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HVAC Control System - BMS / DDC

Johnson - Shteva - Honeywell - Sauter - Seimens

Al-Suez Steel Co. - A.Sokhna, Suez

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DDC Direct Digital Control Systems

Introduction in DDC

Purpose of this Guide
The purpose of this guide is to describe, in generic terms, the various architectures, hardware components and software associated with Direct Digital Control (DDC) systems. To accomplish this goal, a generic framework of the various components and configurations used in current DDC systems has been defined. This framework is used as a yardstick for several DDC manufacturers so readers may compare the relative features and benefits.

Intended Audience
Due to the complexity and proprietary nature of DDC systems, it has become difficult to stay current with the designs, installations, operation and maintenance of DDC systems. This guide was developed specifically to help building owners and consulting/specifying engineers with these issues.

What is an Energy Management System?
For the purposes of this guide, an energy management system (EMS) is defined as a fully functional control system. This includes controllers, various communications devices and the full complement of operational software necessary to have a fully functioning control system. This guide addresses approximately twenty of the DDC vendors who serve the institutional and commercial marketplace in the United States. Vendors who supply a complete line of all the necessary hardware and software are included. This guide does not cover specialty markets (retail grocery, hotels), nor does it cover industrial or process controls.

What is Control?
The process of controlling an HVAC system involves three steps. These steps include first measuring data, then processing the data with other information and finally causing a control action. These three functions make up what is known as a control loop. An example of this process is depicted in Figure 1.

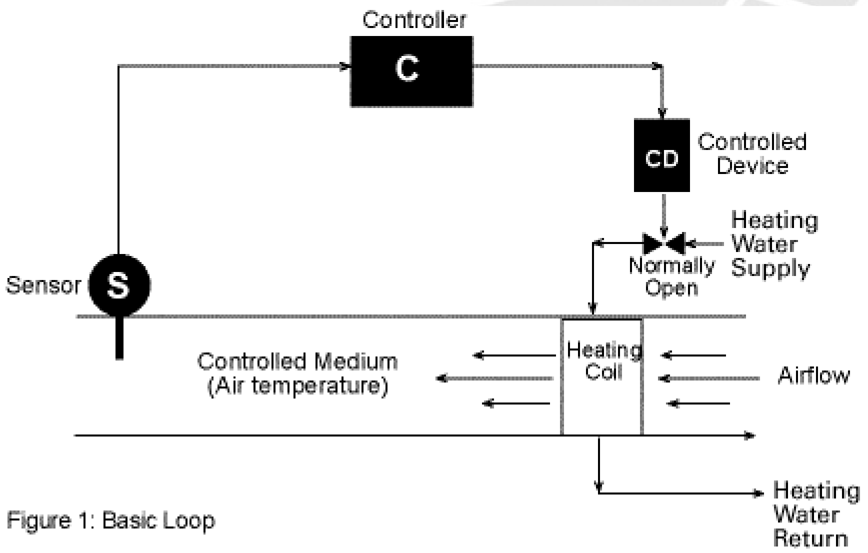


Figure 1: Basic Loop

Basic Control Loop
The control loop shown in Figure 1 consists of three main components: a sensor, a controller and a controlled device. These three components or functions interact to control a medium. In the example shown in Figure 1, air temperature is the controlled medium. The sensor measures the data, the controller processes the data and the controlled device causes an action.

The Figure 1 could be an example of a pneumatic or electronic control system, where the controller is a separate and distinct piece of hardware. In a DDC system, the controller "function" takes place in software as shown in Figure 2.

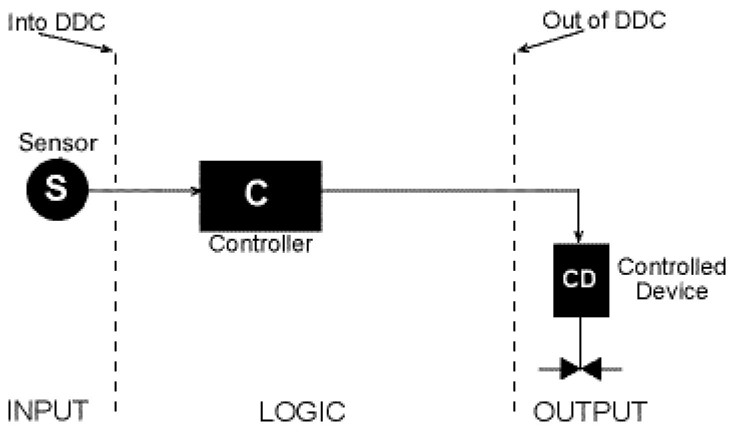


Figure 2: DDC Control Loop

Sensor
The sensor measures the controlled medium or other control input in an accurate and repeatable manner. Common HVAC sensors are used to measure temperature, pressure, relative humidity, airflow stateand carbon dioxide. Other variables may also be measured that impact the controller logic. Examples include other temperatures, time-of-day or the current demand condition. Additional input information (sensed data) that influences the control logic may include the status of other parameters (airflow, water flow, current) or safety (fire, smoke, high/low temperature limit or any number of other physical parameters). Sensors are an extremely important part of the control system and can be the first, as well as a major, weak link in the chain of control.

Controller
The controller processes data that is input from the sensor, applies the logic of control and causes an output action to be generated. This signal may be sent directly to the controlled device or to other logical control functions and ultimately to the controlled device. The controller's function is to compare it's input (from the sensor) with a set of instructions such as setpoint, throttling range and action, then produce an appropriate output signal. This is the logic of control. It usually consists of a control response along with other logical decisions that are unique to the specific control application. How the controller functions is referred to as the control response. Control responses are typically one the following:

- **Two-Position**
- **Floating**
- **Proportional (P only)**
- **Proportional plus Integral (PI)**
- **Proportional plus Integral plus Derivative (PID)**

Controlled Device or Output
A controlled device is a device that responds to the signal from the controller, or the control logic, and changes the condition of the controlled medium or the state of the end device. These devices include valve operators, damper operators, electric relays, fans, pumps, compressors and variable speed drives for fan and pump applications

Control Response

Two-Position Control
Two-position control compares the value of an analog or variable input with instructions and generates a digital (two-position) output. The instructions involve the definition of an upper and lower limit. The output changes its value as the input crosses these limit values. There are no standards for defining these limits. The most common terminology used is setpoint and differential. The setpoint indicates the point where the output "pulls-in," "energizes" or is "true." The output changes back or "drops-out" after the input value crosses through the value equal to the difference between the setpoint and the differential.

Two-position control can be used for simple control loops (temperature control) or limit control (freezestats, outside air temperature limits). The analog value can be any measured variable including temperature, relative humidity, pressure, current and liquid levels.

Time can also be the input to a two-position control response. This control response functions like a time clock with pins. The output "pulls-in" when the time is in the defined "on" time and drops out during the defined "off" time.

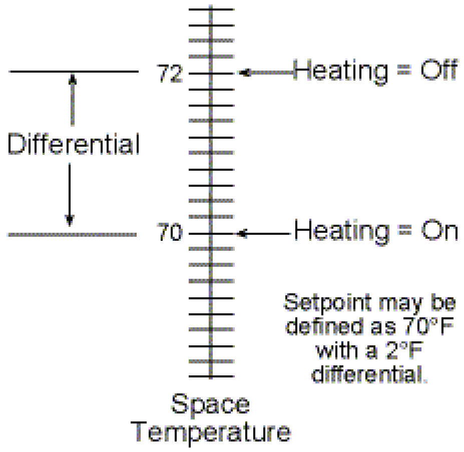


Figure 3: Two-Position Control Response

Figure 3, shows an example of two-position control in a home heating system, where the thermostat is set to energize the heating system when the space temperature falls below 70° F and turn off when the temperature rises to 72° F in the space. This is an example of a setpoint of 70° F with a two-degree differential.

Floating Control
Floating control is a control response that produces two possible digital outputs based on a change in a variable input. One output increases the signal to the controlled device, while the other output decreases the signal to the controlled device. This control response also involves an upper and lower limit with the output changing as the variable input crosses these limits. Again, there are no standards for defining these limits, but the terms setpoint and deadband are common. The setpoint sets a midpoint and the deadband sets the difference between the upper and lower limits.

When the measured variable is within the deadband or neutral zone, neither output is energized

and the controlled device does not change - it stays in its last position. For this control response to be stable, the sensor must sense the effect of the controlled device movement very rapidly. Floating control does not function well where there is significant thermodynamic lag in the control loop. Fast airside control loops respond well to floating control. An example of floating controls is shown in Figure 4.

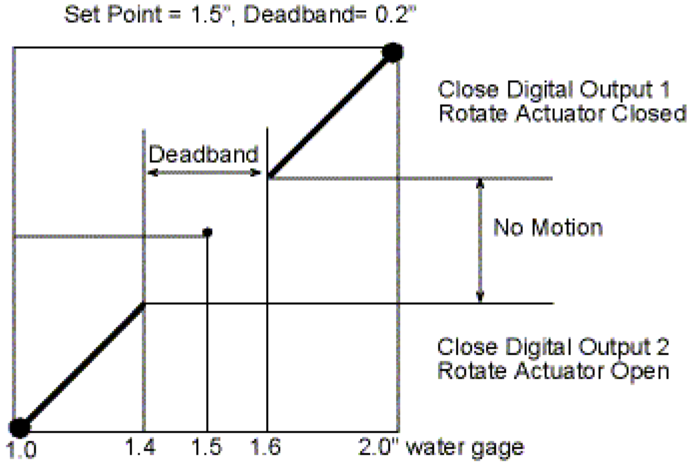


Figure 4: Floating Control Response

Proportional Control

A proportional control response produces an analog or variable output change in proportion to a varying input. In this control response, there is a linear relationship between the input and the output. A setpoint, throttling range and action typically define this relationship. In a proportional control response, there is a unique value of the measured variable that corresponds to full travel of the controlled device and a unique value that corresponds to zero travel on the controlled device. The change in the measured variable that causes the controlled device to move from fully closed to fully open is called the throttling range. It is within this range that the control loop will control, assuming that the system has the capacity to meet the requirements.

The action dictates the slope of the control response. In a direct acting proportional control response, the output will rise with an increase in the measured variable. In a reverse acting response, the output will decrease as the measured variable increases. The setpoint is an instruction to the control loop and corresponds to a specified value of the controlled device, usually half-travel. An example is shown in Figure 5.

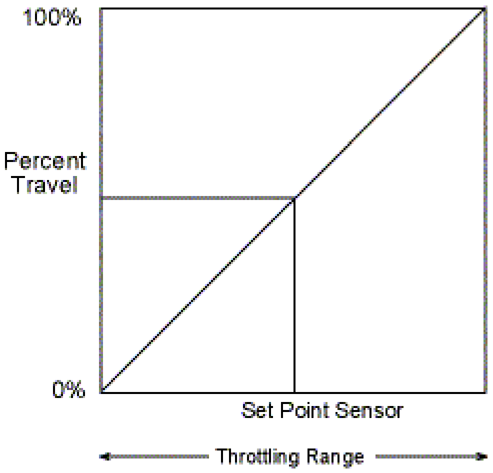


Figure 5: Proportional Control Response

In a proportional control system, the value of the measured variable at any given moment is called the control point. Offset is defined as the difference between the control point and the desired condition. One way to reduce offset is to reduce throttling range. Reducing the throttling range too far will lead to instability. The more quickly the sensor "feels" the effect of the control response, the larger the throttling range has to be to produce stable control.

Proportional plus Integral (PI) Control

PI control involves the measurement of the offset or "error" over time. This error is integrated and a final adjustment is made to the output signal from the proportional part of this model. This type of control response will use the control loop to reduce the offset to zero. A well set-up PI control loop will operate in a narrow band close to the setpoint. It will not operate over the entire throttling range (Figure 6).

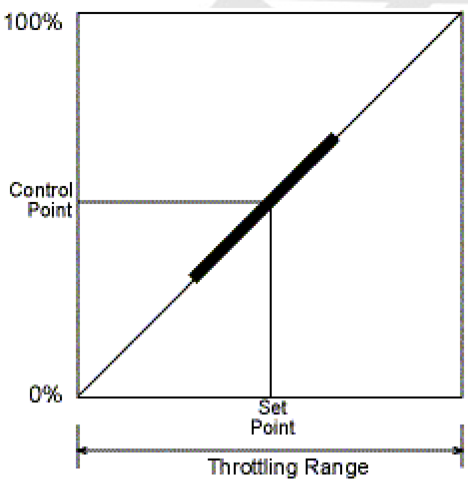


Figure 6: Proportional Integral Control Response

PI control loops do not perform well when setpoints are dynamic, where sudden load changes occur or if the throttling range is small.

Proportional plus Integral plus Derivative (PID) Control

PID control adds a predictive element to the control response. In addition to the proportional and integral calculation, the derivative or slope of the control response will be computed. This calculation will have the effect of dampening a control response that is returning to setpoint so quickly that it will "overshoot" the setpoint.

PID is a precision process control response and is not always required for HVAC applications. The routine application of PID control to every control loop is labor intensive and its application should be selective.

Definition of Direct Digital Control (DDC)

DDC control consists of microprocessor-based controllers with the control logic performed by software. Analog-to-Digital (A/D) converters transform analog values into digital signals that a microprocessor can use. Analog sensors can be resistance, voltage or current generators. Most systems distribute the software to remote controllers to eliminate the need for continuous communication capability (stand-alone). The computer is primarily used to monitor the status of the energy management system, store back-up copies of the programs and record alarming and trending functions. Complex strategies and energy management functions are readily available at the lowest level in the system architecture. If pneumatic actuation is required, it is accomplished with electronic to pneumatic transducers. Calibration of sensors is mathematical; consequently the total man-hours for calibration are greatly reduced. The central diagnostic capabilities are a significant asset. Software and programming are constantly improving, becoming increasingly user-friendly with each update.

Benefits of DDC

The benefits of direct digital control over past control technologies (pneumatic or distributed electronic) is that it improves the control effectiveness and increases the control efficiency. The three main direct benefits of DDC are improved effectiveness, improved operation efficiency and increased energy efficiency.

Improved Effectiveness

DDC provides more effective control of HVAC systems by providing the potential for more accurately sensed data. Electronic sensors for measuring the common HVAC parameters of temperature, humidity and pressure are inherently more accurate than their pneumatic predecessors. Since the logic of a control loop is now included in the software, this logic can be readily changed. In this sense, DDC is far more flexible in changing reset schedules, setpoints and the overall control logic. Users are apt to apply more complex strategies, implement energy saving features and optimize their system performance since there is less cost associated with these changes than there would be when the logic is distributed to individual components. This of course assumes the user possesses the knowledge to make the changes.

DDC systems, by their very nature can integrate more easily into other computer-based systems. DDC systems can integrate into fire control systems, access/security control systems, lighting control systems and maintenance management systems.

Improved Operational Efficiency

Operational improvements show the greatest opportunity for efficiency improvements in direct digital controls. The alarming capabilities are strong and most systems have the ability to route alarms to various locations on a given network. The trending capabilities allow a diagnostic technician or engineer to troubleshoot system and control problems. They also allow the data to be visualized in various formats. These data can also be stored and analyzed for trends in equipment's performance over time.

Run-times of various equipment can be monitored and alarms/messages can be generated when a lead/lag changeover occurs or if it is time to conduct routine maintenance.

The off-site access/communication capability allows an owner/operator to access their system remotely. Multiple parties can also be involved in troubleshooting a problem. The control vendor, design engineer and commissioning authority can use these features to more efficiently diagnose and visualize problems.

Increased Energy Efficiency
There are many energy-efficient control strategies employed in pneumatic logic that can be easily duplicated in DDC logic. Due to the addition of more complex mathmatical functions (easily obtained in software), there are many additional energy-efficient routines that can be used with DDC.

Strategies such as demand monitoring and limiting can be more easily implemented with DDC systems. The overall demand to a facility can be monitored and controlled by resetting various system setpoints based on different demand levels. If a DDC system is installed at the zone level, this could be accomplished by decreasing the requirement for cooling on a zone-by-zone basis.

By storing trends, energy consumption patterns can be monitored. Equipment can also be centrally scheduled "on" or "off" in applications where schedules frequently change.

Elements of a Direct Digital Control System

Points
The word points is used to describe data storage locations within a DDC system. Data can come from sensors or from software calculations and logic. Data can also be sent to controlled devices or software calculations and logic. Each data storage location has a unique means of identification or addressing.

Direct digital controls (DDC) data can be classified three different ways - by data type, data flow and data source.

Data Type
Data type is classified as digital, analog or accumulating. Digital data may also be called discrete data or binary data. The value of the data is either 0 or 1 and usually represents the state or status of a set of contacts. Analog data are numeric, decimal numbers and typically have varying electrical inputs that are a function of temperature, relative humidity, pressure or some other common HVAC sensed variable. Accumulating data are also numeric, decimal numbers, where the resulting sum is stored. This type of data is sometimes called pulse input.

Data Flow
Data flow refers to whether the data are going into or out of the DDC component/logic. Input points describe data used as input information and output points describe data that are output information.

Data Source
Points can be classified as external points if the data are received from an external device or sent to an external device. External points are sometimes referred to as hardware points. External points may be digital, analog or accumulating and they may be input or output points. Internal points represent data that are created by the logic of the control software. These points may be digital, analog or accumulating. Other terms used to describe these points are virtual points, numeric points, data points and software points.

Global or in-direct points are terms used to describe data that are transmitted on the network for

use by other controllers. These points may also be digital, analog or accumulating.

Analog input points typically imply an external point and represent a value that varies over time. Typical analog inputs for HVAC applications are temperature, pressure, relative humidity, carbon dioxide and airflow measurements. Typical analog outputs include control signals for modulating valve positions, damper positions and variable frequency drive speed.

Typical digital inputs for HVAC applications represent the status (example: whether or not the motor is running) of fans, pumps, motors, lighting contactors, etc. A temperature high limit is considered a digital input because, although it is monitoring an analog value (temperature), the information that is transmitted to the controller is a digital condition (whether or not the temperature has exceeded a defined value). Digital outputs are typically motors or other devices that are commanded "on" or "off." Digital outputs include fans, pumps, two-position (solenoid) valves, lighting contactors, etc.

A "true" analog output (voltage or current) is a varying DC voltage or milliamp signal that is used to drive a transducer or controlled device. Another type of analog output is pulse width modulation (PWM). PWM is accomplished by monitoring a timed closure of a set of contacts. The amount of time the contacts are closed is proportional to a level of performance for the controlled device.

Software Characteristics

There are basically three common approaches used to program the logic of DDC systems. They are line programming, template or menu-based programming and graphical or block programming.

Line programming-based systems use Basic or FORTRAN-like languages with HVAC subroutines. A familiarity with computer programming is helpful in understanding and writing logic for HVAC applications.

Menu-driven, database or template/tabular programming involves the use of templates for common HVAC logical functions. These templates contain the detailed parameters necessary for the functioning of each logical program block. Data flow (how one block is connected to another or where its data comes from) is programmed in each template.

Graphical or block programming is an extension of tabular programming in that graphical representations of the individual function blocks are depicted using graphical symbols connected by data flow lines. The process is depicted with symbols as on electrical schematics and pneumatic control diagrams. Graphical diagrams are created and the detailed data are entered in background menus or screens.

Architecture

System architecture is the term used to describe the overall local area network or LAN structure, where the operator interfaces connect to the system and how one may remotely communicate to the system. It is the map or layout of the system.

The network or LAN is the medium that connects multiple intelligent devices. It allows these devices to communicate, share information, display and print information, as well as store data. The most basic task of the system architecture is to connect the DDC controllers so that information can be shared between them.

Controller

A control loop requires a sensor to measure the process variable, control logic to process data, as well as calculate an instruction, and a controlled device to execute the instruction. A

controller is defined as a device that has inputs (sensors), outputs (controllable devices) and the ability to execute control logic (software) (Figure 7).

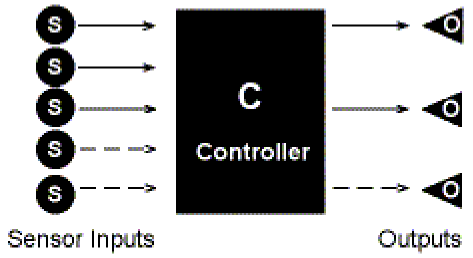


Figure 7: Controller

LAN Communication

Communications between devices on a network can be characterized as peer-to-peer or polling. On a peer-to-peer LAN, each device can share information with any other device on the LAN without going through a communications manager (Figure 8).

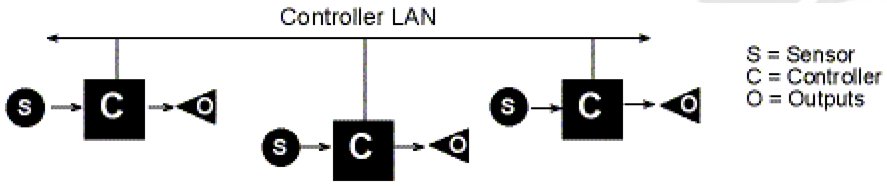


Figure 8: Peer-to-Peer LAN Diagram

The controllers on the peer-to-peer LAN may be primary controllers, secondary controllers or they may be a mix of both types of controllers. The type of controllers that use the peer-to-peer LAN vary between manufacturers. These controller types are defined later in this section.

In a polling controller LAN, the individual controllers can not pass information directly to each other. Instead, data flows from one controller to the interface and then from the interface to the other controller (Figure 9).

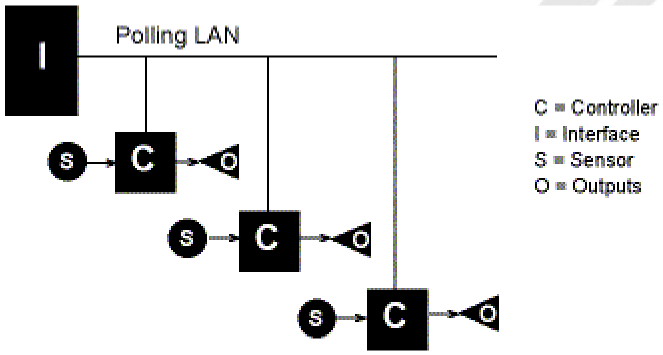


Figure 9: Polling LAN Diagram

The interface device manages communication between the polling LAN controllers and the higher levels in the system architecture. It may also supplement the capability of polling LAN controllers by providing the following functions: clock functions; buffer for trend data, alarms, messages; and higher order software support.

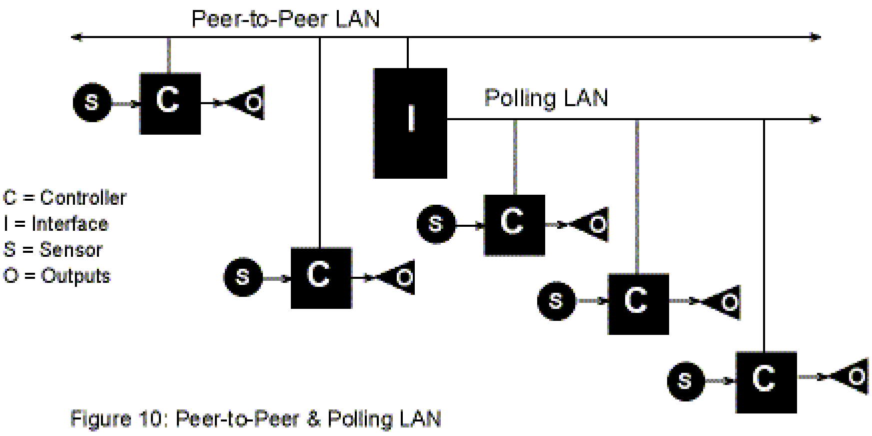


Figure 10: Peer-to-Peer & Polling LAN

Many systems combine the communications of a peer-to-peer network with a polling network. In Figure 10, the interface communicates in a peer-to-peer fashion with the devices on the peer-to-peer LAN. The polling LAN-based devices can receive data from the peer-to-peer devices, but the data must flow through the interface.

Controller Classification
Controllers can be categorized by their capabilities and their methods of communicating (controller-to-controller). In general, there are two classifications of controller - primary control units and secondary control units

Primary controllers typically have the following features:

- Real-time accurate clock function
- Full software compliment
- Larger total point capacity
- Support for global strategies
- Buffer for alarms/messages/trend & runtime data
- Freeform programming
- Downloadable database
- Higher analog/digital converter resolution
- Built-in communication interface for PC connection.

Secondary controllers typically have the following features:

- Not necessarily 100% standalone
- Limited software compliment
- Smaller total point count
- Freeform or application specific software
- Typically lower analog-to-digital converter resolution
- Trend data not typically stored at this level
- Typical application is terminal equipment or small central station equipment.

Operator Interfaces
The next critical element in the system architecture is an operator interface. Operator interfaces are required to:

- See data
- Program the system
- Exercise manual control
- Store long term data
- Provide a dynamic graphical interface.

There are five basic types of operator interfaces. They include:

- Desktop computers which act as operator workstations
- Notebook computers which act as portable operator workstations
- Keypad type liquid crystal displays
- Handheld consoles/ palmtops/ service tools
- Smart thermostats

Desktop computers are centralized operator workstations where the main function is programming, building and visualizing system graphics; long term data collection; and alarm and message filtering.

Notebook computers may connect to the LAN through a communication interface that stands alone or is built into another device. The notebook computer connected to the LAN at a particular level may not have the same capability as a computer connected to the LAN at a higher level.

Keypad liquid crystal displays typically are limited to point monitoring and control. They may have some limited programming capability, such as changing a set point or time schedule.

Handheld consoles, palmtops and service tools are proprietary devices that connect to primary controllers or secondary controllers. Typically they allow point monitoring and control, controller configurations (addressing and communication set-up), and calibration of inputs and outputs.

Smart thermostats are sensors with additional capabilities. They connect to secondary controllers and have a service mode to allow for point monitoring, control and calibration. They also have a user mode that allows point information to be displayed, setpoint adjustment and an override mode.

PC/Network Interface
The communications interface shown in the Figure 11 is a communication interface device. It provides the path between devices that do not use the same communications protocol. This includes computers, modems and printers.

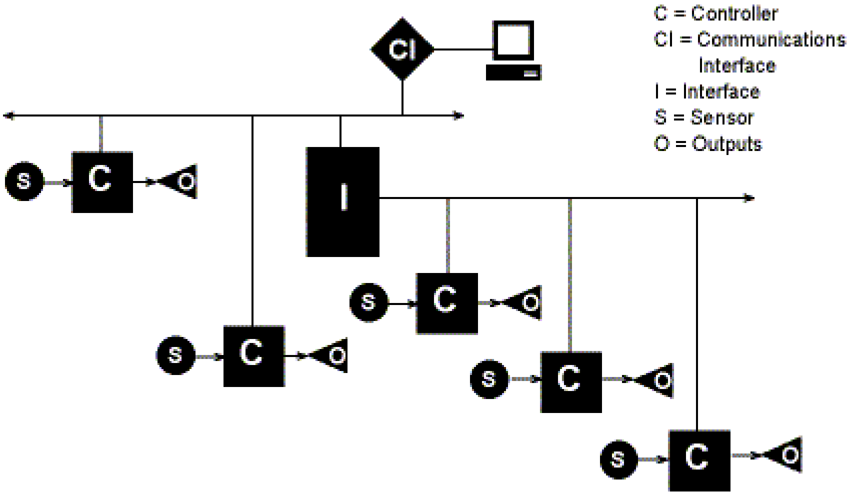


Figure 11: Communications Interface

It may be a stand-alone component or it may be built into another device as shown in Figure 12.

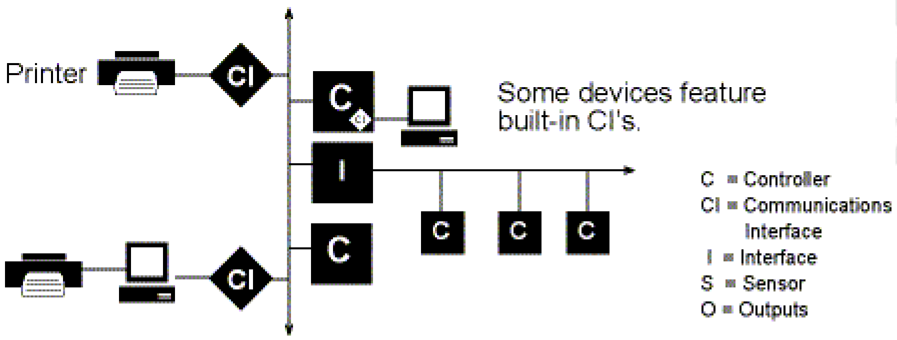


Figure 12: Built-in Communications Interface

Each communications interface on Figure 12 may:

- **Translate protocol**
- **Provide a communication buffer**
- **Provide temporary memory storage for information being passed between the network and the external PC, modem or printer (mailbox function)**

Larger System Architectures
When systems become larger than the capacity of a single sub-network, a higher level of architecture is added to allow the use of multiple sub-networks.

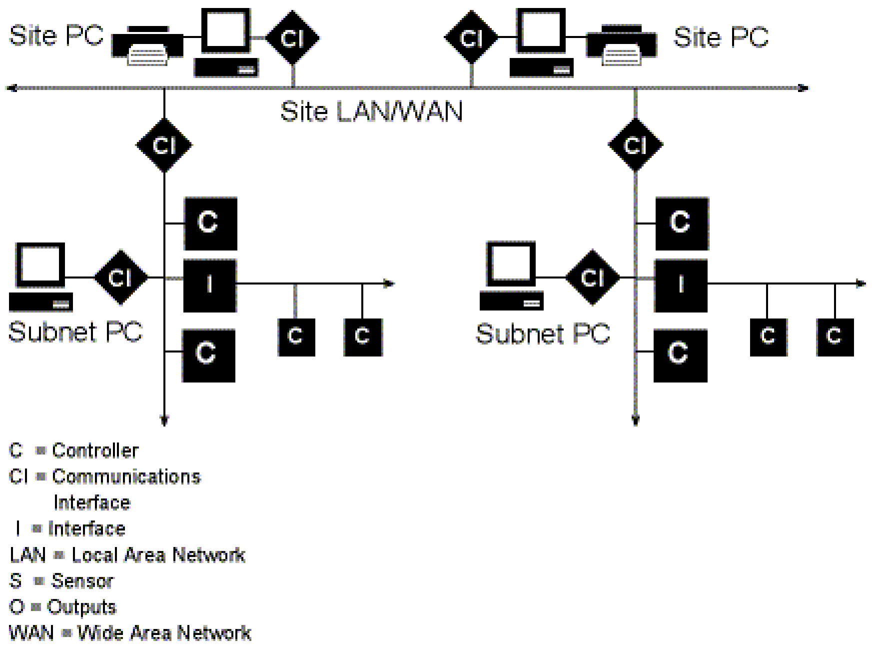


Figure 13: Multiple-Subnet Works System Architecture

The site LAN wide area network or WAN is used to connect multiple sub-networks and site computers. Multiple sub-networks can be connected to a single site LAN/WAN that allows information sharing between devices on different sub-networks (Figure 13). There may be a limitation on the number of site computers. The site LAN/WAN may include routers if TCP/IP is used. If no routers are used, the protocol can be totally proprietary. If TCP/IP is used, the EMS site LAN/WAN can be the information system backbone within the facility or between facilities.

Multiple site computers can be added to the site LAN/WAN. They can connect the site LAN/WAN via a communications interface, which may be a router. Site LAN/WAN computers can send and receive information from the entire system. Information can be received by each of the site computers, but can not be subsequently shared from one computer to another. Sub-network computers may only be able to see their own sub-network.

Site LANs allow multiple computers to communicate with each other. They may use commercially available computer network software and hardware. Messages, alarms and other data can be re-routed to other computers on the primary site LAN. Information stored in other computers can be remotely accessed. This includes graphics, programming and stored trend and operational data.

Combined Components

Some vendors combine multiple functions into a single device. In the following system architecture, Figure 14, the communication interface is built into the primary controller. A peer-to-peer LAN or sub-network is connected directly to the device.

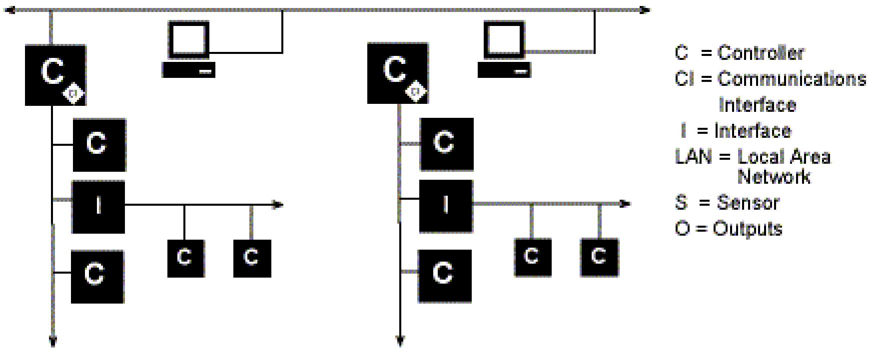


Figure 14: Combined Components

In Figure 15, the key component in the system consists of a communication interface, a primary controller and an interface to the secondary polling network.

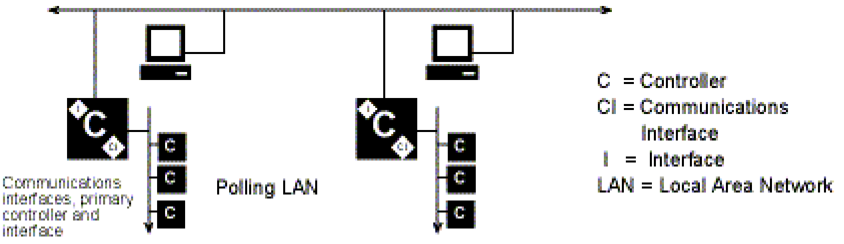


Figure 15: Combined Components

The addition of a site LAN allows a system to gain size in terms of the number of devices that are served, but in some applications, the location of the devices, rather than the number of devices, is the bigger challenge. In this situation, modem-based communication is used to expand the geography of the system.

Auto-Answer/Auto-Dial System Architecture

In auto-answer/auto dial systems, a specialized communication interface is substituted which introduces a modem and phone lines into the standard architecture. These communication interfaces are made with built-in modems or use external commercial modems. Auto-answer/auto-dial configurations are used to provide monitoring and access to remote buildings. They are used where traditional direct-wiring methods are impractical; and where central site monitoring is desired; or where remote access to controllers is desired.

In an auto-answer/auto-dial system, the central communications interface may call the individual sites or vice versa. Information and data can be passed to and from the layer above the central communications interface (Figure 16).

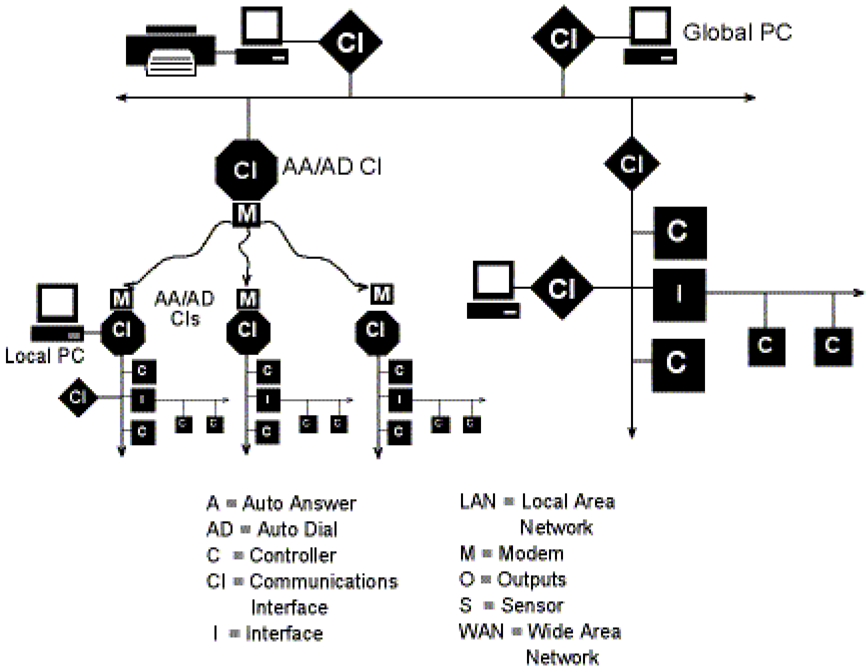


Figure 16: Auto - Auto/Answer - Dial Architecture

The auto-answer/auto-dial LAN architecture is typically used by installations with multiple facilities where control and monitoring needs to be centralized. Multiple LANs are used to maintain the groupings of devices, or to separate controllers into defined groups.

Multiple Dial LAN Support

In a system's architecture, the local sites have the ability to call an alternate communication interface, if the primary is not available (Figure 17).

One-Way Dial System Architecture

One-way dial systems, Figure 18, are typically used to enable system owners to access their systems from a remote location, such as their home. It is used where auto-dial monitoring is not required. It can also be used by the installation and service company or by the commissioning authority to troubleshoot and program from remote locations. One-way dial can also be used to dial into remote site LANs or sub-networks.

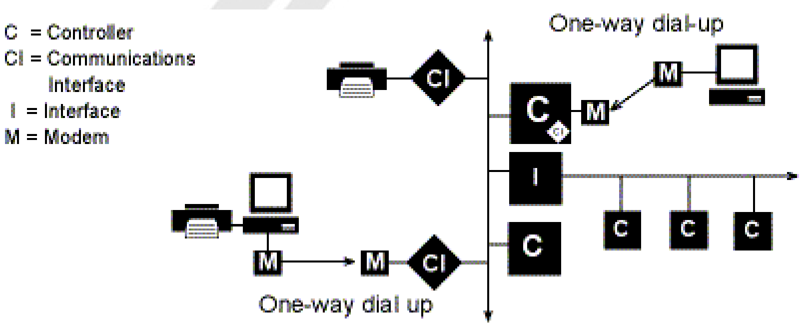


Figure 18: One-Way Dial Architecture

Two modems are required, one located at the remote computer and one at the system site.

Typically, the DDC operating software must be installed on the remote computer.

Communication
Communication between two different devices controlling equipment, requires a common protocol, a common communication speed and known data formatting. Vendors build their devices around these criteria, so communication between devices by the same manufacturer is routine.

Third Party Interfaces
In many installations, it is desirable for a proprietary building DDC system to communicate with other proprietary DDC systems controlling pieces of equipment. Examples would include a building DDC system and a chiller DDC system (Figure 19) or a fume hood DDC system. Communication between the two systems will require an interface or gateway, due to different proprietary protocols, communication speeds and data formatting.

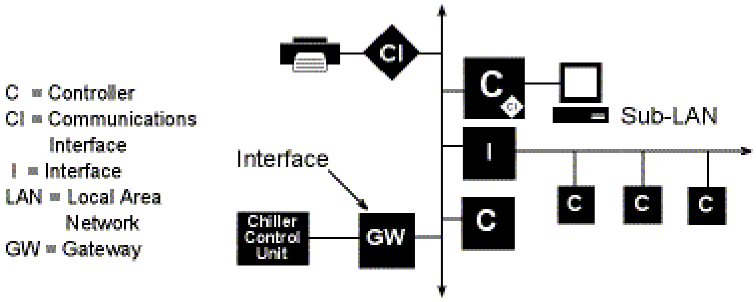


Figure 19: Third Party Interfaces

The gateway or interface translates protocol between the two proprietary systems. The proper operation of the gateway is dependent on the continued use of the specific revised levels of software on both systems. It typically requires the support of the manufacturer at the corporate level to implement and cooperation between the manufacturers. In addition, the costs can vary widely.

Protocols
In the DDC world, there are the three classifications of protocols: closed protocol, open protocol and standard protocol.

A closed protocol is a proprietary protocol used by a specific equipment manufacturer. An open protocol system uses a protocol available to anyone, but not published by a standards organization. A standard protocol system uses a protocol available to anyone. It is created by a standards organization.

Open Systems
An open system is defined as a system that allows components from different manufacturers to co-exist on the same network. These components would not need a gateway to communicate with one another and would not require a manufacturer specific workstation to visualize data. This would allow more than one vendor's product to meet a specific application requirement.

The sole use of an open or standard protocol does not guarantee that a DDC system will be an open system. A manufacturer has the ability to use open or standard protocols, yet create a closed system, thus continuing a building owner's dependence on a single manufacturer. This can be accomplished by using unique communication speeds, unique data formatting and by

not adopting the full range of an open protocol.

Note: A building owner/engineer should thoroughly research a manufacturer's claim of an open system.

BACNET

BACNET is a standard protocol published by a standards organization (American Society of Heating, Refrigerating and Air-conditioning Engineers or ASHRAE). It is a specification for a protocol. DDC vendors create a communication protocol that complies with this specification.

BACNET is a relatively complex standard. The standard defines protocol implementation conformance statements (PICS) that define different levels of compliance. A given vendor may or may not support the level required for a given application. In other words, a vendor could meet a very low level of compliance and be BACNET-compatible. The key question is, "At what level?"

In Figure 20 the chiller control unit's DDC will communicate with the building DDC system if each has a BACNET gateway and their PICS match.

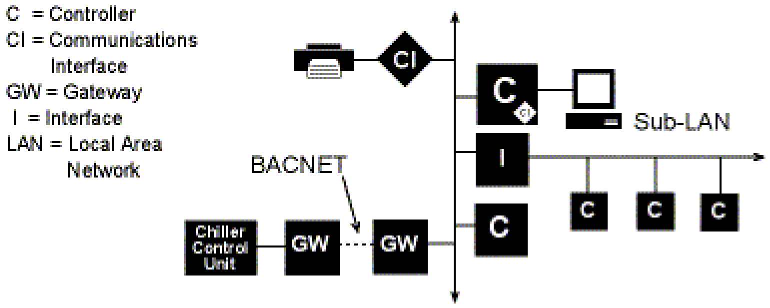


Figure 20: BACNET Gateways

Native BACNET

If a vendor states their product is native BACNET, they are using the BACNET protocol in lieu of a proprietary protocol on their LAN. In Figure 20, a native BACNET building system would be able to communicate to the chiller control DDC with one less gateway.

Overlay Systems

An overlay system is a high-end workstation that communicates with multiple manufacturers' proprietary EMS systems. An overlay system supplier creates drivers to "talk" to the different systems. The vendors must have a cooperative relationship and revision control is important for continued successful use. The workstation typically displays data, allows manual control and setpoint changes, and handles alarms and messaging. Any detailed editing of the control sequence will still require knowledge of the underlying proprietary software.

LON

The Echelon Corporation has created an open protocol that uses a standard processor and a set of standard transceivers, which allows components from different manufacturers to co-exist on the same LAN. The protocol is available to anyone and is called LONTALK. A unique chip is required for any device that uses LON. Standard network variable formats have been established to allow the transfer of data from one device to another regardless of origin.

Presently, various vendors are competing to become the defacto standard for the network database structure. The network database is a map of the components and the relationship of the data moving between them. The operator workstation needs this structure to visualize the data.

Software suppliers providing the software for the operator workstation may be independent of those providing the software for the database structure and the EMS vendors.

Input / Output (I/O) Basics

Terminology

The following terms have been defined to help readers better understand the material covered in the Input/Output document.

Accuracy
The term accuracy describes the total of all deviations between a measured value and the actual value. Accuracy is usually expressed as the sum of non-linearity, repeatability and hysteresis. Accuracy may be expressed as the percent of a full-scale range or output, or in engineering units.

Address
An address is a unique numeric or alphanumeric data (point) identifier.

Analog/Modulating/Continuous
These synonymous terms are used to describe data that has a value that is continuous between set limits represented by a range or span of voltage, current or resistance. The value is non-integer (real) with a resolution (number of significant digits) limited only by the measurement and analog-to-digital signal conversion technology. In typical DDC systems, analog data from an input device is converted into a value for processing within the controller. Likewise, values are converted into analog output signals for use by a controlled device, such as an actuator.

Controlled Medium
A controlled medium is a process medium of which one or more properties are made to conform to desired conditions by means of a control loop (see EMS Systems Overview Basic Control loop).

Digital/Binary/Discrete
These synonymous terms are used to describe data that has a value representing one state or another. Typical values are "on/off", alarm or normal, 0 or 1, high or low, etc. In the hardware side of the DDC world, these values most commonly relate to the state of a set of switch or relay contacts (open or closed).

External Point
Data that is received by a controller from an external source, or sent by a controller to an external source, is an external point. The terms hardware, input or output may be used to describe an external point.

Global Point
Global points originate from a controller within a network that is broadcast via the network to other controllers.

Hysteresis
Hysteresis is the maximum difference in measured value or output when a set value is approached from above, and then below the value.

Input
The term input is used to define data flow into a controller or control function.

Internal Point
An internal point is one that resides within a digital controller that does not directly originate from input or output points. Internal points can be constants such as fixed set points created by a programmer's or operator's assignment. Internal points may also be created as defined by the programmer/ operator by applying logic and mathematics to other virtual, input or output points or combinations of points. The terms virtual, numeric or data may be used to describe an internal point.

Non-linearity
Non-linearity is the maximum difference in measured value or output from a specified straight line between calibration points.

Output
Output defines the data flow out of a controller or control function.

Point
Point is a generic term used to describe a single item of information in a control system. Points may be further described as input, output, digital, binary, discrete, analog, modulating, internal, external, virtual or global. Each unique point used by digital controllers, or in digital control systems, is typically identified by an address.

Process Medium
A process medium is a material in any phase (solid, liquid or gas) that is being used in a process. The most common types of process mediums used in commercial and industrial heating ventilating and air conditioning systems are liquid mediums (i.e., chilled water for cooling) or gaseous mediums (i.e., airflow in a duct).

Repeatability
Repeatability is the maximum difference in a measured value or output when a set value is approached multiple times from either above or below the value.

Sensor
A sensor is a device in primary contact with a process medium. It measures particular properties of the process medium (i.e., temperature, pressure, etc.) and relates those properties to electrical signals such as voltage, current, resistance or capacitance.

Transducer
Transducers accept an input of one character and produce an output of a different character. (Examples: voltage to current, voltage to pneumatic (pressure) and resistance to current.)

Transmitter
A transmitter is a transducer that is paired with a sensor to produce a higher-level signal (typically) than is available directly from the sensor. These sensors may be integral or remote and may include digital or analog signal processing. (Examples: temperature transmitter employing a temperature sensor. The temperature sensor varies the resistance with temperature change and the transmitter outputs a related 4-20 mA current output for use by a controller.)

Switches

In the world of HVAC control, there is basically one type of device used to complete a digital input (DI) circuit. A switch, employed in various forms, is this device.

A switch is an electrical device used to enable or disable flow of electrical current in an electrical circuit. Switches may be actuated in a variety of ways, including movement of two conducting materials into direct contact (mechanical), or changing the properties of a semi-conducting material by the application of voltage (electronic).

Switches are typically rated in terms of voltage, voltage type (AC or DC), current carrying capacity, current interrupting capacity, configuration, and load characteristic (inductive or resistive). Also specified are applicable ranges of ambient conditions over which the ratings are valid. Current carrying capacity (or current rating) is the maximum current that may continuously flow through the closed switch contacts without exceeding the maximum permissible temperature.

Process medium property sensing switches are also rated by parameters such as adjustment range, accuracy or repeatability, and deadband or differential. The range of a control switch is specified by upper and lower process values between which the switch has been designed to operate. The accuracy or repeatability of a control switch is a value typically measured in process units or percent of range that represents the expected maximum deviation from setpoint at which the switch will operate under test conditions. The switch differential or deadband is the change in process value required to cause the state of the switch to change. For example, a pressure switch that makes at 10 psig and breaks at 8 psig has a 2 psig differential.

Switch contacts are characterized in much the same way as relay contacts.
Figure 2.1 describes the most common contact configurations using industry standard terminology and symbols. Many other configurations are available.

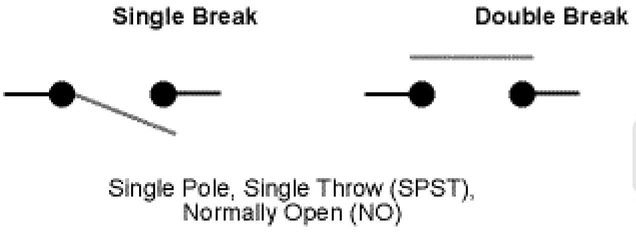


Figure 2.1a - Common Contact Configurations

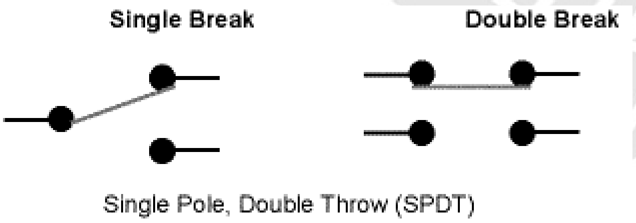
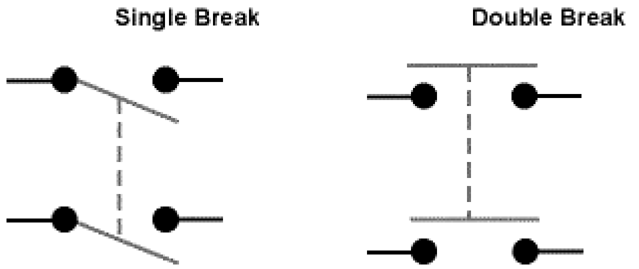


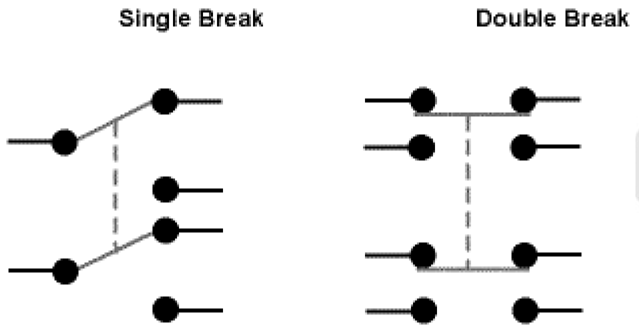
Figure 2.1b - Common Contact Configurations

Figure 2.1c - Common Contact Configurations



Double Pole, Single Throw (DPST), Normally Open (NO)

Figure 2.1d - Common Contact Configurations



Double Pole, Double Throw (DPDT)

Figure 2.1e - Common Contact Configurations

Analog Devices

There are numerous analog devices used in the HVAC controls world. Typically, analog output devices are used to provide modulating control of valves, dampers, electric motors through variable speed drives and a wide variety of other devices. The most common devices associated with analog outputs are sequencers, variable speed drives, silicon controlled rectifiers and actuators.

Sequencers

Sequencing of multiple on-off devices based on a single analog output from a control loop is often required for items, such as cooling towers with multiple two-speed fans, multi-stage electric heaters and multi-stage refrigeration systems. This sequencing can be accomplished within the DDC controller, or it may be accomplished externally using a discrete sequencing device. These devices have two or more relay or digital outputs that are adjusted to spread the signal range that they turn on and off. For example, a two-stage sequencer might be adjusted so the stage one relay turns on at 37.5% analog signal level and off at 12.5%. The stage two relay would be adjusted to turn on at 87.5% analog signal and off at 67.5%. More advanced sequencers may incorporate adjustable inter-stage time delays, minimum on and off times, etc.

Variable Speed Drives

Variable speed drives are used to vary the speed of AC and DC motors in order to control the output of driven equipment. DC variable speed drives are costly and offer very precise control. They are widely used in industry for precise speed control of conveyors and printing presses, but are not widely used in the HVAC industry. AC variable speed drives are less costly and offer good control for equipment, such as centrifugal compressors, fans and pumps.

AC variable speed drives operate on the principle that the synchronous speed of an AC induction motor is directly proportional to the frequency of the AC power supplied to the motor. In the US, the standard frequency at which AC power is distributed and motors are rated is 60 cycle per second (hertz). Virtually all AC variable speed drives currently manufactured use solid state components to accept AC power at standard distribution voltages and 60 hertz frequency (50 hertz in Europe) and output a variable frequency power supply to the controlled motor(s). Commonly available drives have provisions for external on/off control by a contact closure, analog speed feedback signal for monitoring, and accept a standard analog voltage or current signal for speed input. Many drives are available with one or more drive status alarms. Some are also available with digital communication interfaces that allow detailed status and fault monitoring by DDC control systems.

Most drives use an AC to DC converter and a DC to AC inverter. The converter may consist of a diode rectifier, a diode rectifier with a DC chopper, or a silicon controlled rectifier (SCR) sometimes called a thyristor. The simple diode rectifier creates a constant DC voltage for input to the inverter. The addition of the DC chopper allows regulation of the voltage to the inverter. Silicon controlled rectifiers also allow regulation of the voltage to the inverter.

The inverter section of the drive consists of solid state switching devices that reconstruct an AC power signal with controlled frequency. The three most common types of inverters are variable voltage source (also called six step), current source and pulse width modulated (PWM). The six step inverter uses six solid state switching devices in combination with six diodes. The solid state switches are controlled to produce a six step voltage wave form for each phase. Changing the conducting time for each of the six switches results in a change in frequency of the output wave. The current source inverter operates much the same as the six step variable voltage source except that solid state switching devices construct a six step current wave for each phase instead of a voltage wave. Pulse width modulated inverters use solid state switching devices to produce a series of constant voltage pulses of various widths to produce an AC output. The timing and number of pulses are varied to produce the varying frequency.

Application Considerations For Motors and Drives. The following items should be considered for any variable speed drive application:

1. **Normally, NEMA Design B squirrel cage induction motors with continuous duty rating are used.**
2. **Multiple motor loads can be controlled from a single AC variable speed drive, however the manufacturer's guidelines must be followed regarding operation if some or all motors are not connected. This applies in particular to drives with current source-type inverters.**
3. **With current source and PWM-type inverters there is some additional stress on the motor insulation. These stresses are usually not significant.**
4. **PWM inverters usually cause motors to produce more noise than normal.**
5. **Any type of inverter produces a current waveform that contains harmonics that do not produce any additional torque, but do cause additional heating in the motor windings. This will typically produce 5% - 15% additional heating load and must be considered when operating motors controlled by drives near full load conditions.**
6. **With current source inverters, an open circuit (such as a disconnected load) will cause an excessive voltage rise in the inverter. Unless appropriate protection is provided, this condition may cause inverter failure.**
7. **Jerky shaft motion can result with any inverter type at low speed (typically below about 10 hertz) due to badly distorted waveforms at these frequencies. Some PWM drives are available that are optimized for operation at low speed and can reduce this effect.**

8. It is important to consider the torque - speed characteristic of the load to be imposed on the drive. Most HVAC applications are for centrifugal machines (pumps, fans and compressors) and are described as "variable torque" because the torque is low at low speed and rises according to the cube of the motor speed. Infrequent applications for HVAC, such as positive displacement pumps, may have constant torque characteristics.

Silicon Controlled Rectifiers (SCRs)
SCRs are used to regulate an AC power supply to a typically resistive electrical load, such as an electric heater, to provide continuously variable output. SCRs accept standard analog control signals (usually voltage or current) and regulate the output of their load proportionally.

With microprocessor-based controls, SCRs can be used in combination with sequenced contactors to provide vernier control that is continuous in proportion to the input signal, but does not require control of the entire load by a SCR and thus reduces the cost.

Actuators
Analog signal controlled actuators are one of the most important components of DDC systems today. Air temperature control is commonly accomplished with actuators of various types through the control of damper position and valve position. The majority of modern HVAC designs include actuators of one type or another.

Types of Actuators
With the invention and continual refinement of DDC systems, electric motor controlled actuators are steadily replacing pneumatic controlled actuators as the application allows. There are still a large number of both types available and in service today.

Pneumatic Actuators
The pneumatic actuator has been widely used for HVAC control for decades. With the inventions of the electric-to-pneumatic signal transducers and EP relays, DDC systems can readily integrate pneumatic actuators into the control scheme for steam valves, dampers, etc. Diaphragm- and piston-type actuators are the two most common pneumatic actuators.

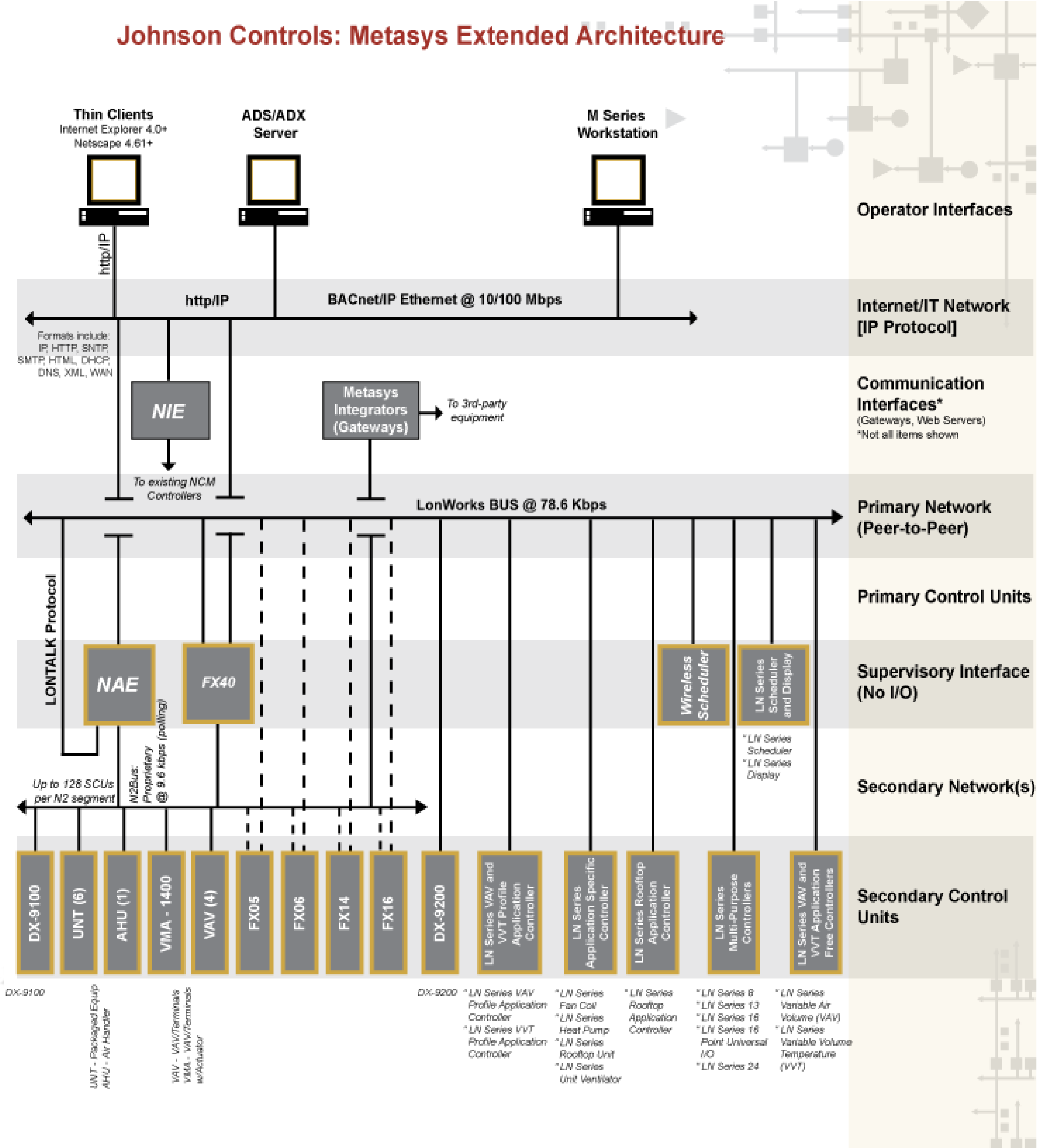
Diaphragm-type actuators are most commonly used with low pressure pneumatic control signals in the range of 0 to 30 psig, but are available for industrial application at higher pressures. Diaphragm actuators typically have an opposing spring, with air supply to only the side of the diaphragm opposing the spring. The spring constant sets the range of air pressure over which the valve will operate and also provides for failure in an open or closed position, depending on orientation. The action of diaphragm actuators is normally linear, but may be converted to rotary motion approaching 180 degrees through the use of suitable links.

Piston-type actuators are most commonly used with higher air pressures in the range of 80 to 100 psig. Piston actuators are generally more compact than diaphragm-type actuators, particularly for larger valve sizes. Pistons may be single acting (air applied to piston on one side, spring pressure on opposite side of piston provides return pressure) or double acting (air pressure is applied alternately to either side of the piston to produce bi-directional motion). Piston actuators may have linear or rotary motion through the rack and gear or other mechanisms.

Positioners are commonly used with a pneumatic actuator to control the stroke or rotation of the actuator so that it positions the controlled device in a fashion that is linear in proportion to the control signal. Limit switches may be mechanical- or proximity-type actuators and are often mounted within a positioner enclosure.

Electric Actuators
A wide variety of sizes and shapes of electric actuators are available to meet the requirements for valve and damper actuation for HVAC systems. Most electric actuators are based on an electric motor and output mechanism. Some mechanisms are designed for spring return; others are designed so that the mechanism locks in place when the motor is off. Most actuators relate the analog control signal proportionally to the position or

percent of total travel. Torque switches may be used on large electric motor-driven actuators to stop the valve motor when the valve has reached full open or closed position.



Control System Architecture
Metasys Extended Architecture

System Architecture

Human/BAS Interfaces

This section distinguishes between Operator Interfaces and Field Interfaces to the BAS. The Operator Interface refers to the main 'front-end' method for accessing and operating the BAS. The Field Interfaces typically access the BAS from the controller-level and have limited functionality, and may include HID, LDP, and ZBI as described below. This section describes the devices only; OI functionality is generally covered in the Software, while Field Interface functionality is detailed further in the individual Controllers

Operator Interfaces (OI)	
Dedicated Operator Workstation (OWS) Dedicated PC(s) with proprietary workstation software	PC with Metasys M3 or Metasys M5 software. M-Series software consists of many individual packages depending on level of functionality and features desired. The M5 Workstation is the flagship product in the Metasys line and can communicate with both the Proprietary and BACnet protocols. The M5 also has OPC capability, which is required by many of the data analysis, plotting, and diagnostic utilities provided as options by Johnson Controls. The M3 Worstation is a simpler BACnet-only version of the M5, with less software utility options and typically used in smaller installations. M3 and M5 workstations are only necessary on networks that contain NCMs.
"Thin" Client Browser	Netscape Navigator 4.61+ or Internet Explorer 4.0+.
"Thick" Client Browser	N/A
Handheld Interface Devices (HID)	
PDA-Based	A Palm-OS handheld can be used with Johnson Controls software and specialized cable to perform commissioning and diagnostic procedures on VMA (VAV/terminal unit) controllers.
Proprietary	Local Display Panels (see below) can be used as handheld devices or can be mounted.
Local Display Panel (LDP) Note: See 'Controller Information' for functions that can be carried out by these devices	The following LDPs are available as options for the indicated equipment: Local Display Terminal (LDT): The LDT is a 4x20 character LCD display with LED backlight. The LDT also has a red LED alarm light on the faceplate. The LDT mounts on the N30 and is not recommended to be used as a handheld device due to electrostatic concerns. The Network Terminal (NT) is an field-based operator interface that has a touch-sensitive screen and is used to make control adjustments at any NCM, including overrides; changes to schedules, loop parameters, set points, and alarm limits; view trends; and perform status checks. The NT can also be permanently mounted. DT-9100 Display (for DX-9100 and DX-9200):Optional zone-mounted, handheld, or controller-mounted display panel with LED display of viewing trend data/plots as well as other more typical functions. Can display up to 96 points of data. The DT-9100 also increases the scheduling capability of the DX-Series controllers by extending the weekly schedule to a yearly schedule with holidays and exceptions.
Zone Based Interfaces (ZBI)	
Thermostat with communication port to access local controller/network	A variety of thermostats are available with small displays. Consult Johnson Controls for latest offerings. The Zone Terminal (ZT) is a smaller field-based operator interface that allows for simple controller monitoring and adjustment. It can be used as a handheld device or can be field-mounted to a specific controller. The ZT uses five-digit LCD display and shows 3 values simultaneously. A red LED shows points in alarm, and a battery-backed clock allows for time

	scheduling. ZT cannot be used with the DX-9100. It connects to the AHU controller directly, and to the UNT and VAV controllers through the zone sensor or specialized cable.
Other thermostat types available (without communication ports)	yes Zone sensor yes Zone sensor w/ occupant override yes Zone sensor w/ setpoint adjustment yes Zone sensor w/ occupancy sensor

Internet / IT Network	
Interface to BAS Networks	Ethernet/IP, BACnet/IP, and proprietary N1

Primary Network	
Compatible with the building's IT network?	Yes
Protocol(s)	LonTalk
Cabling and Speeds	Twisted Pair @ 78.6 Kbps
Expansion Capability	Information not provided
Additional Information	

Secondary Network	
Peer-to-Peer or Polling?	Polling
Protocol(s)	*Proprietary*
Cabling and Speeds	UTP @ 9.6 kbps
Expansion Capability	Up to 128 SCUs per N2 Segment
Additional Information	

Control Secondary Control Units

LN Series Rooftop Application Controller

Description	
Product Name(s)	• LN Series Rooftop Application Controller
Product Description	LN Series Rooftop Application Controller is a microprocessor based rooftop unit controller that can support a wide variety of sensors and controls.
Product Application(s)	Rooftop units, lighting controls, and power monitoring.

Input/Output Processing

Control Unit Model #:	AI	DI	UI	DO	AO	UO	Other
LN-PRGRTU-0			8	6	2		

Operator Interfaces (via Controller) *	
Network Accessing Capabilities via Controller	no Access controller only yes Access controller plus additional controllers on network segment / LAN no Access all controllers on system no No access available on this controller no Other
Controller Access Devices	no Laptop/PC no Local Display Panel (controller-mounted) no Local Display Panel (zone-mounted) no Handheld Interface Device (proprietary device) no PDA (3rd-Party HID) no Zone-Based port (details below)
Zone Interface Hardware	no Zone-Mounted touchpad (thermostat or stand-alone display) no HID (proprietary device) no PDA (3rd party HID, with software) no Laptop/PC no none

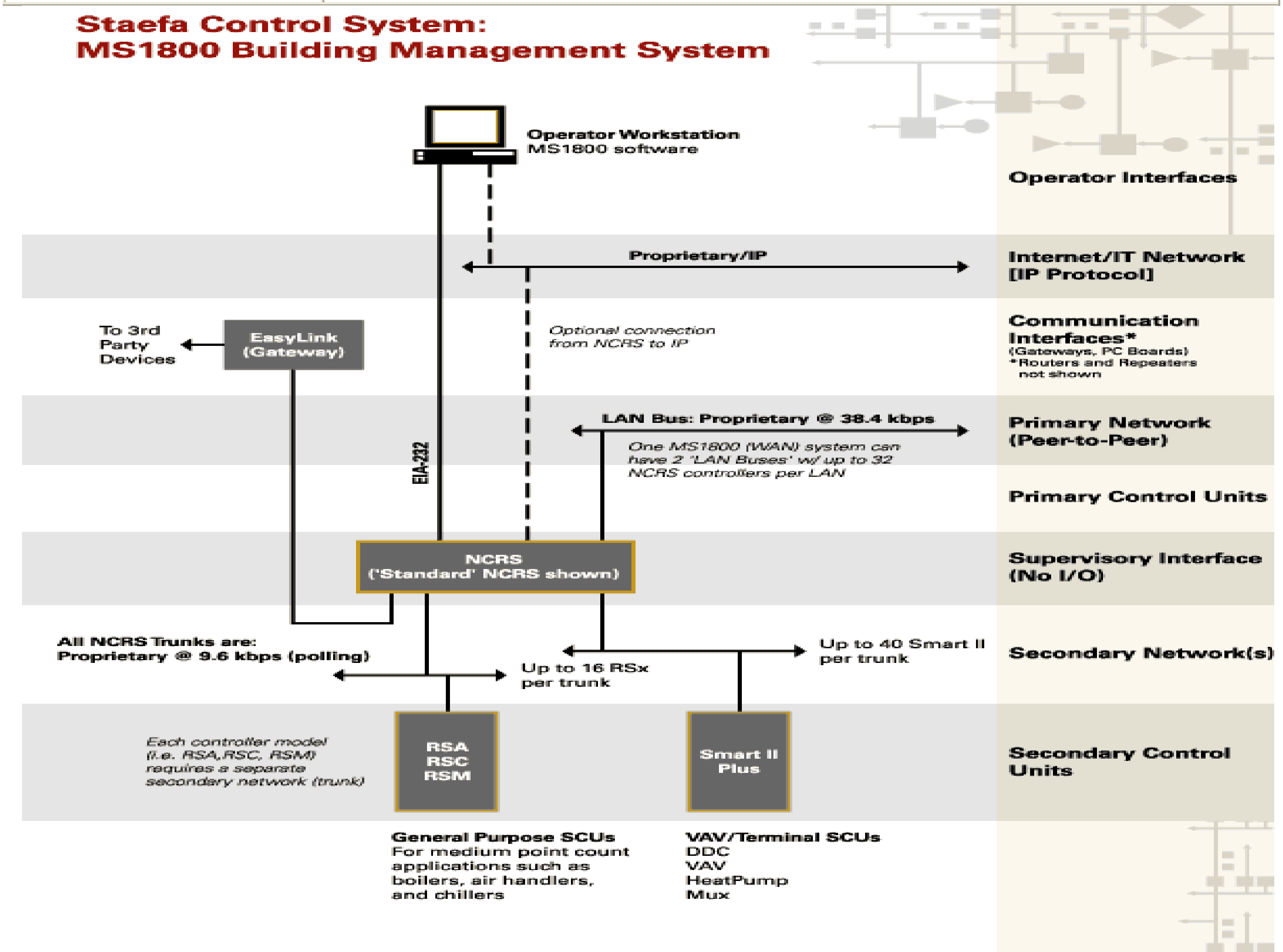
*Note: This section covers the capabilities for accessing the controller or other parts of the network from the controller (i.e. 'bottom-up'). Standard access functionality is covered in the Architecture and Software sections.
**Does NOT include front-end OI functions. See vendor for specific functions available.

Processor, Memory, and Battery	
Microprocessor(s)	Neuron 3150, 8 bits, @ 10 MHz
Clock Type	yes Powered, battery-backed no Battery powered no Powered, no battery backing no None no Other
Volatile Memory (RAM) Uses	- RAM use unrestricted - RAM use restricted as shown below
	no Program Execution / Calculation storage no Data / Trends / Alarms storage no Configuration / Parameter storage no Control Programming storage no Others
Non-Volatile Memory Capacity (EEPROM/Flash) *	128 Kb Flash 64 Kb Non-volatile
Non Volatile Memory Uses	yes Data / Trends / Alarms / Calculation

	Storage yes Configuration / Parameter Storage no Control Programming Storage no Controller Operating System yes Other (APB application and schedules)
Additional Information	
* Items in NV memory are not lost upon power or battery failure. Other types of NV memory such as EPROM, NOVROM, etc. do not directly impact system performance.	

Power Supply

Power Supply Required	
Voltage	24 VAC +/- 15%, 50/60 HZ or 24 VDC Class 2 Power supply
VA	Maximum: 10 VA Typical 5 VA
Surge Protection	1.35 Amp Auto-Reset Fuse



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٦ب شارع ٦ أكتوبر منشيه السد العالى - السلام - القاهرة.
تليفون : ٢٢٩٥٨٥٣٠ – ٢٢٩٥٥٤٨٧ (+٢٠٢) فاكس : ٢٢٩٩٥٨٦٠ (+٢٠٢)

Description

Product Name(s)	• Network Control Remote Station (NCRS) • Standard NCRS - has 4 trunks • Mini-CNRS - has 2 trunks
Product Description	Supervisory Interface Device. Serves as a system coordinator for Smart II Plus and RS controllers and provides information to the MS1800 workstation. Supports up to two PC workstations. Also serves as portal for the Easylink 3rd party interface.
Product Application(s)	Performs global control/logic functions, alarm handling, and trend data storage (described in the 'Software' form.)

Network and External Communication Ports

Network Ports, Protocol(s), and Speed(s) Supported (Note: See 'Architecture' for network details)	Primary dual-redundant primary LAN, proprietary EIA-485 @ 38.6 Kbps (peer-to-peer) Ethernet option (in place of EIA-232 'Communication Port') 2 or 4 secondary LAN trunks (depending on NCRS model) Proprietary EIA-485 @ 9.6 Kbps (polling interface)
External Communication Ports, Speeds and Access Devices	Two (2) EIA-232 (to OWS, POT, and/or Ethernet)
Additional Information (Optional)	Standard NCRS - 4 trunks. Mini-NCRS - 2 trunks. Each trunk is dedicated (can have any type of controller on a trunk, but cannot mix and match different controller types). Each trunk can accommodate: 40 Smart II Plus, or 16 RS controllers Capacities: Mini-NCRS (controllers per NCRS): 80 Smart II, or 32 RS Standard NCRS (controllers per NCRS): 160 Smart II, or 64 RS

Processor, Memory, and Battery

Microprocessor(s)	16-bit, 12Mhz, Zilog Z280
Volatile Memory (RAM) Capacity	1 Mb RAM
Is Volatile Memory Supported By Battery?	Yes
Battery Life	8 years
Backup Battery Operating Time	2 year power fail backup
Non-Volatile Memory Capacity (EEPROM/Flash) *	64 Kb EEPROM

Power Supply

Power Supply Required	
Voltage	24 Vac
VA	30 VA
Surge Protection	Provided - Transzorb, 1/2 Amp fuse

DDC Control system Consolidated list

S/N	DESCRIPTION	Qty.
1	DI MODULE 12 POINTS	2
2	DO MODULE 6 POINTS	2
3	TERMINAL BLOCK	2
4	TERMINAL BLOCK	2
5	LON CONNECTOR MODULE	2
6	AI MODULE 8 POINTS	1
7	DDC Controller CPU 190 points	1
8	TRANSFORMER 220/24V (144 VA)	2
9	DUCT Smoke Detector	4
10	DUCT TEMP. SENSOR	4
11	Enclosure IP 56 RITTAl	1
12	Assembling the panel	1
13	Engineering , Testing & Commissioning	1

EXCEL 5000 OPEN SYSTEM

DDC Systems:

Trane - Tracer/MTEZ/E-ware
Siemens Apogee
Landis Steafa I and II - CSI/MMI
Alerton Ibex
Alerton BacTalk
Johnson Metasys
Johnson M5
Johnson Controls
Robert Shaw
Honeywell
Richards Zeta
Barber Coleman