Fiber versus Copper Links:

Making the Right Choice for Industrial Environments

AVAGO
TECHNOLOGIES

White Paper

Industrial environments are particularly challenging for data communications network designs for a variety of reasons. Typically rife with electromagnetic interference (EMI), unless every precaution is taken, these extremely noisy environments can wreak havoc on process control, automation feedback monitoring and data networks built with twisted-pair copper links. These environments also introduce the potential for excessive ground-loop currents due to different ground potentials between links, placing a premium on galvanic insulation between systems, I/O cards, and components. Increasing data rates further exacerbate these problems, making effective network design challenging and media selection critical.

Optical fiber links offering a solution for these and other problems posed by the industrial environment. For example, polymer optical fiber (POF) is steadily replacing copper cabling in many industrial applications such as RS-485 and Fast Ethernet. Unlike copper cables that can act as an antenna and propagate noise throughout a network, glass and plastic fibers are dielectric materials and are therefore immune to the stray electromagnetic fields that are common in motors drives, AC/DC power inverters and power distribution systems. These fibers can even be placed in a duct alongside high-voltage power cables without concern of crosstalk, whereas twisted-pair copper cables require a minimum distance or expensive shielding from power lines to guarantee error-free data transfer.

Optical fiber also completely eliminates ground loops and their potential noise and safety issues. Its inherent insulation characteristics make system integration straightforward and efficient. Fiber is also ideal for many monitor and control functions needed in high-voltage applications and it is by far the best medium for connecting control triggers to high current/voltage switching circuits through an isolation barrier.

Many design engineers have been reluctant to use fiber optics in their data and control networks. In most cases this is due to a perceived cost disadvantage, concerns about ease of use and/or installation, or simply a greater familiarity with copper, compounded by an overabundance of legacy copper infrastructure. However, as this white paper will demonstrate, fiber is a viable alternative to copper for galvanic insulation, common mode immunity and electromagnetic interference (EMI) immunity. Moreover, it is competitive in terms of cost, and for some environments, it provides easier use, design and installation compared to copper.

Galvanic Insulation

Copper wire is an established technology that has been successfully used to transmit data in a wide range of industrial, medical and proprietary applications, but in many situations copper can be difficult or impossible to use. Designers typically employ differential line receivers, RF, magnetic, capacitive or opto couplers as well as transformers to ensure adequate galvanic insulation (i.e., the separation of functional sections of electrical systems to prevent DC current flow). However, designers must also make every effort during and after the initial installation not to corrupt the data with noise induced into the cable by adjacent power lines or differences in ground potential. In cases where extremely large switching currents and voltages exist, such as large wind turbines or solar panel arrays, these precautions can prove inadequate.

Unlike copper wires, optical fibers do not require rigorous grounding rules to avoid ground loop interference, nor do they need termination resistors to avoid reflections. Properly utilized, optical transceivers and fiber cables can prevent lightning strikes from causing expensive damage to equipment and offer safe isolation for outdoor and tower-mounted applications.

According to the IEC 664-1:1992 standard values (Figure 1), even in the worst possible environment (i.e., outdoor) the minimum standard distance for a working voltage of 10kV is 45cm, which is considered an ultra-short link of a typical plastic optical fiber application. Given the average installation length of 10m the possible working voltage exceeds the standard by twenty times. Therefore, the galvanic insulation properties of optical fibers are extremely well-suited for harsh industrial environments.

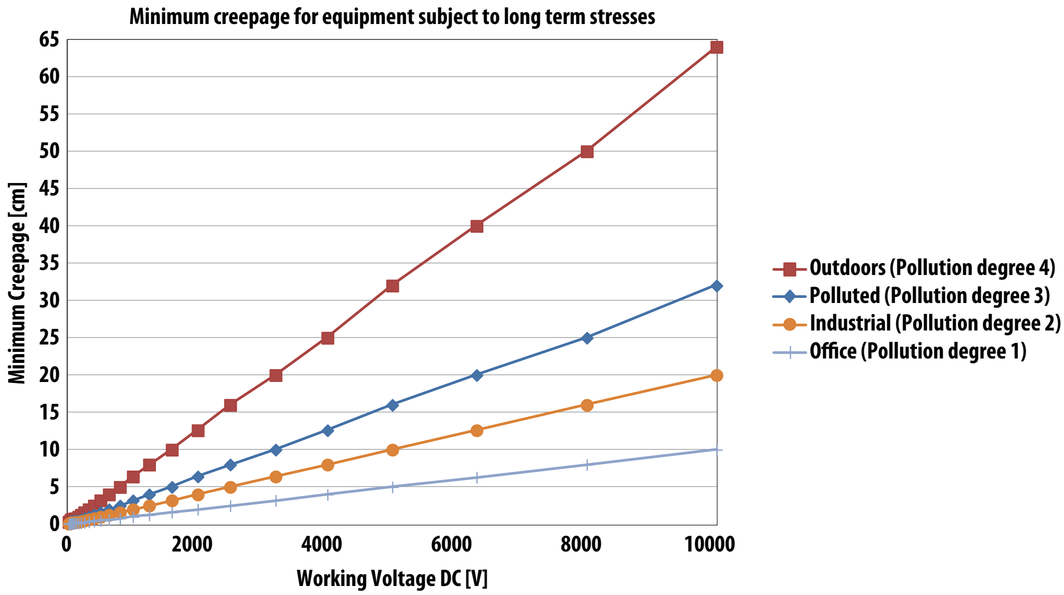

Figure 1. Recommended minimum creepage distances based on IEC 664-1:1992 standard values

Links must also provide sufficient clearance to inhibit arcing due to high-voltage spikes. To demonstrate the efficacy of optical fiber, we created a test setup using 40mm optical link (the shortest possible link length) with 45mm clearance and 55mm creepage setup (Figure 2). The set-up was subjected to 20kV (14kVrms) - the maximum possible with the available test equipment- no electrical discharge occurred. This close proximity of the transmitting and receiving end, however, is atypical of a real-world fiber link. Nonetheless, this demonstrates that optical fibers easily provide sufficient clearance to inhibit arcing due to high voltage spikes.

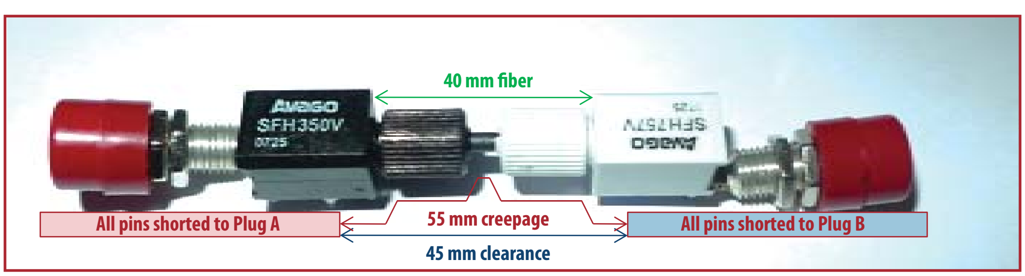

Figure 2. Test configuration for galvanic insulation

Common Mode Isolation

Rejection of common mode noise or ground loops in an industrial communication link is a major consideration for a robust link design. One common solution is to use an opto coupler to place up to 15 mm of galvanic insulation between the data source (µP, UART, etc.) and the copper transceivers driving twisted-pair cable. This can prevent common mode noise from propagating into sensitive Rx decision circuits, which can cause errors in the data transmission. However, due to the close proximity of trans-mitter and receiver in couplers, this is effective only to the extent that the stray capacitance is minimized across the isolation barrier. The use of isolation material ensures that the common mode noise "spikes" cannot cross from input to output. With a fiber link approach, due to standard link length of several meters, the actual effective isolation barrier becomes meters (not millimeters). This effectively reduces the stray capacitance to zero, thus eliminating any practical common mode noise pathway.

Electromagnetic Interference Immunity

Electromagnetic interference (EMI) refers to any electro-magnetic disturbance that disrupts, degrades, or other-wise interferes with authorized electronic emissions, thereby limiting the effective performance of electronics and electrical equipment.

Addressing EMI issues is a challenge. When electromagnetic interference is suspected, the first step in resolving the problem is to determine the mechanism of energy transfer to the affected device(s): radiation, conduction, or induction. Improvements can be achieved by limiting the amount of induced energy or by removing the root cause with improved grounding or termination techniques. One can also use physical separation or shielding to protect the failing device. The best approach to avoid potential EMI problems is to choose less sensitive or immune devices, to optimize the layout to minimize coupling effects, and to use proper shielding.

Industrial copper links are highly susceptible to EMI emissions that are so prevalent in industrial environments. With this concern, designers must often go to great lengths to ensure there is adequate physical separation between the cables and adjacent power line. In contrast, fiber optic cables are completely immune to EMI. The optical transmitters and receivers are designed with harsh industrial environments in mind, making them the best, or in some cases, the only choice in these environments.

A special EMI immunity test setup (Figure 3) demonstrates the susceptibility of copper cable and the immunity of POF when exposed to EMI. Using a transverse electromagnetic (TEM) cell into which a 50 MBd PRBS7 signal is fed through a POF transmitter and receiver, an amplifier sweeps across a range of frequencies from 0 to 3 GHz while the bit error rate is measured. A one-meter shielded twisted-pair cable provides an external loop back of the data passing through the EMI-saturated TEM cell. Depending on the orientation of the cable, bit errors begin appearing at various frequencies above 1.5 GHz (coincidentally, this is within the mobile phone frequency spectrum).

The field strength is then reduced at each of the failing frequencies until the bit errors disappear. The resulting graphs (Figures 4 and 5) show the respective results for vertical and horizontal orientation of the twisted-pair cable loop. In the worst-case frequency, the electrical field had to be reduced to 40 V/m with the shielded copper cables attached. Predictably, tests performed with unshielded twisted pair cables showed them to be unusable in this noisy environment (Figure 6).

When the copper cable is removed and only the fiber optic transmitter and receiver devices with a direct loop back path on PCB level are exposed to EMI, the results showed no bit errors (Figure 7). In this configuration, the POF link withstood an electrical field of >150V/m across the entire frequency range of 0-3 GHz.

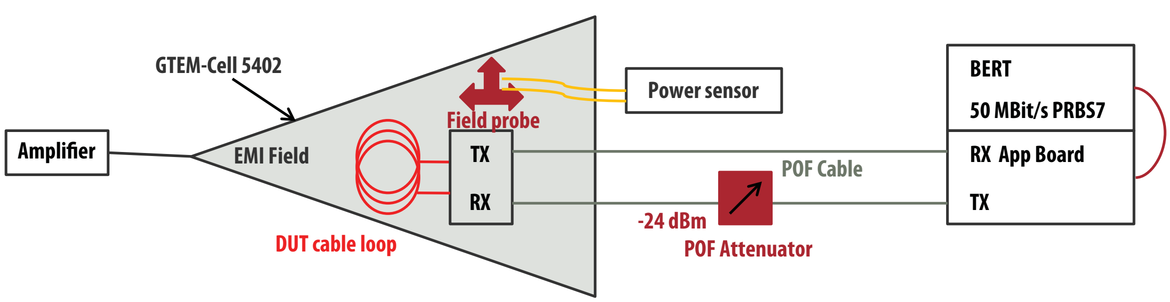

Figure 3. Test configuration for EMI immunity

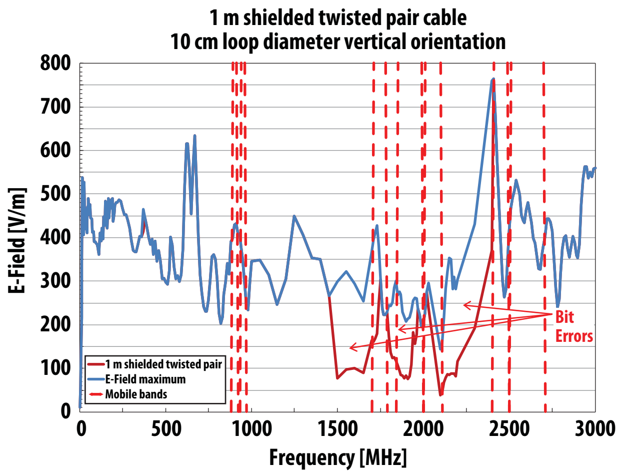

Figure 4. Bit errors caused by EMI with vertically oriented copper cable loop

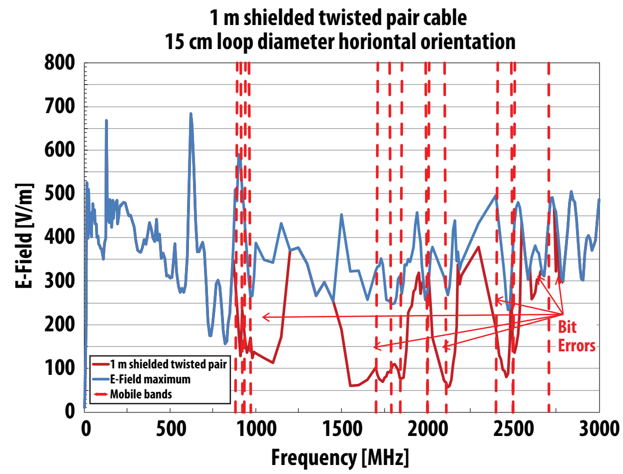

Figure 5. Bit errors caused by EMI with horizontally oriented copper cable loop

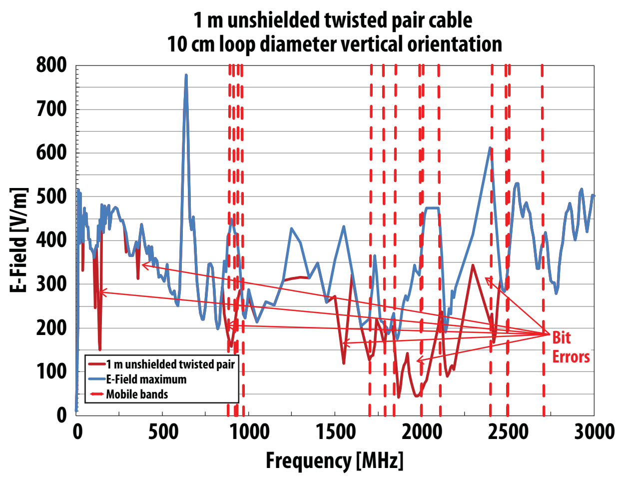

Figure 6. Bit errors caused by EMI in unshielded twisted pair cable

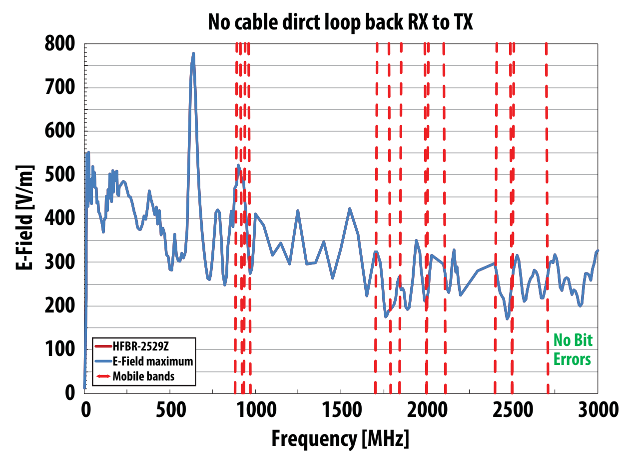

Figure 7. No bit errors when copper cables removed and direct fiber link employed

This test demonstrates that the copper cable acted as an antenna, absorbing EMI and propagating the energy to the receiving circuits, causing bit errors. When the identical test was done with only a fiber loop in the chamber, there were no errors induced by the strong EM fields. While this test could be extreme in terms of magnitudes and frequencies, one does encounter applications where hundreds of amps are switched within a micro-second. Examples of these applications are motor drives, IGBT, SCR trigger circuits, and power contactors. This type of current switching causes large magnetic and electric fields to radiate (including higher frequency harmonics), thus creating very aggressive and noisy environments. For these environments, optical fiber is clearly the better choice.

Cost

Having established the performance advantages of fiber links in terms of galvanic insulation, common mode voltage and EMI immunity as compared to copper links, it would be reasonable—but erroneous—to assume that these benefits always come at a substantial increase in relative cost. To illustrate this point, consider the following two bills of materials (BOMs) for equivalent industrial link designs, the first (Table 1) for a 10m RS-485 copper link, the second (Table 2) for a 10m POF link. As the requirements for shielded/certified cables increase, so do the associated costs. Plastic fiber solution costs remain the same regardless of the application environment.

Table 1. Bill of material for a Copper RS-485 link without any insulation and isolation products.

Component	Quantity	PN/Desc	Unit Cost (@ 5 K)	Subtotal	Comments
DB9 Connector	2	SPC15477	$1.80	$3.60	SPC Tech
DB9 Twisted Pair Cable	10 m	Belden 9481	$2.70/m	$27.00	Belden 9481, STP120 ohm, RS-485 rate cable $2.80/m
Line Driver	2	LTC1485	$1.50	$3.00	Linear Tech
RSMD 603	2	120 ohm	$0.02	$0.04	Panasonic ECG
RSMD 603	4	10 kohm	$0.02	$0.08	Panasonic ECG
CSMD 1206 10 V	2	10 µF	$0.12	$0.24	AVX
				$33.96	

Table 2. Bill of material for an Avago industrial POF link

Component	Quantity	PN/Desc	Unit Cost (@ 5 K)	Subtotal	Comments
Duplex POF Assembly	1	HFBR-RMD010z	$14.56	$14.56	Plastic Fiber Cable, 1mm POF, 10 meters (Avago)
Versatile Link™ Tx/Rx	2	AFBR-1624Z/2624Z	$9.78	$19.56	Pair price/Versatile Link Devices (Avago)
L SMD 1206	4	1 µH	$0.20	$0.80	AVX
R SMD 603	2	4.7 kohm	$0.02	$0.04	Panasonic ECG
CSMD 603	4	0.1 µF	$0.05	$0.20	Panasonic ECG
CSMD 1206 10 V	4	10 µF	$0.12	$0.48	AVX
				$35.64	

Clearly, the cost of the copper link is dominated by the copper cable itself. In a conservative or in a high-reliability design, most engineers will choose such a well-shielded, high-quality cable to help prevent noise ingress and egress. In such cases, fiber is easily competitive on cost. If less shielding and lower quality copper cabling is sufficient (i.e. CAT5), the cost of the copper cable drops, making it the more cost-effective solution for 10m cabling. For longer length cabling, however, the polymer optical fiber (POF) gets more economical due to lower cost per meter ($0.20/m) compared to copper ($1/m) without connectors. The POF maximum length without the use of repeater is typically 50m.

Ease of Use, Design and Installation

Typically terminating glass fibers is more time consuming than connecting twisted-pair wire because these fibers require epoxy and their ends needed to be polished. The POF however, due to its large 1mm polymer core is much easier to handle. Avago offers two options – the SFH series "connectorless" family and the Versatile Link snap-in (or "crimpless") style connector (Figure 8) – these allow fiber optic cables to be terminated more easily than shielded twisted-pair cables.

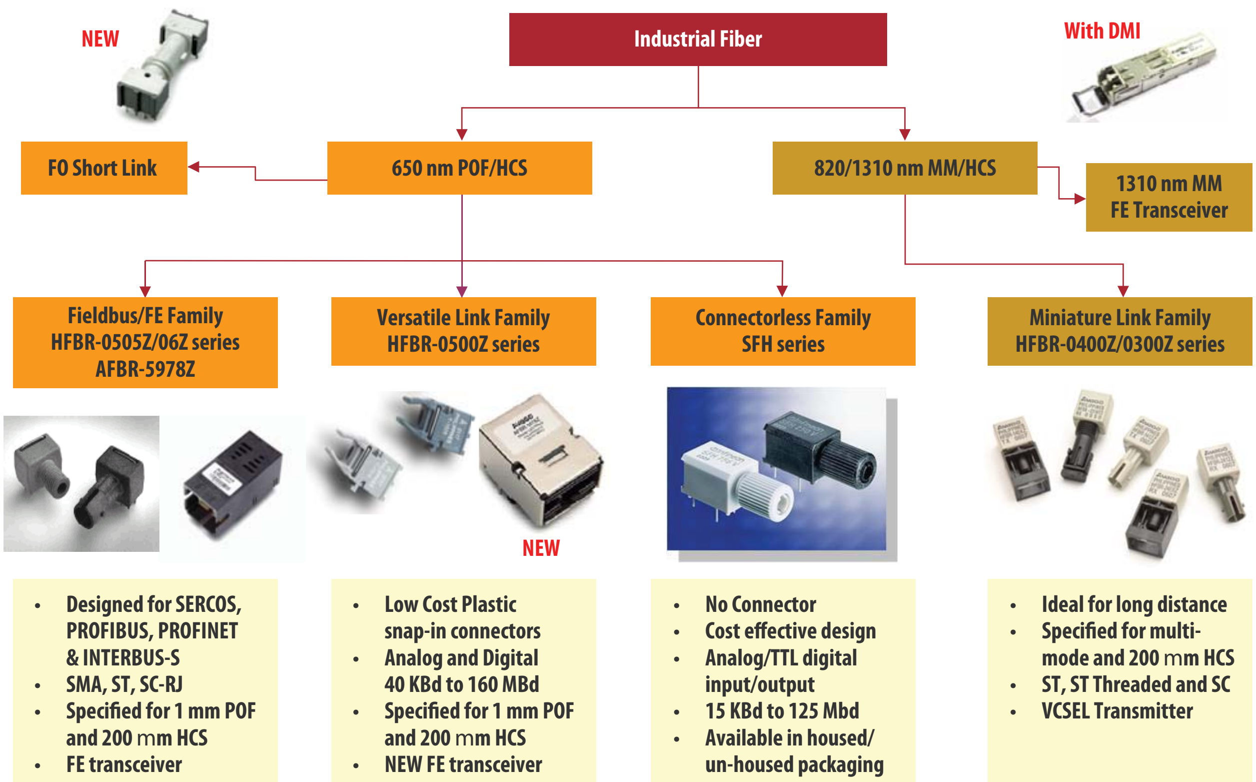

Figure 8. The variety of industrial fiber connector families available from Avago

The SFH-series or "connectorless" transmitters and receivers (Figure 9) have 650 nm fiber optic components that work with "un-connectorized" POF for which no polishing is required. The user simply cuts the fiber to the desired length, inserts it into the active component ports and tightens the built in locking mechanism.

The HFBR-453XZ series connectors are an enhanced version of the HFBR-4501Z and HFBR-4503Z connectors for plastic optical fiber, compatible with Avago's Versatile Link series transmitters and receivers which are capable of up to 160 MBd (Figure 10). This design uses a simple, snap-together concept that eliminates the need for crimping, thereby greatly reducing labor and tool costs as well as potential yield loss due to installation error.

Figure 9. The SFH series of connectorless technologies greatly simplifies POF installation

Figure 10. The Versatile Link family makes installation a "snap"

In addition to providing a simple, rugged medium for optical connections, Avago has recently integrated the driver IC's for many products into the transmitter package and the receiver IC in the receiver package. Such is the case for the 650nm Versatile Link Transmitter AFBR-1624Z and Receiver AFBR-2624Z (Figure 11). With little or no knowledge of optical drive circuits, the designer can simply add the component by connecting the specified signal (TTL, LVTTL, PECL, LVDS) to the inputs. This integrated design uses less board space, consumes less power, and reduces the cost of the overall link. It also reduces the signal trace length which improves the EMI performance of the parts.

Moreover, optical fibers offer another advantage against copper with regards to diameter and weight. For equivalent lengths of copper cable, the fiber is thinner and weighs substantially less. This implies that for the same installation space for a copper cable, it can hold several optical fiber links and is much easier to handle.

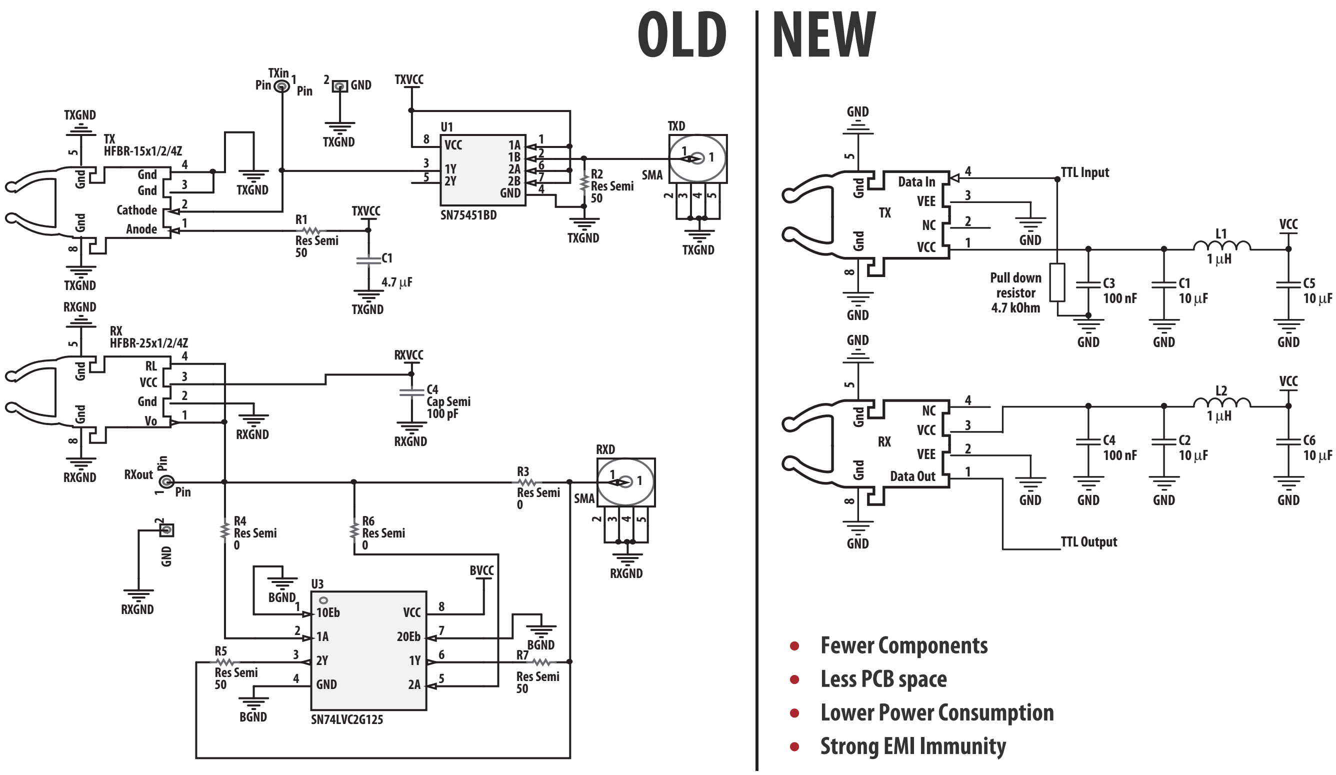

Figure 11. The comparative simplicity of design using the AFBR-1624Z and AFBR-2624Z Versatile Link Transmitter and Receiver

Markets and Applications

The advantages offered by fiber as a data exchange medium have proven invaluable to a wide range of applications within a number of markets (Table 3).

Table 3 . The advantages of optical fiber links for key markets and applications

Market	Value
Power Generation and Distribution Systems • Substation control • LV/MV electrical distribution • Network control • Power switching, relays, switchboards • Wind turbines • Hydro-power stations • Photovoltaic systems	• Shields integrated in receiver IC for additional localized noise immunity • Up to 50 m link distances over POF • Superior EMI immunity options: conductive packaging and metal ports • Up to a few hundred meters using HCS • Up to few kilometers using multimode
Industrial Communications and Factory Automation Test and measurement instruments • Audio/video communications • Industrial control • Industrial fieldbuses (SERCOS, Profibus, InterBus, etc.) • Industrial Ethernet • Data communications and LANs • Industrial communications	• Superior performance compared with copper communication links EMI/EMC • Full portfolio of components with data rates up to 160 MBd
Transportation • Automotive communications • In-car communications • Car-to-car communications • Traffic signaling • Highway SOS boxes and monitoring systems • Toll station networking • Civil and military avionics • Subways and tramways • CCTV in transportation • Maritime	• Voltage isolation • Use of 3.3 V for greater power savings • Weight savings from low-density fiber
Medical, Consumer and Gaming • MRI Machines • X-Ray Machines • Satellite TV over fiber • Distributed Antenna Systems (DAS) • Casino machines	• High noise immunity suitable for mission-critical medical equipment • Superior performance in mission-critical medical equipment where downtime cannot be tolerated

As communication data rates increase, the optical fiber's value strengthens because it a good choice for "future proofing" today's application designs. For example, transmitting 125 Mb/s Fast Ethernet (100BASE-FX) up to 2 km is possible with fiber links while an equivalent copper link (100 BASE-TX) is limited to 100 meters.

Conclusion

Optical fiber technology must be considered a viable medium for data exchange, especially in harsh industrial environments, because the dielectric properties of the core make it immune to electromagnetic radiation, ground loops, EMI ingress form nearby switching circuits, and crosstalk. Fiber also weighs substantially less than equivalent lengths of copper cabling, is readily capable of very high data rates (present components deliver up to 160 MBd), and even the cost-efficient POF can span as far as 50 meters. Yet, for all of the aforementioned benefits, it remains cost competitive with copper links that serve in these demanding applications, and in many cases, easier to design, install and use.

For product information and a complete list of distributors, please go to our web site: **www.avagotech.com**

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