Agilent 125 Mb/155 Mb Multimode and Single Mode Small Form Factor (SFF) Transceivers

Application Note 1189

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Agilent Technologies

Overview of 125 Mb/155 Mb SFF Transceivers

125 Mb/155 Mb SFF Transceivers

The HFBR-5903/05 and HFCT-5903E/05E/15E family of transceivers represent the OC3 industry standard package from Agilent. Between them, these transceivers cover 125 Mb and 155 Mb data rates for both multimode and single-mode applications. Their package style is a 2 x 5 DIP with MT-RJ connector, more commonly referred to as Small Form Factor (SFF). Additionally, these transceivers operate at a nominal wavelength of 1300 nm and are designed for either LED-multi-mode or Laser-single-mode applications. Due to the industry-standard footprint as agreed in the MSA, all SFF transceivers within this product family are physically interchangeable. In addition, the single 3.3 V power supply and PECL logic interface for these transceivers ensures that recommended power supply filtering and termination schemes are also interchangeable. Table 1 summarizes the transceivers and their specific application standards, their respective data rate, link distance and fiber cable type.

In addition to the multisourced SFF package, all transceivers within this Agilent product family have several other common features. All operate from a single 3.3 V power supply resulting in significantly less power consumption when compared to the previous generation of 5 V transceivers. In addition, these transceivers are compatible with typical wave solder and aqueous wash processes. Both LED and Laser versions meet their respective eye safety standards.

The operating temperature range for this family of transceivers is from 0°C to +70°C (-40°C to +85°C for HFBR-5903A). All are manufactured in an ISO 9002-certified facility.

Multimode and Single Mode Small Form Factor Transceivers

While the receiver sections within this product family are similar, there are the expected differences in transmitter sections for the multimode and single-mode transceivers. The multimode transceivers are LED based with a 1300 nm Surface Emitting InGaAsP LED. The single-mode transceivers use an advanced SMQW Fabry Perot laser.

The HFBR-5903 and HFCT-5903E are multimode and single-mode transceivers, respectively, compatible with various 125 MBd standards. Similarly, the HFBR-5905 multimode and HFCT-5905E, HFCT-5915E single-mode transceivers are compatible with 155 MBd standards. Table 2 cross references these part numbers to the various standards. The relevant information from the standards is repeated here for convenience. Each standards organization maintains a web site where up-to-date information can be found.

Table 1 - 125 Mb/155 Mb Multimode and Single Mode SFF Applications

Agilent Part Number	Transmitter Type and Wavelength	Physical Layer Application	Data Rate	Connector Style	Fiber Type	Link Distance
HFBR-5903 Multimode Fiber Transceiver	LED Based 1300 nm	FDDI PMD FDDI LCF-PMD Fast Ethernet 100 Base-FX IEEE 802.3	125 Mb/s 125 Mb/s 100 Mb/s 100 Mb/s	MT-RJ	Multimode Fiber 62.5/125 um	2 Km
HFCT-5903E Single Mode Fiber Transceiver	Laser Based 1300 nm	FDDI SMF-PMD Fast Ethernet 100 Base-FX IEEE 802.3	125 Mb/s 100 Mb/s 100 Mb/s	MT-RJ	Single Mode Fiber	15 Km
HFBR-5905 Multimode Fiber Transceiver	LED Based 1300 nm	ATM SONET OC-3 SDH STM-1	155 Mb/s 155 Mb/s 155 Mb/s	MT-RJ	Multimode Fiber 62.5/125 um	2 Km
HFCT-5905E Single Mode Fiber Transceiver	Laser Based 1300 nm	ATM SONET OC-3 SDH STM-1 (S1.1)	155 Mb/s 155 Mb/s 155 Mb/s	MT-RJ	Single Mode Fiber	15 Km
HFCT-5915E Single Mode Fiber Transceiver	Laser Based 1300 nm	ATM SONET OC-3 SDH STM-1 (L1.1)	155 Mb/s 155 Mb/s 155 Mb/s	MT-RJ	Single Mode Fiber	40 Km

Note: Not listed in this table are the HFCT-5903, HFCT-5905 and HFCT-5915 without nose shields. These transceivers are offered on the rare occasion that a system mechanical design does not allow for a nose shield.

Table 2 - References

Standard	Specification	Source/Comment
FDDI PMD - Fibre Data Distributed Interface	ANSI X3.166-1990	American National Standards Institute
Physical Layer Medium Dependent	ISO/IEC 9314-3:1990	Joint development by International Organization for Standardization/International Electrotechnical Commission
FDDI LCF-PMD	ANSI LCF-PMD ISO/IEC WD 9314-9	
FDDI SMF-PMD1	ANSI X3.184-1993	
100 Base-FX Fast Ethernet	IEEE 802.3u	Institute of Electrical and Electronic Engineers
ATM	Version 3.0	ATM User Network Interface (UNI)
Synchronous Optical Network (SONET) OC-3	ANSI T1.105.06-1996	
Synchronous Digital Hierarchy (SDH) STM-1	ITU-T G.958	International Telecommunication Union - Telecommunication Standardization Sector

Termination Schemes for 125 Mb/155 Mb SFF Transceivers

Standard PECL Voltage Levels

Agilent's serial data transceivers rely on Positive Emitter Coupled Logic for a high-speed interface. The PECL voltage levels shown in Figure 1 are measured with respect to the positive power supply. For measurement with respect to ground, these values would be subtracted from V_{CC}. For example, VDC_{BIAS} measured with respect to ground with a V_{CC} of 3.3 V would be 3.3 V – 1.3 V = 2 V. Figure 1 shows the minimum and maximum PECL levels for both input and output signals per the popular 100 K series of ECL logic. These voltage levels and the dc bias voltage will be referred to as Standard PECL. Note that Nonstandard PECL typically has a significantly different dc bias voltage but retains the standard peak-to-peak voltage swing of Standard PECL. The onset of 3.3 V products has resulted in the acronym of LVPECL meaning 3.3 V PECL.

There are several required design criteria that can be readily seen in the PECL levels of Figure 1. One requirement is that the dc voltage bias be V_{CC} -1.3 V at the input and output of Standard PECL. Another requirement is that the worst-case output voltage levels cannot allow the output transistor to enter cutoff mode. By definition, the output transistor of ECL gates must conduct current during the entire peak-to-peak voltage. It will be emphasized that the cutoff mode is possible with the cumulative effects of a lower than expected VOL_{MIN} and a marginal power supply.

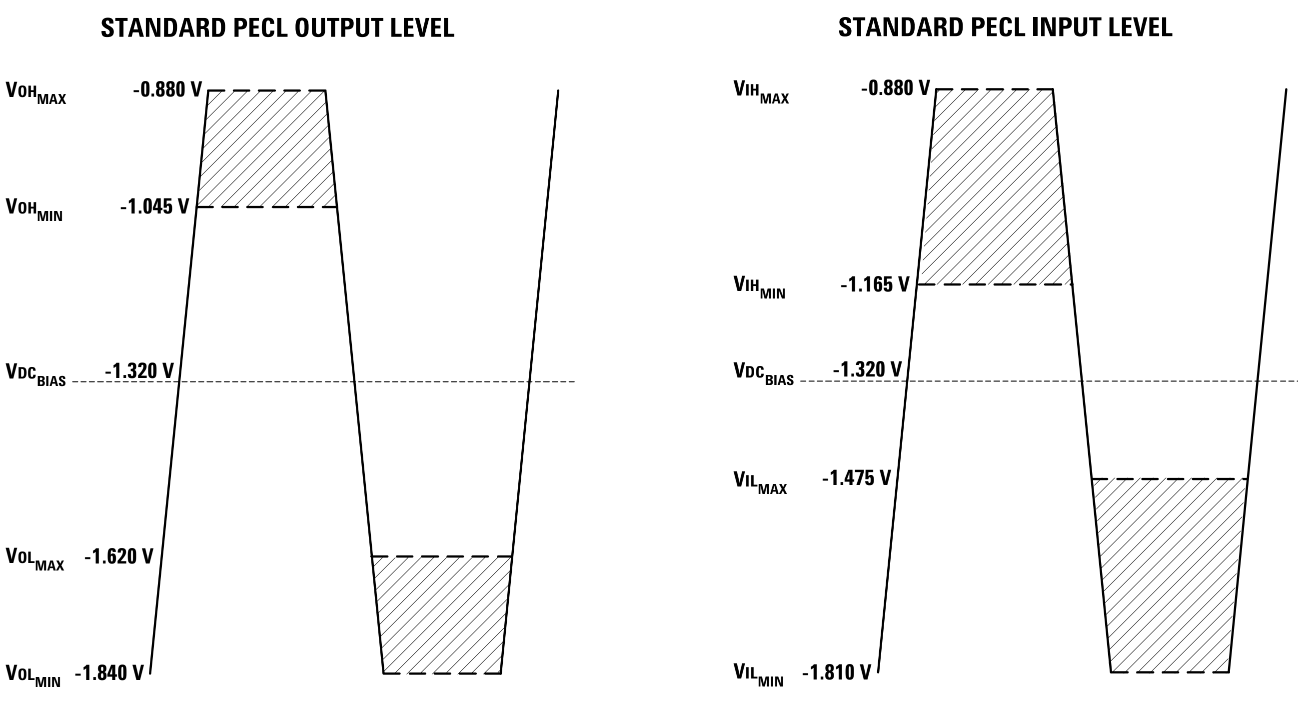


Figure 1 - Standard PECL Input, Output Levels

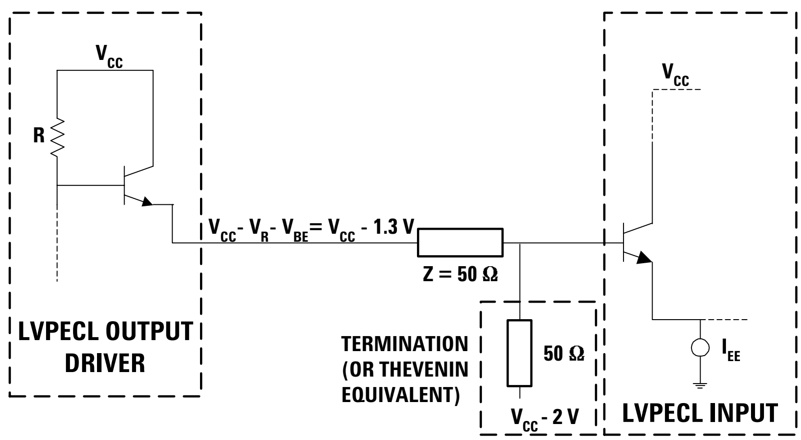
Thevenin Equivalent of Standard PECL Terminations

The Thevenin equivalent for any Standard PECL termination scheme should match one of the two termination schemes shown in Figure 2. All PECL termination circuits strive to match an ideal 50 Ω termination with an ideal 50 Ω transmission line to prevent unwanted reflections. The 50 Ω termination resistor is mounted as close to the PECL input as possible. In addition, standard PECL terminations ensure the correct dc bias voltage of V_{CC} -1.3 V. In some cases, designers may prefer the dc isolation of the ac coupling capacitor shown in Figure 2 (b). In the case of mixing Standard with Nonstandard PECL, the ac coupling capacitor would be required. This is due to Nonstandard PECL having a dc bias voltage significantly different from V_{CC} -1.3 V. A potential pitfall when using ac coupling capacitors is that significant distortion could be introduced in a 125 Mb FDDI interface or any other interface that must meet the FDDI standard. This distortion is caused by the FDDI DDJ pattern and it's 50 KHz base- line wander effect described in the FDDI PMD standard, see Note 1 below.

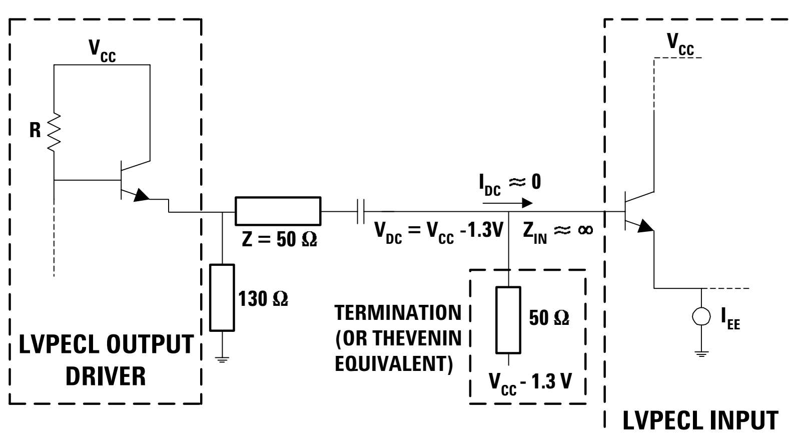
In Figure 2 only partial internal schematics of a PECL gate are shown to emphasize a specific point. Also, only one side of the differential I/O pair is shown. There is an array of technical material readily available that exhaustively describes the remaining ECL/PECL circuit.

Note: 1 FDDI PMD Token Ring Physical Layer Medium Dependent (PMD) standard is ISO/IEC 93 14-3: I990 and ANSI X3.166-1990 American National Standard

The LVPECL Output Driver in Figure 2 (a) shows only the open-emitter output driver. This is to emphasize that all Standard PECL will set up a dc bias level of V_{CC} -1.3 V at the output after termination. Also in Figure 2 (a), the LVPECL Input shows one transistor of the emitter-coupled pair. This is to emphasize that PECL has a high input impedance. The standard 50 Ω termination voltage of V_{CC} - 2 V is determined by two major requirements. The first is to reduce power consumption as much as possible by reducing the voltage drop across the 50 Ω termination resistor. The second requirement is to minimize any chance that the output driver would not enter a cutoff mode under worst case PECL levels. The culmination of all these requirements resulted in the Standard PECL termination, or Thevenin equivalent of 50 Ω into a termination voltage of V_{CC} - 2 V with a dc bias voltage of V_{CC} - 1.3 V. For dc coupled Standard PECL terminations, the Thevenin equivalent of any termination scheme should match Figure 2 (a).



(a) 'STANDARD LVPECL' TERMINATION, DC COUPLED



(b) 'STANDARD LVPECL' TERMINATION, AC COUPLED

Figure 2 - 'Standard LVPECL' Terminations

For various reasons, some interface designers may prefer ac coupled LVPECL terminations. Figure 2 (b) shows that the addition of an ac coupling capacitor isolates the PECL input and output circuits and changes the Thevenin equivalent circuit. The LVPECL open emitter transistor requires a path to ground so a 130 Ω resistor is added to sink about 15 mA. At the PECL input there is no current flow through the ac coupling capacitor or through the input of the high impedance emitter follower. So, there is no dc current flow in this branch and the termination voltage of V_{CC} -1.3 V becomes the common dc voltage in this entire circuit branch. We know from Figure 1 that Standard PECL levels expect a dc bias of -1.3 V with respect to V_{CC}. Consequently, the termination voltage must be V_{CC} - 1.3 V. For Standard PECL with an ac coupling capacitor, the Thevenin equivalent of any termination scheme should match Figure 2 (b).

Note that there are interface ICs that have Nonstandard LVPECL levels and require ac coupling in order to interface with Standard LVPECL. In these cases, Standard LVPECL termination can be used on one side of the ac coupling capacitor and the supplier recommended Nonstandard LVPECL termination on the other side.

Recommended SFF LVPECL Terminations

Two termination schemes for 125 Mb/155 Mb single mode and multimode SFF's are presented in this section. Figures 3 and 4 are recommended terminations and, the trade-offs of circuit complexity and reliability will have to be decided by each designer. Both termination schemes assume that the fiber optic transceiver and interface ICs require a power supply voltage of 3.3 V. In addition, both termination schemes are the Thevenin equivalent of Figure 2 (a). Note that wide design latitude can be given to the Signal Detect (SD)

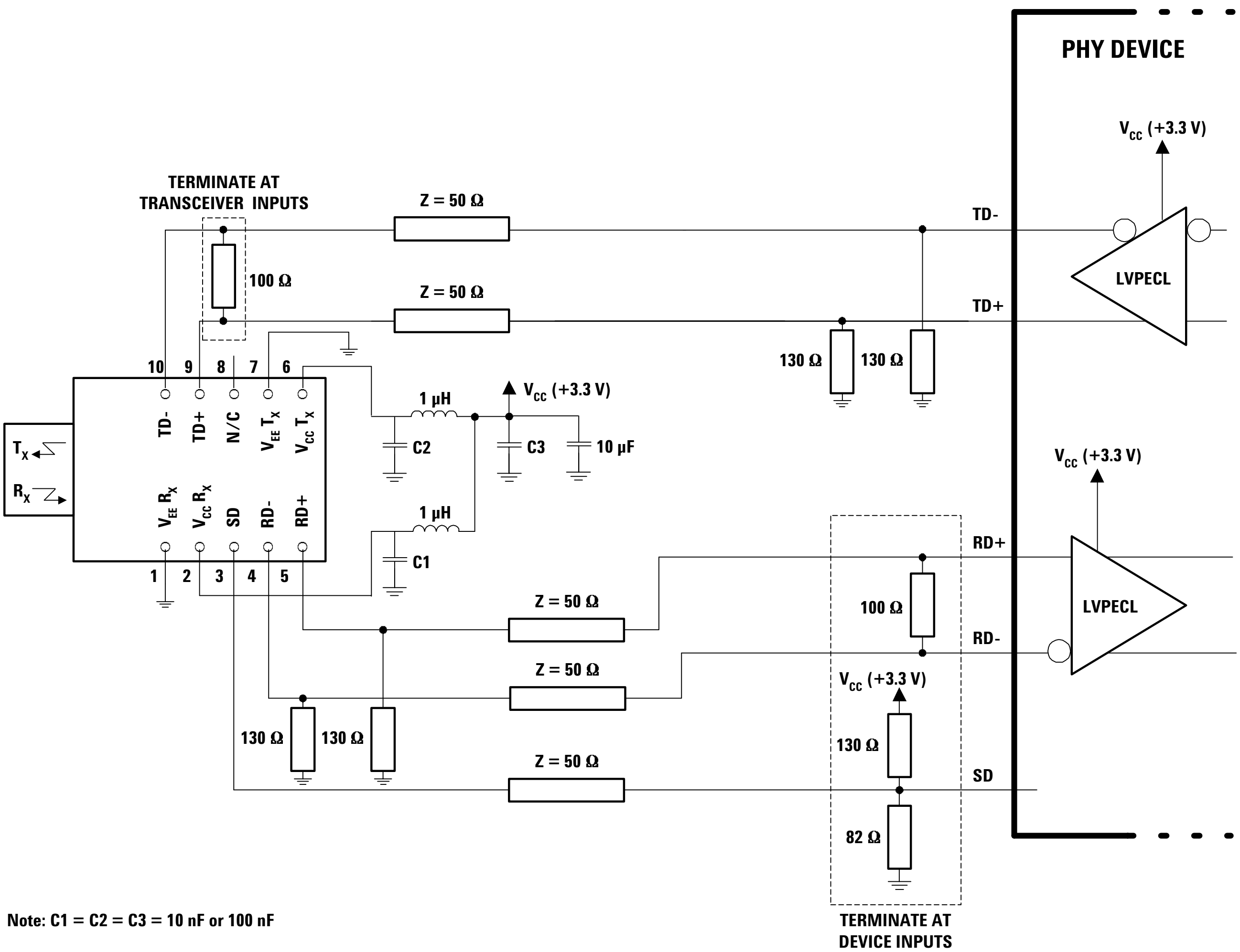
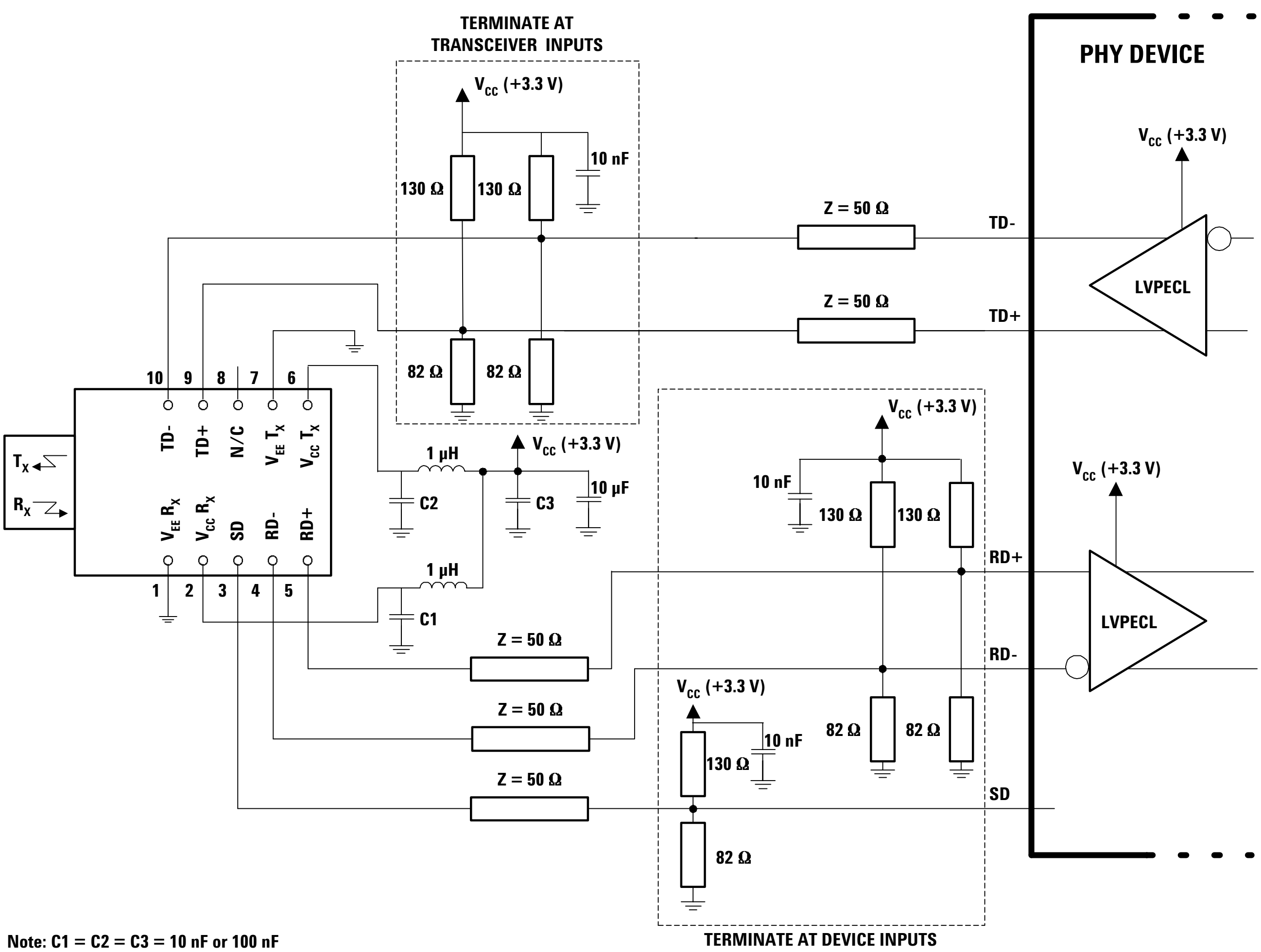


Figure 3 - LVPECL Optical Transceiver Interface: Standard LVPECL to Standard LVPECL

LVPECL termination as the assert and deassert times are in microseconds. One recommended termination that has a Thevenin equivalent of 50 ohm to V_{CC} -2 V, is shown in Figure 4.

Figure 3 shows one of the termination schemes agreed upon by partners in the SFF multi-source agreement (MSA). This recommendation requires that both input and output devices use Standard LVPECL. It also assumes that the 3.3 V power supply is common to both the fiber optic transmitter and receiver so that only one 10 uF capacitor is required for the power supply filters. The 130 Ω resistor sinking about 15 mA of dc current at the output of the open emitter transistor is typical of LVPECL outputs. The 100 Ω resistor across the differential inputs is equivalent to two of the Thevenin equivalent circuits shown in Figure 2 (b), that is, two sets of 50 Ω resistors and termination voltages terminated to V_{CC} -1.3 V.

Many interface designers may be familiar with the termination scheme in Figure 4. This termination circuit was recommended on the widely used Agilent 1 x 9 SC Duplex 125 Mb/155 Mb multimode fiber optic transceiver. This termination scheme, sometimes referred to as a split load or parallel termination, uses one more resistor than the previous set up and may have some worthwhile advantages as determined by the interface designer. Referring to the worst case voltage levels in Figure 1 and the termination voltage in Figure 2 (a), there is an extreme case where the cumulative effects of a lower than expected V_{OLMIN} and a higher than expected V_{CC} would cause the LVPECL open emitter output transistor to enter cutoff mode. This would occur when V_{OLMIN} falls below the termination voltage of V_{CC} -2 V resulting in no positive current flow across the 50 ohm termination resistor. Some designers may prefer extra margin to ensure that this extreme case does not occur.



Note: C1 = C2 = C3 = 10 nF or 100 nF

Figure 4 - Alternative LVPECL Optical Transceiver Interface: Standard LVPECL to Standard LVPECL

The termination scheme of Figure 4 allows VOL_{MIN} to be less susceptible to a non-optimal V_{CC}. From the Thevenin equivalent, the termination voltage is V_{CC} -2 V. Intuitively, it can be seen from Figure 4 that any change in termination voltage of V_{CC} -2 V is a ratio of the change in V_{CC}, that is, $\Delta V_{TERMINATION} = (82/[82+130]) \Delta V_{CC} = 0.4\ \Delta V_{CC}$. So, a -5 percent change in V_{CC} would cause a -2 percent change in $V_{TERMINATION}$. Since the termination voltage is less susceptible to changes in power supply voltage, there is increased margin for VOL_{MIN}. Another advantage of this termination scheme is that the dc bias current flows in the termination resistors only, reducing the power dissipated by the IC and increasing its reliability.

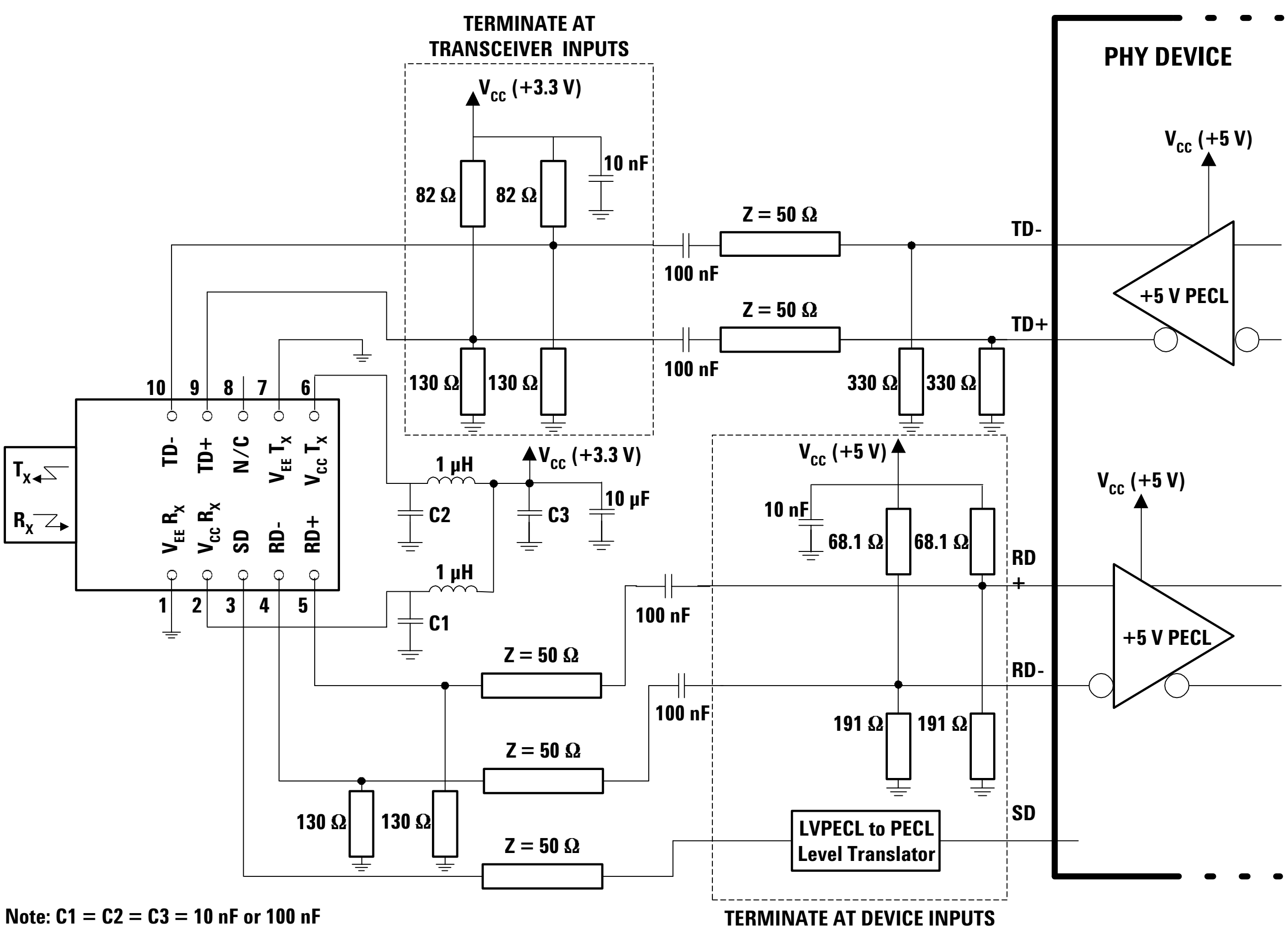
Alternative PECL Terminations

There are many other versions of PECL terminations possible especially when considering the mixing of Nonstandard and Standard PECL. For this reason, only two other termination schemes will be presented. The first is a PECL interface from LVPECL to +5 V PECL. The second PECL termination scheme is on an Agilent test fixture board designed to evaluate 1 .25 Gb SFF units and was modified slightly for evaluating 125 Mb/155 Mb SFF products.

Figure 5 summarizes the interface between a 3.3 V optical transceiver and a +5 V physical layer IC. On the 3.3 V optical transceiver side of the ac coupling capacitor, the split load terminations shown were discussed previously. On the +5 V Interface IC side, the split load resistor values are adjusted for +5 V but are still the Thevenin equivalent of Figure 2 (b). The output of standard PECL can function correctly with a fairly wide range of output currents. To remain consistent with the SFF Multi Source Agreement, the output of the +5 V PECL IC is given as 330 Ω, resulting in an output current of about 11 mA.

Figure 5 also shows that the Signal Detect (SD) output requires a level translator when interfacing LVPECL to PECL. Since SD is a near static voltage level, ac coupling cannot be used. To increase the output level from LVPECL to PECL, a voltage level translator circuit is required.

A fuller detailed circuit of termination for various interconnect schemes can be found in the MSA agreement.



Note: C1 = C2 = C3 = 10 nF or 100 nF

Figure 5 - Optical Transceiver Interface: LVPECL to +5 V PECL, ac Coupled

PC Board Layout and Panel Opening for MT-RJ SFF Transceivers

Introduction

The partners in the MT-RJ alliance agreed that all SFF transceiver products will have the same physical PCB footprint and connector panel opening as documented in the Multi-Source Agreement (MSA). However, the MSA does not define all SFF physical parameters, such as the overall length, in order to give the partners some latitude in their designs. For this reason, exactly what parameters are defined by the multisource agreement (MSA) will be emphasized in the text reviewing the Agilent SFF dimensions. Note that the MSA does not require shield ground tabs on SFF products even though the MSA includes ground pads on the recommended PCB layout. The shield grounding differences in the various Agilent SFF products will be discussed during the presentation of both the PCB layout and panel opening drawings. Also described are elements not controlled by the MSA such as the SFF housing material and color.

The Agilent multimode 2 x 5 SFF 125 Mb/155 Mb transceivers, HFBR-5903 and HFBR-5905, were the first SFF products to be delivered in volume to customers. In order to accomplish this quick time-to-market, the production design requirements and recommendations were locked-in before the final revision of the MSA was completed. For this reason, the optional shield ground tabs are not on the HFBR-5903 and HFBR-5905.

Another major difference between the HFBR-5903 and HFBR-5905 with respect to other Agilent SFF products is that there is no metal nose shield over the MT-RJ connector port. Both products, HFBR-5903 and HFBR-5905, have superior EMI performance typically 15 dB of margin to FCC Class B. If necessary, Agilent has the option of revising these transceivers to include ground tabs and/or metal nose shields in the future. If Agilent adopts either shield option in the future, **no changes** to the currently recommended MSA footprint and panel layout would be required. Figure 6 shows the HFBR-5903 that is physically identical to the HFBR-5905. Both modules include an internal receiver shield to ensure that the transmitter section is not a source of crosstalk.

While all Agilent 155 Mb/s SFF transceivers meet the MSA requirements, there are differences between the multi-mode and single-mode parts. The HFBR-5903/5 shown in Figure 6 has a metal housing shield which includes ground tabs that are connected to signal ground via the recommended PCB layout.

Shown in Figure 7 is the single-mode 2 x 5 SFF 125 Mb transceiver: HFCT-5903E. This module is physically identical to the HFCT-5905E and HFCT-5915E, which are the 2 x 5 SFF 155 Mb transceivers, Table 1. A major physical difference is the metal nose shield over the MT-RJ connector port. This metal nose shield is connected to chassis ground via the spring contact fingers. The metal nose shield and metal housing shield are electrically isolated. These transceivers also have ground tabs on the metal housing shield, spring contact fingers on the metal nose shield and electrical isolation between these shields.

All 155 Mb/s SFF transceivers show similar EMI performance.

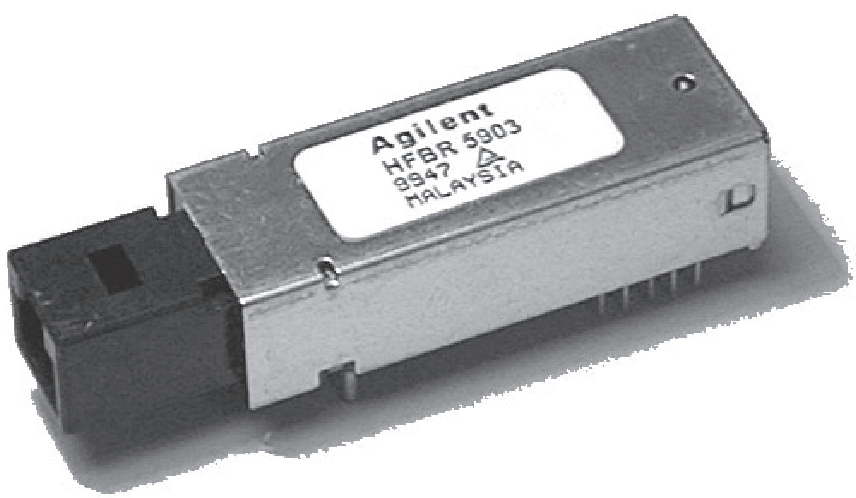


Figure 6 - HFBR-5903 2 x 5 125 Mb Multimode SFF Transceiver

SFF PCB Footprint and Mechanical Outline

All Agilent SFF product sheets include, at a minimum, a PCB layout, a MT-RJ front panel layout, and a package outline drawing. All initial dimensions on the circuit board layout and MT-RJ front panel layout were taken directly or indirectly from the MSA requirements.

Shown in Figure 8 is the recommended PCB layout for Agilent's 155 Mb/s SFF products: HFBR-5903/05, HFCT-5903/05E, and HFCT-5915E. The length of the port plug is not precisely controlled by the multisource agreement. The length and width of the port plug dimensions shown fall easily within the maximum dimensions allowed by the MSA. The diameters of the solder post holes, housing shield tab holes and 2 x 5 pins are directly controlled by the MSA. The critical dimension for the transceiver in relation to the front panel is 14.79 mm (0.589 in) as shown in Figure 12. This dimension from the solder posts to front panel will ensure that a transceiver with nose shield fits correctly in the front panel opening. The length of the solder posts, housing shield tabs and 2 x 5 pins are not controlled by the MSA. The transceivers body length, nose length are not explicitly controlled by the MSA.

An important note is that there is no dimension that controls the distance from the solder posts to the edge of the PCB. This distance is a function of the PCB material and PCB layout rules. As long as the solder posts are properly soldered to the PCB, there is enough strength in the transceiver port for repeated connections.

Emphasized in Note 4 of Figure 8, is that the solder posts of all SFF transceivers should be soldered to chassis ground for mechanical integrity and footprint compatibility with other SFF transceivers. The HFCT-5903E/5905E and HFCT-5915E SFF transceivers include a nose shield intended to make contact with chassis ground via the front panel. This transceiver also includes solder posts electrically connected to the nose shield and consequently these posts should be soldered to chassis ground. The HFBR-5903/5 products were the first SFF transceivers delivered to market in large quantities. Due to the superior radiated EMI performance of the HFBR-5903/5, a nose shield was not included and the solder posts were left floating. Note that the EMI performance results for the HFBR-5903/5 are with the solder posts floating. Future proliferation's of these transceivers may include a nose shield that is electrically connected to the solder posts and would require the same chassis ground connection as the HFCT-5903/05. Connecting the present HFBR-5903/05 solder posts to the PCB chassis ground would ensure design compatibilty with other SFF transceivers as well as compatibility with any future proliferation of these transceivers.

Figure 9 is the package outline drawing for the single mode SFF products: HFCT-5903E, HFCT-5905E and HFCT-5915E.
Figure 10 is the package outline drawing for the single mode products without a nose shield: HFCT-5903, HFCT-5905 and HFCT-5915. These unshielded modules are not recommended for high density, EMI critical system design. If mechanical design does not allow for the recommended nose shield, unshielded modules are available.

Figure 11 is the package outline drawing for the multimode SFF products: HFBR-5903 and HFBR-5905. The only difference between this drawing and the single mode SFF package outline drawing are the holes on top of the metal shield housing.

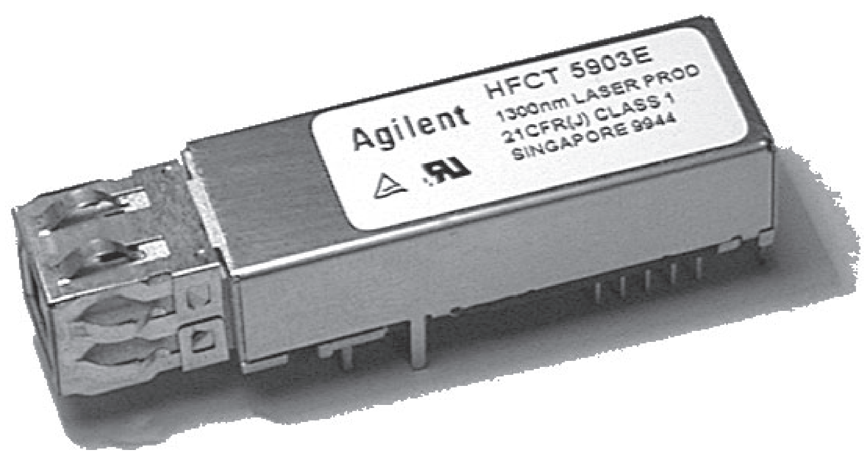
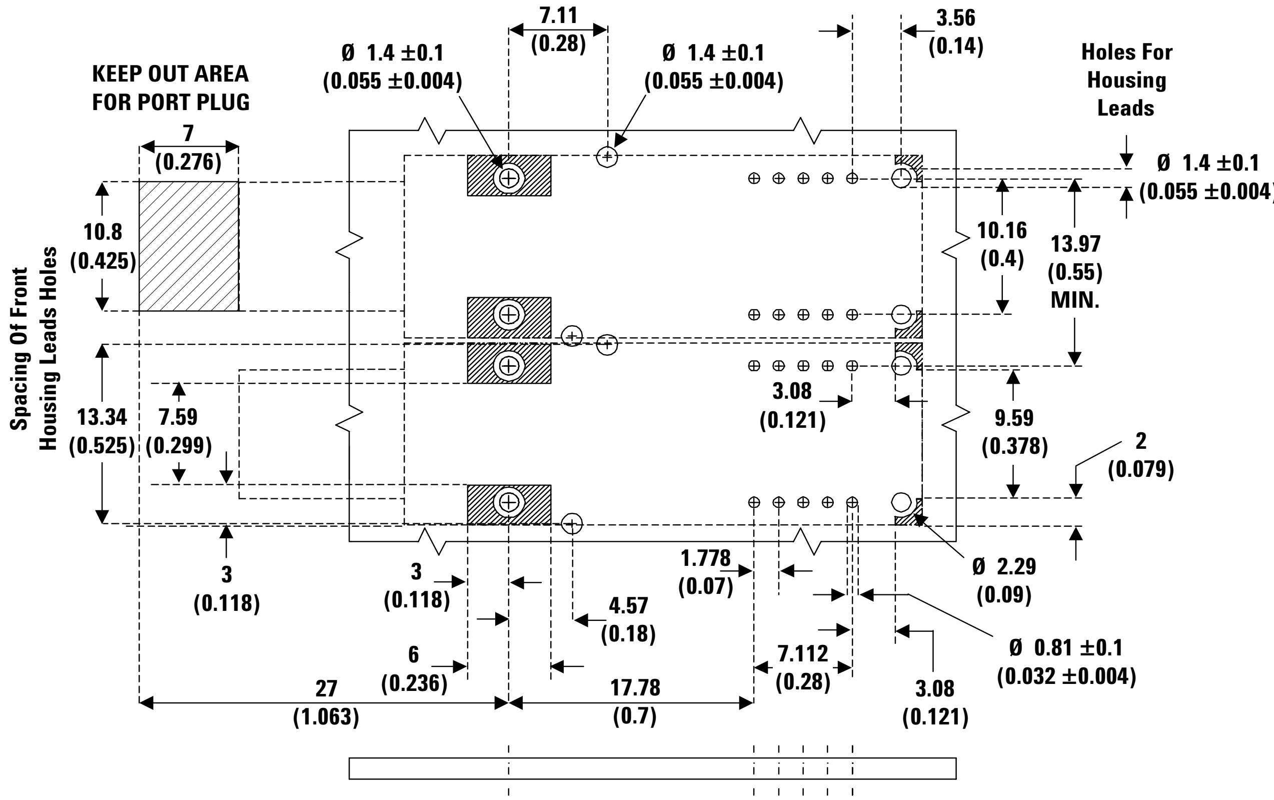


Figure 7 - HFCT-5903E 2 x 5 125 Mb Single Mode SFF Transceiver

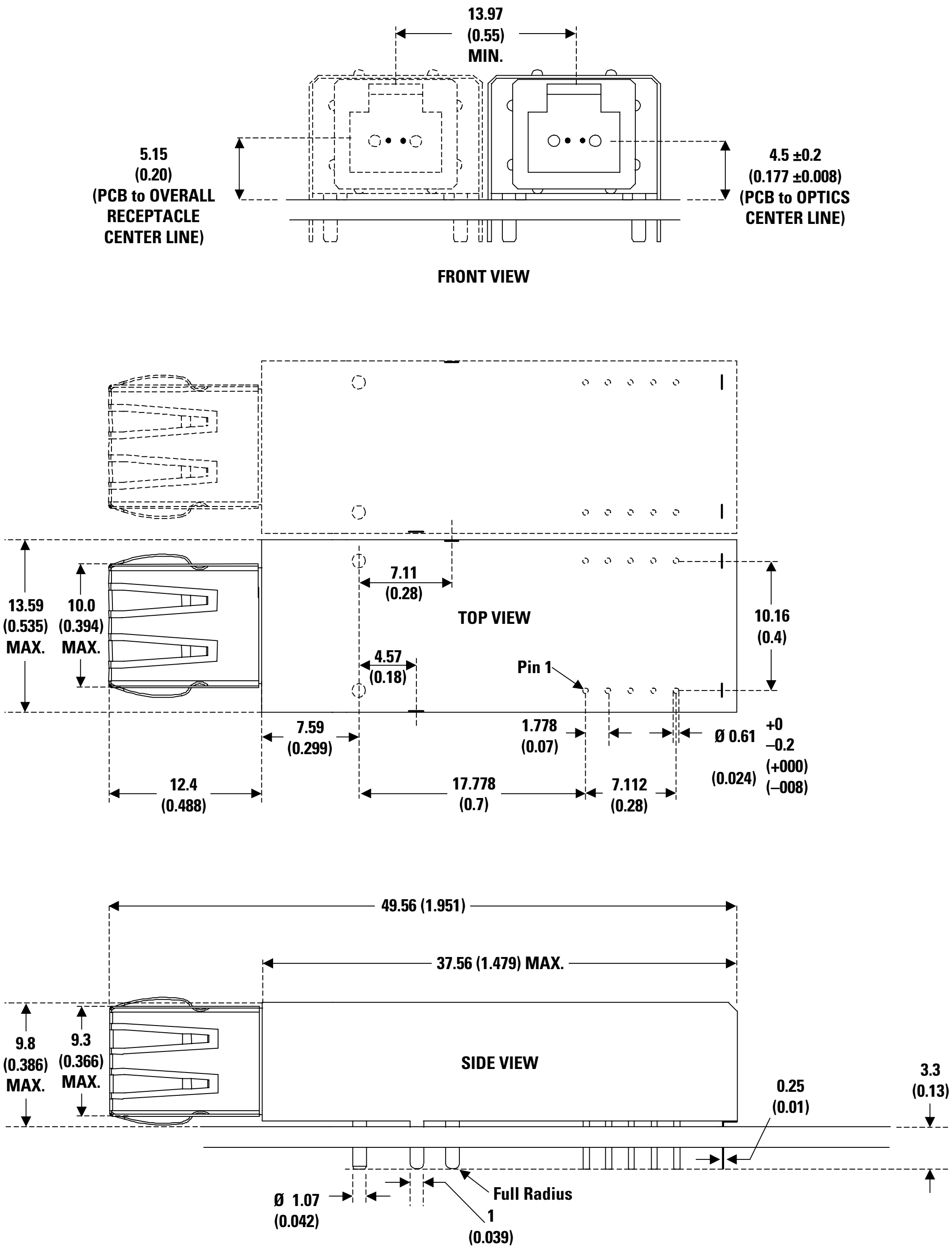


DIMENSIONS IN MILLIMETERS (INCHES)

NOTES:

1. **THIS FIGURE DESCRIBES THE RECOMMENDED CIRCUIT BOARD LAYOUT FOR THE MT-RJ TRANSCEIVER PLACED AT .550 SPACING.**
2. **THE HATCHED AREAS ARE KEEP-OUT AREAS RESERVED FOR HOUSING STANDOFFS. NO METAL TRACES OR GROUND CONNECTION IN KEEP-OUT AREAS.**
3. **10 PIN MODULE REQUIRES ONLY 16 PCB HOLES, INCLUDING 4 PACKAGE GROUNDING TAB HOLES CONNECTED TO SIGNAL GROUND.**
4. **THE SOLDER POSTS SHOULD BE SOLDERED TO CHASSIS GROUND FOR MECHANICAL INTEGRITY AND TO ENSURE FOOTPRINT COMPATIBILITY WITH OTHER SFF TRANSCEIVERS.**

Figure 8 - Recommended Board Layout, All SFF Transceivers

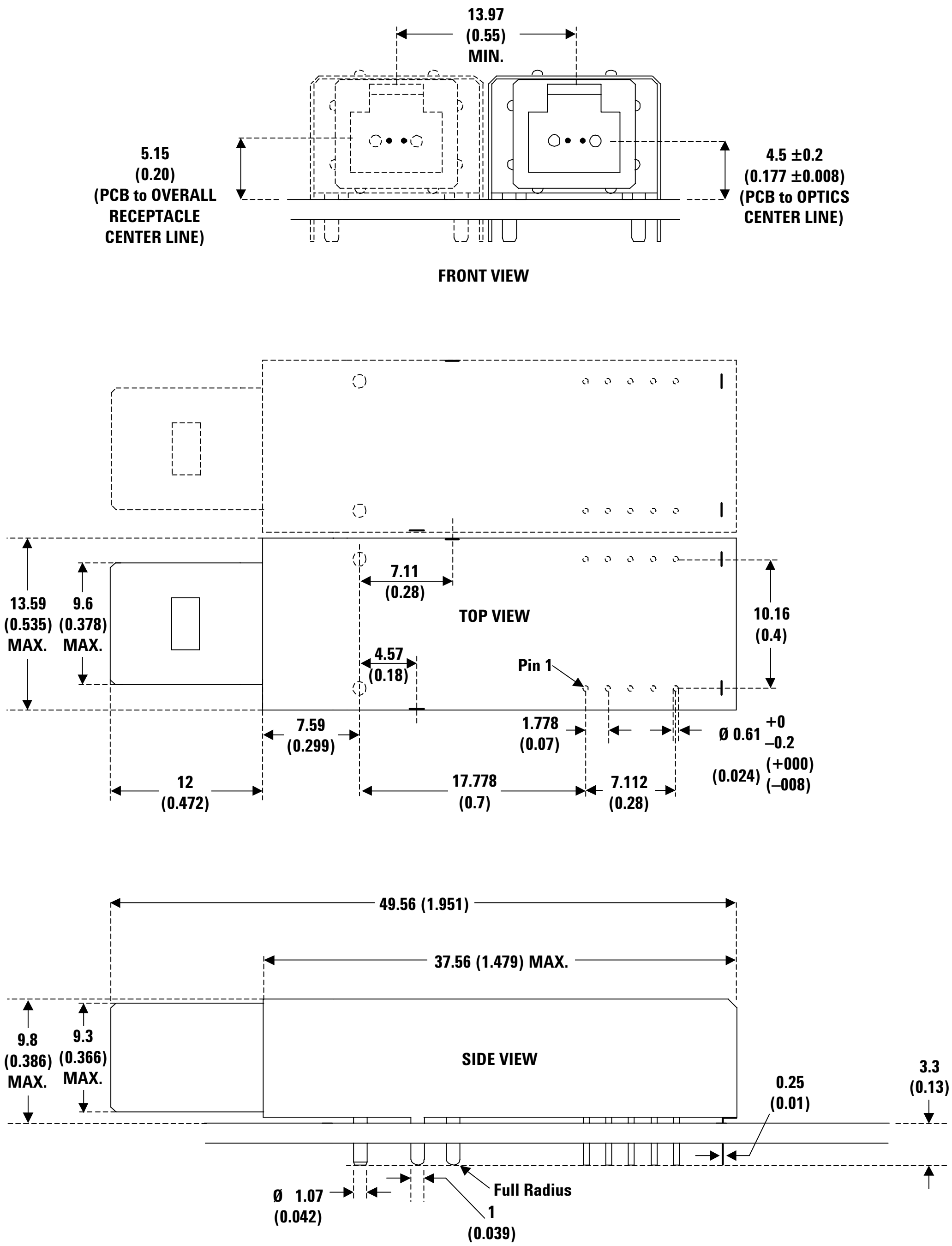


DIMENSIONS IN MILLIMETERS (INCHES)

NOTES:

1. THIS PAGE DESCRIBES THE MAXIMUM PACKAGE OUTLINE, MOUNTING STUDS, PINS AND THEIR RELATIONSHIPS TO EACH OTHER.
2. TOLERANCED TO ACCOMMODATE ROUND OR RECTANGULAR LEADS.
3. THE 10 I/O PINS, 2 SOLDER POSTS AND 4 PACKAGE GROUNDING TABS ARE TO BE TREATED AS A SINGLE PATTERN, SEE FIGURE 8.
4. THE MT-RJ HAS A 750 µm FIBER SPACING.
5. THE MT-RJ ALIGNMENT PINS ARE IN THE MODULE.
6. SEE MT-RJ TRANSCEIVER PIN OUT DIAGRAM FOR DETAILS.

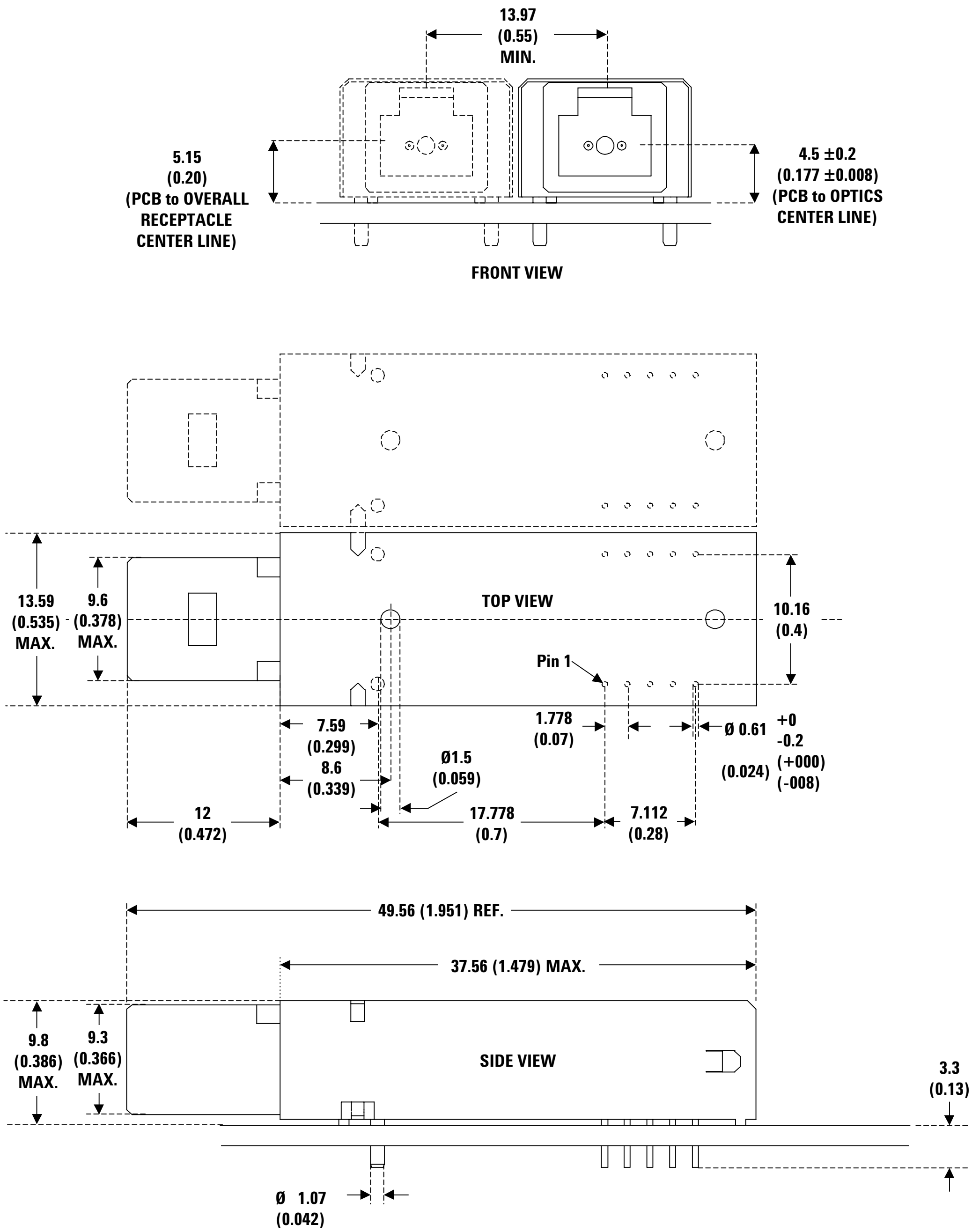
Figure 9 - Package Outline Drawing for 155 Mb/s Single Mode SFF Products: HFCT-5903E, HFCT-5905E and HFCT-5915E



DIMENSIONS IN MILLIMETERS (INCHES)

NOTES:
1. THIS PAGE DESCRIBES THE MAXIMUM PACKAGE OUTLINE, MOUNTING STUDS, PINS AND THEIR RELATIONSHIPS TO EACH OTHER.
2. TOLERANCED TO ACCOMMODATE ROUND OR RECTANGULAR LEADS.
3. THE 10 I/O PINS, 2 SOLDER POSTS AND 4 PACKAGE GROUNDING TABS ARE TO BE TREATED AS A SINGLE PATTERN, SEE FIGURE 8.
4. THE MT-RJ HAS A 750 µm FIBER SPACING.
5. THE MT-RJ ALIGNMENT PINS ARE IN THE MODULE.
6. SEE MT-RJ TRANSCEIVER PIN OUT DIAGRAM FOR DETAILS.

Figure 10 - Package Outline Drawing for Single Mode SFF Products: HFCT-5903, HFCT-5905 and HFCT-5915



DIMENSIONS IN MILLIMETERS (INCHES)

NOTES:
1. THIS PAGE DESCRIBES THE MAXIMUM PACKAGE OUTLINE, MOUNTING STUDS, PINS AND THEIR RELATIONSHIPS TO EACH OTHER.
2. TOLERANCED TO ACCOMMODATE ROUND OR RECTANGULAR LEADS.
3. ALL 12 PINS AND POSTS ARE TO BE TREATED AS A SINGLE PATTERN.
4. THE MT-RJ HAS A 750 µm FIBER SPACING.
5. THE MT-RJ ALIGNMENT PINS ARE IN THE MODULE.
6. FOR SM MODULES, THE FERRULE WILL BE PC POLISHED (NOT ANGLED).
7. SEE MT-RJ TRANSCEIVER PIN OUT DIAGRAM FOR DETAILS.

Figure 11 - Package Outline Drawing for Multimode SFF Products: HFBR-5903, HFBR-5905

MT-RJ SFF Panel Opening

Figure 12 shows the recommended panel mounting for all Agilent SFF transceivers. This drawing precisely follows the MSA's drawing "Front Panel Opening for MT-RJ". All Agilent SFF transceivers, with or without the metal nose shield, will conform to this front panel layout. The PCB must be mounted perpendicular to the front panel in order for the nose shield chassis 'fingers' to fit correctly. All LED and Laser optical sources for Agilent transceivers meet regulatory requirements. There is no need to protect users from optical sources by any mechanical methods such as blocking optical ports when not in use. Note that the port plugs supplied with SFF transceivers were designed to protect the optics from contamination.

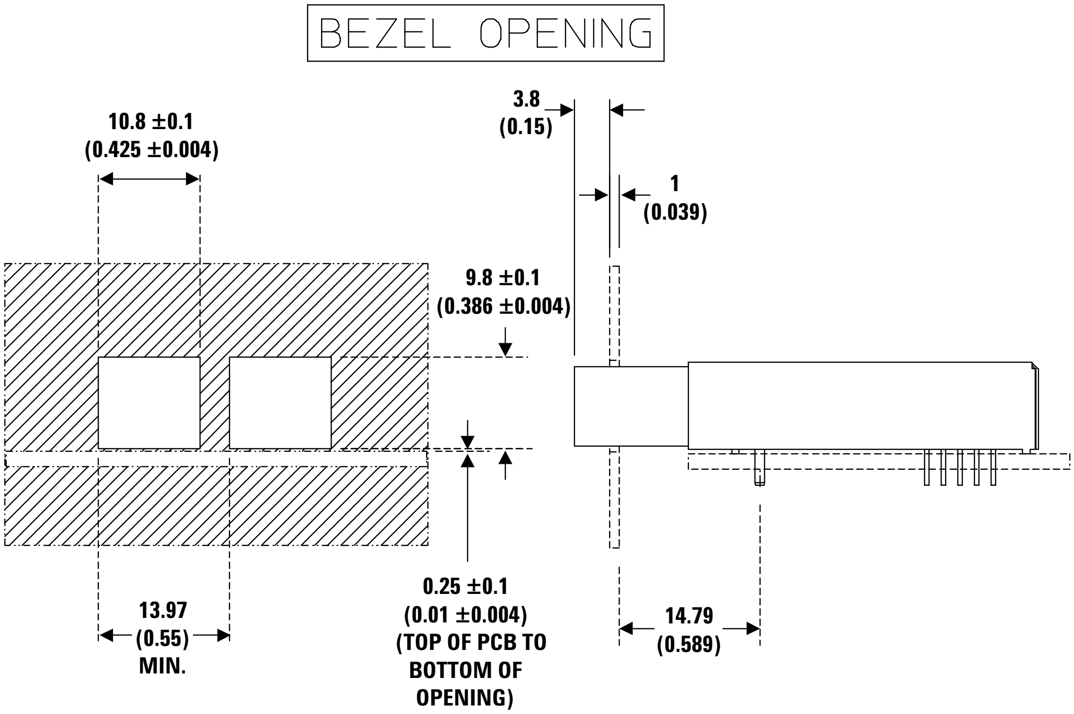
For the Agilent SFF transceivers, which employ the metal nose shield, optimum EMI system performance depends on a low impedance path from nose shield to system chassis. It is important that the edges of the panel opening be free from any nonconductive paints or adhesives. In addition metals, which can build up insulating oxides such as unplated aluminium, should be avoided.

The SFF grounding scheme is described in the relevant data sheets. The important point described in the data sheets is that all Agilent SFF transceivers have separate V_{CC} and ground planes for the transmitter and receiver sections. Isolating or connecting system chassis ground to system signal ground varies among existing designs.

PCB Design Guideline

High-speed PCB design guidelines and rules are well covered in many references and automated design programs. A few related guidelines were already covered in the section "Termination Schemes for 125 Mb/155 Mb SFF Transceivers" such as termination of differential lines should be done at the receiver input. The in-depth coverage of high-speed design will be left to the substantial reference material already available. For reference, summaries of high-speed layout guidelines from another Agilent document follow. A few of these guidelines are more applicable to gigabit data rates but additional performance margin can be gained when applying these rules to these megabit speeds.

1. Make data lines, transmission lines of fixed impedance such as Microstrip or Stripline. This should be done even if these trace lengths are so short that the propagation delay of the line is small relative to the transition time of the signal. In general, Microstrip lines of the 50 Ohms impedance should be used to help dominate parasitic effects of the board and devices on the signal quality (reflections, ringing, distortion) and minimize unwanted electrical noise.
2. Keep data lines as short as possible and of equal length to minimize pulse-width distortion of the differential data lines. Load the differential lines symmetrically to prevent pulse-width distortion.
3. Keep differential data lines in the same approximate location to prevent unbalanced crosstalk coupling. Use differential signals to interconnect components. Avoid unbalanced, single-ended use of the data lines, which can cause pulse-width distortion.
4. Place power supply filter circuits as close as possible to the V_{CC} pins of the fiber-optic transceiver for best power supply conductive noise filtering.
5. Place data line terminations at the load end of the transmission line where the input of the receiving circuit is located.
6. Use a wide-area, continuous ground plane to provide a low-inductive impedance return path for the power supply ground currents. Minimize holes in the ground plane to allow ground currents to take direct paths to the return point, and to form a shielding plane and reference plane for Microstrip transmission lines. It is possible to provide a cut in the ground plane underneath the fiber-optic transceiver (along the centerline of the length of the device) from the front of the transceiver to the rear end of the transceiver. This cut does not disconnect the ground plane into independent sub-portions; the ground plane is still one plane. This cut merely causes logic ground currents not to flow under the sensitive receiver section of the transceiver.
7. If possible, distribute V_{CC} power via a plane rather than by traces. This helps minimize the inductive effect of traces on the switching logic currents supplied from V_{CC}.
8. Place V_{CC} bypass capacitors as close as possible to the V_{CC} locations that require bypassing.
9. Use high-quality, high-frequency surface-mount components for best high-frequency performance. Surface mount coil inductors should have $\leq 0.7\ \Omega$ series resistance and a high self-resonant frequency. Ferrite beads can be substituted for coil inductors if the power supply noise is fairly quiet. The 0.01 µF and, 0.1 µF capacitors should be monolithic, ceramic capacitors and the 4.7 µF or 10 µF capacitor be a tantalum capacitor.



DIMENSIONS IN MILLIMETERS (INCHES)

Figure 12 - Front Panel Opening for all MT-RJ SFF Transceivers

Radiated EMI and 125 Mb/155 Mb SFF Transceivers

Radiated Emissions for the HFBR-5903/05, HFCT-5903/05E and HFCT-5915E have been tested successfully in several environments. Data sheet values will normally describe emissions behavior in a worst-case, open box, or open-board, unshielded environment. While this number is important for system designers in terms of emissions levels inside a system, Agilent recognizes that the performance of most interest to our customers is the emissions levels, which could be expected to radiate to the outside world from inside a typical system. In their application, SFF transceivers are intended for use inside an enclosed system, protruding through the specified panel opening at the specified protrusion depth. (See data sheet for appropriate dimensions and layout information). For more detailed information on fiber-optic system applications on EMI, test chambers and testing, please also refer to AN 1166, *Minimizing Radiated Emissions of High-Speed Data Communications Systems*.

Two methods are used to try to characterize and predict typical system performance. The most obvious, of course is to work directly with customers and test actual fiber-optics systems with Agilent transceivers. While we cannot disclose any actual performance, we have seen results passing to FCC-B/CISPR-B limits in systems using more than fifty HFBR-5903 transceivers. While direct feedback from our customers is always valuable, Agilent also performs its own single transceiver tests in open board, open box and closed box environments. These internal results help our design teams to continually monitor and improve emissions performance during product development. They also provide our customers with initial predictions of relative performance between a worst-case, unshielded (open) box environment and a best-case, well-shielded (closed) box environment. One can usually assume that actual system performance would fall somewhere between open box and closed box results.

Starting from the radiated emissions (in dBuV/m) generated by a single transceiver, L, and the number of transceivers, N, we can theoretically scale multiple transceiver performance using 10log(N)+L. For example, if we measure 20 dBuV/m for a single transceiver, we would theoretically expect for 100 of the same transceivers, an increase of 10log(N) or 20 dB to 40 dBuV/m. We have measured some systems that follow the slope of this curve quite closely. Repeatability of the measurement setup and repeatability in reassembling the system for different configurations can have a large impact on actual results. Transceivers from different vendors can produce very different radiated emission levels at different worst-case frequencies. The radiation patterns produced by dense, two-dimensional arrays of SFF transceivers are very complex and difficult to accurately characterize or predict, so 10log(N) should only be used as a rough guideline.

The evaluation board used for EMI testing contains just one SFF transceiver and the specified terminations. Rx output signals are looped back to Tx inputs electrically through 50-ohm stripline transmission lines. Layout is per the recommendations in the 5903/5 data sheet with the exception of mounting holes, which are slightly larger to accommodate pin sockets, allowing easy installation and removal of the transceiver. In addition, the solder posts are not soldered for ease of exchanging units for testing. For closed box measurements, the evaluation board is screwed into a small metal box with just the recommended panel opening for the transceiver. The 3.3 V dc bias is brought in through the wall of the box using a shielded, coaxial, bulkhead connection. An RF-tight lid seals off the only other apertures.

The data set, shown in Figure 13, was measured in a certified facility 10-meter, semi-anechoic chamber, using an open evaluation board (without any enclosure) and a 0101 data pattern at 155 Mb/s. A single transceiver, HFBR-5905, was rotated on a table over 360° with antenna height varied to determine maximum available emissions and provide results in margin below FCC-B (CISPR-B) limits. An average of five of these units are shown in Figure 13. The HFCT-5903/05/15E radiated emission performance is below the noise floor.

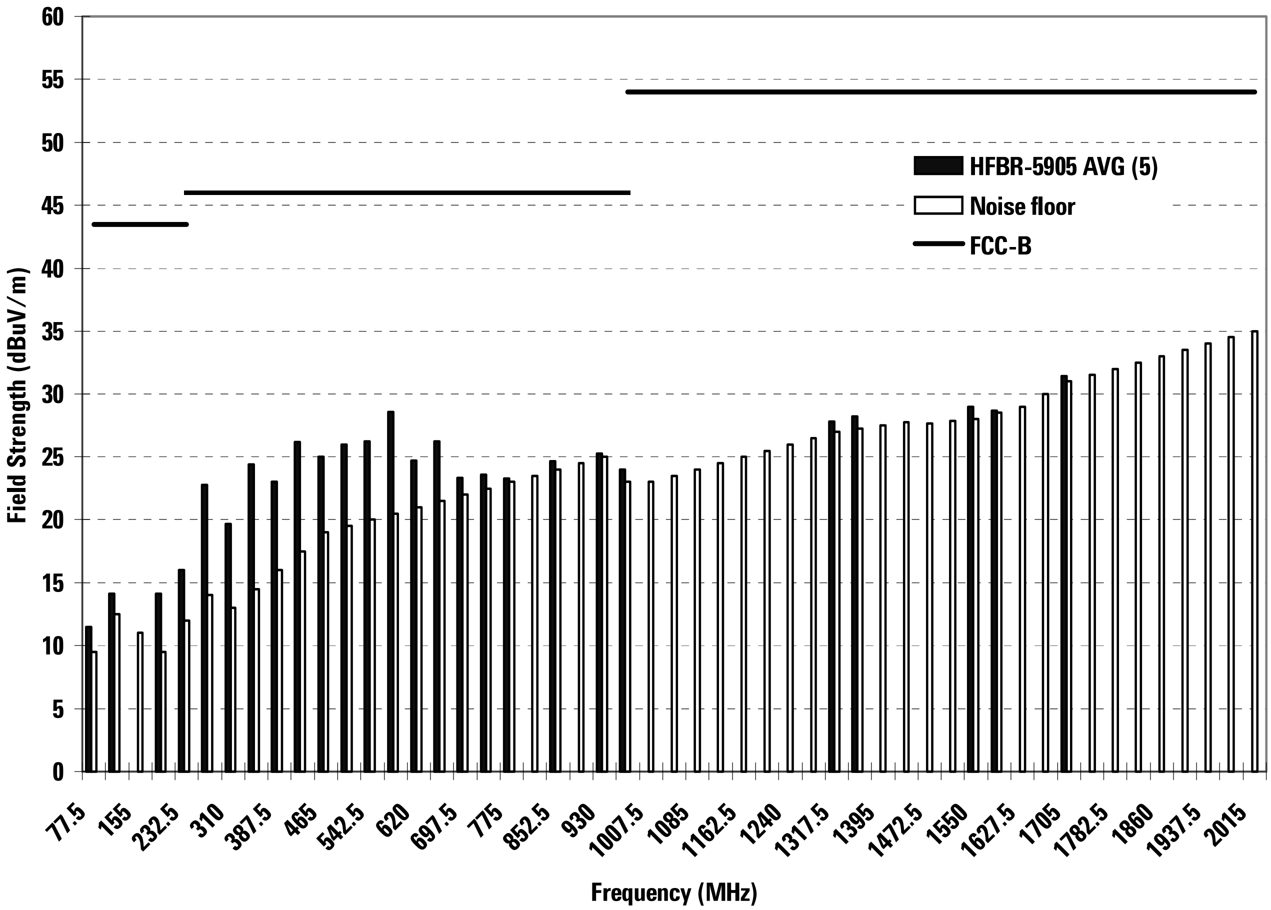


Figure 13 - Radiated Emissions SFF Multimode MT-RJ Single HFBR-5905 on Open Board in Semi-anechoic Chamber 155 Mb/s 0101 Pattern

The data-sets, shown in Figures 14 and 15, were made in a GTEM cell, using an evaluation board inside a small test box and a 0101 data pattern at 125 Mb/s. Open box measurements are with the lid removed, exposing the entire top surface of evaluation board and transceiver. The nose of the transceiver protrudes through the side of the test box. Closed box measurements are made with a well-sealed lid enclosing the entire evaluation board and transceiver inside the test box, with just the nose and its MT-RJ connector protruding. Maximum available emissions are recorded on an EMC (spectrum) analyzer and provide results in relative field strength (dBuV/m) which are used to compare performance between transceivers.

According to the open board chamber results, shown in Figures 13 and 14, the transceivers pass FCC-B limits by at least 15 dB and at many frequencies, by more than 20 dB. Closed box GTEM results, shown in Figure 15, suggest an additional shielding effectiveness of another 15 to 20 dB, indicating that it should be feasible from an emissions standpoint to use the SFF transceivers in systems with port densities of well over 100. Higher densities may be possible with careful enclosure and PCB layout design. Along with the system advantage of high port density comes the increase in the number of apertures. Careful attention must be paid to the locations of high-speed clocks or gigabit circuitry with respect to these apertures. While our measurements and experiences do not indicate any specific transceiver emissions issues on

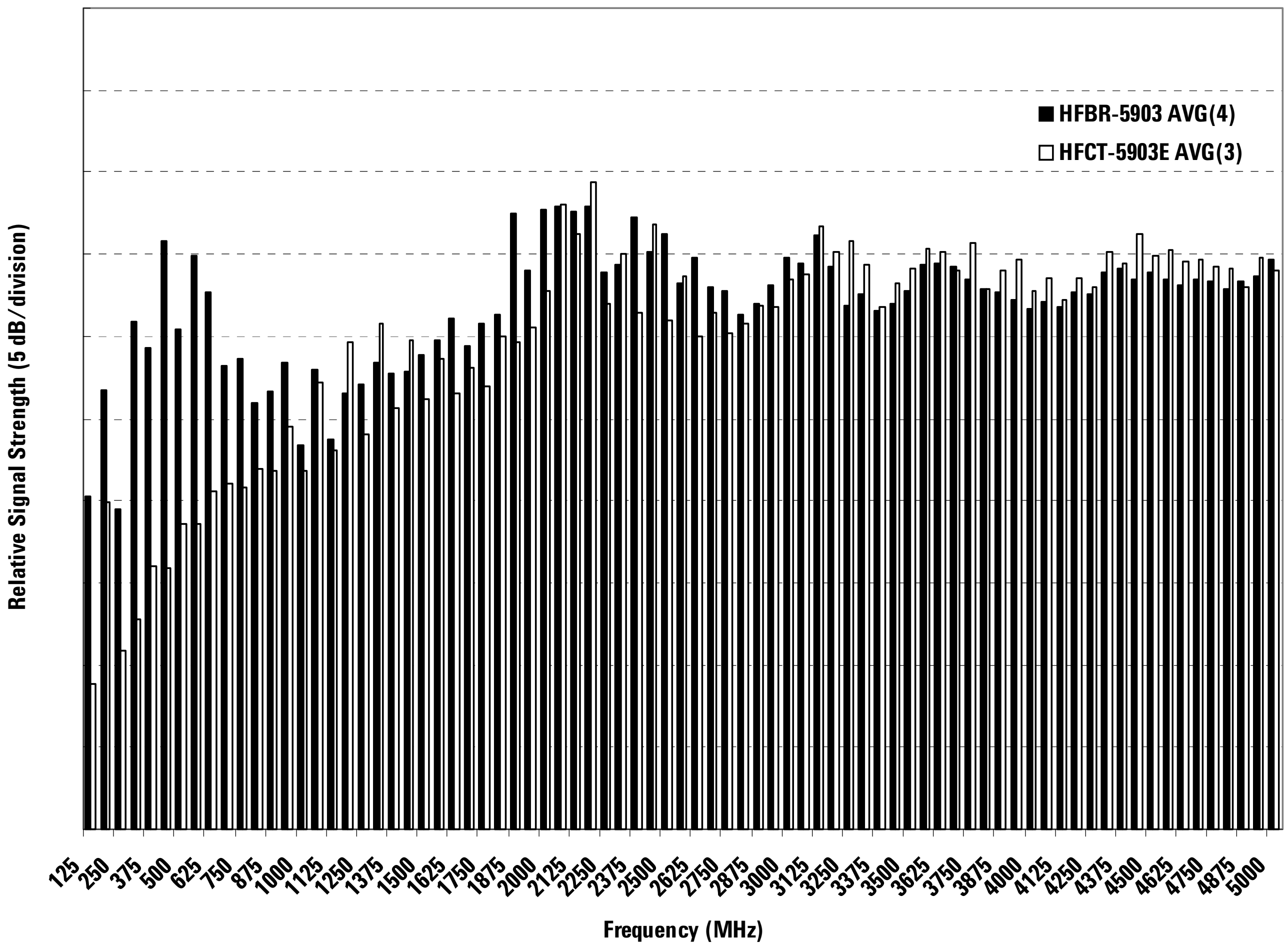


Figure 14 - Radiated Emissions HFBR-5903 and HFCT-5903E Single Module on Open Board in GTEM 125 Mb/s 0101 Pattern

these transceivers, Agilent recognizes that the transceiver aperture is often the weakest link in system enclosure integrity and has designed the modules to minimize emissions and if necessary, contain the internal system emissions by shielding the aperture.

To that end, our single mode MT-RJ transceivers (HFCT-5903/05E and HFCT-5915E) have metal nose shields, which provide a convenient chassis connection around the MT-RJ connector. The metal nose shield improves radiated emissions performance of the HFCT-5903E, and in addition, improves system emissions performance by closing off the MT-RJ aperture. Localized shielding is also improved by tying metal housing solder pins to signal ground on the PCB. Though not obvious by inspection, the metal nose shield and metal housing are electrically separated for customers who don't wish to directly tie chassis and signal grounds together. The recommended transceiver position, PCB layout and panel opening for both HFBR-5903 and HFCT-5903 are the same, making them mechanically drop-in compatible. The HFBR-5903E and HFBR-5905E, which include a metal nose shield, are available primarily to improve system level radiated EMI by reducing the transceiver's aperture opening. The improvement in system level EMI can be seen in Figure 15.

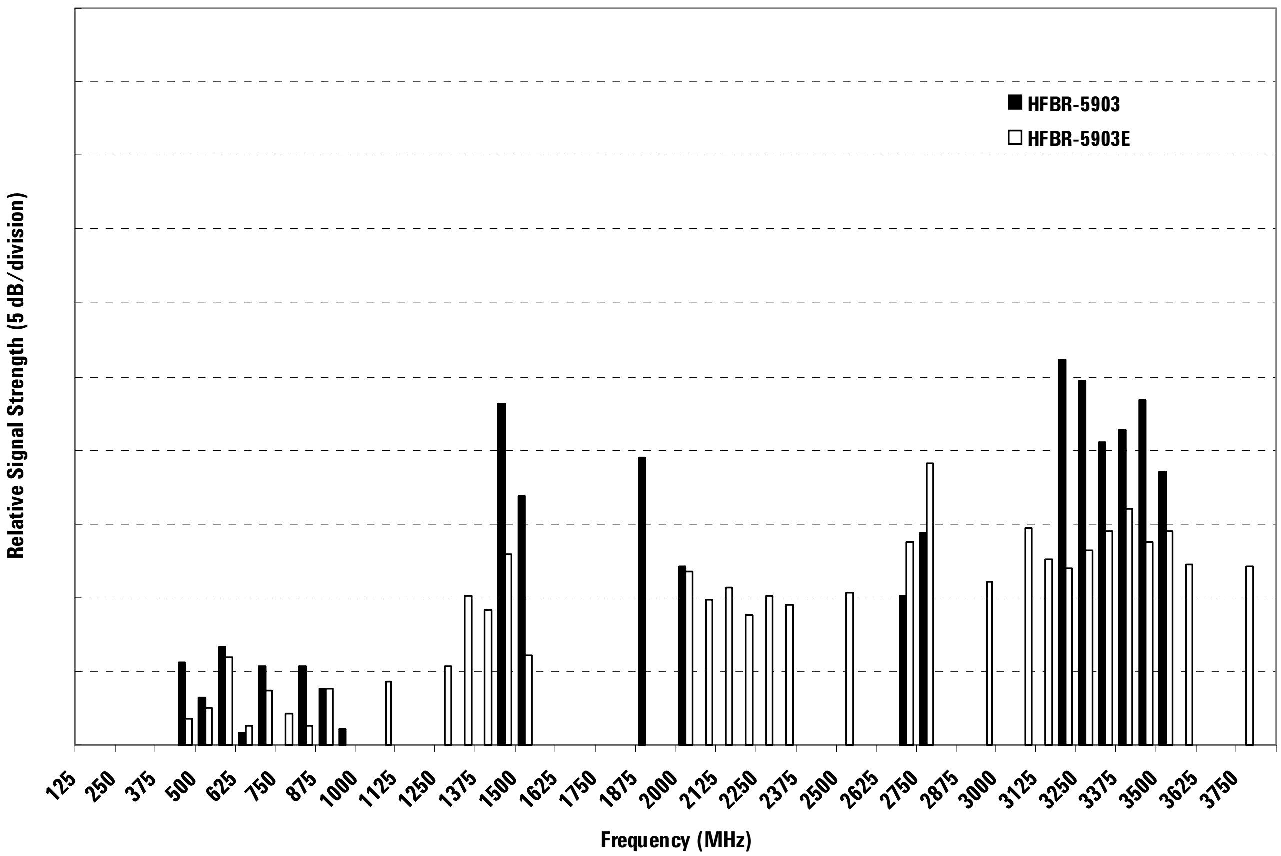


Figure 15 - Radiated Emissions HFBR-5903 and HFBR-5903E Single Module in Closed Box in GTEM 125 Mb/s 0101 Pattern

Aqueous Wash Systems and 125 Mb/155 Mb SFF Transceivers

Introduction

Electronic assembly operations can employ a range of aqueous wash systems for cleaning printed circuit board assemblies. Typically these systems include an automated movement of the PCB assembly through several aqueous wash and rinse cycles. Within these aqueous cleaning systems is a number of variables that can make each system unique. Aqueous wash system are comprised of the following variables at a minimum: conveyor speed, number of wash and rinse cycles, temperature, number of nozzles, nozzle pressure and angle of nozzle to PCB assembly. Fiber optic transceivers are also burdened with ensuring the optics are not contaminated with an aqueous solution. For these reasons, fiber optic transceivers are qualified on what is considered a 'typical' aqueous wash system. The aqueous wash qualification process described in the next section was implemented to ensure that properly inserted port plugs will protect transceiver optics in typical aqueous wash systems.

Aqueous Wash Qualification

The Fiber-Optic Communication Division's manufacturing facility qualifies the aqueous wash process by a new product verification build as well as reliability monitoring after the product becomes mature. The verification build can be a minimum of 100 units to more than 400 units. Monthly reliability checks ensure a stable assembly process and typically have a minimum of 60 units that complete the aqueous wash process.

The aqueous wash performance is evaluated by comparing the before wash and after wash Light Output Power and Rx Sensitivity. Test and control units go through wave solder, aqueous wash and electrical/optical test for three complete cycles. Due to logistics, test does not occur for two to four hours after the aqueous wash process. Light Output Power and Rx Sensitivity are allowed a maximum variation of 0.8 dBm, typically this variation is much less. Table 3 shows an abbreviated description of the aqueous wash process used for qualification.

During this wash process, the transceivers are subjected to water injected from the top, bottom and sides. The modules are not fully submersed in water. The HFBR-5903/5, HFCT-5903/5 and their variants all passed this aqueous wash qualification process.

Most transceivers are also qualified at a second facility with a different aqueous wash system to ensure that they pass a more stringent aqueous wash process. At this second facility, the transceivers are fully submersed in an aqueous solution that is agitated by very high pressure nozzles.

Table 3 - Summary of Qualification Wash Process

Conveyer Speed: 1 meter/minute		
Stage	**Temperature (°C)**	**Nozzle Pressure (psi)**
Prewash	50	20
Wash	50	Upper Manifold 40 Lower Manifold 20
High Pressure	50	60
Recirculating Rinse	50	Upper Manifold 40 Lower Manifold 15
Final Rinse	50	15
Drying Chamber	100	

Power Dissipation of Multimode 125 Mb/155 Mb SFF Transceivers

The HFBR-5903/5, multimode SFF transceiver, consumes a typical 700 mW of power due to being an LED based product. The mechanical design of LED based transceivers are constrained by the industry demand for a low cost product. For these reasons, the HFBR-5903/5's, high power consumption was an early development issue. On an evaluation fixture, a single HFBR-5903/5 will stabilize at a typical temperature of +40 °C. While this may appear to be an unusually high temperature, reliability tests have proven that temperatures up to the data sheet specification of +70 °C (+85°C for HFBR-5903A) are not an issue. High temperature operating life test results are covered in the document "1300 nm Small Form Factor Transceivers Reliability Data".

Since any component that runs at a higher than typical temperature can cause customer concerns, a brief description as to how the HFBR-5903 dissipates heat is warranted. The metal housing is attached by two tabs that are received by two indentations in the plastic nose as well as a single tab that is soldered to an electrically isolated printed circuit board pad. The only thermal paths from the metal housing to the customer PCB is through the plastic nose and PCB's FR4 material. The poor thermal conductivity of the plastic nose and FR4 leave the metal housing without an efficient path to dissipate heat. So, the metal housing is not only electrically isolated but is essentially thermally isolated as well. In still air the metal housing will stabilize to the transceiver's PCB temperature only after several minutes. The HFBR-5903/5's most efficient thermal path from the IC's to customer board is through the copper on the transceiver's PCB, to the 2 x 5 arrangement of PCB pins, and finally to the customer PCB. The final temperature of the HFBR-5903 is highly dependent on the size, thickness and other components of the customer PCB. Of course, there are the system level variables that effect final temperature such as component arrangement and presence of forced air. In a customer application, the temperature of the HFBR-5903/5 can be more accurately gauged by measuring at the customer PCB as close as possible to the 2 x 5 rows of pins.

In the case of the HFBR-5903/5, a maximum case temperature is not a descriptive or accurate specification since it would have to be further qualified by still air or forced air as well as time to stabilize at a temperature. The data sheet specification of 0 °C to +70 °C (-40°C to +85°C for HFBR-5903A) was characterized by bringing an environmental chamber to the required temperature via a forced air stream. So, the entire external transceiver, test socket and test board were brought to the range of data sheet temperatures. Temperatures measured at the customer board near the transceiver's 2 x 5 pins would be sufficient to compare to the data sheet specification of 0 °C to +70 °C (-40°C to +85°C for HFBR-5903A).

The Single Mode HFCT-5903/05/15E, laser based SFF transceiver, has a typical power consumption of 400 mW at +25°C and has higher cost packaging enabling efficient power dissipation.

SFF MT-RJ Connector Repeatability

Introduction

In this discussion, connector repeatability is defined as 500 insertions of the fiber optic MT-RJ cable connector into the SFF's MT-RJ receptacle where the light output power is measured before and after the insertions. The typical industry expectation is that the light output power vary by less than ± 0.5 dBm after 500 insertions. Five hundred insertions is based on the improbability that this number of insertions will never be reached in practice. Both the HFBR-5903/5 and HFCT-5903/05/15 easily met this 500 connector insertion criteria. MT-RJ fiber optic cables are also tested with this 500 insertion repeatability. The Fiber-Optic Communications Division's manufacturing facility retires MT-RJ fiber optic cables after 500 insertions since there are no cables presently available with a higher rating. There were also more esoteric tests performed that are dedicated to the fiber/ module connection like the 'axial pull' test where a predefined force is applied to the cable and a delta in light output power is recorded.

A visual inspection of the MT-RJ SFF connector design may leave a new user with unwarranted concerns. To alleviate any concerns with the SFF MT-RJ connector designs, a brief description of both the multimode and single mode SFF's connector designs are cited. Both the HFBR-5903/5, multimode SFF, and HFCT-5903/05/15, single mode SFF, pass the previously discussed typical industry connector tests.

Multimode 125 Mb/155 Mb SFF MT-RJ Connector

The HFBR-5903/5 development was constrained by two major demands, that is, time-to-market and low cost. To meet the short time-to-market requirement, the use of existing transceiver optical subassemblies became essential. The MT-RJ multisource agreement allows for long guide pins in the SFF connector. In the HFBR-5903/5, long guide pins would require space inside the module to support the guide pin that would have extended into the cable MT ferrule holes. The use of existing optical subassemblies occupied the space required by long connector guide pins which forced the use of short guide pins.

A copper bulkhead is visible through the HFBR-5903/5 nose and in Figure 16. This bulkhead has two slight protrusions that are received by the fiber ferrule guide holes. These slight protrusions are formed by a punch process that is consistent with the low cost manufacturing demand. The disadvantage to this punch process is that the copper bulkhead can be deformed by a relatively small amount resulting in the short guide pins.

The short guide pins were a concern in the early development as the wear points shown in Figure 16 were inevitable. As the corners of the MT ferrule wear away the short guide pins lose their function. This alignment concern led to a qualification process early in the development showing that any wear degrading optical performance did not occur until well in excess of 500 insertions.

Single Mode 125 Mb/155 Mb SFF MT-RJ Connector

The nature of single mode light forced the design of the HFCT-5903/05 and HFCT-5915, single mode SFF, to maintain critical optical alignment. Part of this requirement, was contact of the optical fibers between the cable connector MT ferrule and the SFF connector. This contact was required to maintain the required Total Return-Loss, that is, minimize the optical power reflected by a connector back to the light source. For these and other reasons, the development of the HFCT-5903/05 and HFCT-5915 required a complete redesign of the optical subassembly. This new process for the optical subassembly or Silicon Microbench technology is thoroughly discussed in "New Fiber-Optic Devices Demand New Manufacturing Processes", Lightwave, September 1998, page 107.

This redesigned optical sub-assembly allowed the use of the long guide pins visible through the nose of an HFCT-5903/05 and HFCT-5915. With the new optical subassembly design, the long guide pins are able to extend back into the transceiver for support.

Cross Section of HFBR-5903/5 Nose and Fiber Optic Cable MT Ferrule

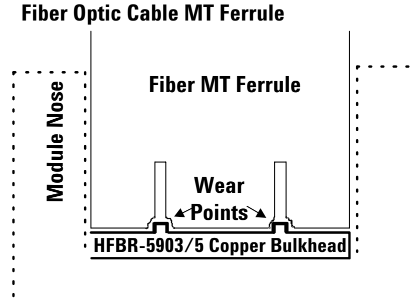


Figure 16 - Fiber Connection: HFBR-5903/5 and Fiber Optic Cable

The length of these guide pins caused concerns early in the development of this module. This included the concern that the outside diameter of the long pins would wear after repeated insertions. This wear would allow movement between the guide pins and cable ferrule holes allowing for optical fiber misalignment. Early in the development cycle, typical industry connector tests were performed including the 500 insertion test. The variation in light output power was ± 0.2 dBm which is well under the industry expectation of ± 0.5 dBm.

SFF Optics Cleaning Statement

The multimode SFF, HFBR-5903/5, has recessed optics that are visible through the nose of the transceiver. The port plug provided should be installed anytime a fiber cable is not connected. The port plug ensures the optics remain clear and no cleaning should be necessary. In the event that optics become contaminated, forced nitrogen is the only recommended cleaning.

The single mode SFF, HFCT-5903/05 and HFCT-5915, have optical fibers that are flush with the end of it's MT ferrule visible through the nose of the transceiver. The guide pins are stainless steel and the MT ferrule is molded plastic. The port plug provided should be installed anytime a fiber cable is not connected. In the event that optics become contaminated, forced nitrogen is the only recommended cleaning. It is possible to clean the fibers in the MT ferrule with Isopropyl Alcohol but this is not advised due to potential mechanical damage.

Regulatory Compliance for SFF Transceivers

Laser Safety - United States – US FDA/CDRH 21 CFR
The HFCT-5903E, HFCT-5905E and HFCT-5915E transceivers contain a 1300 nm laser system and are classified as a “Class I Laser Product” under the U.S Department of Health and Human Services (DHHS) Radiation Performance standard according to the Radiation Control for Health and Safety Act of 1968. Class I laser products are considered “eye safe” and pose no biological hazard when used within the data sheet limits and instructions.

Caution:
Use of controls, adjustments or performance procedures other than those specified may result in hazardous radiation exposure. There are no user serviceable parts nor any maintenance required for the HFCT-5903E, HFCT-5905E and HFCT-5915E transceivers. All adjustments are made at the factory before shipment to our customers. Tampering with or modifying the circuitry by prying open the enclosure may result in improper operation and overstress of the laser source. Device degradation or product failure may result. The person(s) performing such an act is required by law to recertify and reidentify the laser product under the provisions of 21 CFR (US Code of Federal Regulations – Subchapter J).

Laser and LED Safety – European Union
The HFCT-5903E, HFCT-5905E and HFCT-5915E transceivers contain a laser (1300 nm) system. The HFBR-5903 and HFBR-5905 transceivers contain an LED (1300 nm) system. All four models are classified as “Class 1 Laser Products” per EN 60825-1(+A11), Safety of Laser Products. Class 1 laser and LED products are considered “eye safe” and do not pose a biological hazard if used within the data sheet limits and instructions.

Caution:
Use of controls, adjustments or performance procedures other than those specified may result in hazardous radiation exposure. There are no user serviceable parts nor any maintenance required for the HFCT-5903E, HFCT-5905E, HFCT-5915E, HFBR-5903 and HFBR-5905 transceivers. All adjustments are made at the factory before shipment to our customers. Tampering with or modifying the circuitry by prying open the enclosure may result in improper operation and overstress of the laser or LED source. Device degradation or product failure may result.

Safety certificates can be found at the following URL:

http://www.semiconductor.agilent.com/fiber/lasercert.html

125 Mb/155 Mb Small Form Factor Transceiver Test Fixture Evaluation Kits - HFBR-0559, HFBR-0555, HFBR-0560, HFBR-0561

Introduction

The HFBR-5903/5905, HFCT-5903/5903E/5905/5905E/5915E series of small form factor transceivers are designed to provide multimode and singlemode solutions for 125 Mb and 155 Mb applications. These MT-RJ receptacled transceivers allow increased port density over standard duplex SC modules. Most fibre-optic designers have previously used Agilent's industry-standard duplex SC transceivers and so, are experienced with evaluation boards and test methods. To the new user, a universal SFF test fixture is available for easy testing and evaluation purposes. This text fixture is found in the four evaluation kits detailed in Table 4. This document describes the dedicated SFF test fixture and is aimed at providing operational information to the user.

Description

The SFF test fixture has a four layer FR-4 printed circuit board with ground planes on both sides. It is designed to be footprint compatible for all single and multimode FDDI and Fast Ethernet variants. A mass-loaded base enclosure is provided for stability on the bench.

Figure 17 shows the SFF test fixture. Edge-mounted SMA connectors are provided for data inputs and data outputs. Standard 2 mm sockets are included for easy connection to dc power supplies. A sliding switch is provided for selecting the transmitter disable function. Gold contact pin sockets are used to allow interchangeability between transceiver modules while assuring good connection integrity. Ground tab connection holes are provided on the test fixture for grounding the SFF transceiver body. Grounding the transceiver body is not necessary for normal operation but is recommended in high-speed PCB design for optimum EMI compliance. Generous grounding is provided around the transceiver footprint using plated through holes.

Circuit Schematic

Figure 18 shows the circuit schematic for the test fixture. Separate power supplies are provided to the transmitter and receiver sections and recommended filtering arrangements are used.

The Signal Detect (SD) function is provided for the user. This is single ended PECL output for the HFBR-5903/5903E/5903A/5905, HFCT-5903/5903E/5905/5905E/5915E parts.

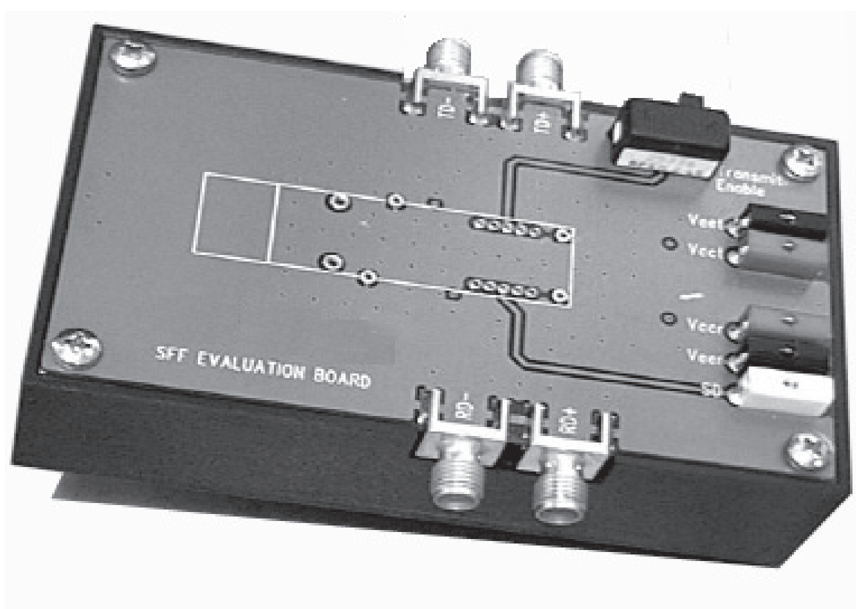


Figure 17 - SFF Test Fixture

Operation

The test fixture requires +3.3 V voltage supplies to both V_{CCT} and V_{CCR}. The Transmitter Enable/Disable switch needs to be in position 2 for normal operation while position 1 disables optical data transmission. The test fixture is rated for repeated temperature evaluation from 0°C to +70°C (-40°C to +85°C for HFBR-5903A).

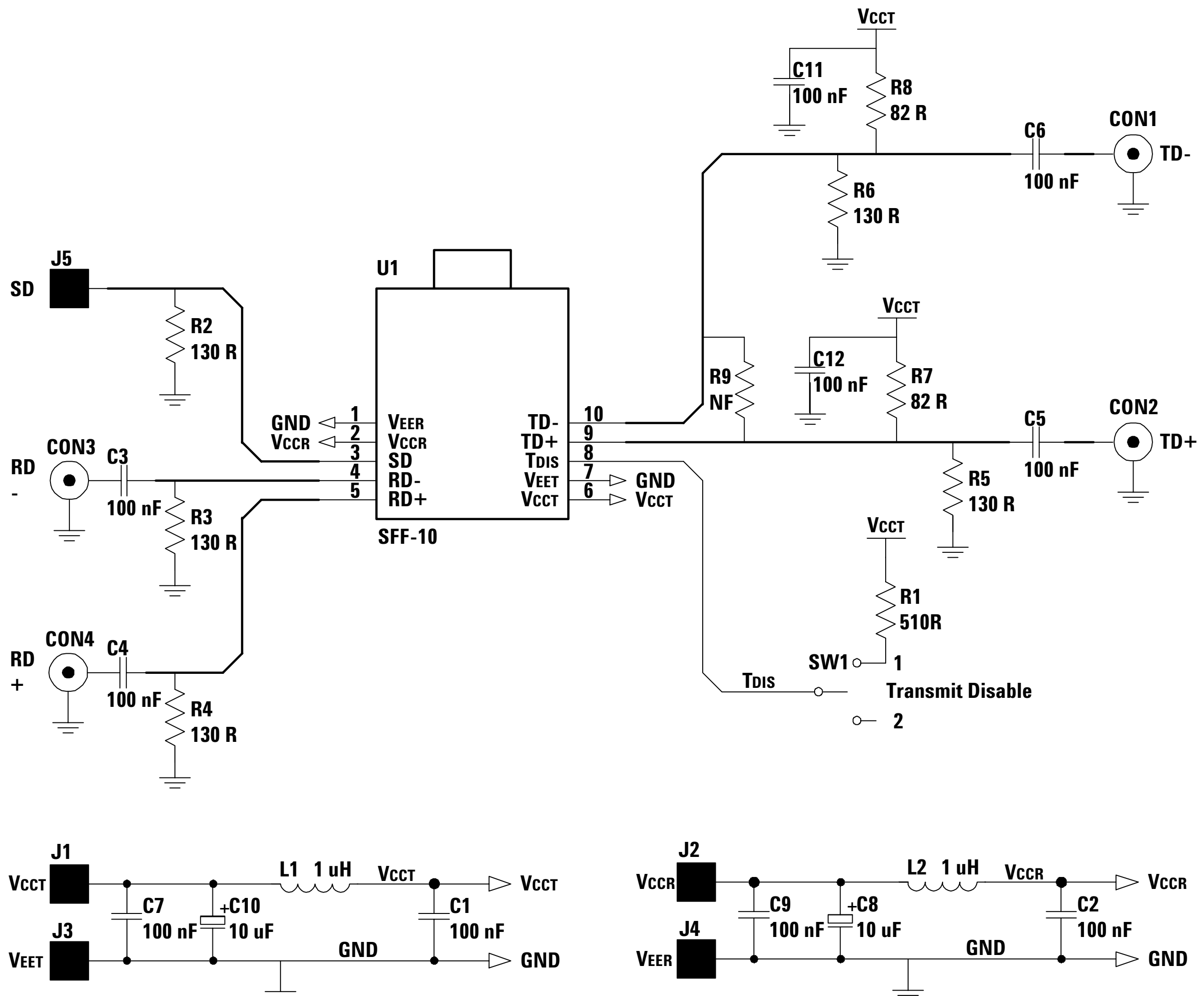


Figure 18 - SFF Test Fixture Circuit Schematic for 125 Mb/155 Mb Transceivers

Table 4.

Kit Part Number	Physical Layer Application	SFF Module(s) Included
HFBR-0559	125 Mb Fast Ethernet	HFBR-5903 Multimode Transceiver
HFBR-0555	155 Mb ATM	HFBR-5905 Multimode Transceiver
HFBR-0560	125 Mb Fast Ethernet	HFCT-5903 Single Mode Transceiver HFBR-5903 Multimode Transceiver
HFBR-0561	155 Mb ATM	HFCT-5905 Single Mode Transceiver HFBR-5905 Multimode Transceiver HFCT-5915 Single Mode Transceiver

Note:

All kits include the identical test fixture along with documentation, power cables and the appropriate MT-RJ to duplex SC fiber cable.

For product information and a complete list of Agilent contacts and distributors, please go to our web site.

www.agilent.com/semiconductors

E-mail: SemiconductorSupport@agilent.com
Data subject to change.

Obsoletes: 5988-3730EN
December 10, 2001
5988-5100EN

Agilent Technologies