Complete Solutions for IEEE 802.5J Fiber Optic Token Ring

Application Note 1065

Introduction

Avago Technologies' HFBR-0400Z fiber optic components are widely used in Ethernet LAN systems. These same 820 nm wavelength components are also used in Token Ring LAN systems. The HFBR-14X4Z, and HFBR-24X6Z, comply with the IEEE 802.5J Trial-Use Standard for both 4 and 16 M bit/s transmission rates. Distances that range from 1 m to 2 km can easily be achieved when Avago Technologies' inexpensive short wavelength components are used with the circuits recommended in this publication. Several integrated circuits that work well with the HFBR-14X4Z, and the HFBR-24X6Z, are discussed in the following text. These integrated circuits reduce the amount of board space required and lower the number of components needed to build the fiber optic transceiver. The objective of this application note is to make it simple for designers to use Avago's HFBR-0400Z components in LAN equipment such as multi-station access units (MAUs), bridges, fiber optic media converters, repeaters, and adapter cards that are used in Token Ring LANs. The following text will show that it is easy to build high-performance Token Ring transceivers, when using inexpensive off-the-shelf integrated circuits, with Avago's low-cost HFBR-14X4Z, and HFBR-24X6Z fiber optic components.

IEEE 802.5 System Specifications

Tables 1 and 2 provide a brief listing of some key parameters specified in the 802.5J Trial-Use Standard.

Capabilities of HFBR-0400Z Components

The transmitter and receiver circuits recommended in this application note characteristically exceed the performance called for in IEEE 802.5J by a comfortable margin. The optical power launched into 62.5/125 μm fiber by the HFBR-14X4Z LED is typically -12 dBm peak at a DC forward current of 60 mA. When Manchester encoded data with a 50% duty factor is applied to the LED transmitter the HFBR-14X4Z LED can typically launch -15 dBm average into the core of a 1 meter length of 62.5/125 μm fiber with a numerical-aperture of 0.275. This 3 dB difference between peak and average power is due to the 50% duty factor of Manchester data and the averaging response of most optical-power meters. The HFBR-24X6Z is a simple hybrid component that contains a silicon PIN detector and a transimpedance amplifier. The HFBR-24X6Z can be combined with simple, inexpensive integrated circuits to build digital receivers that have an optical dynamic range and sensitivity greater than called for in the IEEE 802.5J specifications.

Recommended Transmitter Designs For Token Ring.

Two different techniques have commonly been used to drive the HFBR-1414Z LED in Token Ring applications. Both of the LED drivers recommended in this application note will address the requirements called out in the IEEE 802.5J Token Ring specification. The HFBR-14X4Z LED has typical rise/fall times of less than 4 ns when used in the circuits recommended in Figure 1 or Figure 2. Transmitter jitter and duty-cycle distortion are normally less than 1 ns when using either of the recommended LED drivers. The cost complexity and performance tradeoffs associated with these two different LED drivers will now be discussed in greater detail.

Table 1. Key IEEE 802.5 LED Transmitter Specifications

Parameter	Symbol	802.5J Limits @ 8 MBd	802.5J Limits @ 32 MBd	Units
Launched Optical Power Over Life	P_T on	-12 to -19	-12 to -19	dBm avg
Extinction	P_T extinct	13 dB less than P_T on	13 dB less than P_T on	
Average Power Transmitter Disabled	P_T off	-38	-38	dBm avg
Maximum Optical Rise Time	t_r	25	6.0	ns
Maximum Optical Fall Time	t_f	25	6.0	ns
Maximum Difference Between Optical Rise and Fall Times	$\|t_r-t_f\|$	12	3	ns
Maximum Symbol Width Distortion (OTA)		±4.0	±1.5	ns

Table 2. Key IEEE 802.5 Fiber Optic Link Specifications

Test Conditions	Receiver Input Conditions			Required Link Performance	
Length of 62.5/125 µm Fiber Optic Cable (meters)	Maximum Rise/Fall Time of Received Optical Pulse at 8 MBd (ns)	Maximum Rise/Fall Time of Received Optical Pulse at 32 MBd (ns)	Received Optical Power (dBm avg.)	Maximum Jitter at 8 MBd (ns_{pp})	Maximum Jitter at 32 MBd (ns_{pp})
10	25	6.0	-12 max.	9.9	5.8
2 k	60	27	-32 min.	18.3	9.2
Length of 62.5/125 µm Fiber Optic Cable (meters)	**Maximum Rise/Fall Time of Received Optical Pulse at 8 MBd (ns)**	**Maximum Rise/Fall Time of Received Optical Pulse at 32 MBd (ns)**	**Received Optical Power (dBm avg.)**	**Minimum Eye Opening at 8 MBd (ns)**	**Minimum Eye Opening at 32 MBd (ns)**
10	25	6.0	-12 max.	115	25.5
2 k	60	27	-32 min.	107	22.1

The LED forward current (I_F) supplied by the simple voltage-source driver shown in Figure 1 will change with variations in V_{CC} and LED forward voltage (V_F). The tolerance of resistors R7, R8, and R9 will also effect the magnitude of I_F. Deviations in I_F due to the 74ACT11000 NAND-gate voltage-source are insignificant. The typical output impedance of the three parallel connected NAND gates is only 1 Ω and the external resistors R7 and R8 which limit the LED current total to 66 ohms. This large difference between the source-impedance of the NAND-gate voltage-source and the sum of R7 and R8 makes it improbable that changes in LED I_F will result due to process variations in the 74ACT11000.

A voltage-source drive-circuit suited for Token Ring applications is shown in Figure 1. This simple circuit is designed to nominally drive the LED at a forward current (I_F) of 60 mA DC, when logic "0" is applied to pin 9 of U4D. Normal tolerances of the circuit cause the LED current to be greater or less than the 60 mA forward current recommended for the HFBR-14X4Z. Since the light output of the LED is proportional to the forward current, this variation in I_F causes changes in the optical power coupled into the fiber. The elements contributing to the variations in forward current are LED forward voltage (V_F), tolerance of the resistors which set the drive current, and variations in V_{CC}. When

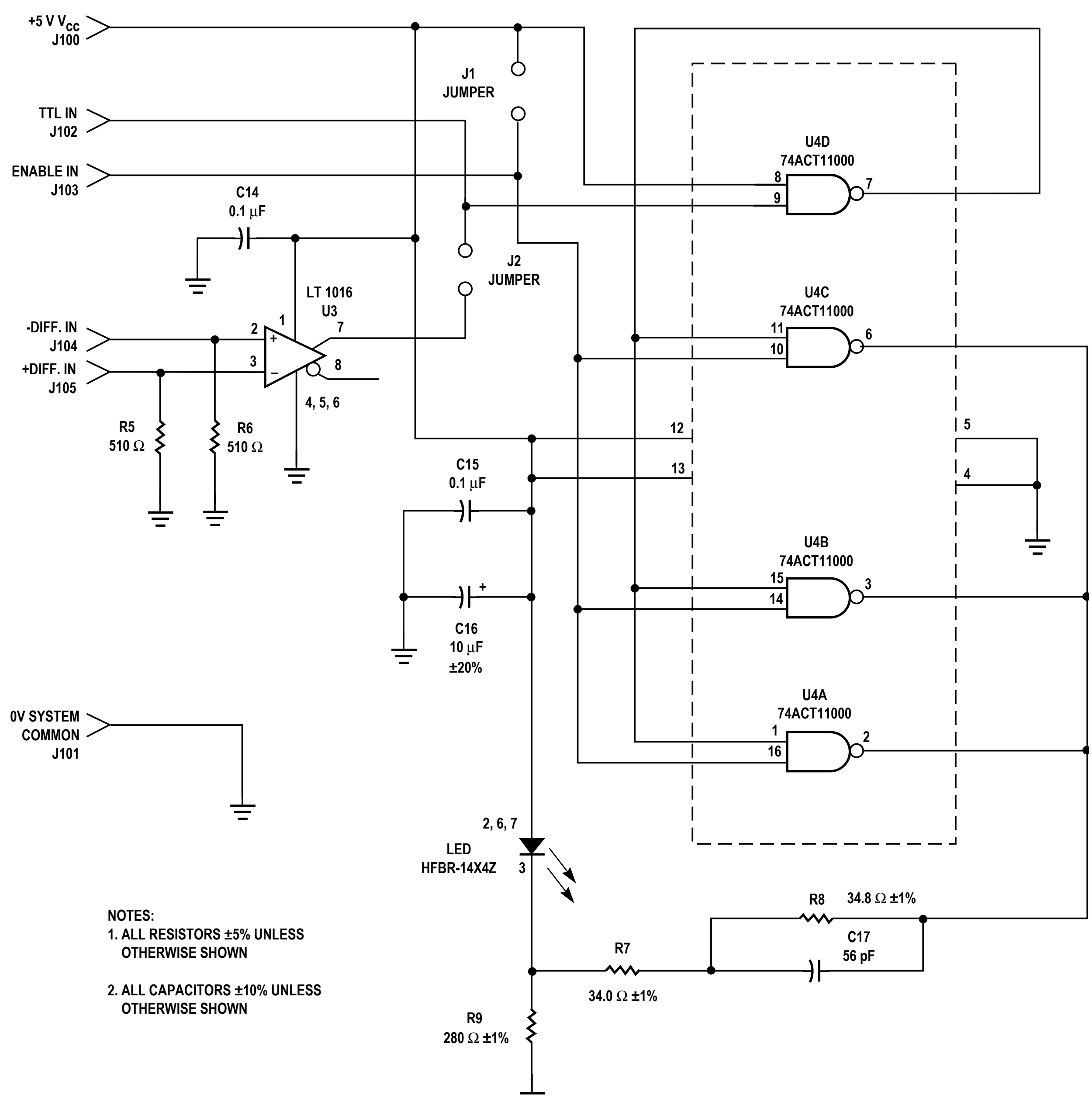

Figure 1. Voltage-source Transmitter for Token Ring LAN applications

tolerances of the circuit add up to increase the forward current of the LED, about a 0.8 dB increase in the light output can be expected. This light output level is well within the limits of the IEEE 802.5J standard, and is less than the saturation point of the recommended receiver. Decreases in LED forward current due to circuit tolerances cause a 1.0 dB drop in the light coupled into the fiber under worst-case conditions. The worst-case condition occurs when V_{CC} is low, LED forward voltage (V_F) is high, and resistor tolerance is high.

The HFBR-14X4Z data sheet specifies launched power at I_F = 60 mA, and assumes that LED forward current is constant. Normal tolerances of the voltage-source LED driver will cause variations in LED I_F that lower the minimum power launched into the fiber. This reduction in launched power relative to the P_{t62} specification given in the HFBR-14X4Z data sheet is expected. Voltage-source drive-circuit tolerances will lower LED forward current and the amount of light coupled into the fiber optic cable is directly proportional to I_F.

For applications that require tighter control of the launched optical power, the current-source transmitter shown in Figure 2 is recommended. Figure 2 shows an LED drive-circuit which provides a forward current that is independent of V_{CC}, and LED forward voltage. The LED current provided by this driver is primarily determined by the tolerance of the bandgap reference U3, and the tolerance of resistors R5 and R6. The -2 mV/° C temperature coefficient of the base-emitter junction of Q3 or Q4 increases the voltage applied to R5 and R6 as ambient temperature rises. The temperature coefficient of NPN transistor base-emitter voltage is thus used to increase the magnitude of the current applied to the LED as temperature rises. This technique prevents LED light output from decreasing as temperature rises by compensating for changes in the LED quantum efficiency.

Either of the LED drivers shown in this application note will address the requirements called out in the IEEE 802.5J specifications. The design rules for the LED driver shown in Figure 1 are given in Equation 1 and the design rules for the LED driver shown in Figure 2 are provided in Equation 2.

When choosing the driver, the designer should consider the following factors. The LED driver shown in Figure 1 is simple, but has a slight variation in the power coupled from the LED to the fiber. The circuit shown in Figure 2 is more complex, but offers tighter control over variations in launched optical power. System designers are encouraged to choose the LED driver which best meets their requirements. If cost and board space are of greater concern than variations in launched optical power then the voltage-source transmitter circuit shown in Figure 1 makes the most sense. If the designer desires to maximize the optical power budget of the fiber optic link then the transmitter circuit shown in Figure 2 is a better choice.

Equation 1

Design rules for a voltage-source LED driver circuit.

N = Number of gates connected in parallel.
B = Empirically determined constant for optimum relationship between prebias and LED forward current.

$$R9 = \frac{(V_{CC} - V_F)(1 + B)}{I_{F_{ON}}}$$

$$R8 = \frac{R9}{2B}$$

$$R7 = \frac{R9}{2B} - \frac{3}{N}$$

$$C = \frac{2.0 \times 10^{-9}}{R8}$$

Recommend B = 3.97

Equation 2

Design rules for a temperature compensated current-source LED driver circuit.

$$I_F = \frac{\Delta V_{U3} - V_{BE_{Q3}}}{R5} + \frac{\Delta V_{U3} - V_{BE_{Q4}}}{R6}$$

$$I_F = \frac{1.24 - 0.7}{R5} + \frac{1.24 - 0.7}{R6}$$

$$I_F = (1.24 - 0.7) + \left(\frac{1}{R5} + \frac{1}{R6}\right)$$

$$R3 = \frac{V_{OH} - V_{OL}}{I_F} = \frac{5V}{I_F}$$

$$C4 = \frac{2.0\ \text{ns}}{R3}$$

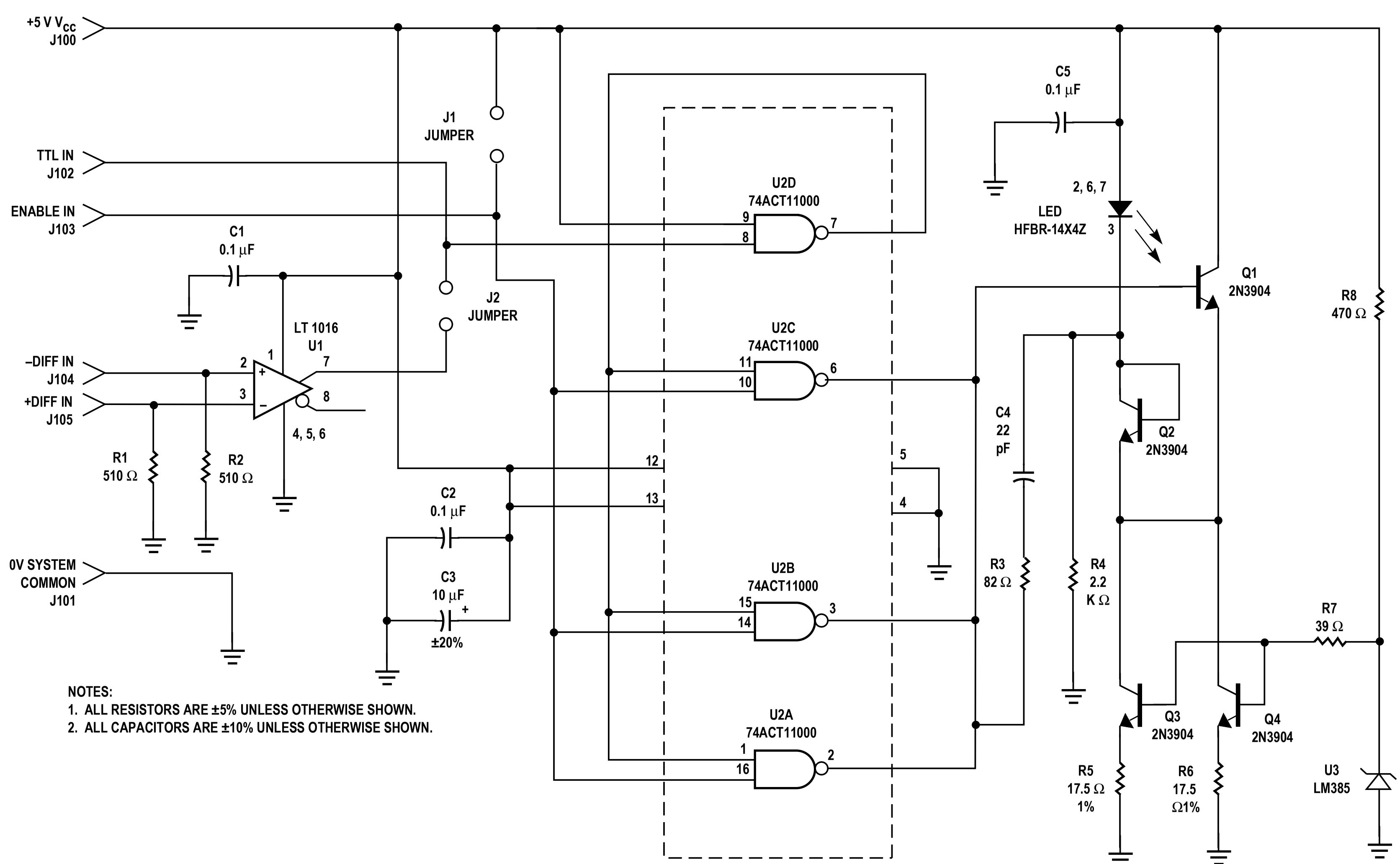

Figure 2. Current-source Transmitter for Token Ring LAN Applications

Recommended Receiver Designs For Token Ring

A simple receiver which complies with IEEE 802.5J specifications is shown in Figure 3. The post-amplifier comparator function used to convert the analog output of the HFBR-24X6Z to digital data is generally referred to as a quantizer. Micro Linear's ML-4622 quantizer also contains a link-monitor function. The link monitor inhibits the data output when optical power drops below the minimum level needed to ensure that the receiver's output is error free.

The receiver recommended in Figure 3 has a typical sensitivity of -34 dBm average at a Bit-Error-Rate (BER) of 1×10^{-10} when receiving 32 MBd Manchester encoded data. This receiver performance was measured using 2 km of 62.5/125 µm fiber with the BER tester's clock centered in the middle of the received 32 MBd Manchester symbols. The link-monitor function must be disabled by grounding pin 15 of the ML-4622 quantizer in order to measure the ultimate sensitivity of the receiver. In normal operating mode, the ML-4622's link monitor disables the data output of the fiber optic receiver before the probability of an error exceeds 1 in 10^{10} bits.

When receiving a repetitive 32 MBd D2D2 hexadecimal word, the total peak-to-peak jitter at the data output of the circuit shown in Figure 3 is typically less than 7 ns. A D2D2 hexadecimal pattern was used to test the complete fiber optic link because it emulates the worst data dependent stress possible with Manchester encoding. The excellent performance of the circuits recommended in this application note allows low jitter to be achieved when data is transmitted over a 2 km segment of 62.5/125 µm fiber with a received optical power of -32.0 dBm average. The low jitter attained at the receiver's output corresponds to a clear eye-opening which is typically > 24 ns. A wide eye-opening is desirable because this minimizes the accumulation of jitter when data is passed from station-to-station in the Token Ring LAN.

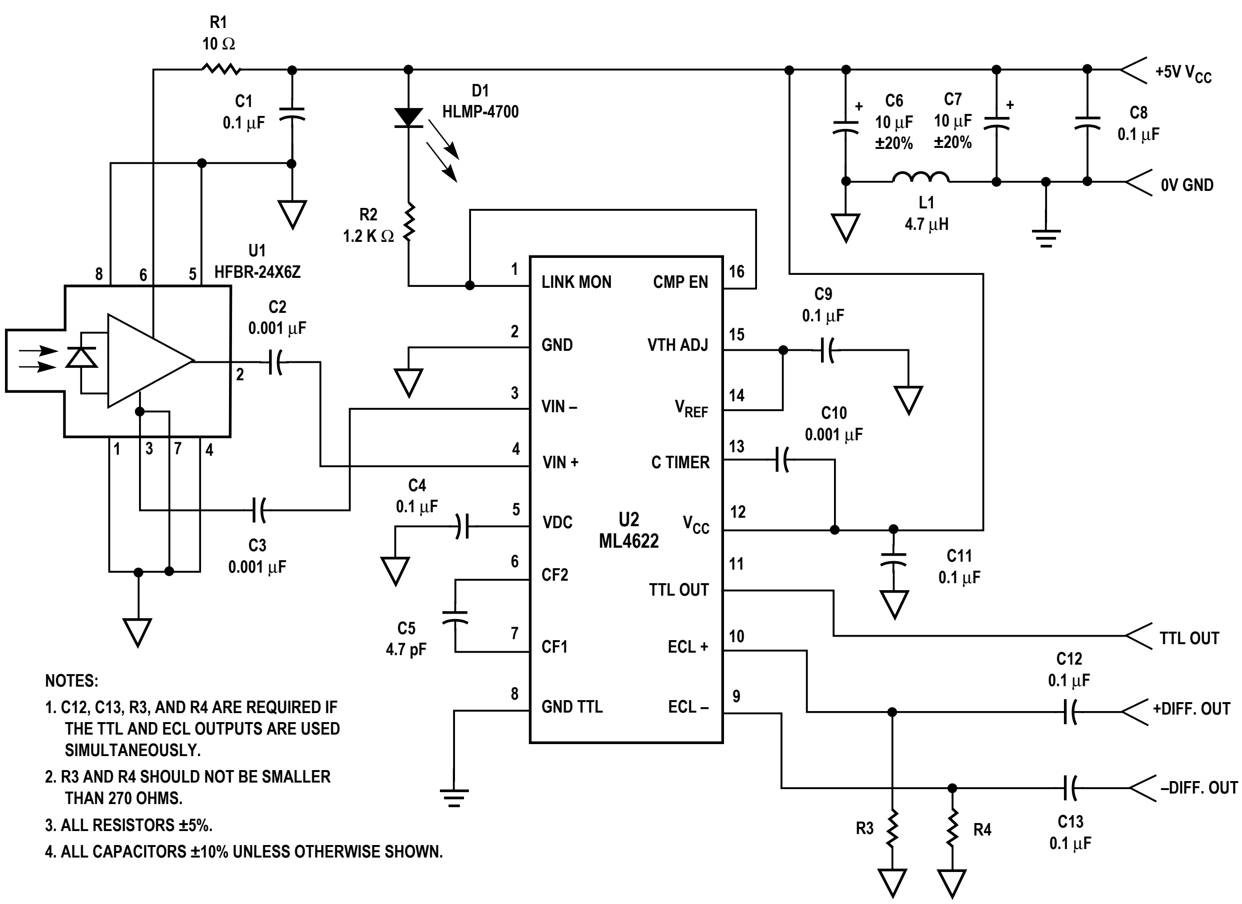

Figure 3. Receiver for Token Ring LAN Applications

Demo Kit For Fiber Optic Token Ring

The transceiver circuits shown in Figures 1, 2, and 3 are suited for use in fiber optic multi-station access units (MAUs), bridges, fiber optic media converters, repeaters, and adapter cards. This recommended transceiver can easily be compared to the IEEE specifications listed in Tables 1 and 2 by ordering the HFBR-0414Z demo kit. The HFBR-0414Z kit contains a small 2¾ by 1¾ inch through-hole printed circuit board and all of the active devices needed to build the circuits shown in Figures 1 and 3. This inexpensive kit can be completed using readily-available passive components such as radial-lead monolithic ceramic capacitors, radial-lead epoxy-dipped tantalum capacitors, and axial-lead ¼ W resistors. The passive components needed to assemble this fiber optic demonstration are available in most engineering stock rooms. The HFBR-0414Z demo kit minimizes the engineering cost of building the fiber optic transceiver recommended in this application note, reduces time-to-market by minimizing the effort required to construct working prototypes, and enables designers to quickly confirm that Avago Technologies' HFBR-0400Z fiber optic components can meet Token Ring LAN requirements. The measured performance of the circuits used in the HFBR-0414Z demonstration can be found in Tables 3 and 4. Table 3 shows the measured performance of the transmitter recommended in Figure 1. Table 4 shows the measured performance of an entire fiber optic link which uses the circuits recommended in Figures 1 and 3.

Measured Performance of the Complete Fiber Optic Link

Figure 4 shows the TTL output of a fiber optic transceiver constructed using HFBR-14X4Z and HFBR-24X6Z components. The results shown in Figure 4 were obtained at room temperature when 32 MBd data is transmitted through 3.32 km length of 62.5/125 μm fiber terminated with ST con-nectors. Figure 4 shows that average jitter is approximately 7 ns and that the eye opening is roughly 24 ns when an optical attenuator is used to adjust received power to -32 dBm average. Figure 4 was measured using a D2D2 hexadecimal test pattern that simulates the worst stress possible with Manchester encoded data. The waveform shown in Figure 4 was obtained by connecting an Agilent 54100A Digitizing Oscilloscope to the receiver's TTL output. The infinite persistence mode of the Agilent 54100A Digitizing Oscilloscope was used to determine the peak-to-peak jitter and eye opening. Figure 5 shows that the receiver does not overload when a short 1 m length of 62.5/125 μm fiber is substituted for the long cable.

A more accurate method of determining the performance of a complete fiber optic link is to use a computer controlled delay line and a BER test set. The computer is used to adjust the position of the BER test set's clock sothat the probability of error is measured in 1.5 ns steps through the entire 31.25 ns period of every 32 MBd symbol. This technique was used to create the plot of BER versus clock delay. Figure 6 shows that BER is $\leq 1.1 \times 10^{-10}$ for 24.9 ns of each symbol transmitted through the 2 km length of 62.5/125 μm fiber. This performance was obtained when using the transmitter and receiver shown in Figures 1 and 3. The measured results shown in Figure 6 were obtained by using an optical attenuator at the end of the 2 km fiber. For these tests the attenuator was adjusted so that the optical power applied to the receiver was -32.0 dBm avg.

Table 3. Measured Performance of the Transmitter Shown in Figure 1
Mean Performance of Five Transmitters Tested at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
P_t On	-12.2 dBm pk	Logic "0" at Transmitter TTL Input, I_f dc = 60 mA
P_t Off	-82.2 dBm pk	Logic "1" at Transmitter TTL In
LED t_r	1.30 ns	1 MHz Square Wave Input
LED t_f	3.08 ns	1 MHz Square Wave Input
$\|t_r-t_f\|$	1.77 ns	1 MHz Square Wave Input
Tx jitter	0.823 ns pp	32 MBd D2D2 Hexadecimal Input

Table 4. Measured Performance of the Transceiver Shown in Figures 1 and 3
Mean Jitter of Five Transceivers at Maximum Received Optical Power at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
1 m Link Jitter @ Rx ECL Output	3.04 ns pp	P_r = -11.3 dBm avg. with 32 MBd D2D2 Hexadecimal Data
1 m Link Jitter @ Rx TTL Output	2.18 ns pp	P_r = -11.5 dBm avg. with 32 MBd D2D2 Hexadecimal Data

Mean Performance of Five Receivers with 1 m of 62.5/125 μm Fiber at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
Mid Bit Rx Sensitivity	-36.1 dBm avg. @ BER of 1×10^{-10}	32 MBd D2D2 Hexadecimal Data
Link Monitor Assert Threshold	-34.4 dBm avg.	32 MBd D2D2 Hexadecimal Data

Mean Performance of Five Links with 2 km of 62.5/125 μm Fiber at Room Temperature

Parameter	Measured Typical Performance	Test Conditions
Mid Bit Rx Sensitivity	-34.1 dBm avg. @ BER of 1×10^{-10}	32 MBd D2D2 Hexadecimal Data
Link Jitter @ Rx ECL Output	6.91 ns pp	P_r = -32.0 dBm avg. with 32 MBd D2D2 Hexadecimal Data
Link Jitter @ Rx TTL Output	5.52 ns pp	P_r = -32.0 dBm avg. with 32 MBd D2D2 Hexadecimal Data

CH #1 BER MACHINE CLOCK (400.0 mV/div).
CH #2 RECEIVER TTL OUTPUT (1.0 V/div).
TIMEBASE = 10.0 ns/div

TEST CONDITIONS:
32 MBd D2D2 HEXADECIMAL DATA.
3.32 km OF 62.5/125 μm FIBER.
RECEIVER OPTICAL POWER, P_r = -32 dBm AVERAGE.
TRANSMITTER OPTICAL POWER, P_t = -14.8 dBm AVERAGE.

Figure 4. Receiver Output vs. Clock with Long Fiber

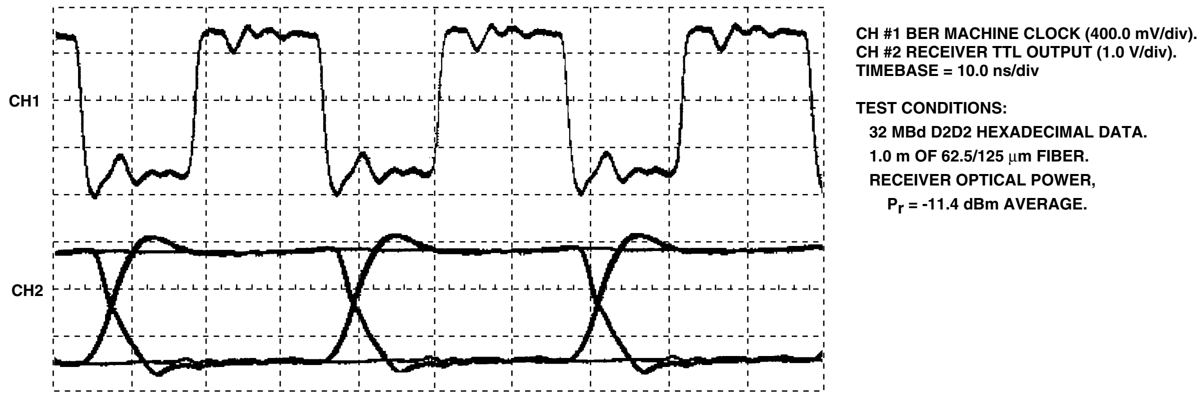

Figure 5. Receiver Output vs. Clock with Short Fiber

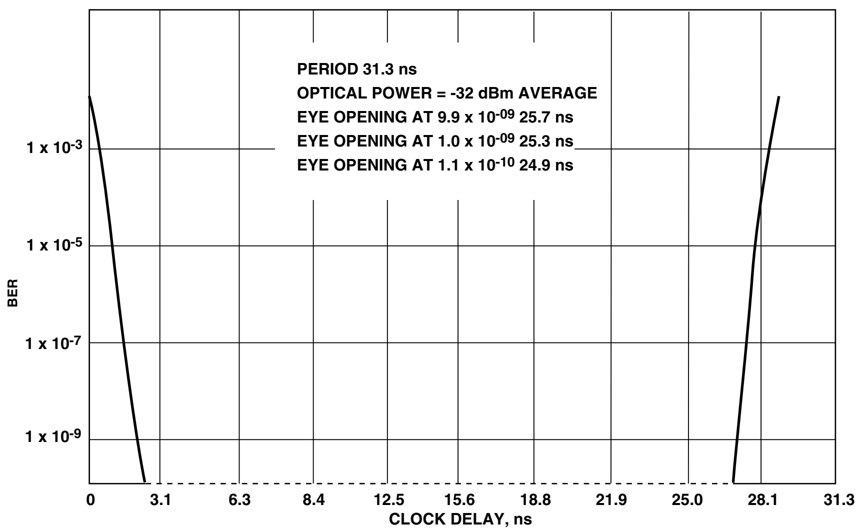

Figure 6. BER vs. Clock Delay

Insert and Bypass Key Timing Requirements

Another important characteristic that must be measured is the response of the complete fiber optic link to the insert and bypass keys used in Token Ring applications. The insert key is the most critical of these two functions because it interrupts the Manchester encoded data at the transmitter for a time interval that is much shorter than the bypass key. Stations will fail to insert into the ring if the pulse width of the insert key is altered by the fiber optic transceiver. The insert key must remain undistorted while received optical power changes from a minimum of -32 dBm average to a maximum of -12 dBm average. Figures 7 and 8 show that the pulse width of the insert key does not change as received optical power and fiber optic cable length vary over the ranges defined by the 802.5J Trial Use Standard.

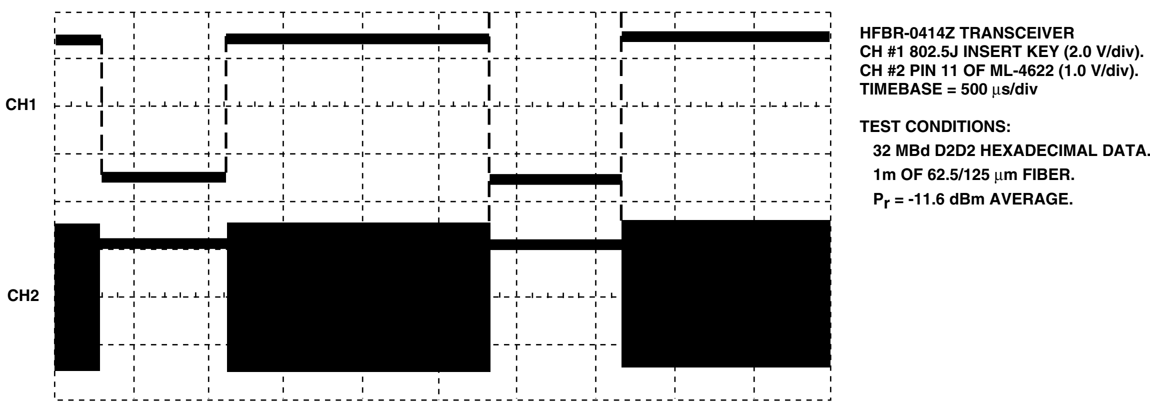

Figure 7. Insert Key Response with Short Fiber

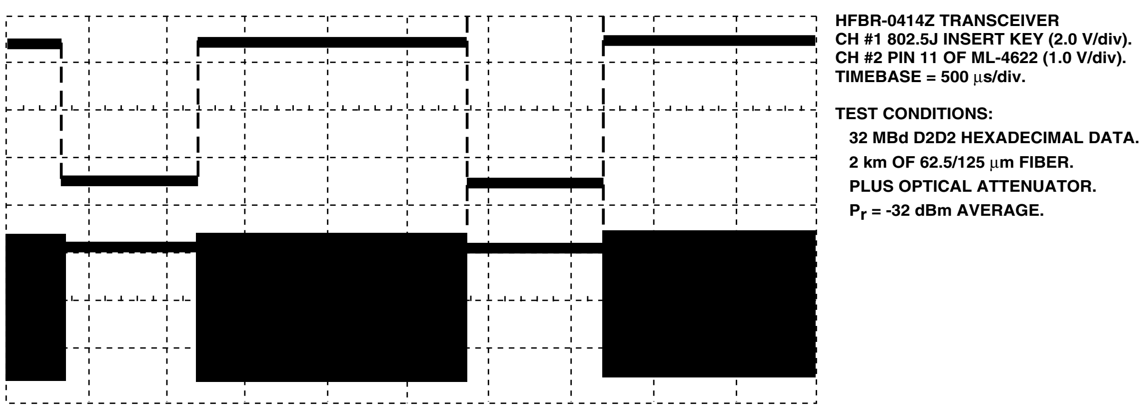

Figure 8. Insert Key Response with Long Fiber

Printed Circuit Layout Techniques

The circuits given in this application note are recommended for use in any system which addresses the requirements specified in the IEEE 802.5J Trial-Use standard. Avago encourages customers that want to use HFBR-0400Z components in fiber optic Token Ring applications to utilize these circuits in their products. The performance of the fiber optic transceiver shown in this publication is partially dependent on the layout of the printed circuit board on which this recommended circuit is constructed.

The following simple rules should be followed if you desire to layout a unique printed circuit (PC) board for the fiber optic transceiver recommended in this publication.

1. Design the PC board with a ground plane. Use a ground and a power plane if possible. This minimizes the inductance of the ground and power leads connected to the transceiver.
2. Minimize the size of cuts or openings in the ground and power planes. This minimizes the parasitic inductance and improves the dampening of both the transmitter and receiver circuits.
3. The two circuit traces connected between the HFBR-24X6Z and the differential input of the receiver's quantizer should be of equal length, and the components in both traces should be placed to achieve symmetry. This minimizes the cross-talk between the fiber optic transmitter and receiver and improves the receiver's immunity to environmental noise.
4. Connections between the drive circuit and the LED should be of minimum length. This minimizes the noise emitted by the transmitter and improves the optical rise/fall time of the LED.
5. A large 10 μF electrolytic capacitor and a 0.1 μF monolithic-ceramic capacitor should be located as close to the signal source which drives (current-modulates) the LED. This minimizes the noise emitted by the transmitter and improves the optical response time of the LED.
6. The low-pass filters shown on the recommended schematics must be used to protect the fiber optic receiver from noise that is present in the V_{CC} power supply.
7. If an inductor is used in series with the receiver's V_{CC} and V_{ee} connections the receiver should be referenced to V_{CC} and V_{ee} islands that are isolated from the remainder of the transceiver's power planes. A differential interface at the receiver's output is required if inductors are used in series with V_{CC} and V_{ee}. This dual-inductor filter is recommended if the receiver is operated in a noisy environment.

Printed Circuit Artwork

Variations in transceiver performance due to circuit layout can be avoided by using the artwork shown in Figure 9. Designers that would like to use the artwork provided 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 down loaded using a 2.4 kBd telephone modem. The Orcad file for the through-hole transceiver shown in Figures 1 and 3 is 802KITP.EXE. The through-hole transceiver is also available as a Gerber file under the file name 802KITG.EXE. The file name for the current-source LED driver shown in Figure 2 is IDRIVE.EXE.

Designers should note that printed circuits for the fiber optic solutions recommended in this application note are not difficult to create. If your product requires a unique printed circuit this can easily be accomplished by following the 7 layout rules previously discussed. The printed circuit art provided in this application note was developed in one design cycle using these PC design rules.

System designers that want to quickly evaluate the transceiver recommended in this application note should order the HFBR-0414Z demo kit. The HFBR-0414Z contains a printed circuit board and all of the active devices needed to build the transceiver shown in Figures 1 and 3 of this application note. A list of the components needed to construct the transceiver shown in Figures 1 and 3 is shown in Table 5. The HFBR-0414Z evaluation kit minimizes the design effort needed to implement fiber optic systems that comply with IEEE 802.5J standards and reduces the time needed to bring new Token Ring LAN products to market.

Conclusion

The transmitters and receivers shown in this application note have excellent performance. Engineers designing systems for use in fiber optic Token Ring applications can save a considerable amount of time and effort by utilizing the circuits recommended in this publication. Designers that are planning to build products which address the specifications called for in IEEE 802.5J are encouraged to evaluate these recommendations and determine how well Avago Technologies' HFBR-0400Z fiber optic components can address their Token Ring applications.

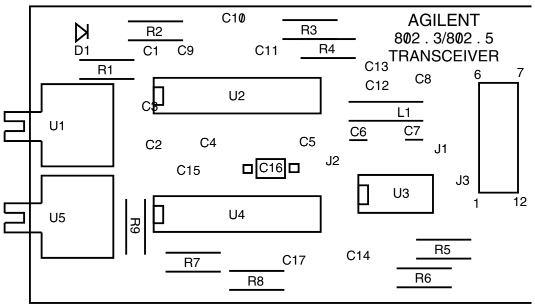

Figure 9a. Silkscreen Artwork for the HFBR-0414Z Demonstration Kit. Transmitter per Figure 1. Receiver per Figure 3.

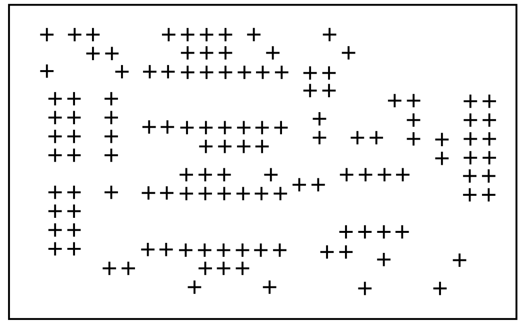

Figure 9b. Drill

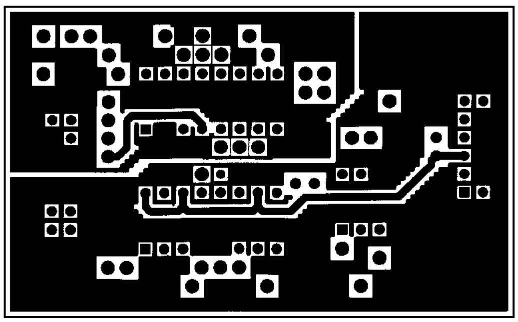

Figure 9c. Layer 1 Component Side

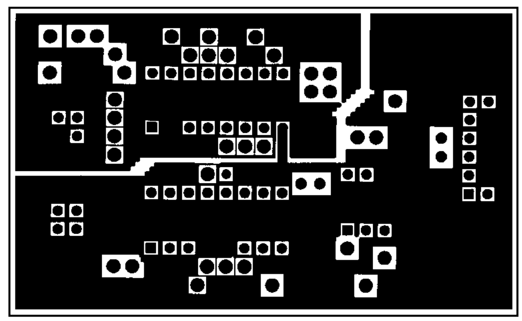

Figure 9d. Layer 2

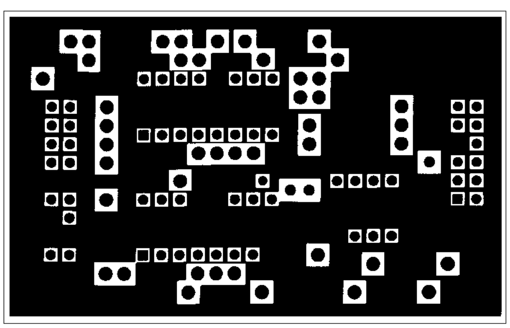

Figure 9e. Layer 3

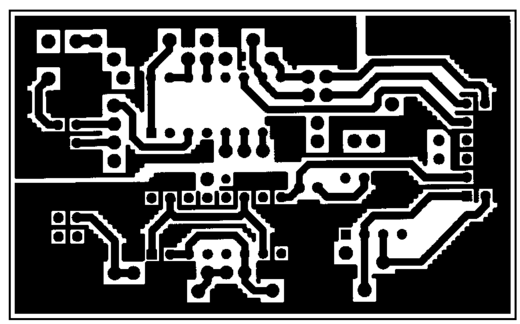

Figure 9f. Layer 4

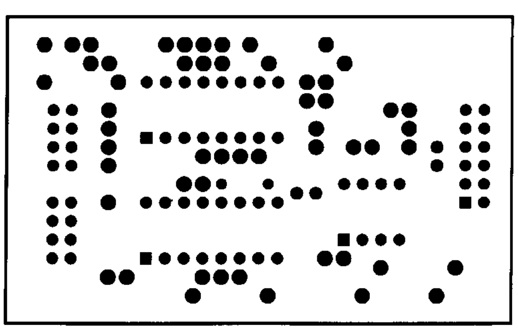

Figure 9g. Solder Mask

WARNING: DO NOT USE PHOTOCOPIES OR FAX COPIES OF THIS ARTWORK TO FABRICATE PRINTED CIRCUITS.

Table 5. Bill of Materials for the Circuits in Figures 1 and 3

Item #	Ref. Desig.	Qty. Each	Description	Vendor	Vendor Part Number
1	R1	1	Axial lead resistor 10 Ω, ±5% 1/8 W		
2	R2	1	Axial lead resistor 1.2 kΩ, ±5% 1/8 W		
3	R3, R4, R5, R6	4	Axial lead resistor 510 Ω, ±5% 1/8 W		
4	R7	1	Axial lead resistor 34.0 Ω, ±1% 1/8 W		
5	R8	1	Axial lead resistor 34.8 Ω, ±1% 1/8 W		
6	R9	1	Axial lead resistor 280 Ω, ±1% 1/8 W		
7	C1, C4, C8, C9, C11, C12, C13, C14, C15	9	Monolithic Ceramic Radial Lead Capacitor 0.1 μF ±10% 50 V X7R		
8	C2, C3, C10	3	Monolithic Ceramic Radial Lead Capacitor 0.001 μF ±10% 50 V X7R		
9	C5	1	Monolithic Ceramic Radial Lead Capacitor 4.7 pF ±10% 50 V COG		
10	C17	1	Monolithic Ceramic Radial Lead Capacitor 56 pF ±10% 50 V COG		
11	C6, C7, C16	3	Tantalum Radial Lead Capacitor 10 μF ±20% 10 V		
12	L1	1	Axial Lead Molded Inductor 4.7 μH ±10%, Resonant Freq. 75 MHz, 1.2 Ω DC Res.	Delevan	1025-36K
13	U1	1	125 MHz Low Cost Miniature Fiber Optic PIN-Amplifier Receiver	Avago	HFBR-2416Z
14	U2	1	Integrated Post Amplifier/Comparator (Quantizer)	Micro Linear	ML-4622
15	U3	1	Comparator	Linear Tech.	LT-1016
16	U4	1	Quad Two Input NAND Gate, Ni Barrier, Sn or Sn/Pb Plated	Texas Instr.	74ACT11000
17	U5	1	820 nm LED Transmitter	Avago	HFBR-1414Z
18	D1	1	Low Current LED Lamp	Avago	HLMP-4700

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

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