1-Wire

FAQ

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Design Guide v1.0

Understanding 1-Wire Series

Credits:

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A design guide for the layman: understanding, designing and building MicroLan™ (1-Wire) networks.

Or an introduction to everything you wanted to know but didn't know enough to ask.

Overview

Our doubts are traitors, And make us lose the good we oft might win, By fearing to attempt. – **William Shakespeare,** Measure for Measure

Introduction

What is 1-Wire?

Taking a quick look at 1-Wire.

The 1-Wire® network, **originally** known as a MicroLAN™, as defined by [Dallas Semiconductor](#) is a communication system between electrical devices. It consists of three main elements: the 1-Wire interface called a bus master, slave devices, and the electrical connection between the bus master and slave devices.
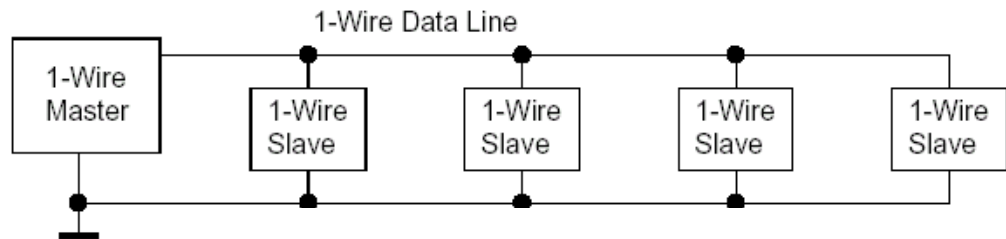
Figure 1. Drawing of a 1-Wire network with 1 bus master and 4 slaves

In many ways it's similar to a very old fashion party line telephone system. In a party line telephone communications system, one person places a call to another. The caller or the originator of the call (known as the 1-Wire bus master) dials onto the communications network (the 1-Wire network). The signal (traveling through wires) may be first routed through a switch at a central office (Not shown in above drawing), where it is routed to the correct party line. This can be done using what is known as MicroLan hubs in the case of a 1-Wire system. All members of the party line (this is known as multi-drop capability) receive the rings of the incoming call. The number of rings (the address) tells you which person (a slave device) should answer the call. Like a telephone conversation, where one person talks while the other listens, the bus master tells the slave(s) who answer the call what it wants. It can ask for information or tell it what to do. And the person (the slave device(s)) on the other end of the phone listens to what is said and responds. Like a telephone conversation if both people were to talk at the same time, they could not understand one another, the same holds true for 1-Wire communications. So in the case of a 1-Wire system it is up to the calling system (the bus master) to control the conversation

A more technical description

All 1-Wire communications takes place digitally (on or off logic states), over a wire cable (typically twisted pair). The network is defined with an open drain (wired-AND) master/slave multi-drop architecture that uses a resistor pull-up to a nominal 5 Volt supply at the master. We will talk later more about this pull-up resistor and the important part it plays later in this document.

The master device initiates and controls all activities on the network bus. This is why it is known as the bus master. The bus master acts as a protocol and timing interface between a PC or microcomputer and the 1-Wire network. Both the bus master and all slave devices internally act as transceivers. These are devices that can both send and receive data on a single data line. You can think of this single communications line as a single lane road, where traffic takes turns, first going one way, then the other. So data can flow in either direction, but only one direction at a time (half duplex operation). Data transfers are bit sequential with the least significant bit of a byte being transmitted first, over a single pair of wires, a data and a ground return line. Synchronizing of the devices is handled by the 1-Wire data protocol (regulating who talks and who listens at any given time). This allows tight control of the data bus because the protocol allows no slave to speak unless requested by the master, and then communication is only allowed between the selected slave and the bus master; no communication is allowed slave to slave.

The Signals

What voltages define the 1-Wire signals?

In order to understand how all this works and the implications for a network design we have to delve deeper into our understanding of the data signals used, the protocol and the effects of how we interconnect the various elements, on the data signals. Since we know the 1-Wire information is transmitted digitally, let's start by taking a quick look at the logic levels used in 1-Wire components.

The Logic Levels

A 1-Wire network's logic levels are roughly compatible with conventional CMOS/TTL logic levels, with an approximate[1] maximum 0.8V (known as the $V_{IL\ MAX}$) for logic "zero" and an approximate minimum 2.2V (known as $V_{IH\ MIN}$) for logic "one". In the region between these two voltages, the logic level is indeterminate. Consequently any signal **transi-**

5 volts	**Logic 1 Area**
2 2	**Indeterminate Area**
8v	
0 volts	**Logic 0 Area**

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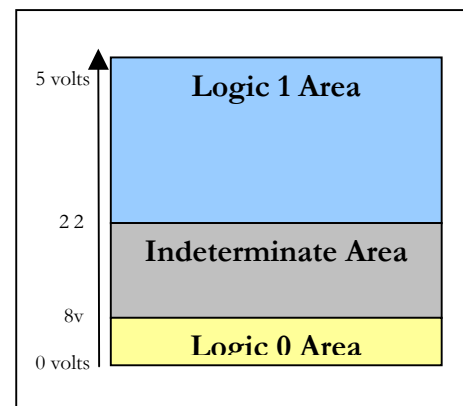
[1] Approximate values are given because this varies slightly according to the 1-wire slave devices used. Consult your device datasheets.

tions through this area should ideally be fast since the logic state is undefined in this region.

Defining the 1-Wire bus lines

The Data or OWIO line

The actual 1-Wire data signal line is commonly marked as the DQ, Data or OWIO (One Wire I/O) line. In this document, we will use the name OWIO or data line interchangeably when referring to this line. Though the actual voltage on this line changes as the logic level changes, for the purposes of this document it will be assumed to be a signal falling between 0 and 5 volts, and operating at a frequency of up to 1MHz. (1μs pulse duration) This signal carries the bi-directional data based on the 1-Wire protocol. The name 1-Wire is derived from the fact only 1 wire is used to carry *communications* in both directions. The actual data bit stream is read as a series of discreet timed events defined by the 1-Wire protocol.
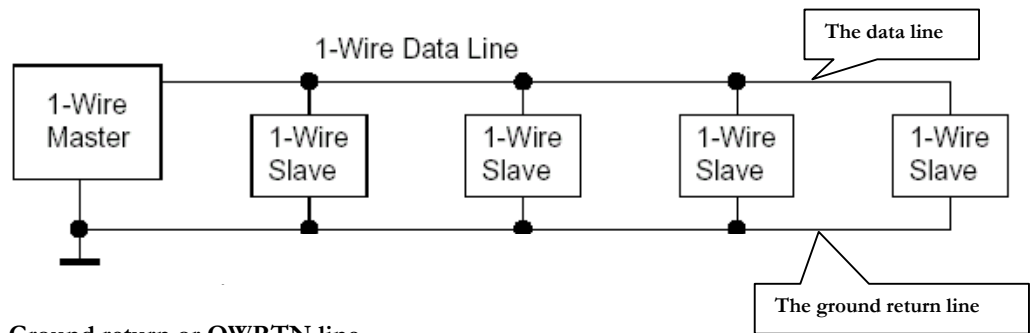
The Ground return or OWRTN line

The second line of the 1-Wire network is the 1-Wire signal return line (or ground return). Again it is commonly marked as GND or Return or OWRTN. We will use the nomenclature OWRTN (One Wire Return) or return for this line. Though this line is often at ground level it should NOT be confused with a true ground in that it may or may not be tied to a true earth ground level depending on the system. There is only one ground point in a 1-Wire network, and that is done at the 1-Wire bus master device.

The Pull-Up resistor

A resistor typically connects the data line of the 1-Wire network to the 5V supply of the bus master (this acts as a "resistive" or "weak" pull-up). So the data line is constantly being pulled towards the logic 1 state by this weak pull-up resistor. By

means of their open-drain output (think of it as a switch that can be closed to ground) the master and slaves can short-circuit the data line (over coming the weak-pull-up resistor) to the ground reference to change the logical state from a 1 to a 0. So the non-transmitting or default idle state of the bus is a logic 1 or high level (≥2.2 volts). And the transmitting state is a logic 0 or low level (≤.8 volts,). This defines the bus as what as known as an inverted logic bus.
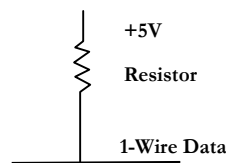
While the bus is in the default idle (high or logic 1 state), a small amount of current (power) limited by the size of the pull-up resistor is available to slave devices during that time. This fact is used in the clever design of 1-Wire components to power the interface logic of slave devices. The high level charges a small internal capacitor (typically 800pf) in the slave device, which can hold enough reserve power for slave operations while the bus is in a low state. In other words it acts as a small battery for the device. Since its energy storage capacity is small, it must be recharged constantly or the device will lose too much power (the battery dies) and turn off.

Some devices are able to use only this power for all their normal operations and are known as true parasitic devices (they draw their power from the data signal line only). Other more power hungry 1-wire devices require additional power sources for their operation. But all 1-wire slave devices use this parasitic power for their fundamental 1-wire interface power.[2]

The resistance value

The pull-up resistor value must be low enough to provide sufficient current through it to power devices on the bus, but not so low that the open drain slaves are unable to successfully pull the data line down to a logic 0 level.

Slave devices are typically able to pull the bus line down to about 0.4 volts when faced with 4 ma of pull-up current due to their internal resistance of approximately 100 ohms. **Any additional resistance (due to wiring or other devices) will limit this ability even more.** This defines what is referred to as the base floor for logic 0 states. As you may have recognized from this the theoretical noise immunity has been cut in half. To only 0.4 volts (0.8 -0.4 = 0.4 volts)

Typical values for the pull-up resistor are between about 1K ohms to 4.7K ohms. This sets the current range to between 5 ma and 1.06ma. A DS2480B (DS9097, etc) based bus master's range is between 1.5-5ma, and is typically 3 ma[3]. The LINK bus master (a more advanced design) weak-pull-up is about 4.93ma by comparison[4].

While this weak pull-up current (the power source for the data line) is adequate for powering small 1-Wire nets, large networks or networks with parasitic device (explained latter in this document) may require additional pull-up current at times. This is known as the active pull-up current. The DS2480B can increase it's pull-up current

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[2] This is why slave devices may show up on the 1-wire bus even if they are not connected to any other power device.

[3] Consult the Dallas semiconductor DS2480B datasheet for actual values

[4] Calculated from the Link schematic. Note the Link uses an out of spec higher logic 0 level to increase the noise immunity at the bus master.

to 9-15ma while the LINK can generate as much as 47.08 ma. Consult your manufacturer's datasheets for details on these and other bus master devices.

The 1-Wire Protocol

How does it work? Now that we know about the 1-Wire signal levels used, let's take a closer look at how the 1-Wire protocol allows you to transmit and receive data at a signal level. 1-Wire signals require a strict protocol to insure data integrity. The bus master as we said before, initiates all communications on the bus. The basic 1-Wire protocol consists of four types of signaling on the data or OWIO line: These are

1. **Reset Sequence with Reset Pulse and Presence Pulse**

   The reset pulse is used to put all devices on the 1-wire bus into a known state. When a slave, or slaves, sees the Reset Pulse, they acknowledge receipt by returning a Presence Pulse to indicate their "presence" or existence in an active state on the bus.

2. **Write 0**

   Send a '0' bit to the 1-Wire slaves (Write 0 time slot).

3. **Write 1**

   Send a '1' bit to the 1-Wire slaves (Write 1 time slot)

4. **Read Data**

   Read data sequences are similar to the write 1 time slot but the bus master samples the bus state after it releases the line to read data back from a slave device. In this manner it is able to read back either a 0 or a 1 from the slave.

Lets take a closer look at each of these signals and see exactly how they are done.

The Reset Sequence with Reset Pulse and Presence Pulse

The initialization sequence required to begin any communication with a slave device is shown below. It starts out when the bus master transmits the negative going Reset Pulse (TX) of t_{RSTL} μs duration.
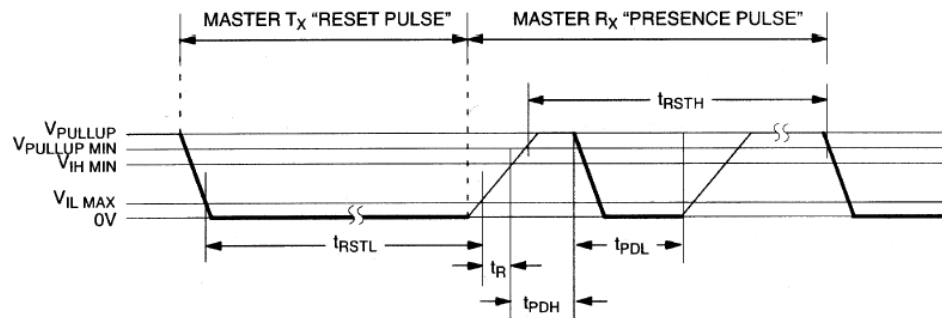
Figure 2. Reset Sequence with reset pulse and presence pulse.

The bus master then releases the line and goes into receive mode (RX). The 1-Wire bus is pulled back to a high state via the pull-up resistor. After detecting the rising edge on its data line, any slave device on the bus will wait **(t_{PDH}) μ**s and then transmit a Presence Pulse **(t_{PDL})** back to the bus master. The line is again pulled back (if needed) to its high state via the pull-up resistor.

In this way the bus master is able to detect if any 1-Wire slave devices are on the bus.

But what does this look like in the real world? Let's take a look at an oscilloscope image of a real Reset sequence waveform.
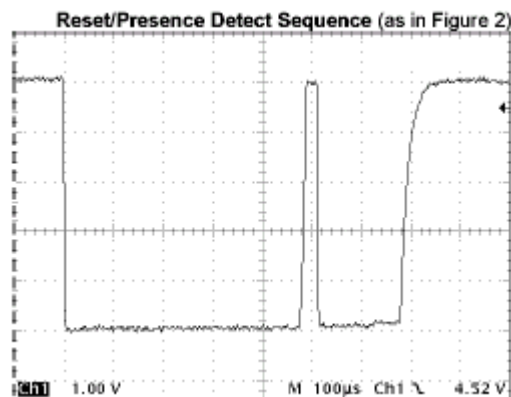
Figure 2a. You can clearly see the negative going reset and the presence pulse

Writing data

A write time slot is initiated when the bus master pulls the data line from a high (inactive) logic level to a low logic level. There are two types of write time slots: Write 1 time slots and Write 0 time slots. All write time slots must be a minimum of 60 μs in duration with a minimum of a 1 μs recovery time between individual write cycles. The slave device samples the I/O line in a window of 15 μs to 60 μs after the I/O line falls. If the line is high, a Write 1 occurs. If the line is low, a Write 0 occurs (See Write 0 drawing below). . For the bus master to generate a Write 0 time slot, the data line must be pulled to a logic low level and remain low for the duration of the write time slot. For the bus master to generate a Write 1 time slot, the data line must be pulled to a logic low level and then released, allowing the data line to pull up to a high level within 15 microseconds after the start of the write time slot. (See Write 1 drawing below)

Write 0
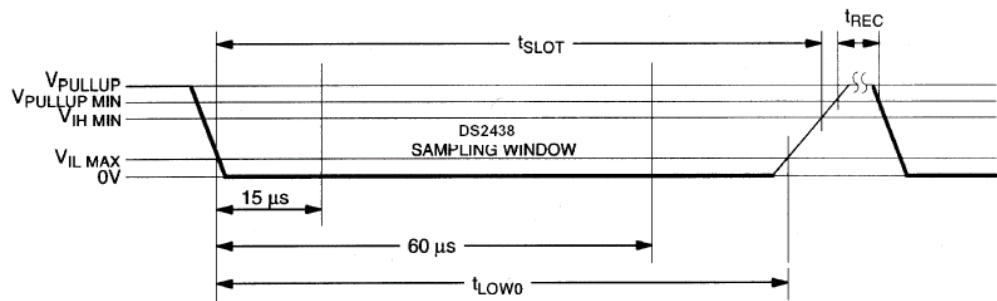
Figure 3. An example of typical slave device, the DS2438 write 0 time slot.
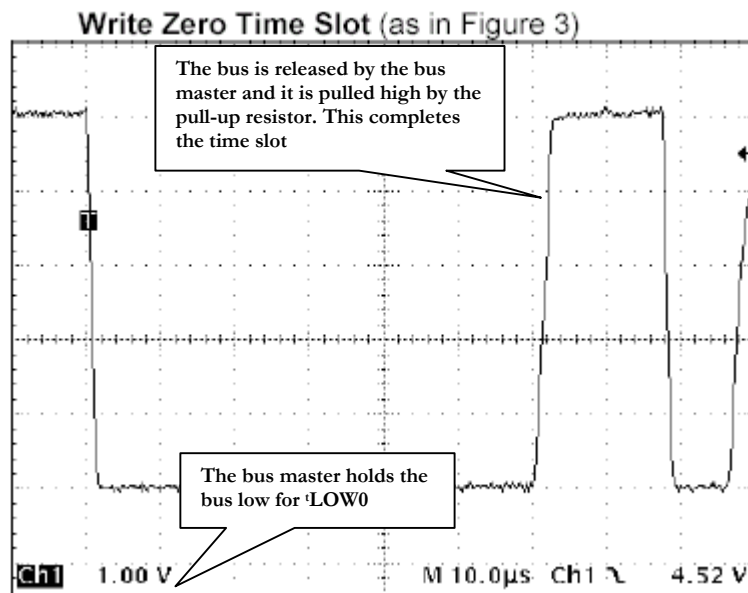
In this real world image of a write 0 timeframe you can see the write 0 time slot. It is being followed by the next time slot, which is a write 1.

Write 1

V_{PULLUP}
$V_{PULLUP\ MIN}$
$V_{IH\ MIN}$
$V_{IL\ MAX}$
0V

t_{SLOT}
t_{REC}

DS2438
SAMPLING WINDOW

t_{LOW1}

15 µs

60 µs
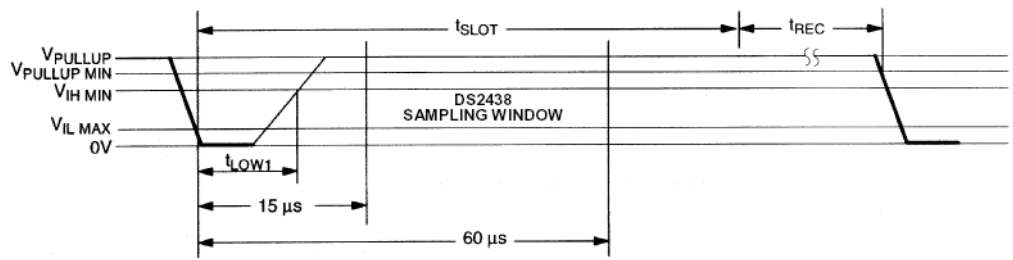
Figure 4. An example of typical slave device, the DS2438 write 1 time slot.

Write One/Read One Time Slot (as in Figure 4)

The bus is sampled by the bus master

The bus master release the bus and the weak pull-up current pulls the bus high

Ch1   1.00 V   M 10.0µs Ch1 ⅃   4.52 V
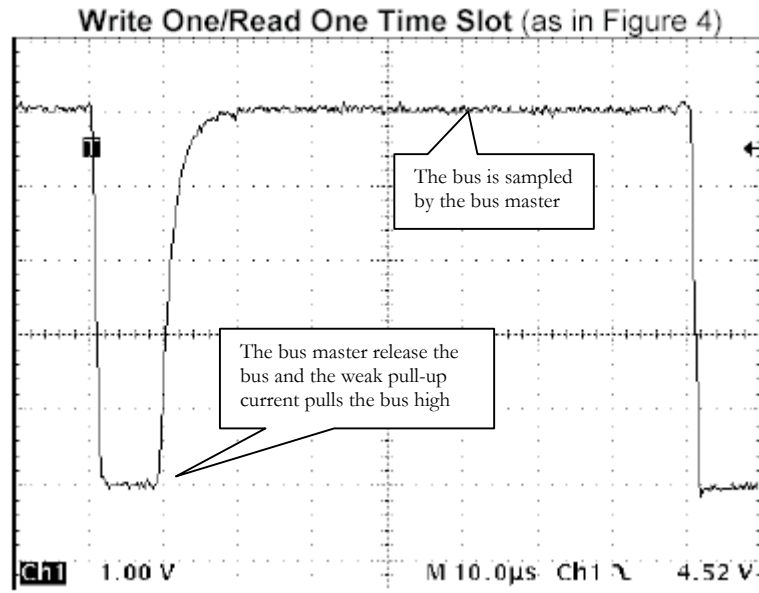
In this real world image you can see a write 1 time slot. Note that this is the same wave shape as a read 1 time slot.

Read Data

The bus master generates read time slots when data is to be read from the slave device. A read time slot is initiated when the bus master pulls the data line from a logic high level to logic low level. The data line must remain at a low logic level for a minimum of 1 µs; output data from the slave is then valid within the next 14 µs maximum. The bus master therefore must stop driving the I/O pin low in order to read its state 15 µs from the start of the read slot. (See the following idealized drawing). By the end of the read time slot, the I/O pin will pull back high via the external pull-up resistor. All read time slots must be a minimum of 60 µs in duration with a minimum of a 1 µs recovery time between individual read slots.
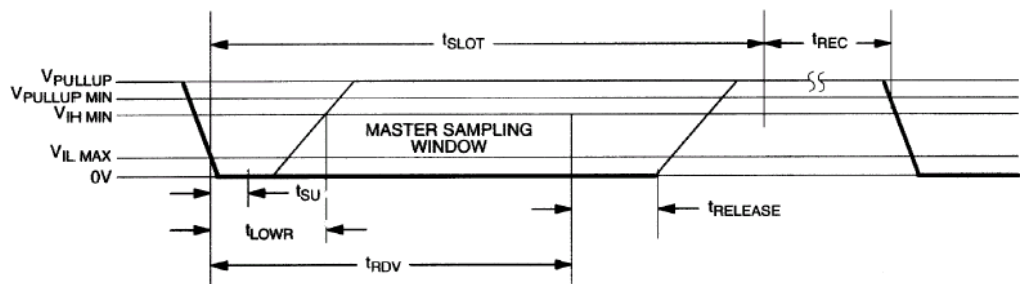
Figure 5. A read time slot
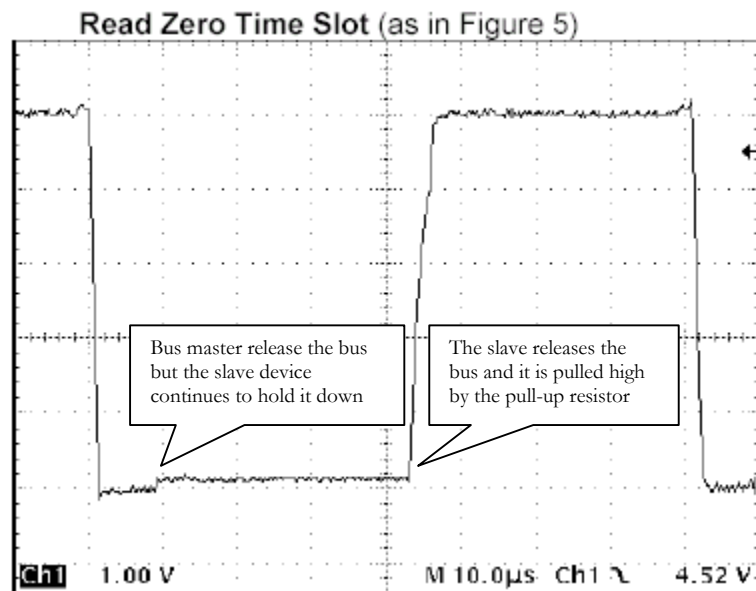
In this real world image of a read 0 wave shape you can clearly see when the slave device took over control of the bus from the bus master and continued to hold down the bus. Thus returning a 0 to the bus master. The bus voltage rises slightly but is still ≤.8 volts

A typical 1-Wire conversation
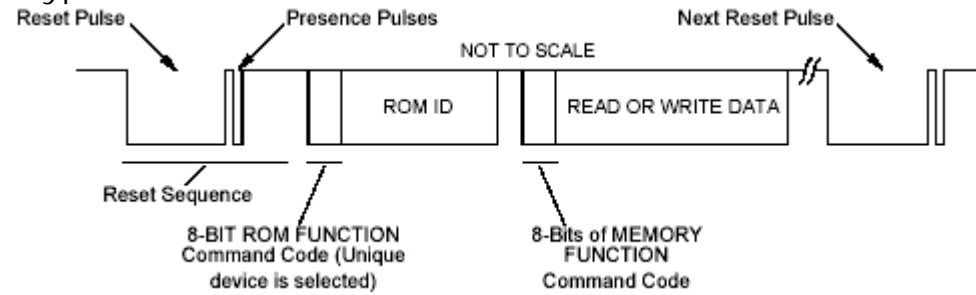
Diagram 1 typical 1-Wire communication sequence.

So in a typical 1-Wire communication sequence:

- The master resets the network by holding the bus low for at least 480 microseconds, (See Diagram 1 again) releasing it, and then looking for a responding Presence pulse from any slave connected to the line. This is the Reset Sequence with Reset Pulse and Presence Pulse that we talked about before.

- If a Presence pulse is detected, it then accesses the slave by calling its address. Using Write 0 and Write 1 sequences.

  - Within each 1-Wire slave created is stored a lasered ROM section with its own guaranteed unique, 64-bit serial number (assigned at the factory), that acts as its node address. This unique address is composed of eight bytes divided into three main sections.

  - Starting with the LSB, the first byte stores the 8-bit family code[5] that identifies the device type. The next 6 bytes store the unique 48-bit address, while the last byte (MSB) contains a cyclic redundancy checksum (CRC[6]) with a value based on the data contained in the first seven bytes. This allows the bus master to determine if an address was

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[5] For a good table of 1-wire family codes try this internet web site: Complete 1-wire family command codes

[6] Refer to Dallas Semiconductor Application note #27: Understanding and Using Cyclic Redundancy Checks with Dallas Semiconductor iButtonTM Products for details of calculating 1-Wire CRC's.

read without error. With 2^{48} serial numbers set by the factory, conflicting or duplicate node addresses on the 1-Wire network will never be a problem.

- The master issues any device specific commands required (the memory function desired), and performs any needed data transfers between it and the slave. It controls the information transfer by generating time slots and examining the response from the slave. These may include both reads and write sequences.

  - Except for the presence detect cycle, Search, Skip and Read ROM commands, only one slave device of then will be responding when addressed by the bus master.

Details of how a 1-wire bus master can search for a particular device can be found in the App Note 187: 1-Wire Search Algorithm

Building a network of devices

**How do I organize
the 1-Wire parts
into a system?**

So you now have a rough idea of the protocol and what the idealized form of the signals on the bus should look like. Let's put a bus master together with some slave devices to form a 1-Wire network. Like this:
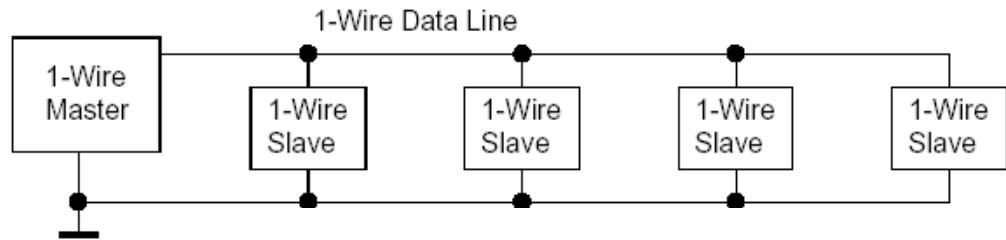
In the above drawing, you can see the single bus master to the left (there is only one on a 1-Wire network) connected to four slave devices. The 1-Wire data bus line (OWIO) is on the top and the ground return line is on the bottom (OWRTN). These two wires form the 1-Wire bus communications network. A network with this sort of topology is known as having a linear topology. We will talk more about this later in this document.

1-Wire Slave Devices

We will start looking at our 1-Wire devices in more detail by looking at a slave device first. A typical slave device model, has an internal interface that might be represented like this:

Internal power for the slaves 1-wire network operation is developed from the data line when it in its high state. A blocking diode (Di) keeps power from being lost when the data line is low. The current is limited in the slave by the internal 1000-ohm resistor (Ri). The current charges the 800pf capacitor (C_{LOAD}), which acts as a local power source for the chip. This power source is known as the parasitic power circuitry and is used to power the basic 1-Wire functions of the chip. Some chips require additional power sources for their operation (not shown in the drawing). Also notice that there is a 30pf (average) input capacitance (C_{IN}) between the Data and Return lines
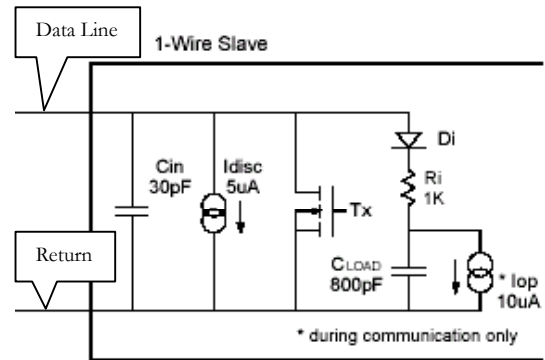
Every slave contains an internal oscillator that is synchronized by each falling edge of the data signal. This oscillator controls the slaves timing responses. Timing responses are basically done as self-timed events (think of it as 1-shots timers) triggered by the falling edge of the data line. Because the protocol allows for considerable slop in timing responses while not an issue in communications, it explains why devices may respond at slightly different times.

When the slave device wishes to transmit (TX), it does so through the open drain transistor. This port transistor inside the slave allows it to place a logic zero on the network. While this structure allows multiple paralleling of slaves on a single pair of conductors (multi-drop), it does not allow for the bus or cable to be terminated in its characteristic impedance. When the 1-Wire port transistor is on, its impedance is nominally less than 100Ω, which provides a 0.4V logic zero with a 4mA current sink.

A constant discharge current 5μ (Idisc) per slave is required to keep its interface synchronized with the communication protocol. This increases to 10μA (Iop) during communications

If multiple 1-Wire devices are residing on the bus, you should multiply Cin, Idisc, Iop and Cload by the number of slave devices. Ri needs to be divided by the number of devices.

1-Wire Master Device

While there are many possible forms a Master device can take we will look at only at a simplified model for now. The weak current pull-up resistor (Rpullup) is used to pull the data line high. Values for this resistor typically are between 1000-4700 ohms with a Vs voltage of 5 volts. This works out to a possible weak current range of 5ma to 1.06ma. You must supply enough current for quick pull-up of the line but not too much which would raise the 0 state voltage floor of the farthest slave device.
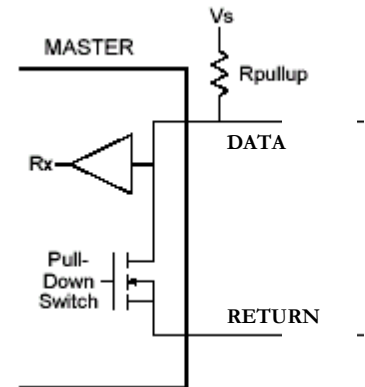
An internal buffer is used to sense the level of the data line (RX). A pull-down transistor switch is used to short the data line to the return line in order to pull the data line low.

There are other features of most bus master devices, some of which we will touch on later in this document. But this simplified version is enough for our understanding for now.

Connecting the Slave and the bus master

So far we have defined both our 1-wire slave and bus master devices, we now need to interconnect them. This is where things begin to get complex and where most of the issues in designing and building successful 1-wire networks happen.

What sort of cable should we use to make our network?

To answer that, we first need to look at the characteristics of 1-Wire slave and bus master devices along with some details about cable (wire) itself.

Basic Cable Factors

When selecting a cable for 1-Wire use it is **helpful** to start with the basic factors affecting all wire. Every wire cable has certain characteristics such as resistance, capacitance, inductance and impedance. The wiring (between the master and the slaves), can be modeled by the inductance and resistance of the data and return lines, and the lumped capacitance of the cable. A simple model for a 1-Wire cable is shown in the image to the right.
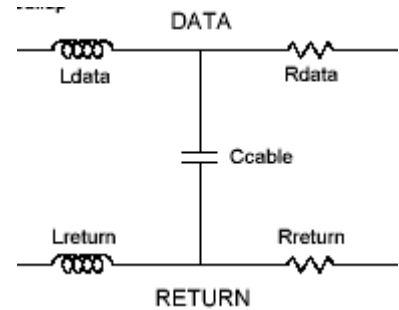
What is Cable capacitance and resistance?

Cable capacitance is simply the product of cable length times its unit capacitance. This is roughly about 50pF/m for Category 5 twisted pair cable. Better quality CAT5E or CAT6 cable can have lower numbers. Similarly, line resistance represents cable length multiplied by the specified resistance per meter of a single wire.

What is cable impedance?

Characteristic impedance is the impedance that a cable would have if the cable were infinitely long. Impedance is a type of resistance that opposes the flow of alternating current (ac). A cable's characteristic impedance is a complex property resulting from the combined effects of the cable's inductive, capacitive, and resistive results. These values are determined by physical parameters such as the size of the conductors, distance between conductors, and the properties of the cable's insulation material.

The characteristic impedance of a cable is given in its simplified form by:

$$Z_o = \sqrt{L/C} \qquad \text{Equation 1}$$

Where Z_o = square root of (L / C), where L is inductance per unit length, and C is capacitance per unit length. This is the input impedance of either an infinite length of the cable, or more practically of a finite length terminated by impedance equal to the

characteristic impedance. Real cables have resistive losses, which must also be taken into account.

> **The *characteristic impedance* (*Zo*) of a cable is independent of its length.**

Twisted Pair versus Ribbon Cable

The two most popular cables used for 1-Wire networks today are twisted pair cable (typically CAT5 or better) and flat ribbon cable.

30m 6 Conductor Phone (26 AWG) Red/Green ~ 96 Ohm Impedance

NC
NC
DATA
GND   } 1,870pf
POWER
POWER

Connecting conductor No. 5 (Shown as Yellow) to No. 3
(Red) raises the load capacitance to 2,150pf
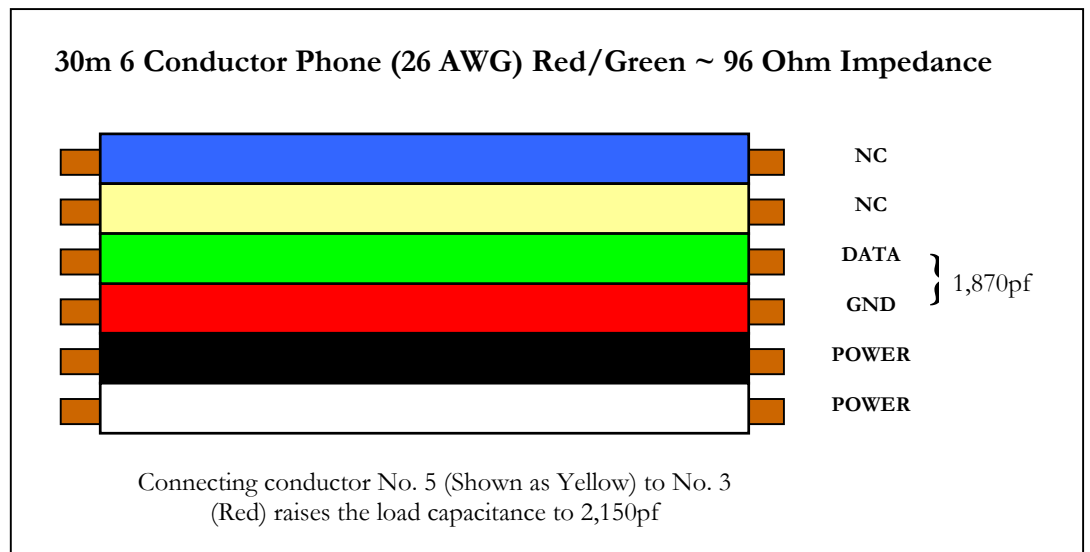
Example of a 6-conductor flat ribbon cable used for a 1-Wire network

COMPARISON OF CAT 5 (RECOMMENDED) AND 6-CONDUCTOR PHONE CABLE

Type	Wire Size	Resistance	Capacitance	Inductance	Impedance
CAT 5 UTP	24AWG	$.083\Omega/m$	48.5pF/m	$.58\mu H/m$	$Zo = 100\Omega$
6 Conductor phone[1]	26AWG	$.133\Omega/m$	62.5pF/m	$.52\mu H/m$	$Zo = 96\Omega$

Table 1. - [1]Data given for the inner most 2 wires

Twisted pair cabling is currently the preferred cabling choice for 1-Wire networks because of its lower capacitance, and resistance values. As network cable lengths increase this becomes very important. There are relatively few variations from manufacture to manufacture due to standard testing and it is widely available at low cost. However flat ribbon "silver satin" type telephone cable was the original 1-Wire network cable used even though it does not have these benefits and is still found in many older 1-Wire installations.

Let's look at what twisted pair cable actually looks like. The individual pairs are twisted together, and then these pairs are twisted also. This helps lessen crosstalk (induced noise) between any two wires.

Category 6 CMP FEP Jacketed, PVC-Free
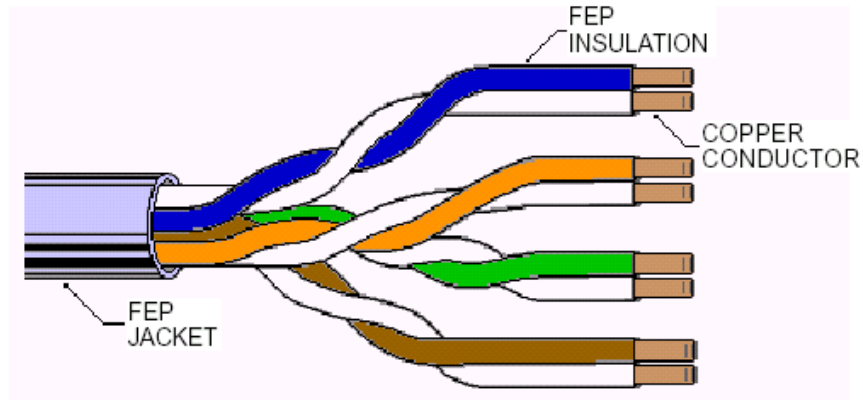
If we were to compare the inner most twisted pair wires with a flat ribbon cable of the same length it would look like the following image. Note that the capacitance figures are lower in the twisted pair cable, both in the wires and in between wires. This is very important, as wire lengths get longer.
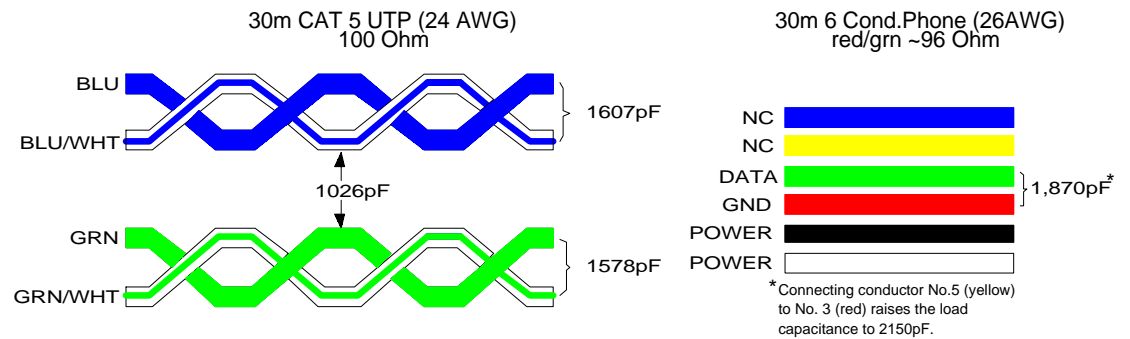
Categories of Twisted-Pair Cable

Twisted-pair cable has been used for decades to transmit both analog and digital information. The existing telephone system is mostly wired with voice-grade twisted-pair wires (the wire is not twisted in some cases). As we said before, twisted-pair wire is now the preferred wire for 1-Wire network cabling. The twisting of pairs, the quality of the conductive material, the type of insulator, and the shielding largely determine the rate at which data can be transmitted over twisted-pair cable.

The following categories of cable are recognized throughout the industry, and Category 3, Category 4, and Category 5 cable are specified in the TIA/EIA 568-A specification.

- **Category 1**   Traditional unshielded twisted-pair telephone cable that is suited for voice. Most telephone cable installed before 1983 is Category 1 cable. It is not recommended for network use, although modems do a good job of transmitting over it.

- **Category 2**   Unshielded twisted-pair cable certified for data transmissions up to 4 Mbits/sec. This cable has four twisted pairs. It was commonly used for IBM mainframe and minicomputer terminal connections and was also recommended for low-speed ARCNET networks. This cable should not be used for high-speed networking or 1-Wire network use.

- **Category 3**   This category is rated for signals up to 16 MHz and supports 10-Mbit/sec Ethernet, 4-Mbit/sec token ring, and 100VG-AnyLAN networks. The cable has four pairs and three twists per foot (although the number of twists is not specified). Costs are around 10 cents per foot. Plenum cable costs about 40 cents per foot. This cable is installed at many sites as telephone cabling. While some installations use this cable for 1-Wire networks using the newer CAT5 or above cable is a better choice due to its stricter design. Best to use a better cable such as CAT5E than save a few pennies. You will have fewer problems if you do.

- **Category 4**   This category is rated for signals up to 20 MHz and is certified to handle 16-Mbit/sec token ring networks. The cable has four pairs and costs under 20 cents per foot. Plenum cable costs less than50 cents per foot. While some installations use this cable for 1-Wire networks using the newer CAT5 or above cable is a better choice due to its stricter design tolerances.

- **Category 5**   This category has four twisted pairs with eight twists per foot and is rated for signals up to 100 MHz at a maximum distance of 100 meters. Ethernet 100Base-TX, FDDI, and ATM at 155 Mbits/sec use this cabling. The cable has low capacitance and exhibits low crosstalk due to the high number of twists per foot. It costs less than 30 cents per foot. Plenum cable costs under 60 cents per foot. This is the predominant cable installed in all new

buildings since the early 1990s. This is the lowest CAT type cabling currently recommended for 1-Wire installations.

- Even though Category 5 is widely used, there are many factors that can prevent a cabling system from delivering the intended data rate. Category 5 installations must use Category 5 connectors, patch panels, wall plates, and other components. In addition, proper twisting must be maintained all the way up to connectors, even if you use screw terminals or directly solder your connections.

Enhanced Cabling

Even though Category 5 was once considered future-proof, new Ethernet gigabit-per-second networking schemes have emerged that call for a better class of cable. As mentioned, you can have existing Category 5 cable tested to see if it supports Gigabit Ethernet, but if you are installing new cable for Gigabit Ethernet, choose Category 5E cable, or if you really want to future-proof your installation, consider Category 6 and Category 7 cable. Since these cables also have improved specifications they make excellent choices for 1-Wire networks. Though care **may be** needed with CAT7 cables.

- Category 5E (Enhanced). This cable has all the characteristics of Category 5, but is manufactured with higher quality to minimize crosstalk. The cable has more twists than traditional Category 5. It is rated at frequencies up to 200 MHz, which is double the transmission capability of traditional Category 5. However, at these frequencies, crosstalk can be a problem, and the cable does not have shielding to reduce crosstalk. This cable is defined in TIA/EIA-568A-5. With its improved crosstalk numbers this is our recommended minimum cable for use when you must include power in the same cable as the 1-Wire network.

- TIA Category 6 and ISO Class E These cable types are designed to support frequencies over 200 MHz using specially designed components that reduce delay distortion and other problems. They have a higher twist ration than CAT5E. The TIA and ISO are cooperating on this category.

- TIA Category 7 and ISO Class F. These cable types are designed to support frequencies up to 600 MHz. Each pair is individually shielded and a shielded jacket then surrounds the entire cable. Connectors are expected to be specially designed proprietary components. The TIA and ISO are cooperating on this category. At this time (7/4/2004) we have no experience with CAT 7 cables and its additional shielding may be a problem with 1-Wire networks.

Cable Summary

While the number of 1-Wire devices on the line affects the performance of the MicroLAN, it is the cable connecting the master and the 1-Wire devices that largely controls and limits the MicroLAN network. For short runs (where the total length of the 1-Wire bus is < 30 meters and the network only has a few slave devices on it), cable selection for use on the MicroLAN is reasonably simple, as even flat modular phone cable can work with a small numbers of 1-Wire slave devices. However, the longer the MicroLAN, the more important cable properties and therefore cable selection become.

Cables display distinctive properties of resistance, capacitance and inductance, which in turn are determined by cable geometry, and the size and spacing of the conductors and their surrounding dielectric. These physical properties define the characteristic impedance, the signal bandwidth supported and the propagation velocity of the cable. Specifically**, cable resistance reduces the 0 logic level noise margin**. Although resistance values up to 100 ohms are acceptable. Cable capacitance, however, which can range from 30 pF/m to 100 pF/m, loads the MicroLAN driver, increasing not only the pull-up time (The time it takes for the weak-pull-up resistor to restore the signal level to its high state) constant (RC) but also the peak current flowing in the cable as the master transistor turns on and discharges the line. If this transistor turns off before the charge stored in the line capacitance is completely discharged, the residual current left flowing in the line determines the amplitude of the inductive voltage generated. The resulting voltage seen at the driver can become large enough to interfere with communication. At the far end of the cable, this inductively generated voltage swings negative, reverse biasing the substrate of the 1-Wire device closest to the cable end, which in turn clamps the voltage at a diode drop.

The inductance of concern is the differential inductance, which is that measured across the cable input with the two wires of the line shorted together at the far end. Differential inductance is substantially lower than the inductance of a single wire because the current flows in opposite directions in the pair, and in the ideal case would cancel completely. Differential inductance decreases as the distance between conductors is reduced, so use of adjacent pairs or, preferably, twisted pair is recommended. Twisted pairs reduce unwanted coupling from nearby interference sources because the currents induced in the wires flow in opposite directions in the two conductors and tend to cancel. Category 5 twisted pair is recommended for all but the most demanding performance requirements.

A characteristic of cable that must not be overlooked is its fire rating. Cable installed in the plenum space, which is the airspace between the ceiling and the next floor or roof, must be installed in metal conduit, or must meet local fire codes. In the event of a fire, the cable must not produce noxious or hazardous gases that would be pumped to other parts of a structure through the plenum. Non-plenum cables have PVC (polyvinyl chloride) jackets while plenum-rated cables have jackets made with fluoropolymers such as Du Pont's Teflon, which can be very expensive.

The Entire network model

So now that we **know** a little about each of the various parts of a 1-wire network we can start to put them all together into something like the simplified model below.
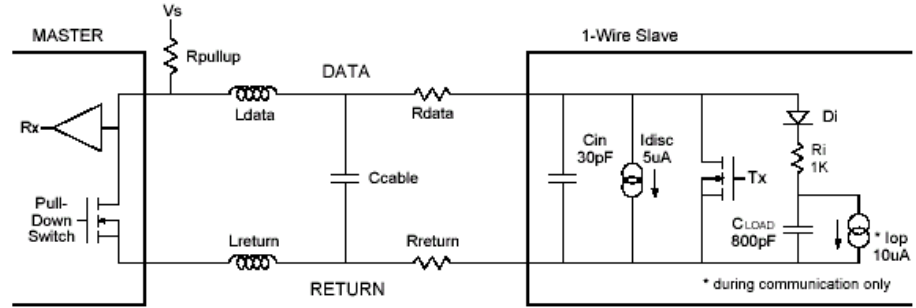
Signal integrity

Up to now we have been dealing with semi-idealized forms of timing and waveforms. We now need to turn our attention into understanding real world situations and effects.

The Rise and Fall time of a signal

The time it takes a signal to switch between voltage levels is known as the signals transition time. This is shown as the t_r or t_f in the drawing below. The time it takes the signal to rise from 10% of the low level to 90% of the high is known as the rise time (or t_r), conversely the same is true with a signal that goes in the opposite direction (t_f).
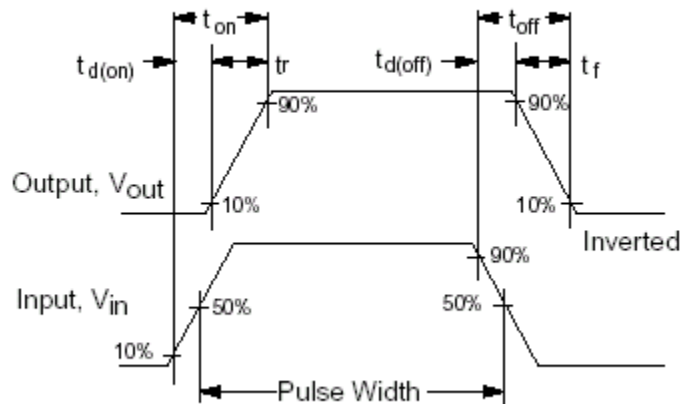
With a typical FET such as the popular 2N2700, this time, t_r or t_f is around 5 ns. So we can see it takes a definitive time for a signal to change state. This rate of change can also be known as a signals slew rate by measuring the change of voltage over time. If the signal level is 0 and changes to 5 volts in 5 ns, the slew rate is 1000 volts per μs.

Calculating propagation time

Calculating Cable Line Length

So how long does it take for this change of state to propagate through a network of a given length? In other words, go to the end of the network and return. We can calculate this if we know the NVP of the cable used.

The path of the signal through a cable
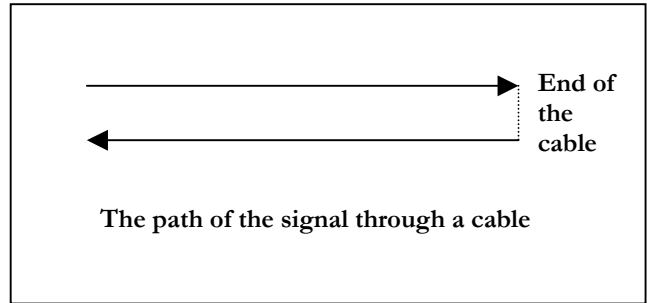
The speed of light in a vacuum is about 299,792,458 meters per second. A typical CAT5E cable has a NVP (the acronym for Nominal Velocity of Propagation) of 69% of the speed of light. Knowing the NVP of a CAT5 cable the speed of a signal in a CAT5 cable can be roughly calculated as follows:

Speed of Light * NVP = Signal Speed in Meters per second or

299,792,458 * 69% = 206,856,796.02 meters per second

Converting that, into meters per nanosecond gives us 0.206856796.

Or expressed in inches 8.143952059 inches per nanosecond

So an electrical signal travels a little over 8 inches every nanosecond in CAT5E cable. We can now calculate our cable line length like this:

Cable Line Length = (Output Rise or Fall Time)/ 2* (Signal delay per unit length)

The signal delay per unit of line length depends on the line's characteristic impedance and the load on the line. This is the length of the signal line at which transmission-line ringing becomes a major factor. When this time is less than the time it takes for the signal to travel the length of the line and return, a transmission line exists.

> **If the time it takes a signal to switch between voltage levels (transition time) is less than the time it takes for the signal to travel the length of the line and return, a transmission line environment exists.**

Using the above our 5 ns signal will travel a total of **5 * 0.206856796** meters or **1.03428398** meters (A little above **3.3** feet) total while it changes levels. The signal at the cable end will just be starting to change when the signal at the beginning of the cable will already be at its maximum level. When we divide by 2 (to allow for the return path of the signal), we find that the maximum length the cable can be without becoming a transmission line is **0.517142** meters of cable (About **20** inches). So we can

see that any network greater than **0.517142** meters will be working in what is known as a transmission line environment when the transition time is 5 ns. You can use the supplied spreadsheet **Calc-Line.xls**[7] to calculate this point for any given time or slew rate.

Impedance Effects.

Example 1 - A Properly Terminated line

Let's stop for a moment and consider the idealized properties of two conductors such as those in the CAT 5 cable Dallas Semiconductor currently recommends for use on the 1-Wire net. This twisted pair cable is characterized as having an impedance of 100 Ohms. If a zero to 5V step function is introduced to the left-hand end of the cable from a 100Ω source, the signal will propagate through to the right-hand end where it will be smoothly absorbed without reflections –assuming a 100Ω resistance is across the ends.

In the absence of the 100Ω terminating resistance, however, only half the step function amplitude will exist on the line until it reaches the right-hand end where it will then jump back to full swing and **be reflected** back toward the start! When this reflection (echo) arrives back at the 100Ω source at the left-hand end it will be smoothly absorbed without reflections.
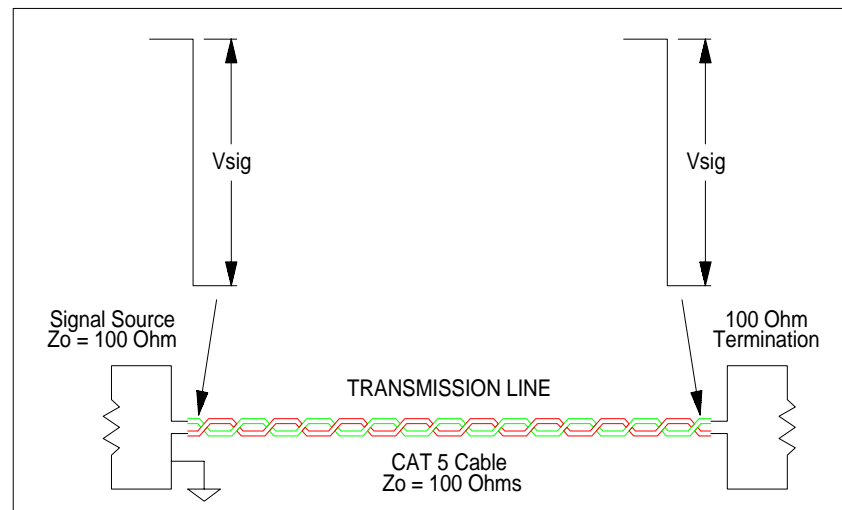
FIGURE 1 To achieve the best performance a cable can provide, you must drive it with signal source of equal impedance and terminate the opposite end in the cable's characteristic impedance.

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[7] A spreadsheet, Calc-Line.xls, is provided as a companion to this document to ease doing some of the calculations

A signal transition that instantaneously switches between two levels is termed a step function. When a step function (V_{sig}) is introduced to a transmission line, it initially propagates at a level equal to the source impedance divided by the line impedance (Z_0). That is:

$$V_{siq} = V_{init} \, (Z_{source}/Z_0) \qquad \text{Equation 2}$$

An example of this can be seen in these images of a 1-wire system.

Falling edge at the far end of a 300m cable

Ch1   1.00 V   M 1.00µs Ch1 ⅄   4.52 V

Same edge seen at the near end of the 300m cable

The "saddle" in the center of the falling edge ends when the signal reflected from the far end has returned back to the driver. This is a natural behavior of transmission lines. The saddle will not be visible with cables shorter than ~100m.

Ch1   1.00 V   M 1.00µs Ch1 ⅄   4.52 V

Example 2 - With a single 1-Wire slave at the end of the line

With these facts in mind, consider what occurs when the 1-Wire master is an n-channel MOSFET without slew-rate control and the 'end termination' is a single 1-Wire slave. The normal quiescent state of the 1-Wire network is 5V with communication starting when the master pulls the line low. For convenience sake, we will assume the on-resistance of the FET to be 10Ω, only one-tenth the 100Ω impedance of the cable. Since the FET acts as a switch, it can pull the line to ground in 10 nanoseconds or less creating a negative transition that goes below ground. For practical purposes this transition represents a step function as previously described, meaning that 1-Wire communication would be occurring in a transmission line environment for any cable length exceeding about 20 to 40 inches (roughly 0.5 to 1 meters).

When this signal reaches the 1-Wire slave at the other end of the cable it sees an unterminated line as the slave is quiescence and in a high impedance state. At this point two things happen closely in time, the unterminated open end of the cable reflects the signal and the slave responds to the signal by turning on its internal pull down transistor assuming 1-Wire communication is in process. The mismatch between the 50Ω on-resistance of this transistor with the natural impedance of the cable generates a perturbation that sends a second small step of oppose polarity following the first reflection. When these reflections arrive back at the master and see the mismatched impedance of the FET they are again reflected as opposite polarity steps. This oscillatory condition will continue until the signal dies out exponentially due to attenuation losses in the cable.
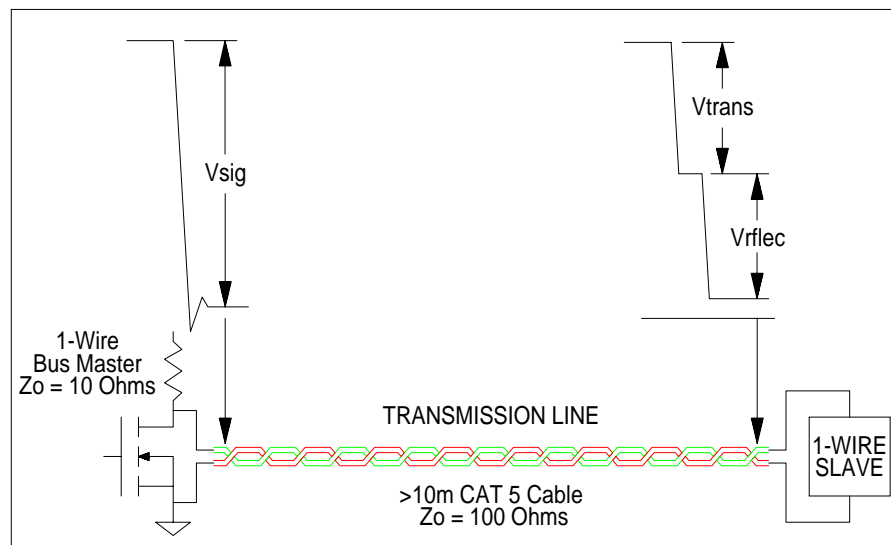
Figure 2 Even a simple 1-Wire network can end up operating in a transmission line environment due to the fast pull down edge of a FET and the impedance mismatch to the cable

> **If the impedance across the end of the line is higher than the natural impedance of the line (Z_0), a step function will be reflected with the same magnitude and polarity as the incident signal. This is typically what occurs when a data transition arrives at the unterminated end of a 1-Wire net.**

> **If the impedance across the end of the line is lower than the natural impedance of the line (Z_0), a step function will be reflected with the same magnitude but of opposite polarity as the incident signal. This is typical of what happens at the master end of a 1-Wire network due to the low impedance of the FET.**

Example 3 - With one slave at midpoint and a second slave at line end
Again using a plain n-channel MOSFET pull-down transistor with 10 Ohms on-resistance as the signal source we launch a step function down the line. When the transition reaches midpoint on the line, it encounters a discontinuity due to the 1-Wire slave, which causes the signal to split into a reflected signal, which travels back toward the master, and the remnant of the original signal that continues down the line. Given that the propagation time for both signals is identical, the reflected signal arrives back at the master and is reflected as a negative step at the same time that the remnant of the original arrives at the cable end and second slave and is reflected in the same manner as described in Example one.

Notice that the reflected signal from each end of the line is now advancing toward each other and will arrive simultaneously at the midpoint slave. The case where both reflections arrive simultaneously only occurs at the midpoint making it unique, at all other points on the line a slave will see the two reflections at different times. If the slave is passive, that is, not communicating and in a high impedance state, two new signals will be generated –one new reflection from each of the two original signals making a total of four signals now transversing the line.

How the interaction of these two affect the slave depends on a number of variables including the physical length of the line, whether communication is in progress with the master, the amplitude of the reflections and the thresholds of the slave. From this example it should be apparent that placing 1-Wire slaves at integer fractions of the line length could lead to difficulties. And the reason moving a slave a short distance in either direction from where it is non-responding can result in reliable communication.
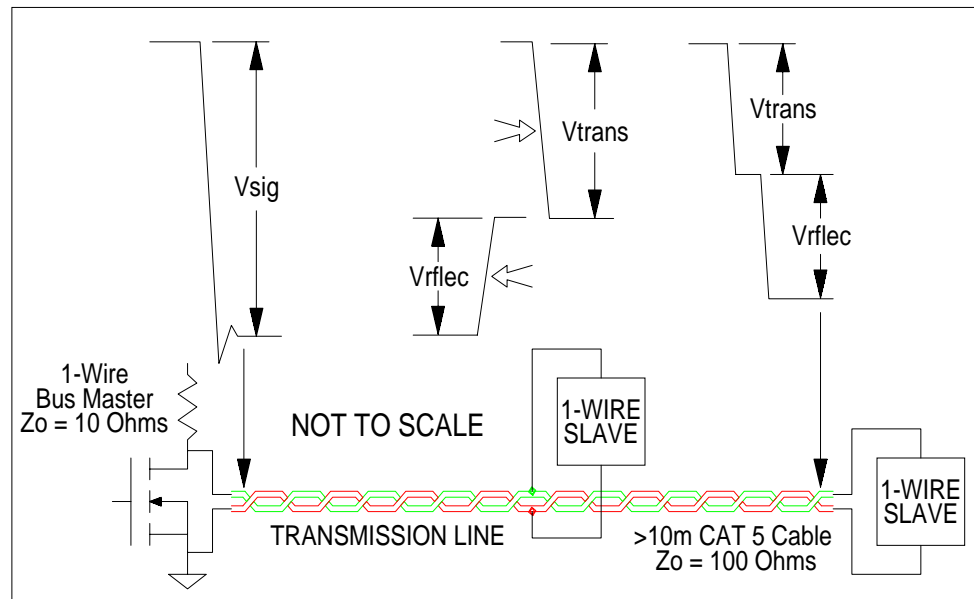
FIGURE 3 Any discontinuity on the line, including slaves can cause reflections. Locations that are at integer fractions of the line length are particularly problematic as they can resonant.

When a step function (V_{sig}) is introduced to a transmission line from a matched source (Z_0), it travels down the line until it encounters an impedance mismatch (Z_1). At that point the signal will split into reflected (V_{rflec}) and transmitted (V_{trans}) fractions. The reflected portion (V_{rflec}) travels back toward the driver, while the transmitted portion (V_{trans}) continues down the line in the original direction. This phenomena occurs at each slave and connection positioned along the length of the 1-Wire net. The relationship between (V_{trans}) and (V_{rflec}) is given as:

$$V_{trans} = V_{sig} + V_{rflec} \qquad \text{Equation 3}$$

$$V_{rflec} = V_{sig} (Z1\text{-}Z0) \, / \, (Z1 + Z0) \qquad \text{Equation 4}$$

Wavelength effects

In addition to the adverse effects on communication that can occur due to placement of slaves at integer fractions of the line length, slaves that are located one-quarter of the length of the cable from an end are susceptible to resonant effects. For example, a 1MHz signal has a wavelength approximately 300m[8] long; consequently a 1-Wire network of this length will be both a radiator and a receiver for signals with this frequency content. If a slave is placed 75m from either cable end it will be exposed to the maximum signal amplitude of a signal at the tuned frequency as illustrated in Figure 4.
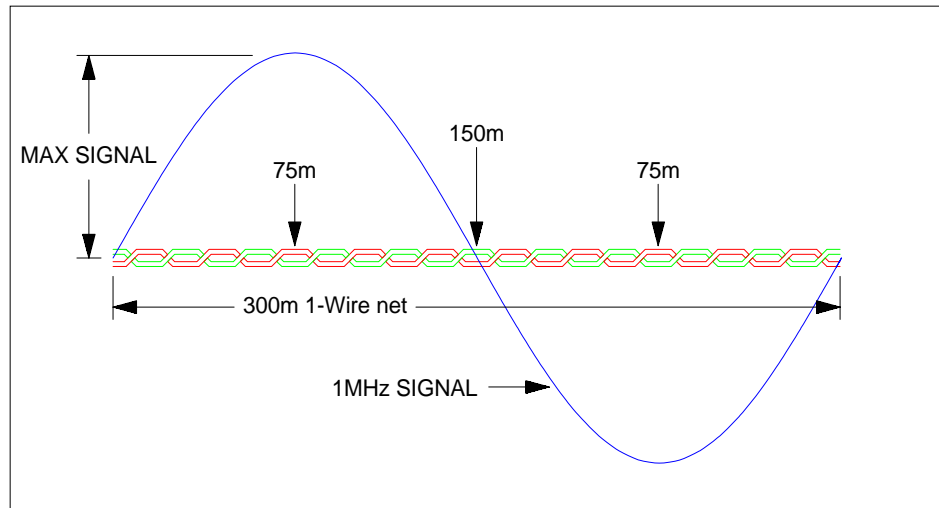
FIGURE 4. Placing slaves at one-fourth the length of the cable can lead to communication problems.

> **The current required to change voltage (V_{chg}) on a transmission line is given by:**
> $$I = V_{chg} / Z_0 \qquad \text{Equation 5}$$

You can use the supplied spreadsheet[9] to help calculate wavelength nodal points for any cable length given. Don't forget that with the use a hub chip you can change the effective total length of the cable.

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[8] EM radiation in air is approximately the same as a vacuum so it's the speed of light / frequency or 299,279,458 / 1,000,000 Hz = 299.79246 meters or approximately 300 meters

[9] See spreadsheet Calc-Line.xls[9]

Slew Rates

What are slew rates

Because it is not possible to terminate the end of the cable in its characteristic impedance in order to help prevent ringing, the alternative is to control the slew rate (how fast the voltage changes logic states) of the bus master pull down transistor. This is done through additional circuitry in the bus master.[10], which slows the rate of falling transitions from high to low. Devices like the DS2480B have this circuitry built into the chip.
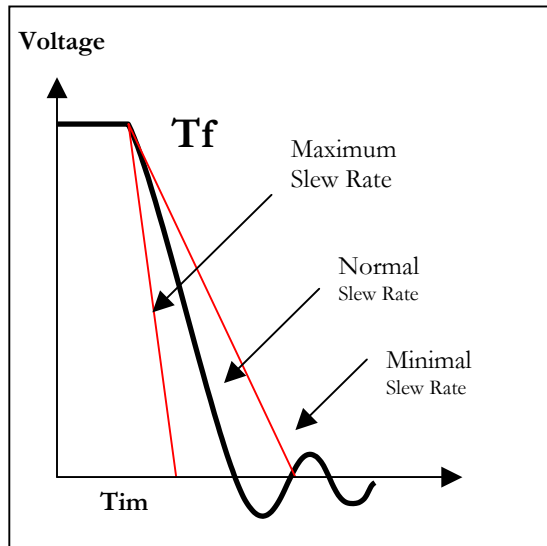
Figure 5 showing the range of different slew rates

Ringing or Ring back

Excessively fast fall times (high slew rates) can cause ringing and generate signals on the 1-Wire bus that are unwanted and may interfere with valid data waveforms. This can be seen in Figure 5 where the falling voltage causes temporary ringing (voltage oscillations above and below the eventual steady-state level) Eventually the cable attenuates (dampens) these oscillations to the steady state level.

By slowing the slew rate you can lessen the effects of ringing. Excessively slow rise and fall times may not meet timing requirements, and may expose the transition period to the effects of noise and reflections.

The maximal slew rate setting is achieved if the voltage drop from 5V to 0V takes twice as long as the signal propagation delay from the driver to the far end of the cable and back (roundtrip propagation delay).

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[10] See App Note 244: Advanced 1-Wire Network Driver

The effect of differing slew rates in the time it takes to cross the 1-wire indeterminate region can be seen in the following table. Those in gold/green are the rates found in a DS2480B or DS2490 USB adapter. While the orange/yellow slew rate might be found in a non-slew rate controlled 2N7000 switch.

Time periods for slew rates						
		Vs to VIH		VIH to VIL		VIL to 0
Device Slew Rate		Vs to VIH				
			Intermediate Region			
Device	V/µs					VIL to 0
2N7000	1000.00	0.0028	µs	0.0014 µs		0.0008 µs
DS2480B	15.00	0.1867	µs	0.0933 µs		0.0533 µs
DS2480B	2.20	1.2727	µs	0.6364 µs		0.3636 µs
DS2480B	1.65	1.6970	µs	0.8485 µs		0.4848 µs
DS2480B	1.37	2.0438	µs	1.0219 µs		0.5839 µs
DS2480B	1.10	2.5455	µs	1.2727 µs		0.7273 µs
DS2480B	0.83	3.3735	µs	1.6867 µs		0.9639 µs
DS2480B	0.70	4.0000	µs	2.0000 µs		1.1429 µs
DS2480B	0.55	5.0909	µs	2.5455 µs		1.4545 µs

From this it can be seen that an appreciable amount of time can be spent in this region with slower slew rates. This increases the likelihood of noise events effecting the 1-wire switching and causing communications errors. So finding the right balance between a slow slew rate and the cable length is important.

Calculating the slowest slew rate - example
Based on the DS2480B and Ds2450 datasheets, the maximum time you can take to slew from 5 Volts to <VIL MAX is 8 µs – tsu (1µs max) or about 7µs given the shortest possible sample point time[11]. This works out to about to a slew rate of 0.7V per µs. To use any slower slew rate you must delay the sample time. These relationships can be seen in the following drawing.
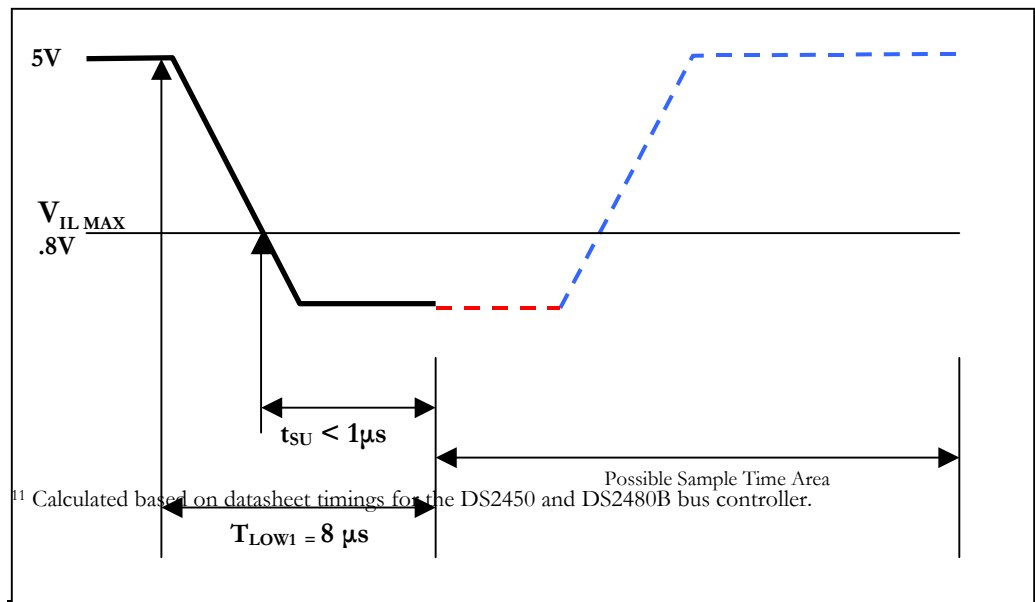
11 Calculated based on datasheet timings for the DS2450 and DS2480B bus controller.

The slew rate should never be slower than ½ of the roundtrip duration time of the sample time in the cable.

A common rule of thumb is to use a slew rate with a ratio of the falling edge (Tf) to the one-way electrical propagation length of the cable of 8 to 1. This ratio sets a minimal signal reflection for the signal based on the slew rate and gives **maximum** performance. When the slew rate is in the ratio of 5 to 1 it is considered **normal** range and a 2 to 1 ratio is used for **minimal** control of signal reflections. Consult the companion spreadsheet for help calculating these values.

The advantages of controlling the slew rates are:[12]

- Helps provide clean signals with minimal signal reflections
- Reduces to reduce RF emissions

Cable Length Slew Rates

Calculating Cable Length Slew Rates

The effect of changing the slew rates in a DS2480B on the theoretical point where line effects are a major issue in a CAT5 cable (69% NVP) can be seen in the following table with different ratios given (2,5 and 8). Additional effects such capacitive load will change these distances.

Recommended cable lengths based on DS2480B slew rates					
Cable length should be < given value for performance category					
Slew Rate	Slew Rate	2	5	8	
		2 to 1 ratio	5 to 1 ratio	8 to 1 ratio	
Volts per µs	Volts/µs	Minimal	Normal	Optimum	Units
2N7000	1000.00	0.517	0.207	0.129	Meters
DS2480B	15.00	34.476	13.790	8.619	Meters
DS2480B	2.20	235.065	94.026	58.766	Meters
DS2480B	1.65	313.419	125.368	78.355	Meters
DS2480B	1.37	377.476	150.990	94.369	Meters
DS2480B	1.10	470.129	188.052	117.532	Meters
DS2480B	0.83	623.063	249.225	155.766	Meters
DS2480B	0.70	738.774	295.510	184.694	Meters
DS2480B	0.55	940.258	376.103	235.065	Meters

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[12] See App Note 132: Quick Guide to 1-Wire net (Has been replaced by App note #148)

Negative Transitions

Undershoot

The falling edge (T_f) of any falling edge must be monotonic (Single edged). Excessively fast fall times (high slew rates) cause ringing and undershoot or rings back) from its initial minimum- low level. . This may occur on a non-slew rate controlled edge and can also be seen on the falling edge of an uncontrolled slave presence pulse. Undershoot events can be the cause of increased errors. If the signal retreats to far, it can cause false clock triggering of 1-wire circuits.

If the ringing is severe enough it may exceed the negative limits of the devices to handle. Therefore at a minimum, we recommend for good design practice to add an Schottky diode (like a BAT54S[13] or a 1N5817[14]) to help limit these signal excursions.

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[13] See Bat54S PDF datasheet

[14] See 1N5817 PDF datasheet

The following image shows a bus reset and presence sequence, but more importantly it shows the difference between the behavior of the slew-rate controlled master and an uncontrolled slave device[15]. The falling edge created by the master is clean and does not undershoot or ring. The falling edge caused by the slave device is uncontrolled, and it can be observed to cause ringing and undershoot on the bus.
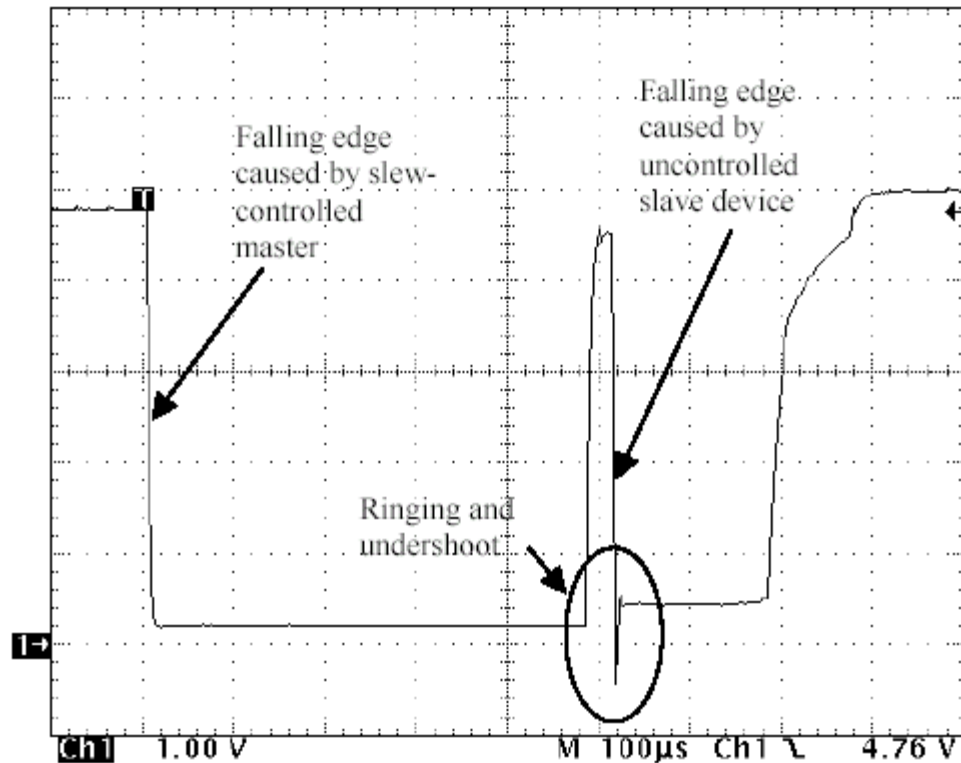
In order to help dampen undershoots that go below ground Schottky diodes are often used. It is recommended that these be used across each slave and at cable ends. Connect the diode across the cable with the cathode on the data line, and the anode on the return. Other circuit protection schemes are also possible. Remember to consider the impact of these diodes or other circuitry when considering your network loading (total capacitive loads of **all devices on the network**, including diodes, etc.)

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[15] Not all slave devices have uncontrolled presence pulses. Devices like the DS2408 and DS2431 use the new improved edge circuitry now offering controlled slew rates. Consult your datasheets for information.

Phantom Presence pulse

If the net consists of a fixed collection of 1-Wire slaves, the slew rate problem of their Presence pulse can be overcome by generating a "Phantom Presence Pulse" with the bus master. This is simply an artificial slew rate controlled Presence pulse created by the bus master that starts at 10 µs and terminates at 60 µs. A sample pulse can then be generated at 70 µs to see if a slave is on the bus or node if desired. This technique masks the high slew rate of the slave high-to-low Presence pulse transitions because the bus is already at logic zero when they occur. However, the Phantom Presence pulse technique is obviously ineffective when dealing with newly connected slaves, which arrive at unpredictable times on the bus.
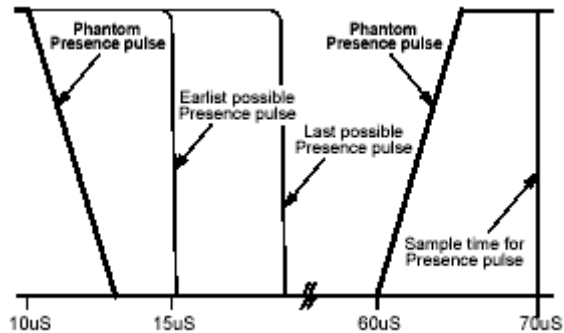
Figure 6 The bus master can generate a Phantom Presence pulse prior to any possible presence pulse from a slave. It must last until the slowest possible Presence pulse has started.

Positive Transitions

Pull-Up Currents

The Weak Pull-up

The rising edge (T_r) must be monotonic (Single edged).

Once both master and slave turn off, the bus pull-up resistor pulls the data line high. As the capacitive load on the net increases by adding 1-Wire devices, the time to raise the data line to the supply voltage also increases. This also occurs when the network is lengthened due to the 50pF of capacitance added per meter of twisted pair cable. This can be seen in Figure 7 as the number of slaves is increased from 1 to 300. If the product of the total capacitive load (including cable, device, stray capacitance, etc.), and the pull-up resistor value results in a time constant (RC) that exceeds the bit time slot defined by 1-Wire protocol, communication stops.
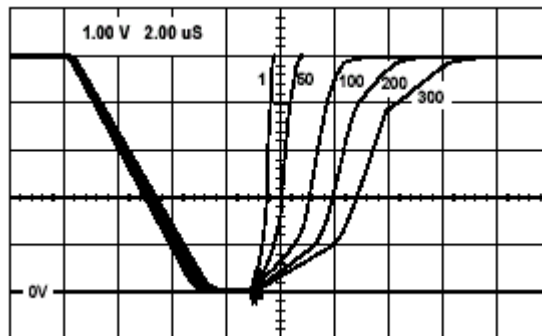
Figure 7 Loading effect of increasing the number of 1-Wire devices using active pull-up, and 2m cable. Protocol, communication stops because grounding unused wires or shields in a cable adds capacitance

Because **grounding unused wires or shields in a cable adds capacitance**, which can significantly increase the RC time constant, they should be left disconnected. You want to limit capacitance throughout a 1-wire system as much as possible to maximize cable length and limit RC effects.

Calculating the Max Fan Out.

The product of the pull-up resistor value and the idle current of all devices on the line determine the maximum voltage to which the bus pull-up resistor can raise the data line. The more devices, the greater the voltage-drop across the pull-up resistor.

The fan out limit of a particular 1-Wire net is reached as the voltage drop across the pull-up resistor reduces the net supply voltage to 2.8V. This is the minimum voltage that will recharge the parasitic power supply of the 1-Wire devices. From this, the maximum theoretical fan out may be calculated. It is equal to the supply voltage (Vs) minus 2.8V (the minimum operating voltage) divided by the pull-up resistor value. The resultant is divided by 15μA, the worse case device supply current. For a 5V supply and 1.5K minimum pull-up resistor value we have the following.

$$\text{Fan out Max} = (Vs\text{-}MaxOpV)/Resistance$$

Fan out Max = (5-2.8)/1.5K=1.47mA/15μA=98 devices

This represents the theoretical maximum number of 1-Wire devices that can successfully communicate with the master using a 1.5K pull-up resistor and 5V supply over worse case conditions of current and temperature. The assumptions being that all devices are drawing the maximum supply current and operating in a -40 to 85_°C environment.

The starting charge time for a slave device

In the real world, all devices will only be drawing the 15μA maximum supply current during System Reset and Presence Detect. At that time all device oscillators turn on for 5T times. Since 1T time typically lasts 30 microseconds, 5T times represent 150 microseconds, with a worse case of 255 microseconds. The Dallas Semiconductor design team always referred to 1-Wire timing in terms of multiples of the divider output of the oscillators. So 5T times means five periods of the divided down internal oscillator. Circuit design ensures that all 1-Wire devices will be able to operate from their internal parasite power source for the duration of this interval once fully charged. Thereafter, they will be drawing 5μA maximum, which permits tripling the previously calculated fan out of 98. In addition, most systems will be operating over a much narrower temperature range, which allows still larger fan-outs. For example, in a typical lab environment, over 500 1-Wire devices in continuous communication had only a 1.2V drop across the pull-up resistor. This implies that typical idle current per device is less than 2μA when environmental and supply ranges are limited.

Active Pull-up

Active Pull-up, what is it?

Most bus masters use an additional circuit called the active pull-up to help the weak pull-up resistor insure that the bus returns to the high state in a timely manner. This acts as a power boost to the weak pull-up current resistor. This is done by having a circuit that turns on a current boast as soon as the voltage has risen sufficiently turning off the boost and allowing the weak pull-up current to finish pulling up the line. Its looks something like this:
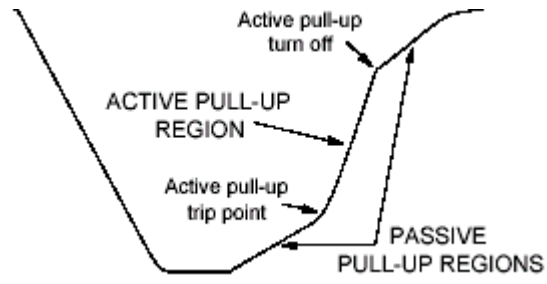
You can see that on the rising edge, the voltage is originally is pulled up by the weak pull-up current. At the Active pull-up trip point the current is increased and the rate of the rising edge increases. At the Active Pull-up turn off point, the active pull-up current boast is stopped and it is left to the weak pull-up current to pull the line up the rest of the way.

The advantages of an active pull-up in the bus master are:

- Gets the signal to 5V faster
- Gets more energy to the slaves (good for recharging the parasitic capacitors)
- Minimizes the effects of the droop when the slaves start recharging their parasite power supply
- Allows more slave devices in the network

The slew rate for the rising edge is not that critical. As a recommendation it should be four times as fast as that of the falling edge, but not faster than 5V/μs.

Care must be used to prevent the active pull-up circuit pulling the line high from fighting with a slave device trying to make the line low.

Avoiding false triggers of a active pull-up circuit
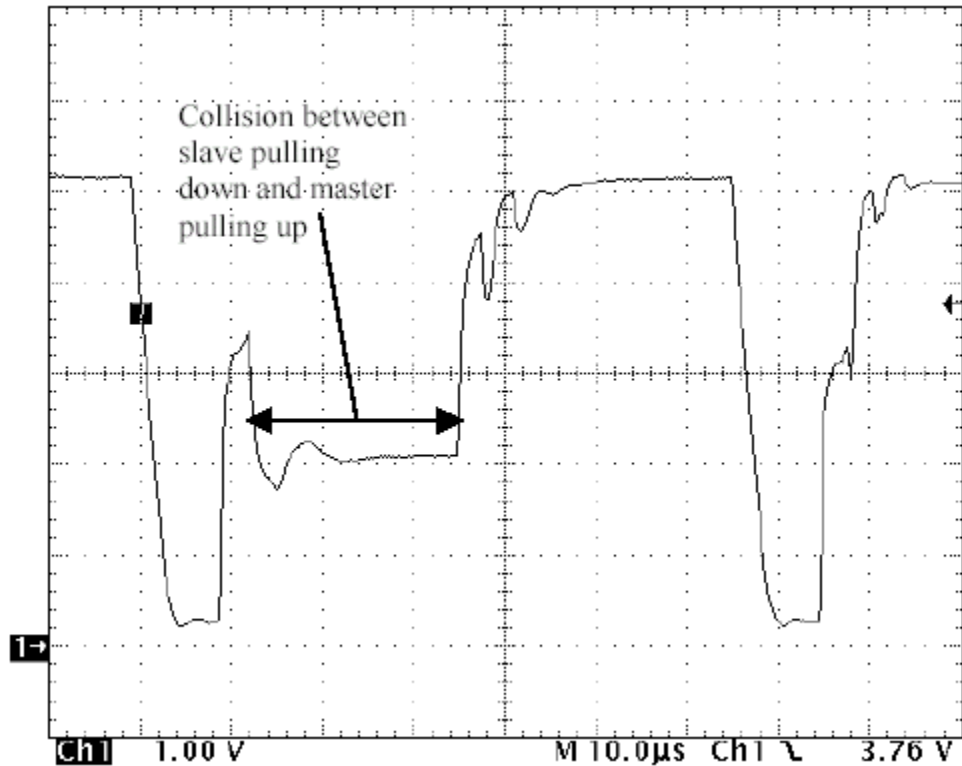
When a bus master has a dynamic pull-up as in the DS9097 or the LINK a situation can occur if the feature has been falsely turned on by a signal reflection. This image shows the resulting chaos that occurs when the dynamic pull-up is falsely triggered by reflections on the cable due to stubs and branches. This is a Read Zero time slot, where a reflection has caused the dynamic pull-up to activate and collide with the pull-down in the slave device.

Parasitic Power

Parasitic Power Threshold

Problems with Parasitic power

1-Wire devices derive the power they need to communicate with the bus master from the DATA line by use of an internal diode and the 800pf capacitor that steals power from the bus (See 1-Wire Slave Devices). Whenever the DATA line is at or above approximately 2.8V, the internal capacitor charges to one diode drop below the voltage on the line. In the case where there are many 1-Wire devices on a long line, this recharging of the parasite power capacitors can produce perturbations that include voltage reversals, that is, the signal becomes non-monotonic.
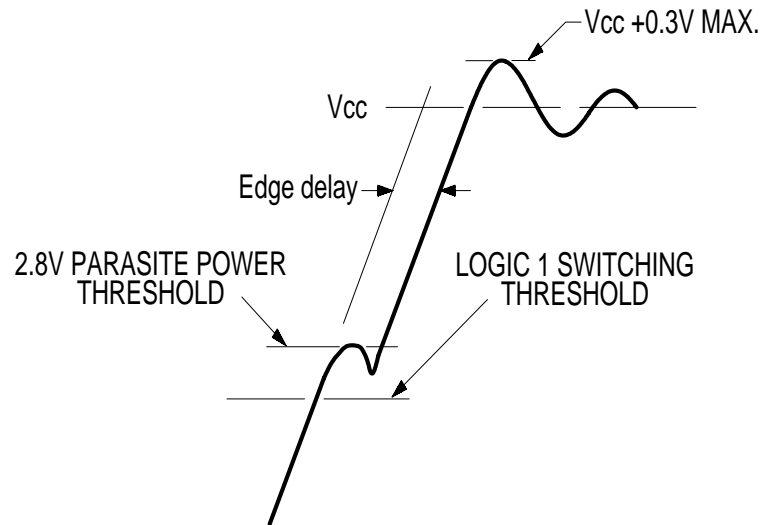
Figure 8 Effects of charging parasitic power on Tr when a long 1-Wire network is heavily loaded.

Because this occurs at a level approximately one-diode drop above the logic one switching threshold a heavily loaded long line can potentially produce voltage reversals from parasite recharging that pass back through the switching threshold causing communication problems. This suggests that the active pull-up current (if any) should be increased in the 2.2 to 2.8V region.

Capacitive loading from Slave devices and cable

At power up, capacitive loading of the cable and slave devices can require several milliseconds (See The original charge time for a slave device) to charge before communication can start on the net, especially if a passive (resistive) pull-up is used. Also on long lines with many slaves grouped at the end, the parasitic power requirements create a dip or slope change in the rising edge of the waveform at about 2.8V as the energy reservoirs of the devices are filled. Once full, the recovery time after each time slot will be sufficient to maintain the charge.

Figure 7 shows the effect charging the parasite power capacitance has on different numbers of 1-Wire devices at the end of 100 meters of Category 5 cable. Notice that the slope of the rising edge decreases as it crosses the 2.8V threshold finally reversing

direction to form a dip when loaded with 100 or more devices. These "dips" become more pronounced the longer the bus remains low.
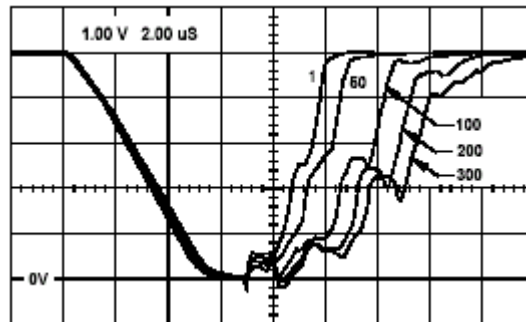
Figure 9 Parasitic power loading during the 0 to 1 transition. Notice that the dip becomes more pronounced with increasing number of devices at end of 100m of cable.

What happens when there is a slow rise time or insufficient recovery period
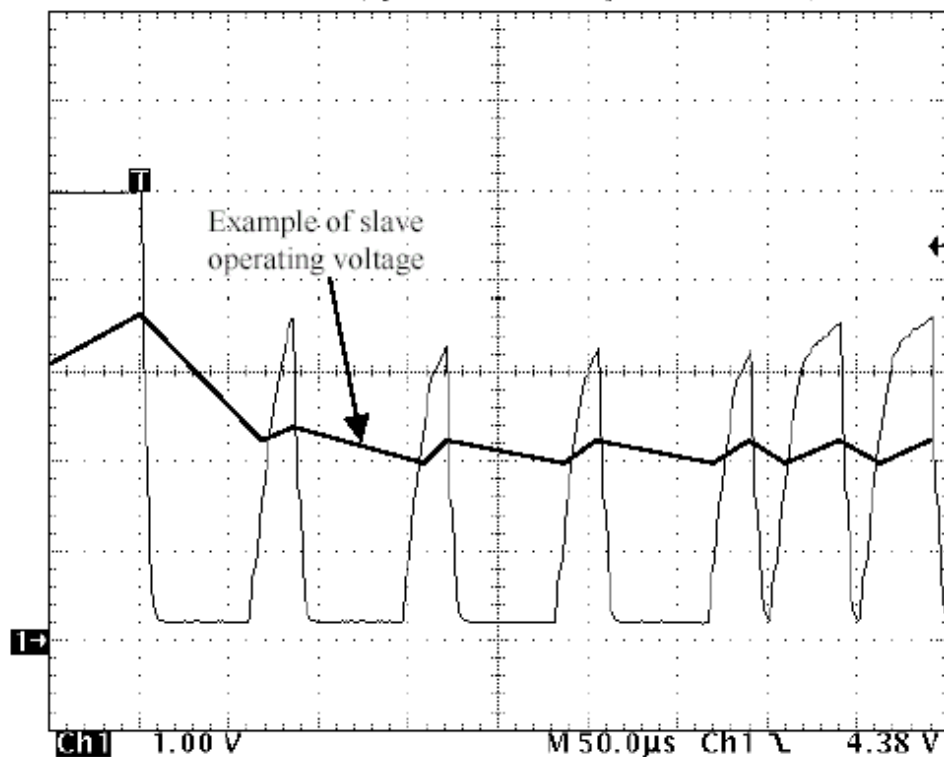
When the 1-Wire rise time is insufficient, recovery time (the period between time slots) may be insufficient to allow the bus to reach a level sufficient to recharge the slave devices. In the image above, the average DC level that the slaves have to work with has become dangerously low. Slaves may reset due to power starvation, especially during long strings of Write Zero time slots.

Cable Length Issues

Several factors determine how long the cable for the 1-Wire network can extend, all of which were not covered in the preceding examples.

Line Loading

One important factor not previously mentioned is *line loading* this consists not only of the number of slaves on the line but the loading due to the cable itself. Slaves add about 30pF apiece while CAT 5 cable adds almost 50pF/m (which increases the interval of time required for a passive pull-up to return the line to a valid logic one value. As this interval increases, there comes a time when the voltage on the line will not reach a level sufficient to recharge the internal energy capacitor in one or more slaves. These will then effectively cease to exist on the net. As a rule of thumb, when using a 1-Wire adapter such as the DS9097U, limit the maximum value of capacitance to 10,000pF or less. For example, twenty slaves would load the line with 600pF (30pF x 20 = 600pF) leaving 9,400pF for the cable. Dividing this value (9,400) by 50pF/m gives 188m for the maximum suggested line length.

$$Maxlength = (10,000pf - (30pf \times Number\_of\_Slaves)) / LineCapacitance$$

Given twenty slaves on the 1-Wire network and recalling the transmission line effects discussed in the preceding it is evident that where these are located on the line can have a profound bearing on communication reliability. In a system that consists of a single close grouping of slaves at one end with a remote master, reflections between individual slaves are less of a problem. However, a more typical system would have small numbers of slaves grouped at staggered intervals along the cable. Since, as it has been discussed, the line cannot be properly terminated and slaves act as discontinuities on the line, reflections will be a problem.

Capacitance

Once both master and slave turn off, the bus pull-up resistor pulls the data line high. As the capacitive load on the 1-Wire network increases by adding 1-Wire devices, the time to raise the data line to the supply voltage also increases. This also occurs when the network is lengthened due to the 50pF of capacitance added per meter of twisted pair cable. This can be seen in **Figure 10** as the number of slaves is increased from 1 to 300. If the product of the total capacitive load (including cable, device, stray capacitance, etc.), and the pull-up resistor value results in a time constant (RC) that exceeds the bit time slot defined by 1-Wire protocol, communication stops. ***Because grounding unused wires or shields in a cable adds capacitance, which can significantly increase the RC time constant, they should be left disconnected.***
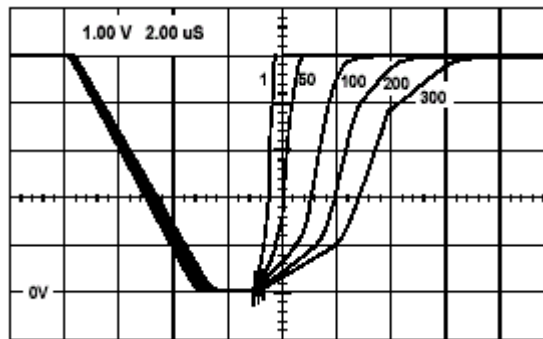
Figure 10 Loading effect of increasing the number of 1-Wire devices using active pull-up, and 2m cable.

As can be seen in Figure 10, the input capacitance of the slaves, contribute to the total capacitive load on the network. However, the slaves' internal 800pF parasitic power supply capacitance only exists at voltage levels above 2.8V minimum. Ignoring the capacitance of the parasitic power capacitor, the bus pull-up resistor value, together with the cable capacitance and 1- Wire device input capacitance represent the network time constant τ. This is a reasonable omission since parasitic capacitance does not become a factor until the bus has already passed the 2.2V logic one threshold. The network time constant determines the rate at which the data line returns to a logic one voltage. With the requirement that at τ equals 13.02 microseconds (the original data sample time) the 1-Wire voltage needs to have reached the 2.2V threshold of a logic one, the value of τ can be calculated as follows.

$$\tau = 13.02\,\mu s \; / \; \ln\,(Vs/(Vs\text{-}2.2V)) = 22.4\mu s$$

Where Vs is the pull-up supply voltage. Using the recommended 1.5K minimum pull-up resistor value and 5V supply voltage τ is calculated as 22.4 microseconds. Assuming the 1-Wire network is loaded with the maximum fan out as calculated previously, the cable capacitance alone must not exceed 12nF to yield a network time constant no more than the value just calculated. Using 50 pF/m for the typical cable capacitance implies that the theoretical maximum cable length is 240 meters. If the data sample time is recalculated with the new value of 21.7 microseconds, τ becomes 37.4μs. This permits 22nF of cable capacitance, which represents a cable length that exceeds the maximum allowed round trip propagation time.

The effect of cable capacitance on the signal can be seen in **Figure 11**, where 100 1-Wire slaves were addressed at the end of a 2 and 100-meter cable. The 100-meter cable added 5000pF of capacitance.
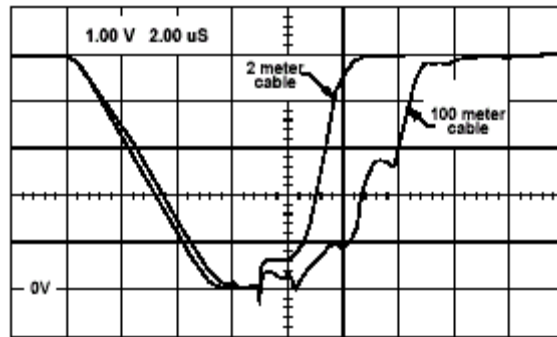
Figure 11 Effect of cable capacitance on signal driving 100 1-Wire devices.

The 100m cables adds 5nF. Reducing the value of the pull-up resistor, using lower capacitance cable, shortening the cable, or reducing the number of devices on the bus can improve the rise time. The pull-up resistor, however, should not be reduced below 1.5 k_. Reducing the value of the pull up resistor increases the logic zero voltage on the network, reducing system noise immunity. If the value of the pull-up resistor is already minimum, an active pull-up may be substituted. This also allows use of longer cables by decreasing the network time constant. Of course, the same rules apply to an active pull-up as to a pull down, and slew rate must be controlled to avoid operating in a transmission line environment. The effect of residual current flowing in the bus when the active pull-up turns off can be seen in **Figure 12**. This was of little concern with a passive pull-up as an RC time constant has an inherently slow slew rate.

Effects of line capacitance (Long lines)
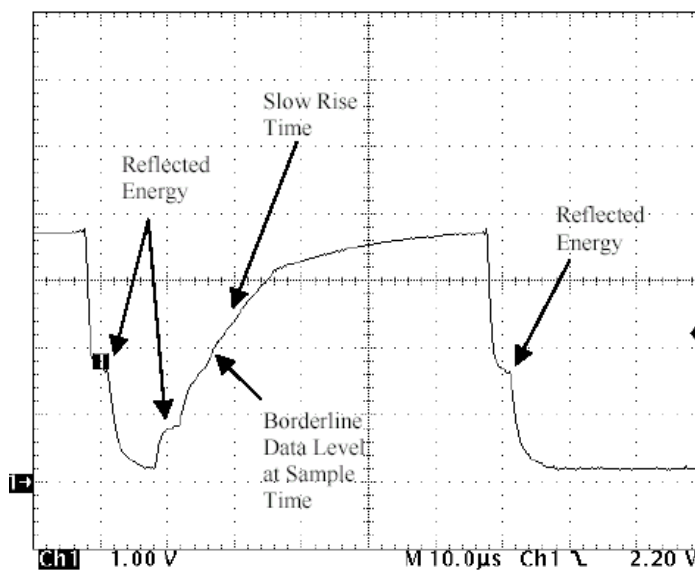
Figure 12 This image shows the effect of excessive weight when using a master with resistor pull-up only. The network radius in this example is 1000 feet and there are 30 devices at the far end of the network. The reflections from the end of the network can be clearly seen, as can the very slow rise time. Note that although this is a Read One time slot, the data level at the sample time is near the borderline and could be misread by the master.

Summary of capacitive loading

On the rising edge, as the capacitive load on the MicroLAN increases either by adding 1-Wire devices or cable capacitance by making the line longer, the time to return the line to the supply voltage increases. If the product of the total capacitive load (which includes line, device and stray capacitance) and the pull-up resistor value results in a time constant (RC) that exceeds the bit time slot defined by protocol, communication ceases. ***For this reason unused wires in a cable should be left unconnected.*** Grounding them can increase the capacitive load so significantly that the pull-up cannot raise the line above the logic-switching threshold in the bit time. If the value of the pull-up resistor is already the minimum (1100 ohm is recommended) that generates a recognized 0 level, an active pull-up must be substituted. Of course, the same rules apply to an active pull-up as to a pull down, and the slew rate must be controlled when operating in a transmission line environment. This is of little concern with a passive pull-up resistor as the RC time constant has an inherently slow slew rate.

Propagation time

Propagation time on the cable is also a factor, as a slave nearer to the master will see a command such as a RESET earlier than one more distant. In reply a slave will generate a Presence Pulse with a slew rate that places the 1-Wire network in a transmission line environment for line lengths greater than three meters. Given an example of 188m with twenty slaves it takes a little over $1\mu S$ (0.18cm/nSec times 5.55 times 188m) for the RESET from the master to reach a slave situated at cable end. The other nineteen slaves will have seen the command and started sequencing to respond before this last device even receives it! Therefore, a slave next to the master will transmit its Presence Pulse about $1\mu S$ before the one at the opposite end. The high-to-low transition at the start of this Presence Plus will propagate down the line generating reflections as it passes the discontinuity created by each slave reaching the last slave at about the time it is starting to generate it's own Presence Plus. Whether this transition is reflected by an unterminated end, (same amplitude and phase) or one with a lower impedance, (same amplitude, opposite phase) is determined by the state of the end slave. In this example, slaves between the two end ones will be still be in a high impedance state preparing to generate their own Presence Pulse. This scenario illustrates one of the numerous interactions that can occur on a 1-Wire network when it is operating in a transmission line environment with an unterminated line.
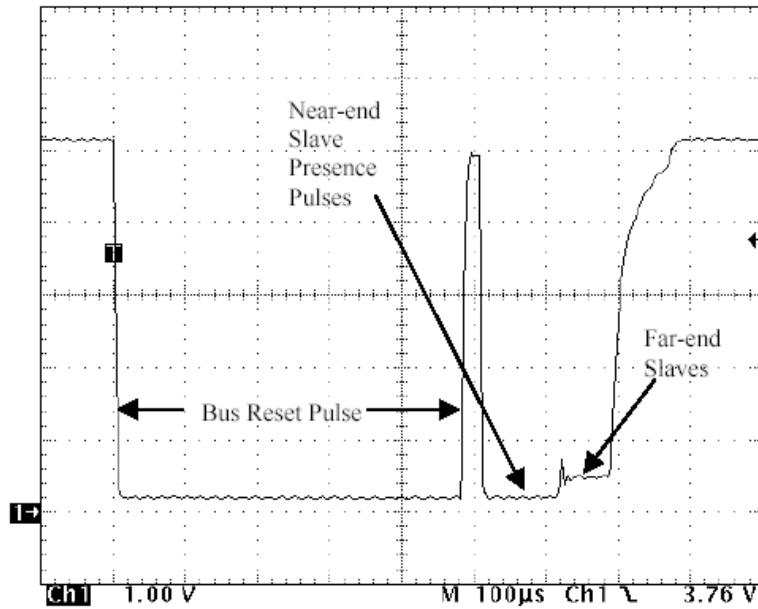
Figure 13. During Bus Reset sequences, the dynamic pull-up is used to overcome the network weight after the reset pulse, and then again after the end of the presence pulse(s). In this image, the overlap of near- and far-end presence pulses can be observed. The added resistance of the cable between the master and the far-end slave causes the low level to be higher for far-end devices than for near-end devices.

Avoiding line inductance problems

Line Inductance

As line inductance increases, the product of L Ldata/Lreturn can generate voltage excursions that cause bit errors and reverse bias the substrate of at least the first 1-Wire device at the far end of the cable. The current still flowing in the data and return lines of the cable when the transistor in the master is turned off before the charge stored in the line capacitance is fully discharged generates these voltages. The obvious and recommended solution is to maintain the pull down transistor in the on state until the current in the line discharges.
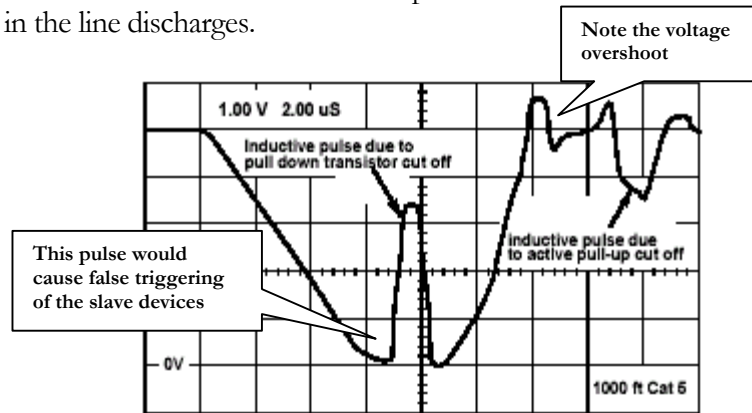
Figure 12. Inductively generated voltage spikes such as seen here, can occur on long lines due to residual current flow when pull down or pull-up circuits turn off.

A reason why the last slave device on the cable may disappear…

The residual current left flowing in the line determines the amplitude of a transient voltage spike generated as a product of this current and the cable inductance. The resulting voltage spike seen at the driver can become large enough to interfere with communication. The effect of residual current flowing in the cable when the bus pull down transistor and the active pull up turns off can be seen in **Figure 12**. Notice that in each case, the spike generated is in the direction of the opposite rail. At the far end of the cable, when the pull down transistor turns off it's inductively generated voltage spike swings negative, reverse biasing the substrate of the 1-Wire device closest to the cable end which clamps the voltage excursion at a diode drop. This device will then not respond to the bus master.

…How to fix it

If it is not possible to stretch the timing, an Schottky diode placed across the bus at the far end is suggested to clamp the inductive generated voltage overshoot. This is good general advice anyway as noted when we talked about undershoots, since it can help prevent voltage excursions caused by other events also. Connect the diode across the cable with the cathode on the data line, and the anode on the return. Only one diode is required for each length of MicroLAN with problem inductance.

Now that we have an idea of some of the many ways line issues can cause 1-Wire network problems, lets take a look at network topologies.

A introduction to Topology

A network may be represented as a collection of nodes, which are linked together by connections. Network topology is determined only by the configuration of connections between nodes; it is therefore a part of Graph theory. Distances between nodes, physical interconnections, transmission rates, and/or signal types are not a matter of network topology, although they may be affected by it in an actual physical network.

Linear Topology is the recommended topology for 1-Wire networks

Linear Topology

Example of Linear Topology using 1-bus master device and 4 slave devices
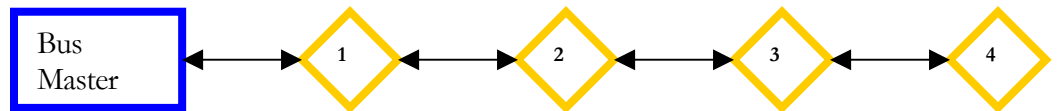
In linear topology, the 1-Wire bus starts at the bus master device and extends to the last slave device on the network. Each device is directly connected to the network so in essence the network passes through each device. This is the most desirable network configuration.

Short Stubbed Topology
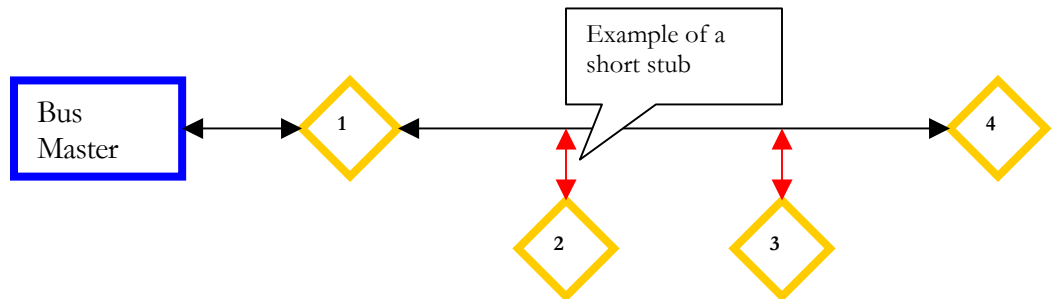
Example of a 1-Wire short stub network topology.

Slave devices 2 and 3 have short stubs (indicated in red) to the main network bus.

In a short stub network, very short lengths of wire connect the slave devices to the 1-Wire network bus. This can be seen in connections of slave devices number 2 and 3 in the above drawing. The devices are tapped onto a bus that extends through the slave devices 1 and 4. While Dallas Semiconductor recommends these to be <3 meters in length we suggest these should be kept as short as possible. With a range of centimeters in length (a few inches max) being desirable, with the shorter the better.

Short Stub networks are often used because of the use of a PCB board design or physical limitations when installing a network.

Long Stubbed Topology

Example of a long stub (>3 meters)

Bus Master

1

4

2

3
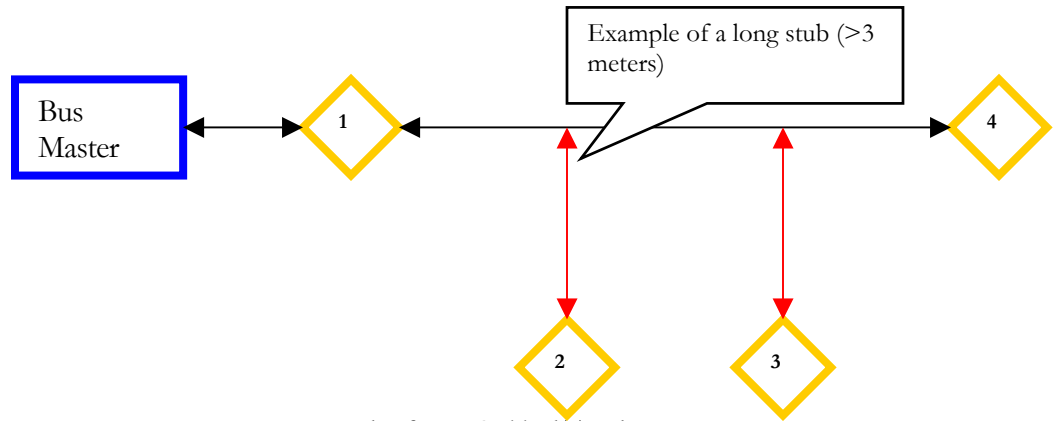
Example of Long Stubbed Topology

In this example slave devices 2 and 3 are connected to the network with cable lengths > 3 meters.

In a long stub network, lengths of wire (> 3 meters) connect the slave to the 1-Wire network bus. This can be seen in connections of slave number 2 and 3 in the above drawing. The devices are tapped onto bus that extends through the slaves 1 and 4 with long leads of wire. Many first time designers build their networks like this because of the physical ease in doing so. However, this form of network can lead to severe problems due to signal reflections. If the lengths are "just right" the network may work (because the signal reflections and cancellations have been "tuned"), but the slightest change to the network may cause it to fail again. ***Do not build this sort of network!***

Star Topology

In a star topology the 1-Wire bus is split at or near the master end and extends in multiple branches of varying lengths, typically with slave devices along or at the ends of the branches. Since each branch has its own characteristics reflection it once again becomes difficult to control reflections and signal cancellations. ***Do not build this sort of network***!

Bus Master

4   3

1   2
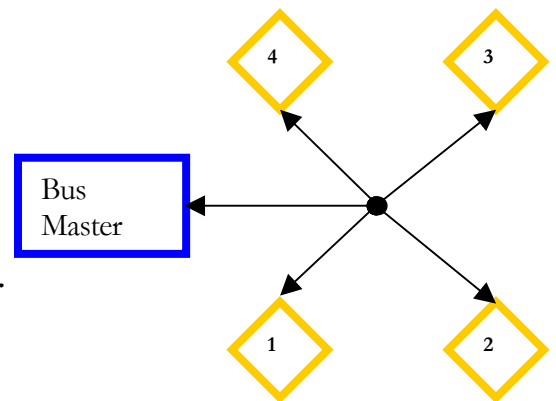
Branch Topology

However branching topologies can be created. By using a device such as the DS2409 MicroLAN Coupler[16] a 1-wire hub device, at the branch point, a tree structure is made. Branches made up of only wires (that is, without the supporting DS2409) are not considered branches but long stubs, and **should not be used**.
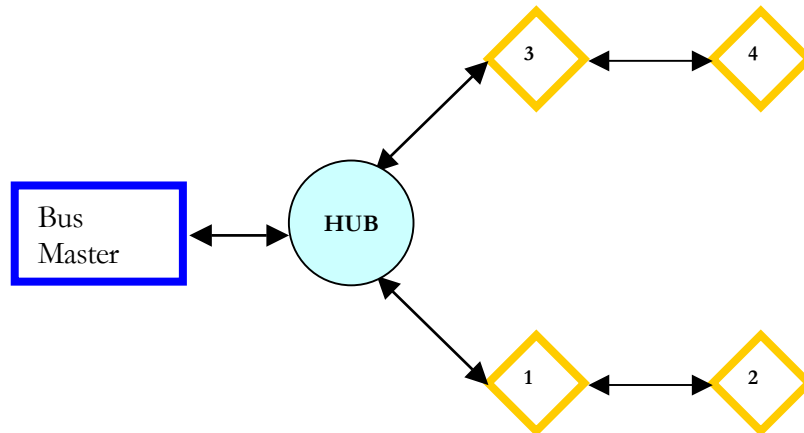
In this example the 1-Wire bus extends to the hub device, which splits it into two branches. Only one of which is active at any given time (If both were active then you would have created a stub) When a particular branch is active, only the slaves on that branch are available. So in essence the bus appears to be a linear topology at any given time.

This switched hub concept can be repeated as many times as needed (up to the limits imposed by the hub devices and the wire used to make the bus, since they add additional resistance to the bus each time) to develop a fuller "tree" with lots of branches.

Intermixing of topologies.
When different topologies are inter-mixed, it becomes even more difficult to determine the effects of signal reflections. **<u>As a general rule, don't even think about it!</u>** Leave these forms of 1-Wire networks to experts on line transmission theory. While any given stub or star network configuration may work at a given time, they tend to become highly tuned networks, which may fail with the slightest change. Even a change in weather may be sufficient to change their operation.

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[16] See the <u>DS2409 Datasheet</u> for more information on branching topologies

SUMMARY

Review of how 1-Wire communications works

Power is supplied to the 1-Wire slaves during idle communication periods and at bit times when the bus is in its default logic one (+5V) high state. During these bus high intervals, each slave stores energy by charging an internal capacitor that serves as its power source when the bus is in the logic zero (GND) state. Every slave also contains an internal oscillator that is synchronized by each falling edge of the data signal. The master reads and writes to a slave by pulling the line low for either long or short intervals that represent logic ones and zeros. A slave replies by continuing to hold the line in the logic zero state -or not- after the master releases it at which time a passive pull-up resistor pulls the line high.

Working in a transmission line environment

In the case where a 1-Wire network is long enough that it is operating in a transmission line environment, additional 'noise' is created in the form of reflections at each discontinuity in the cable, such as a slave or connection, along the line and at its unterminated end. If this noise level (crosstalk, glitches, etc.) on the bus is sufficient to cause a slave to see an extra clock edge, the slave losses synchronization to the master and communication ceases or is no longer in synch with the bus master. If a simple 1-Wire device such as the DS2401 is affected, it simply loses communication with the bus master for that interval. However, if a slave that has control or memory functions is affected, not only could communication be lost, but the system adversely affected by unwanted changes to the slave's function.

Planning is important!

Except in the simplest 1-Wire net, such as a single slave at the end of less than 2 meters of cable, it may take some careful planning or even tinkering to get a 1-Wire network to work acceptably due to transmission line effects. This is due to the 'bare-drain' I/O structure of the master and slave, which does not allow the line to be terminated. Further, some bus masters and all 1-Wire slaves have different characteristic impedance that does not match the 100Ω of the recommended CAT 5 cable. Worse, these impedance's are neither specified or controlled and change dependent on logic state. In the case of a slave, the impedance exhibits three distinct values, a low value around 50Ω when in a logic zero state with a 5V supply; a very high impedance when the 1-Wire network is in a logic one state and a variable impedance when the internal capacitor is being charged through a $1K\Omega$ resistor.

1-Wire networks provide for a unique class of unmatched low cost, long line multi-drop capable sensing. However, they do require careful planning and design to help 'tune' the system in order to help prevent signal integrity problems from occurring. Over the next few pages we will look at some of the things you should do (or be aware of) when designing and building a 1-wire network.

Rules to follow

The Network

Network Design

Design your network on paper before you build it. Don't forget to provide for any planned future devices.

1. Create a detailed drawing of your network design. Besides being very useful for reference purposes this makes it much easier if you need to ask someone else about your network. Keep good records, such as when you added or changed a component or a part in your network. While some 1-Wire devices may last for a lifetime, others may have a much shorter lifetime and may need to be replaced on a regular schedule. Things like batteries, and iButtons have a definitive lifetime associated with them. So good records can ease your maintaince worries.

2. Use a linear topology for your network. ***<u>Do not use a 'star' or long stub architecture.</u>***

3. Calculate total device and cable capacitance values.

4. Figure out power requirements for the network. While power over the same cable as 1-Wire is not optimum it can be used with care.

    a. 1-Wire devices are VERY susceptible to power transients due to the long time they may be in the indeterminate state (especially with long slew rates). So clean and noiseless power is highly recommend. The rising edge time in slave devices is of particular concern since voltage transients on the data bus can cause false clocking of the slave devices.

    b. While parasitic power can be very attractive, it can lengthen the response time in some devices like temperature sensors and does not allow mass temperature conversions. Consult the individual datasheets as needed to understand these issues and the trade-offs.

    c. When designing a network based on parasitic power, be sure to keep track of the total power requirements needed and check that you will be able to supply sufficient power to all the 1-Wire devices on the network. We suggest you add in a safety margin of at least 22%.

5. Figure out any power grounding issues. Help avoid ground loops by making sure there is only one network ground point back at the bus master device.

6. For outdoors installations, figure out how you are going to protect the network, from nature and induced man made EMI. (Lightning, power lines, etc)

7. Build into your design logical protection points such as the transition from indoors to outdoors. Or the interface to the bus master. Don't forget you may have expensive equipment to protect from the network and vice versa. Expect a worst-case scenario to happen eventually, (like a direct or a nearby lightning strike[17][18].).

8. Avoid fractional integer nodal points on the bus for slave devices

   a. Avoid placing slaves at integer fractions of the cable length, as communication can prove unreliable at those positions due to interaction of reflections and resonance effects. (Read about wavelength effects this here)

9. If the complexity of your network demands it, consider using a 1-Wire HUB[19] multiplexer to split the network into branches. This creates a tree like topology with hub devices at the branch junction. In this way you can address a particular branch of your network. This can have several benefits:

   - Logical clusters of similar devices

   - Possible logical/physical device orientation instead of individual slave devices. For instance you can create an instrument cluster behind a HUB device that can be uniquely addressed. Or a named bus segment (i.e. The flag pole instruments for example, which again could be turned on or off as needed).

   - Shorter total cable length (less capacitance due to shorter cable and fewer slaves on the network at a given time). Since only the branches that are turned on are enabled this helps a large system still appear and respond like a smaller system. A branch for instance could be a collection of temperature sensors in a particular location

   - If temperature sensors are powered instead of using parasitic powered you can also do quicker temperature conversions along with mass conversions. All sensors on the branch can be told to do a temperature reading at the same time, and then each one quickly read one at a time.

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[17] For a circuit for 1-wire transient protection

[18] One discussion about Lightning Protection can be found in the Weather Station FAQ

[19] Hub multiplexers are available from several manufactures (consult the manufactures list on www.1wire.org for manufactures of units) or you can make your own using a DS2409 chip.

- Better protection of the network against total network failure.

- When using a DS2409 as the HUB device, it offers some short circuit protection for the network. A shorted bus segment (maybe caused by a failed instrument or sensor) is automatically taken off the bus so the entire network does not fail, only that segment or branch of the network.

- It is also possible to use DS2409 HUB chips to help determine physical location of devices through a technique called "Chain Sequencing"[20]

While there are several commercial hubs available, most hubs are built around the DS2409 MicroLAN Coupler. Since the DS2409 adds resistance to the data path (like putting a resistor in series with the data line) care must be used in designing your network. Each time you add resistance in the data path you effectively raise the logic level 0 base data floor and decrease noise immunity. Note that there is a difference between the DS2409 data channels. The Main data branch has a resistance of 10 ohms while the AUX path has a resistance of 13 ohms. Be sure to include this value in your network calculations. And do your calculations for each branch
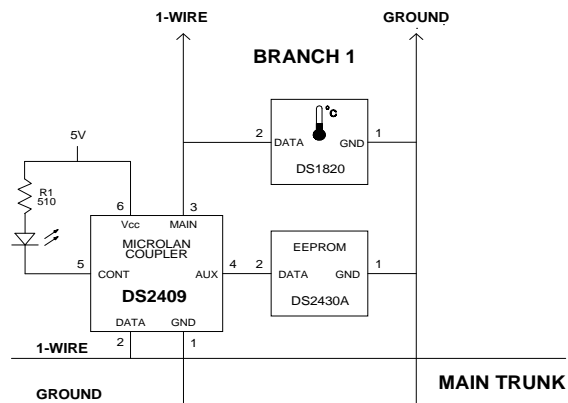
Separating the 1-Wire bus into branches using the DS2409 MicroLAN Coupler

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[20] See the document <u>Chain sequencing to electronically determine sequence</u>

Cable planning

1. Use High quality CAT5E or better, twisted pair cable (unshielded). Install it following good CAT wiring practices.

2. Follow a standard wiring scheme for all your 1-Wire wiring.

    a. There are currently two standards available (links to both are available at www.1wire.org.

        i. The Original RJ11/12 standard

        ii. And a Proposed 1WRJ45 standard for RJ45 connections

3. **Any unused wires in the 1-Wire cable should not be terminated**. Because grounding unused conductors will increase the capacitive load seen by the line master, Dallas Semiconductor recommends that unused wires and shields be left unconnected at both ends of the cable. The wires should be left floating.

    a. A look at some cable properties will help in understanding how such an arrangement affects the 1-Wire network performance. In a CAT 5 cable with multiple twisted pairs, on average any given conductor in a pair is adjacent to a second conductor in another pair for half its length. Typically, the capacitance seen between the two conductors of a twisted pair is approximately 50 pF/m while that between the conductors of two different pair runs about 30 pF/m.

    b. If you must use flat ribbon cable (**which is not recommended**) flat 6-conductor phone (silver satin) may be used up to about 200 feet. Follow the Dallas standard[21] for this sort of cable.

        i. This arrangement helps shield the critical DATA lead from the additional capacitive load and cross talk of the external power leads. Note that the two conductors prior to the 1-Wire DATA line are to be left uncommitted. As previously emphasized, if connected they will substantially increase the capacitive load seen by the DATA line.

            1. One possibility is to use 4- conductor silver satin and assemble the cable with these two slots in the RJ11 connector empty.

            2. Unfortunately, a significant disadvantage of flat cable is that it lacks the noise rejection properties of twisted

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[21] See Dallas RJ11/12 standard here

pair cable, so EMI can be a significant performance problem if the network is routed near sources of electrical noise.

3. If power is to be routed over flat phone wire along with 1-Wire DATA and GND, use the outer two conductors by 1-Wire GND to minimize cross talk and capacitive loading.

4. Quality of the cable can vary quite a bit depending on the manufacture. Think of moving toe CAT5 cable instead.

4. Use the same type of cabling for the entire network. Preferably the same cable. This helps avoid manufacturing impedance mismatches.

   a. For Belden 1588A, each pair has a different number of twists. Use the blue blue/white pair for the 1-Wire network since this pair has the most twists. If using a CAT5 cable from another manufacture, examine the twist count for each pair and use the pair that has the most twists per inch. Document if you do this or any other deviation from one of the wiring standards.

5. We suggest that you follow some sort of in-house plant color scheme to help keep track of your 1-Wire cables. By selecting a particular color cable for your entire plant for your 1-Wire cables you can help different it from other twisted pair cables you may have. So you could reserve orange for instance for 1-Wire cables and some other color for your Ethernet cables. The important thing is to document this and be consistent.

   a. Where possible add your standard wiring chart to the inside of any device cases for reference, this can make it during future maintenance for proper wiring connections and standards to be maintained.

6. Try to avoid routing 1-Wire cables near strong EMI fields such as motors. Remember the 1-Wire cable acts as an antenna. Any induced noise on the cables often presents problems. This noise, generally show up as an increased data transmission error rate (or no data transmission at all). Typically control of the slope of the transitions between logic levels is used to minimize cable transmission line reflection noise. Induced power spikes on the cabling can be of fairly low energy levels that only lead to transmission errors. Or the noise can be large enough potentially to create fatal voltage/current spikes or glitches, which can cause premature hardware failure. These spikes can often slowly stress or destroy the built in chip protection devices on board the 1-Wire network circuitry. Generally higher energy levels (such as lightning or

electrical surges[22]) induced from remote events (or nearby electrical fields) are often the cause of this sort of noise and are more likely to lead to total part failure.

7. For common mode RF interference reduction, try looping the 1-Wire cable through a single ferrite toroid core a few times. You can experiment with the size of the toroid and how many turns you need for the desired suppression. You should experience little or no signal loss in the 1-Wire bus itself.

General
1. Have backup components in case of failures (having a backup bus master and a known good working cable can be very useful for trouble shooting device problems).

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[22] 1-Wire Surge Protection ideas from Philip Gladstone

The Devices

Bus Masters

Configure the circuitry of the bus master so that it maintains constant impedance equal to that of the cable impedance. For example since the recommended CAT 5 cable has an impedance of 100Ω, use a bus master with a 100Ω impedance, or add circuitry to the existing one to meet 100Ω.

Select a bus master suitable for your needs. Extensive 1-Wire bus testing has produced data on working limits that should be observed when using the available standard interface devices listed below. The following includes suggested limitations that should be observed when designing 1-Wire networks with these masters:

2. We recommend the bus masters based on the advanced network driver described in the Dallas Application note #244. The **Advanced Bus Interface** is a specially designed circuit for use with large and small 1-Wire networks. It has special provisions to operate reliably when connected to a network with high weight and radius values, up to 500m.

   The Link Interface uses a Advanced Bus Interface

   a. The LINK is a good implementation of this and has many advanced features besides the driver.

      i. These are:

         1. Better timing selection for sample points

         2. Relaxed timing

         3. Uses a higher threshold logic 0 switching point (1.2 to 1.6 volts) than the 0.8 volts of the Dallas specification. This allows greater noise immunity (at the cost of not being exactly in spec)

         4. Multiple sample point tests (best 2 out of 3) to help overcome possible noise at sample point time.

   b. Be aware that the LINK uses an RS232-E interface so check for compatibility with your system before use.

2. The DS2480B interface chip used in the standard DS9097U-S09[23] and TINI is the standard against which all other interfaces are measured. The DS2480 is available with and without an ID in a DB9 to RJ11 COM port adapter as the DS9097U-009 and DS9097U-S09 respectively. The circuitry is also available as the DS1411 with a DB9 to DS9098 iButton socket. When used on short

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[23] Schematic for the DS9097U-09 available here

(>1m) or medium (<100m) sized networks the addition of a RC filter can help dampen reflection problems.). Using the filter, this master can reliably support a network with a radius or weight of up to 200m. It is important to note that the DS2480B interface device has variable timings that can also be used to improve 1-Wire network reliability and performance. These timings are set to optimum values by some software (like TMEX) but may not be adjusted by all software. Proper timings are critical to reliable network performance.

- Insert a low pass filter[24] between the bus master and the 1-Wire net. Connect a 4700pF capacitor across the bus at the master and insert a 100Ω resistor in series with the bus.
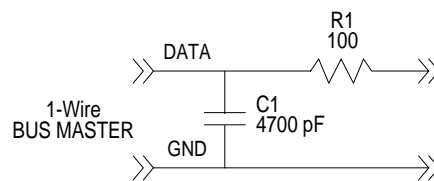
The simple R-C filter improves DS2480B or DS2490 USB adapter operation on short to medium length lines, with weights up to 200m. This filter should **always** be used on networks longer than 1m and less than 100m when using DS2480-based or DS2490 master end interfaces such as the DS9097 or DS2490 USB adapter. In **should not** be used when using the LINK bus master. Since it adds capacitance to the network it limits the maximum length of the network.

The purpose of the filter is to prevent reflections on the bus from coming back into the DS2480B/DS2490 and falsely triggering the dynamic pull-up in the device.

- Adjust the rise and fall times of the DS2480B/DS2490 master to be at least twice the time that a transition takes to propagate to the cable end and return. For example, a signal transition will take approximately 5.4µS to reach the end of a cable 300m long, adjust the slew-rate of the master so that it takes at least twice this value (10.8µS) to switch between its upper and lower voltages.

OPTIMIZED DS2480B TIMINGS

The DS2480B serial-to-1-Wire converter (used in the DS9097U series of PC interface adapters) has default 1-Wire timings that are optimized for small networks. These settings will not always perform well with medium or larger

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[24] App Note 148: Guidelines for Reliable 1-Wire Networks

networks. The timing and slew-rate settings in the DS2480B can be adjusted under software control. Indeed, the TMEX operating system makes some adjustment to these values as a matter of practice when used with this interface. Programmers should always place the DS2480B/DS2490 into "flex mode" and adjusted to optimize timing values for reliable performance. (See the DS2480B data sheet for detailed information on flex mode settings.)

Settings that may be adjusted in the DS2480B include the following:

Pull down Slew Rate Control—This is the rate at which the bus is pulled from a high level to a low level. Excessively fast fall times (high slew rates) cause ringing and generate unwanted signals on the 1-Wire that may interfere with valid data waveforms. Excessively slow rise and fall times may not meet timing requirements, and may expose the transition period to the effects of noise and reflections.

Write-One Low Time—This is the length of the low-going pulse that begins each time slot. If this pulse is too narrow, the end of a long line may never reach valid low levels before the pulse is ended.

Data Sample Offset/Recovery Time—This parameter defines when then data from slaves will be sampled. If this parameter is too small, the line may not have sufficient time to rise to a valid high level before the sample occurs. If this time is too long, then slaves operating near the fast end of their range may be misread. This parameter also defines the time between bits, during which time the parasite capacitors in the slaves must recharge.

Testing with long and short bus lines has shown that the optimum timings for all networks are as follows:

- Pull-down Slew Rate 1.37V/μs

- Write-One Low Time 11μs

- Data Sample Offset/Recovery 10μs

These timings provide the latest possible sample time (21μs, see note below) and the longest possible recovery time (10μs) along with a well-controlled slew rate.

These timings apply only to networks where the pull-up voltage is between 4.5V and 5.5V.

The original discrete **DS9097**[25] serial port interface was designed for use with very short (local) iButton probes. It is not recommended to support medium or large 1-Wire networks. Radius should be limited to tabletop distances for this master, on the order of 3m. Weight should be under 40m.

The **DS1410E**[26] parallel port interface was designed for use with very short (local) iButton probes. It is not recommended to support medium or large 1-Wire networks. Radius should be limited to tabletop distances for this master, on the order of 3m. Weight should be under 40m. The Dallas DS1410 series of parallel port 1-Wire interfaces generate narrow pulses (actually out-of-spec). It makes 600-800ns pulses to start time slots

Micro-controller Interfaces:
Simple micro-controller **port pin interfaces** are not capable of the drive currents necessary to support large- or even medium-sized networks. The pull-up resistor value is often limited by the port pin pull-down capability to around 2,200 Ω, which precludes heavy networks (networks with high weight values).

Port pin- only interfaces should be limited to networks with a tabletop radius and weight, about 3m maximum.

Micro-controller interfaces that include a **FET driver with slew rate control** and a 1,000 Ω pull-up resistor can support medium-sized networks. A radius of up to 200m, and a weight of up to 200m, can be reliably supported using this interface.
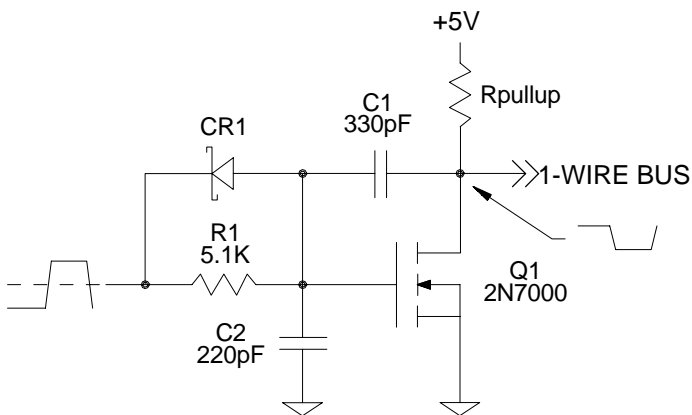
A controlled slew rate pull down for the 1-Wire net bus master. Transistor type is not critical.

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[25] Schematic for the DS9097 is available in App Note 74: Reading and Writing iButtons via Serial Interfaces (see figure 13)

[26] Schematic for the DS1410E is available from Dallas Semiconductor here.

Slave Devices

Keep the signal clean at the slave device

1. Insert a lossy ferrite bead such as a P/N 2512061527y0 from Fair-rite Products Corp., or equivalent, in series with the DATA line at the slave.

    a. Fair-Rite Products Corporation URL: http://www.fair-rite.com/

        1.   Telephone: (888) FAIRRITE (324-7748) or (845) 895-2055
                    FAX: (888) FERRITE (337-7483) or (845) 895-2629
                    Postal Address: PO Box J, 1 Commercial Row, Wallkill, NY 12589
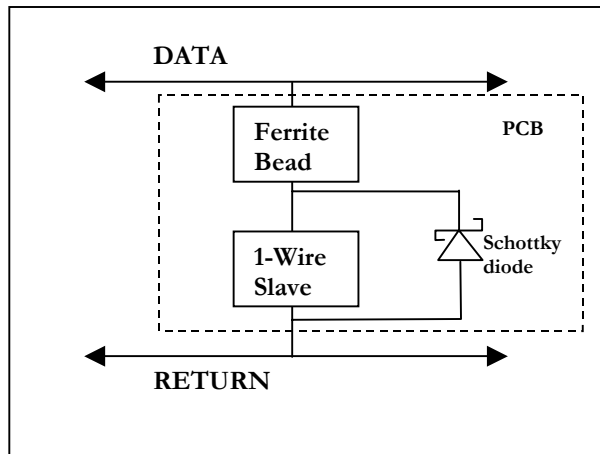
Example of use of Ferrite Bead and Schottky diode on a PCB design

Some 1-Wire chips are very susceptible to noise at the time that the rising waveform is crossing threshold during signal edge events. Even a few mv of noise will cause problems. Use of a lossy ferrite bead can help prevent these problems. The Schottky Diode is typically a BAT54 or equivalent and is used to help prevent undershoots that go below ground.

This is the recommended PCB board design (at this time).

2. If a ferrite bead is not available, then good success has been achieved by inserting a small value of resistant (100 to 150Ω) instead between the bus and an individual slave to improve the impedance match. CAUTION: do not place resistors so that they add in series along the line. This is not as effective as the ferrite bead as it increases the 0 level base voltage floor of the device.
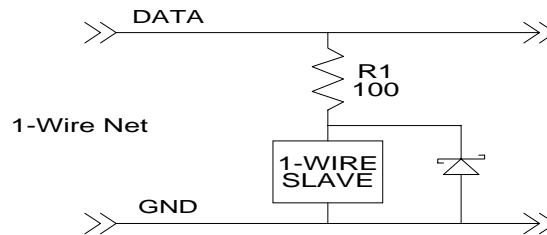
Protect against undershoot (ring back)

3. When using a single slave directly connected to a cable the use of Schottky diodes across each slave and at the cable end is still recommended in all cases to control undershoots that go below ground. Connect the diode reverse bias across the bus with the cathode to the DATA line and the anode to GND. While BAT54 are used on most boards for this function, the 1N5817 (the 1N5818, or 1N5819 or equivalent may also be used for direct wire attachments.
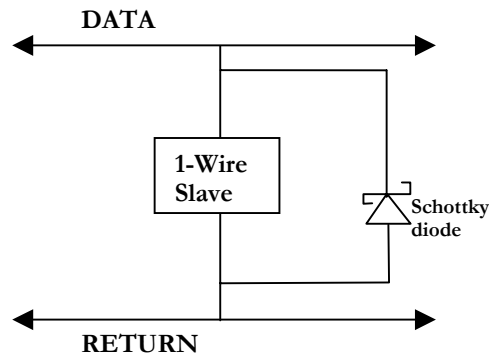
Example of protecting an individual slave device with a Schottky diode

4. The use of other line protection devices such as low capacitance TVS units, voltage clamp circuits, etc. can be used to help protect signal integrity. Care must be used to select low capacitance units so there are minimal effects on the data line. One popular unit for extending the 1-wire ESD protection is the DS9502 and the DS9503[27].

- This DS9503 is an ESD protection device for 1-Wire**®** interfaces. In contrast to the DS9502, the DS9503 includes two 5Ω Ω isolation resistors on chip. Although 5Ω Ω are negligible during communication, they represent a high impedance relative to the conducting diode during an ESD event. Thus, the diode absorbs the energy while the resistors further isolate and protect the circuit at the other side of the package. If used with circuits that already have a strong ESD-protection at their I/O port, the ESD protection level is raised to more that 27kV (IEC 801-2 Reference model). In case of abnormal ESD hits beyond its maximum ratings the DS9503 will eventually fail "short" thus preventing further damage.

  During normal operation the DS9503 behaves like a regular 7.5V Zener diode. When the voltage exceeds the trigger voltage, the I/V characteristic of the device it will "snapback" allowing the same or higher amount of

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[27] See DS9503 datasheet

current to flow, but at a significantly lower voltage. As long as a minimum current or voltage is maintained, the device will stay in the "snapback mode." If the voltage or the current falls below the holding voltage or holding current, the device will abruptly change to its normal mode and conduct only a small leakage current.

5. Avoid placing slaves at integer fractions of the cable length, as communication can prove unreliable at those positions due to interaction of reflections and resonance effects.

    a. Consult the supplied spreadsheet Calc-1Wire.xls for assistance in calculating these values

Don't use Stubs!

6. Avoid using 'stubs' off the main line as they diminish the signal level on the main line and generate reflections from the stub that can interfere with communication. If a short stub must be used, insert a low value resistor (100-150Ω) in series with the stub at the intersection with the main line. This is the same technique as shown before. The resistor helps absorb some of the reflection energy caused by the stub.

DATA

1-Wire Net

R1
100

GND

STUB
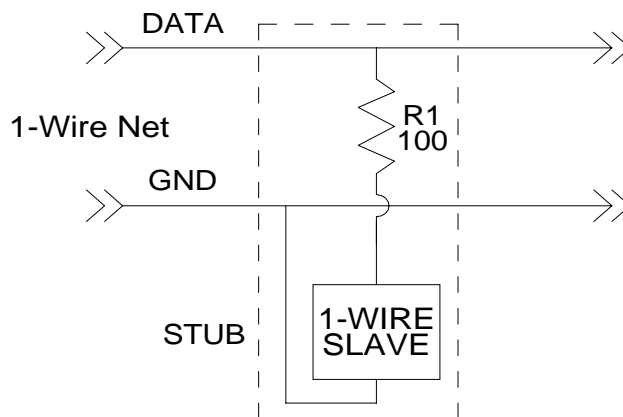
1-WIRE
SLAVE

7. A few new 1-Wire slave devices (introduced with the DS2408, see its datasheet for details) use a new internal 1-Wire interface circuit designed to slow down the detection of a time slot and to add hysteresis. These chips are much more able to handle the millivolt ringing that may occur on the rising edge at the threshold point that could cause the premature start of a new time. 1-Wire systems are very sensitive to asynchronous impulse interference

When using the DS2450 A/D chip

Note about the DS2450

> The DS2450 is one of those sensitive devices mentioned above. The use of a ferrite bead on the PCB next to the DS2450 is recommended as the 1-Wire bus feeds spikes through to the I/O pins and if the V_{CC} pin does not see an absolutely clean source various communications errors can occur. (Transients from switching power supplies are one potential source of noise on the V_{CC} pin). Also the use of buffers on the I/O may be needed for proper operation.

When using the DS18X20 chips

DS18X20 B7 chip die problem

The DS18X20 B7 chip die (found in the DS18B20, DS1820S, and DS1822 products) can experience EEPROM data corruption failures during power on reset. While this is an unusual event, this is a possibility that can happen to any device during any power up while in either normal or parasite power operation modes. This failure occurs randomly but is dependent upon fabrication lot variation and the signal noise and rise time of the VDD/DQ pin. Since the EEPROM holds internal trim values (in addition to the user data in the TH and TL registers) that control the conversion process of the DS18X20 this may show up as inaccuracy of temperature readings. And can cause temperature measurement errors of up to $\pm60°C$.

Since there are a large number of BS18X20 B7 chips in service around the world so you never know when you may be dealing with one on a network so all software writers are recommended to code their software to handle this problem. A replacement die, the C2 version of the chip will be available later this year but it would still be good coding practice to handle the older chips correctly.

- Power may be lost due to many operational failures (such as normal cycling, shorts, **loss** of power, etc. for instance: "Under parasite power, if $t_{RSTL} > 960us$, a power on reset may occur.")

- There is a limited number of times you can re-write lost data to the chips EEPROM (min. 50K times)

For details on this problem programmers are referenced to the PDF document AN247 that details this problem and code (using undocumented op codes) to fix the problem and is available form Dallas semiconductor on request. If you have problems getting this document from Dallas let us know.

Our recommended solution is to read known good trim values once and then store in either EEPROM or in an initialization file for later use. During actual operations the procedure would then be something like the following:

Normal operational flow procedure for handling B7 versions of the DS18X20

1. Compare serial number of device with bad list

2. If device serial number not on list, code normally... skip to number 8

3. If on bad list, read the scratch pad (8 bytes)

    a. This tells you if device is in power on reset state, like this
        Byte 0 = 50h
        Byte 1 = 05h
        Byte 2 = TH
        Byte 3 = TL
        Byte 4 = Config Register
        Byte 5 = FFh
        Byte 6 = 0Ch
        Byte 7 = 10h
        Byte 8 = CRC

4. If device is not in POR state, skip to 8

5. Read the DS18X20 Trim values

6. Check Trim data against known good data for the particular chip

7. If not same as saved data, Write new Trim values, etc., (you may wish to keep track of number of times you have updated the EEPROM so if needed you could replace chip when exceeding the lifetime of the EEPROM.)

8. Do regular temperature conversion sequence

How to identify DS18X20 B7 chip die chips

To tell if your DS18B20 is a B7 die, and therefore may have a potential corruption problems:

1. Read the 18X20's ROM code. Look at only the serial number portion of the ROM code:

List of Chips with the B7 Die

1. Read the 18X20's ROM code. Look at only the serial number portion of the ROM code:

0xCC00000SSSSSSSFF

where CC is the CRC
00000 is the customer code
SSSSSSS is the serial number
FF is the family code

DS1822
Starting ROM code of rev B7	4A00000008978A22
Ending ROM code of rev B7	3B0000000CB81922
Starting ROM code of rev C2	620000000CB81A22

DS18S20
Starting ROM code of rev B7	E0000800591D2010
Ending ROM code of rev B7	AB00080080885F10
Starting ROM code of rev **C2**	6200080080886010

DS18B20
Starting ROM code of rev B7	0600000054501028
Ending ROM code of rev B7	5E000000662B4F28
Starting ROM code of rev **C2**	21000000662B5028

General Troubleshoot Tips

If you are having difficulties in finding devices,

      a.   Detach the network and connect one device alone one at time to the bus master adapter. Check operation as you add each device.

References

1. True, K M, "Reflections: Computations and Waveforms" The Interface Handbook, Fairchild Corp., Mountain View, CA, 1975, "Chapter 3.

2. Burton, E A, "Transmission-Line Methods Aid Memory-Board Design", Electronic Design pp 58-62 Jan 1989

3. Sutherland, J, "As Edge speeds increase, wires become transmission lines", EDN pp 75-93 Oct 14, 1999

4. Chipman, R A, TRANSMISSION LINES, Schaum's Outline Series in Engineering, McGraw-Hill 1968.

5. Awtrey, Dan, 1-WIRE IN A TRANSMISSION LINE ENVIRONMENT 4/26/2004 (102,400 bytes doc format)(*Document has been basically included as a sub part of this document with minor changes*)

Dallas Application Notes of interest
– Much of this information is taken from these sources (with updates as needed)

6. App Note 126: 1-Wire Communication Through Software

7. App Note 132: Quick Guide to 1-Wire net (Has been replaced by App note #148)

8. App Note 147: Supplying Power via the 1-Wire Bus

9. App Note 148: Guidelines for Reliable 1-Wire Networks

10. App Note 244: Advanced 1-Wire Network Driver

11. App Note 937: Book of iButton Standards

12. Tech Brief 1: 1-Wire Net Design Guide

13. Transmitting Data and Power over a One-Wire Bus

14. App Note 2420: 1-Wire Communication with a Microchip PICmicro Microcontroller

Additional reading

Web Links

Prime Resources

Dallas Semiconductor

> Dallas Semiconductor is the manufacture of most 1-wire semiconductors

1-Wire.Org

> This community oriented web site is a prime resource for anything dealing with 1-wire. There are additional resources for developers and interested hobbyist; lists of manufactures and archival reference information not found anywhere else. Dan Awtrey's original paper that sparked this compilation can be found there.

Cable Information

> http://www.epanorama.net/documents/wiring/cable_impedance.html

> IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 20, NO. 5, JUNE 2002

> Loop Makeup Identification Via Single Ended Testing: Beyond Mere Loop Qualification

> By: Stefano Galli, *Member, IEEE,* and David L. Waring, *Senior Member, IEEE*
> **http://www.argreenhouse.com/papers/sgalli/JSAC_LoopID.pdf**

Cable Standards

Today, there are a variety of standards that define cable and component specifications, including the configuration, implementation, performance, conformance, and verification of cabling systems. The most prominent standards are listed here:

International standards

- **United States** TIA/EIA-568-A (Telecommunications Industry Association/Electronic Industries Association-568-A), defines how to design, build, and manage a structured wiring system. Note that the specification is also called the EIA/TIA-568 in some references. Refer to "TIA/EIA Structured Cabling Standards" for more information.

- **International** ISO/IEC IS 11801 (International Organization for Standardization/International Engineering Consortium) defines generic cabling for customer premises. It is being used in Europe, Asia, and Africa. See ISO/IEC-11801 Cabling Standards.

- **Europe** Cenelec EN 50173 was derived from ISO 11801 and defines generic cabling and open-market cabling components.

- **Canada** CSA T529-Canadian Standards for Telecommunications Wiring Systems that closely follows the TIA/EIA-568 specifications.

- **Australia and New Zealand** SAA/SNZ HB27: 1996. This standard is based on the TIA TSB67 standard. It specifies field testing of balanced copper cabling and the methodology of specifying field tester accuracy

You can learn more about international cabling standards by visiting the Agilent's wirescope.com Web page at http://www.wirescope.com/.

1-Wire wiring standards:

At the time of this writing the following wiring standards are available, one for RJ11/12 connectors and the other for RJ45 connectors.

1. This was the original standards document from Dallas Semiconductor that recommended wiring standards for 1-wire devices using RJ11/12 connectors.

   Written by Dallas Semiconductor

   RJ11_1wire_standard.pdf

2. This guide expands on the Dallas RJ11/RJ12 wiring standard document and adapts it to use industry standard cabling (Ethernet TIA-568 color coding) and RJ-45 connectors. The document tightens the power specifications and gives manufactures implementation recommendations while explaining the reasoning for the changes.

   Draft written by Springbok Digitronics.

   Prelim Draft Version 1.0

   A Guide to the 1WRJ45 Standard.zip

Addendum

Cable Specifications and what they mean

Nominal Velocity of Propagation

An additional number that is useful to know about for a cable is its NVP. The NVP, the acronym for Nominal Velocity of Propagation, expresses the speed with which electrical signals travel in the cable relative to the speed of light in space or vacuum. When we measure the time required for a signal to travel the length of the link and back, and we know the NVP of the cable, we can calculate the electrical length of the link. Since the signal has traveled up and down the cable (twice the length), the equation for length is:

$$Length = (Measured\_Time\_Delay * NVP * Speed\_of\_Light)/2$$

The speed of light in space (or vacuum) is 300,000,000 meters/second or 0.3 meters per nanosecond. (A nanosecond [ns] is one billionth of a second.) NVP for a Category 5 UTP cable is approximately 69%, which means that an electrical signal travels along a Category 5 cable at approximately 0.2 m/nanosecond or 8 inches/nanosecond.

Velocity of propagation is inversely proportional to the square root of the dielectric constant; a lower dielectric constant will result in an increase in velocity. As we said, velocity of propagation is expressed as a percentage of the speed of light in a vacuum and can be calculated by the following formula:

$$V_p (\%) = \left(1/\sqrt{\varepsilon_r}\right) \times 100$$

Not all cables are alike:

- As you may have guessed from the proceeding paragraph, the speed with which electrical signals travel slightly varies from cable lot to lot (even of the same make and model). Differences of 5 to 8% are quite common.

- The pairs in a 4-pair cable all have different twist rates (and therefore different lengths) in order to improve crosstalk performance. This results in a slightly different NVP value for each pair. The different twist rate also means that the lengths of the copper wires are different for each pair. The combination of these factors is the main cause that the (electrical) lengths for the individual pairs yield slightly different results. Differences of 2 to 4% are quite common.

Propagation delay in twisted pairs

The propagation delay, or the time required by the electrical signals to travel from one end of the cabling link to the other end, is half of the round trip propagation delay measured when a signal travels in a 1-Wire network. Because in twisted pair cables not all cables are twisted the same amount, some wires end up being longer than others.

You may notice that the 4 pairs in a Cat5 (e) or 6 cable in the examples below have different twist ratios as shown below: (Check with your manufacture propagation time for your cables)-

Propagation Delay differences between pairs

If all the signals start at the same time, the pair with the least twist will send the signal quicker than the other pairs; in our example here it is the brown pair.

Delay Skew

Delay Skew is a calculation based on the propagation delay of the different pairs. First we select the quickest pair, in this example it is the brown pair. This is marked 0ns, then we look at the blue pair, there is a 9ns difference (99ns-90ns), so this has a delay skew of 9ns and so on.

Delay skew has recently been added to several cable testing standards because some Category 5 cables are constructed with different insulating materials around the copper conductors. This construction is referred to as heterogeneous. Homogeneous cable construction requires that all wire pairs is constructed with one and the same kind of insulating material. The insulating material has a major influence on the NVP of the cable. An example of a commonly marketed cable with heterogeneous construction is the so-called 2+2 cable. In this cable construction, the wires in two pairs are insulated using Teflon FEP while the wires in the other two pairs are insulated using a polyethylene compound. This heterogeneous construction method has been used to meet the demand for Category cable in view of the Teflon shortage that plagued the industry for a few years. The Teflon FEP insulated wire pairs exhibit the typical Category 5 NVP value of 69% while the other pairs transmit the signals somewhat slower and have an NVP value that is several points lower (65% or 66%).

The time required for a transition to propagate the length of the cable is given by:

$$T = \sqrt{LC} \qquad\qquad \text{Equation 6}$$

Attenuation

Signal transmissions over long distances are subject to *attenuation,* a loss of signal strength or amplitude. Broken or damaged cables also cause attenuation. Attenuation is the main reason why networks have various cable-length restrictions. If a signal becomes too weak, the receiving equipment will interpret it incorrectly or not at all. This causes errors, which require retransmission, and loss of performance.

The following shows the weakening of signal due to attenuation and frequency spread:
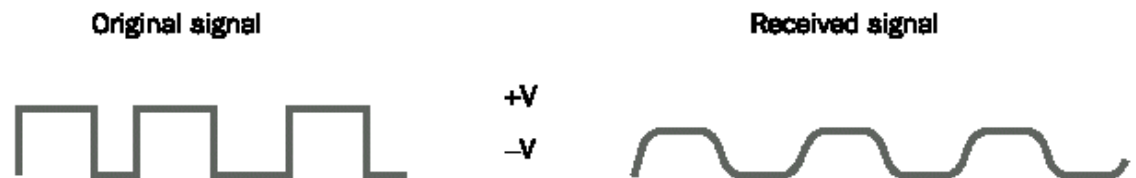
Attenuation is measured in dB (decibels) of signal loss. For every 3dB of signal loss, a signal loses 50 percent of its remaining strength. Attenuation can be measured by cable testers that inject signals with a known power level at one end of the line and measure the power level at the other end of the line.

Attenuation is fairly easy to understand. The illustration is primarily meant to show how cable testers graphically display the test values of cable over the entire frequency range against the TIA-rated values.

Attenuation increases with frequency, so 100Base-TX at 80 MHz has higher attenuation than 10Base-T at 10 MHz. Attenuation also increases with temperature, so cable installers may need to plan shorter cable runs in hot environments. Metal conduit also increases attenuation and should be considered when planning cable length. Cable vendors should provide you with technical specifications for their cables.

Capacitance

Capacitance is the ability of a material to store a charge. Copper cables have capacitance that can distort signals by storing some of the energy of a previous signal bit. Capacitance is a measure of the energy that a cable and its insulator can store. Adjoining wires in wire bundles also contribute to the capacitance of a wire. Cable testers can check capacitance values to determine if a cable has kinks or has been stretched. All cable has known capacitance values that are measured in pF (Pico farads). Twisted-pair wire used for network cabling is rated at 17-20 pF.

Impedance and Delay Distortion (Jitter)

A signal is prone to delay distortion caused by *impedance,* which is resistance that changes at different frequencies. It can cause the different-frequency components within a signal to arrive out of step at the receiver. The effect is more problematic on high-data-rate networks that use high frequencies. Impedance may change abruptly due to kinks and excessive bends in the cable, which cause *signal reflections* that, distort data. That leads to retransmissions and a loss in network performance. In the worst case, the network may not operate.

Different types of cable should not be mixed along the same signal path, since a change of impedance at the junction causes a signal reflection back to the source. On high-speed networks, a connector used to join two cables will almost certainly cause an impedance problem because of the untwisting of the wire pairs at the connector. Such connectors should never be used when high-performance networking is implemented over Category 5 cable.

Decreasing the cable length and/or lowering the transmission frequency may solve these problems. Note that the impedance value of a cable can be measured to detect breaks or faulty connections. Data-grade cable should have an impedance value of 100 ohms at the frequency used to transmit data.

Delay skew is a problem in networks that transmit on multiple pairs in the same direction at the same time, such as Gigabit Ethernet. It is caused when signals travel at different speeds in each of the wire pairs of a cable.

Noise

Transmission lines are susceptible to background noise generated by external sources. This noise combines with and distorts a transmitted signal. While noise may be minor, attenuation can enhance its effects. As shown here, the signal is higher than the noise level at the transmitter but is equal to the noise level at the receiver due to attenuation:
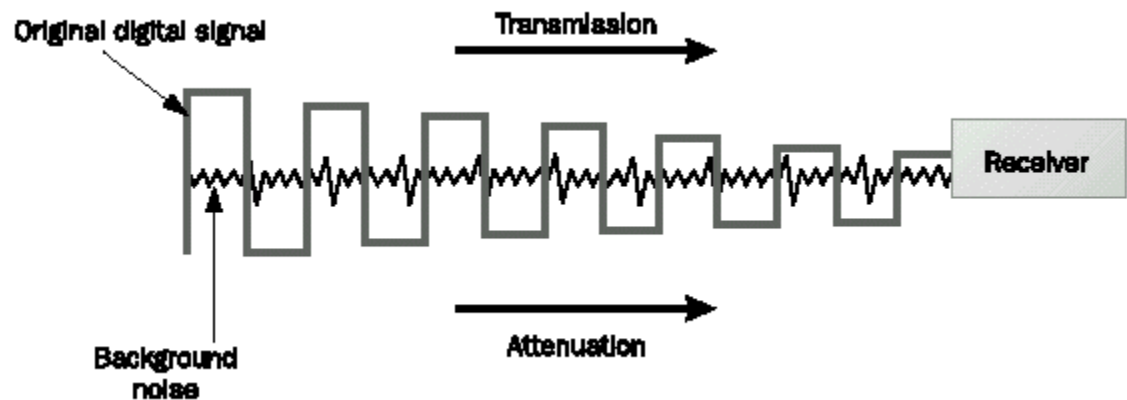
Ambient noise on digital circuits is caused by florescent lights, motors, microwave ovens, and office equipment such as computers, phones, and copiers. If noise is a

persistent problem in some areas, it can be avoided by running wire away from sources of noise, by trying shielded cable, or by using fiber-optic cable.

As mentioned, twisted-pair cable is supposed to form a balanced circuit where one wire in a pair is equal in amplitude but opposite in phase to the wire it is twisted with. If this characteristic changes due to cable distortion or other factors, the cable becomes unbalanced and starts acting like an antenna, picking up noise from all over, including machines, fluorescent lights, radio stations, and alien transmissions.

Inductance and NEXT (Near-End Crosstalk)
Inductance occurs when current flows on two adjacent metallic conductors. Electromagnetic fields created by the current flows can create signal distortions in adjoining wires. The biggest problem this creates is near-end cross talk (NEXT), which is basically the crossing over of a signal on one wire pair to another wire pair (electromagnetic disturbance). NEXT occurs near the transmitter and creates distortions that typically affect signals on adjacent receive pairs, as shown here:
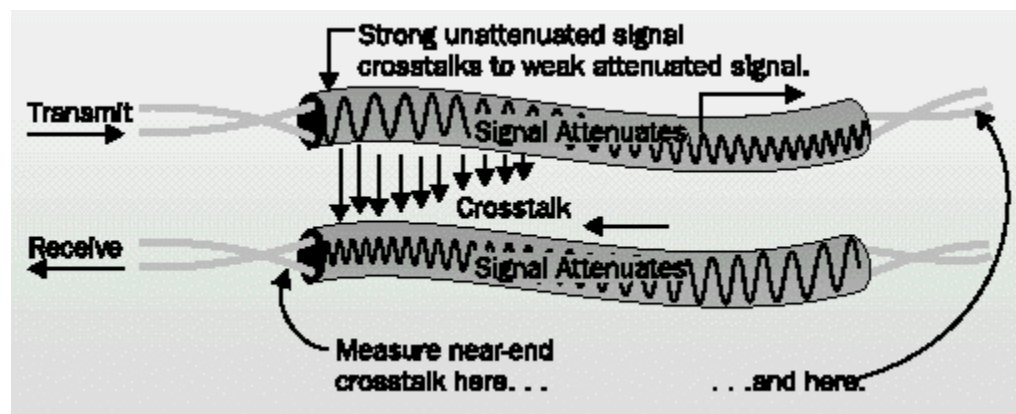
Note that strong fields from the transmit line may overwhelm the weak (attenuated) signal arriving on the receive line, which can lead to intermittent problems, lockups, or complete failure of the system. NEXT should be measured at both end of the cable.

A typical NEXT measurement is shown in the following illustration. This illustration is derived from a Fluke tester. NEXT is measured in dB, with higher values being better. Note that NEXT is measured for all frequencies between 0 and 100 MHz and that crosstalk varies across the spectrum. The lower line indicates the TIA minimum allowed value across the spectrum.
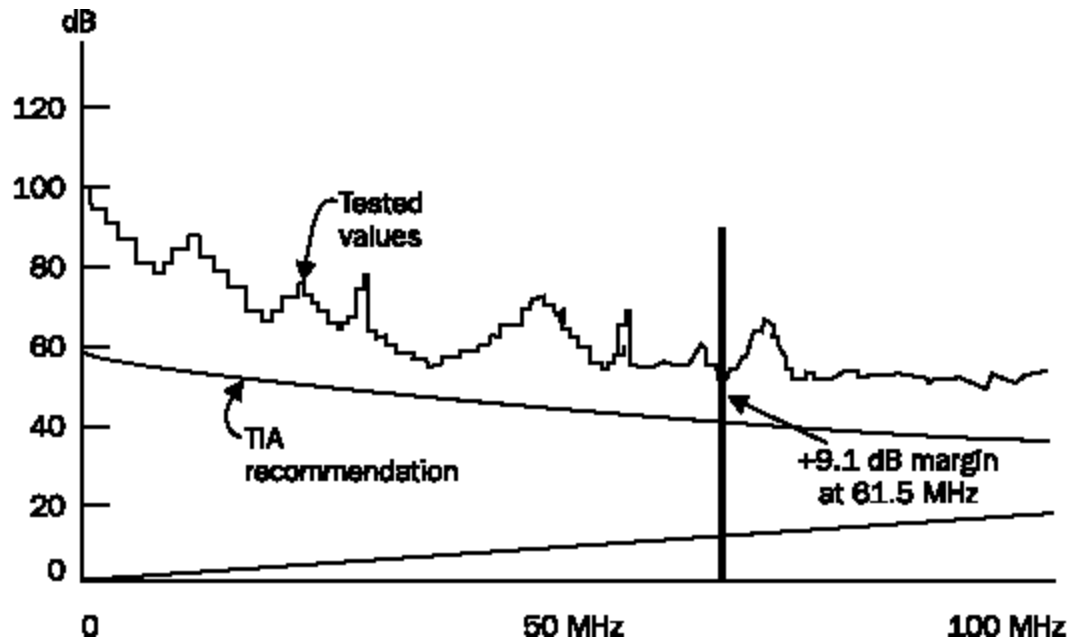
Twisting wire pairs is the primary method for reducing the effects of inductance, but the type of conductor and insulation also play a role. Twisting wire pairs cancels the positive and negative energy on the cable. Because of this, twists in cable must be preserved all the way up to the connection, especially on high-performance networks. In addition, wires cannot be untwisted more than one-half inch from their connection points.

NEXT is measured by injecting a signal on a wire pair and measuring its crosstalk on another wire pair. Every pair must be tested in this way. Fortunately, cable testers make this job easy and automatic. Keep in mind that NEXT refers to crosstalk at the near end, as the name implies. Crosstalk lessens down the cable as the signal strength weakens due to attenuation. However, this also implies that NEXT should be measured at both ends of a link.

FEXT (Far-End Crosstalk)
FEXT is a relatively new cable measurement requirement. It is a measure of the crosstalk noise that exists at the opposite end of a cable (at the receiver) and is only relevant on network technologies that transmit on multiple pairs in the same direction at the same time-that is, Gigabit Ethernet (1000Base-T). What happens is that crosstalk occurs between transmitters as signals are transmitted down the line.

FEXT can be tested by putting a test signal on one pair and measuring how much of that signal crosses over to the other pairs at the far end of the cable. You will often see FEXT discussed in terms of ELFEXT (equal-level far-end crosstalk). ELFEXT provides a standard way to measure far-end crosstalk no matter what the cable length, so that all cabling can be tested to the same certification levels.

ACR (Attenuation to Crosstalk Ratio)

ACR is the ratio at which crosstalk affects an attenuated signal. In other words, how much does the noise on the cable distort the signal I am receiving? If the noise is high, and the signal being received is attenuated, the bit error rate (BER) will be high and retransmissions will be necessary, which leads to a loss in network performance. ACR is important because it provides a useful indication of a cable's performance and is helpful when making purchasing decisions. High ACRs indicate high-capacity cables.

The ratio is calculated by dividing attenuation by NEXT. Most cable testers gather all the information about a cable and perform this calculation automatically. Figure C-4 illustrates the relationship between NEXT and attenuation.
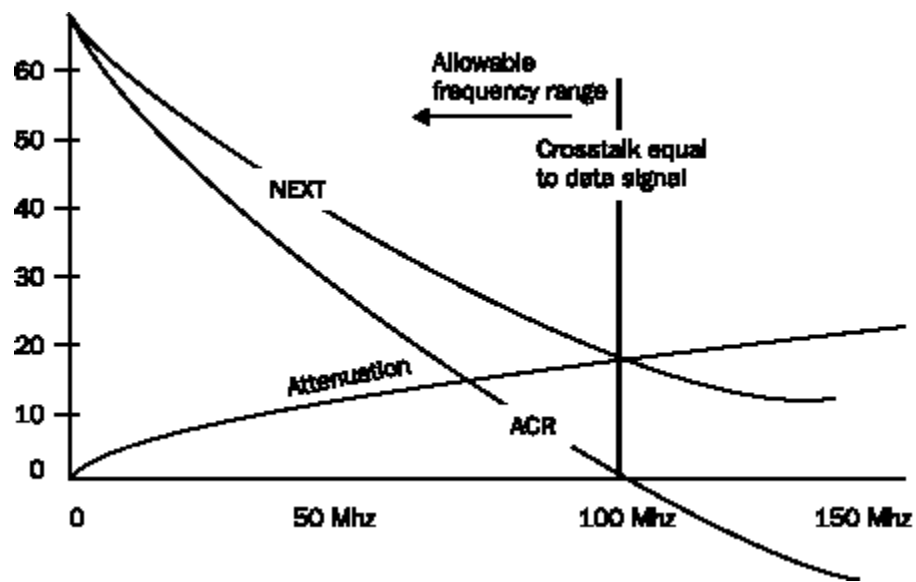
Note that at the point where NEXT and attenuation meet, the crosstalk and data signal are equal, and the crosstalk exceeds the signal strength at higher frequencies. A cable meter like that from Fluke will measure the ACR and compare it against a TIA limit for NEXT. The margins between the worst-case ACR and the TIA limit are outlined in the following table.

Parameter	Category 5	Proposed Category 5E	Proposed Category 6, Class E (Performance at 250 MHz Shown in Parentheses)	Proposed Category 7, Class F (Performance at 600 MHz Shown in Parentheses)
Specified frequency range	1-100 MHz	1-100 MHz	1-250 MHz	1-600 MHz
Attenuation	24 dB	24 dB	21.7 dB (36 dB)	20.8 dB (54.1 dB)
NEXT	27.1 dB	30.1 dB	39.9 dB (33.1 dB)	62.1 dB (51 dB)
Power-sum NEXT	Pending	27.1 dB	37.1 dB (30.2 dB)	59.1 dB (48 dB)
ACR	3.1 dB	6.1 dB	18.2 dB (-2.9 dB)	41.3 dB (-3.1 dB)
Power-sum ACR	N/A	3.1 dB	15.4 dB (-5.8 dB)	38.3 dB (-6.1 dB)
ELFEXT	17 dB	17.4 dB	23.2 dB (15.3 dB	Pending
Power-sum ELFEXT	14.4 dB	14.4 dB	3.2 dB (12.3 dB)	Pending
Return loss	8 dB	10 dB	12 dB (8 dB)	14.1 dB (8.7 dB)
Propagation delay	548 ns	548 ns	548 ns (546 ns)	500 for ns (501 ns)
Skew	50 ns	50 ns	50 ns	20 ns

Cable parameters

ACR (attenuation to crosstalk ratio) values for the above cable types are listed in the following table. Note that these values for Category 6 and Category 7 are still tentative. The table is meant to provide a comparison at this point in time. Always ensure that new cable is certified for the maximum bandwidth required. Category 5 and 5E cable should be tested at 100 MHz over a 100-meter cable. Category 6 should be tested at

Category 5 cable	6 to 10 dB ACR at 100 MHz
Category 6 cable	6 to 10 dB ACR at 130 MHz
Category 7 cable	6 to 10 dB ACR at up to 200 MHz

250 MHz over a 100-meter cable.

The ISO/IEC 11801 groups and the TIA TR42.1.2 committee have formulated category 6 and Category 7 specifications. One of the best places to find information on these specifications is http://cabletesting.com.

Cable Velocity of Propagation (VOP)

The following table lists many cable types and their associated VOP's (both straight and coiled).

Wire	VOP (range)	VOP (nominal)	VOP (flat)	VOP (coiled)
12/2 w/G Romex, Coiled or on a spool	63 to 75	-66-		
12/2 BX, Coiled	63 to 75	-65-		
14/3 BX, Coiled	63 to 75	-70-		
12/3 Orange Outdoor Extension Cord	55 to 60	-56-		
14/3 Orange Outdoor Extension Cord	55 to 60	-59-		
16/3 Orange Outdoor Extension Cord	55 to 60	-59-		
8 to 16 Guage THHN in Conduit (See Note 1)	74 to 84	-77-		
Belden 8737, 2 wire shielded, R/B			-48-	-45-
Belden 8737, 2 wire shielded, R/Shield			-55-	-53-
Belden 9114, RG-6/U 75 Ohm Coax			-78-	-78-
Belden 8216, RG-174/U			-64-	-64-
RG-58/U 50 Ohm Coax			-63-	-63-
RG-59/U 75 Ohm Coax			-63-	-72-
300 Ohm Black Foam Antenna Wire			-77-	-72-
300 Ohm Brown Antenna Wire			-77-	-67-
16 to 22 Gauge Speaker Wire			-77-	-58-
18 Gauge Twisted Bell Wire			-73-	-69-
Quad Flat Telephone Wire, Red/Green			-62-	-58-
CAT-5, Blue/White pair (See Note 2)			-66-	-66-

Note 1:	The VOP for THHN wires inside a conduit varies greatly based on the overall contents of the conduit For 8 to 16 guage wires in 1/2 inch to 1 inch conduit, the VOP is approximately 77, with a range of 70 (crowded) to 84 (sparse) depending on how crowded the conduit
Note 2:	With double twisted cables such as CAT-5, where the individual pairs are twisted around each other, the ength of each of the pairs is slightly different In CAT-5 cables, this difference from the shortest wire to he longest wire is approiximately 3%

Cable Installation Notes
Proper network operation depends on maintaining constant characteristic impedance throughout the system's cables and connectors. Abrupt changes in characteristic impedance, called impedance discontinuities or impedance anomalies, cause signals transmitted through 1-Wire cables and cause network faults.

Characteristic impedance is usually altered slightly by cable connections and terminations. Sharp binds or kinks in a cable can also alter the cable's characteristic impedance. Networks can operate with small discontinuities because the resulting signal reflections are small and are attenuated in the cable. Larger impedance discontinuities can interfere with data transmission. Such discontinuities are caused by poor electrical contacts, improper cable terminations, mismatched cable or connector types, and by disturbances in the twisting pattern of twisted pair cable.

You can avoid problems with impedance discontinuities by observing the following precautions during cable installation:

- Never mix cables with different characteristic impedance's (unless you use special impedance-matching circuitry.)

- When untwisting cable pairs to install connectors or make connections at punch-down blocks or screw terminals, make the untwisted sections as short as possible.

- Do not make sharp bends or kinks in the cable. The radius of bends in a cable should be larger than 1 inch (2.54 cm).

- Handle all cables carefully during installation. Do not step on the cable or pinch it with tight cable ties.

High-performance cable requires special handling procedures. The physical shape of the cable cannot be drastically altered, meaning that it should not be stretched, twisted, or bent beyond a radius that is 10 times the outside diameter of the cable. Figure 3 illustrates what can happen to wires that are excessively bent. The twisted pairs are pushed closer together, which causes signal interference between wire pairs and signal distortion.

Normal cable   Excessively bent or flattened cable

Potential crosstalk
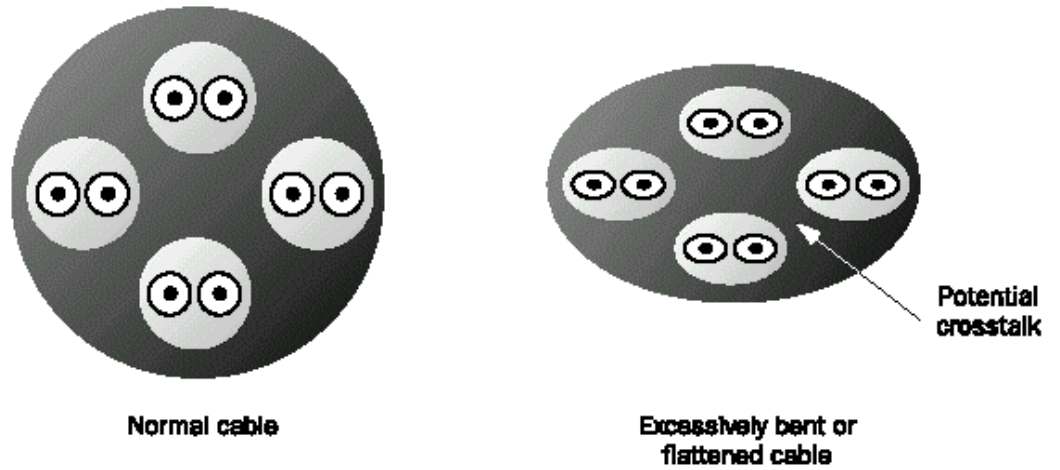
Figure 3

Cable quality may be poor if a cable manufacturer has substituted some material because another material is in short supply, as happened several years ago during the worldwide shortage of FEP (Fluorinated Ethylene-Propylene Teflon). According to Anixter, there now exist more than 45 plenum and non-plenum cable designs that exhibit varying electrical performance characteristics but are still labeled Category 5 compliant. Look for low capacitance and good ACR values.

Word Definitions

1-Wire - A single-wire (plus ground) communications protocol.

A - Ampere(s), the unit of electrical current. (A unit of measurement)

AMP - Ampere(s), a unit of electrical current or the rate of flow of electrons through a conductor. One volt across one ohm of resistance causes a current flow of one ampere. One ampere equals 6.25 x 1018 electrons per second passing a given point in a circuit; abbreviated amp. Named after the scientist Andre Marie Ampere, who did studies with electricity and magnetism.

AC - Alternating current: A signal or power source that varies with time, switching polarities.

ANSI - American National Standards Institute

AWG - American wire gauge

BER - Bit Error Rate: A measure of the number of erroneous bits, which can be expected in a specified number of bits in a serial stream.

Bidirectional - The device accommodates signals traveling either direction though a single channel.

C - Capacitance, capacitor; coulomb (A unit of measurement)

Capacitance - The property of an electric nonconductor that permits the storage of energy as a result of electric displacement when opposite surfaces of the nonconductor are maintained at a difference of potential. In a capacitor, capacitance is the measure of the property (the amount of charge that can be stored) equal to the ratio of the charge on either surface to the potential difference between the surfaces.

Capacitive Crosstalk - A phenomenon where a signal on one line/trace is capacitively coupled to an adjacent line/trace.

Cm - Centimeter: (A unit of measurement) 1/100 of a meter, 0.39 inches.

CMOS - Complementary metal-oxide semiconductor

Crosstalk - Signals or noise induced onto other lines. Crosstalk increases bit-error rate Reflections on an improperly terminated transmission line cause larger voltages and currents, which radiate larger electric and magnetic fields and transfer more crosstalk energy into neighboring wires.

Data Sample Offset/Recovery Time – This parameter defines when the data from slaves will be sampled. If this parameter is too short, the line may not have sufficient time to rise to a valid high level before the sample occurs. If this time is too long, then slaves operating near the fast end of their range may be misread. This parameter also defines the time between bits, during which time the parasitic capacitors in the slaves must recharge.

DB - Decibels: A method for specifying the ratio of two signals.

> DB=10 times the log of the ratio of the power of the two signals. This is equal to 20 times the ratio of their voltages, if the signals are driving equal impedances.

> Decibels are also used to describe a signal level by comparing it to a reference level. The reference is usually defined as 0dB and the dB value of the signal is 10 times the log of the signal's power over that of the reference. A letter is sometimes added to signify the reference. For instance, dBm is relative to 0 dBm=1mW.

DC - Direct current. An electric current flowing in one direction only.

Diode - The diode is the simplest and most fundamental non-linear circuit element. It is a two terminal device, which only allows current to flow in one direction (low resistance) and to block current in the opposite direction (high resistance). As a semiconductor that consists of a p-n junction it exhibits a non-linear current-voltage characteristic.

EEPROM - Electrically erasable programmable read-only memory

EIA - Electronic Industries Alliance: Among other things, the EIA sponsors electrical and electronic standards.

EMI - Electromagnetic Interference: Unwanted noise from electromagnetic radiation.

EPROM - Erasable programmable read-only memory

ESD - Electrostatic Discharge: Release of stored static electricity. Most commonly: The potentially damaging discharge of many thousands of volts that occurs when an electronic device is touched by a charged body.

> See the following application notes that describe how ESD is generated, how it damages electronic systems, human body and machine models for testing, IEC compliance levels, and design approaches.
>
> • [App note: Maxim Leads the Way in ESD Protection](#)

- App note: ESD Protection for I/O Ports

ESD Protection - Devices added to input and output pins on an IC to protect the internal circuitry from the damaging effect of electrostatic discharge.

ESR - Effective/Equivalent Series Resistance is the effective series resistance in a capacitor.

Farad - The unit of capacitance in the meter-kilogram-second system equal to the capacitance of a capacitor having an equal and opposite charge of 1 coulomb on each plate and a potential difference of 1 volt between the plates

FET - Field-Effect Transistor: A transistor in which the voltage on one terminal (the gate) creates a field that allows or disallows conduction between the other two terminals (the source and drain).

Full Duplex - A channel providing simultaneous transmission in both directions.

Glitch - General term used to describe an undesirable, momentary pulse or unexpected input or output

GPIO - General Purpose I/O: A flexible parallel interface that allows a variety of custom connections.

Ground Loops - A ground loop occurs when there is more than one ground connection path between two pieces of equipment. The duplicate ground paths form the equivalent of a loop antenna, which very efficiently picks up interference currents. Lead resistance transforms these currents into voltage fluctuations. As a consequence of ground loop induced voltages, the ground reference in the system is no longer a stable potential, so signals ride on the noise. The noise becomes part of the program signal.

Half-Duplex - Data transmission over a circuit capable of transmitting in either direction, but not simultaneously.

Hz - Hertz: A measure of frequency. An older term is cycles per second, or cps.

I/O - Input/output

IC - Integrated circuit: A semiconductor device that combines multiple transistors and other components and interconnects on a single piece of semiconductor material.

IEEE - A professional organization.

> From http://www.ieee.org/: "The IEEE (Eye-triple-E) is a non-profit, technical professional association of more than 360,000 individual members in approximately 175 countries. The full name

DESIGN GUIDE – INTRODUCTION TO 1-WIRE NETWORK ISSUES

is the Institute of Electrical and Electronics Engineers, Inc., although the organization is most popularly known and referred to by the letters I-E-E-E." IEEE also sponsors many electrical and electronic standards.

Impedance - The combined effect of capacitance, inductance, and resistance on a signal. According to Ohm's law, voltage is the product of current and resistance at a given frequency. Impedance is a measure of resistance to electrical current flow when a voltage is moved across it. Impedance is measured in ohms and is the ratio of voltage to the flow of current allowed.

Inductance - (L), In general, the ability of a conductor to produce a magnetic field. In particular, magnetic flux divided by current, measured in henries (H). L=F/I. Or, the voltage (back emf) a conductor generates divided by rate of change of current in that conductor (self inductance) or another conductor (mutual inductance). L= -V/(dI/dt), where dI/dt is the rate of current change.

Inverted Logic – In an inverted logic the default logic state is a high or 1 state, this is the idle state of the 1-wire bus. When nothing is going on this is the logic state of the bus.

ISO - International Standards Organization

k - Kilo: Metric unit representing 1000. E.g.: 1 kHz is a 1 kilohertz (1000 Hertz). Note that the k is always lowercase

mA - Milliampere(s), a unit of electrical current. (A unit of measurement)

MHz – Megahertz

MicroLAN - A 1-Wire network. A low-cost network, in which PCs or micro-controllers communicate digitally over twisted-pair cable using 1-Wire components.

MOSFET - Metal-oxide semiconductor field-effect transistor; metal-oxide silicon field-effect transmitter

Murphy's Law - "Anything that can go wrong, will."

nA - Nanoampere(s), One billionth (10^9 of a ampere of electrical current. (A unit of measurement)

Nanosecond - One billionth (10^9) of a second

Noise – Noise is any signal other than the desired signal. 1-Wire signals have a limited noise margin in that small amounts of noise on the signal can cause false triggering of

the devices from non-monotonic edges. This is especially true on the rising edge, where added noise can multiple clocking of a slave device. So reduced noise margins increases bit-error rate. In certain configurations, improperly terminated lines cause half- or less-than full- amplitude signal levels to exist during transition periods. A small noise pulse can carry a signal that is at less than the final amplitude level across the threshold, where it can appear as false data or can cause false triggering. Switching power supplies are a possible source of this noise.

Overshoot – When the signal exceeds the high-level steady state overshoot can exceed maximum-IC-voltage ratings. A reflection can cause a voltage to rise above or, because of negative overshoot, fall below the minimum or maximum rating. When the excessive voltage persists for more than a trivial amount of time, the IC is overstressed and may latch up. Latch-up can cause temporary or permanent damage to the IC. (Latch-up is the result of a parasitic NPN transistor that causes a CMOS circuit to cease functioning or even to destroy it self.)

pF - Pico farad(s) One trillionth (10^{-12}) of a farad

PoE - Power-over-Ethernet: A means for delivering power to a remote device using the same cable lines used to deliver Ethernet data.

Pull-Down Slew Rate Control – This is the rate at which the bus is pulled from a high level to a low level. Excessively fast fall times (high slew rates) cause ringing and generate unwanted signals on the 1-Wire bus that may interfere with valid data waveforms. Excessively slow rise and fall times may not meet timing requirements, and may expose the transition period to the effects of noise and reflections.

Resistance - In dc circuits, the opposition a material offers to current flow, measured in ohms. In ac circuits, resistance is the real component of impedance and may be higher than the value measured at dc.

Rx – Receive

Schottky Diode - In its simplest form, a Schottky diode consists of a metal layer, which contacts a semiconductor element. The metal/semiconductor junctions exhibit rectifying behavior (i.e. the current passes through the structure more readily with one polarity than the other). Unfortunately, the fabrication of conventional metal/semiconductor structures often results in chemical damage at the interface between the two layers. This leads to non-ideal device performance characteristics. Recently, researchers have found that conductive polymer structures can be utilized to replace the metal layer, thereby yielding more ideal devices

Temperature - The average kinetic energy of the atoms or molecules of a body or substance, perceived as warmth or coldness. Temperature may be expressed in degrees Fahrenheit, Celsius, or Kelvin.

Transceivers - A device that contains both a transmitter and receiver.

Transistor - A basic solid-state control device invented in 1947, which allows or disallows current flow between two terminals, based on the voltage or current delivered to a third terminal.

Transmission lines - A cable interconnect is considered electrically long when the round trip propagation delay of the signal from the driver to the load is equal to or greater than the transition time of the driver's rise or fall time. At this point, transmission line effects become significant. And the line is considered to be working in a transmission line environment.

TTL - Transistor-transistor logic. TTL logic levels are 0V (low) and +5V (high). The TTL switching threshold is around +1.3V (+2V max).

Twisted pair cable - The type of cable used for most telephone wiring. It has pairs of copper wires twisted together, to minimize electrical noise. There are shielded twisted pair (STP) and unshielded twisted pair (UTP) cables. In shielded twisted pair cables, each pair has a metal sheath around it for better protection against interference. Unshielded twisted pair lacks the sheath, but has the advantage of being more flexible and thinner.

Tx – Transmit. To cause a disturbance or signal to propagate through a medium.

Undershoot - Transient change in an output voltage that does not meet the lower limit of the voltage accuracy specification.
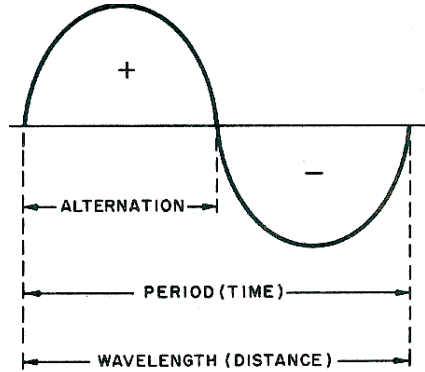
USB - Universal Serial Bus: A standard port that enables you to connect external devices (such as digital cameras, scanners, and mice) to computers. The USB standard supports data transfer rates of 12Mbps (million bits per second).

V - Volt(s) The International System unit of electric potential and electromotive force, equal to the difference of electric potential between two points on a conducting wire carrying a constant current of one ampere when the power dissipated between the points is one watt

VOP - Velocity of propagation is the speed of signal transmission relative to the speed of light. Since it is inversely proportional to the square root of the dielectric constant, a lower dielectric constant will result in an increase in velocity. Velocity of propagation is expressed as a percentage of the speed of light in a vacuum and can be calculated by the following formula:

$$V_p\,(\%) = \left(1 \middle/ \sqrt{\varepsilon_r}\right) \times 100$$

Wavelength - indicated by the λ (Greek lambda), is the distance along the waveform from one point to the same point on the next cycle. You can observe this relationship by examining the image below.

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                        +

                       −

|←— ALTERNATION —→|
|←——————— PERIOD (TIME) ———————→|
|←——————— WAVELENGTH (DISTANCE) ———————→|
```

Write-One Low Time - This is the length of the low-going pulse that begins each time slot. If this pulse is too narrow, the end of a long line may never reach valid low levels before the pulse is ended.

Final thoughts - A General Remark
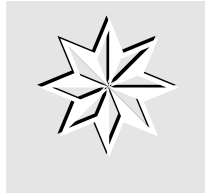
The ideas presented in this document are part of Springbok Digitronics efforts to share and distribute knowledge among the 1-Wire community. Much of the background data has been collected from a wide variety of resources. We wish to thank in particular Dan Awtrey for his many 1-Wire application notes when the was at Dallas Semiconductor and for sharing his own private papers which act as the heart of this paper, and for the editing and valuable comments and other additions of Kelly Smith. This paper could not have been written without their help.

Contact info to the authors and contributors

Dan Awtrey –

Independent Consultant

Email address: mailto:dawtrey@1wire.org

Kelly Smith –

Independent TINI and 1-Wire Consultant

Email address: mailto:bebop1@earthlink.

David Lissiuk –

Sr. Computer Scientist, Springbok Digitronics

Acting admin of www.1wire.org

Email address: mailto:admin@1wire.org