Why is Cable Capacitance Important for Electronic Applications?

High speed data (greater than 1Mb/sec) in digital systems requires precise cable electrical performance. This article examines what determines capacitance in a cable and how it affects system performance.

High Speed Digital Systems and Networks

When computer systems were first introduced decades ago, they were all large, slow speed devices that were incompatible with each other. Today, national and international networking standards have established electronic control protocols that enable compatible systems to communicate with each other. The Electronic Industries Alliance (EIA), Telecommunications Industry Association (TIA), American National Standards Institute (ANSI), and the Institute of Electrical and Electronics Engineers (IEEE) developed standards that establish common terminology and interface requirements, such as EIA RS-232 and IEEE 802.3. If a system designer builds equipment to comply with these standards, the equipment will interface successfully with similar systems. A few common standards are listed below.

Standard	Typical Use
EIA RS-232	Equipment-to-modem interface
EIA RS-422	Equipment-to-modem Interface and other balanced interconnects
EIA RS-485	Multiple equipment interconnect
ANSI T1-403	DS-1 (T-1) Network to Customer Interface
TIA 568-B.2	Balanced twisted pair cable for commercial premise networks
IEEE 802.3	Ethernet* baseband network
IEEE 802.4	Manufacturing automation protocol (MAP) systems
IEEE 802.5	IBM Token Ring systems
*Ethernet is a trademark of Xerox Corp	

Most of these standards specifically identify cable constructions and electrical performance necessary to meet the system data speeds and transmission distances. If a certain cable design is specified by a system or standard, it is done so with a reason: any cable with less than the specified performance criteria will degrade the system or not transmit at the specified maximum distance.

Data Signals: Input vs. Output

When a high-speed data system is designed, the engineers must consider many technical aspects such as band width, packet design, BAUD rate, shielding effectiveness, wave form definition, etc. These are all complex system requirements, but when you transmit data through cable, the requirement usually simplifies into comparing what goes in one end with what comes out the other. High speed data pulses degrade or deteriorate when they are passed through any cable. Both the height of the pulse (magnitude) and the shape of the pulse (wave form) change dramatically, and the amount of change depends on the data rate, transmission distance and cable electrical characteristics. If the output signal deteriorates too much, then the device at that end won't recognize it or, worse, will record false data. Sometimes a marginal electrical cable may perform adequately if used in only short lengths, but the same cable with the same data stream in long lengths will fail. This is why system designers and industry standards specify precise cable criteria.

Cable Electrical Characteristics

The most important characteristics in an electronic cable are impedance, attenuation, shielding and capacitance. In this article, we can only review these characteristics very generally, however, we will discuss capacitance in more detail.

Impedance (Ohms) represents the total resistance that the cable presents to the electrical current passing through it. At low frequencies the impedance is largely a function of the conductor size, but at high frequencies, conductor size, insulation material and insulation thickness all affect the cable's impedance. Matching impedance is very important. If the system is designed to be 100 Ohms, then the cable should match that impedance, otherwise error-producing reflections are created at the impedance mismatch (See related articles in this section on Return Loss).

Attenuation is a ratio comparing power input to output. It is measured in decibels per unit length (db/ft) and provides an indication of the signal loss through the cable. Attenuation is very dependent on signal frequency. A cable that works very well with low frequency data may do very poorly at higher data rates. Cables with lower attenuation are better.

Shielding is normally specified as a cable construction detail. For example, the cable may be unshielded, contain shielded pairs, have an overall aluminum/mylar tape and drain wire or even a double shield. Cable shields usually have two functions: the first to act as a barrier to keep external signal from getting in and internal signals from getting out and the second to be a part of the electrical circuit. Shielding effectiveness is very complex to measure and depends on the data frequency within the cable and the precise shield design. A shield may be very effective in one frequency range, but a different frequency may require a completely different design. System designers often test complete cable assemblies or interconnected hardware for shielding effectiveness to prove their system complies with FCC electromagnetic emission requirements.

Capacitance in cable is usually measured as picofarads per foot (pf/ft). It indicates how much charge the cable can store within itself. If a voltage signal is being transmitted by a twisted pair or coaxial cable, the insulation on the individual wires becomes charged by the voltage within the circuit. Since it takes a certain amount of time for the cable to reach its charged level, this slows down and interferes with the signal being transmitted. Digital data pulses are a string of voltage variations that can be represented by square waves with near-vertical rise and fall transitions. A cable with a high capacitance slows down these voltage transitions so that they come out of the cable looking more like "saw-teeth", rather than square waves, and the circuitry may not recognize the pulse. The lower the capacitance of the cable, the better it performs at higher frequencies.

Controlling Cable Capacitance

Since cable capacitance is so important, a lot of analysis goes into minimizing it. This can be accomplished by:

- Increasing the insulation wall thickness

- Decreasing the conductor diameter
- Using an insulation with a lower dielectric constant.

The size of the conductor is usually determined by the electrical requirements of the circuit that the cable interconnects. If the circuit has been designed to require a 22 AWG wire, you cannot reduce it to 28 AWG just to reduce the capacitance. Also, the insulation wall thickness cannot be increased beyond reason since this increases the diameter of the cable, increasing costs and affecting terminations. Thus, the insulation chosen for the cable often becomes the critical variable.

All dielectric constants are compared to air or vacuum, which is given a value of 1.0. A poor-quality PVC insulation may have a dielectric constant of 5.0 to 6.0 or higher. Polyethylene has a much better dielectric constant of approximately 2.0. Foamed polypropylene or polyethylene insulations have constants as low as 1.6.

By balancing conductor size, insulation material and insulation wall thickness, the cable designer can produce electronic cables that are tailor made to transmit high frequency digital data pulses over a maximum distance. The signal output from these cables maintains the required wave form definition and minimizes possible data errors.

How Low is Low Cap?

Years ago, most computer cables were insulated with PVC and a capacitance of 40 or 50 pF/ft for a pair component was adequate. That was because those systems signaled at slow Kilobit (Kbit) rates. Today, with more stringent and faster system requirements, most true low cap cables have capacitance values of approximately 12 or 13 pF/ft. Some systems now being designed will require capacitances as low as 9 pF/ft or even lower.

Today Quabbin Wire & Cable Co., Inc. manufactures and stocks a family of low cap cables, from 2 pair thru 18 1/2 pair constructions. These cables meet most system requirements that require true low capacitance. They utilize polyethylene insulation with a flexible PVC jacket that provides an ease of termination and installation unmatched in competitive products. These cables do not use band-marked color coding because many customers find this system very difficult to read. Instead, Quabbin Wire provides an extruded, integral color stripe to identify leads. This stripe is impossible to wipe off and is much easier to see. Part number 8508 listed below is a 4-pair member of that family.

To compare the dimensions, insulation systems, capacitance and other electrical characteristics of several cables, refer to the following cables found in Quabbin Wire's catalog and on this web site.

P/N	Construction	OD	Mutual Capacitance
2210	4 pair 24 AWG no shield Category 6	.220"	13.5 pf/ft
8508	4 pair 24 AWG O/A shield (RS232)	.277"	13 pf/ft
9508	4 pair 28 AWG O/A shield (RS422)	.233"	15.5 pf/ft
9720	2 pair 22 AWG pairs shielded DS-1	oval	15.0 pf/ft