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# Versatile Link

## Application Note 1035

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### Introduction

This application note describes how fiber optics can be used to solve many different types of application problems, introduces Agilent Technologies' Versatile Link plastic fiber optics, and shows how to design a fiber-optic link using the Versatile Link. Below is an outline of this application note.

- I. Introduction
- II. Example Applications
- III. Versatile Link Description
- IV. System Specifications and Link Design
- V. Pulse-Width Distortion
- VI. Additional Circuit Recommendations
- VII. Appendix

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Optical fiber is typically made from either plastic or glass. Because both plastic and glass are electrical insulators, there is no direct electrical connection between the transmitter and the receiver of a fiber-optic link. This helps to alleviate ground-loop and common-mode noise problems, as well as to isolate large common-mode voltages. Another useful property of optical fiber is that it does not emit radiation and is not susceptible to electromagnetic interference (EMI). This prevents an optical fiber from interfering with neighboring wires and also

gives it inherent immunity to induced or coupled noise from adjacent wires.

Fiber optics can protect equipment from excessive voltages, reduce EMI, increase safety by eliminating the hazard of generating sparks, and ensure data integrity in environments with large amounts of noise or with high common-mode voltages.

### Example Applications

Different applications have different requirements and, therefore, different reasons for using fiber optics. The following paragraphs discuss some examples of common fiber-optic applications and why fiber optics are used in those applications.

The first type of application utilizes the EMI immunity of fiber-optics for data transmission in electrically noisy environments. A good example is data transmission between a programmable logic controller (PLC) and the computer that is directing it, illustrated in Figure 1a. The two computers might be in a factory containing machinery that generates large amounts of electrical noise. Data transmission lines commonly run alongside lines that supply power to the machinery. There may be

large amounts of electrical noise present on the power lines caused by the machinery. This noise can couple electromagnetically into any adjacent lines. If one of those adjacent lines is a twisted-pair or coax line carrying data, the coupled electrical noise may significantly interfere with the data transmission. The noise may cause only periodic errors, or it might completely corrupt all of the data being sent. Because optical fiber is not susceptible to EMI, it can eliminate the undesirable coupling of noise from the power lines onto the data lines and ensure error-free data transmission.

Figures 1b, 1c and 1d illustrate other applications which utilize the EMI immunity of fiber optics. Figure 1b shows how fiber can connect a robot controller with the cell controller and the robot. The fiber eliminates the large amounts of noise generated by the motors, solenoids, etc. that are part of the robot. Figure 1c illustrates how fiber is used to network point-of-sales terminals (cash registers) in a retail store. Fiber optics ensures that sales information is not corrupted or lost due to noise generated inside the building. Figure 1d shows fiber optics connecting two HPIB (IEEE-488) data buses. The HPIB data bus

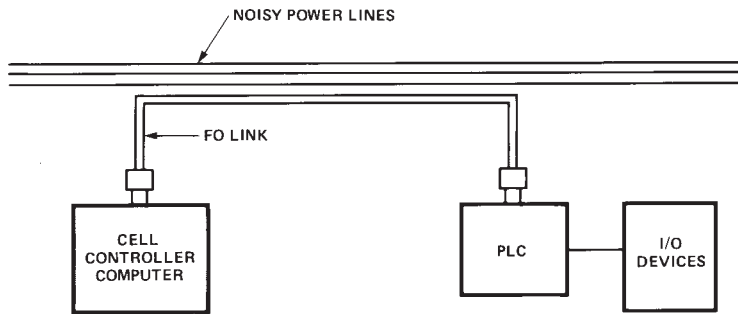


Figure 1a. Programmable Logic Controller.

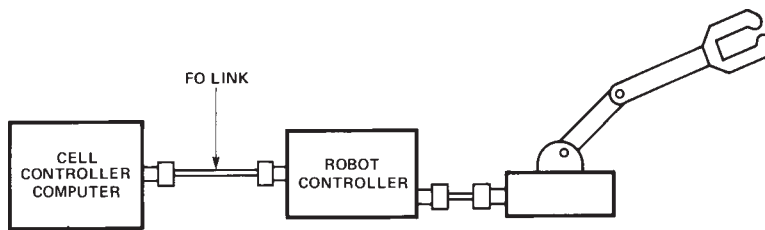


Figure 1b. Robot Controller.

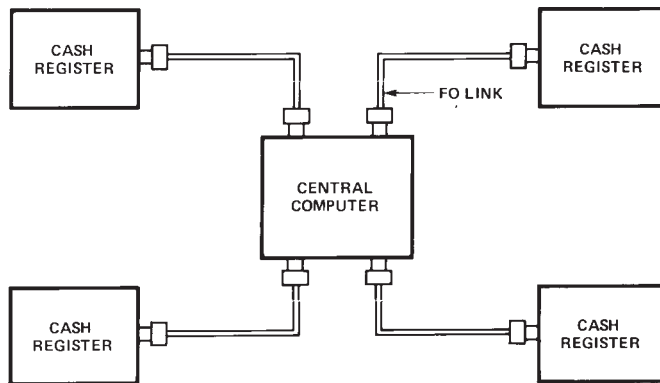


Figure 1c. Point of Sales Terminals

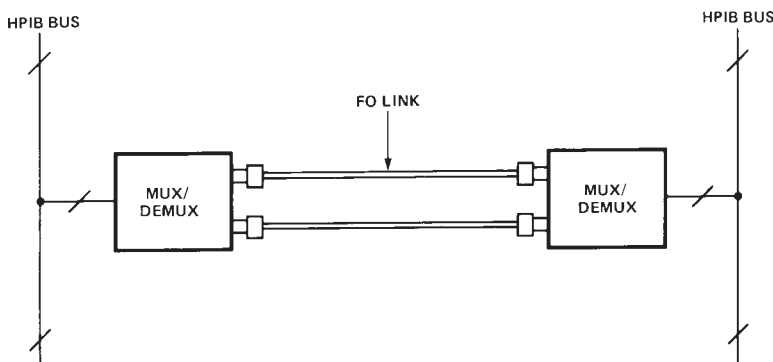
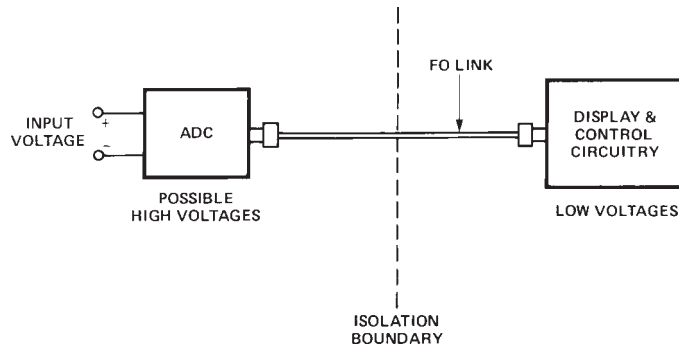


Figure 1d. HPiB (IEEE-488) Bus Extender.

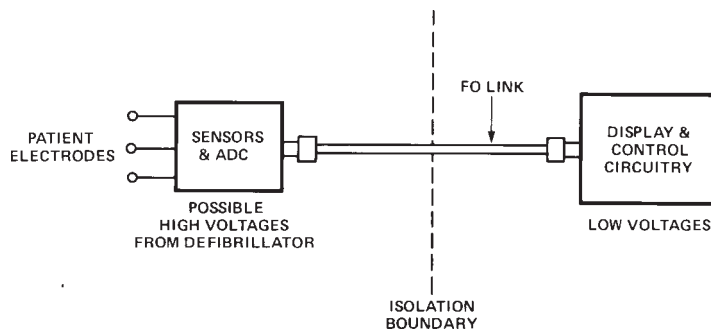
is commonly used to connect test instruments in manufacturing automated test systems. Again, fiber optics eliminates the noise that is commonly present in a factory and ensures that correct test data is transferred to the test system controller.

The second type of application uses fiber-optics for voltage isolation. A digital voltmeter, illustrated in Figure 2a, is a good example. There is typically some circuitry at the input of the voltmeter that converts the analog voltage across the input terminals into a digital signal; this circuitry is called an analog-to-digital converter (ADC). The output of the ADC is then sent to processing circuitry that displays the information on the front panel or, perhaps, sends the information to an external computer. A problem arises, however, when the signal to be measured has a very high common-mode voltage component. An example of this is measuring the difference between two very high voltages. The ADC will also be at the same common-mode voltage, causing a problem in safely sending information from the ADC to the digital control circuitry at ground potential. Because of its insulating properties, an optical fiber is not affected by such high voltages and does not conduct any current that might interfere with or damage the circuitry to which it is connected. Fiber optics allow data to be transmitted and still maintain a high degree of voltage isolation.

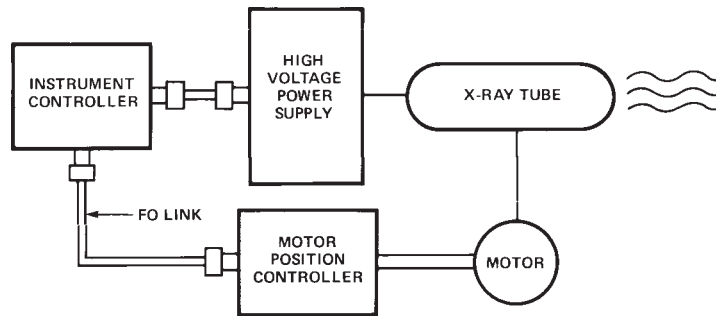
Figures 2b, 2c and 2d also illustrate the use of fiber in voltage-isolation applications. Figure 2b is a simple block diagram of an electrocardiograph, which is



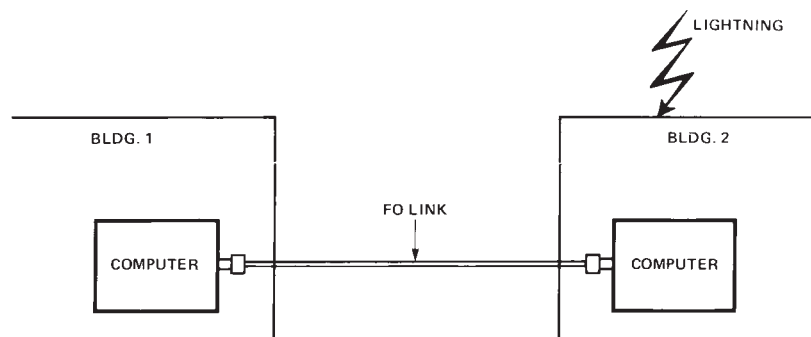
**Figure 2a. Digital Voltmeter.**



**Figure 2b. Medical Equipment - Heart Monitor.**



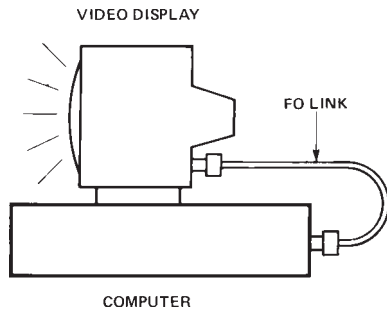
**Figure 2c. X-Ray Machine.**



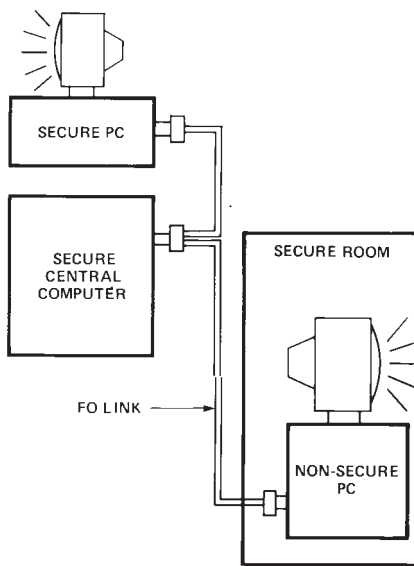
**Figure 2d. Lightning Protection.**

used to monitor a patient's heart. If the heart were to stop beating, a defibrillator might be used to restart it. The fiber protects the electrocardiograph from the very high voltages that are generated by the defibrillator. Figure 2c shows the use of fiber in a clinical X-ray machine. The fiber isolates the high voltages used to power the X-ray tube and provides EMI immunity from the noise generated by switching high voltages and currents. Figure 2d illustrates how fiber can protect electronic equipment from the high voltages generated by nearby lightning strikes.

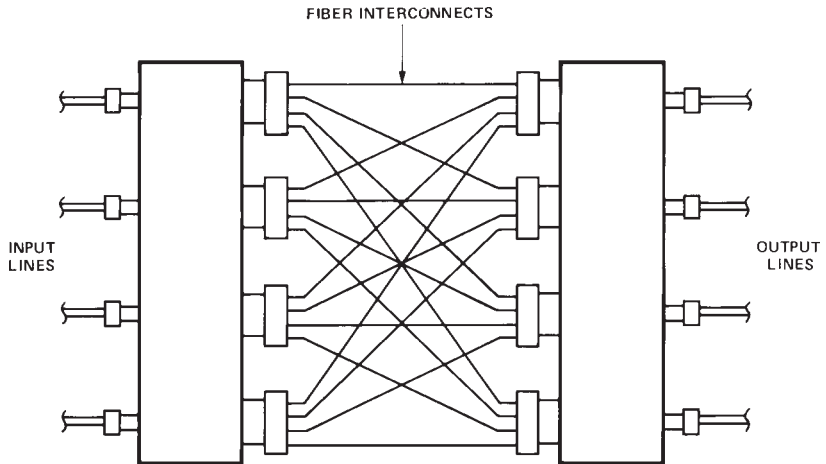
Another type of application reduces the amount of unwanted electromagnetic radiation emitted by a transmission line. This type of application is the converse of the first type; the idea is to minimize the amount of EMI that is radiated from the transmission line itself, rather than being concerned with the susceptibility of the transmission line to external interference. An example is high speed video transmission from a workstation computer to a high resolution video monitor, shown in Figure 3a. As the resolution of a video monitor increases, the number of pixels (dots) on the screen also increases. If the computer is updating the screen with the same number of frames per second, the computer must send more pixels per second as the resolution increases. Therefore, the bandwidth of the video transmission link must increase as well. If a coaxial cable is used to transmit the video information, it becomes more and more difficult (and expensive) to shield the cable and reduce unwanted radiation as the frequency of the transmitted information



**Figure 3a. High Speed Video Transmission.**



**Figure 3c. Tempest Applications.**



**Figure 3b. Telephone Switching Network.**

increases. Because an optical fiber does not emit radiation, it can significantly reduce the amount of EMI generated in transmitting information at very high data rates or when there are many transmission lines.

Figures 3b and 3c show two additional applications that use fiber optics to reduce the amount of unwanted emissions. Figure 3b illustrates the use of fiber in the telephone switching network of a central office switch. Fiber

helps to minimize the amount of unwanted radiation generated by the large number of interconnects in the network. Figure 3c illustrates how fiber might be used in Tempest applications. Tempest is a federal government specification that restricts the amount of radiation that can be emitted by "secure" electronic equipment. Because fiber does not emit any radiation, it is well suited for Tempest applications. Figure 3c shows how fiber is used to connect a secure personal

**Table 1. Distance and Data Rate Summary**

| Versatile Link            |                     | Guaranteed Minimum Link Length<br>Metres  |                   |                   |                   | Typical Link Length<br>Metres |                   |
|---------------------------|---------------------|---|-------------------|-------------------|-------------------|-------------------------------|-------------------|
|                           |                     | 0°C - 70°C  |                   | 25°C              |                   | 25°C                          |                   |
|                           |                     | Standard<br>Cable   | Improved<br>Cable | Standard<br>Cable | Improved<br>Cable | Standard<br>Cable             | Improved<br>Cable |
| High Performance          | 5 MBd               | 12  | 17                | 17                | 24                | 35                            | 40                |
| High Performance          | 1 MBd               | 24  | 34                | 30                | 41                | 50                            | 65                |
| Low Current Link          | 40 kBd              | 8   | 11                | -                 | -                 | 30                            | 35                |
| Extended Distance<br>Link | 40 kBd              | 60  | 82                | 65                | 90                | 100                           | 125               |
| Standard                  | 1 MBd               | 5   | 7                 | 11                | 15                | 30                            | 40                |
| Photo Interrupter         | 500 kHz             | N.A.  | N.A.              | N.A.              | N.A.              | N.A.                          | N.A.              |
| Evaluation Kit            | 1 MBd<br>(Standard) | Contents: Horizontal transmitter, horizontal receiver packages; 5 metres of simplex cable with simplex and simplex latching connectors installed; individual connectors: simplex, duplex, simplex latching, bulkhead adapter; polishing tool, abrasive paper, literature. |                   |                   |                   |                               |                   |

computer (i.e., a computer constructed to limit the amount of emissions) with a secure central computer. The fiber also connects the secure central computer with a non-secure personal computer, located inside of a secure room (i.e., a room specifically designed to limit unwanted emissions).

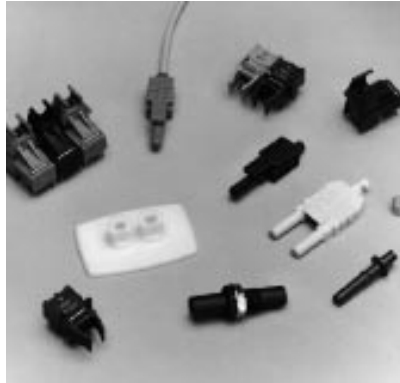
The above examples illustrate how the features of fiber optics can be used to solve problems found in many different types of applications.

### Versatile Link Description

The Agilent Technologies HFBR-0501 series low-cost fiber-optic system, the Versatile Link, was designed for ease of use, versatility, and reliability. Table 1 summarizes the data rate and distance capabilities of the Versatile Link family. Typical distances at room temperature are also shown. The maximum data rates for Versatile Link components range from 40 kBd to 5 MBd, with even higher data rates available in the future.

Agilent Technologies guarantees minimum and maximum specifications of its components both at room temperature and over the full operating temperature range (0 to 70°C). These guaranteed specifications were obtained from extensive characterizations of the Versatile Link components and cover the full range of manufacturing process variations. This ensures reliable circuit operation and allows Agilent to guarantee minimum link distances.

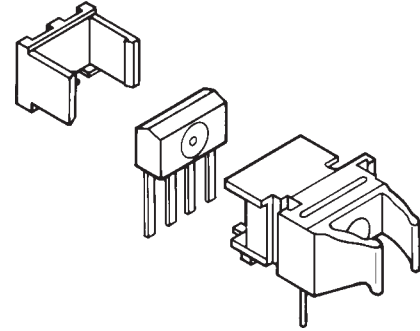
The Versatile Link family, shown in Figure 4, is intended



**Figure 4. Versatile Link Family.** for use with 1 mm plastic optical fiber. No optical design is required because the specifications include any connector losses at the transmitter and at the receiver. The compact, low-profile package is color coded to distinguish transmitters from receivers; connectors are also color coded. Both horizontal and vertical package styles are available with standard 8-pin DIP pinouts. The packages can also be interlocked or stacked ("n-plexed") to decrease the required amount of PC-board space.

Figure 5 shows an exploded view of the Versatile Link horizontal style package. The package was designed for improved performance and ease of manufacturing. The active components are attached to a lead frame which is then transfer molded with clear plastic to form the insert. A precision lens is molded into the insert to optimize the optical coupling from the package to the fiber. The insert is held in the main part of the housing by a snap-on cap on the back of the package.

The Versatile Link package uses an active optical alignment system to ensure proper coupling between the connector and the package. Figure 6 illustrates



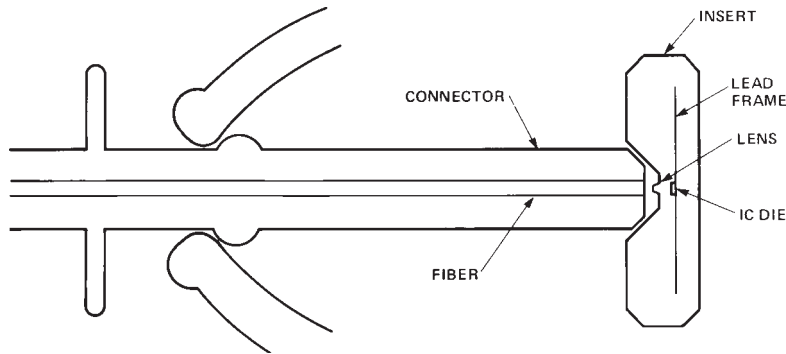
**Figure 5. Exploded View.**

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. When the connector is inserted into the package, the jaws of the housing force the beveled end of the connector into the cone-shaped depression. This accurately centers the fiber directly above the molded lens on the insert and ensures reliable and repeatable connections.

The gray transmitter modules contain 660 nm large-area LEDs that can be easily interfaced to all standard logic families. The blue receiver modules contain monolithic integrated optical detectors with TTL/CMOS-compatible outputs.

Four connector options are available for use with the Versatile Link:

1. Simplex connector, which is compatible with our previous Snap-In Link family,
2. Latching simplex connector, for applications that require increased connector pullout force,
3. Duplex connector, which incorporates a lockout feature that ensures correct orientation of the connector when used with interlocked packages,
4. Latching duplex connector.



**Figure 6. Connector Alignment.**

Agilent Technologies offers simplex and duplex cables with two grades of attenuation, standard and improved. Cable with connectors is offered in one meter increments of length; unconnected cable is available in lengths of 25, 100, and 500 meters. These cables are UL-recognized and pass UL VW-1 flame-retardancy specifications.

An evaluation kit is available which contains a standard 1 MBd transmitter and receiver, 5 m of connected cable, individual simplex, simplex latching, and duplex connectors, a bulkhead adapter, polishing tools and literature.

The data sheet for the Versatile Link family contains complete guaranteed specifications for entire links and individual components, electrical pinouts, interface circuits, connecting information, mechanical dimensions, part number and ordering information.

Reliability Data Sheets are available which provide complete reliability information for all Versatile Link components.

### System Specifications and Link Design

To obtain optimum performance under a variety of different conditions, it is helpful to understand some of the basic specifications of the Versatile Link and how to use them in designing a fiber optic link. This section will first discuss how Agilent Technologies specifies its transmitters, receivers, and plastic fiber-optic cable, then explain how to use those specifications in determining proper operating conditions. This section will also explain what a link operating diagram is and how to use it to quickly determine transmitter drive current or link length.

A basic fiber-optic system is very simple: an LED transmitter couples light into a fiber, the light travels down the fiber to an optical detector, and the detector converts the light into a digital output signal. The important specifications of the fiber-optic data link are:

1. How much light is coupled into the fiber by the transmitter,
2. How much light the receiver needs to function properly,
3. How much light is lost on the way to the receiver.

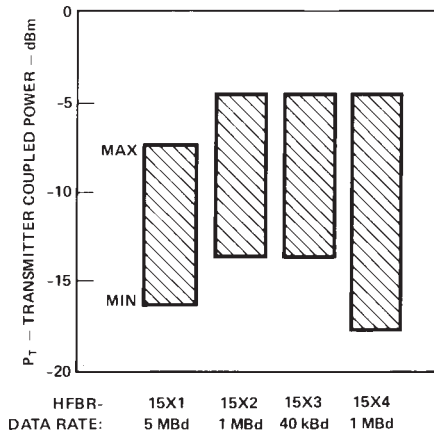


For a brief explanation of how optical power is specified in “dB” and “dBm”, see the Appendix.

### Transmitter Specifications

The primary transmitter specification is  $P_T$ , the amount of optical power coupled into the fiber at a specified LED drive current.  $P_T$  specifies how much power is actually coupled into the fiber; this eliminates the need to calculate the loss in coupling light from the LED to the fiber. Due to normal process variations, Agilent specifies a range of coupled power for each type of transmitter. Figure 7 shows the coupled power specifications for each of the Versatile Link transmitters. Guaranteed specifications over the full operating range are shown in Figure 7 because these values typically are used in “worst-case” designs and are also used in our examples.

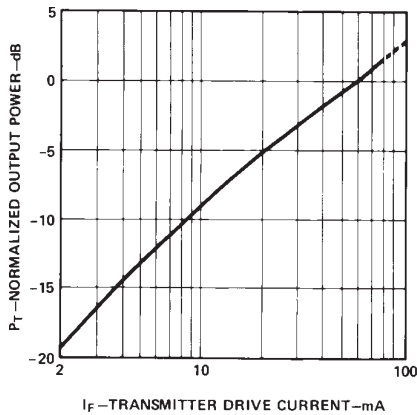
The amount of coupled power can be easily adjusted by changing the LED forward drive current,  $I_F$ , as indicated in Figure 8. Notice that the coupled power is normalized to the value at



**Figure 7. Transmitter Specifications.**

$I_F = 60$  mA. The graph, therefore, represents the CHANGE in output power for different drive currents. For example, operating the transmitter at a drive current of 20 mA will drop the output power by about 5 dB. There is an approximately linear relationship between drive current and output power; therefore, the output power will drop approximately in half (i.e., about 3 dB) when the drive current is cut in half.

Figure 9 shows the recommended transmitter drive circuits. You should note that for the 5 MBd and 40 kBd drive circuits, an input-high level turns



**Figure 8. Normalized Typical Output Power vs. Drive Current.**

the LED on; for the 1 MBd circuit, an input-high level turns the LED off. The capacitor in the 1 MBd circuit slows the falling edge of the optical waveform and allows the receiver to operate up to the maximum output power of the 1 MBd transmitter. The value of R1 can be determined from the equations in the figure. Typical values for the forward voltage of the LED,  $V_F$ , and the output low voltage of the gate,  $V_{OL}$ , are 1.6 V and 0.25 V respectively.

Additional transmitter drive circuits will be covered later in the application note.

### Receiver Specifications

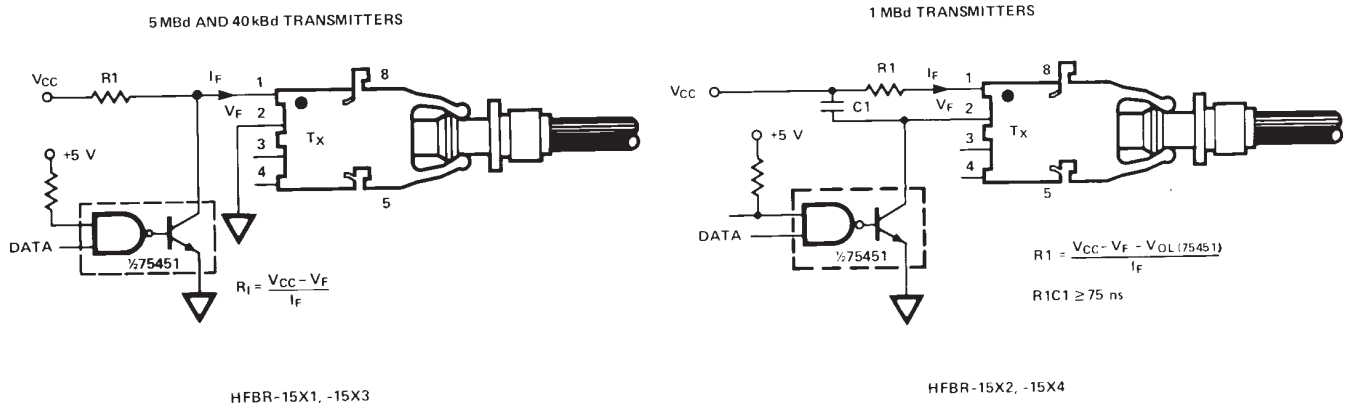
The Versatile Link receivers function somewhat as optical inverters: high input power causes a low output voltage, and low input power causes a high output voltage.

There are two primary receiver specifications:

1.  $P_{R(L)}$  specifies the input power required for a LOW output voltage,
2.  $P_{R(H)}$  specifies the input power required for a HIGH output voltage.

Figure 10 shows the ranges of  $P_{R(L)}$  and  $P_{R(H)}$  for each of the receivers over the full operating temperature range.

Typically, both a minimum and a maximum are specified for  $P_{R(L)}$ . For proper operation, the received optical power must be between the minimum and the maximum  $P_{R(L)}$ . If no maximum is specified, the corresponding transmitter (i.e., the HFBR-15X2 transmitter for the HFBR-25X2 receiver) is not capable of overdriving the receiver for drive currents up to the recommended maximum value of 60 mA, and



**Figure 9. Transmitter Drive Circuits.**

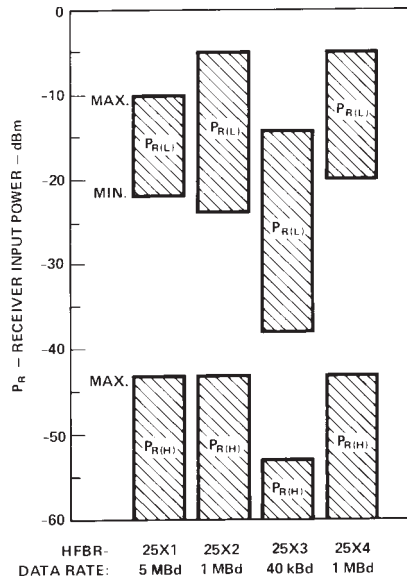


Figure 10. Receiver Specifications.

you need ensure only that the input power is greater than the minimum  $P_{R(L)}$ . If the maximum  $P_{R(L)}$  is exceeded, the receiver may exhibit excessive pulse-width distortion (discussed later) or multiple edge transitions.

Only a maximum  $P_{R(H)}$  is specified for each receiver. When the transmitter LED is in the off state, the received optical power

must be less than the maximum  $P_{R(H)}$  for proper receiver operation.

The minimum  $P_{R(L)}$  is called the sensitivity of the receiver. A receiver with good sensitivity (lower minimum  $P_{R(L)}$ ) will allow longer link lengths or lower transmitter drive current. The difference between the minimum and maximum  $P_{R(L)}$  is called the dynamic range of the receiver. A receiver with a large dynamic range can handle a wider variation in received power and therefore more variation in the length of the link. Note that the 40 kBd receiver has very good sensitivity and a large dynamic range. The 40 kBd link can therefore handle long link lengths and large variations in the length of the link. Also note that the maximum  $P_{R(L)}$  for the 1 MBd receivers is determined by the maximum coupled power of the 1 MBd transmitters.

Because the receiver switching threshold is between the minimum  $P_{R(L)}$  and the maximum  $P_{R(H)}$ , the receiver input power should be within this region only very briefly during signal transi-

tions. Very slow rise or fall times of the input optical waveform may cause multiple transitions on the output of the receiver.

Figure 11 shows how simple the receiver interface circuits are, requiring only one or two external components. The 0.1  $\mu\text{F}$  bypass capacitor is mandatory and must be located close to the receiver; the total lead length between the ends of the capacitor and the receiver power supply pins should not exceed 20 mm. The external pull-up resistor is optional. The 1 MBd and 5 MBd receivers have an internal 1K ohm pull-up resistor, and the 40 kBd receiver has an internal 150  $\mu\text{A}$  pull-up current source. All data sheet specifications for propagation delay and rise/fall time use an external pull-up resistor, a 560 ohm resistor for the 1 MBd and 5 MBd receivers, and a 3.3K ohm resistor for the 40 kBd receiver.

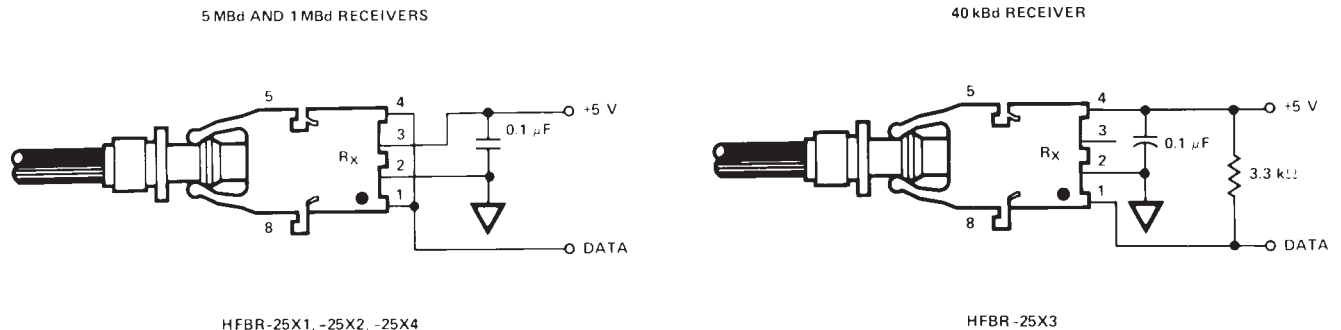


Figure 11. Receiver Interface Circuits.



## Optical Losses

There are two primary causes of optical loss in a fiber-optic link: losses due to cable attenuation and connector coupling efficiency.

Attenuation is defined as loss per unit length of fiber, expressed in dB/m. To obtain the optical loss in a fiber, simply multiply the length of the fiber by the attenuation. Figure 12 shows the range of attenuation for the two grades of fiber, standard and improved, that Agilent Technologies offers.

For a given length and type of fiber, there will be a range of optical loss due to the range of attenuation of the fiber. For our standard fiber, Figure 13 illustrates how the range of loss, as well as the magnitude of the loss, increases as the length of the fiber increases. You can see that for a 40 m length of fiber,

the losses due to attenuation will be between 7.6 dB and 17.2 dB, a range of almost 10 dB. A fiber optic receiver must be able to handle the range of loss as well as the magnitude of the loss. Therefore, receivers with both large dynamic range and good sensitivity are required for long link lengths.

Connector losses at the transmitter and receiver are already included in the transmitter and receiver specifications. However, connector losses due to connections through bulkhead adaptors need to be determined. There should be a minimum and a maximum loss specified for the bulkhead connection. Agilent Technologies specifies the loss of a bulkhead connection as a minimum of 0.7 dB and a maximum of 2.8 dB. As you increase the number of bulkhead connections, the range of loss increases as does the magnitude of the losses.

It is important to remember that the range of loss is just as important as the magnitude of the loss.

The total loss in a system is the sum of the individual losses due to attenuation and connectors. It is important to calculate both the minimum and the maximum losses of the system due to attenuation and connectors. A wide range of losses results in a wide range of input power at the receiver. This places greater requirements on the dynamic range of the receiver.

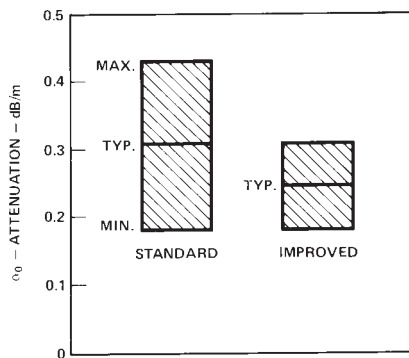


Figure 12. Cable Attenuation.

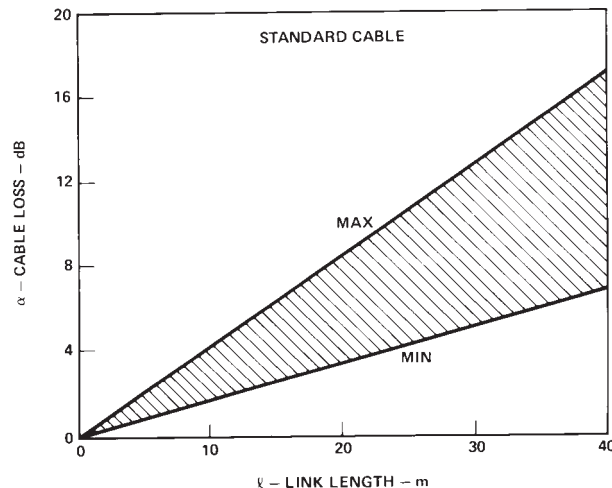


Figure 13. Possible Range of Cable Loss vs. Cable Length.

**Table 2. Example Loss Calculation**

| <b>Attenuation Loss - dB</b>         |                   |                   |
|--------------------------------------|-------------------|-------------------|
|                                      | min.              | max.              |
| loss/meter                           | 0.19              | 0.43              |
| total                                | 0.95              | 2.15              |
| <b>Bulkhead Connection Loss - dB</b> |                   |                   |
|                                      | min.              | max.              |
| loss/bulkhead                        | 0.7               | 2.8               |
| total                                | 1.4               | 5.6               |
| <b>System Loss - dB</b>              |                   |                   |
|                                      | min.              | max.              |
| total                                | 2.35              | 7.75              |
|                                      | = $\alpha_{\min}$ | = $\alpha_{\max}$ |

Table 2 shows the results of calculating the minimum and maximum losses for a 5 m link of standard cable with two bulkhead connections.

You can see that even for this relatively short link, there is over 5 dB difference between the minimum and maximum losses.

### Link Design

The fundamental requirement in the design of a fiber-optic link is to ensure that the receiver gets the proper amount of light. As mentioned earlier, this actually places three requirements on the design:

For a high output voltage,  
1. input power must be LESS than the maximum  $P_{R(H)}$ .

For a low output voltage,  
2. input power must be GREATER than the minimum  $P_{R(L)}$ ,

3. input power must be LESS than the maximum  $P_{R(L)}$ .

The first requirement is usually easy to meet: just ensure that the LED drive current is below about 20  $\mu\text{A}$ , or that the forward voltage drop of the LED is less than about 1.0 V.

The second requirement defines the underdrive, or sensitivity, limit of the receiver. You must ensure that the receiver has enough input power. This requires that the minimum transmitter coupled power minus the maximum system losses be GREATER than the minimum  $P_{R(L)}$ . In equation form:

$$P_{T\min} - \alpha_{\max} > P_{R(L)\min}$$

You should start your design with the transmitter drive current at the maximum recommended current of 60 mA, and decrease it later on in the design if required. Remember to use the maximum link length when calculating the maximum system losses.

Another way of looking at the same requirement is in terms of an optical power budget (OPB). The optical power budget is how much optical power you can "spend" on losses in your system; it is defined as the difference between the minimum transmitted power and the minimum  $P_{R(L)}$ :

$$\text{OPB} = P_{T\min} - P_{R(L)\min}$$

Your total system losses must then be less than the optical power budget:

$$\alpha_{\max} < \text{OPB}.$$

You may want to include a safety or power margin (PM) in your design. This margin is included to account for any decreases in the received optical power over the lifetime of the link. The received power may decrease over time due to increases in attenuation of the fiber, due to optical contamination of the connectors or active components, or due to a drop in the output power of the transmitter. If you include a power margin in your calculations, your system losses plus the power margin must be less than the optical power budget:

$$\alpha_{\max} + \text{PM} < \text{OPB}.$$

A typical power margin is around 3 dB; choose a larger margin for harsh environments and a smaller margin for more benign environments. For example, if your maximum system losses are 12 dB and you want a power margin of 3 dB, then you must have an optical power budget of greater than 15 dB. As another example, if you have an optical power budget of 10 dB and you want a power margin of 3 dB, then your maximum system losses must be less than 7 dB.

To calculate the minimum allowable transmitter drive current, determine if there is any budget left over after subtracting system losses and the power margin. This is the amount that you can decrease the transmitter output power by decreasing the drive current:

$$\text{Remaining budget} = \text{OPB} - (\alpha_{\max} + \text{PM}).$$

As an example, let's assume we have a 40 kBd 5 m link with standard cable, 2 bulkhead connections, and a power margin of 3 dB. We have already calculated the maximum losses for this system:

Maximum system losses:  
 $\alpha_{\max} = 7.75 \text{ dB}$ .

With a power margin of 3 dB, the optical power budget, OPB, must be greater than  $7.75 \text{ dB} + 3 \text{ dB} = 10.75 \text{ dB}$ , or

$$10.75 \text{ dB} < \text{OPB}.$$

The 40 kBd transmitter can couple a minimum power of -13.6 dBm over temperature at 60 mA, and the receiver has a minimum  $P_{R(L)}$  of -39 dBm. Therefore the optical power budget is given by:

$$\text{OPB} = -13.6 \text{ dBm} - (-39 \text{ dBm}) = 25.4 \text{ dB}.$$

There is plenty of power budget to cover the system losses and power margin. To determine the minimum transmitter drive current, determine the remaining budget:

$$\text{Remaining budget} = 25.4 \text{ dB} - (7.75 \text{ dB} + 3 \text{ dB}) = 14.65 \text{ dB}.$$

This is how much we can decrease the transmitter output power and still guarantee that we will not underdrive the receiver. According to Figure 8, decreasing the drive current to about 4 mA will drop the output power by about the right amount. You can see why we call the 40 kBd link a "low-current" link!

So far, we've covered the first two requirements for designing a fiber-optic link. The third

requirement defines the overdrive limit of the receiver; you must ensure that the receiver does not get too much power. In other words, the maximum possible received optical power, which equals the maximum transmitter power minus the minimum system losses, must be LESS than the maximum  $P_{R(L)}$ . In equation form:

$$P_{T\max} - \alpha_{\min} < P_{R(L)\max}$$

Remember to use the shortest link length for calculating the minimum system losses.

If the received optical power is too high, then the transmitter coupled power must be decreased by decreasing the drive current. To calculate the maximum allowable transmitter drive current, first determine how far above  $P_{R(L)\max}$  the received power is, and then decrease the transmitter output power by that much:

$$\text{Amount of decrease} = (P_{T\max} - \alpha_{\min}) - P_{R(L)\max}$$

Let's use our previous example to illustrate. We have already calculated the minimum system losses:

Minimum system losses:  
 $\alpha_{\min} = 2.35 \text{ dB}$ .

The 40 kBd transmitter can couple a maximum power of -4.5 dBm at 60 mA, and the receiver has a maximum  $P_{R(L)}$  of -13.7 dBm. First determine the maximum possible received power:  
 $-4.5 \text{ dBm} - 2.35 \text{ dB} = -6.85 \text{ dBm}$ .

This is above the overdrive limit,  $P_{R(L)\max}$ , of -13.7 dBm. Therefore, we must decrease the

transmitter drive current to decrease the transmitter coupled power:

$$\begin{aligned} \text{Amount of decrease} &= \\ &= -6.85 \text{ dBm} - (-13.7 \text{ dBm}) \\ &= 6.85 \text{ dB}. \end{aligned}$$

According to Figure 8, decreasing the transmitter drive current to about 14 mA will ensure that the receiver is not overdriven. For the example link discussed above, the minimum transmitter drive current is about 4 mA, and the maximum current is about 14 mA. Choosing a current between the minimum and maximum currents will provide additional safety or power margin.

After you have determined the minimum transmitter drive current from underdrive considerations and the maximum current from overdrive considerations, it might turn out that the maximum is less than the minimum (this did not happen, however, in the above examples). This occurs when the maximum possible range, or variation, of received power is greater than the dynamic range of the receiver. If this does occur, you can reduce the possible range of received power by doing any or all of the following:

1. Use improved cable. Improved cable has a smaller range of attenuation than standard cable and will therefore reduce the possible range of loss in the link.
2. Reduce the maximum link length.
3. Restrict the allowable variation in the length of the link. A link that is designed to operate from 0 m to 10 m will have

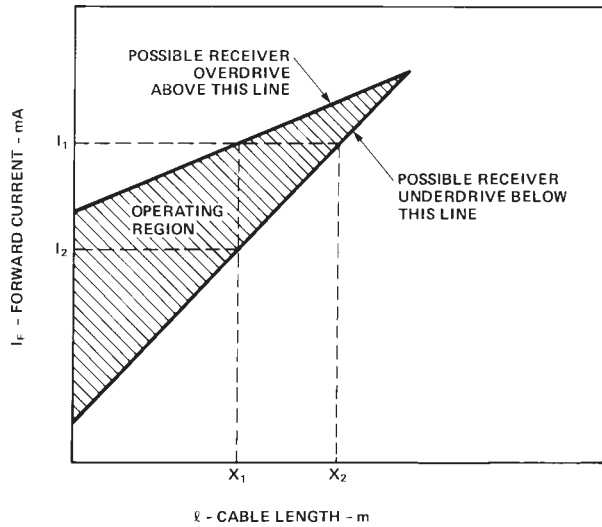


Figure 14. Link Operating Diagram.

more possible variation in the received power than a link designed to operate from 8 m to 10 m (the above examples dealt with a fixed link length of 5 m).

4. Reduce the number of bulkhead connections. There is a possible connection loss variation of  $(2.8 \text{ dB} - 0.7\text{dB}) = 2.1 \text{ dB}$  per bulkhead connection.

**Link Operating Diagram**

A link operating diagram, shown in Figure 14, can simplify the design of a simple point-to-point fiber-optic link, defined as a link with no bulkhead connections and a single length of fiber between the transmitter and the receiver. It illustrates the allowable combinations of link length and transmitter drive current.

The two primary features of the diagram are the overdrive and underdrive lines. If you operate a link in the region above the overdrive line (i.e., a combination of transmitter drive current and link length that lies above the overdrive line), then it is possible that you might over-

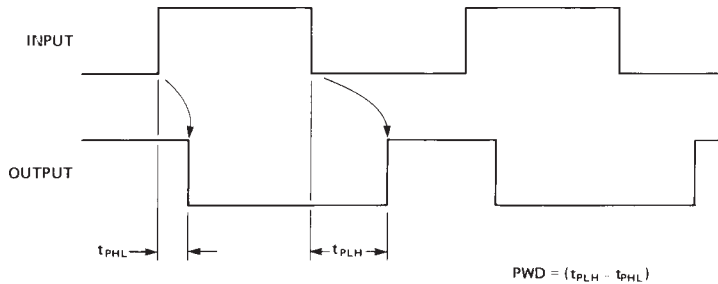


Figure 16. Pulse-Width Distortion.

drive the receiver. Conversely, if you operate the link below the underdrive line, then it is possible that you might underdrive the receiver. Therefore, the region between the two lines defines the valid operating region.

As shown in Figure 14, operating the transmitter at a fixed drive current of  $I_1$  allows link lengths from  $X_1$  to  $X_2$ . For a fixed link length of  $X_1$ , a drive current of between  $I_1$  and  $I_2$  is required for proper operation.

As an example, Figure 15 shows the link operating diagram for the 40 kBd link with standard cable. Operating the transmitter at 40 mA allows link lengths from about 40 m to 55 m. Or, for a fixed link length of 20 m, a transmitter drive current between about 4 mA and 17 mA is required.

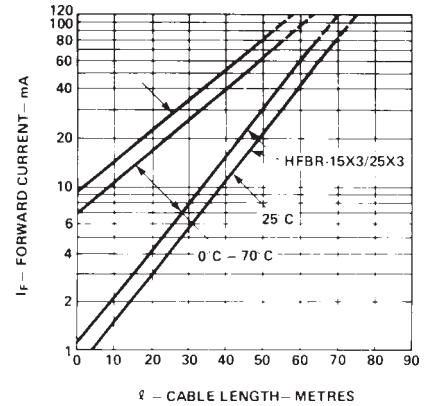


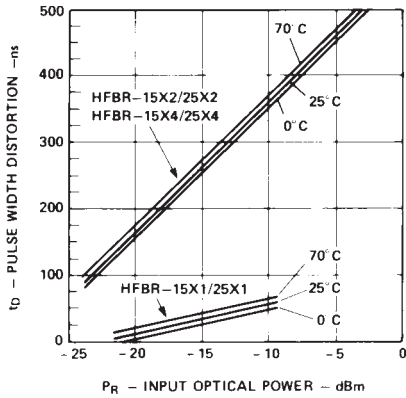
Figure 15. 40 kBd Link Operating Diagram.

**Pulse-Width Distortion**

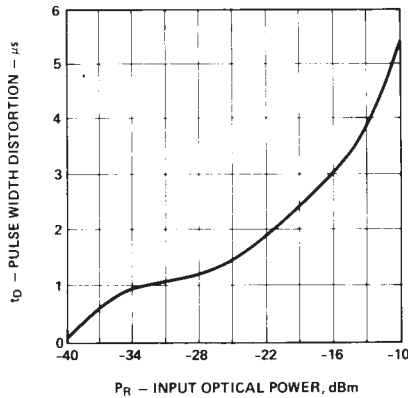
Pulse-width distortion (PWD) is often the limiting factor that determines the maximum data rate of a fiber-optic link. Pulse-width distortion is caused by unequal propagation delays and is defined as the difference between the propagation delays, as shown in Figure 16:

$$PWD = t_{PLH} - t_{PHL}$$

The term  $t_{PHL}$  refers to the propagation delay from the input to the high-to-low transition of the OUTPUT, as shown in Figure 16. Pulse-width distortion lengthens or shortens the duration of transmitted pulses, depending on the polarity of the pulse.

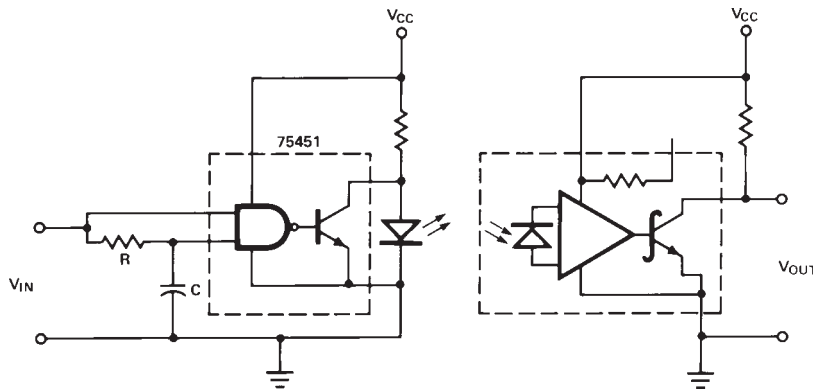


**Figure 17. Typical Pulse-Width Distortion vs. Input Power of 5 MBd and 1 MBd Receivers.**

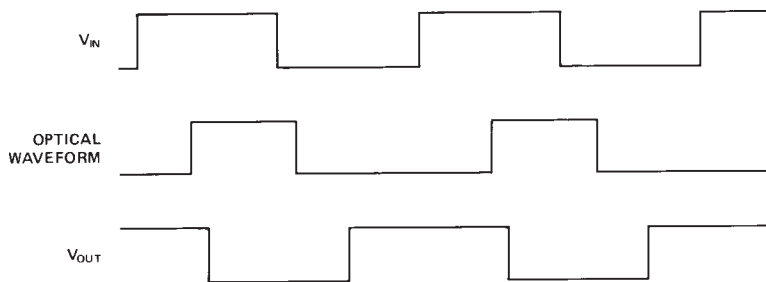


**Figure 18. Typical Pulse-Width Distortion vs. Input Power of 40 kBd Receiver.**

Figure 17 shows the pulse-width distortion specifications for the 1 MBd and 5 MBd Versatile Links. Note that the 5 MBd link has significantly less distortion than the 1 MBd link and much less variation in distortion over the full input optical power range. Figure 18 shows the distortion for the 40 kBd link. Notice that the PWD is always positive for all three receiver types (i.e.,  $t_{PLH}$  is always longer than  $t_{PHL}$ ). We can utilize this fact to correct or compensate for the PWD by selectively delaying one of the transmitted edges.



**Figure 19. Pre-Correction of PWD.**



**Figure 20. Pre-Correction Timing Diagrams.**

Figure 19 illustrates how to implement a “pre-correction” circuit, which corrects for distortion at the transmitter. The circuit is almost the same as our recommended 5 Mbd transmitter circuit, except for the RC network at the input of the gate. The RC network delays the turn-on of the LED, but not the turn-off. Both inputs must be high for the LED to turn on; the RC network delays one of the inputs and, therefore, delays the turn-on of the LED. However, only one of the inputs needs to go low for the LED to turn off. Figure 20 is a timing diagram which illustrates the operation of the correction circuit. Note how the turn-on of the LED is delayed and how the distortion is reduced. It is possible to calculate the required values for R and C to achieve the desired amount of correction; however, it is usually just as easy to experimentally determine their values. For the 5 Mbd link, start with  $R = 100$  ohms and  $C = 390$  pF and adjust the values to obtain the desired amount of correction.

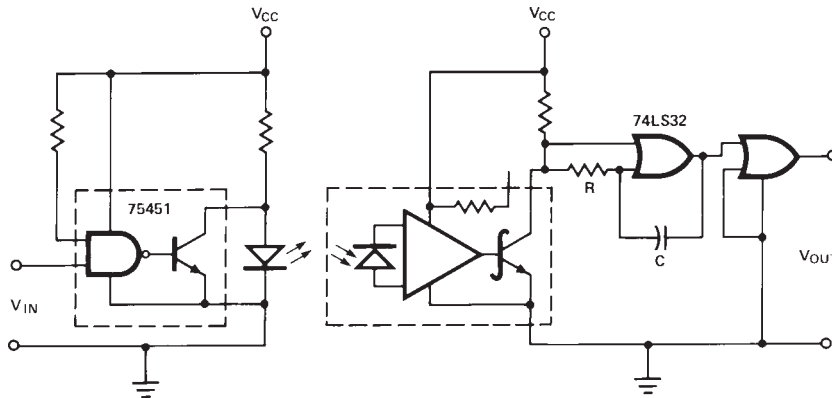


Figure 21. Post-Correction of PWD.

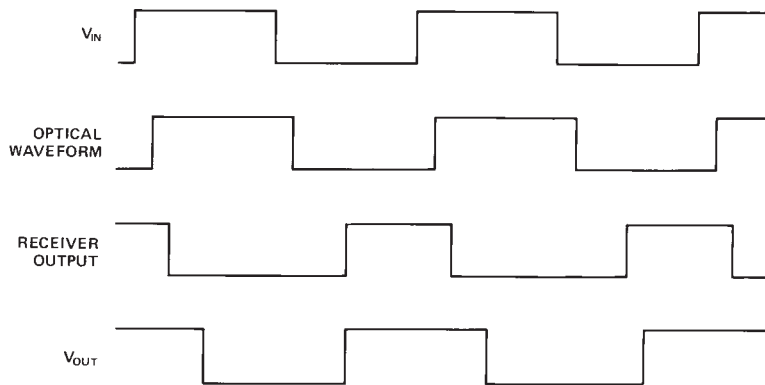


Figure 22. Post-Correction Timing Diagrams.

It is also possible to correct the distortion at the receiver using “post-correction”. Figure 21 shows a post-correction circuit. It works on the same principle of delaying one of the edges. Again, it is similar to the recommended circuit, except for the addition of a delay circuit on the output of the receiver. The RC network delays the falling edge of the receiver output. Both of the inputs to the OR gate must go low for the output to go low; the RC network delays one of the inputs and, therefore, delays the falling edge. Connecting the capacitor to the output provides positive feedback to ensure rapid switching of the output. Only one of the

OR gate inputs needs to go high for the output to go high; therefore, there is no delay of the rising edge.

Figure 22 is a timing diagram illustrating the operation of the circuit. Notice the distortion of the receiver output and how the post-correction circuit delays the falling edge to reduce the amount of distortion. Again, it is easiest to experimentally determine the values of R and C to achieve the desired amount of correction. For the 5 MBd link, start with  $R = 330$  ohms and  $C = 39$  pF and adjust the values to get the desired amount of correction.

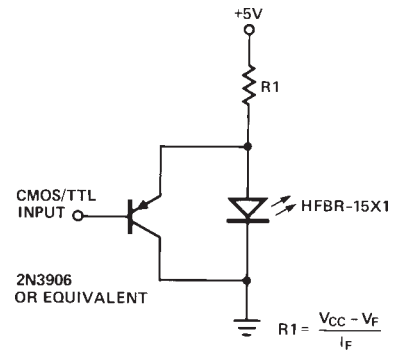


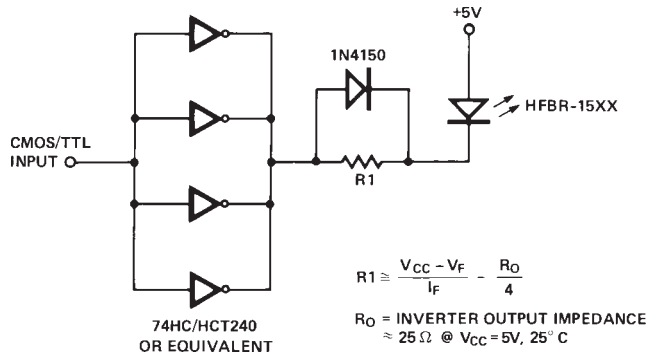
Figure 23. Simple 5 MBd PNP Transmitter Circuit.

Although it is possible to use pre-correction and post-correction in the same link, there is no need to incorporate both, and we recommend using only one type of correction. The choice of which circuit to use depends on external system constraints, such as a limit on the total number of system components, or other constraints on the transmitter or receiver circuitry.

## Additional Circuit Recommendations

This section presents several additional circuits that can be used with the Versatile Link. The transmitter circuits discussed below should be used only with the 5 MBd and 40 kBd links; the 1 MBd link requires the transmitter circuit shown in Figure 9 for proper operation.

The first circuit, shown in Figure 23, is a simple PNP transmitter circuit. The primary feature of the circuit is its simplicity: only two components are required other than the transmitter. It uses an inexpensive PNP transistor in a shunt drive configuration; when the input (i.e. the base of the transistor) is high, the transistor is cut off and the LED is on.



**Figure 24. Low-Current CMOS Transmitter Circuit.**

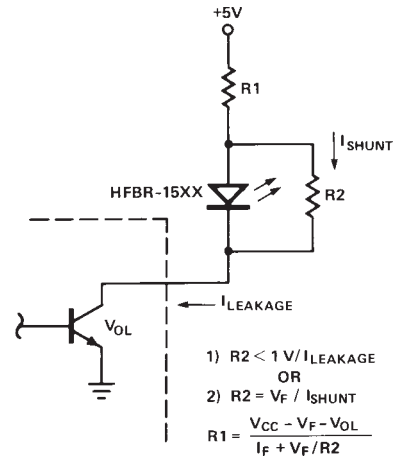
When the input is low, the transistor turns on and shunts current away from the LED, turning the LED off.

The circuit is very fast for several reasons. The transistor alternates between the cutoff and active regions of operation and, therefore, never saturates. The circuit presents a very low impedance during turn-off of the LED, which helps to turn off the LED more rapidly. And finally, the emitter base junction voltage of the transistor “pre-charges” the junction capacitance of the LED to about 700 mV, which helps to turn on the LED more rapidly. The “pre-charge” eliminates the time that would otherwise be required to charge the LED capacitance from 0 V to the pre-charge voltage of 700 mV during turn-on of the LED.

The circuit has a high input impedance because the input source need supply only the base current of the transistor; the large LED drive current is handled by the transistor. This allows the circuit to be driven directly from low-current outputs, such as CMOS. Choose the value of R1 according to the equation in Figure 23.

Figure 24 is the schematic of a low-current CMOS-compatible transmitter circuit. The circuit operation is straightforward. The outputs of four CMOS buffers are arranged in parallel to ensure adequate drive capability for large LED currents. For smaller LED currents, fewer buffers can be used. The circuit has a very high input impedance, is CMOS compatible, and draws essentially no quiescent current when the LED is off. The diode helps to speed up the circuit. The capacitance of the diode provides additional current during the turn-on transition to help turn on the LED more rapidly. It also provides a low impedance during turn-off, which helps to turn the LED off more quickly. Choose the value of R1 according to the equation in Figure 24. If fewer buffers are used, divide  $R_O$  by the number of buffers in the circuit, instead of the four shown in the figure.

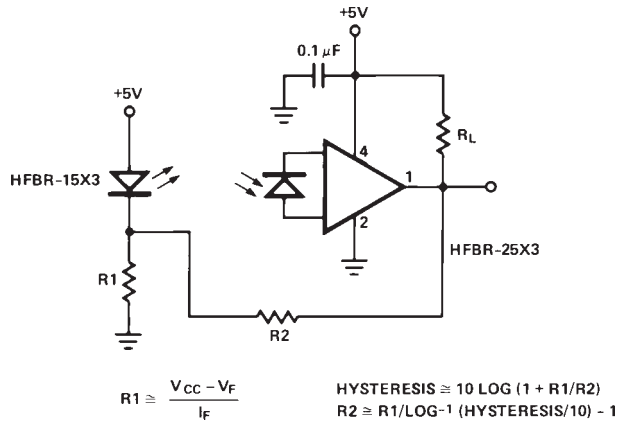
If an open-collector output is used to drive the LED, a shunt resistor in parallel with the LED, shown in Figure 25, can improve the performance of the transmitter. The shunt resistor R2 serves two purposes:



**Figure 25. LED Shunt Resistor for Open Collector Drive.**

1. It shunts any output leakage current around the LED, ensuring that the LED is off when it is supposed to be off. The leakage current will cause a voltage drop across R2; as long as the voltage drop is less than about 1 V, the LED will not turn on. Equation No. 1 in the figure can be used to determine the value of R2 in this case.
2. It also helps turn the LED off more quickly by discharging the stored charge in the junction of the LED. Smaller resistors will shunt more current and will turn the LED off more rapidly, at the expense of more overall drive current. Equation No. 2 in the figure can be used to determine the value of R2 in this case.

In either case, select R1 according to the equation in Figure 25.



**Figure 26. Photo Interrupter Hysteresis Circuit.**

The final application circuit is used in photo-interrupter applications. A photo-interrupter is comprised of a transmitter and a receiver connected by two lengths of fiber. The ends of the fibers are not connected directly together, but have a small separation between them. This allows small objects to pass between them and interrupt the light from the transmitter. The Versatile Link data sheet discusses how to use Versatile Link components in photo-interrupter applications. The circuit shown in Figure 26 illustrates how to add hysteresis to the recommended photo-interrupter circuit shown in the data sheet. Hysteresis may be required because it is possible that the received optical power may occasionally be at the threshold of the receiver. This could cause multiple transitions on the output and lead to improper circuit operation. It is common in this application for the transmitter and the receiver to be located next to each other. This allows a small amount of positive feedback to be applied from the receiver to the transmitter, resulting in hysteresis.

The hysteresis will rapidly switch the output and eliminate the problem mentioned above. The amount of hysteresis is determined by the values of R1 and R2. Choose R1 to achieve the desired drive current according to the equation in Figure 26. The amount of hysteresis, expressed in dB, is given approximately by the following equation:

$$\text{Hysteresis} = 10 \log (1 + R1/R2).$$

Solving for the value of R2 yields:

$$R2 = R1 / [\log^{-1} (\text{Hysteresis}/10) - 1]$$

Values of hysteresis from 0.25 to 1 dB should be sufficient for most applications. As an example, for hysteresis of 0.25 dB, R2 should be about 17 times the value of R1.

For additional information regarding the photo-interrupter application, please refer to the Versatile Link data sheet.

## Summary

The Versatile Link low-cost fiber optic components were designed and specified for easy design. Guaranteed electrical and optical parameters ensure reliable system performance. The wide variety of package configurations and connector types allow maximum flexibility to meet application requirements. The Agilent Technologies HFBR-0501 series of fiber optic components offer guaranteed performance, quality, and reliability.

For more information, please call your local Agilent Technologies Components Sales Office or authorized Agilent Components Distributor.

## Appendix

We quantify the amount of light by measuring its power. Optical power is measured in watts or, more commonly in fiber optics, in microwatts ( $\mu\text{W}$ ). Optical power is also commonly expressed in dBm. dBm is a logarithmic measure of power relative to 1 milliwatt (mW), as explained below.

The ratio of two powers, P1 and P2, can be expressed in dB as follows:

$$\text{dB} = 10 \log (P1/P2).$$

A positive number indicates that P1 is greater than P2, and a negative number indicates that P1 is less than P2. Remember, dB is a relative measure of two powers.

The ratio of a power, P1, to 1 mW is expressed in dBm as follows:

$$\text{dBm} = 10 \log (P1/1 \text{ mW}) \text{ or } 10 \log (P1/1000 \mu\text{W}).$$



Negative numbers do not indicate negative power, only power less than 1 mW. Remember, dBm is an absolute measure of power because it references the measured power to 1 mW.

To convert from dBm to mW or  $\mu$ W, use the following equations:

$$\begin{aligned} \text{mW} &= \log^{-1}(\text{dBm}/10), \text{ or } , \\ \mu\text{W} &= 1000 \log^{-1}(\text{dBm}/10). \end{aligned}$$

As an example, to convert 150  $\mu$ W to dBm:

$$\begin{aligned} \text{dBm} &= 10 \log^{-1}(150 \mu\text{W}/ \\ &\quad 1000 \mu\text{W}) \\ &= -8.24. \end{aligned}$$

To convert -24 dBm to  $\mu$ W:

$$\begin{aligned} \mu\text{W} &= 1000 \log^{-1}(-24/10) \\ &= 3.98. \end{aligned}$$

If optical power is lost in the fiber, the loss can be expressed in dB as the ratio of output power to input power as follows:

$$\text{loss (dB)} = 10 \log(P_{\text{out}}/P_{\text{in}}).$$

Expressing power loss in dB allows the different losses in a system to be added together to determine the total loss. Therefore, the output power can be determined simply by subtracting the total system losses, expressed in dB, from the input power, expressed in dBm:

$$P_{\text{out}} \text{ (dBm)} = P_{\text{in}} \text{ (dBm)} - \text{losses (dB)}.$$

As an example, if the input power to the system is -10 dBm and the total system losses are 12 dB, then the output power is:

$$\begin{aligned} P_{\text{out}} \text{ (dBm)} &= -10 \text{ dBm} - 12 \text{ dB} \\ &= -22 \text{ dBm}. \end{aligned}$$



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