A Few (Technical) Things You Need To Know About Using Ethernet Cable for Portable Audio

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June 1, 2013

Digital Audio Data Transmission over Twisted-Pair

This paper was written to introduce the reader to the physical and electrical parameters of a twisted-pair cable and how they relate to the transmission of high-speed multi-channel digital audio. It is believed that a physical description of the cable and some of the concepts of what digital data is electrically comprised of will aid in understanding the specifications written for high-speed data cables. The example provided will specify some of the physical aspects of SuperMAC AES50 compliant data transmitted over Cat5 UTP (un-shielded twisted-pair) cable.

The Electrical Media

Twisted-pair is exactly that, a pair of conductors "twisted' together to provide a signal path for the transmission of information. In a standard Cat5 Ethernet cable there are four pairs of conductors in an un-shielded cable.

The method utilized by the AES50 standard of transmitting high-speed data over a twisted-pair of conductors is known as "differential mode transmission". In this method, digital signals (data bits) of equal amplitude and composition but of opposite polarity are sourced from a differential transmitter on one end of the cable and sent to a differential receiver (load) on the other end. In normal operation, the receiver measures the difference of the two signals ((+signal) – (- signal) = 2*signal) and electrically "reconstructs" the original source data as shown in figure 1.

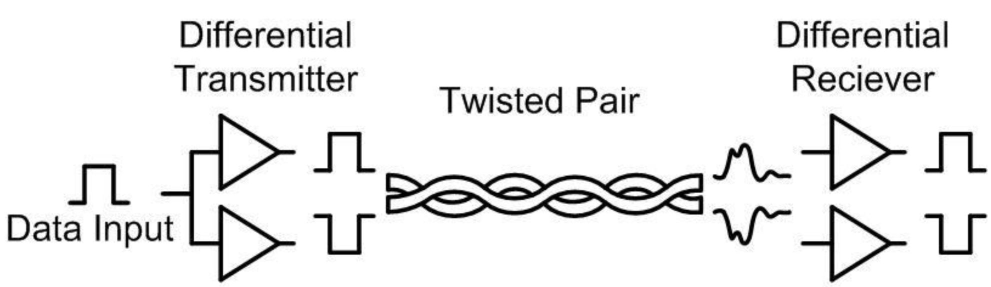

Fig 1. Differential Mode of data transmission

The conductor pair is “twisted” (or, inter-twined) primarily for two reasons. The first being to insure the equal exposure of the differential pair of conductors to a potentially un-wanted external noise source (e.g. a fluorescent light ballast or an electric motor) with the desired effect of the noise being “coupled” equally across the transmission line. The unwanted signals(s) are known as common-mode noise and, by design, will be “nulled”, or eliminated, by the differential mode receiver.

How this works is that the differential receiver is designed to subtract the common-mode noise signal between the two conductors according to function, ((+signal)-(+signal) = 0). This type of differential transmission provides excellent noise rejection as shown in figure 2.

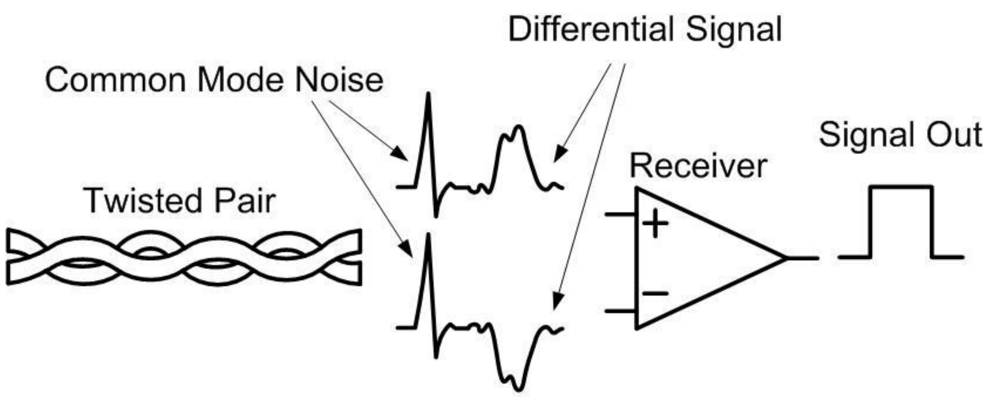

Fig 2. Noise rejection in a differential transmission line.

The second reason for the wires of a differential pair being “twisted” together is to provide good “coupling” between the differential conductors. This structure will tend to cancel the magnetic flux lines and minimize the radiated transmission of electric field lines which are generated by the differential charge (current) flowing through the conductors during data transmission; refer to figure 3.

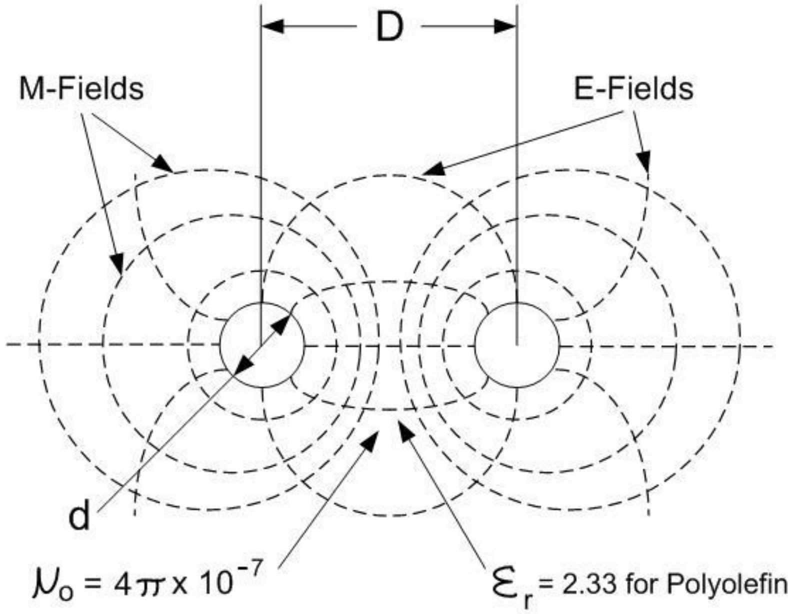

Fig 3. Transverse view of Twisted-Pair conductors showing electric and magnetic field lines.

Another functionally important characteristic of many twisted-pair cables is that they are sometimes constructed with twisted-pairs of different twist-rates (number of twists in each pair for a given length). The reason for this is to prevent extended exposure (and, therefore, coupling) of one conductor in a twisted-pair to an adjacent conductor of another twisted-pair (which would occur within adjacent pairs of equal twist-rate). This practice is done to minimize “crosstalk” between different sets of twisted-pair transmission lines within the cable.

It should be mentioned that when the twisted-pairs of a cable have different twist rates, they will also have un-equal lengths and, therefore, different propagation delay times. If this is a problem, additional lengths of cable can be “spliced” into the transmission line at the receiving end.

The Electrical Model

In essence, there are two methods of modeling a twisted-pair of conducting wires when transmitting data. The first method is known as a “Lumped” model and is, in essence, a circuit of electrical components composed of a resistor, an inductor, a capacitor and a conductance (known as “lumped” parameters similar to the model shown in figure 4). The second method, and the one that is most applicable to our discussion on high-speed data transmission, is known as the “Distributed” model and is essentially a transmission line characterized by an impedance, propagation delay, frequency dependent attenuation (the “skin effect”) and cable length relative to transmission frequencies (known as “distributed” parameters).

The choice of modeling method to be used depends on the relationship between the wavelength of the transmitted data to the overall length of the cable.

NOTE: In the “lumped” parameter model, the resistor represents losses in signal amplitude, the inductor represents an opposition to high frequency signals, the capacitor represents a “shunting” of high-frequency signals (which limits the band-width) and, lastly, the conductance (which is the inverse of resistance) represents a “leakage” of signal between the two conductors of a twisted-pair. In the long transmission line model, the same fundamental parameters are utilized, however, with an additional “distributed” effect that takes into account the relation of the signal wavelength to the overall cable length as-well-as frequency and time dependent characteristics (e.g. propagation-delay, phase velocity, rise-time, fall-time) of the signal as it traverses the conductive path.

Lumped model

The modeling of a transmission line where the wavelength of the transmitted signal is much greater than the length of the cable (the wavelength of a 20 kHz electrical signal in a conductor is about 10 miles) can be done by using the before-mentioned four fundamental parameters of RLCG. These parameters provide a good representation of the cable at lengths at or less than 1/10 the wavelength of the signal being transmitted (as is the case with audio signals).

Distributed Model

When the length of the transmission line is greater than the wavelength of the data being transmitted, the long transmission line (distributed parameter) model must be used. This model is composed of circuit “cells” which contain the fundamental parameters of RLCG along with other parameters derived from the cable material and cable geometry.

Each RLCG section is specified with a wavelength dependent coefficient that is related to the maximum frequency of data. The wavelength dependence on modeling accuracy is the reason behind specifying the electrical parameters of a high-speed cable as: Resistance per unit length (R, in Ohms, per meter), Capacitance per unit length (C, in Farads, per meter), Inductance per unit length (L, in Henry’s, per meter) and Conductance per unit length (G, in Siemens per meter) as shown in figure 4.

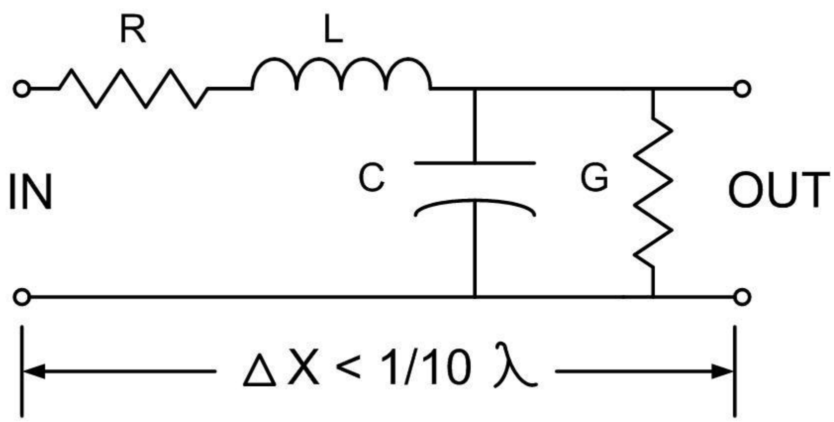

Fig 4. One section of an RLCG Transmission Line “cell” showing its fundamental parameters

When specifying a cable for transmission of high-speed data, it is of primary importance to note that the relationship between the cell parameters (cell geometry) and how they equate to the characteristic impedance, Zo, of the cable (100 Ohms in the case of Cat5 cable).

Cat5 cable

The Cat5 specification states a maximum data transmission band-width of 100MHz. Unlike the maximum transmission bandwidths of audio signals which usually range between 70kHz to 100kHz, digital signals are composed of high-speed data “bits” which require large bandwidths to maintain the “shape” (low distortion) and propagation velocity (speed) of the data packets.

When using audio signal transmission interconnects in systems with bandwidths less than 100kHz in either the home and/or project studio applications, the cables (e.g. speaker cables and patch cables) can be thought of as nothing more than “zero” resistance (or, more inclusively, as “zero” impedance) interconnects. If, however, you are dealing with large power amplifiers and/or large distances between amps and speakers (which is usually the case in public address and “live” sound applications) you must take into account the DC resistance and the capacitance of the cables as they limit the maximum power and signal bandwidth delivered to the load (speakers).

Digital Signal Distortion Artifacts in Distributed Parameter Transmission Lines

Generally speaking, the rise-time and fall-time of the digital signal should be greater than the propagation delay time of each cell by a factory of 5 or more. Since the fundamental wavelength of a 100MHz data stream is about 0.3 meters (about a foot) in length, a simulation model of a 100 meter long Cat5 cable should be composed of no less than 300 RLCG "cells" to ensure an accurate representation of reality. This type of modeling is best accomplished by a simulation software tool.

The distributed parameters of a transmission line will affect the fidelity a digital signal (which, in theory, is composed of a high number of electrical sinusoids of different frequencies traversing the twisted-pair transmission line) in such a way that they tend to distort and attenuate the signal in a manner which is frequency dependent. Distortion artifacts exacerbated by the distributed parameters of a transmission line and the effects they have on a data "bit" signal can be quantified as shown in figure 5.

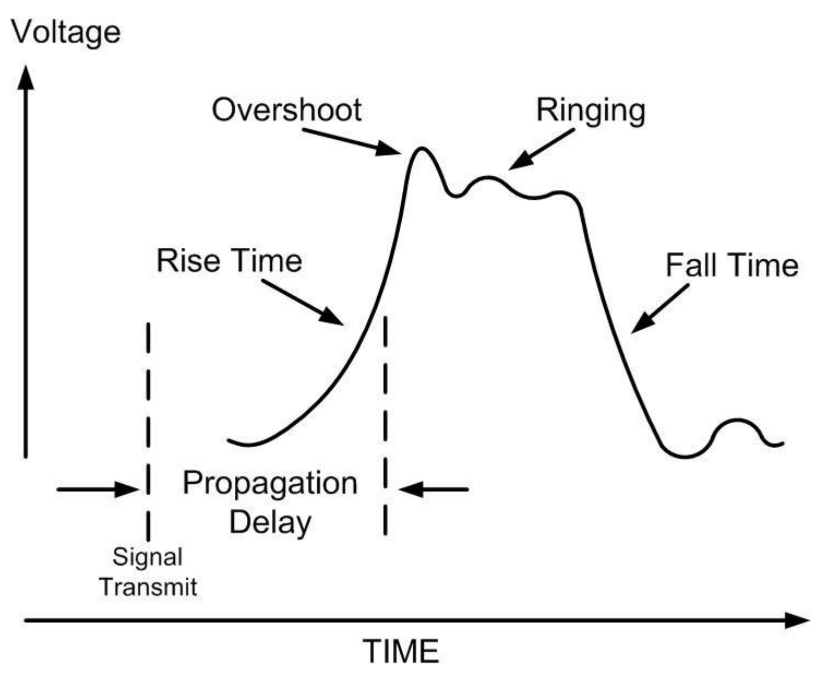

Fig 5. Distortion characteristics of a transmitted data bit down a cable

The level of distortion will affect the quality of the data signal and, therefore, the error-rate in your data transmission system. For this reason, it is wise to never deviate from a system specification by using a data transmission cable that is not specifically recommended by the manufacturer.

Characteristic Impedance (Zo) and TDR (Time Domain Reflectometry)

The characteristic impedance of a transmission line is found by taking the square root of the ratio of the inductance per unit length (L), to the capacitance per unit length (C). In order to maintain the most efficient interface between source and load, the characteristic impedance of the transmission line must match the source and load impedance (100 Ohms in the SuperMAC AES50 complient system). If there is a miss-match in impedance between the source, load and transmission line, reflections of the sourced signal will occur. These reflections are undesirable and can cause the original sourced signal to become distorted which, in many cases, will result in errors at the receiving end of the transmission system.

Any dimensional changes in the transmission line due to damage by over-extended "bending" or compressive "crushing" can cause a change in the characteristic impedance of the transmission line. In principle, this is how TDR (Time Domain Refletometry) works; if there is a change in characteristic impedance on a transmission line due to damage, a "ping" (stimulus) will be reflected (response) back to the refletometer from the defect point. With the change in time measured between the source of the ping and the reception of the reflection, the location of the damage on the transmission line can be determined.

NOTE: Non-electrical characteristics of the cable may include maximum tension and maximum operating temperature but, for the sake of simplicity, we will not discuss these parameters here.

Cable Specifications

The following is a specification for Belden 7923A Multi-Conductor – Category 5E Data Tuff® Twisted Pair Cable:

Physical Characteristics

Conductor AWG:

# Pairs	AWG	Stranding	Material	Dia. (mm)
4	24	Solid	Bare-Copper	0.508

Insulation Material:

Insulation Material	Wall Thickness (mm)	Dia.
Polyolefin	0.2286	0.889

Overall Cable:

Cable Pair Number	Color
1	White/Blue Stripe and Blue
2	White/Orange Stripe and Orange
3	White/Green Stripe and Green
4	White/Brown Stripe and Brown

Electrical Characteristics:

Maximum Conductor DC Resistance: 9 Ohms / 100m

Nominal Mutual Capacitance: 49.215 pF/m

Characteristic Impedance: 100 Ohm at 100MHz

Calculated Inductance: L = (Zo)^2 * C = (100)^2 * 49.215pF/m = 0.492 mico-H/m

Nominal Velocity of Propagation: 70% C (the speed of light in a vacuum)

Maximum Delay Time: T = 510nS/100m

Maximum Delay Skew: T = 25nS/100m

Some Additional Physical Specifications of the AES50 Standard

The Cat5 cable pairs for HRMAI AES50 pin assignments are as follows:

Pin assignment	MDI signal allocation	MDI-X signal allocation
1	Audio Data Transmit +	Audio Data Receive +
2	Audio Data Transmit -	Audio Data Receive -
3	Audio Data Receive +	Audio Data Transmit +
4	Sync Signal Transmit +	Sync Signal Receive +
5	Sync Signal Transmit -	Sync Signal Receive -
6	Audio Data Receive -	Audio Data Receive -
7	Sync Signal Receive +	Sync Signal Transmit +
8	Sync Signal Receive -	Sync Signal Transmit -

Differential Output Voltage: Max = 650mV, Min = 247mV

Rise/Fall Times: Max = 3nS, Min = 1.5nS

Jitter: Cycle-to-cycle Jitter shall be less than 500pS

The non-hardware (or, software protocol) specifications of the AES50 standard are written in the following paper: “AES standard for digital audio engineering – High-resolution multi-channel audio interconnection (HRMAI)”; paper published by the Audio Engineering Society.

Testing a Cat5 cable to insure its quality

There are many instruments available on the market to aid in the verification of twisted-pair cable quality; most will insure that the cable under test meets the specification published by the manufacturer. If the cable is damaged by misuse or deformation, these anomalies can, with most instruments, be determined and, in many cases, located on the cable by TDR methods.

In Conclusion

The successful transmission of high-speed digital information is highly dependent on the specified type and physical quality of the twisted-pair cable used in a system. If an AES50 system is interconnected with inferior, non-specified, and/or damaged cable, there will exist a high probability of failure in the field. For this reason, always use the cable recommended by the manufacturer as interconnects for your system. In addition, like most things in life, a superior grade of cable will translate to higher reliability in the field.

Glossary of Terms

Attenuation: The reduction of signal strength during the transmission of information along a conductive medium.

Coefficient: A constant term that is used as a factor to a product; the constant is often related to the properties of the product.

Common-mode: Common-mode signals are identical signals that are equally present on a differential pair.

Cross-talk: A phenomenon by which a signal transmitted on one transmission medium creates an undesired effect on another transmission medium. This effect is usually caused by undesired coupling of variations within an electric and/or magnetic field via parasitic capacitance and mutual inductance.

Data-bit: A "1" or a "0" that represents the most fundamental unit of information in a digital system. In many cases, the "1" and "0" are represented by a difference in voltage level.

Differential-mode: The transmission of information electrically with two complementary signals sent on two conductors known as a differential pair.

Impedance: The opposition by an electrical component or circuit to a time-varying voltage or current. AC impedance is analogous to DC resistance.

Model: A model is a mathematical abstraction of reality usually composed and/or derived from differential equations.

Phase velocity: The characteristic of the individual sine waves of different frequencies (of which a data-bit is composed of) to travel, or propagate, down a transmission line at different velocities. This phenomenon (along with attenuation due to the skin-effect) is responsible for distorting the shape of the original data-bit transmitted.

Relative Permittivity: The nature of material to concentrate electrostatic flux lines relative to that of free space.

Propagation delay: The time required for a digital signal to travel from the input of an electrical device or transmission medium to the output.

Rise-time/Fall-time: The amount of time it takes for an electrical signal to either rise or fall from 10% of the original value to 90% of the final value.

Skin Effect: The increase in resistance in a conductor as a function of frequency. The higher the frequency, the more concentrated the current flow is to the surface of the conductor, thereby raising the over-all resistance of the conductive path. The skin effect is the major contributor to distortion in transmitting a data-bit down a transmission line.

UTP: Unshielded twisted-pair.