

# DC to 10 MBd Versatile Link with Plastic Optical Fiber or Hard Clad Silica Fiber (HCS®) for Factory Automation and Industrial Control Applications



## Application Note 1080

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*HCS® is a registered trademark of OFS*

#### I. Introduction

This application note discusses the functions and features of the **10 MBd HFBR-0508Z Fiber Optic Versatile Link**, which is designed for a variety of industrial applications. These include serial data interfaces in robots, machine tools, assembly and printing machines, and gate-drive circuits in frequency inverters. Circuit design hints and other subjects not found in the product data sheet will also be presented. The reader can use this information to design reliable fiber-optic links based on plastic optical fibers (POF) for distances below 50 m and hard clad silica (HCS®) fibers for distances up to 500 m.

Further information about fiber-optic link design can be found in Application Briefs AB 73 and AB 78, and Application Notes AN 1035 and AN 1066, which are listed in appendix VII. Avago Technologies' applications engineers or your local certified distribution application engineers are available for further design assistance.

## 1. Interconnects without Crosstalk

Fiber-optic technology is completely changing data communications, particularly in industrial environments, where data must be transferred between machines more quickly than ever before. Avago Technologies believes that fiber optics is replacing copper cabling in many of these applications because of the wide range of advantages inherent to fiber cable. Glass and plastic fibers, being dielectric materials, are completely immune to stray electromagnetic fields, which are common in industrial applications that use motors and power switches. These fibers can be placed in a duct alongside high-voltage metal cables without being susceptible to crosstalk. This feature simplifies system installation. Twisted-pair copper cables require a minimum distance from power lines to guarantee error-free data transfer.

## 2. International EMC Regulations

Due to increasingly stricter international control over electromagnetic compatibility of electronic equipment, manufacturers often cannot legally sell their products in many countries unless specific immunity and emission limits are met. These limits are based on standards such as FCC, VCCI, EN, CISPR, IEC, VDE, and so forth. For example, beginning January 1, 1996, all equipment and systems that will be sold into the European Union have to meet European EMC standards, otherwise they can be excluded from the market. The generic standards for the industrial field are EN 50081-2 (emission) and EN 50082-2 (immunity). In many applications design engineers do not have a cost-effective alternative to fiber optics if their systems must meet the national or international regulations for electromagnetic compatibility.

## 3. Fiber Optic Connectors vs. Electrical Connectors

In the past, many design engineers were reluctant to design with fiber optics. Terminating fiber cable was more time consuming than connecting twisted-pair wire because fibers required epoxy and their ends needed to be polished. Large-core polymer optical fiber [POF] and the new crimp and cleave technology for the Versatile Link Snap-in connector (V-System) allow fiber optic cables to be terminated more easily than shielded twisted-pair cables, while offering an electromagnetic-compatible communication link. This is a very strong reason for using fiber optic cables, a reason that the installation and service divisions of a company should also accept.

## 4. Galvanic Insulation

Ground-loop currents due to different ground potentials are a common problem in industrial communication networks. Ground loops and their associated noise problems are totally eliminated by the insulation characteristics of fiber, allowing a straightforward and fast system integration. In addition, the insulating property of glass and plastic fibers is ideal for many monitor and control functions needed in high-voltage applications. For intrinsically safe applications, which are common in the chemical industry, fiber optics is easy to qualify and is also the best medium for connecting one electrical device to another through an isolation barrier.

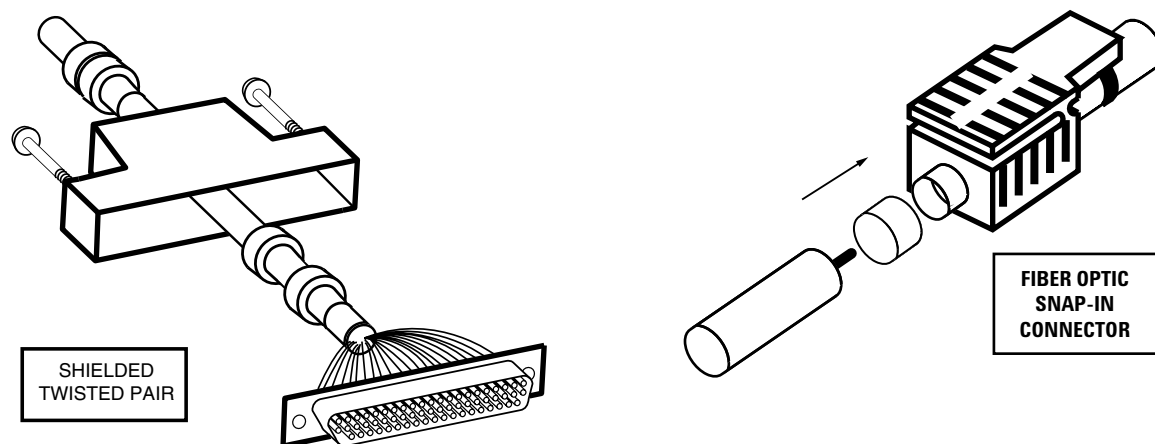


Figure 1. Comparison of Shielded Twisted Pair vs. Fiber Optic Snap-in Connector.

## II. Product Description

### 1. Housing and optical port

The Versatile Link family has been used successfully in many different industrial applications based on plastic fibers. Users have the benefit of a reliable system that is easy to install in the field. The compact package is made of a flame retardant (UL V-0) material in a standard, six-pin DIP. Transmitters or receivers can be stacked together, creating duplex optical ports that save printed circuit board space and avoid fault connections. The conductive housing of the HFBR-2528Z receiver provides an excellent EMI shield. The color-coded packages eliminate confusion between transmitters and receivers. A plug protects the optical port during auto-insertion and soldering.

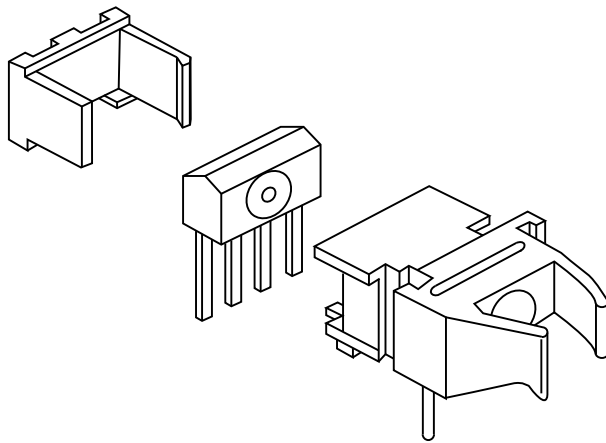


Figure 2. Package Construction.

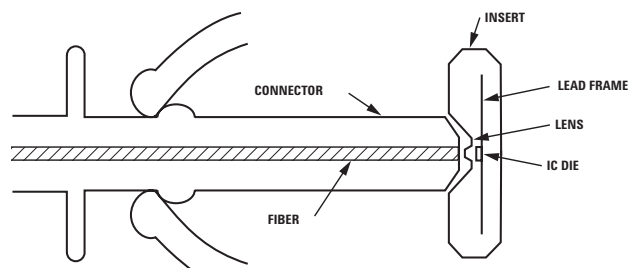


Figure 3. Connector Alignment to Transmitter LED or Receiver IC.

The Versatile Link package uses an active alignment system to ensure proper coupling between the fiber and the optoelectronic converter. Figure 3 illustrates how the alignment system operates. The precision-molded lens on the insert is located at the bottom of a depression in the shape of a truncated cone. The connector is inserted into the package; the jaws of the housing force the bevelled end of the connector into the cone-shaped depression. This accurately centers the fiber directly above the molded lens on the insert and ensures efficient, reliable and repeatable connections.

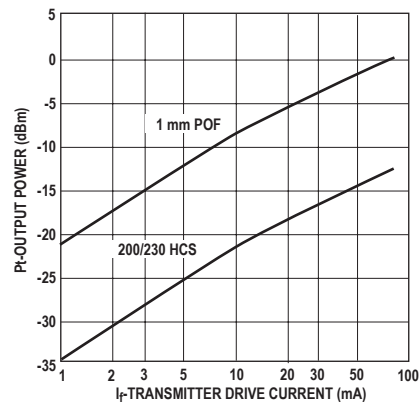


Figure 4. Typical Transmitter Output Power vs. Drive Current.

### 2. Transmitter Technology

The new HFBR-1528Z transmitter uses a high quantum efficiency LED based on a new Avago Technologies AlIn-GaP technology. At a 60 mA drive current, the coupled power into a 1 mm POF is typically -3 dBm, a 6 dB improvement over previously used transmitters. With a center wavelength of 650 nm at room temperature, the transmitter is in the minimum attenuation window of the POF. Typical link distances of 100 m with low-cost plastic fibers are now a reality. When using the 200  $\mu$ m HCS fiber link, 500 m distances are possible. In addition to the higher coupled power, the optical rise and fall times have become much faster, allowing much simpler LED drive circuits without the need for peaking and pre-biasing for data rates of 10 MBd.

### 3. Receiver Technology

The new HFBR-2528Z receiver with its TTL/CMOS-compatible output is specified for data rates from dc to 10 MBd NRZ (non-return to zero). It has a sensitivity of -21 dBm peak with 1 mm POF, or a sensitivity of -23 dBm peak with 200 HCS<sup>®</sup> fiber. Propagation delay times  $t_{PLH}$  (output low to high) and  $t_{PHL}$  (output high to low) are equally distributed to achieve pulse-width distortion (PWD) of less than  $\pm 30$  ns over a large input power range. As a result, LED drive current adjustments for different link lengths and fiber types are unnecessary.

A patented first-bit PWD correction circuit makes the HFBR-2528Z the ideal product for arbitrary duty-cycle links or for the use in frequency inverters such as gate-drive applications. Other products on the market with similar optical and electrical specifications require the transmission of overhead bits prior to the data because of heavily distorted first bits. Therefore, the user has to add additional circuitry to transmit a preamble prior to the data bits, making the transmit and receive circuit more complex and costly. For better electromagnetic compatibility, a conductive housing material has been chosen for shielding the receiver in electromagnetically polluted industrial environments.

#### 4. Types of Fiber Optic Cables

Historically, glass fibers have been used in long-haul telecommunication links and local-area networks because of low attenuation and large bandwidth. Ethernet and FDDI (Fiber Distributed Data Interface) standards, for example, have specified multimode 62.5/125  $\mu\text{m}$  glass fibers. These small-core fibers need high-precision connectors to minimize the coupling loss. For industrial application, fibers with lower-cost connectors, which are easier to install and less sensitive to dirty environments, are required. For these applications, 1 mm POF (Polymer Optical Fibers) and 200  $\mu\text{m}$  HCS (Hard Clad Silica) fibers are the best media.

While there are many types of fiber-optic cables (a cable is composed of a fiber and a jacket), only two types, 1 mm POF and 200 HCS, are specified for use with Versatile Link POF and HCS Snap-In Connectors. These step-index fibers are made from silica (HCS) or a polymer (POF) in which the core has a higher refractive index than the cladding. A 2.2 mm jacket around the fiber protects against mechanical or thermal damage and increases the strength of the cable.

#### 4.1. Polymer Optical Fiber (POF)

The large-core diameter (980/1000  $\mu\text{m}$ ) and numerical aperture of the POF (Polymer Optical Fiber) are well matched to the large effective diameter and numerical aperture of the optical ports, allowing the power launched into the core to be as high as 0 dBm with the HFBR-1528Z transmitter. The POF also offers comparably low-cost termination, which can be done “in the field” in less than a minute using a simple and inexpensive crimping and cutting procedure. The attenuation minimum is at 650 nm and is typically about 0.2 dB/m. It should be noted that the spectrum of the new transmitter has a center wavelength at 650 nm at the minimum attenuation of the POF.

#### 4.2. Hard Clad Silica Fiber (HCS)

Step-index silica fibers, such as PCS (Plastic Clad Silica) or HCS<sup>®</sup> (Hard Clad Silica) fibers with a large-core (200  $\mu\text{m}$  diameter compared to glass fibers with 62.5  $\mu\text{m}$  core diameter) permit the use of low-cost transmitter/receiver lensing systems. Because of the high attenuation in the visible red wavelength range, PCS fibers are commonly used in a lower attenuation window with higher-cost infrared LEDs. The fiber with the lowest attenuation in the visible red wavelength range is the HCS fiber. At 650 nm the attenuation is typically 8 dB/km.

The core of the HCS fiber is silica and the cladding is a proprietary hard polymer that also acts as a strength enhancer and makes it impervious to moisture and impurities. High temperature specifications for extended industrial temperature ranges, and UL ratings for plenum and riser applications are also available.

The snap-in V-System connectors can be crimped directly onto the HCS fiber because the proprietary hard cladding bonds to the silica core material, thus eliminating the need for messy epoxies. A patented cleaving tool cuts the excess fiber protruding from the connector end. Due to the simplicity of the termination process, the Versatile Link Snap-In connector can be mounted in less than 45 seconds.

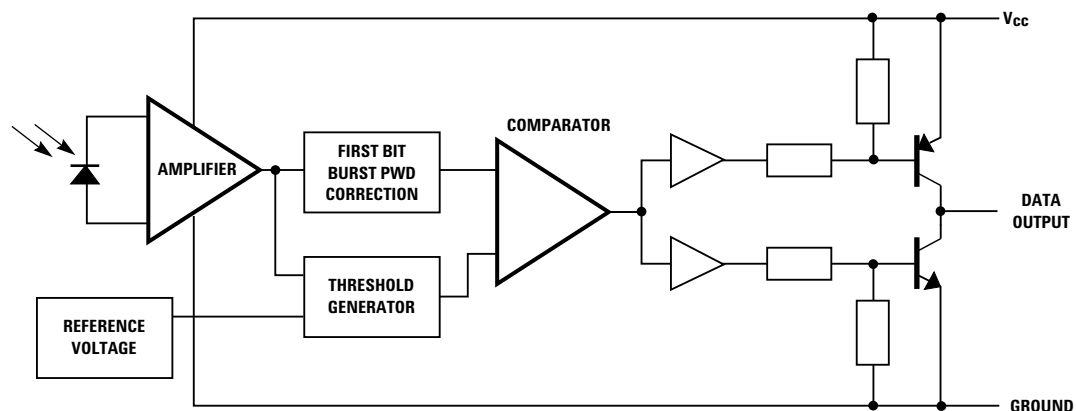
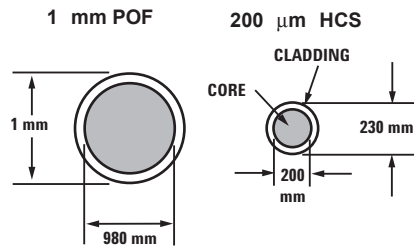


Figure 5. Receiver Block Diagram.



PARAMETER	POF 1 mm	HCS 200/230 $\mu$ m
TENSION (60 min)	50N	100N
TENSION (10 YEAR)	1N	25N
BEND RADIUS (1H)	25 mm	10 mm
FLEX	1,000 X	50,000 X
ATTENUATION (660 nm)	200 dB/km	6 dB/km
NA	0.47	0.37
INSTALLATION TEMPERATURE	-20 C TO +70 C	-20 C TO +85 C
FLAMMABILITY	VW1	RISER PLENUM LSZH

Figure 6. Polymer vs. Hard Clad Silica Cables.

### III. Fiber Optic Link Design

The HFBR-0508Z family is designed and characterized for data rates from dc to 10 MBd; Avago Technologies specifies link length for 1 mm POF fibers (0 to 60 m) and 200  $\mu$ m HCS fibers (0 to 500 m). Power supply variations, connector coupling loss and temperature drift effects are part of the guaranteed data sheet specifications. In addition, a 3 dB margin takes aging into account. Avago Technologies specifies the link performance using the transmitter and receiver interface circuits described in the product data sheet, which gives Avago Technologies' customers the maximum available design security. The following considerations will help the design engineer to become more familiar with low-cost, fiber-optic link design and gives guidelines to optimize the link performance for particular applications.

#### 1. Link Length Considerations

A fiber-optic system basically consists of an LED, a length of fiber, and an optical detector. The LED transmitter, modulated by the electrical input signal, couples light into the fiber. The light travels along the fiber to an optical detector, which converts the light into an electrical signal again. The important specifications for fiber-optic links are how much light is coupled into the fiber, how much light the receiver needs to function properly, and how much light is lost in the fiber between the transmitter and the receiver.

Depending upon the fiber length and wavelength of the signal source, if data rates are very high (125 MBd or greater), the optical signal is distorted. This effect, called dispersion<sup>[3]</sup>, limits the bandwidth of the fiber-optic system. Fortunately, in most industrial communication systems the data rate is less than 10 MBd and the dispersion effect contributes only if the link length exceeds 100 m with POF or 1000 m with HCS Fibers. Below these values the links are limited by attenuation, so a straightforward optical power budget calculation is the only consideration.

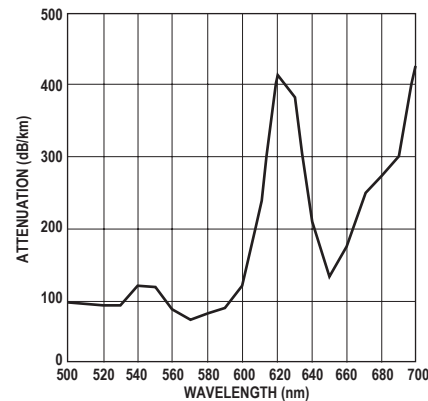


Figure 7. Attenuation vs. Wavelength for POF.

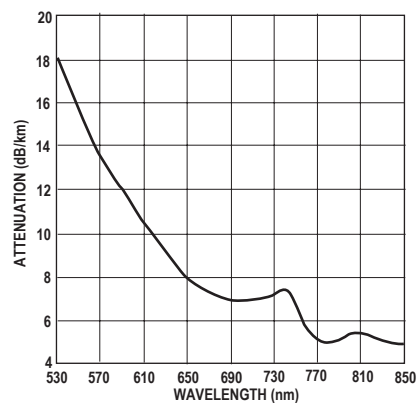


Figure 8. Typical Attenuation vs. Wavelength of HCS Fibers.

#### 1.1 Optical Power Budgeting Computation

The optical power budget is the difference between the output power of the transmitter and the sensitivity of the receiver. The maximum length of the optical fiber is determined by the attenuation of the fiber, additional losses due to feed-through connections and a "safety factor" called optical power margin (see chapter III/1.4). Formula III/1 gives the maximum link length for worst-case conditions: Versatile Link transmitter and receiver specifications account for coupling losses to and from 1 mm POF or 200  $\mu$ m HCS fiber.

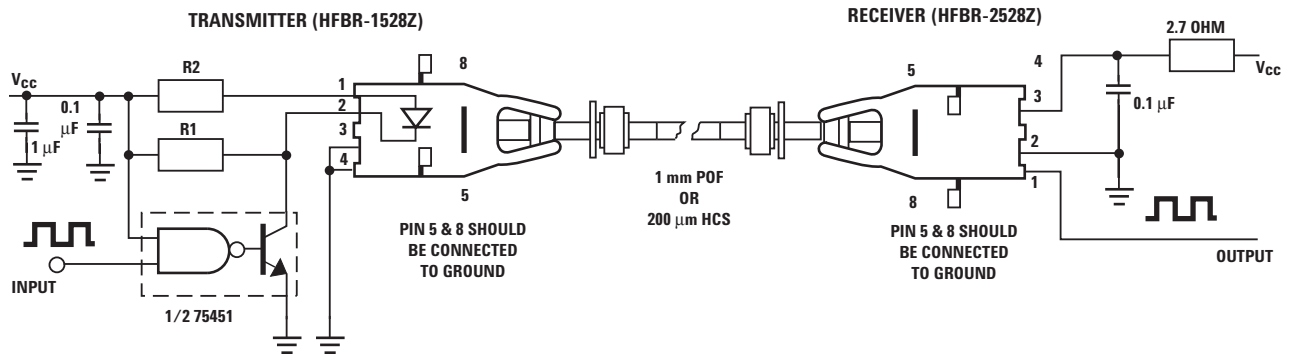


Figure 9. Versatile Link Set-Up.

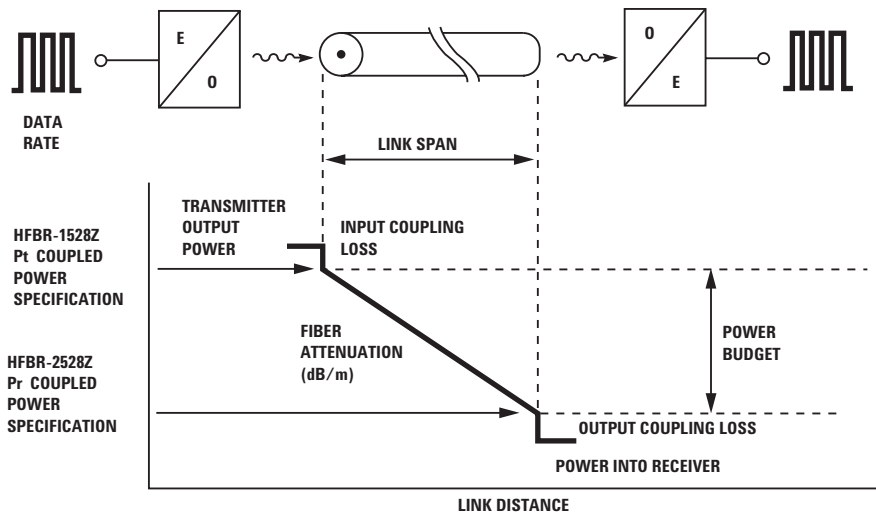


Figure 10. Fiber Optic Link Main Parameters.

## 1.2. Dynamic Range

An important link design consideration is the receiver's optical dynamic range, the difference between sensitivity ( $P_{RL, \min}$ ) and overdrive conditions ( $P_{RL, \max}$ ): in other words, the dynamic range specifies the minimum-to-maximum link length. Exceeding the dynamic range of the receiver may lead to an increase in PWD. The maximum allowed power level of the receiver specifies the minimum link length needed to avoid overdrive condition. The maximum optical power that the HFBR-1528Z can launch, however, is well matched to the HFBR-2528Z receiver's overdrive characteristics. If the LED drive circuit recommended in the HFBR-1528Z data sheet is used, the transmitter cannot over-drive the HFBR-2528Z receiver even when the length of the fiber-optic cable is virtually zero meters.

### Equation III/1:

$$l(\max) = \frac{P_T(\min) - P_{RL, \min} - IL - OPM}{a(\max)} \quad (m)$$

$P_T(\min)$ : Minimum coupled power of transmitter (dBm)

$P_{RL, \min}$ : Sensitivity of the receiver (dBm)

IL: Sum of insertion loss of feed-throughs (dB)

OPM: Optical power margin, which accounts for LED degradation, supply voltage variation, etc. (dB)

$a(\max)$ : Maximum attenuation of fiber (dB/m)



### Equation III/2:

$$l(\min) = \frac{P_{T(\max)} - P_{RL, \max}}{a(\min)} (\text{in m})$$

$P_{T(\max)}$ : Maximum coupled power of transmitter (dBm)

$P_{RL, \max}$ : Maximum optical power level of receiver (dBm)

$a(\min)$ : Minimum attenuation of fiber (dB/m)

The extremely large dynamic range of the HFBR-2528Z receiver typically allows room-temperature distances from 0 to 100 meters when using 1 mm plastic fibers. Typically, LED current adjustments are not needed as the length of the plastic fiber can vary from 0 to 100 meters at room temperature, and the maximum adjustment-free distances possible over the temperature range are specified in the HFBR-0508Z series data sheet.

### 1.3 Temperature Drift Considerations

The data sheet includes the transmitter output power range for ambient temperatures at  $T_A = 25^\circ\text{C}$ ,  $T_A = 0$  to  $+70^\circ\text{C}$ , and  $T_A = -20^\circ\text{C}$  to  $+85^\circ\text{C}$ , in addition to the guaranteed link length specifications. But by knowing and understanding all different temperature drift effects that the link depends on, the design engineer will be able to optimize the link performance, particularly, the maximum fiber length.

The output power of the transmitter is inversely proportional to the junction temperature, resulting in a lower output power at high temperatures ( $\Delta P_T / \Delta T$ ).

### Equation III/3:

$$P_T(T) = P_T(25) - \frac{\Delta P_T}{\Delta T} \cdot (T - 25)$$

$P_T(T)$ : Output power at desired temperature (dBm)

$P_T(25)$ : Output power at room temperature specified in the data sheet (dBm)

$\Delta P_T / \Delta T$ : Output power temperature coefficient (dB/°C)

The forward voltage ( $\Delta V_F / \Delta T$ ) of the LED will drop with an increase in temperature, causing an increase of drive current, which partially compensates for the decreasing output power.

### Equation III/4:

$$V_F(T) = V_F(25) - \frac{\Delta V_F}{\Delta T} \cdot (T - 25)$$

$V_F(T)$ : Forward Voltage at desired temperature (V)

$V_F(25)$ : Forward Voltage at room temperature, specified in the datasheet (V)

$\Delta V_F / \Delta T$ : Forward Voltage temperature coefficient ( $\Delta V / \Delta ^\circ\text{C}$ )

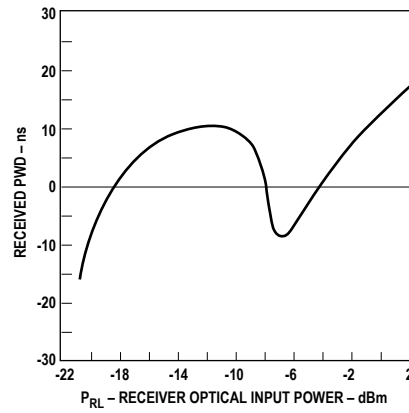


Figure 11. Typical Receiver Pulse-Width Distortion vs. Optical Input Power at 10 MBd.

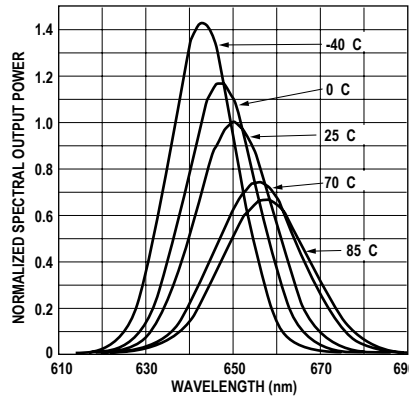
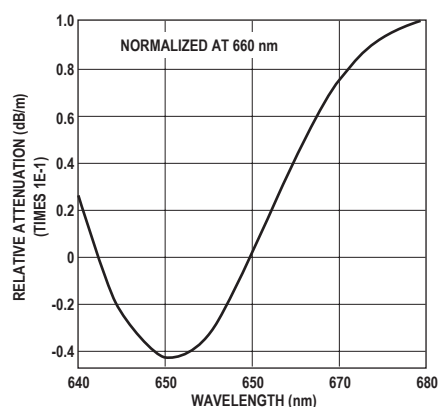


Figure 12. Typical Normalized Optical Spectra to Peak at 25°C.

The center wavelength of the LED transmitter, typically 650 nm at room temperature, changes wavelength as the temperature changes. In the POF data sheet, attenuation is specified at 660 nm because of compatibility with the older type, lower output power 660 nm GaAsP transmitters. At room temperature the center wavelength of the new AlInGaP transmitter is exactly in the minimum attenuation window of the POF. Therefore, the optical power budget allows a longer link distance at 25°C than specified in the data sheet. Attenuation at 650 nm is about 0.05 dB/m less than at 660 nm, which permits a 65 m link. (Please see note 3 in the HFBR-0508Z Series data sheet. <sup>[5]</sup>)



**Figure 13. Typical Normalized Spectral Attenuation of 1 mm POF.**

Because of the complexity of the receiver circuit IC, a detailed discussion about sensitivity temperature drift is beyond the scope of this application note. Drift effects are specified in the product data sheet and one should not be concerned about them.

#### 1.4. Reliability Considerations

The service lifetime of the fiber-optic link is, however, quite often a concern. One can separate link reliability into transmitter, receiver, connector and fiber reliability. HCS fibers are known to be very stable under harsh ambient conditions and have been qualified for 30-year lifetimes. POFs are estimated for up to 20-year lifetimes. Short-term and long-term bend radius, tensile load, flexing, as well as the mechanical properties of the connectors are specified in the cable data sheet [8]. A detailed discussion about fiber [11,12] and connector [8] reliability is beyond the scope of this application note.

More of a concern is the useful lifetime of short-wavelength LED transmitters, which must be taken into account in power budget calculations. It can be assumed that the receiver sensitivity will not change over time. The transmitter light output reduction is a function of junction temperature, drive current, and endurance time. The useful lifetime of the LED transmitter is typically defined when the initial light output is reduced by 3 dB. Reliability tests of the HFBR-1528Z transmitter project a median useful life of 9 years at -3dB, 85°C, 50 % duty cycle, and forward current equal to 60 mA. Therefore, the optical power budget must be decreased by the expected reduction in light output at the end-of-life specification. More detailed information can be found in the reliability data sheet [6].

**Table III/1: Projected useful life for various temperatures, where end of life is defined as a 50% drop (-3dB) in light output.**

$I_f$ [mA] 50% DC	$T_A$ [°C]	Median Useful Life [y]	90% Survival Life [y]
60	85	9	4
60	70	17	8
60	55	33	15
60	40	68	32

#### 1.5. Connector Loss

Connector coupling losses at the transmitter and receiver are already included in the data sheet specifications. Connector coupling losses due to connections through bulkhead adapters need to be determined. The following table shows the minimum and maximum insertion loss specifications for Avago Technologies' 1 mm POF bulkhead connections. As the number of bulkhead connections increases, the range of losses increases, as does the magnitude of the losses. Coupling loss characterization of special bulkhead connectors for the 200 µm HCS fiber was not completed when this application note was printed.

**Table III/2. Feed Through Loss Specifications.**

Part No.	Fiber Size	Min. Loss	Typ. Loss	Max. Loss
HFBR-45X5Z	1 mm POF	0.7 dB	1.5 dB	2.8 dB

#### 1.6. Coupling Loss

If light from a larger-core fiber is coupled into a smaller-core fiber, a significant loss of optical power can be measured. The loss is a function of the difference in area (d) and the numerical aperture (NA), and is expressed by the following formula:

**Equation III/5:**

$$IL(dB) = 20 \cdot \log \frac{d1}{d2} + 20 \cdot \log \frac{NA1}{NA2}$$

d1: Emitting fiber diameter

d2: Receiving fiber diameter

NA1: Numerical Aperture emitting fiber

NA2: Numerical Aperture receiving fiber

Light from a smaller core fiber will be coupled into a larger core fiber without area and NA losses.



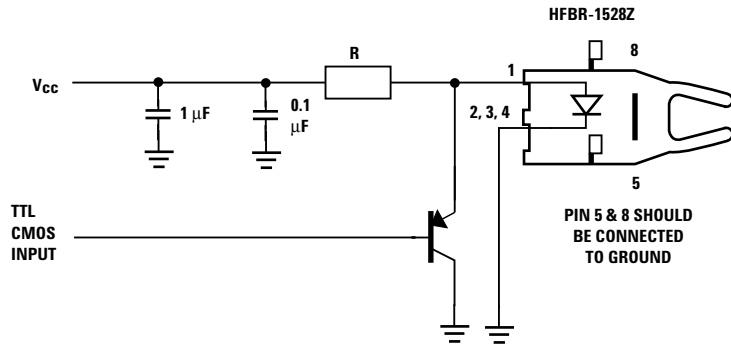


Figure 14. PNP Shunt Drive Circuit.

## 2. Transmitter Drive Circuits

LED-based transmitters are easy and simple to drive because the current through the LED is proportional to the optical output power. The current can be amplitude modulated using only a switching transistor and a single resistor in series with the LED. Because of the simplicity of the drive circuit, the design engineer has many options to realize this function. As mentioned previously, the HFBR-0508Z link performance is guaranteed when using the drive circuit in the data sheet (see also 2.2), as it meets most application requirements. The pros and cons of a few other approaches that will help design engineers to optimize their link performance for specific applications are discussed in the following section.

### 2.1. Pros and Cons of Parallel and Series Transmitter Drive Circuits

Basically, two methods exist for driving LEDs. One uses a series driver (Figure 9), the other is based on a parallel driving scheme (Figure 14). Series driving circuits consume only half the power but generate higher transient noise in the power supply line when the LED current is switching. The parallel driver uses a constant current from the power supply rail, thus minimizing power supply noise, which could couple into the receiver and degrade sensitivity. The parallel drive circuit also presents a very low impedance to the LED junction during turn off. This low impedance rapidly discharges the junction and quickly extinguishes the optical output of the LED.

One should keep in mind that the transmitter drive circuit topology contributes to the overall pulse-width distortion (PWD) of the fiber optic link. Therefore, it is important that the optical rise and fall times are fast compared to the symbol time. The transmitter propagation delay times,  $t_{PLH}$  and  $t_{PHL}$ , should also be equally balanced for the PWD of the entire link to be low. Fortunately, the HFBR-1528Z transmitter has rise and fall times that are fast enough to be switched without peaking and prebias<sup>[3]</sup> for data rates as high as 10 MBd. This keeps the drive circuit as simple as possible. Drive circuits for rise and fall times on the order of 3 ns are discussed in AN1066<sup>[3]</sup>.

### 2.2. Series Driver Circuit using Standard TTL Buffer ICs Data sheet Drive Circuit

The driver circuit, Figure 9, is designed in such a way that the LED is in series with the open-collector output of the driving gate. Resistor R2 sets the drive current through the LED, and resistor R1 provides a discharge path when the LED forward current is turned off.

Equation III/2:

$$R1 = \frac{V_{CC} - V_{CE} - V_F}{I_F}$$

The low-impedance path R1 quickly discharges the LED, decreasing the optical fall time. A 2 kOhm resistor was empirically found to be an optimum value for best PWD. It is important to note that capacitors C1 and C2 near the LED anode filter the noise in the power supply line during switching periods.

Figure 16 shows how LED forward current deviates from the intended or nominal room temperature design value when using a series drive circuit, due to the following factors:

- part-to-part variations in LED forward voltage,
- current-limiting resistor tolerance,
- power supply tolerance, and
- variations in the Vce saturation potential of the 75451 peripheral driver.

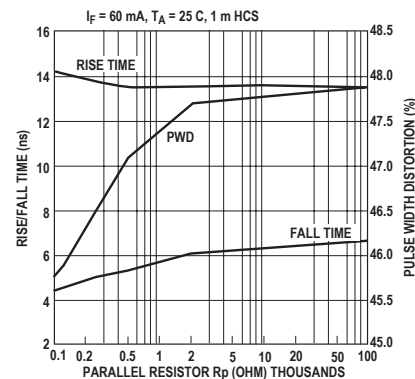


Figure 15: Typical Optical Switching Speed vs. Parallel Resistor R1.

Figure 16 also shows that as  $V_{CC}$  increases, the total variation in LED forward current, due to other circuit tolerances, is minimized.

The recommended LED driver shown in Figure 9 takes advantage of the negative temperature coefficient of the HFBR-1528Z LED forward voltage. When temperature rises, the forward voltage of the LED decreases and a greater percentage of the supply potential must be dropped across resistor R2. As temperature increases and LED forward voltage declines, the potential difference across R2 increases and Ohm's law dictates that the current through R2 and the HFBR-1528Z will increase. This increase in the drive current partially equalizes the reduced light output due to the negative output-power temperature coefficient.

The coupled power into 1 mm POF and 200  $\mu\text{m}$  HCS is specified for minimum and maximum values versus the temperature range for 20 mA and 60 mA. Intermediate power levels can be calculated based on Figure 2 in the HFBR-1528Z data sheet. At drive currents less than specified in the data sheet, the part-to-part variation of the output power increases.

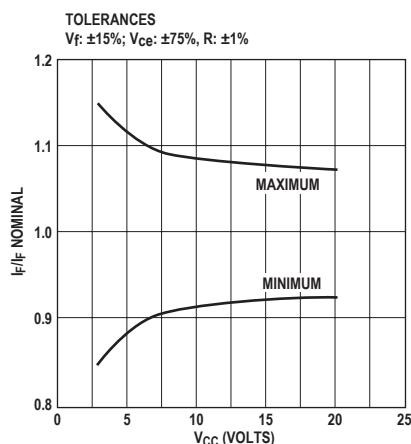


Figure 16. Output Power Variation vs. Supply Voltage and Components Tolerances.

### 2.3. The Simplest LED Trans-mitter Shunt Drive Circuit

The circuit shown in Figure 14 is a simple-shunt drive transmitter circuit that uses a pnp transistor. The primary feature is its simplicity: only two components are required and the circuit can be interfaced to TTL or CMOS gates without additional components. The circuit is also fast for several reasons:

- the transistor never saturates,
- it presents a very low impedance during turn off of the LED, and
- the emitter base junction voltage “prebiases” the LED junction resulting in a faster optical rise time

In addition, the pnp drive circuit generates low power-supply ripple because of the constant load during LED switching. The drawback is increased power consumption due to the constant current flow through the bias resistor.

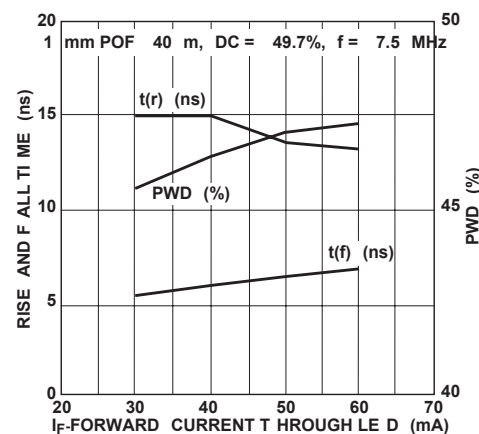


Figure 17. Switching Speed vs. Drive Current.

## 3. Receiver Interface Circuit Design

The HFBR-2528Z receiver has a push/pull digital output. It is capable of sourcing and sinking current as high as  $\pm 6$  mA (receivers HFBR-25X1Z,2Z,3Z,4Z need pull-up resistors) and can drive CMOS and TTL logic families without external resistors. Avago Technologies recommends that an RC first-order, low-pass filter (see Figure 9) be used to minimize the power-supply noise between the ground and power supply terminals of the receiver. This arrangement will meet the power-supply rejection specification. The bypass capacitor should be connected as close as possible to the power supply terminals of the HFBR-2528Z receiver. A ground plane underneath the conductive receiver housing and connected to pins 5 and 8 provides an excellent shield against electric fields as high as 8 kV/m, which could otherwise interfere with the receiver IC.

### 3.1. Sensitivity

DC-coupled receivers, such as the HFBR-2528Z, are specified for sensitivity at different conditions than ac-coupled receivers<sup>[3]</sup> in which the bit-error ratio (BER) is an important criterion. For the HFBR-2528Z, sensitivity is the minimum optical power level for a PWD of less than [30] ns, measured with a 50 percent duty cycle, square-wave signal.

### 3.2. Off-State-Limit

Avago Technologies recommends that no light be coupled to the receiver when it should remain in the logic-high state. In some instances, it might not be possible to turn the transmitter totally off. But the power delivered to the receiver should be always less than -42 dBm for 1 mm POF or -44 dBm for 200  $\mu\text{m}$  HCS fibers to ensure that the output does not randomly change state.

### 3.3. Overdrive Limit

The overdrive limit is specified where the PWD exceeds [30] ns. For example, at low temperatures, power levels can be above  $P_{RL,max} > +1$  dBm and PWD may exceed 30 ns, when using a driver circuit topology other than specified in the data sheet. The transmitter application circuit, recommended in the product data sheet, decreases the LED drive current at low temperatures because of the higher voltage drop across the LED transmitter.

## IV. Manufacturing Consideration

### 1. Handling and Assembly Guidelines

Non-stacked Versatile Link parts do not require special handling during assembly onto printed circuit boards. Avago Technologies advises, however, that normal static precautions be taken in handling and assembly of these components to prevent damage and/or degradation, which may be induced by electrostatic discharge (ESD).

HFBR-1528Z	Class 3
HFBR-2528Z	Class 1

*ESD Human Body Model*

*Mil. Std. 883 Method 3015*

All transmitters and receivers are delivered to customers in standard tubes for dual in-line packaged components and can be easily picked and placed with auto-insertion machines. During soldering, an optical port plug is recommended to prevent contamination of the port. Solderability is specified under Mil. Std. 883 Method 2003. Please follow the maximum time and temperature guidelines given in the product and reliability data sheet. Water-soluble fluxes, not rosin-based fluxes, are recommended.

### 2. Connecting Guidelines

#### 2.1. Plastic Fiber

Plastic optical cables can be terminated in less than 30 seconds by using Versatile Link Snap-in connectors and standard tools<sup>[27]</sup>. After cutting the cable to the desired length, 7 mm of the fiber jacket should be removed with a 16-gauge wire stripper. The crimp ring and connector are positioned then crimped over the end of the cable. Any excess fiber protruding from the connector end may be cut off. For better light coupling the fiber end must be polished by using 600-grit abrasive paper. See the detailed connecting instruction in the appendix of the fiber-optic cable data sheet<sup>[8]</sup>.

#### 2.2. 200 $\mu$ m HCS Crimp and Cleave Termination

The 200  $\mu$ m HCS fiber can be easily terminated by using the Snap-in V-System connector and the termination kit<sup>[28]</sup>. The entire process does not need either epoxy or polishing and so can be completed in less than a minute. The following is an abstract from the detailed Crimp and Cleave Connecting manual:

1. Remove cable jacket
2. Remove fiber buffer
3. Apply first crimp ring to fiber buffer
4. Crimp connector to jacket
5. Cleave the fiber end

#### 2.3. Optical Port Protection

During equipment manufacture Avago Technologies recommends using the optical port plug inserted into the transmitter and receiver when delivered to prevent contamination of the port. During the operational life of the communication equipment the port plug may be misplaced or lost. Therefore, a very simple "optical short circuit" between the transmitter and receiver can be constructed of a short length of 1 mm POF and a duplex connector (Figure 18). A small ring and chain can be fed through the cable opening and screwed to the front or back panel of the system so that the port plug can always be located.

Whenever the connector is inserted the station will receive its own signal and the function of the optical serial interface can be tested. In addition, a warning message telling the user that the serial port is not connected might be displayed on a system monitor.

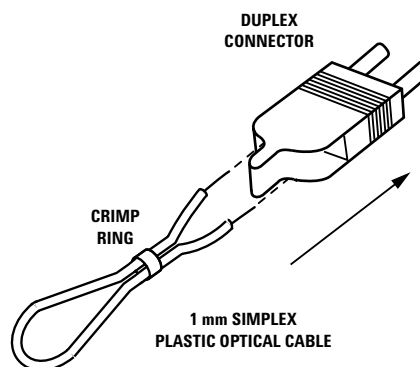


Figure 18. In use Optical Port Protection Connector.

## V. Application Examples

### 1. Introduction to Industrial Communication Networks

Compared to 10 years ago, today's industrial control equipment has changed dramatically. No longer are many single twisted-paired lines from sensors and actuators bundled into one huge and heavy cable and connected to a programmable logic controller. Today, the intelligence is distributed in the network; the actuators and sensors are connected via a bus, star or ring topology to a master unit. Standards committees and user groups have defined serial data rates from several kBd to more than 2 MBd for twisted pair and fiber-optic media interfaces. But these open-system standards do not always meet the application requirements because of speed, noise immunity, and distance specifications. Proprietary networks for critical, real-time applications, for example, must have faster response times than today's standards are specified for. These applications need serial noiseless communication channels with data rates as high as 10 MBd to achieve the desired performance of the control system. At these conditions, it is worth considering the de-facto industry standard HFBR-0508Z, fiber-optic link for isolated and reliable optical interconnects.

#### 1.1. Interface to RS 422 and RS 485

Many networks are based on an RS-485/422 physical media interface, which are based on a bus topology. Different ground potentials and noise sources may not allow a non-isolated bus structure. Therefore, active star couplers with fiber-optic ports are preferred. Quite often, a mixed topology consisting of fiber cable and twisted-pair wire is desired. In this case, the Versatile Link family is the most cost-effective line of products for fiber-optic inter-repeater links. The Versatile Link's small package allows Avago Technologies' parts to be assembled into an adapter housing for an electrical-optical converter. One side of the housing holds the electrical subminiature connector to interface with the twisted-pair bus, the opposite side has the duplex, snap-in, fiber-optic connection. Standard "off-the-shelf" line drivers and receivers for RS-422 and RS-485 [15,16,20] interface between the twisted-pair bus and the TTL receiver output and transmitter input.

While the majority of industrial communication applications are specified for data rates of 2 MBd and below (much lower than the speed of the HFBR-0508Z link), the large dynamic range of the HFBR-2528Z receiver allows a fiber-optic link to be designed without transmitter optical output power adjustment. This factor makes the installation instruction much simpler and avoids troubleshooting exercises due to receiver overdrive conditions. Whether the link is anywhere from zero meters up to the maximum length specified in the data sheet or whether the fiber is HCS or POF, the link will work reliably the moment that the power is turned on.

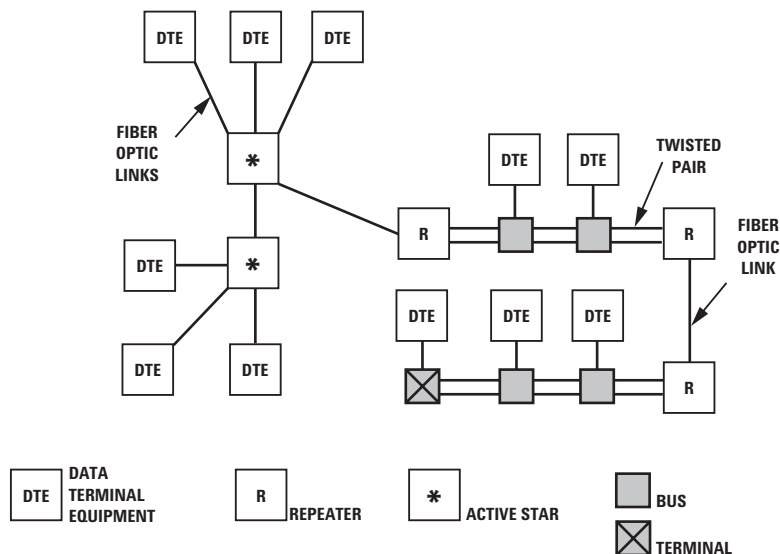


Figure 19. Network Overview with RS 485 TP Bus and Fiber Optic Active Star

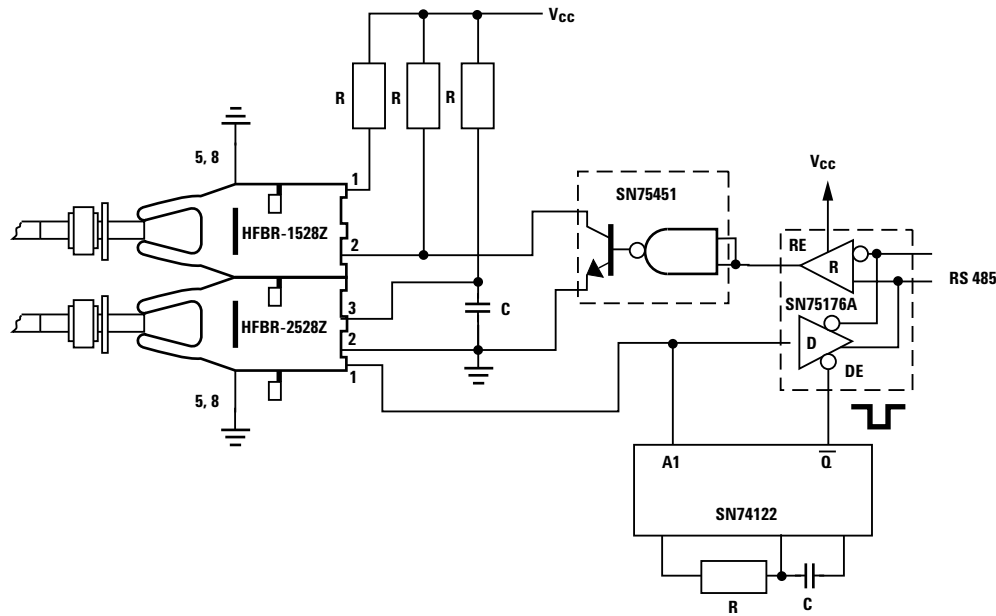


Figure 20. Basic RS 485 Fiber Optic Interface Adapter to Data Terminal.

Table V/1. Link Length Overview of HFBR-0508Z for POF and HCS Fibers.

Fiber Type	Guaranteed Link Distance	Temperature Range	Conditions
1 mm POF	0.1 to 50 m	$T_A = 25^\circ\text{C}$	$I_F = 60 \text{ mA}$ ,
	0.1 to 40 m	$0^\circ\text{C} < T_A < +70^\circ\text{C}$	10 MBd
	0.1 to 30 m	$-20^\circ\text{C} < T_A < +85^\circ\text{C}$	
200 HCS	0.1 to 500 m	$T_A = 25^\circ\text{C}$	$I_F = 60 \text{ mA}$ ,
	0.1 to 300 m	$0^\circ\text{C} < T_A < +70^\circ\text{C}$	10 MBd
	0.1 to 100 m	$-20^\circ\text{C} < T_A < +85^\circ\text{C}$	

For more details please see product data sheet!

## 1.2. Controller Area Network (CAN)

A special controller-area network (CAN), which meets the stringent reliability requirements of automobile manufacturers, has been developed for low-cost, real-time applications in cars. CAN can be found in field buses because of its open-system interface and high noise immunity. Semiconductor manufacturers<sup>[18,19,21]</sup> offer integrated circuits for ISO layer 1 (Physical) and 2 (Data Link). When using fiber optics the best network configuration is a passive star coupler. The passive star coupler<sup>[23,24,25,29]</sup> divides the optical signal from one source into multiple optical signals of nearly equal amplitude. Therefore, all devices connected to the coupler receive the transmitted data at the same time.

In the past, the high insertion loss of the passive star couplers for 1 mm POF (see Table V/2) reduced the optical power budget to nearly 0 dB, making the use of fiber

optics impossible. The new transmitter technology, with 6 dB-higher output power, allows expanded networks based on passive star couplers. Because the coding is NRZ, a dc-coupled receiver with TTL output should be used. Design engineers have two choices for the receiver interface. For data rates of 125 kBit/s (ISO/DIS 11519-1), they can use the HFBR-25X2Z receiver. If the serial bit rate is 1 MBit/s (ISO/DIS 11898), they should consider the HFBR-2528Z receiver because of its lower pulse-width distortion (PWD) specification and large dynamic range. The large dynamic range will compensate for the spread of insertion loss by the coupler. The following equation ( $V/2$ ) should be used to calculate the maximum possible link length. The maximum link length is the sum of the distance from the transmitter to the bulkhead connector and from the bulkhead connector to the receiver.

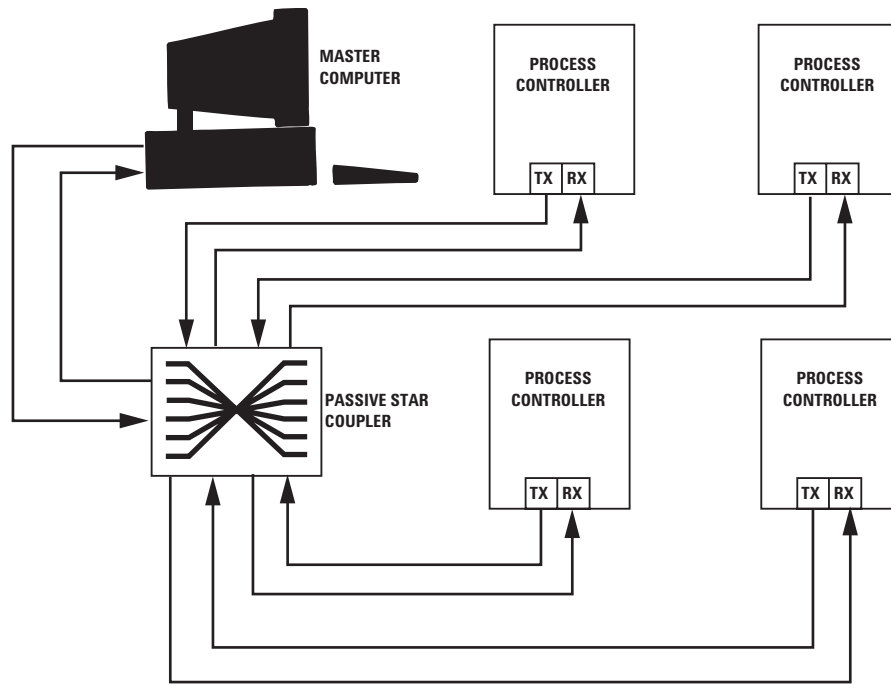


Figure 21. CAN with Passive Star Coupler.

Table V/2: Typical Insertion Loss at 660 nm for 1 mm POF Star coupler.

Ports	Insertion Loss
2•2	4 dB
3•3	7 dB
4•4	7 dB
5•5	10 dB
7•7	11 dB

For detailed specifications, please contact suppliers <sup>[23,24, 25]</sup>.

#### Equation V/2:

$$I = \frac{P_T(\min) - P_{RL, \min} - IL(\max) - OPM}{a(\max)}$$

$P_T(\min)$ : Minimum coupled power of transmitter in (dBm)

$P_{RL, \min}$ : Sensitivity of the receiver [coupled power] (dBm)

IL: Insertion loss measured from input port to output port (dB) of the passive star coupler

OPM: Optical power margin in (dB)

$a(\max)$ : Maximum attenuation of fiber in (dB/m)

The maximum data rate is also a function of the maximum distance between two nodes, because the propagation delay time must be less than half the bit time. The propagation delay constant for optical signals is 4.8 ns/m in fiber-optic links because the signal speed is equal to the speed of light divided by the refractive index. The propagation delay of the transmitter and receiver are listed in Table V/3. Transmitter and receiver delays must be added to the propagation delay of the fiber to determine the total delay of the fiber-optic link.

## 2. Gate Driving Using Fiber-Optic Interfaces

With the improvements in the development of power switches such as GTOs and IGBTs, frequency inverters can be operated at higher speed and higher power levels. On one hand, the circuit needed to drive the gates of IGBTs and GTOs has to be fast. On the other hand, the gate-drives must reliably reject the higher and faster switching transient voltages caused by the large variations in current in the power rails.



Traditional techniques based on transformers for galvanic isolation and shielded cables require very experienced engineers to design a “trouble free” interface. Even so, minimum distance requirements between the signal lines and power units and good ground contacts can make the system larger and more costly than it would be if the features inherent to fiber optics are taken advantage of. In these applications, transformers will become redundant because of the dielectric property of the fiber and the fact that it will easily meet any regulatory requirements of IEC, UL, CSA, CENELEC, VDE, etc. In addition, the fiber is immune to any kind of electromagnetic fields and can be placed alongside power lines without affecting the transmission quality. The result is a simplified design with higher reliability and less sensitivity to system failures during installation and maintenance.

The following aspects should be considered when taking advantage of the many features the new Versatile Link offers for gate-drive applications. These include shielded housing, high-temperature HCS fiber, low PWD, and the fact that the receiver can accept arbitrary duty-cycle. Avago Technologies recommends one of the transmitter drive circuits from chapter III because the switching speed is a major design issue. Because the link distance is very short in such applications, the drive current can be set to a value as low as 20 mA. The output power at 20 mA is specified in the data sheet and the power budget calculation from chapter III should be followed. The receiver and its conductive housing should be grounded and a good power-supply filter should be used because the isolated power supply is known to be very noisy.

The dead-time specification is one of the most important design parameters. A worst-case propagation delay from the controller to the gate of the power switch has to be computed. For the fiber-optic link, the overall propagation delay time is the sum of transmitter, receiver and fiber delay times. Typical fiber optic link delay times are listed in Table V/3. The PWD is specified in the HFBR-2528Z data sheet. Since the speed of light is limited to about 2.99E-8 m/s in a vacuum, photons will travel at a lower speed in dense media such as glass or plastic fibers.

#### Equation V/2:

$$v_p = \frac{c}{n} \text{ in m/s}$$

c: Speed of light in vacuum,  $c = 2.99\text{E}-8 \text{ m/s}$

n: Refractive index of the media  $n = 1.5$  for PMMA

**Table V/3: Typical Propagation Delay Times at 25°C for HFBR-0508Z Link with 1m POF**

Parameters	Tx(in) to Rx(out) with 1 mm POF	Units
tp LH	140	ns
tp HL	158	ns

To avoid fault connections, which can cause shoot-through conditions in a half bridge, Avago Technologies recommends that the transmitters for a single half bridge be latched in pairs. Duplex connectors have a key function and will fit into the latched pair in only one position. Therefore, human error, such as mixing the cables, can cause only a fail function and will not destroy the power switches.

## VI. Introduction to Optical Power and Loss Measurements

The theoretical methods used to specify optical parameters were discussed in chapter III. Theoretical values must be verified, however, not only by empirical functional tests but also by optical power and loss measurements. The relevant standard for loss measurements on cables and connectors is IEC 874-1. A detailed discussion of all the different methods described in the standard is beyond the scope of this application note. Only the most important methods will be briefly described. The recommendations in this application note for measurement equipment and accessories will help the newcomer to fiber optics, even one with financial constraints, to quickly implement a system.

### 1. Recommended Equipment and Accessories

The following items are needed: connectors, several meters of cable, transmitters and receivers, and tools to terminate the plastic or HCS cable. The lowest-cost approach is the POF termination kit <sup>[27]</sup>. For details, please see fiber-optic cable data sheet <sup>[8]</sup>. One of the Versatile Link transmitters can be used as an optical reference source. Power meters with a large-area Si detector, LED sources for 1 mm POF and 200  $\mu\text{m}$  HCS, and adapter accessories are available from several manufacturers listed in the appendix <sup>[26]</sup>.

#### 1.1. Transmitter Output Measurement

A reference cable of 50 cm should be terminated with a carefully polished connector on each end. The cable is connected to the transmitter and the optical power meter. The coupled power into a 1 mm POF can be read in the display in power (mW) or reference power (dBm).

#### Equation VI/1:

$$P \text{ (dBm)} = 10 \bullet \log \frac{P(\text{mW})}{1\text{mW}}$$

P(mW): Power in mW

P(dBm): Power in decibels referenced to 1 mW

If the detector area is larger than the fiber's cross-sectional area, the coupling loss between connector and detector can be neglected. Avago Technologies also recommends repeating the measurement with the connections reversed. A different power-level reading will indicate coupling loss variation.

It is also possible to measure the output power of a pulsed transmitter. A 50% duty-cycle pulse gives an average power-level (Pavg) reading. The actual peak amplitude (Ppk) is twice as high (3 dB in referenced power) as the average.

Example: Pavg = -21 dBm

Ppk = -18 dBm

## 1.2. Receiver Sensitivity Measurement

The transmitter and receiver are linked by a fiber-optic cable and pulsed with the desired data rate at a 50% duty cycle. An optical attenuator or different fiber length is used to lower the power at the receiver while monitoring the pulse-width distortion (PWD). Using a simple vise, one can also construct a gap attenuator by increasing the Z-axis spacing of the two fibers. When the PWD is 30 ns, the fiber is disconnected from the receiver and inserted into the optical power meter. The optical power meter shows the average received power. To calculate the receiver peak-power sensitivity,  $P_{RL,min}$ , add 3 dB to the reading.

## 1.3. Cable Attenuation Measurement

First the reference cable is connected to the transmitter and the power meter is set to zero (0 dB). Then the attenuation of the fiber being tested is measured. The power meter displays the incremental change in attenuation. This value is divided by the length of the fiber to calculate the optical loss per meter in dB/m. Typically, longer cables are measured; and so, the attenuation of the reference cable (about 0.1 dB to 0.2 dB) can be neglected. Avago Technologies recommends repeating the measurement with the connections reversed. A different power reading will indicate coupling loss variation due to connector-port dimension tolerances and/or uneven polished fiber surfaces.

## VII. Appendix

### 1. Literature Reference

- [1] Application Bulletin 73; Low Cost Fiber Optic Transmitter and Receiver Interface Circuits
- [2] Application Bulletin 78; Low Cost Fiber Optic Links for Digital Applications up to 155 MBd
- [3] Application Note 1066; Fiber Optic Solutions for 125 MBd Communication Applications at Copper Wire Prices
- [4] Application Note 1035; Versatile Link
- [5] Data sheet HFBR-0508Z Series; 10 MBd Versatile Link Fiber Optic Transmitter and Receiver for 1 mm POF and 200  $\mu$ m HCS
- [6] Reliability Data sheet HFBR-1527Z/8Z
- [7] Reliability Data sheet HFBR-2528Z
- [8] Data sheet; Plastic Optical Fiber and HCS Fiber Cable and Connectors for Versatile Link
- [9] Fiber Optic Handbook, Avago Technologies, Christian Hentschel
- [10] IEC 874-1
- [11] POF Data book, MRC Techno Research
- [12] High Strength, Reliable, Hard Clad Silica HCS® Fibers, Ensign-Bickford Industries
- [13] Elektronik Plus, Automatisierungstechnik 1,
- [14] EMV Störfestigkeitsprüfung, Fischer, Balzer, Lutz, Franzis Verlag

### 2. Supplier Reference

- [15] Texas Instruments
- [16] Motorola
- [17] SGS Thomson
- [18] Siemens
- [19] Philips
- [20] Maxim
- [21] Intel
- [22] OFS
- [23] Kabelwerke Rheinshagen GmbH
- [24] MicroParts
- [25] Nichimen
- [26] a. RIFOCS "V-Kit Measurement Instruments" 557B Power Meter, 253B LED Source; b. Photodyne, Model 18XTA; c. Mitsubishi, Rayon, EMT 100-205
- [27] Plastic Fiber Termination Accessories, HFBR-4593 Polishing Kit, HFBR-4597 Plastic Fiber Crimping Tool

For product information and a complete list of distributors, please go to our web site: [www.avagotech.com](http://www.avagotech.com)

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