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TecNote 3032 - Modem Communications Basic Settings

The primary building block of any ATMS system is its communication platform. Many legacy systems rely on simple modem communications schemes including dial-up from a central computer as well as hardwire interconnect between field devices. The purpose of this TecNote is to explain modem basics as well as offer the user advice on setting up hardwire field communications (including proper grounding techniques).

The TecNote covers basic information as it pertains to hardwire modems that utilize a Frequency Shift Keying (FSK) scheme. It is meant to accompany the manufacturer provided manual that discusses the detailed specifications for the modem being utilized.

Modem Basics

Modulation/Demodulation

A modem is simply a device to transfer information from one transmission medium to another. The word modem is derived from the words ***mod***ulate and ***dem***odulate. Information passes into the modem from a computer, it is then modulated for the transmission line and then passed over that line. A modem at the other end of the line receives the data, demodulates it, and passes it on to the computer.

Frequency Shift Keying (FSK)

A common form of modulation used for hardwire modems is Frequency Shift Keying (FSK). In an FSK scheme, two different frequencies are transmitted to represent a '1' and '0' data bit. The '1' bit is referred to as a Mark, and the '0' bit is referred to as a Space. An additional frequency provided in FSK schemes is a Carrier. The Carrier is a frequency that differs from the Mark and Space frequencies. The Carrier is used to balance the transmission line, and to alert other modems on the line of the pending transmission.

Modem Control Signals

Modems also have a variety of control signals that are used for controlling the timing of communications. The Data Terminal Equipment (**DTE**, i.e. Controller, PC) can not arbitrarily force the Data Communication Equipment (**DCE**, Modem) to put data on the transmission line. This is where the control signals provide handshaking so the **DCE** can arbitrate transmission. The following signals are described from the **DCE** (Modem) point of view

- **TX** (Transmit) Line used to transmit data from the **DTE** to the **DCE**

- **RX** (Receieve) Line used to transmit data from the **DCE** to the **DTE**

- **CTS** (Clear To Send) Indicates to **DTE** that it is clear to put data on the **TX** line

- **RTS** (Request To Send) Indicates to the **DCE** that the **DTE** has data to put on the **TX** line

- **CD** (Carry Detect) Indicates that a modem is transmitting on the line

Transmission Protocol Sequence

The Modem utilizes the above signals to coordinate communications. There is a very strict protocol that guarantees successful communications. If this protocol is not obeyed, communications may be corrupted.

The following list details this sequence for a Half Duplex (2-Wire) System, since it is the most rigorous. It first starts with what occurs at the originating location, then list what occurs at the secondary location in parallel.

The Originating Point (Master/Central PC)

1. **DTE** (PC/Controller) applies signal the **RTS** on the **DCE** (Modem) indicating a need to transmit
2. **DCE** applies the Carrier to the transmission line, to balance it and prepare other modems for the data.
3. **DCE** applies signal to **CTS** on the **DTE** indicating that it is clear to start transmitting data
4. **DTE** has been Marking, so the **DCE** transmits the Mark frequency
5. **DTE** sends out byte, thus alternating between Marks and Spaces, the modem transmits the correlating data.
6. **DTE** completes transmission of message and deactivates the **RTS** to the **DCE**

The Receiving Point (Secondary Controller)

1. No correlating action
2. **DCE** activates **CD** to the **DTE** indicating that a modem is on the line
3. No correlating action
4. **DCE** sets the **RX** line to a '1' in accordance to the Marking of the line
5. **DCE** toggles the **RX** line in accordance to the reception of Mark and Space frequencies

6. **DCE** deactivates **CD** to the **DTE**, indicating that a modem is no longer on the line

As stated before, if the modems do not, or are not permitted to operate in such a manner, data will be corrupted.

Transmission Line Characteristics

Parameters and Characteristics

A transmission line is a very complex system whose behavior is determined by a wide arrays of parameters. The responsibility to the transmission line is to pass information with minimum distortion. Distortion can be introduce by a variety of sources ranging from environment to the dielectric surrounding the wire. The following list describes basic parameters and characteristics that are further discussed in this section.

☞ **Characteristic Impedance:** Transmission lines are described by distributed parameters, such as capacitance, inductance, and resistance per foot. The characteristic impedance is a function of these parameters. It indicates the load as seen by the transmitting device.

☞ **Bandwidth:** Bandwidth denotes the range of frequencies that may be transmitted along a line without significant signal strength loss. It is usually denoted by two frequencies; however, when only one is identified, it is assumed that the other is 0 Hertz. Typical transmission lines tend to decrease relative signal strength as the frequency of the signal increases.

☞ **Reflected Waves:** Reflected energy, or reflected waves is a phenomenon created by a propagating signal reaching the end of a transmission line. The energy in the signal must be absorbed, or it is reflected at the line's end, and propagates back down the line toward the originating point. The reflected energy can combine with the transmitted signal, and corrupt the data.

☞ **Cross-Talk:** Cross-Talk is energy that is coupled from one transmission line to another, thus imparting a signal onto it, that may either corrupt a signal already on the line, or cause false reception of data by devices listening on the line

☞ **Noise:** Noise is energy from the environment that is coupled onto a transmission line that has a tendency to corrupt the data signal

☞ **Termination:** Termination is the application of a load at the end of a transmission line for the purpose of absorbing energy to prevent reflected waves.

☞ **Shielding:** Shielding is a protection measure against noise. It consists or wrapping the transmission lines in a conductive foil, so that stray energy around the transmission line will be routed to ground via the shielding, as opposed to inducing a signal onto the transmission line.

Characteristic Impedance

Transmission lines have a certain amount of capacitance, inductance, and resistance associated with each unit of linear measure (per foot). The distance of the conductors from each other, the size of the conductor, and the dielectric constant are used to calculate these parameters. From these measurements it is possible to acquire the characteristic impedance of the line.

The characteristic impedance is the same at any point on the transmission line. While the total capacitance may vary depending upon the length of the line, the impedance does not change. Impedance itself is a sort of dynamic characteristic since it is a combination of reactance and resistance that vary relative to frequency.

Knowing the characteristic impedance tells the value required for the source impedance and the load impedance. Matching impedance determines the amount of energy that will be transferred from the source to the transmission line, and from the transmission line to the load.

Minimizing reflection is done by matching the load impedance with the impedance of the transmission line. However, typical traffic installations rarely hold the characteristic of the line due to multiple termination points, and splices in the line. Many modems are equipped with a terminating resistor (Naztec modems typically incorporate 600-Ohm), it is typical that they are only engaged on an as needed basis, or only the end of the line modem engages the terminator.

Although 600-Ohm impedance is typical, it may not necessarily be what every agency has installed. Therefore, before blindly engaging the terminating resistor, check the cable specifications. Applying the incorrect terminator can have both effects -- excessive dampening of the signal, and creating reflection. If the resistance of the agency's cable varies from 600-Ohm, then use the alternative of applying a resistor of the correct value across the connections on the termination panel.

The option of applying a resistor separate from the one supplied inside the modem, allows the user the flexibility of matching whatever impedance the line may have. However, one word of caution about varying greatly from 600-Ohm, the drivers of the modem are optimized for a load impedance of 600-Ohm. The drivers have the capability of driving much lower loads, but it is best to specify 600-Ohm cable.

Another situation that is not commonly thought of with characteristic impedance, is when cable is spliced. If cables of different characteristic impedance are spliced, it is possible that the splice will become a source of reflections. Aerial cables, and bury-able when spliced together can provide sources of mismatched impedance.

Bandwidth

Transmission lines are also characterized by their bandwidth. In transmission lines, bandwidth is commonly indicated as the highest frequency the cable can pass without attenuating more than 50% of the signal's power.

Typically, as the frequency of transmission increases, the lower the signal strength at the receiving end -- this is the attenuating (dampening) effect of the transmission line. However, the bandwidth is only a limitation if the receiving modem is not capable of filtering the desired signal out from the noise. As a matter of practice, it is advised that the bandwidth of the transmission line be able to accept the frequency range of the modems. In the case of Naztec modems, a bandwidth of 20KHz will provide a 10% safety margin.

There are other limiting factors on bandwidth beside the manufacturer's specifications. Anything that modifies the cable from its original form is a source for change. Some common items are splicing, terminations at comm-panels, worn insulation, and water seepage into the cable jacket. Although these items may not eliminate the utility of the cable, over time they can worsen, or a combination of items can render a transmission line useless. The best option is prevention, such as water-proofing splices, and watching for worn insulation while pulling lines.

Reflected Waves & Termination

As seen in the section on characteristic impedance, reflected waves and termination go hand in hand. Essentially, a reflected wave is cause by energy not absorbed into a load. Take the example of a wire with an open end. When the signal propagates to the end of the line, there is no load to absorb the signal; therefore, the signal proceeds to head back down the transmission line towards the signal's origin, hence reflection.

Reflection can have a devastating effect on signals received by modems between the end points on a transmission line. A reflective wave is an additive signal. This means that the signal coming from the origin and the reflected signal can combine to form a new signal. The filtering on the modem is designed to pass just the frequencies of interest; however, a reflected wave also contains frequencies of interest to the receiving modem since it came from a legitimate signal. The combined signal creates a new signal that is in the accepted frequency range of the modem, and therefore the signal is essentially scrambled.

Applying terminating resistors at the end of each transmission stub, and matching impedance between two spliced cables are the only common ways to eliminate reflection.

Noise & Shielding

The most detrimental form of interference is noise. Noise is a generic word that implies any unwanted signal. There is never just one source of noise. Noise can be generated from nearby radio towers, radio equipment in passing vehicles, other lines that share the cable or conduit, and 60Hz from adjacent power lines.

The most effective guard against noise is using twisted pair cable, and shielding. Twisted pair cable is effective because the noise is induced equally on both lines. In some cases, the twist allows the cancellation of noise, and in all cases, common mode noise does not effect the differential information on the line. Therefore, if the receiving modem is able to handle the common mode noise, then the signal can be extracted successfully.

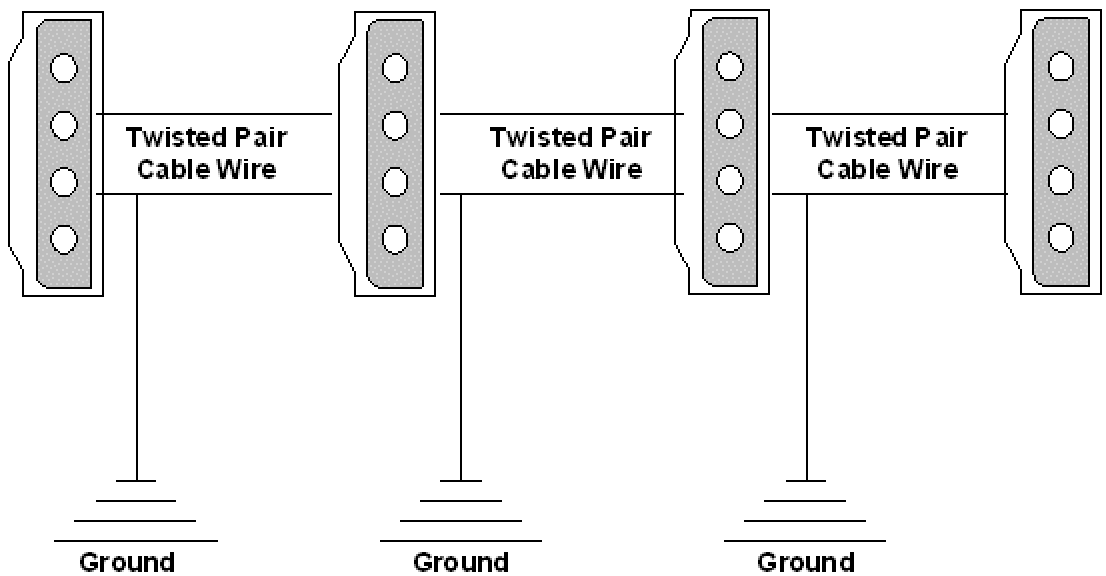
Common mode noise presents its own hazards. As stated before, common mode noise is not a problem, if the modem can handle it. Every modem has a limitation, and this limit is best expressed as a noise to signal ratio. Typically, you do not want the magnitude of noise on the line to be greater than 10% of the incoming signal. This denotes a signal to noise ratio of 10 (for every Volt of signal, 100mV of noise is acceptable). The best example of common mode noise is an induced 60Hz signal from adjacent power lines.

Noise, and the signal itself, can also overdrive the modem filter. If the incoming waveform is of a sizeable amplitude, the op-amps inside the filter will reach their rail (the supply voltages), at which point there is no more dynamic range to perform its function.

Another option for noise reduction is shielding. Shielding is usually a metal foil wrapper that encompasses the conductor. External radiation strikes the foil and conducts. The shield is grounded at a single point, so the induced signal travels through the shield to ground.

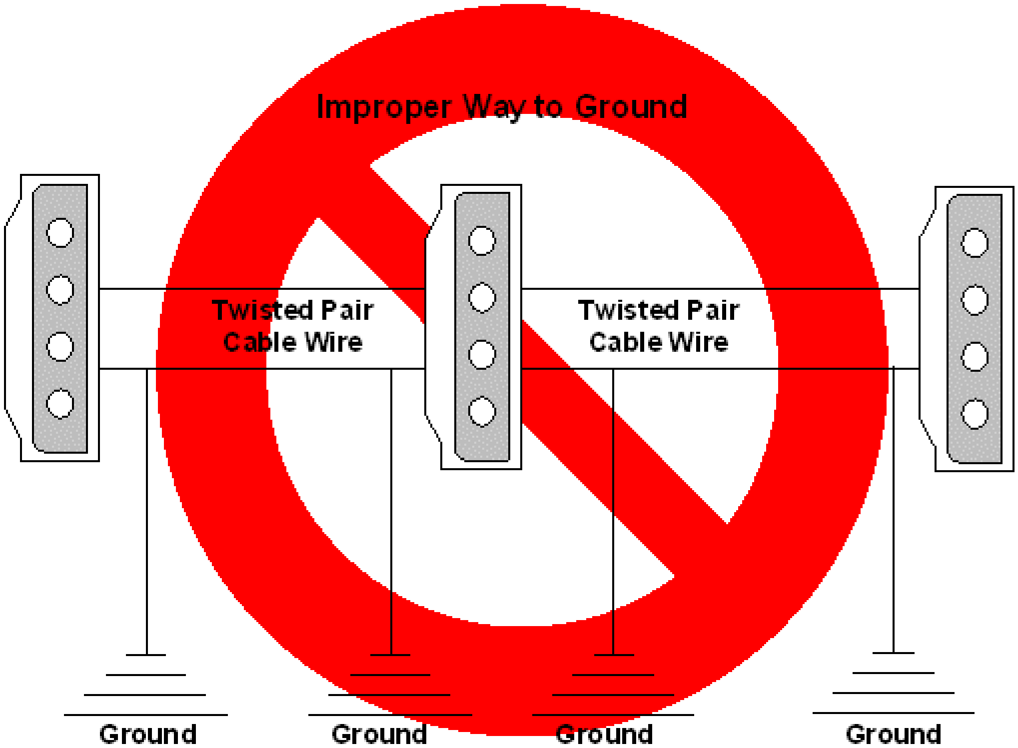
It is key that a shield only be grounded at a single point. Any two bodies have differences in their electric potential, and grounds that are separated by hundreds or thousands of feet are also not at the same potential. Therefore, if the shield is grounded at two points, the potential difference between the two point will create a current flow through the shield at the frequency determined by the differences of the points. The oscillation in turn will induce noise onto the signal wires.

A Proper Way to Ground



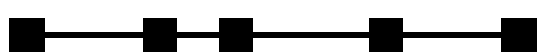
In the diagram above, the agency has decided to be consistent by grounding each cable as it exits each modem (or signal cabinet.).

The diagram below depicts an improper way to ground your communication cables that will result in a Ground Loop and Communications errors. Here



Modem Network Configurations

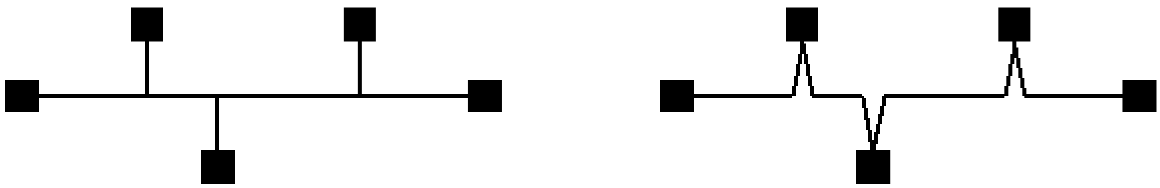
Straight Lines
A line configuration is the most common configuration for hardwire modem networks in the transportation industry. This is probably due to the fact that most closed loop system operate on a single arterial, and do not affect cross streets. A line configuration does not necessarily mean the Master controller is at one end.



Straight Line

A straight line is the simplest form to stabilize. Since there are only two end to the line, termination can be simply applied at these points. Also, when the Master is at the end of one of the lines, if the rate of polling of the secondaries is low, then reflection from the Master end is not of concern, since the reflected energy will be dissipated by the time another Secondary is polled. **In this configuration, simply applying termination resistors to the two ends will suffice.**

Stars and Stubs
Another configuration is a star, or a line with many stubs. This configuration is used when secondary units are also present off the main path. A configuration with many stubs can present immense opportunity for reflective noise. In this format, it is advised that each stub be terminated with the appropriate resistor.
A user does not have to have a system with stubs to gain access to intersections that may be off the main path. The alternative is to simple have a straight line configuration with some excursions.

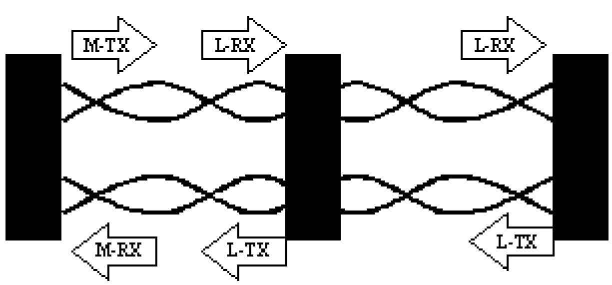


Stub Configuration

Alternate to Stub

A word of caution, however. In the alternate configuration, notice that the total length of the transmission line increases by twice the sum of all the stub lengths. This needs to be considered, because controlling reflection can be accomplished, while a signal that has been completely attenuated is not recoverable.
If an alternate to a stub is utilized, and the increased line distance becomes a problem, hardware such as line amplifiers can be placed in the system to boost the signal.

Full Duplex (4-wire)
A full-duplex system uses two twisted pairs (4 wires). As depicted, one pair is dedicate as the master's transmit pair, and the other as the local unit's transmit pair.



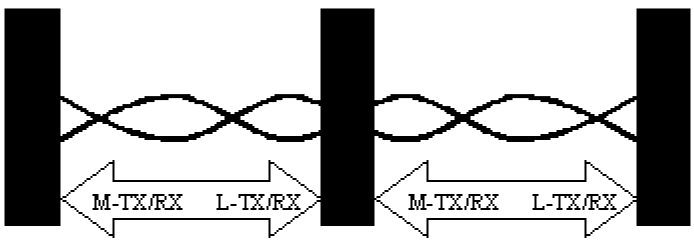
Full-Duplex Configuration

In this configuration, the master modem (the one on the farthest left), has a single pair dedicated to its transmission. The local modems (center, right) utilize the master's transmit pair only for receiving. Because the master is the only unit transmitting on this pair, it is acceptable for the unit to be constantly driving the line (**RTS**/**CTS** active). In fact, by constantly asserting the **RTS** signal, the turn around time that it usually experienced in waiting for the **CTS** signal is eliminating. This can produce an observable difference in data throughput.

While the master is allotted its own transmit pair, the local units must share a transmit pair. Therefore, the local units may not have their **RTS**/**CTS** constantly activated. The local units must take turns using the second transmit pair. If the more than one unit attempts to transmit at a time, then the data is instantly lost in the collision.

While in the field, if the **RTS**/**CTS** LED indicators are active on the master modem, then all of the secondary modems should have their **CD** LED indicators active. This tells the user that the master modem is marking the line (**RTS**/**CTS**), and that the local modems are detecting the carrier (**CD**). Likewise, when a local modem's **RTS**/**CTS** LED indicators are active, then the master's **CD** LED indicator should light accordingly.

Half Duplex (2-wire)
Half-duplex operation uses a single twisted pair of wire (2 wires). In this configuration, both the master and local modems share the same twisted pair from transmission and reception.



Half-Duplex Configuration

Unlike full-duplex, neither the master nor the local modems should assert **RTS** simultaneously. This, obviously, is due to the fact that when **RTS**/**CTS** is activated, the modem is driving the line, and if more than one modem is driving a single pair, then there will be a data collision.

While in the field, the user should only see a single modem, either local or master, light the **RTS**/CTS indicators, at which time, all other modems in the system will light the CD indicator to display that the carrier has been detected.

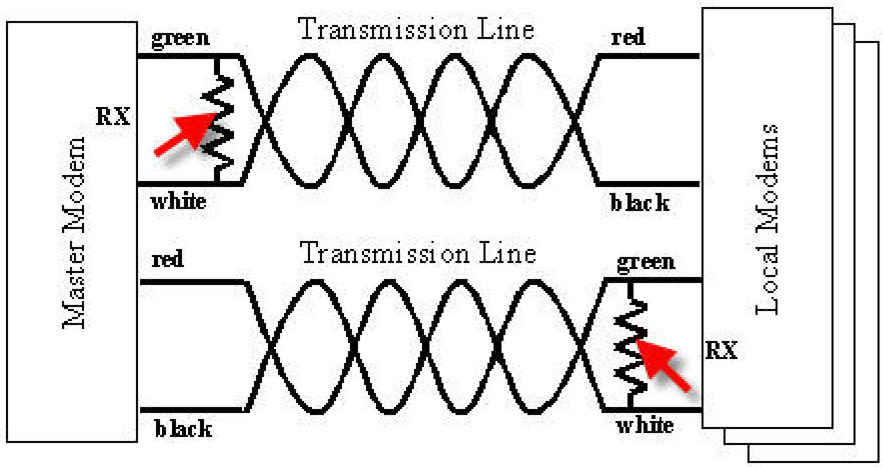
Termination

As previously discussed, terminating the transmission line is necessary to eliminate reflections on stubs. These reflections can combine with other signals on the line, thus corrupting the data. Elimination of reflections in a half-duplex system is especially important, since the same pair that was used to transmit data must be immediately able to re-transmit data to the master.

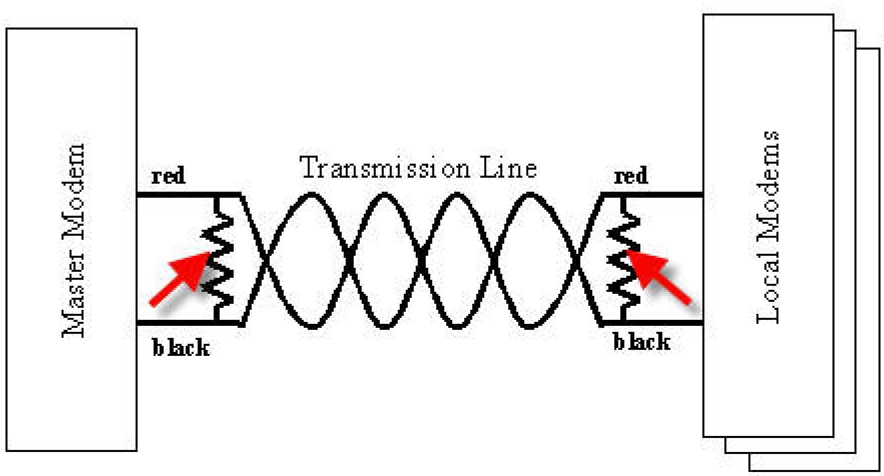
The value of the terminating resistor should match the impedance of the transmission line. Doing so will maximize imparted energy, thus reducing reflected energy.

The following pictures illustrate the proper placement of resistors for termination.

Full Duplex
In a full duplex system, only the receiving pairs should be terminated in the characteristic impedance of the line using resistors as indicated by the red arrows.



Half Duplex
In a half duplex system, both ends of the pairs should be terminated in the characteristic impedance of the line using resistors as indicated by the red arrows..



Simple Debugging Tests

The following are simple tests that can be used to debug field communications problems. Refer to the specific modem manufacturer's procedures for detailed testing.

Hardwire Modem Transmission Line Analysis

In all communications cable, a specification is provided which gives a plot of Decibel (Db) loss per 1000ft of cable at a certain frequency. Most cable will not carry frequencies in excess of 1 mega-hertz over large distances. For example, the Naztec 9600 baud modem uses two frequencies of 10khz and 18khz. Before beginning testing, the user should gather this info about their infrastructure

Twisted Pair Assignments using Full Duplex

In all Communication cable, each cable comes with pairs of wires which are twisted together at about 20 to 30 twists per foot. Many modems, including the Naztec modem works better when using two of these pair and operating in a full duplex mode. One pair is always assigned as the receive pair and the other is assigned as the transmit pair. This assignment is made at the master modem on multi-drop connection because all of the local modems receive on the master's assigned transmit pair and transmit on the master's assigned receive pair.

Because there is only one master modem, the transmit line is normally has an active carrier all of the time. When operating with an active carrier, the turnaround time on the master modem is decreased because the transmit line does not have to be electrically charged.

Testing for Continuity

A Continuity test insures that each pair in the cable is continuous for the entire length of the run. The continuity test is begun at the master modem by first placing the ohmmeter on the kilo ohm scale and placing the probe between the two wires of each pair. The reading after about 30 seconds of holding the probes on the wires should be infinite or "open" for each pair.

When the above test is completed, a technician should go to farthest point from the master modem and twist both wires for each pair in the cable together. Using an ohmmeter set on a scale that allows for a maximum resistance of 20 ohms per 1000ft of conductor, make a measurement of the loop impedance at the master modem site. Keep in mind that the resistance measured will be twice what is expected for a single wire. (for example, #22 awg wire has a loop resistance of 180 ohms per mile). A reading in the range expected says that your cable is continuous. Don't forget to untwist the cable at the end of the test.

Continuity Test checklist: The user should test for each pair of wire over entire length of wire run using this checklist:

Test for Shorts

Set Ohmmeter in Kilo-ohm scale
Test single twisted pair at a time
Connect probes to each wire of the pair
After 30 seconds the reading should be open (infinite resistance)
If not there is a short

Test for Line Opens

Test single twisted pair at a time
Connect probes to each wire of the pair
The pair should be shorted together at the furthest point from the master
Set Ohmmeter on a scale that allows for a maximum resistance of 20 ohms per 1000ft of conductor
Measure of the pair's impedance
ForExample: #22 awg wire has a loop resistance of 180 ohms per mile
Un-short the cable when finished
Repeat above for all pairs

Measuring Insulation Resistance

Insulation of the communications cable is very important to the proper operation of the cable. The cable shield should be connected at only one and only on point along any given run. It is very important that the shield is continuous along the cable run being tested and that no part of the cable is unshielded.

To test the shield, go to the point at which the shield is attached to earth ground and remove the connection to earth ground. Now take an ohmmeter and using the a low resistance scale, make a measurement between the shield and earth ground. There should be an open circuit. Now bond all conductors and shield together at the far end of the cable. Now separate from the rest, one conductor at a time. Apply a D.C. voltage of 300 volts on the separated conductor at the far end. Using your voltmeter, carefully make a measurement at the master end. The reading should be around 270 volts or greater at the master modem end.

Measuring Insulation Resistance and Shield Continuity Checklist: The user should test the cable shield and using this checklist:

Test for Shield Continuity

Test for short by not connecting an end of the shield to anything

Test for continuity by tying one end of the shield to a single wire of a pair, and checking the resistance of the loop.

Open Circuit Test
Remove the shield’s connection to earth ground
Take an ohmmeter and using the a low resistance scale, make a measurement between the shield and earth ground.
There should be an open circuit.
If the circuit is not open, then it means that the shield is connected to earth ground at multiple points in the system.

Voltage Test
Bond all of the pairs together at the ends of the line.
Remove one wire at a time from both sides, and apply a 300VDC potential.
Using a voltmeter at the other end of the line, measure the voltage.
The voltage reading should read greater than 270VDC for each wire.
After the test is conducted for an individual wire, bond it back with the remaining wires, and conduct the test again with the next wire.

Final Testing Using Naztec Modems

As with all tests, the final result is that the cable is compatible with the Naztec modem. If all of the above tests above are good, then the final test is to operate a modem. The test requires that a Naztec modem be attached at the far end with its RS232 inputs being looped back on each other. i.e. Transmit and Received pins connected together and the modems transmitter being keyed.

At the master end, a Naztec modem should be attached so that its transmit connects to the far end modem’s receive and its receive to the far end modem’s transmit. Attached to the master end’s modem should be a computer running a keyboard simulation set at 9600 baud. When a key is pressed at the master site, it should be echoed so that the display of that character shows up on the computer screen.