Simplifying the Complexity of Engineering a Process with FOUNDATION™ Fieldbus

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KEYWORDS
Project Engineering, Process Engineering, Configuration Tools, Fieldbus, DCS, PAS, Communications Standards, Architecture, FOUNDATION™ Fieldbus, Network Loading, ISA SP50, Open Systems

ABSTRACT
FOUNDATION™ Fieldbus installations differ dramatically from conventional device installations. Small scale trial-type installations are yielding to larger scale installations as user confidence builds and device selection increases. Multi-drop busses, control in field devices, bus power distribution, and device grouping are among the characteristics of Fieldbus that influence changes to the project engineering process for these larger installations. This paper deals with these changes to process planning, documentation, and installation, and with the advanced tools that can simplify and hide the complexities of networking devices in highly distributed control and monitoring environments.

INTRODUCTION
In 1985, ISA’s Standards and Practices Committee number 50, better known as SP50, was re-convened. It was the same committee that provided the 4-to-20mA device interface standard. This time, their charter was to develop a digital communication standard to allow smart, microprocessor-based field devices to communicate using an open standard protocol. Without detailing the resulting “Fieldbus Wars”, it suffices to say that FOUNDATION Fieldbus is today’s protocol that resulted from the completed physical and data link layers, and spirit of the user layer from the work of the SP50 Committee.

But today’s challenge is dealing with the engineering changes necessary to implement this advanced technology in a real plant. That’s the subject of this paper.
WHAT IS FOUNDATION FIELDBUS?

Space limitations do not permit going into much detail here, so I’ll simply outline some of the salient attributes of FOUNDATION Fieldbus (Ref. 1):

- A digital, process control communications protocol, using the enhanced performance architecture (EPA), which includes physical layer, data link layer, and application layer.
- A low speed network at 31.25kbps which provides device power via the bus and optionally supports intrinsically safe device operation. Topologies include bus, daisy-chain, chicken-foot, and hybrids.
- A high-speed network using Ethernet (10/100 Mbps) which is not intrinsically safe and does not provide bus power. Primary topology is a tree (star) through switched hubs.
- A user-layer that includes a robust set of process control function blocks to provide interoperable device-resident control.
- Device-descriptive files provided by the device manufacturers in order to allow configuration devices and interface devices to automatically and intimately understand how to interface to the devices in a fully interoperable and engineeringless manner.
- The capability for a device manufacturer to extend function blocks by providing additional parameters and features. Also the ability to provide manufacturer-specific function blocks.
- A data link layer that synchronizes the function block execution and the publication of data on the bus in order to provide predictable loop performance with minimal latency.

WHAT NEEDS TO BE ENGINEERED?

With conventional 4-20mA signaling, one has to engineer the wiring from the devices to the controllers. One has to consider which functions relate to one another (hence logically belong in the same controller), and what the controller capacity limit is in terms of numbers of function executed at certain periods.

WIRING TOPOLOGY

Fieldbus changes the wiring topology considerably. Point-to-point wiring generally gives way to a single home run cable with short spurs or a multi-drop bus with short spurs. Rules defined by the ISA’s SP50.02 standard, limit the length of the H1 segment to 1900 meters for the better grade of cable (individually shielded twisted pairs) plus a total of 120m of spurs. Other cable types provide less distance but repeaters can be used to provide greater distances. The standard also dictates the maximum length of each spur as a function of the number of devices on the bus. The more devices, the shorter the spurs can be. (For example, a segment with 15 devices can only have spurs of 60m length total while a segment with only 2 devices tolerates 120m meters of spurs.) With all of these values, the SP50 specification is accused of being overly conservative. Spreadsheets are available to help with the calculation. (Ref. 2)
POWER DISTRIBUTION

It is costly to run extra wires to field devices just to power them. Therefore many devices obtain both operating and communications power from the bus. The current draw of each device must be ascertained and an adequate power supply, usually at the host interface, must be provided. Typical devices consume current in the range of 12 to 25 mA and typical supplies provide 350mA to 700mA of current or more, per link. Redundant supplies are now available.

FUNCTION BLOCK RESIDENCY

When it comes to control-in-the-field, there are two camps: Those who could not wait for it and those who can. The input function blocks (AI, DI, PI) reside in the sensing devices and the output function blocks (AO, DO, CAO, CDO, SCO) reside in the actuating devices. But, control class and arithmetic class function blocks may reside in field devices or in a controller. Considerations for the location include (1) availability of best-in-class functionality in the desired devices versus host, (2) control latency through a controller versus directly on the bus, and (3) co-location of devices on a single link versus the need to bridge multiple links due to physical constraints. That leads to yet another engineering consideration—the need for device interaction. Which devices need to intercommunicate? Which ones need to interact tightly? Which ones will interact less tightly? More on this later.

NETWORK SCHEDULING

The FOUNDATION Fieldbus network is a scheduled network. The fundamental user-selectable time period is called the macrocycle. Within the macrocycle the function blocks are scheduled to be executed at certain phases and after their execution, their relevant data is scheduled to be published. There can be multiple loops in the same macrocycle operating at different periods as long as the longest period is an exact multiple of each of the shorter periods.

NETWORK BANDWIDTH

As with all communication protocols, bandwidth must be considered also. Time must be available in the macrocycle for demand messages such as alarms and alerts, operator changes, reads for displays, and downloads. A publication limit of no more than 50% is generally considered reasonable. Since the H1 network operates at 31.25kbps, 12-to-15 publications per second is pushing it, depending on the device response times and schedule’s optimization. Optimization of the link schedule can significantly improve the effectiveness or even the feasibility of a link. Remember that the more devices present, the slower the macrocycle must be. Conversely, the faster the control frequency, the fewer devices that can be supported on a single link. You get to engineer the trade-off.
VCRs and LINK OBJECTS

A not-well-known limit which has become noticed more often is the number of Virtual Communications Relationships (VCRs) provided by a device or host interface. VCR is simply a fancy acronym for a useful logical connection to or from a device or interface device that happens to be implemented over a common wire called a network. Each field device usually needs two VCRs plus one for every subscription or publication that comes into or goes out of it. Each interface device usually needs two VCRs plus one for every subscription or publication that comes into or goes out of it to the devices. The number of VCRs is limited by performance since interrupts must service them in a very short amount of time. The device and host vendors can tell you the maximum count provided.

Link Objects are also limited resources in a device. They are used for all function block interconnections, both internal (without using VCRs) and external (using VCRs). Since the cost of link objects is primarily memory, there are usually sufficient numbers that the users need not be concerned about them.

ADDRESS LIMITATIONS

How about address range limits? Although there are 256 addresses in each link’s address space, save a few for specialized functions, an impedance limit of 32 would be reached long before running out of permanent addresses. But realistically, one or more of the aforementioned limits will kick in first. To be realistic, there is a tradeoff between “as many devices as possible” (to minimize the “per device” cost of the interface) and “as few as possible” (for loop integrity considerations). Most users are going for 2-to-4 control loops (4-to-8 devices) or 8-to-12 monitoring devices. Given these more modest goals, most of the aforementioned limitations will not be too painful. Most users will let the configuration tool assign the addresses for them, only concerning themselves that Link-Master-capable devices get the lowest addresses to insure quicker fail-over.

OVERALL “SYSTEM” CAPACITY

Capacity planning is not limited to the Fieldbus device topology and link loadings. You’ll still have to consider the overall system capacity. Most process control systems are designed with certain patterns of communications traffic in mind. Being aware of this will help application engineers to insure that the equipment is utilized most effectively. FOUNDATION Fieldbus adds one more layer to this pyramid.

Figure 1 shows the basic architectural organization of high-capacity control systems. At the “top” is the plant information network with the devices that need to display process data and perform higher-level (slower) functions on it. Below that network are one or more data servers, used to efficiently gather and route data on a real-time basis to requesting applications including operator display stations. The network below the servers performs primarily in a supervisory role, connecting the servers to controllers beneath and also permitting controllers to communicate with one another.

The controller nodes may either contain local I/O modules or, in turn, network to other chasses of I/O modules over I/O networks. Any of these I/O modules may be replaced with yet another network interface module that interfaces to the FF networks, which support the FF devices (FFDs) themselves.
The servers are at the head of a “pyramid” of controllers. Each controller, in turn, is the head of a pyramid of I/O chasses. Each I/O chassis is a head of a pyramid of field devices. Now, considering, that although any device might need to communicate with any other device, communications is most effective and efficient if nodes communicate through the fewest networks and intervening nodes as possible. This provides minimum traffic and minimum data latency or delay. In other words, put devices that must communicate most frequently together on the same FF link, if possible. Put interacting devices and equipment subordinate to the same controller, wherever possible. As noted earlier, whether or not to utilize control-in-the-devices, depends on the algorithm set available in the controller versus the devices and on the control latency requirements. There will usually be tradeoffs. Some systems will permit the following communication paths between devices:

1. Same Fieldbus link
2. Different Fieldbus links on same interface module
3. Different Fieldbus links on different interface modules in same I/O chassis
4. Different Fieldbus links on different interface modules in different I/O chassis to same controller
5. Different Fieldbus links on different interface modules in different I/O chassis to different controllers
6. Different Fieldbus links on different interface modules in different I/O chassis to different controllers in different “systems”

Clearly, the above list is ordered from best to poorest performance because more and more networks and intervening nodes become involved in the transport of the data. Therefore, the application and control engineers should be mindful to co-locate the majority of interacting equipment as “low” as practical in the pyramid when laying out the plant instrumentation and control networks. The number of communications circuits between points of differing controllers should be kept small because there is a large overhead with each message compared to the number of items in it.

DEALING WITH ALL THIS

With the benefits of this new field network comes the responsibility of establishing and maintaining dozens of network parameters. With the benefits of this new smart field device comes the responsibility of establishing and maintaining dozens of parameters pertaining to the device as a computing environment. With the benefits of this new smart field sensor or actuator comes the responsibility of establishing and maintaining dozens of parameters pertaining to the sensor or actuator. Fortunately, there are tools to provide assistance.

Most engineers see the function block configuration in the field devices as a trade-off—it simply moves from the controller to the field device. Just be sure that your configuring tool deals with interconnections between the FF field devices and the controller by configuring both with the same tool, by permitting them to be drawn on the same diagram page, and by not having to create special conversion or interface blocks. More later on this too…

WHAT DOCUMENTATION NEEDS TO BE CHANGED?

Here are a few documents to consider: P&ID drawings, Loop Drawings, SAMA or Control Strategy Diagrams, Data Sheets, and System Drawings:

**P&ID drawings:** Piping and Instrumentation Diagrams indicate the process flow and the location of instrumentation and actuators relative to the process flow. Fieldbus drives little change in these drawings. The ISA 5.1 Committee is defining the effect of Fieldbus on the P&IDs, but it is not expected to be significant. One recommendation is to use a dotted line with circles to represent the multi-drop signal bus. (See Ref. 3)

How about the **Loop Drawing?** It used to show terminations for wires from the device through a marshalling cabinet to the terminations for a controller. Those terminations are now a port to a powered network. With multidrop networks, should the loop drawing be renamed a “segment drawing” or a network drawing”? These drawings are still used by technicians and engineering for control and
instrumentation concerns. They’ll need to show all the devices on a link, where the power is introduced, where I.S. barriers are positioned, if used, and where the terminators that stop reflections are located. How long are the home runs? How long is each segment? What types of wires are used? Are any “rules” violated?

The SAMA or Control Strategy Diagrams show the function blocks and their interconnections. These are drawn by the configuring engineer using the control system builder configuration tools and may be printed as needed. The primary change here is that some or all of the function blocks reside in the field devices. Make sure your tool permits the blocks to all reside on the same drawing. Otherwise you may have to break up even simple loops into multiple drawings with off-page parameter connectors.

Data Sheets are as useful as ever. But now there’s even more data. Current draw (mA) is important, as is network address, maximum VCRs available and number of VCRs used. What permanent function blocks reside in the device? Can others be instantiated? Listing how many and which ones, may get out of hand since not all blocks carry the same weight in terms of memory or CPU usage. Host system software can help to produce current printouts of device detail information since it can be read from the project copy and can be updated from the device itself, including such gory details as serial numbers, model numbers, device revision numbers, and materials of construction.

System Drawings are usually part of the DCS vendor deliverables. They include all the DCS nodes (operator stations, application stations, printers, servers, controllers, I/O chasses, interfaces, etc.) and the internal networks that interconnect them. These are essential to understanding the infrastructure of the internal and external communications paths. This is where the “pyramids” of communications that I referred to earlier are found.

**MAKING ALL THIS BEARABLE WITH TOOLS**

If it is so complex, why are the vendors saying Fieldbus is simple? Well, it is complex, but help is now available. Look to your experienced host vendor. But make sure they supply comprehensive FF support, not just an “interface” and not just lip service. Do they fully integrate the features, capabilities, and benefits of Fieldbus into the DCS or PAS?

First ask about on-line versus off-line support. Early systems simply met up with a functioning device and started talking to it. In reality, the pressures of short time-to-market means a plant control strategy has to be worked out well before the equipment is available in the plant. Therefore, off-line, before-device-availability configuration is essential. But how does this work? Well, the vendors can provide their device descriptive files long before the devices are installed, shipped, or even manufactured. Look for this capability. These files can be obtained from the Fieldbus Foundation, from the device vendors via their web sites, or on a diskette with the devices.
INTRODUCING DEVICES BEFORE THEY ARRIVE

Using one of the above methods, load the device descriptive files onto your host. Then, using the builder tools, construct a template for each field device model including its blocks (resource, transducer, and function blocks). At this time, you should be able to modify some of the attributes (like minimum and maximum value entries), and add new attributes that the device vendor does not supply, like groupings on display tabs, which parameters to show on block faces by default, and which ones should, by default, provide connecting pins. Also, default values such as alarm hysteresis can be set to reduce the amount of changes for each instance of this device or its blocks. You have now prepared the library with patterned templates to drag-and-drop in order to create instances of each of these device models on your physical “tree” of DCS equipment.

PHYSICAL AND LOGICAL “TREES”

Microsoft Technology has made us all familiar with the hierarchical “tree” of folders and files that the Explorer (formerly the File Manager) presents. That same organizational technique is useful to present first the physical organization of the Fieldbus, and secondly the control strategy organization of the Fieldbus. In Figure 2, the physical Fieldbus Interface Modules (FIMs) are presented at the highest level. Subordinate to them, are the multiple FF links that they support. Subordinate to each link are the individual devices on the link. Then, subordinate to the devices are the blocks within each device. Naming of the block indicates the control strategy containing it. By double-clicking on the any of these elements, one can get a list of all the parameters, grouped by “tabs” of related functionality.

Similarly, control strategies of sequences of blocks are assigned to controllers, or directly to Fieldbus links if no controller is needed. Subordinate to these Control “Modules” are the lists of function blocks contained in them. As above, double-clicking on any element of the tree, one will get a list of all the related parameters. In both sequences, each element can be collapsed [-] to hide or expanded [+] to reveal the more detailed elements that it contains.
DEVICE COMMISSIONING & LOADING

A control engineer will usually build the strategies in project files long before the device is on the wire. When it is connected to a live network wire, it will show up in the “Uncommissioned Device” section of the tree since the FIM can see it, but it has not yet been associated with the device image in the project file. When the user then matches each uncommissioned device with each device in the project file that has not yet been matched, the alignment of the unique manufacturer-assigned device ID, user-assigned tag, and permanent network address takes place. Loading the device with the project-configured information is the final step in commissioning. As the devices and their blocks are loaded, they may be left inactive or placed in their normal execution modes, per user selection.

MONITORING THE FUNCTION BLOCKS

The easiest way to debug a control strategy, is to simply look at the function blocks in the chart while they are active. In monitor mode, they display the live process values and any other values the user requests. This includes both controller and field-device-resident blocks in the same chart.

MAINTENANCE

Maintenance is sometimes considered the crown jewel of Fieldbus. The device’s intelligent diagnostic can now speak out! The FF standardized method of reporting notifications enables the DCS vendor to present the alerts to the proper personnel while recording the event without burdening the network with application polling. Bad and uncertain process values are indicated via mandatory status indications and automatically propagated so that consuming blocks and applications can take appropriate action.

Part of the maintenance responsibility is to document what is in the field. The host should be able to generate reports, by various subordinate classifications, that list the pertinent information regarding the devices, their attributes and parameters, and their function block implemented control strategies.

REPLACING DEVICES

“Openness”, to some, is not proven until a device from one vendor can be replaced by a similar device from another vendor. Obviously it has to be the same type of device and must have the same function blocks that were previously in use. The tool must permit the de-commissioning of an existing device and a commissioning of a replacement. Then, advanced tools can extract the parameters from the old device (or old “save” image if the device has deceased) and insert the parameter values into the new device. When the old and new do not match due to differences in manufacturer-specific extensions, the tool should list the omitted old parameters and their values and the unmatched new parameters (along with the default values) so that the user is aware of them and can take appropriate action. This process “morphs” the old device into the new device as best as it can algorithmically, and notifies the user of differences.
CONCLUSIONS

FOUNDATION Fieldbus technology is indeed complex. It requires a change in culture (Ref. 4). PC technology is complex also, but has been made usable for ordinary beings by advanced software tools. Just as PC tools grew in strength over time, the Fieldbus tools are growing in strength. As experience and volume of sales increase, look for even greater and more powerful features to be built into the Fieldbus-friendly DCS and PAS hosts. Engineeringless Interoperability (ELI) is a goal of the Fieldbus Foundation and these advanced tools, in conjunction with the field device vendor files, are quickly advancing Fieldbus toward the plug-and-play expectation.

NOMENCLATURE

CAO – Complex Analog Output function block
CDO – Complex Discrete Output function block
DCS - Distributed Control System
ELI – Engineeringless Interoperability (complete algorithmic understanding of device’s functions and interface methods)
FF – FOUNDATION™ Fieldbus, the technology, or
FF – Fieldbus Foundation, the promotional, not-for-profit organization
FFD – FOUNDATION™ Fieldbus Device
IS – Intrinsic Safety
ISA – Instrumentation, Systems, and Automation Society
kbps - Kilobits per second
Mbps - Megabits per second
PAS – Process Automation System
PI – Pulse Input function block
SAMA – Scientific Apparatus Makers Association
SCO – Step Control Output (A function block that generates raise & lower ON-OFF pulses of varying length)
SP50 - ISA Standards and Practices Committee assigned to Fieldbus standardization. Previously produced the 4-to-20 ma analog transmission standard.
VCR – Virtual Communications Relationship, a term for a logical connection point within a network device or network interface.

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