ADVANCEMENTS IN HIGH RELIABILITY INTERCONNECTION SYSTEMS:

MINIATURIZATION OF CONNECTORS FOR THE NEW HIGH SPEED DIGITAL ELECTRONICS

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WHITE PAPER

OMNETICS
CONNECTOR CORPORATION

EXECUTIVE SUMMARY

This white paper reviews the improvements and changes needed to serve a very rapid demand for modernized interconnection and wiring systems that serve the new electronic applications in defense, space satellites and portable electronic systems. New electrical power, high speed signal transmission and data collection systems are being used in current semiconductor device driven circuitry in significantly different ways from our past. Interconnection systems must host and deliver new combinations of circuit and signal formats and power levels as well as maintain the highest signal integrity of data being processed from one module to the next. Surveillance and vision systems are chartered with collecting more information, more rapidly at higher resolution. Satellite positon control and direction management demand the highest of controls from inside the instrument as well as from remote sites. Unmanned defense products from missiles to drones process massive volumes of data at extreme signal speeds to detect, guide and follow both computerized controls as well as remote signal directions. Ground troops in the field are being kept in constant communication and control their individual remote vehicles and equipment using the newest of ruggedized portable electronic devices. Maintaining signal quality and routing both analog and digital data over the process of these applications has proven to be both challenging and successful. Lessons learned and key elements considered will be covered in this white paper.

DESIGN FOR HIGH SPEED

Today's higher speed signal data is most often a simple matter of sending coded signals that ride on a main standard line. It is often called multiplexing and the signals are most often formatted in the "on-off mode" and or "voltage-change" mode. A basic review of signal speed analysis is described as the measure of the time it takes to raise a signal to a certain voltage and the time it takes to turn it back off or return the signal to the original voltage level when it is at rest. Circuit "Rise Time" understanding is critical as signal speeds increase. The time to raise signals to certain voltages must become shorter and shorter as signal speed increases. Rise time is specifically described as how quickly the signal grows from 10% of its top height to 90% of that maximum height. To increase circuit chip speeds one must reduce the rise time of the chip. A digital square wave is made up of a number of its base frequency harmonics combined and each harmonic helps shape wave to a more vertical rise. The more vertical the rise, the faster the circuit.

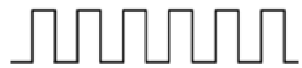
Rise time, is quoted from Signal Integrity Journal as $V(t) = 1 - e^{\frac{t}{RC}}$, and is measured in nanoseconds and equals 0.35 divided by bandwidth (in GHz).

Today an additional way to reduce rise time can be accomplished simply by lowering the voltage between zero and the voltage that the chip is operating on. Speed can increase but output signal strength may be lower.

DIGITAL HIGH SPEED IS DIFFERENT THAN ANALOG HIGH SPEED

Focus on higher speed digital signal management, requires that one must also attend to the key circuit relationship between rise time and bandwidth. Remembering that digital signals travel ideally as straight vertical square waves.

Analog Sine Wave



Equivalent Digital Wave

With perfect conditions, the more perfectly vertical the square wave travels help result in higher bandwidth. Unfortunately, circuit boards, connector interconnections and cable formats are not perfect. Slight variations in impedance matching, physical variations and other factors shift the vertical square wave to a leaning trapezoidal wave that takes additional time and slows down the circuit.

SIGNAL SPEED-UP USING DIFFERENTIAL SIGNAL TECHNIQUES

LVDS, (low voltage differential signaling), was developed to serve the differential serial communication protocols and over the years, similar systems were employed to speed-up today's digital signaling methods. Digital signal output is formed to travel on two complimentary signals with the positive and negative square waves run on their own individual wire within the cable. This allows for much higher speeds, and reduces signal noise, crosstalk and sensitivity to EMI, (electromotive inductive interference).

Two different cable designs are used for the interconnections. The first uses, parallel wire sets that are carefully spaced and shielded similar to a two lane freeway with a barrier between the lanes. The second is to wrap the two signal wires together using a wrap length that helps reduce cross-noise to and from the positive and negative signals running on their separate wires. A grounding wire is included to help subdue noise and drain off inductive circuit signal disturbances. Using either method has one critical element, signal propagation delay! When splitting the signals on separate wires, the signals must arrive at the other end of the cable at exactly the same time. Receiving devices must read the differences between signal A and signal B instead of comparing the signal to a ground reference in analog circuitry. When the signals arrive at different times, the receivers can't decipher the data being sent.

Cable design is critical in matching the signal transmission time from signal A to signal B. One standard cable specification to consider is called the velocity factor of each signal line within the transmitting cable.

$$VF = \frac{1}{c_0\sqrt{L'C'}}$$

L' is the cable inductance in Henries per/inch and C' is a measure of the Capacitance between the two signal lines in farads/per inch and C_0 is the speed of light in a vacuum. The maximum allowable differences in VF per circuit is directly related to the speed of the signal being processed.

We have established guidelines to help for calculating the frequency one can achieve in their cable and signal processing systems. A basic formula to remember is:

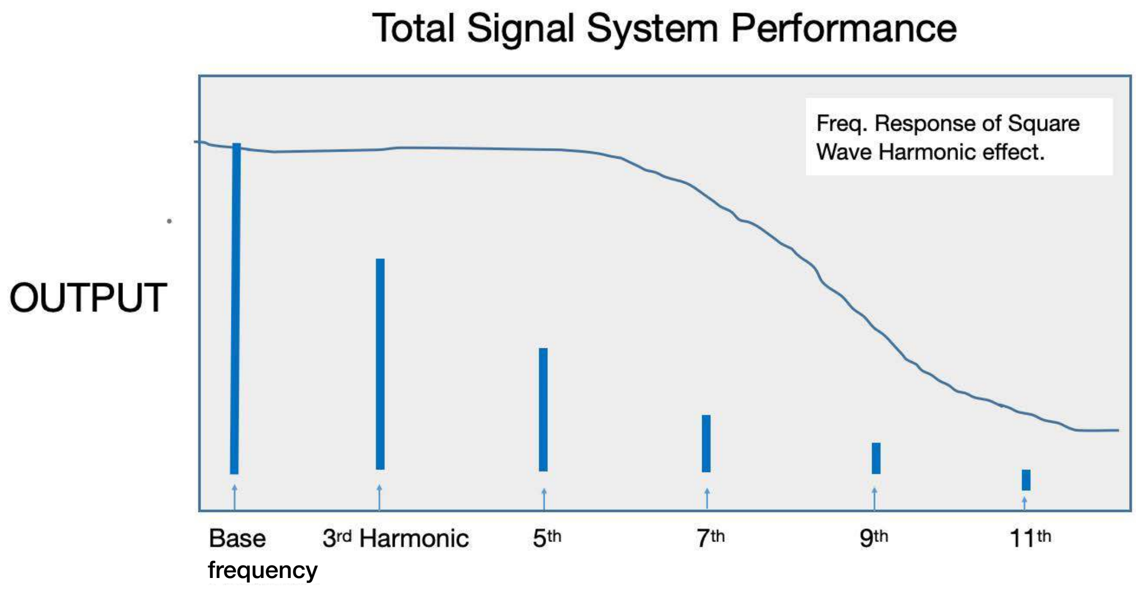
$$f = \frac{1}{2_\pi \sqrt{LC}}$$ where L is the system inductance and C is the system capacitance.

Transmission line wavelength formulas can also be used to help by remembering that $\lambda = \frac{U}{f}$

U = velocity of propagation and f represents the sinusoidal frequency of the connector and cable system as one unit.

THE IMPACT OF THE MULTIPLE HARMONICS OF A BASE FREQUENCY

In addition, the small physical variations can attenuate higher frequency harmonics of the main signal. Fast rise time of the complete signal depends upon reasonable higher frequency harmonics and the attenuation of those harmonics surprisingly slows the speed performance of the signal. Total bandwidth, therefore is a combination of square wave rise time and of the combination of the main frequency and the multiple harmonics of the digital circuit. The circuit board, connectors and cable are all members is the square wave interconnection system. Remembering that a good measure of performance is; “Bandwidth (in GHz) is equal to 0.35 divided by the rise time, (in nanoseconds).” We often look for a defined circuit bandwidth, however sine waves will be attenuated and digital square waves, will change to the trapezoidal form causing rise-times to limit digital transmission speeds. This effect of harmonic attenuation can explain why it is often a surprise that some 3Gbit or 5Gbit systems do not meet their speed expectations as the cable length goes beyond 3 or 5 meters long.



Older silicon chip technology uses a diffusion process that contains a bit of bulk material as well as a fair amount of voltage height to send outer valence bond electrons onto the next part of the chip. Newer semiconductor chip design methods and materials are now solving that problem. Silicon will remain as a good contributor in our industry, but less so with low voltage, lower current high speed digital circuitry.

Silicon based charge coupled devices (CCD) technologies and CMOS chips are rapidly improving their higher resolution capabilities in many rugged applications we see today. The CCD design technique does not rise and lower voltages as much as it gathers voltages and transfers them rapidly across the surface of the chip to the output end of the circuit. This reduces time and increases the speed of image capture and routing from optical scanners and cameras.

High speed complementary metal–oxide–semiconductors (CMOS) function as a low energy field effect transistor that works the positive and negative portions of a chip in a partnership. This allows the chip to process data significantly faster than older methods of switching voltages up and down to generate the signal information. CMOS circuits are one of the most frequent design methods used for making fully integrated circuit chips that handle microprocessors and memory logic.

Gallium arsenide chips are built using a mix of gallium and arsenic that are both in the III-IV portion of our chemical valence table. Combined with other materials they switch and amplify much more rapidly than older silicon techniques. We have been using them for many high speed circuits and are also used for light emitting diodes and laser diodes that can be turned on and off rapidly to couple electrical signals to optical signals for fiber optic transmission.

GaN circuits are driving another new era beyond our previous materials. Gallium Nitride has a higher barrier height between the P and the N sections of the semiconductor and can offer voltage swings of up to 28 volts for higher amplification at higher signal speeds in wireless transmission systems.

Physical chip circuit layouts are also being developed to increase speed by mixing multiple frequencies onto one signal carrier. Using shorter length elements on the chip, it is easier to speed up the switching process to identify the signal in an intelligent format. The combination of higher power levels, shorter elements and use of these new materials exhibit a great future ahead for very high signal process speeds and multiple signals running in parallel.

Parallel chip signal routing in receiver chips are also extending image capture breadth and resolution. As a result, processing speeds are doubling with larger image frames and the use of increased frame rates from the established 30 frames per second to over 100 frames per second. This capability is driving digital signal data rates from the, earlier 5 Gigabits/second to above 10 gigabits/second and beyond.

Newer chip level designs are even emulating the phased-array radar technique of focusing signal coupling within the chip into a high speed focused repeater format to accelerate the signal transmission.

In addition to speed and bandwidth, there is almost an overwhelming trend in the design for new electronics beyond higher signal speed. As mentioned earlier, the newer chips available allow circuits to operate on much lower voltages often at very low current levels. Most circuit design work is focused on smaller size, lower weight and must perform well in exceptionally rugged applications and or in extreme environmental situations. Mini detectors and processor systems on a chip, however, have changed the rules and electrical demands in the whole instrument. Older electronic circuits using analog technology or even earlier digital chips required relatively high voltage and used more electrical current. Instrument design began with large power supplies and large wire systems running circuitry within the instrument to feed the electricity-hungry modules inside. Wires had to be large enough to handle the current flow and insulators had to be thick enough to keep circuits from shorting to one another. Cables were designed to handle analog sine wave signals for long runs and were also shielded to avoid electrical noise to reduce electrical noise inside the instrument. More signals travel from instrument to application via RF or Bluetooth and are then routed within instruments using micro sized interconnections. As the voltages drop to the 3volt to 12-volt range, as current levels more often run below 1 ampere, we see miniature power supply systems as part of the remote instrument electronics. Interconnection systems within the instruments can be significantly reduced in size. In turn, wiring can be nearly half as large with plenty of capacity for current flow. With lower voltages, the insulator materials in circuits can be significantly smaller and more compact. As a result, miniature connectors and smaller wires solve an additional size and reliability problem for medical instruments. High reliability, ruggedness and long life can be achieved as well, if designers use the high reliability standards previously proven in many high-technology applications, such as, military and aircraft circuitry.

The results are shown with a new focus driven towards smaller, more portable, more capable equipment that can fit-in, highly compact electronics from miniature satellites to military drones and on uniforms of ground based troops. Today's battlefield technology and electronics place a strong emphasis on lightweight, feature rich, portable electronics. In addition to military issued radios, modern warfighters are also carrying with them extensive computing power, cell phones, GPS devices, mapping and fire-control electronics, night-vision systems, and hotspots capable of transmitting real-time battlefield intel at 5 GB/second. In all cases these devices require rugged electrical cable and connectors capable of transmitting un-interrupted field data and power transmission in some of the harshest environments on planet earth.

Unlike yesterday's technology, cables and connectors can no longer be heavy, nor can these signals rely on analog transmission and even more importantly these devices cannot be human dependent. These new electrical devices need to be capable of utilizing independent cables using very un-conventional cable and connector technology. From unmanned ground and air devices to soldier worn applications, reduced connector size and weight is critical. Connectors such as MIL-DTL-24308 and 38999's are simply too big and heavy, as these connectors were initially designed to connect to bulkhead-type panels used on many aerospace applications, not in a soldier-worn application. Micro-D, Mil-83513 and Nano-D, Mil-32135 connectors are serving the demand and physically passing high speed data and power simultaneously within portable ruggedized electronic systems from helmets to small surveillance satellites.

In addition, light weight-but-rugged shielded cables are delivering clean data streams, undistorted by electro-magnetic interference or cyber intrusion.

Miniature cable and connectors also offer mixed signal interconnections that carry both power and signal within one cable to reduce the number of cables within one system and capable of transmitting USB and HDMI speeds in the footprint of a thumbtack.

Small satellite interconnection methods within modules, from modules to modules, from power to system and even outside to robotic arms and equipment are employing miniaturized cable and connectors designed specifically for space travel. Signals from surveillance to attitude management and direction control are critical. Surveillance devices pour high volumes of digital image data from camera to processor boards. Again, small, lightweight and rugged performance if required. All interconnects must also achieve compliance to the use of NASA listed low outgassing materials. Today's miniature cable and connectors must meet these physical demands as well as constant vibration, and offer cable that are highly flexible and limp. Thermal cycles are continuous from both high temperatures to extreme cold.

In addition to the classic Micro-D and Nano-D connectors mentioned earlier, Micro-miniature circular connectors are becoming popular and allow designers the ability to transmit as much as 5 amps per contact with selected wiring and can offer IP67 or IP68 moisture seals. The Nano miniature circular connectors at .025" pitch are small, but powerful and only protrude from a panel by 1.975", can be easily mated in the field with one hand (gloved or bare). The connector family also allows for blind mate-ability with a polarized insulator.

INTERCONNECTION SUBCONTRACTORS AND COMPONENT MANUFACTURERS HAVE FOLLOWED SUIT.

Cable and connector manufacturers, such as Omnetics, have developed miniature and Nano-miniature connectors specifically for these new technologies using wiring made up of 30 awg. conductors, (apx. .012 thousandths of an inch in diameter). Cables have become more flexible and can hold more signals in smaller and lighter interconnection systems. The mating connector designs have benefited from previous experience, learned on work with the high-reliability needs of military and aircraft systems. They have reduced sizes from the older 100 mils. size connectors, often used in household computer towers, down to the miniaturized connector systems at .050", (1.3mm) and .025", (.625mm) spacing. These miniature connectors using smaller wiring systems can now contribute to size reduction and handle increased chip function in about one-fourth the space of previous systems. Portable devices can use chips right at the probe tip and be connected by miniature cable to the monitoring instrument. They can be easily disconnected for cleaning or disposal using miniature in-line connectors designed specifically for the instrument.

QUALITY AND RELIABILITY ARE CLEARLY REQUIRED

To achieve that goal, manufacturers have selected the highest reliability elements for use in most medical connectors. The Spring pin and socket system has proven reliability over wide ranges of shock, vibration and thermal changes.

Made of BeCu with high tensile strength, (17,200ksi), it manages to withstand the rigors of use, and abuse, often experienced in the hurried business of patient service. Pin and socket elements selected should also pass plating tests specified in Mil. B488-type II, Code C class 1.27. This requires a strong nickel plate barrier that is then coated with 50 micro-inches of gold. When placed into miniature insulator housings, molded from LCP, (Liquid Crystal Polymer), the connector remains at the highest level of reliability testing in military and aerospace industries. The assembly often consists of Teflon® insulated wiring that is carefully laser stripped to avoid nicking miniature wiring and crimped into the back section of the pin system. The pin-and-wire set are then inserted into the LCP insulator and fixed with epoxy in place. An “over-molded” shell that can be customized to the designer’s criteria completes the assembly. Alternately, the pin and wire set are inserted into a metal housing to finalize the miniature connector. Benefits of this assembly process, are precision, tight tolerances, and high quality miniaturization that greatly exceed the performance of single spade pins in lower quality plastic housings.

Design Engineers can work directly and on-line with connector designers and assure that their interconnect size, shape, weight fit well with the application they are building. They can also specify materials selected to match the specific product service and environmental challenges it might be exposed to. Electrical specifications can be achieved and improved while working directly with the interconnect engineer. Cable ruggedness must be planned to work in hand with limpness and flexibility, while performing the signal management functions on the inside and, if necessary, shielded against outside EMI.

Until recently, only a small handful of suppliers offered higher reliability connectors sized at the .635mm pitch configuration. Nearly every connector cable harness supplier offers some form of Nano-connector in line with miniature electronic cables. SMT technology has also adapted to handle very tight pitch surface mounting to printed circuit boards for the tiny connector mounting leads.

One good example of superior cable and connector supplier can be a reflection of many. Omnetics Connector Corporation, built its strength on a focus of high reliability and miniaturization. It too, responded to the massive military/aerospace industry and cut through the rigors of specifications, and testing. It too, followed design and manufacturing down into the Nano-interconnection foot print. It too learned the needed quality control and manufacturing standards needed to continuously supply medical component level performance and reliability. But it went beyond that point and became a leader in custom design to meet new sizes and shapes demanded by the miniaturization of digital devices used in rugged applications. These new miniaturized connectors match up perfectly with the evolution of miniature electronics and support instrument portability and size reduction while retaining the highest reliability standards.

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