Fiber-Optic Solutions for 125 MBd Data Communication Applications at Copper Wire Prices

Application Note 1066

Introduction

Fiber-optic cables have historically been used when the distance is too long, or the data rate is too high, for the limited bandwidth of wire. Optical communication links are also favored when the environment through which the data will pass is electrically noisy, or when electro-magnetic radiation from wire cables is a concern. Optical fibers have numerous technical advantages over conventional wire alternatives, but the cost of fiber-optic solutions has always been higher until now.

The Inherent Disadvantages Of Wire

Systems which must communicate are often connected to different reference potentials which are not necessarily zero volts, or in other situations ground references that are thought to be 0 V are electrically noisy. Metallic connections between systems with different ground potentials can be implemented by using the proper isolation and grounding techniques, but if these techniques are not strictly adhered to conductive cables will introduce conflicts between systems operating at different ground potentials. Data communication system designers must exercise caution to ensure that conductive cables do not exceed radiated noise limits established by the FCC, and cable installers need to route wire cables away from other power conductors that might couple electrical noise into the data by magnetic induction. Conventional wire transmission lines must also be terminated using a load resistor equal to the characteristic impedance of the metallic cable. This termination resistor must always be connected to the receiving end of every wire cable to ensure that pulses are not reflected toward the data source causing interference with the transmitted data.

Fundamental Advantages Of Optical Communication

Non-conductive optical cables have none of the traditional problems associated with wire. When using a fiber-optic solution, system designers do not need to be concerned about environmental noise coupling into cables, or worry about whether there is a termination resistor at the end of the cable. Conflicts between systems with different reference potentials do not happen when using insulating fiber-optic media because optical cables do not have conductors or shields that can be improperly grounded when the cables are installed or maintained. The fiber-optic receiver is the only portion of the optical link which is sensitive to noise, and it can easily be protected because it is contained within the host system which is receiving the data. A simple power supply filter is usually sufficient to protect the fiber-optic receiver from the host system's electrical noise. Electrostatic shielding can be applied to the receiver if the host system is particularly noisy, but electrostatic shields are not needed in most applications if the circuit techniques recommended in this application note are used.

A Fiber-Optic Solution At Wire Prices

The traditional argument for using copper wire has always been that fiber-optic solutions cost more, but Avago Technologies' Versatile Link components now enable system designers to over-come cost barriers that have historically prevented the use of fiber-optic cables in short distance applications. The HFBR-15X7Z LED transmitter, and the HFBR-25X6Z receiver, can be used with large diameter 1 mm plastic, or 200 µm Hard Clad Silica (HCS™) step index fibers to build unusually low cost data communication equipment. The fiber-optic solution described in this application note can transmit data at rates up to 125 MBd for the same price as shielded twisted pair wire, but this unusually low cost optical data link has none of the disadvantages that are inherent to wire cables.

Distances and Data Rate Capabilities of HFBR-15X7Z/25X6Z

Various distances and data rates are possible when the HFBR-15X7Z and HFBR-25X6Z components are used with large core step index fibers. At low data rates, the distances achievable are determined by the sensitivity of the receiver, cable attenuation, and the amount of light which the LED can launch into the fiber core. As data rate increases, fiber bandwidth will begin to influence how long the optical data link can be, and how fast the data can be transmitted. A plastic fiber with a 1 mm core diameter will couple more light from the LED than a composite fiber with a 200 µm diameter silica glass core and plastic cladding, but greater distances are achievable with the composite fiber since it has significantly lower attenuation than possible with an all-plastic fiber.

The distance data rate curves shown in Figures 1 and 2 are provided to allow designers to quickly determine if HFBR-15X7Z and HFBR-25X6Z can be used with large core optical fibers to meet their system requirements. Figure 1 shows the distances and data rates that can be achieved with Avago's 1 mm plastic fibers and Figure 2 shows what can be accomplished when using Avago's 200 µm hard clad silica fibers. If designers utilize the circuits recommended in this application note, digital fiber-optic links can normally be implemented at distances and data rates within the shaded portions of Figure 1 and Figure 2 . The fiber-optic transceiver shown in this publication was optimized for operation at 125 MBd. Greater distances can be achieved at data rates less than 125 MBd by optimizing the transmitter and receiver circuits for operation at lower speeds.

Figure 1 shows the performance possible with 1 mm diameter plastic fiber. The HFBR-15X7Z/25X6Z components can be used with standard 1 mm plastic cables to build 20 meter links which are capable of transmitting data at a rate of 125 MBd. When low loss plastic fiber is used, distances of 25 meters are possible at 125 MBd. As data rate decreases, the distance achievable with 1 mm fiber increases. Figure 1 shows that a distance of 100 meters is typically possible at rates as low as 33 MBd when using low loss 1 mm plastic fiber.

Composite fiber with a silica glass core and plastic cladding can achieve greater distances than possible with an all plastic fiber. Figure 2 shows what can be accomplished when HFBR-15X7Z and HFBR-25X6Z components are used with 200 µm diameter hard clad silica (HCS) fiber. Substantial increases in cable length are possible when using 200 µm HCS™ fiber since it has a much lower optical attenuation than 1 mm plastic fiber. Figure 2 indicates that 125 MBd data rates are typically possible with 125 meter lengths of 200 µm HCS™ fiber when using the transceiver recommended in this publication. Distances of 1 km can typically be achieved at data rates as low as 20 MBd due to the much lower optical losses of 200 µm HCS™ cable.

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HCS is a registered trademark of OFS.
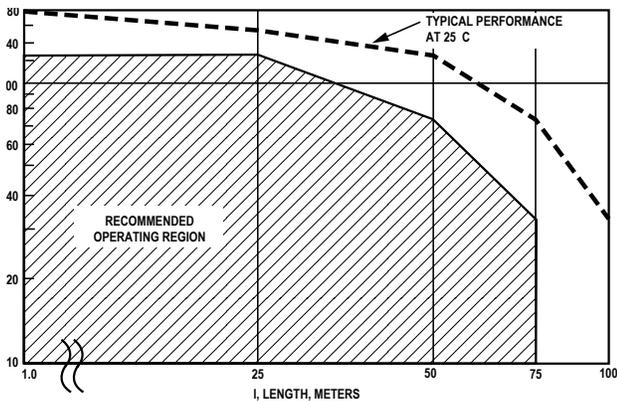
**Figure 1. Distances and Data Rates Possible with 1 mm Plastic Fiber.**
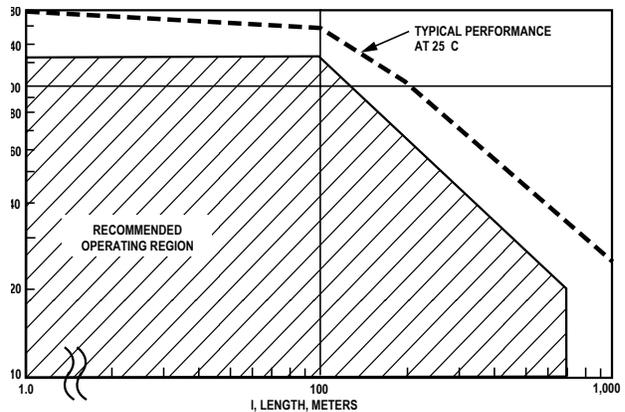
Figure 2. Distances and Data Rates Possible with 200 µm HCS Fiber.

Advantages of Encoded Run Limited Data

Fiber-optic transceivers are commonly used in systems that use some form of encoding. When data is encoded the original data bits are replaced with a different group of bits known as a symbol.

Data is encoded to prevent the digital information from remaining in one of the two possible logic states for an indefinite period of time. When data is encoded, a characteristic known as the "run limit" is established. If data is not changing, the run limit defines how much time may pass before the encoder inserts a transition from one logic state to another. The run length, or run limit of the encoder, is the number of symbol periods that are allowed to pass before the encoder changes logic state. Encoders also force the encoded data to have a 50 % duty factor, or they restrict the duty factor to a limited range, such as 40 to 60 %. When data is encoded, the fiber-optic receiver can be ac coupled as shown in Figure 3. Without encoding, the fiber-optic receiver would need to detect dc levels to determine the proper logic state during long periods of inactivity, as when there is no change in the transmitted data. AC-coupled fiber-optic receivers tend to be lower in cost, are much easier to design, and contain fewer components than their dc-coupled counterparts.

The output of the HFBR-25X6Z should not be direct coupled to the amplifier and comparator shown in Figure 3. Direct coupling decreases the sensitivity of a digital fiber-optic receiver, since it allows low-frequency flicker noise from transistor amplifiers to be presented to the receiver's comparator input. Any undesired signals coupled to the comparator will reduce the signal-to-noise ratio at this critical point in the circuit, and reduce the sensitivity of the fiber-optic receiver.

Another problem associated with direct-coupled receivers is the accumulation of dc offset. With direct coupling, the receiver's gain stages amplify the effects of undesirable offsets and voltage drifts due to temperature changes. These amplified dc offsets will eventually be applied to the comparator and result in reduced sensitivity of the fiber-optic receiver. The dc offset at the comparator can be referred to the optical input of the receiver by dividing by the receiver gain. This division refers the dc offset at the comparator to the receiver input where it appears as a change in optical power that must be exceeded before the receiver will switch logic states. Problems with dc drift can be avoided by constructing the receiver as shown in Figure 3.

Encoding has other advantages. Encoding merges the data and clock signals in a manner that allows a timing-recovery circuit to reconstruct the clock at the receiver end of the digital data link. This is essential because fiber-optic links can send data at such high rates that asynchronous timing-recovery techniques, such as over-sampling, are not very practical. Without encoding, the clock signal required to synchronously detect the data would need to be sent via a second fiber-optic link. Separate transmission channels for data and clock signals are usually avoided due to cost, but problems with time skew between the data and clock can also arise if separate fibers are used to transmit these signals.
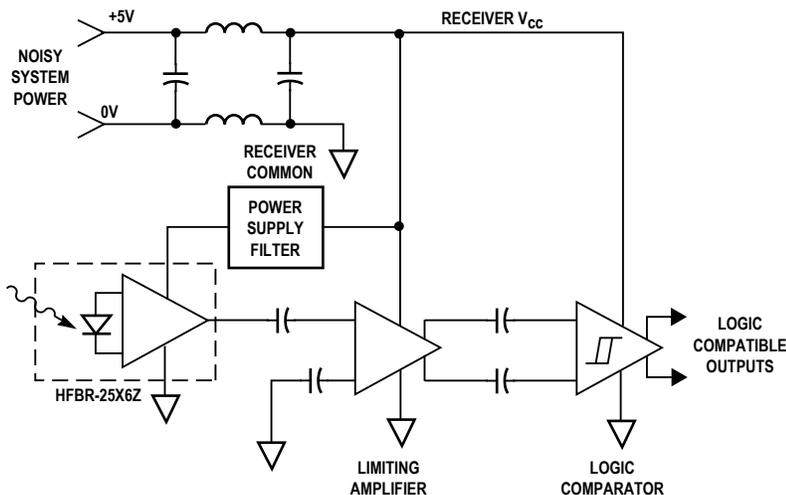

Figure 3. Fiber-Optic Receiver Block Diagram.

Characteristics of Encoders

A Manchester encoder replaces each bit with two symbols, for instance, a logic "1" is replaced by a ("1","0") symbol, and a logic "0" is replaced by a ("0", "1") symbol. Manchester code is not very efficient since it doubles the fundamental frequency of the data by substituting 2 symbols for each bit transmitted. Block substitution codes such as 4B5B replace 4 bit groups of data with a 5 bit symbol. Another popular block substitution code is 5B6B, which replaces each group of 5 bits with a 6 bit symbol. Substitution codes encode the data more efficiently. If a Manchester code is used to transmit data at 100 Mbits/second the fiber-optic channel must be capable of passing 200 M symbols/second. Baud (Bd) is expressed in units of symbols/second, thus the Manchester encoder in this example requires a serial data link that can work at 200 MBd. If the Manchester encoder is replaced by a 4B5B encoder, the 100 M bit/second data can be sent at a signaling rate of 125 MBd. In binary transmission systems the maximum fundamental frequency of the data is half the symbol rate expressed in Bd. When a Manchester encoder is used to send 100 M bit/second data, at a symbol rate of 200 MBd, the maximum fundamental frequency of the data is 100 MHz. By using a 4B5B encoder, the same 100 M bit/second data can be transmitted at 125 MBd, at a maximum fundamental frequency of 62.5 MHz.

The minimum fundamental frequency that the fiber-optic link must pass is determined by the encoding rule chosen. The run limit of the encoder determines the maximum number of symbol periods that the encoder will allow before it forces a transition, thus the encoder's run limit determines the minimum fundamental frequency of the encoded data. Manchester code will allow only two symbol periods to pass without a transition. As many as 3 symbol times without a transition will be allowed by the 4B5B encoder used in the AMD TAXIchip™.

TAXIchip is a registered trademark of Advanced Micro Devices, Inc.

Figure 4 illustrates the attributes of various encoding techniques. Figure 4 shows that as encoder efficiency improves the bandwidth needed in the fiber-optic communication channel is reduced, or conversely, for a fixed communication channel bandwidth the number of bits/second that can be transmitted will go up as encoder efficiency improves.

Total Solution Cost 125 Mbd Link Costs

The cost of a 125 MBd link consists of the cost of the data transceiver, and the cost of the media (cable and connectors). For the recommended +ECL transceiver discussed in this application note, the material costs in low volume are approximately $28.

The total material cost for a logic-to-light transceiver is under $25 in moderate volume, which compares favorably with the cost of a wire transceiver solution capable of 125 MBd performance over 100 meter spans, but the big advantage of this low cost fiber-optic technology is its ability to provide better data integrity than comparably priced wire alternatives.
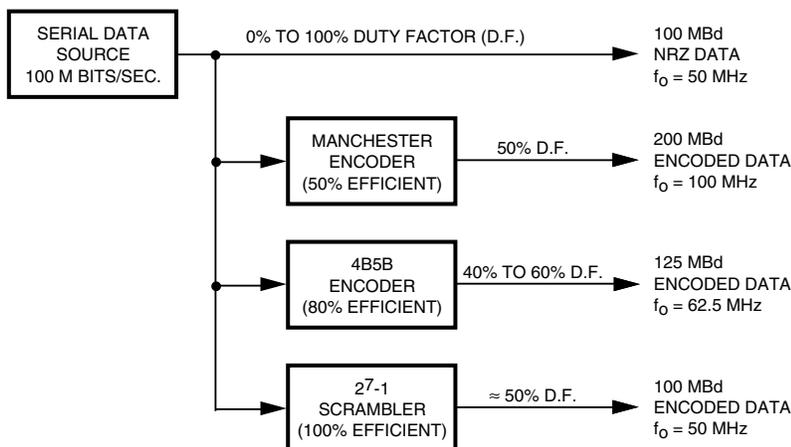

Figure 4. Attributes of Encoding.

Cable costs

The price per meter of HCS cable from Avago and OFS is comparable to the cost of shielded twisted pair wire in similar volumes. Connectors cost approximately a dollar, similar to typical twisted pair RJ jack connectors for data communications. Connector installation requires no epoxy or polishing, and can be completed in less than a minute per connector. Therefore the installed cost of HCS cable is similar to the installed cost of wire links of comparable performance.

For shorter distance links, pre-connected plastic fiber cable assemblies are available from Avago Technologies Distributors at attractive prices. For example, a 1 meter, duplex, pre-connected plastic fiber cable (i.e., part number HFBR-RMD010Z) has a suggested U.S. resale price of $5.70 in quantities of 500-999; a 10 meter cable would cost $16.50. Again, these costs compare favorably with the cost of data grade wire cable assemblies at similar volumes.

The costs of the 125 MBd Versatile Link electronics, cable, and connectors are all competitive with wire solutions. However, wire solutions frequently incur additional costs in use due to unanticipated trouble-shooting of electrical interference due to poor terminations or adjacent sources of electrical noise. The inherent electrical isolation of optical fiber results in a more robust solution and lower cost to the end user.

Circuits Recommended for use with HFBR-15X7Z and HFBR-25X6Z

The HFBR-15X7Z/25X6Z components can be used in a diverse range of applications. Not all applications can be addressed with the circuits shown in this publication, however, the transceiver recommendation which follows is useful in a wide range of systems which transmit encoded data at rates up to 125 MBd. If the design suggestions given in this publication do not meet your needs, you should contact an Application Engineer. The Application Engineering Department of Avago Technologies' Industrial Fiber Products Division has numerous circuit recommendations that will allow the HFBR-15X7Z/25X6Z components to address your specific needs.

Recommended Transmitter

The transmitter shown in Figure 5 is recommended for use with 1 mm plastic fiber. The transmitter in Figure 5 applies a forward current of 20 mA to the HFBR-15X7Z LED. If 200 μm HCS™ fiber is to be used the LED forward current must be increased to 60 mA and the drive circuit shown in Figure 6 is recommended. The forward current applied to the HFBR-15X7Z was chosen so that the LED will couple the maximum amount of light into the core of the fiber without overdriving the HFBR-25X6Z receiver when short optical cables are used.

+ECL Logic-to-Light Transceiver Cost

Non-Avago parts:		
MC10H116FN ECL Line Receiver	$2.15	
3 Transistors	$2.50	
IC Voltage Regulator	$0.98	
Inductor	$0.25	
Assorted Capacitors	$3.89	
Assorted Resistors	$0.78	
Total non-Avago components	~$10.55	(Note 1)

Avago Parts:		
HFBR-1527 Transmitter	$6.75	(Note 2)
HFBR-2526 Receiver	$10.70	(Note 2)
Total optoelectronic components	$17.45	

Complete +ECL transceiver function	$28.00	(Note 3)

Notes:
1. Costs of non-Avago components are based on very low volume price quotes. High volume prices are below $5.00 for all required non-Avago components.
2. Avago Suggested Resale Price in USA, 1994, quantity = 500-999. Contact your local authorized Avago Technologies Distributor or Sales Office for additional price information.
3. $28 is a low volume (<1,000) cost estimate. High volume cost is below $20 for the complete +ECL transceiver function.
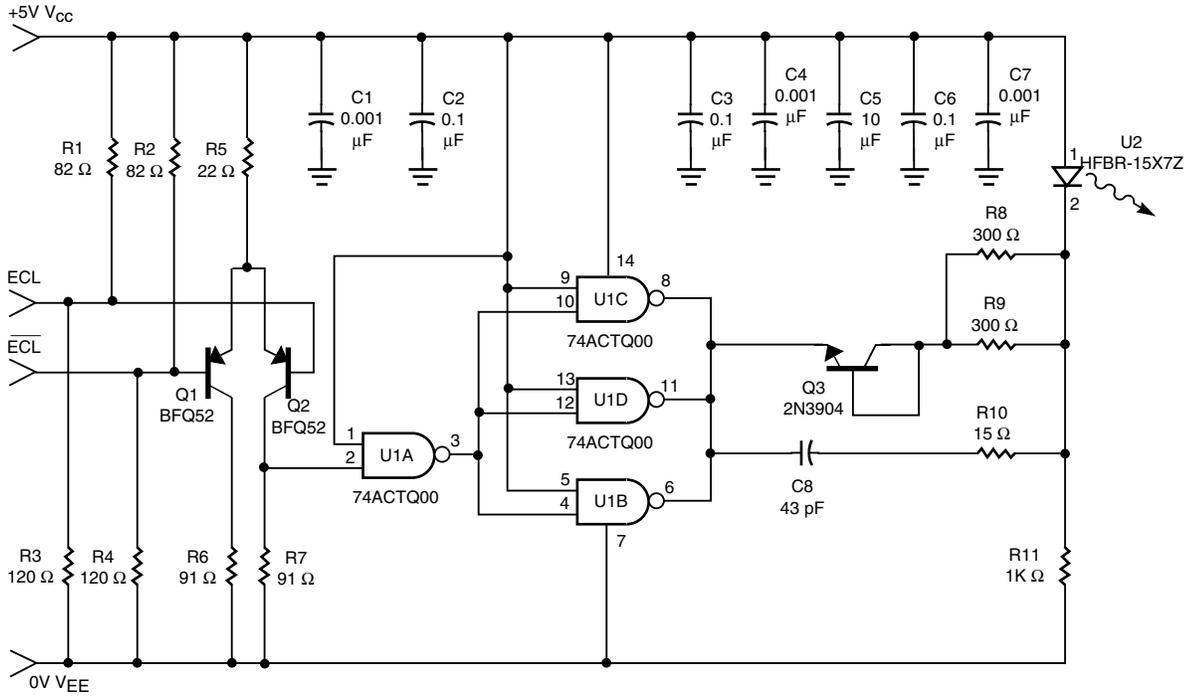
Figure 5. +5 V ECL Through Hole Transmitter for 1 mm Plastic Optical Fiber (POF).
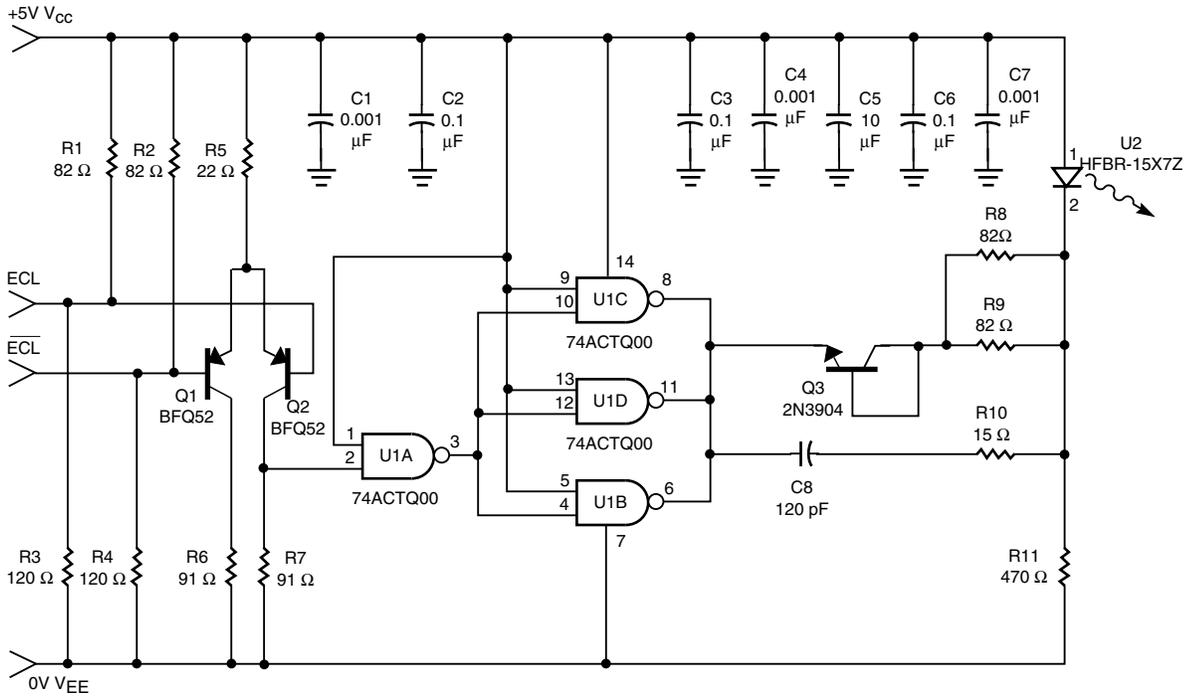

Figure 6. +5 V ECL Through Hole Transmitter for 200 μm HCS™ Fiber.

The transmitters shown in Figures 5 and 6 use the following techniques to improve LED performance. When the output of U1 is a logic "1", resistor R11 applies a small residual prebias current to the LED. This small prebias current minimizes the propagation delay distortion of the LED. Prebias also improves LED linearity sufficiently to permit the use of a frequency compensation circuit, which reduces the optical rise/fall time of the fiber-optic transmitter.

This frequency compensation technique is often called drive current peaking, because it adds brief current spikes to the LED drive current pulses. When prebiased, the HFBR-15X7Z LED has an amplitude versus frequency response which is roughly equivalent to a first order low pass filter. Without prebias and peaking, the HFBR-15X7Z LED has a typical 10% to 90% optical rise time of 12 ns. When prebias is provided by R11, and frequency compensation (peaking) is provided by R10, and C8, the 10% to 90% optical rise time of the HFBR-15X7Z LED decreases to a typical value of 3 ns, when using 1 mm plastic fiber. Optical rise times of 3.5 ns are typical when the peaked LED driver is used with 200µm HCS fiber. The LED's on-state current is primarily determined by the values of resistors R8 and R9, but Equation 1 shows that some on-state current is also provided by R11. Transistor Q3 is connected to form a low cost high speed diode. This diode allows LED prebias current to be set independent of the resistance chosen for R8 and R9. The LED's prebias current can be calculated as shown in Equation 2. Capacitance between the emitter and collector of Q3 changes as a function of the diode connected transistor's forward current. Current dependent changes in the capacitance of Q3 ensure that the current peak which turns the LED off will have a larger amplitude than the current peak applied when the LED is switched on. LEDs are characteristically harder to turn off than on. The difference between the amplitude of the peak current applied at turn on, and turn off, helps to reduce the optical pulse width distortion of the fiber-optic transmitter. One of the best features of this recommended LED driver circuit is that all of the active and passive components needed to build 10,000 of the transmitters shown in Figures 5 or 6 can be purchased for about $8.00 per circuit.

Recommended Receiver

The recommended receiver is shown in Figure 7. The HFBR-25X6Z component used in this receiver linearly converts changes in received optical power to a corresponding change in voltage. The output of the HFBR-25X6Z is an analog signal which can easily be converted to logic by a post amplifier and comparator. This post amplifier comparator function is often called a quantizer. A very inexpensive quantizer can be implemented using an MC10H116 ECL line receiver. The MC10H116 provides three low cost differential amplifiers in a single package. The MC10H116 can accommodate a large range of input voltages. *The large dynamic range of the MC10H116 is very important!* The quantizer must have a large dynamic range because the output

Equation 1:

$$I_{F_{ON}} = \frac{(V_{CC} - V_{F_{ON}})}{R11} + \frac{[V_{CC} - (V_{F_{ON}} + V_{CE_{Q3}} + V_{OL_{U1}})]}{[(R8)(R9)/(R8 + R9)]}$$

Equation 2:

$$I_{F_{OFF}} = \frac{(V_{CC} - V_{F_{OFF}})}{R11}$$

of the HFBR-25X6Z can change from a few millivolts to hundreds of millivolts when fiber length and attenuation are varied.

Several subtle techniques are used to maximize the receiver's sensitivity to optical pulses, while minimizing the receiver susceptibility to electromagnetic interference (EMI). In most systems, the same +5 V dc supply which powers the fiber-optic receiver is also used to power micro processors and digital logic. *The receiver must be isolated from noisy dc power supplies!* This isolation is provided by low pass filters that prevent noise injection into the HFBR-25X6Z, and quantizer, through the +5 V power connections. The HFBR-25X6Z is a miniature hybrid circuit that, due to its small physical size, is relatively immune to environmental noise. In most applications, the HFBR-25X6Z has sufficient noise immunity to operate without any additional electrostatic shielding, but the connection between the HFBR-25X6Z and the non-inverting input of the MC10H116 forms a loop antenna with sufficient area to receive significant amounts of EMI. The receiver's susceptibility to EMI is minimized by connecting a second loop antenna with equal area to the inverting input of the MC10H116 quantizer. When connections to the quantizer's input are symmetric, and have equal loop areas, the common mode rejection of the MC10H116's difference amplifiers will assure that the fiber-optic receiver provides good EMI immunity.

Design techniques which improve the EMI immunity of the receiver help to minimize crosstalk between the transmitter and the receiver. Crosstalk will also be reduced when the printed circuit for the fiber optic transceiver is designed so that pin 4 of the HFBR-15X7Z LED transmitter is next to pin 1 of the HFBR-25X6Z receiver. This arrangement maximizes the distance between pin 2 of the HFBR-15X7Z LED and the power supply lead (pin 4) of the HFBR-25X6Z. When the distance between pin 4 of the HFBR-25X6Z and pin 2 of the LED is maximized, the crosstalk between the LED transmitter and the HFBR-25X6Z receiver's power pin is reduced. The typical transmitter to receiver crosstalk which occurs when using the printed circuit shown in this application note is equivalent to a 0.5 dB reduction in receiver sensitivity. The effect of transceiver crosstalk has already been factored into the recommended distances and data rates shown in Figures 1 and 2.

The 125 MBd receiver shown in Figure 7 typically provides a sensitivity of -28 dBm average modulated when used with 1 mm plastic fibers. The same receiver can be used with 200 µm HCS™ fibers and will provide a typical sensitivity of -29 dBm average modulated at a data rate of 125 MBd. Overload characteristics of the receiver are not influenced by characteristics of the MC10H116 quantizer. The maximum power which can be applied to the receiver shown in Figure 7 is determined by the saturation characteristics of the transimpedance amplifier used in the HFBR-25X6Z. The HFBR-25X6Z is guaranteed to provide pulse width distortion which is less than 2 ns when received optical power is less than -9.4 dBm peak. Many features have been incorporated into the receiver recommended in this publication, but one of the most prominent characteristics of the circuit shown in Figure 7 is that all of the active and passive components needed to build 10,000 fiber-optic receivers can be purchased for about $12.00 per circuit.

A Complete Fiber-Optic Transceiver Solution

Figure 8 shows the schematic for a complete fiber-optic transceiver. This transceiver is constructed on a printed circuit, which is 1" wide by 1.6" long, using surface mount components. When the transceiver shown in Figure 8 is tested at a data rate of 125 MBd, using 100 m of 200 µm HCS™ fiber, it provides a typical eye opening of 5.4 ns at a BER of 1×10^{-9}. The power supply filter and ECL terminations shown in Figure 9 are recommended for use with the transceiver shown in Figure 8. The artwork for the surface mount transceiver is shown in Figure 10, and a complete parts list is shown in Table 1. Designers interested in inexpensive solutions are encouraged to embed the complete fiber-optic transceiver described in this Application Note into the next generation of new data communication products.
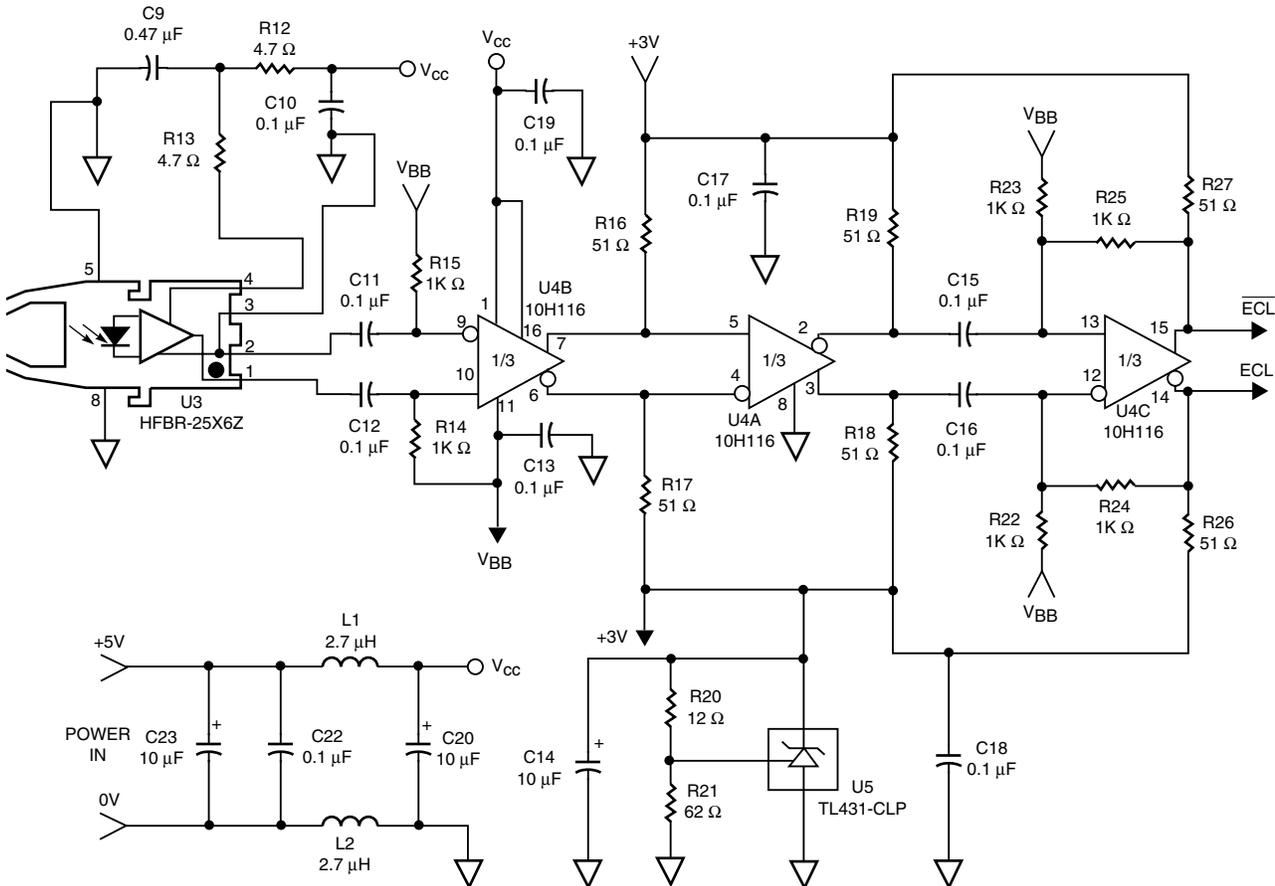
Notes:
VBB: Bias supply for device as a Schmitt trigger or served as stable reference voltage

Pin 11: VBB output pin

**Figure 7. +5 V ECL Receiver with Through Hole Pin Out.**

	POF	HCS™	TOLERANCE
R8	301 Ω	82.5 Ω	1%
R9	301 Ω	82.5 Ω	1%
R11	1K Ω	475 Ω	1%
C8	43 pF	120 pF	5%
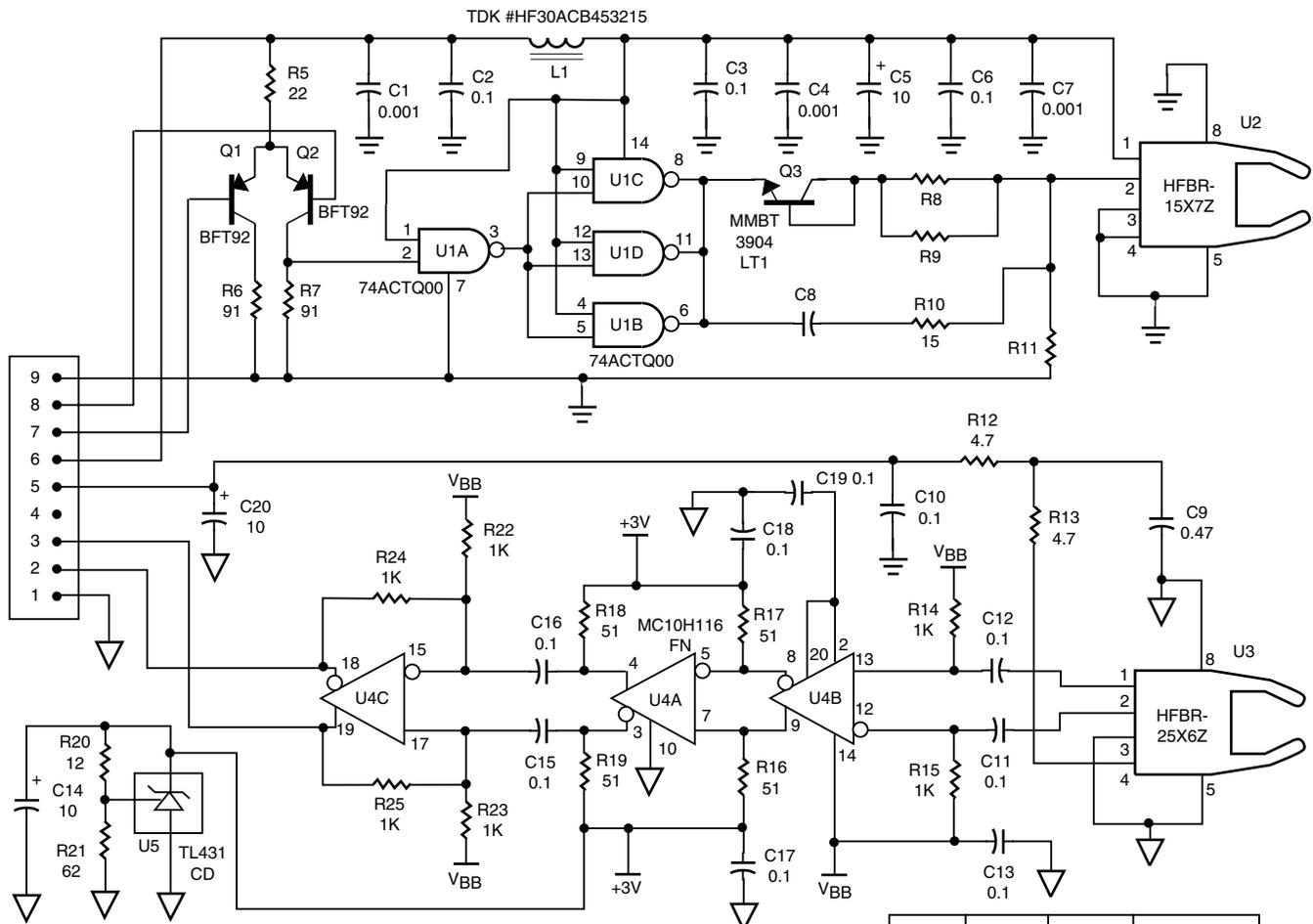
NOTES:

(1) ALL CAPACITORS ARE IN µF WITH ±10% TOLERANCE UNLESS OTHER WISE NOTED.

(2) ALL RESISTORS ARE IN OHMS WITH ±5% TOLERANCE UNLESS OTHER WISE NOTED.

Figure 8. Fiber-Optic Transceiver Using Surface Mount Components.

Local Area Network Links

High speed LANs such as FDDI and ATM have adopted a common footprint +5 V ECL transceiver, often referred to as a "1X9 transceiver". The circuit in Figure 8 matches the electrical functions of these industry standard transceivers, with the exception that there is no signal detect function in the Figure 8 circuit (pin 4 is nonfunctional). Therefore, the recommended circuit can be directly inserted into boards designed for 1X9 transceivers and used as a lower-cost alternative to the industry standard 1300 nm transceivers. If the MC10H116 comparator is replaced with a Signetics NE5224 IC, the signal detect function can also be implemented, at a total transceiver cost that is slightly higher than the MC10H116 circuit, but still significantly less than half the cost of an integrated 1300 nm 1X9 trans-

ceiver. Lower speed LANs such as Ethernet and Token Ring typically use TTL ICs. The circuit of Figure 8 can easily be modified for TTL I/O for such networks. Also note that the HFBR-25X6Z receiver will work well with the Micro Linear ML4622/4624 quantizer ICs designed specifically for Ethernet and Token Ring.

The fiber-optic data links described in this note will not be interoperable with the available industry standard transceivers, and do not conform to the specifications of IEEE or ANSI LAN standards as currently defined. However, these fiber-optic links can be used in proprietary systems where a lower-cost, fiber-optic solution is desired.
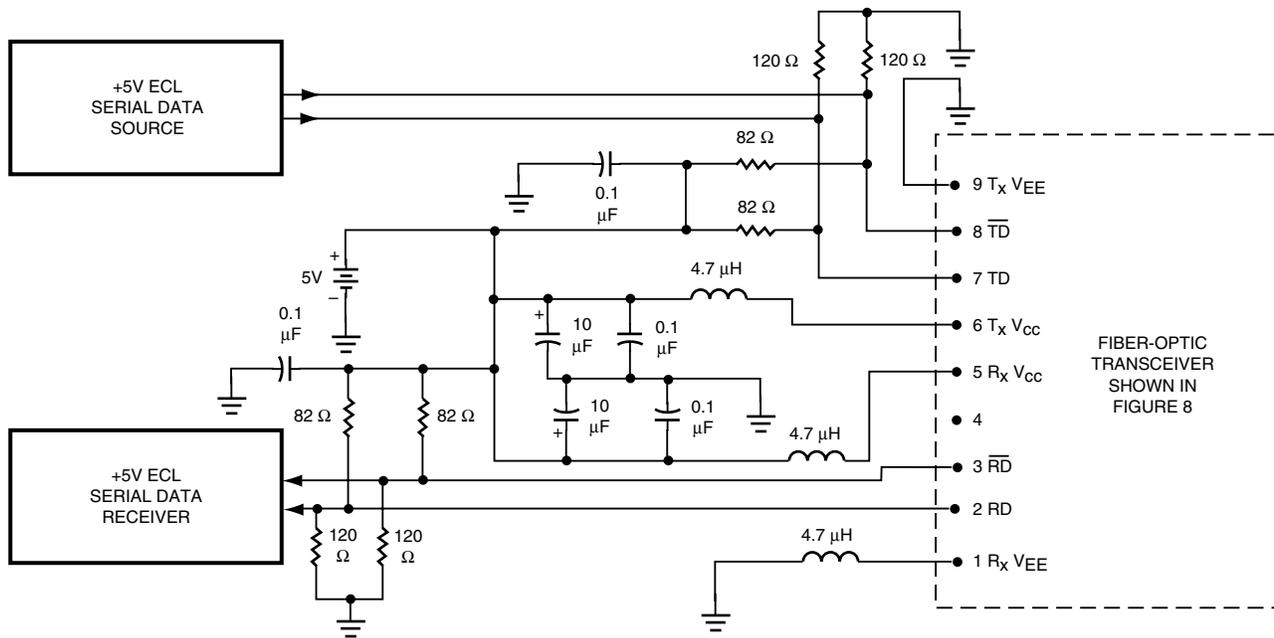
Figure 9. Recommended Power Supply Filter and +5 V ECL Signal Terminations.
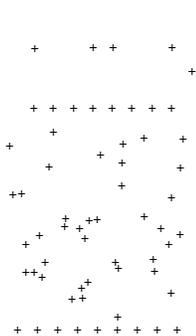
Figure 10a. Drill Drawing
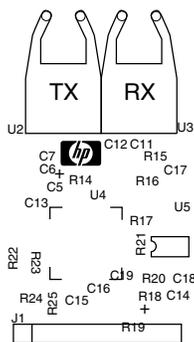
Figure 10b. Top Silkscreen
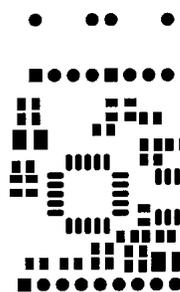
Figure 10c. Top Side Solder Mask
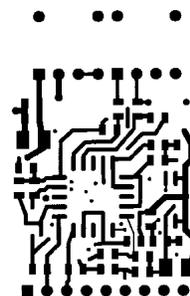
Figure 10d. Top Layer
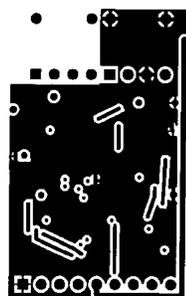
Figure 10e. Second Layer
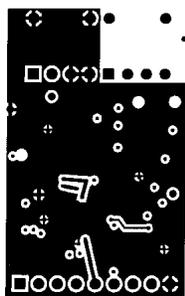
Figure 10f. Third Layer
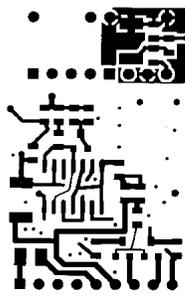
Figure 10g. Bottom Layer
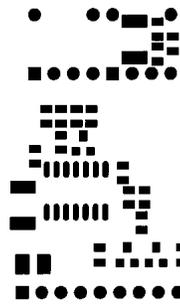
Figure 10h. Bottom Side Solder Mask
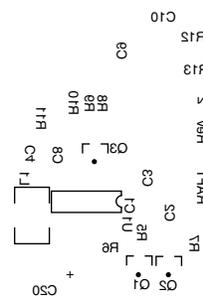
Figure 10i. Bottom Silkscreen

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Byte-to-Light Data Communication

The fiber-optic transceiver shown in Figure 8 has a +5 V ECL interface that is compatible with the AMD TAXIchip. This transceiver can be combined with the TAXIchip to build complete data communication systems that bridge the gap between the serial architecture of optical fibers and the parallel architecture used in computing, peripheral, and telecom systems. TAXIchip provides all of the MUX, DEMUX, encode, decode, and timing recovery functions needed to interface a serial fiber-optic communication channel to a parallel processor. The transceiver shown in Figure 8 provides all of the circuitry needed to interface the HFBR-15X7Z and HFBR-25X6Z components to the Am7968/Am7969 TAXIchips.

Figure 11 shows how the fiber-optic transceiver should be connected to the Am7968 and Am7969.

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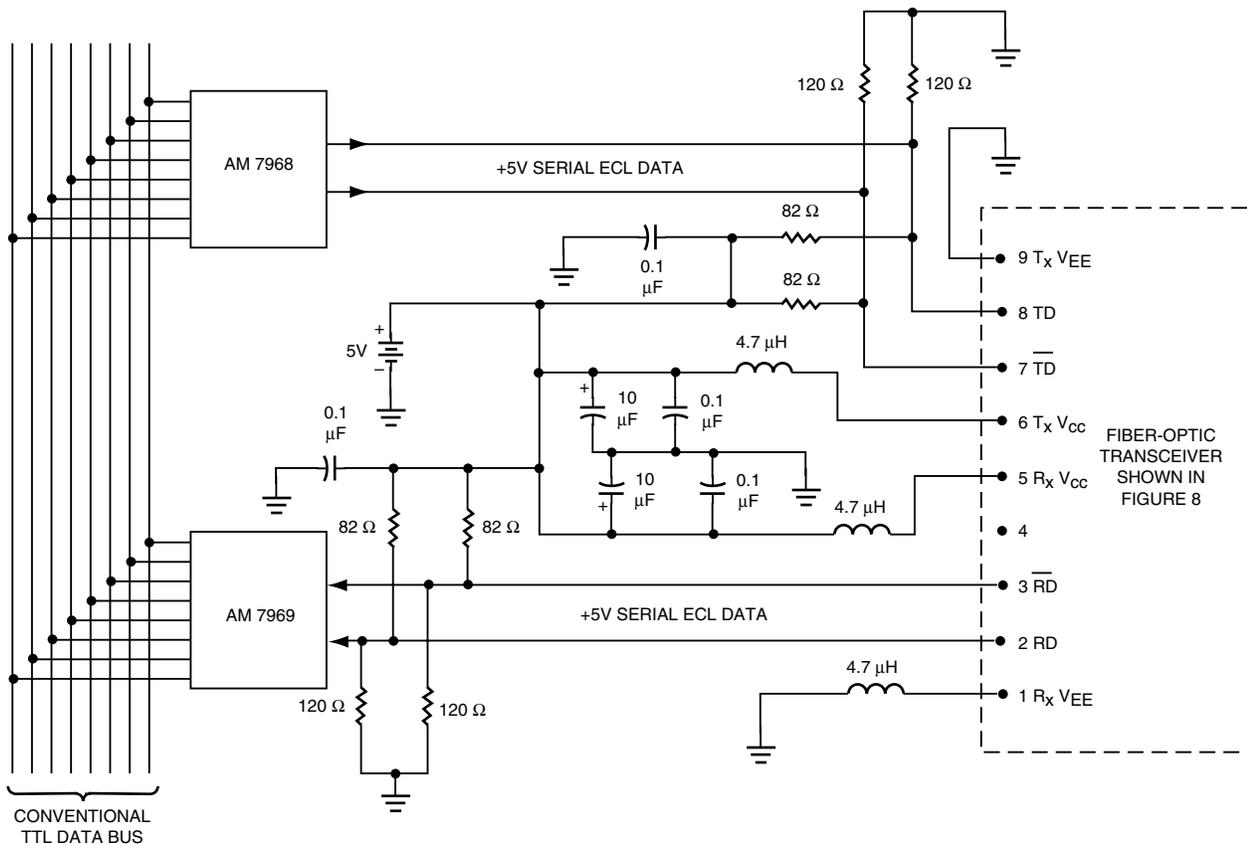
Figure 11. Byte-to-Light Transceiver.

Testing Digital Fiber-Optic Links

The overall performance of a complete digital fiber-optic link can be determined by stimulating the transmitter with a pseudo random bit sequence (PRBS) data source while observing the response at the receiver's output. A PRBS data source is a shift register where data bits from two or more shift register stages are combined using an exclusive-or gate. When a clock signal is applied to the CLK input of the shift register, and the output of the exclusive-or gate is applied to the D_S input of the shift register, the PRBS generator produces a serial bit stream which appears to be random, but is actually periodic and reproducible. If the PRBS generator is constructed using a 23 bit long shift register, the exclusive-or feedback can be configured so that the shift register will be in one of $2^{23}-1$ possible states at any given clock time. The $2^{23}-1$ PRBS data generator appears to be a source of random serial data, but it is actually the output of a shift register which is in one of 8,388,610 precisely repeatable states. PRBS generators send an exactly repeating serial data pattern that can be checked bit-by-bit to determine if the fiber-optic link made errors while transporting the data. A bit-error-ratio test set is an instrument which contains a PRBS generator, a bit-by-bit error detector, and an error counter. Bit-error-ratio test sets measure the probability that the fiber-optic link will make an error. Probability of error is commonly expressed as a bit-error-ratio or BER. The BER is simply the number of errors which occurred divided by the number of bits transmitted through the fiber-optic link in some arbitrary time interval.

The +5 V ECL interface of the transceiver shown in Figure 8 is convenient for use with off-the-shelf VLSI chips like the TAXIchip, but it is not compatible with the majority of the test equipment used to measure the performance of fiber-optic links. Most bit error rate (BER) test sets have conventional -5 V ECL inputs and outputs. The test fixture shown in Figure 12 provides a convenient way to convert +5 V ECL to -5 V ECL. This test fixture allows the transceiver in Figure 8 to be used with any BER test set (BER machine) with a conventional -5V ECL interface. The test fixture in Figure 12 was used to collect the performance data shown in this application note.

The waveforms shown in Figures 13 and 14 are known as eye diagrams. These eye diagrams were measured by connecting a Digitizing Oscilloscope, with a 1 GHz bandwidth, to the receiver's +5 V ECL output. The Agilent 54100A oscilloscope used for these measurements was triggered from the PRBS generator's clock. The lack of correlation between the oscilloscope's time base, and the PRBS generator's clock, assures that the oscilloscope will randomly sample the PRBS data. The infinite persistence mode of the Agilent 54100A Digitizing Oscilloscope was used, and the electrical output of the receiver was measured for roughly 1 hour, to determine the eye opening. As eye opening, or eye width, increases, the probability that the fiber-optic link will make an error decreases. A wide eye opening makes it easier to extract the clock signal which is normally encoded with the data passing through the serial communication channel. Fiber-optic links are less likely to make errors when the eye is wide open, because there is more time for the clock to synchronously detect the data while it is stable and unchanging.

The results measured in Figure 13 were obtained at room temperature when 125 MBd PRBS data was transmitted through a plastic fiber-optic link. Figure 13 shows that the eye opening is typically 5.52 ns when the recommended transceiver in Figure 8 is used with 20 meters of 1 mm plastic fiber. Excellent performance can also be achieved by using the transceiver in Figure 8 with Avago's 200 μm HCS™ fiber. Figure 14 indicates that the eye opening is typically 5.56 ns wide when 125 MBd data is transmitted through 100 meters of 200 μm HCS™ fiber.

A better method for measuring the performance of a complete optical data link is to use a computer controlled delay line and a BER test set. This technique uses a computer to adjust the delay of the BER test set's clock relative to the PRBS data. At a data rate of 125 MBd the clock delay was changed in 100 ps increments. The test system then measures and stores the probability of error at each 100 ps delay step until the clock has been swept through the entire 8.0 ns period of every 125 MBd symbol transmitted through the fiber-optic link. The results in Figure 15 were obtained when the BER test set applied $2^{23}-1$ PRBS data to the transmitter portion of the transceiver under evaluation. Figure 15 shows that when using the transceiver recommended in Figure 8 BER is typically $\leq 1 \times 10^{-10}$ for 5.8 ns of each pseudo random symbol transmitted through a 20 m length of 1 mm plastic fiber. The optical power applied to the receiver was Pr = -16.4 dBm average for the measured results shown in Figure 15. Figure 16 shows the performance that can be achieved at 125 MBd with 200 μm HCS™ fiber. Figure 16 shows that when using the transceiver recommended in Figure 8, BER will be typically $\leq 1 \times 10^{-10}$ for 5.3 ns of each pseudo random symbol transmitted through a 100 m length of 200 μm HCS™ fiber. The optical power applied to the receiver was Pr = -18.0 dBm average for the measured results shown in Figure 16.
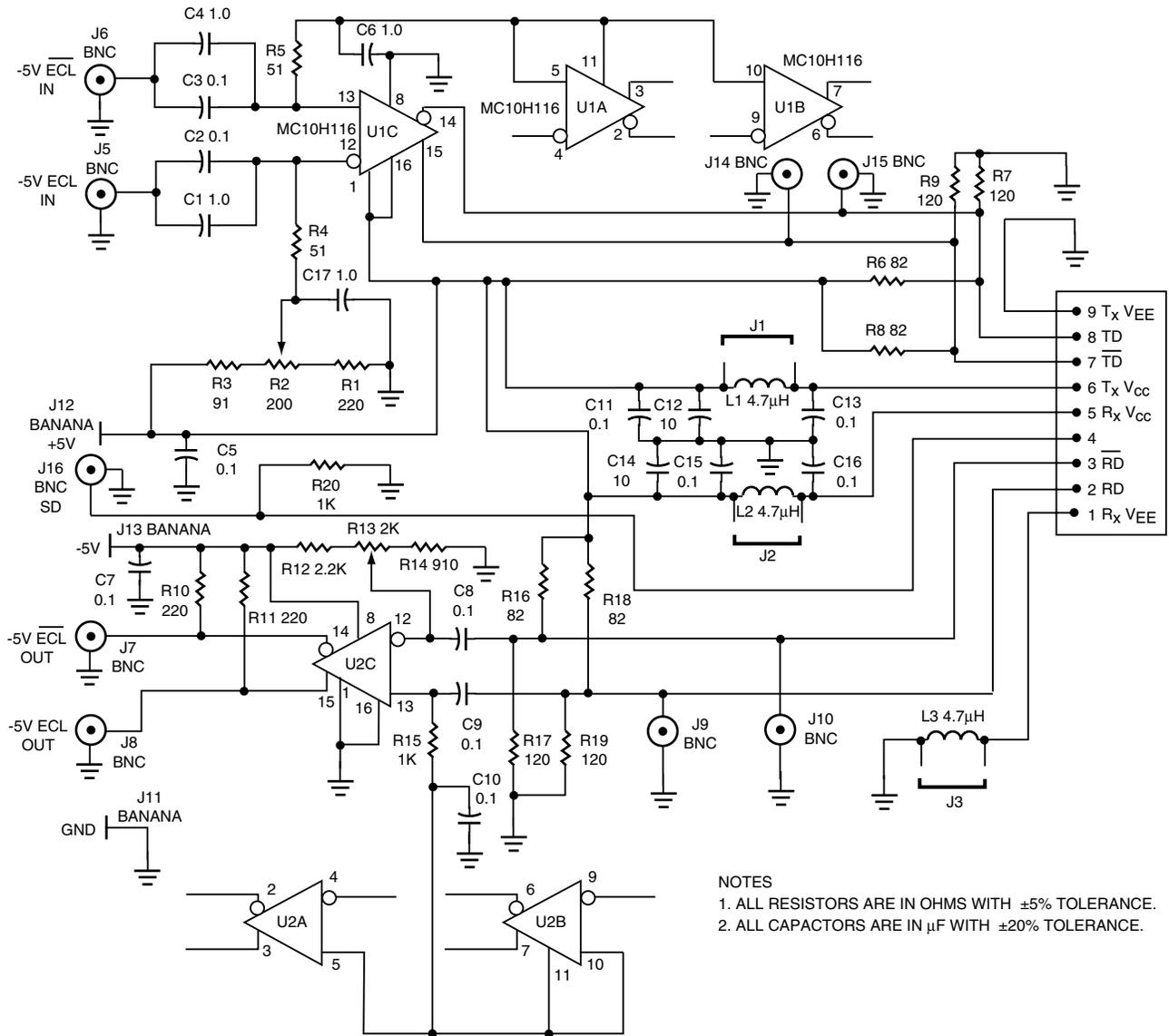
Figure 12. Fiber-Optic Transceiver Test Fixture.

NOTES
1. ALL RESISTORS ARE IN OHMS WITH ±5% TOLERANCE.
2. ALL CAPACTORS ARE IN µF WITH ±20% TOLERANCE.

CH #4 = 200 mV/div.
TIMEBASE = 2 ns/div
DELTA T = 5.52 ns
START = 23 ns
STOP = 28.92 ns
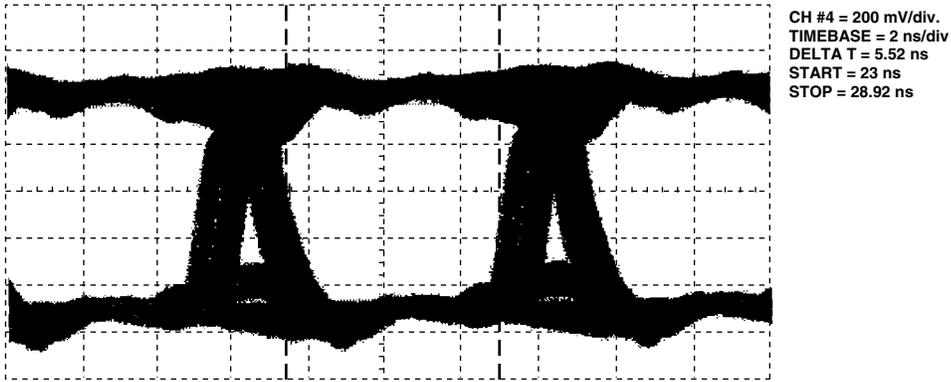
Figure 13. Typical Eye Opening with 25 m of Low Loss 1 mm Plastic Optical Fiber (POF).

CH #4 = 200 mV/div.
TIMEBASE = 2 ns/div
DELTA T = 5.56 ns
START = 21.28 ns
STOP = 26.84 ns
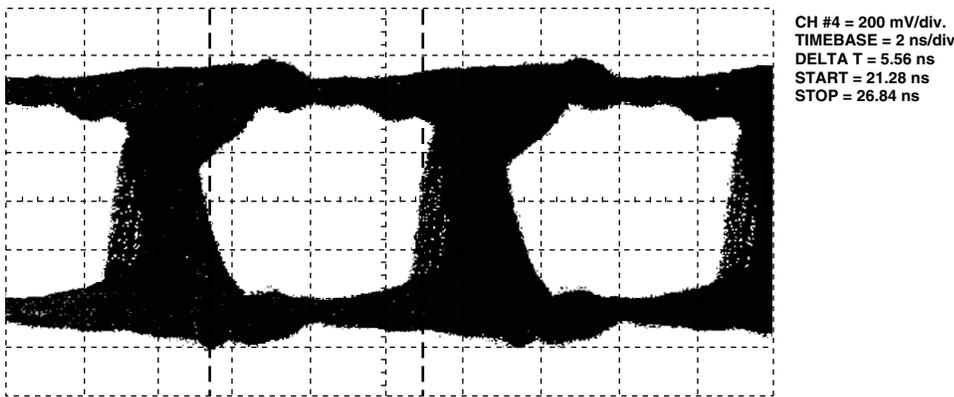
Figure 14. Typical Eye Opening with 100 m of 200 μm HCS™ Fiber.

Applications Support

Variations in performance due to circuit layout can be avoided by using the artwork shown in Figure 10. Designers that would like to use the printed circuit layout developed by Avago are encouraged to embed the PC artwork shown in this Application Note into their systems. The PC art shown here is available from an electronic bulletin board that can be downloaded. Complete documentation which contains the artwork, schematic, and parts list for the fiber-optic transceiver shown in Figure 8 is available in the file named HPRAFTV2.EXE. The artwork, schematic, and parts list for the test fixture shown in Figure 12 are also available in the file named 1X9_FXTR.EXE.

System designers can quickly determine if the HFBR-15X7Z and HFBR-25X6Z will meet their needs by ordering the HFBR-0527Z. The HFBR-0527Z is a completely assembled demo board for the transceiver shown in Figure 8. When using plastic fiber order the HFBR-0527P, and when using 200 μm HCS™ fibers specify the HFBR-0527H. The test fixture in Figure 12 is also available as the HFBR-0319. The HFBR-0319 is a fully assembled test fixture. This test fixture adapts any fiber-optic transceiver with a 1x9 footprint to test equipment with -5 V ECL inputs and outputs. The HFBR-0527 and the HFBR-0319 minimize the effort needed to design new products which use fiber-optic data links. The HFBR-0527 and the HFBR-0319 provide a high level of technical support. This high level of technical assistance drastically reduces the time needed to develop and market new products which utilize the fundamental advantages of optically isolated data communication.
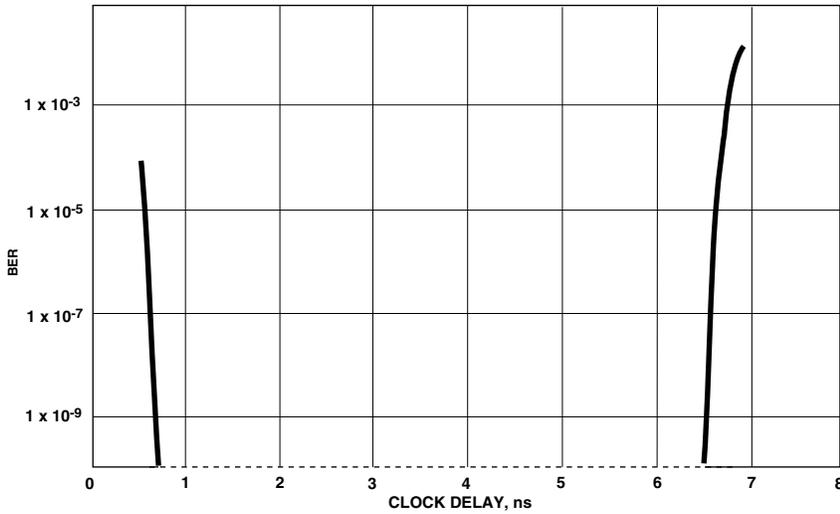
Figure 15. Typical BER vs. Clock Delay at 125 MBd with 20 m of 1 mm Plastic Fiber.
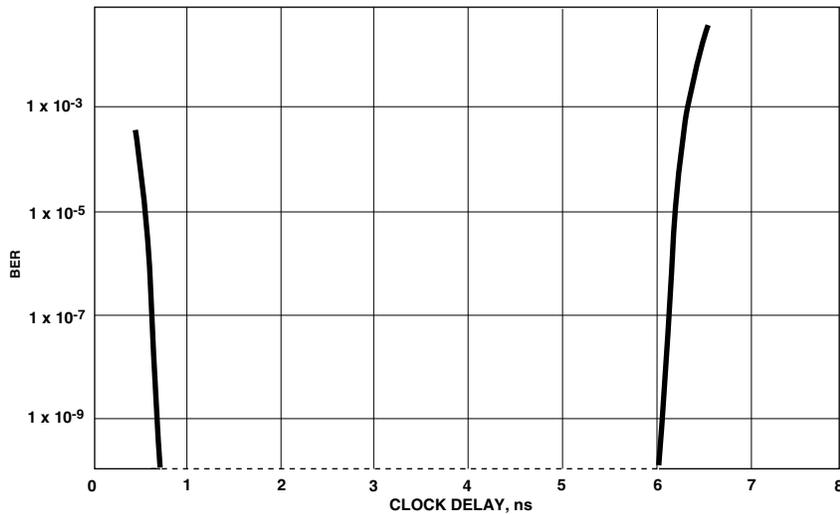

Figure 16. Typical BER vs. Clock Delay at 125 MBd with 100 m of 200 μm HCS™ Fiber.

Conclusion

The HFBR-15X7Z and HFBR-25X6Z components can be used with large core fibers and inexpensive optical connectors to build exceptionally low cost digital fiber-optic links. When these Versatile Link components are used with 1 mm plastic, or 200 μm HCS™ fibers, digital data links that are comparable with the cost of shielded twisted pair wire can easily be implemented. The HFBR-15X7Z and HFBR-25X6Z provide designers with a short haul data communication solution that costs the same as shielded twisted pair wire, but this low cost fiber-optic solution has none of the grounding and electromagnetic compatibility problems inherent in metallic cables.

Table 1. Parts List for Circuit Shown in Figure 8.

Designator	Part Type	Description	Footprint	Material	Part Number	Quantity	Vendor 1
C1	0.001	Capacitor	805	NPO/COG	C0805NPO500102JNE	3	Venkel
C4	0.001	Capacitor					
C7	0.001	Capacitor					
C10	0.1	Capacitor	805	X7R or better	C0805X7R500104KNE	12	Venkel
C11	0.1	Capacitor					
C12	0.1	Capacitor					
C13	0.1	Capacitor					
C15	0.1	Capacitor					
C16	0.1	Capacitor					
C17	0.1	Capacitor					
C18	0.1	Capacitor					
C19	0.1	Capacitor					
C2	0.1	Capacitor					
C3	0.1	Capacitor					
C6	0.1	Capacitor					
C9	0.47	Capacitor	1812	X7R or better	C1812X7R500474KNE	1	Venkel
C14	10	Capacitor	B	Tantalum, 10v	TA016TCM106KBN	3	Venkel
C20	10	Capacitor					
C5	10	Capacitor					
C8 1mm Plastic	43 pF	Capacitor	805	NPO/COG	C0805COG500470JNE	1	Venkel
C8 200HCS	120 pF	Capacitor	805	NPO/COG	C0805COG500121JNE	1	Venkel
U1		NAND Gate	SO-14		74ACTQ00	1	Fairchild
U2		LED Transmitter			HFBR-1527Z	1	Avago
U3		Fiber-Optic Receiver			HFBR-2526Z	1	Avago
U4	MC10H116FN	IC, ECL line receiver	PLCC20		MC10H116FN	1	Motorola
U5	TL431CD	IC, Voltage Regulator	SO-8		TL431CD	1	T.I.
L1	CB70-1812	Inductor	1812		HF30ACB453215	1	TDK
R12	4.7	Resistor	805	5%	CR080510W4R7JT	2	Venkel
R13	4.7	Resistor					
R20	12	Resistor	805	5%	CR080510W120JT	1	Venkel
R10	15	Resistor	805	5%	CR080510W150JT	1	Venkel
R5	22	Resistor	805	5%	CR080510W220JT	1	Venkel
R16	51	Resistor	805	5%	CR080510W510JT	4	Venkel
R17	51	Resistor					
R18	51	Resistor					
R19	51	Resistor					
R21	62	Resistor	805	5%	CR080510W620JT	1	Venkel
R8 1mm Plastic	301	Resistor	805	1%	CR080510W3010FT	2	Venkel
R9 1mm Plastic	301	Resistor					
R8 200HCS	82.5	Resistor	805	1%	CR080510W82R5FT	2	Venkel
R9 200HCS	82.5	Resistor					
R6	91	Resistor	805	5%	CR080510W910JT	2	Venkel
R7	91	Resistor					
R11 1mm Plastic	1K	Resistor	805	1%	CR080510W1001FT	1	Venkel
R11 200HCS	475	Resistor	805	1%	CR080510W4750FT	1	Venkel
R14	1K	Resistor	805	5%	CR080510W102JT	6	Venkel
R15	1K	Resistor					
R22	1K	Resistor					
R23	1K	Resistor					
R24	1K	Resistor					
R25	1K	Resistor					
Q1	BFT92	Transistor	SOT-23		BFT92	2	Philips
Q2	BFT92	Transistor					
Q3	MMBT3904LT1	Transistor	SOT-23		MMBT3904LT1	1	Motorola

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

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