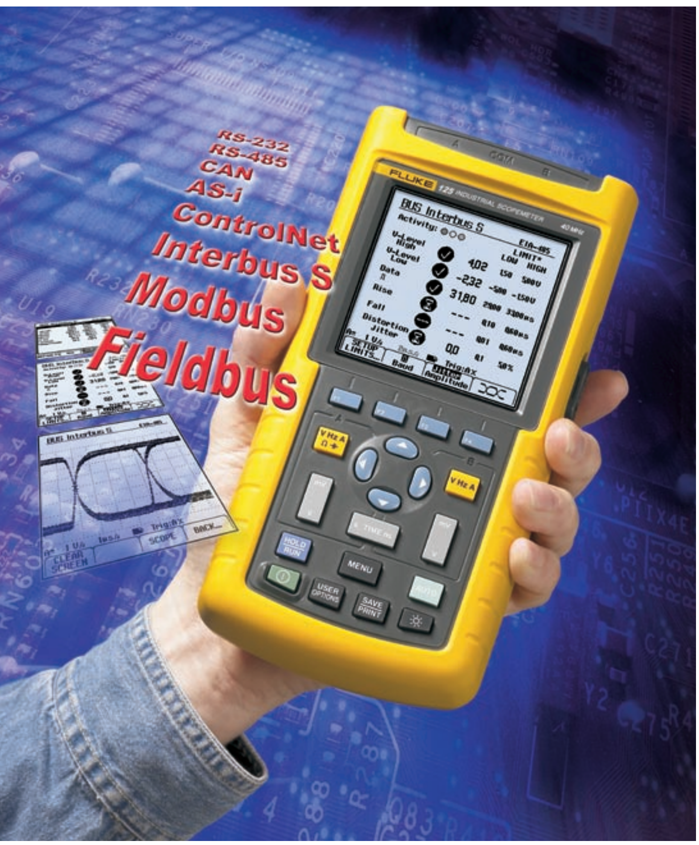
Using a Fluke ScopeMeter 125 to Troubleshoot FOUNDATION™ Fieldbus Installations

Application Note



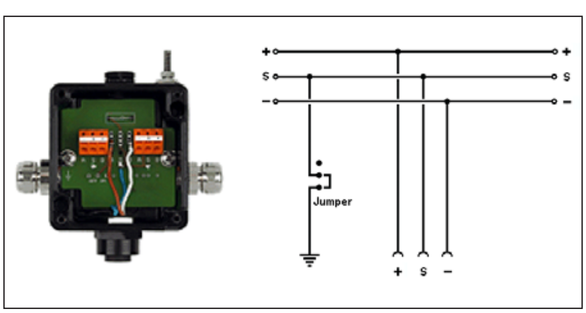


Figure 1: A typical FOUNDATION Fieldbus junction box with wiring diagram.

Industrial fieldbus networks operate under very different conditions than do office and other commercial communications networks. In the industrial world, external influences can play havoc with sensitive electronic devices such as PLCs, network controllers and other instruments supporting process control. These external, industrial influences fall into two categories:

1) **Disruptive environmental conditions**, which include mechanical vibrations, extreme temperature changes, high humidity levels and poor air quality caused by chemicals, dust and other agents. These conditions can create loose or intermittent connections, corrosion in conductors and junction boxes and/or changes in impedance.

2) **Electrical disturbances** come from a variety of sources. Breakers turn high-energy circuits on and off generating transients. Belt conveyors and mechanical drives discharge high-voltage static electricity into electronic systems. Load changes on branch circuits create fluctuations in supply voltages. And there are still other possible sources of electrical disturbances.

Both types of disturbances can temporarily or permanently adversely affect system components—terminators, input components and cabling. The result often is a disruption of the millivolt signals upon which production processes rely. Therefore, it makes great sense to avoid potential process communications problems and pinpoint existing problems by monitoring and troubleshooting industrial digital communications systems using an oscilloscope.

The following discussion focuses on the monitoring of a specific type of system, FOUNDATION Fieldbus 31.25 kb/s (H1) networks, using a new instrument designed and programmed for such monitoring: the Fluke 125 Industrial ScopeMeter® test tool.

(**Note:** The Fluke 125 is not limited to monitoring just Fieldbus H1 networks.)

Troubleshooting procedures

When troubleshooting a Fieldbus system, first attempt to document recent changes to the system: Have any devices or any parts of the network recently been disconnected? Was anything added or modified just before the trouble began?

Determine what's working and what's not. Make notes about what is observed versus what was expected. Investigate whether certain disturbances can be traced back to specific events: a motor starting, a valve opening, a light being turned on, etc.

Next, make measurements to "look into" the network in order to see and understand what's going on. Carefully document each measurement: What was measured? Exactly where was the measurement made? Under what conditions was it made?

To start, measure at both ends of the trunk and compare the results. Next, measure at one or more locations along the trunk and compare the results. If only one device has a problem, make measurements near that device. If multiple devices have problems, then try to determine if there is a pattern. If there is a pattern, is the cause of the pattern evident?

If modifications have been made or devices added recently, make measurements at these places, too. Try to determine which segments, if any, of the network have problems and which are problem free.

A number of measurements will help find discrepancies and thereby help us identify problems. Such measurements include:

- Capacitances and resistances in and between conductors
- Improper shield and conductor contacts
- DC voltages
- AC signal levels
- Noise and signal quality.

These measurements using the Fluke 125 ScopeMeter test tool are discussed in more detail in what follows.

The Fluke 125 is a compact, portable combination oscilloscope and digital multimeter (DMM) that offers dedicated analysis capabilities for troubleshooting industrial bus systems. Being a battery-operated instrument, the 125 can make so-called floating measurements in which neither point of the measurement instrument is at ground (earth) potential. This capability ensures that the floating nature of the network will be maintained, whereas other oscilloscopes may introduce unwanted connections to earth-ground through their safety, ground-referenced input contacts or through large capacitors in their power supplies. Such connections in themselves could disrupt a network's integrity and easily block communications.

The Fluke 125 supports the storage of scope screens in internal memory. These screens can be copied into reports just as has been done (see later) in this application note. Instrument settings used are also stored with the stored screens, and the instrument also allows names to be added to screen copies.

Test connections

Most of the measurements carried out along the trunk of a Fieldbus network require that the hot input of the instrument's channel A (marked "A"), and the ground reference contact ("COM") get connected to the positive and negative conductors of the bus wiring. The most common color coding of Fieldbus compliant cables is orange for positive and blue for negative.

Occasionally, troubleshooting requires measuring the voltage of one or the other conductors over ground. For such measurements, the shield can be taken as the ground-reference contact. However, the shield of the cable should not be connected to the chassis or earth ground at the location of the device.

Bear in mind that the structure of the Fieldbus assumes a floating operation over ground. So, neither of the wires should be connected to earth-ground anywhere in the system. Should an investigation uncover a ground contact, then it should be treated as a likely source of network trouble. According to wiring and installation specification from the Fieldbus Foundation, cable shielding is to be grounded only once in a trunk section at the control room side of the trunk.

Access to the trunk wires can be gained easily at the junction boxes where spurs connect to the trunk, or at the terminals of devices. The junction boxes typically used in Fieldbus networks are built around screw terminals. (See Figure 1). Measuring at junction box terminals means not having to make any changes to the cable structure. Furthermore, the schematic and accompanying text on many of these boxes permit unambiguous conductor identification.

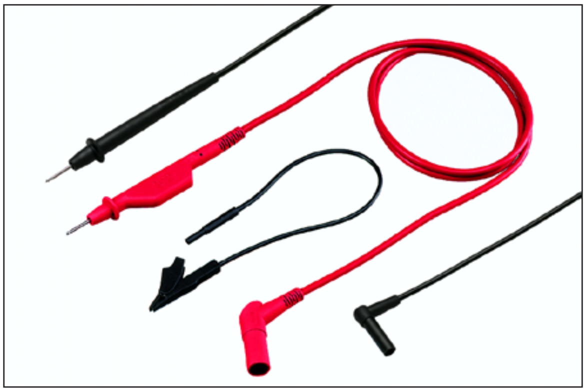


Figure 2: The STL120 (red) and TL75 (black) test leads are the primary tools for making test connections onto a FOUNDATION Fieldbus. When encountering heavy noise on the bus, try the shorter lead with the alligator clip (center Item). All three items are standard with the Fluke 125 Scopemeter.

The screws of the terminals make a good place to apply a STL120 shielded test-lead tip and a TL75 reference lead. Both are standard items with the Fluke 125 ScopeMeter. (See Figure 2.)

In case of heavy noise from the environment, a shorter ground lead with an alligator clip (Figure 2, center item) will help reduce the amount of noise recorded. When using this lead, connect the alligator clip to the negative trunk wire. This shorter lead is also a standard item with the Fluke 125.

One alternative for making test connections is the optional HC120 hook clip (Fgure 3), which allows one to hook the STL120 tip to the actual conductor of the cable. Another alternative connection method uses the optional TP88 back probe-pins (Figure 4), which can be used to probe the screw terminals at wire entry points. These long, thin needles allow easy access to points crowded with wires that are difficult to reach using standard test pins.

Cable hardware verification

When a network is down and the problem is difficult to identify, it often pays to start with verifying the cable installation. A problem may stem from the environment

Figure 3: HC120 Hook Clip

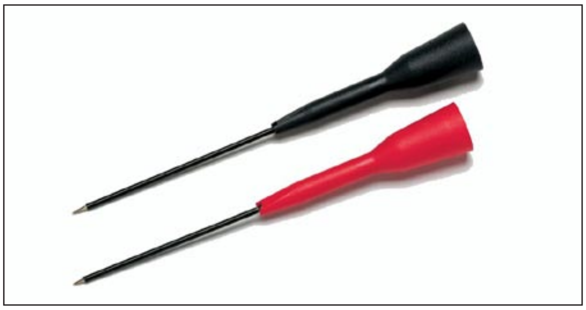


Figure 4: TP88 Back Probe-pins

where humidity or poor air have corroded connectors. Or, perhaps vibration has caused intermittent connections.

In verifying new installations, it makes sense to test trunk cabling before installing spurs and devices. Eliminating the trunk cabling as a source of a problem in an existing network or as the potential source of problems in a new network requires a few simple measurements. The digital multimeter incorporated into the Fluke 125 measures the resistance and capacitance of cables. If problems exist, using these capabilities will detect them.

1. The first step in verifying trunk cabling is to measure the capacitance between individual conductors and the shield. The two values (conductor A versus the shield and conductor B versus shield) should yield about the same value because the trunk is supposed to be fully symmetrical. In making these measurements, compare the capacitance values to the data for the type of cable used, and take the length of the trunk into account. (An example of a manufacturer's cable specifications can be found in the appendix to this application note.)

When a Fluke 125 is the test instrument, the test involves connecting the TL75 lead to the shield connector in control room and applying the hot tip of the STL120 to the A and the B wires respectively. Depending upon the length of the trunk, it may take a few seconds for a capacitance reading to stabilize. When a reading is stable, record it.

2. Next, measure the capacitance between the two conductors, A and B, by connecting the TL75 to one wire and the 'hot' tip of the STL120 to the other wire contact. Record the result.

Failure to get a reading for any of the three capacitances probably indicates a short or a broken connection in that section of the circuitry. An unstable reading may signal a weak connection in a junction box that is creating only intermittent contact with a section of the trunk.

If the capacitances conform to expectations, create a short circuit at the end of the trunk between the A and B wires and measure the resistance between those conductors on the control room side. This measurement should produce a reading representing the total resistance of the copper conductors over the total length of the trunk, back and forth. A comparison of this reading with the specifications for the cable will reveal whether there are any poor connections anywhere along the trunk. Bear in mind that while cable specifications may give the resistance per conductor for a single length of wire, this test measures the return path, too.

3. Next, remove the short circuit at the end of the trunk and measure the resistance between the A wire and shield, and between the B wire and shield. The readings should be high, in the multiple meg-ohms range. A low value indicates a short circuit to the shield. A short might be caused by something as seemingly insignificant as a single thin wire from a braid that's making contact near a screw terminal, or it might be an indication of a cable defect or the result of moisture in a junction box.

4. Once you are confidence that all resistance and capacitance values for the trunk meet expectations and match the cable specifications, inspect the spurs. On new installations, this will follow the initial connection and testing of each spur. Once each spur checks out, repeat the previous tests to find and correct errors in the whole system. If everything checks out, it's safe to power up the network.

Supply voltage

Each of the network devices needs the proper supply voltage. Incorrect dc-supply can cause a variety of errors—sometimes continuously and sometimes intermittently. Incorrect supply voltage can cause devices to fail to handle data consistently, frequently disconnecting and reconnecting or perhaps not responding to the controller at all.

Since supply voltage is distributed through the main network, which may be lengthy, there will be voltage drop within the system. The absolute minimal dc-supply voltage for any Fieldbus device is 9 volts, but a higher voltage is preferable. The absolute maximum supply voltage is 32 volts.

The Fluke 125 ScopeMeter test tool can measure supply voltage and automatically compare it to an upper and a lower limit. As defaults, these limits are set for 5.5 and 35.0 volts. However, the

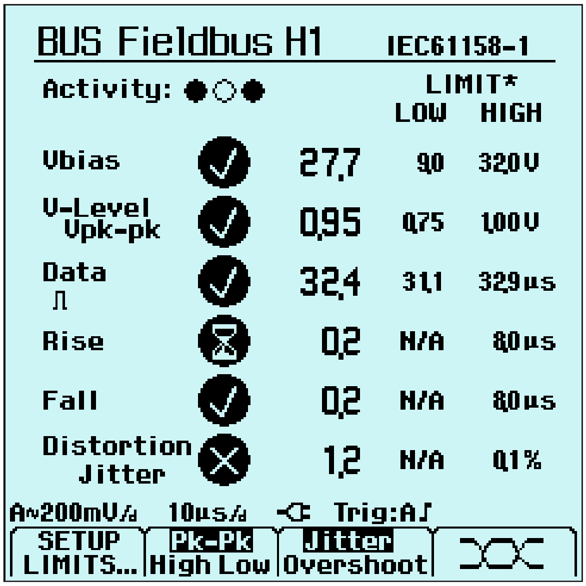


Figure 5: Fluke 125 screen showing results of a Bus Health Test.

user can enter other limits at set up limits on the front menu. For Fieldbus systems, selecting 9 volts as the minimal value and 32 volts as the maximum value will generally do the job.

During use, the Fluke 125 will indicate via icons whether the measured voltage is within the limits: ✔ = OK; X = not-OK. In addition, the icon may change to a warning sign (!) when a reading is within a certain percentage of a limit value.

Figure 5, a screen shot, shows an actual bus-health test screen for an H1 Fieldbus system. If the instrument recognizes that communication is taking place, the activity indicators will blink.

The first line displays bias voltage. OK indicates that the dc-supply voltage (27.7 volts) is within the limit values: 9.0 and 32.0 volts.

The Fluke 125 differs from a standard DMM in that it displays the voltage reading that is closest to a limit over the time span that the measurement is happening. The instrument has a hold function that helps installation and maintenance personnel determine if the supply voltage is at risk of going outside of the preset limits. In other words, during load changes, the instrument displays the value closest to the lower or upper limit.

To reset the hold function, press the Hold/Run key twice to hold and restart the measurements. This action initiates a new measurement cycle in which all result fields are cleared.

The instrument can be used as a standard DMM or as a standard oscilloscope. Then, it can record momentary voltages in order to isolate instabilities in a power supply. In addition, the instrument can record supply-voltage changes on the bus. The function that allows this is TrendPlot™, detailed in the instrument's users manual.

The hour-glass icon on the fourth line of Figure 5 indicates that a rise-time measurement was in progress at the moment the screen-copy was made. Next to the icon is the result of an earlier measurement and the limit to which this rise time is compared. In this application, rise times up to 8 µs are viewed as acceptable.

Because of inevitable voltage drop based on copper resistance and Ohm's-law, supply voltage to devices near the end of a trunk are lower that for those nearer the power supply. Making bias voltage measurements at various junctions can reveal disruptions, such as poor connections, along the trunk. Good notes and knowledge of the trunk layout will help troubleshooters in finding which junction/spur is at fault.

In H1 Fieldbus systems, the maximum cable length in the trunk is 1900m. For a twisted pair cable made from AWG#18 (1 mm in diameter or with a cross section of 0.79 mm^2 per conductor), one must take into account a resistance of 2.26 Ω per 100m of wire, which, of course, translates to 4.52 Ω per 100 m of dual-conductor cable and a total resistance of 86 Ω for the two wires over the maximum trunk length.

If there is only a single device drawing 25 mA connected to the end of the trunk, that device in itself will cause a voltage drop of 2.2 volts across the trunk cable. With multiple devices connected along the line, the voltage drop due to supply-current consumption can make the difference between a good and a poor supply voltage at some devices.

Table 1 (following Figure 6) shows the calculated supply voltages for the network in Figure 6, which depicts a full-length trunk with a limited number of devices. In the design phase of a new network, similar calculations should be made to determine the type of cabling and the power supply needed.

For existing systems, if a plant's archives include "as-builts" with design data and information about the system's physical layout and cable

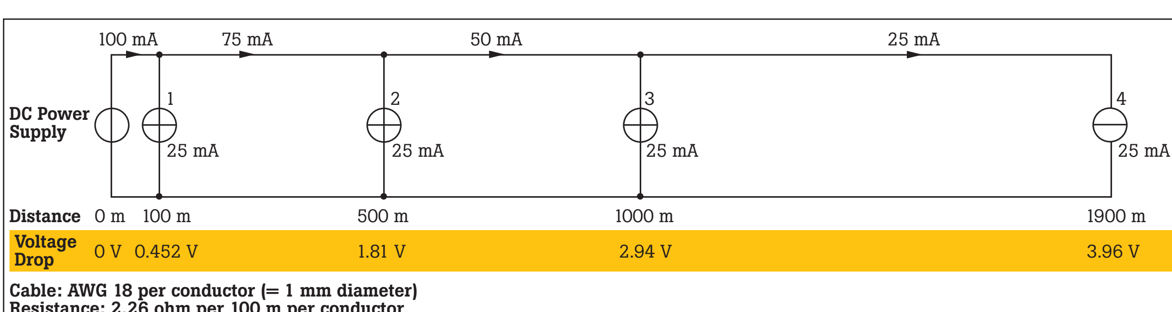


Figure 6: Calculation of voltage drops resulting from connected devices and their distances from the power supply.

	Device 1	Device 2	Device 3	Device 4
Distance from supply	100m	500m	1000m	1900m
Length of section (single conductor)	100m	400m	500m	900m
Resistance of section	4.52 Ω	18 Ω	22.6 Ω	40.7 Ω
Total copper resistance	4.52 Ω	22.6 Ω	45.2 Ω	85.88 Ω
Device current	25 mA	25 mA	25 mA	25 mA
Total current	100 mA	75 mA	50 mA	25 mA
Voltage drop in section	0.45 V	1.36 V	1.13 V	1.02 V
Total voltage drop	0.45 V	1.81 V	2.94 V	3.96 V

Table 1: Supply voltage calculations for the network in Figure 6.

lengths, those data should be kept at hand as an aid during fault finding. Any deviation from the as-builts is a first indication of the quality of the cable installation and connections and may help lead troubleshooters to the location of a faulty connection.

Since current (load) fluctuations are inevitable, when selecting a power supply and voltage level, system designers should take as a basis the full-load output voltage of the power supply, while accounting for any voltage drop in the power conditioner.

Signal levels

Signal level is measured as the peak-to-peak amplitude of the ac-waveform. It is directly related to the impedance of the network trunk, and any deviation from the nominal impedance will impact signal levels.

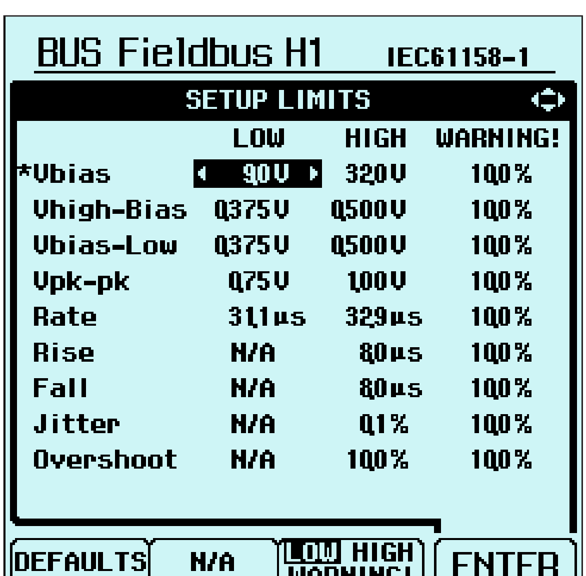


Figure 7: Set-up screen for changing test-limit values.

A common cause of improper impedance is the use of too few or too many network terminators. More or less than two terminators per trunk section will result in incorrect signal amplitude due to impedance as well as reflections and distortions.

A third terminator will cause signal attenuation of about 3 dB (-30 %). A missing or broken terminator will result in an increase in amplitude above nominal by as much as 60 %.

Long stretches of cable also attenuate signals. Commonly used cable in H1 Fieldbus systems attenuate signals by about 0.3 dB per 100m or 5.7 dB over the full length of a 1900m trunk. The 5.7 db value means that for every volt of signal injected at one end of the cable, one should expect to see no more than 520 mV at the other end of the cable.

The nominal output signal amplitude at any device is 800 mVpp to 900 mVpp. (where "pp" stands for "peak-to-peak"). At a distance along the network, the amplitude may be as much as 50 % lower without any risk of error.

The Fluke 125 can be configured to measure peak-to-peak amplitude or to measure the low-level or high-level excursions of the signal compared specifically to the bias voltage. Just as with the dc-voltage measurements described earlier, the Fluke 125 compares the actual reading to pre-set limits and presents on its screen, along with the actual reading, clear indications of good or bad readings.

The most common measurement is peak-to-peak amplitude. See Figure 7. A user of the instrument is free to compare readings to built-in default levels or to enter alternative, user-defined levels instead. When a limit is set to a value other than a default value, the text displays an asterisk (*), as seen on the "Vbias" line in Figure 7.

In troubleshooting, check the signal levels at various points along the network to determine if the values make sense. Look for patterns in amplitude differences. For example, sudden differences at either side of a junction box is a "red flag" suggesting the presence of a hardware fault.

If any particular device appears to be causing difficulties, measure on all sides of the junction box: incoming trunk, outgoing trunk, and spur. There should be no differences in signal level or supply voltage here.

In addition, take a reading at the device end of the spur, and compare this reading to those recorded at the junction box. In transmitting mode, a device should generate a signal in the 800 mVpp to 900 mVpp range. Signals above 1000 mVpp indicate incorrect trunk-section termination.

Ordinarily, depending on the distance to the transmitter, signals in the 250 mV to 950 mV range are acceptable. Levels below 250 mVpp are likely to cause errors in Fieldbus devices and need to be investigated further.

Signal quality and noise

In general conversation, signals on a bus are referred to as "digital signals" as though they change state from low to high almost instantaneously. In reality, that is not the case. For some types of networks, the speed of signal transitions is quite critical.

For Fieldbus networks, transition speeds, as such, are not so critical. However, an excessive slowdown in transitions can eventually lead to signal attenuation, if the transitions take so long that the flat tops and bottoms of pulses do not stabilize. For this reason, the Fluke 125 can record the rise and fall times of pulses and reveal whether the times are within either preset or user-defined limits.

Transitions (edges) that are too slow, may indicate that the trunk section is too long, that the cable is incorrectly specified or damaged or that a terminator is broken or missing. A check of the transition times of the signal will reveal any differences in this parameter along the network and, thereby, help identify hardware faults.

Pulse overshoot is also an indication of out-of-spec impedances within a network. A broken or missing terminator or incorrect wiring can cause such anomalies. So, excessive overshoot should foster further monitoring of the hardware.

If the network picks up noise from other equipment, it will lead to degradation of the signal's fidelity and will manifest itself as noise on the waveform and as instability of the edges. Such instability is often called jitter, which indicates that transitions are not exactly in line with system timing. Too much jitter may lead to communication loss.

Visual waveform inspection

Another level of analysis offered by the Fluke 125 uses what is known as the eye-pattern mode to visually inspect signals on a bus. Once the mode is selected, the Fluke 125 screen shows the waveshape of the ac-signal on the bus. The eye-pattern applies a long-lasting persistence mode to the screen. Any curve drawn will remain on screen until the user decides to clear the screen or to alter the mode of operation of the instrument.

This dedicated scope mode gives a user excellent insight into bus-activity and into overall signal quality. (Of course, there needs to be activity on the bus for the scope to record any curves.)

Slow-changing edges do not necessarily indicate network trouble, but great differences in speed transition are grounds for further investigation.

If only an occasional curve is captured with an obviously different waveshape, chances are that a single device has hardware problems or is not powered properly. Finding the location of that device can be accomplished

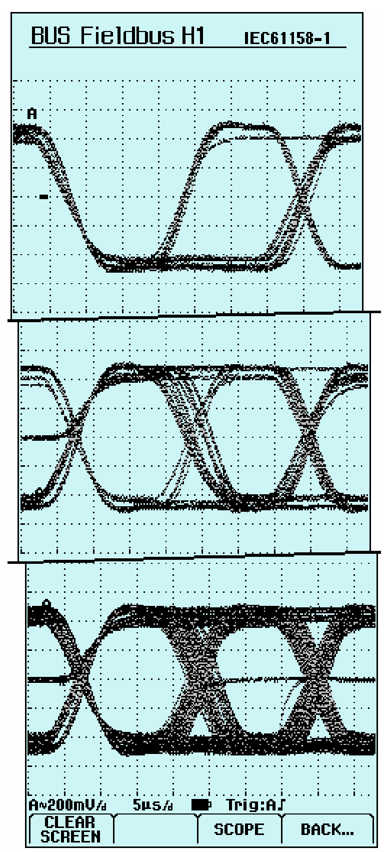


Figure 8: This series of Fluke 125 screens show how the trace builds up over successive acquisitions using the instrument's eye-pattern display mode.

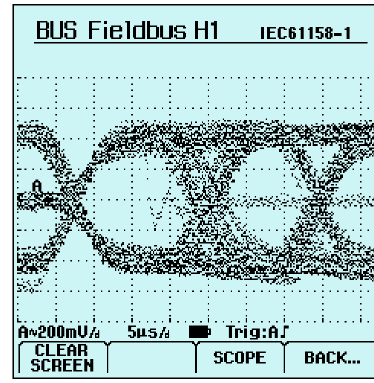


Figure 9: A Fluke 125 screen showing a cluttered and noisy signal.

by monitoring several different points along the trunk while taking into account normal signal attenuation. The closer to the transmitting device that monitoring occurs, the larger the signal amplitude of the pulses from the offending device will be.

Wide spreading of both the high and low levels may serve as an indicator of signal attenuation along the trunk. Inconsistent distribution of signal levels may signal a discontinuity in the network or a device that is putting out a signal too low in amplitude.

The eye-pattern mode also allows for an analysis of the noise levels on the network. Noise can interfere with the signal and corrupt or halt communications. Poor connections in the cable shield or disconnected shielding can allow the picking up of disruptive noise levels.

Installing and routing

When motor drives are present, install network cabling as far away as possible from the motor-drive output cables. Network cables are more sensitive to some devices' power cables than others. For instance, the cables between a motor drive and the motor are a likely source for excessive noise.

Once noise is introduced into a spur or a section of the trunk, the noise signal is easily transferred and will likely manifest itself at various points on the network, depending on how the network routes the noise. That probability means that a source of excessive noise and a device with communication problems do not have to be close to each other for the former to affect the latter.

Figure 9, another screen capture, depicts a somewhat noisy bus signal. In such cases, check the noise level at the middle or baseline level on the left of the screen (just below the "A" trace marking). This segment of the waveform represents the steady-state voltage on the bus just before the capture of any data packets. Since the line should be relatively quiet here, the signal amplitude at this point is a good indicator of the noise level on the bus.

Since there is no clear limit value that can be specified as acceptable or as the certain source of error, evaluating noise signals is necessarily somewhat subjective. Still, heavy bus noise is a likely cause of communication errors. Here are some guidelines:

- A noise level less than 50 mVpp on a signal of 800 mVpp is a near-perfect signal.
- A noise level more than 100 mVpp on a signal level of only 500 mVpp is likely to cause frequent communications faults.

Data analysis and drawing conclusions

Once the tests described here are completed, bringing the collected data together and analyzing the results should allow one to draw conclusions about what is happening on the network and where the weak spots likely are. Sometimes, analyzing the available data will raise additional questions, which can then be the basis for additional tests, bringing investigators closer to finding solutions to troubling network flaws.

Appendix

Example of Cable Characteristics

Characteristics of Fieldbus H1 Cable			
General Characteristics			
Standard	IEC61158 Part 2		
Conductor	stranded plain copper		
Conductor size (multi-wire)	AWG18	AWG16	AWG14
Conductor thickness (approx.)	1 mm	1.3 mm	1.6 mm
Conductor diameter	0.8 mm^2	ca. 1.3 mm^2	2.1 mm^2
Color coding	positive conductor = orange; negative conductor = blue.		
Screen	aluminum tape in contact with continuous copper wire, covered with wire braid		
Overall diameter	7.9 mm (0.311 in)	9.5 mm (0.374 in)	11.5 mm (0.453 in)
Weight	85 g/m	110 g/m	160 g/m
Electrical characteristics			
Conductor resistance (per conductor)	21.8 Ω/km	13.7 Ω/km	8.6 Ω/km
Screen resistance	9 Ω/km	6 Ω/km	6 Ω/km
Attenuation at 39 kHz	3 dB/km	2.7 dB/km	2.7 dB/km
Inductance	0.65 mH/km		
Mutual capacitance	60 nF/km		
Capacitance unbalance to earth	max. 2 nF/km		
Characteristic impedance	100 ±20 Ω		
Test voltage (core-to-core and core-to-screen)	1500 V		
Operating voltage	max. 300 V		

Table 2: Characteristics of three typical Fieldbus H1 Trunk cables.

Bus-health limits used as default settings for Fieldbus within the Fluke 125, based on IEC61158-2.

Fieldbus H1		
	Min	**Max**
Vbias	5.5	35.0
V(high – bias)	0.375	0.500
V(bias – low)	0.375	0.500
Vpp	0.75	1.00
Rate	31.1 µs	32.9 µs
Bit width	32 µs nom.	
Rise Time	N.A.	200 ns
Fall Time	N.A.	200 ns
Jitter	N.A.	0.1 %
Overshoot	N.A.	10.0 %

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