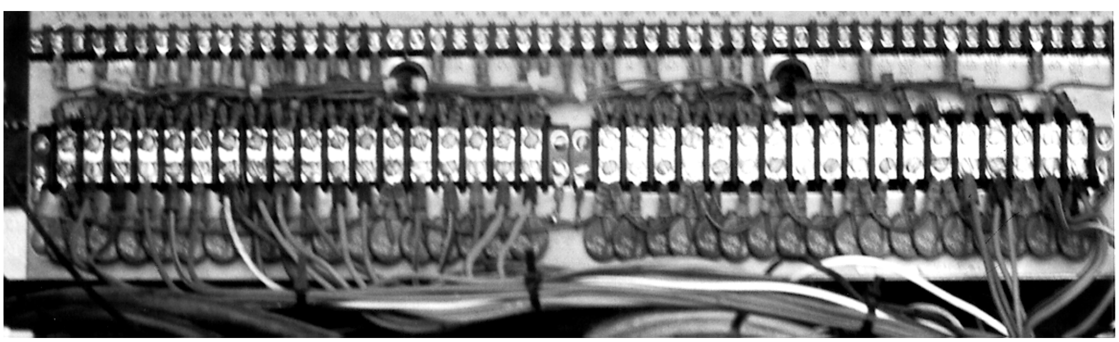
Each switch on the detector panel controls one phase. The switches can be turned off (so the phase never receives a call), can be left in normal operation, or can be used to place a test call on the phase. Activating the switch (or push-button) for a certain phase will place a test call on that phase for as long as the switch (or button) is held in the on position.

The back panel, which is usually the largest and most complex panel in the cabinet, is the primary interface between the controller and the load switches.



Decisions made by the controller are communicated, via the back panel, to the load switches which are plugged into the load switch bays on the back panel. The load switches then activate the field terminals which turn the signal heads red, yellow, and green. In addition, vehicle detections are input to the controller via the detector amplifiers which are also wired to the back panel.

The signal head and pedestrian head field terminals are usually located immediately below the back panel.



The field wires from the pedestrian and vehicular signal heads are attached to these terminals.

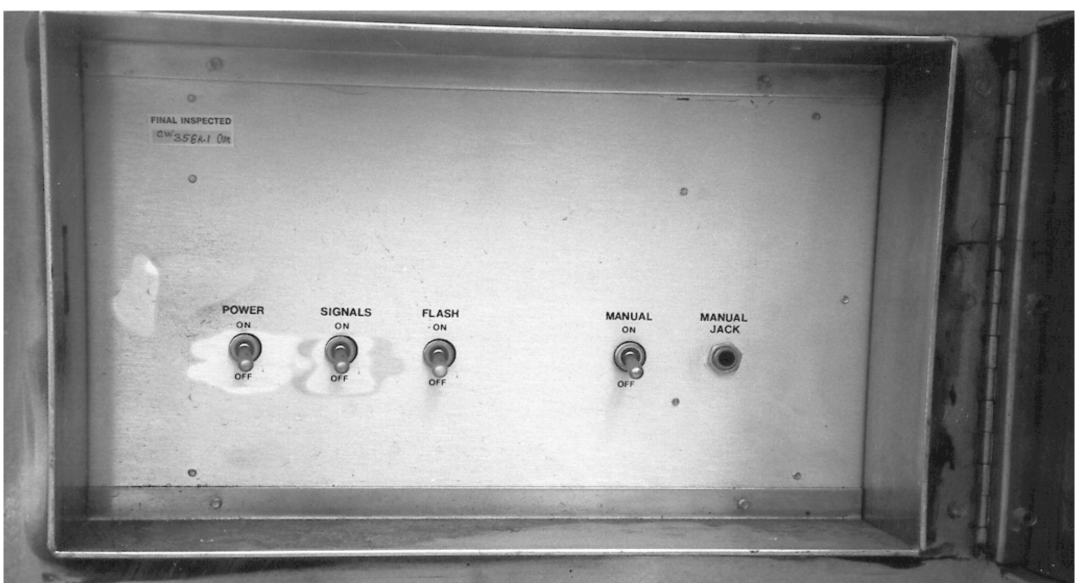
The logic portion of the electrical devices in the controller cabinet operates at 24 volts DC while the power portion operates at 120 volts AC. For example, the controller is powered by 120 volt AC current but the inputs which it receives from the detector amplifiers and the outputs which it sends to the load switches are at the 24 volt DC level.

Other auxiliary panels that are sometimes found in a traffic signal cabinet include the Preemption Panel and the Communications Panel. The preemption panel provides the wiring required to interface the controller with external preemption inputs. Inputs may be received from a variety of sources, including: railroad trains, emergency vehicles, and draw bridges. The preemption panel usually has a test switch that allows the preemption input to be simulated. The communications panel provides the wiring required to interface the controller with communication wires that run to other controller cabinets. These communication wires, which may be fiber-optic cable or copper wire, allow information to be passed between controllers and are an integral part of modern traffic control systems.

THE POLICE DOOR

The police door (police panel) provides access to a small compartment located on the outside of the cabinet door. This compartment typically houses the following items:

- The power ON/OFF toggle switch
- The signals ON/OFF toggle switch
- The AUTO/FLASH toggle switch
- The AUTO/MANUAL toggle switch, and
- A manual push-button cord



The power ON/OFF toggle switch, also called the disconnect switch, controls the electrical service entering the controller cabinet. When this switch is thrown to the OFF position, the signal heads will go dark and every electrical device within the controller cabinet, including the controller and conflict monitor, will lose power. The signals ON/OFF toggle switch, also called the signal shut-down switch, controls the power to the signal heads. When this switch is thrown to the OFF position, the signal heads will go dark but the electrical devices within the controller cabinet will continue to operate.

The FLASH toggle switch, also called the flash control switch, will immediately send the signal into flashing operation if the switch is thrown from its normal AUTO position to the FLASH position. When the MANUAL toggle switch is activated, the traffic signal can be manually controlled using a push-button cord. The manual push-button cord is used to advance the phases of a traffic signal, allowing the timing of each green phase to be controlled by the operator.

The police panel is appropriately named since it is typically used by police departments to change the operation of the signal during special events (parades, road construction, natural disasters, etc). However, the switches located within the panel can also be used by technicians during signal repair or construction activities. The police panel can be opened without having to open the cabinet door. A different key is used for the police panel than for the cabinet door to keep police personnel out of the cabinet.

Some police officers think they are also traffic signal technicians and, if allowed access to the controller, will make unauthorized changes to signal settings.

CONTROLLER GROUNDING

The grounding system in the controller cabinet is divided into three separate and distinct grounding circuits:

- neutral ground
- chassis ground (earth ground)
- logic ground

As is the case with almost any electrical system, good grounding is of utmost importance to ensure proper operation and to help protect sensitive electronic equipment from voltage spikes. Buss bars for the various levels of grounding are located at appropriate points throughout the controller cabinet. These allow convenient grounding connections to be made. All items connected to chassis ground are tied to a series of copper ground rods that are driven into the earth.