FLUKE®

Foundation™ Fieldbus:
System and Diagnostic Basics

Application Note

The current trend in factory automation is to replace traditional control schemes in which each device has its own control wiring with bus systems that link a number of devices via the same cable. One benefit of bus networks is that they require far fewer cables and wires to connect devices to controllers. One of the most popular and widely used of these bus systems is Foundation Fieldbus.

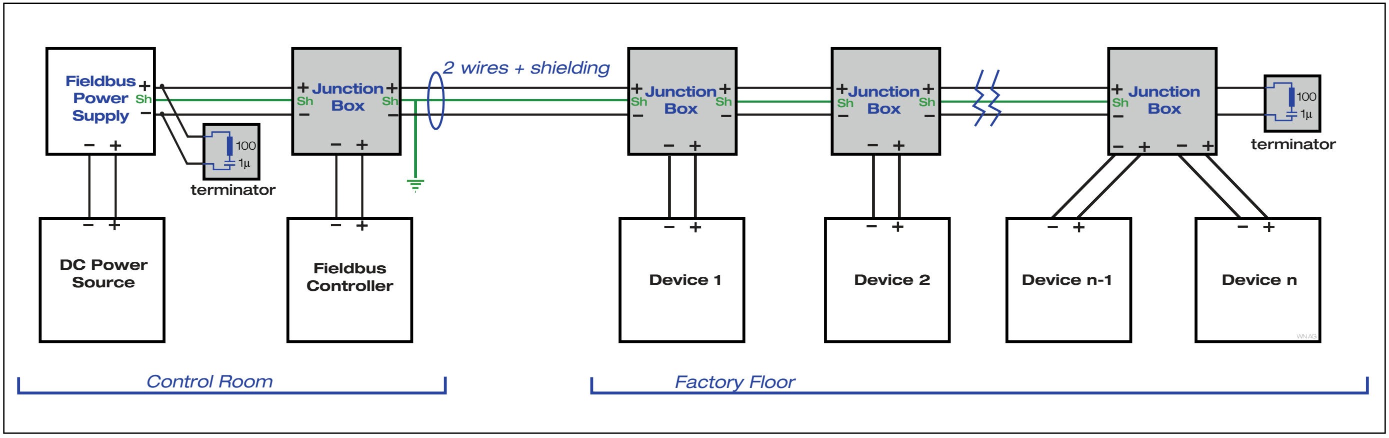

Figure 1: Basic structure of a Fieldbus set-up.

Developed and administered by the Fieldbus Foundation, which was formed by a group of manufacturers of factory automation equipment, sensors and actuators, Fieldbus includes two different protocols to meet different needs within the factory automation environment. The two use different physical media and communication speeds.

The first protocol is H1, which operates at 31.25 kb/s and generally connects to field devices – sensors, actuators, valves, control lights, I/O devices, etc. – and allows for two-way communication between devices and a controller. H1 provides both communications and power over a two-wire system. Standard, shielded twisted-pair wiring is recommended to reduce noise interference on the network.

The second protocol is HSE (High-speed Ethernet) protocol. It operates at 100 Mb/s and typically connects high-speed controllers such as PLCs, multiple H1 subsystems (through a linking device), data servers and workstations. This application note focuses on the H1 protocol.

Network structure

The basic structure of a H1 Fieldbus network is shown in **Figure 1**.

The network comprises the main network cable, which interconnects a series of junction boxes or *couplers*. The couplers allow the devices and the controller to be connected to the main cable or *trunk*. In general, the shorter cables between junction boxes and device are called *spurs*.

Junction boxes can be built to connect single or multiple devices to the trunk. If each device has a dedicated junction box the topology is called a *spur topology*. If multiple devices are connected to the same junction box, the arrangement is typically called a *chicken foot* or a *tree topology*. Most common are mixed networks with both spur and tree topologies, as in Figure 1.

While it is theoretically possible to route the trunk directly from device to device without using junction boxes, the foundation recommends against it. Such a topology (called a *daisy chain*) requires an interruption of the trunk every time a device is removed or added to the network.

Fieldbus' technology imposes limitations on the size of a net work. The maximum length of all the wiring in a trunk and its spurs added together is 1900 m (approx. 6250 ft) per section. If more length is required, one can add a section using a *repeater*. A repeater takes the place of a device, but adding it allows for another 1900 m of cable. A network may use as many as four repeaters for a total length of 9500 m (31000 ft.).

Note that the shielding is connected to earth-ground at only one point in the entire system, and that is important. Grounding the shielding at multiple places can induce stray voltages and currents in the shielding, which can interfere with data communications.

The maximum number of connected field bus devices per section is 32.

As shown in Figure 1, a DC power source is required to provide DC supply or *bias* voltage. If the DC power source were connected directly to the trunk, it would create a short circuit for the AC signals. Consequently, a network must have a Fieldbus compliant power supply, which is a DC source plus a dedicated filter arrangement. The filter lets DC current pass with minimal losses but creates high impedance for the AC signal coming from the network side.

The trunk, then, is a transmission line, on which the propagated speed of AC signals plays an important role. Thus, the trunk must be properly terminated at each end (and only there) for AC signals. Termination is accomplished using a resistor with impedance equal to the characteristic impedance of the cable, usually 100±20 Ω. Given that the network also carries a DC supply voltage, the terminators must have a series capacitor to prevent any DC current from flowing there.

Diagnostic basics

Certain basic diagnostic and troubleshooting procedures can be performed on an H1 Fieldbus network using a Fluke Scopemeter. In the following section, we'll discuss the basics of some of these. More details can be found in a dedicated Application Note 'Using a Fluke ScopeMeter 125 to troubleshoot Fieldbus Installations'.

Detecting reflections

So-called *reflections* on a network affect communications. In the following example, a reflection is explained for a network that is short circuited at one end.

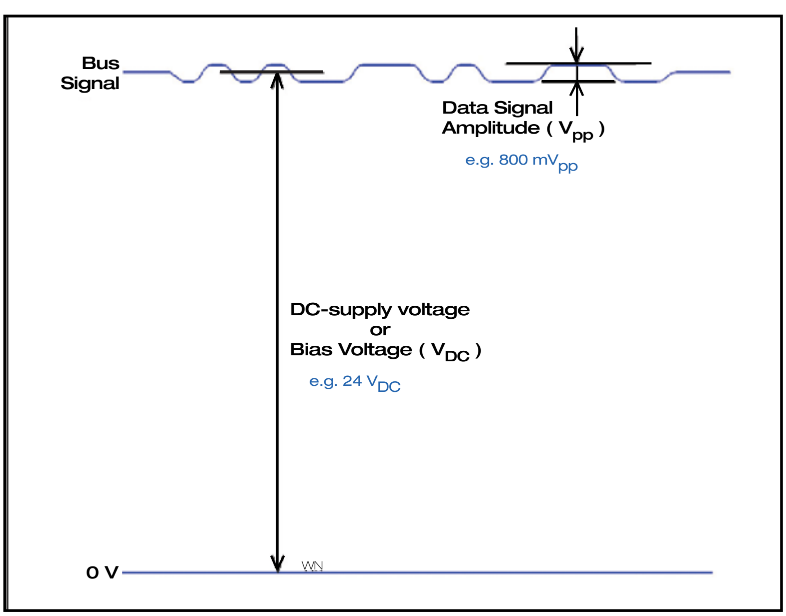

Figure 2: The voltage on the Fieldbus includes a DC-supply voltage and the actual bus signal.

However, it is important to understand that any anomaly, including short circuits and poor terminations, will create reflections.

Consider what will happen when a step voltage is applied to one end of a long cable in which the other end is short-circuited. Initially, the applied voltage will encounter the cable's impedance and will build up a voltage level between the conductors. This step voltage will travel through the cable at a speed determined by the type and construction of the cable. For cables used in H1 Fieldbus networks, that speed is about two-thirds the speed of light in a vacuum: $2/3 \times 3 \times 10^8$ m/s = 2×10^8 m/s, or approx. 660×10^6 ft/s.

When the step voltage reaches the short circuit, the voltage level will suddenly change to zero. This change may be viewed as a step-voltage of opposite polarity, back to zero, because there can be no voltage across a short circuit. At that point, the voltage level anywhere else along the line is still the voltage level originally applied.

Next, this new opposite-polarity step voltage travels back toward the voltage source. Only once it has made the round trip (has been reflected back), will the short circuit at the other end be apparent on the input side. But the reflecting process does take a certain amount of time. How much time it takes will depend upon the length of the cable. Travel time in one direction will be the cable length divided by the speed of the signal.

For the maximum length of an H1 Fieldbus section, the time, t, is

t = {1900 m ÷ (2 x 108m/s)} = 9.5 µs.

The amount of time it would take a step voltage to travel down a maximum-length trunk and back is thus 2 x 9.5 µs = 19 µs.

As noted, an H1 Fieldbus network operates at a speed of 31.25 kb/s, which equals a clock cycle of 32 µs. So, when there is a cable anomaly, one should expect to see reflections of pulses delayed by an amount of time up to 19 µs. The actual time of the reflection depends upon the distance between the pulse source and the anomaly.

While a complete short circuit will cause a full-amplitude reflection, any disruption or deviation from the homogeneous nature of the line will generate a reflection. The amplitude of the reflection depends upon the nature of the anomaly.

For proper network communications, reflections should be avoided and proper cable termination must be maintained. Again, proper termination requires one and only one terminator at each end of a trunk section.

Encoding

With Fieldbus, digital data is transferred using Manchester encoding. That is, a digital *1* is transmitted as a rising edge in the middle of a clock cycle (bit center), whereas a digital *0* is transmitted as a falling edge. This encoding mechanism has several benefits over the transfer of straight binary data. One important benefit is that it allows for an easy recovery of the clock at the receiving end **(see Figure 3)**.

Another consequence is, that pulses are generated that have duration of either a half or a full clock-cycle, whereas the original bit stream comes with pulses that are one or more full clock cycles wide. The resulting bus voltage is schematically depicted in **Figure 2**. A true waveform recording of a data package is seen in **Figure 4,** where the DC bias has been filtered out.

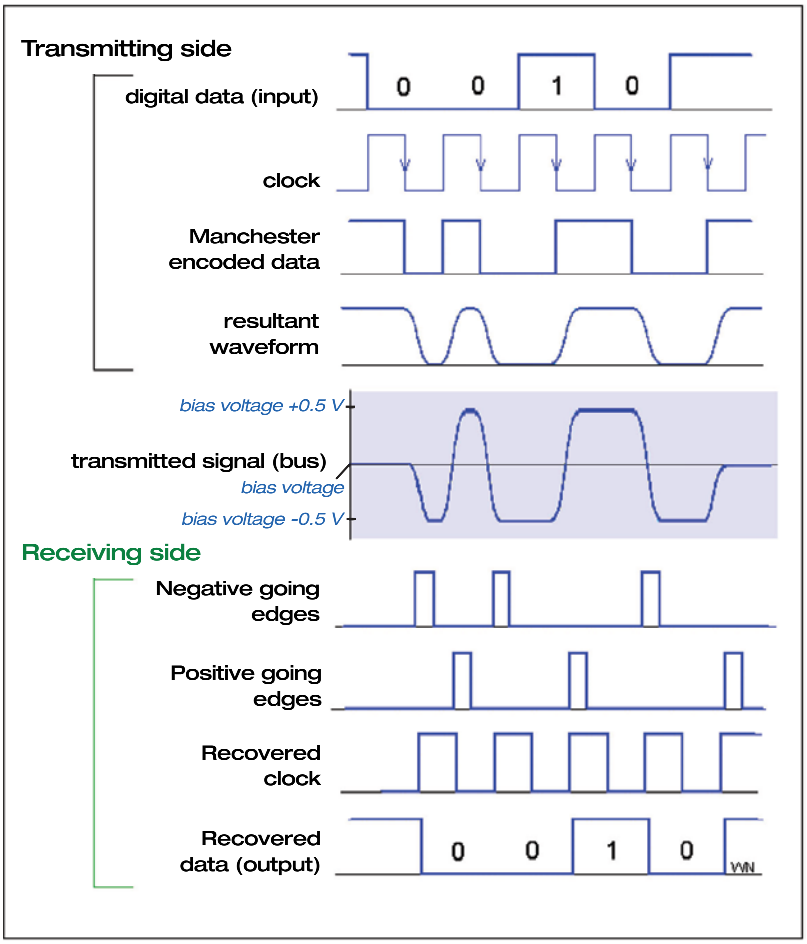

Figure 3: Manchester encoding, transmission, and decoding

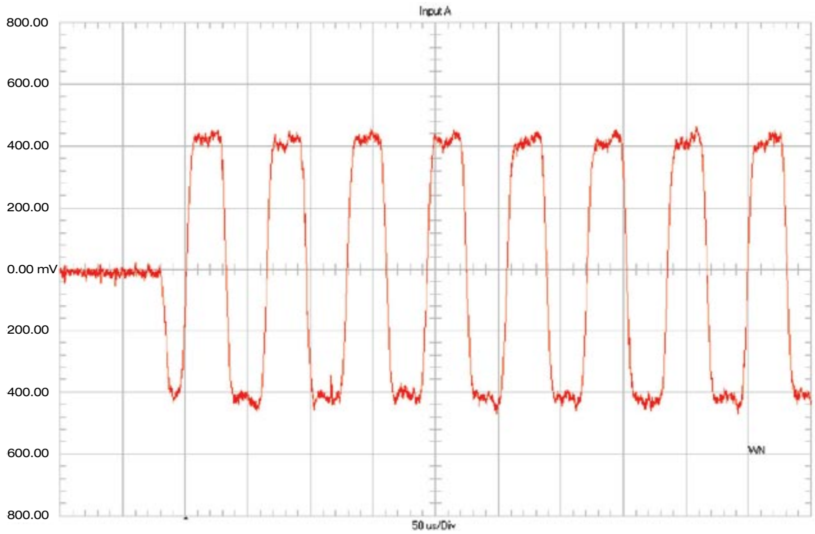

Figure 4: Basic pulse-train, measured with an oscilloscope on a Fieldbus system

Electrical signal generation

If one were to open up the cable at any point along the trunk and access the two wires, he or she would be looking into two sections of cable, going in opposite directions away from the access point. Electrically, those two sections would be seen as connected in parallel. The impedance at any point along the line therefore is equal to the impedance of two sections of cable in parallel. Therefore, the impedance that one observes at any junction box is 50 Ω or one-half the characteristic impedance of the cable.

The bus signal is created electrically by applying a differential current into the two-wire bus system. By doing so, a differential voltage of 800 or 900 mV_{pp} (where "pp" stands for "peak-to-peak") is generated on the bus. This is then also the nominal peak-to-peak amplitude (V_{pp}) of the signal that any Fieldbus device generates. According to the Fieldbus specifications, devices should be able to generate an output signal with amplitude of at least 750 mV_{pp}.

Ideally, this would then also be the amplitude of the signal that Fieldbus devices receive. However, because signal attenuation occurs along the network, an incoming signal will usually have lower amplitude. Fieldbus specifications require that a device keeps on working properly with an input signal as low as 150 mV_{pp}. If amplitude exceeds 1000 mV_{pp}, it usually indicates a network error, e.g. a missing terminator.

Anomalies

If anywhere along the network an additional low-impedance device is connected to the bus, the overall impedance seen at any junction box will be lower because the additional load is connected in parallel to the cable impedance. Lower bus impedance automatically means lower amplitude of the bus signals. Since the bus signals are more or less random pulses, such an additional load will manifest itself as a discontinuity in the transmission line and will cause reflections of the original pulses, where the load was added. Such reflections will lead to distortion of the pulse's wave shape, which, in turn, may lead to incorrect signal detection.

If, for instance, a third terminator is connected, the overall network impedance and the signal amplitude will drop to two-thirds of nominal. This signal loss will lead to more distorted pulses, making proper signal detection more difficult. Field experience shows that one of the most common sources of error in industrial networks is the result of having either too few or too many network terminators connected.

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