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Testing and Measuring Electromagnetic Compatibility Performance of the HFBR-510X/ 520X Fiber-Optic Transceivers

Application Note 1075

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Abstract

This application note explains the main components of electromagnetic compatibility (EMC): radiated emission, immunity, electrostatic discharge, and conducted noise; and describes how the design of the communication network system affects EMC performance. It describes how Agilent Technologies' new HFBR-510X/ 520X 1×9 SC connectored, fiber-optic transceivers for data rates up to 155 MBaud are designed for excellent electromagnetic compatibility while maintaining low cost. The application note also describes the procedures under which the HFBR-510X/ 520X components are tested for EMC, and reports the results of these tests.

The application note summarizes the HFBR-510X/520X components' EMC performance and stresses their reliability under various conditions and applications.

1.0 Introduction

Agilent Technologies has designed its new HFBR-510X/ 520X, 1×9 pinout, SC connector, fiber-optic transceivers for excellent electromagnetic compatibility (EMC) while still maintaining low cost. The HFBR-510X/520X modules are intended for high data rate applications such as ATM (155 MBaud) or FDDI (125 MBaud). At these high data rates, achieving acceptable EMC performance in communications network products while still maintaining low product cost can be quite a design challenge. The excellent EMC performance of the HFBR-510X/520X module, plus its low cost, should make the EMC design challenge for the communication network product easier to overcome.

EMC refers to the capability of electronic equipment or systems to be operated in the intended operational electromagetic environment at their designed levels of efficiency. Specifically, EMC describes how the product behaves in terms of radiated emissions, commonly known as electromagnetic interference (EMI), and also how the product's performance is affected by immunity (susceptibility) to radiated energy, electrostatic discharge (ESD), and conducted power supply noise. This application note describes these EMC components, how communication network design can affect the EMC performance, and how the excellent EMC performance of the HFBR-510X/520X transceivers make it easier to design fiber-optic communication network products with acceptable EMC performance. Since the interconnection and the packaging of the components used in a communication system affect the EMC performance of the system, Agilent performed various tests on our products to determine how our components affect a final system-level EMC performance. This application note presents the component-level EMC testing procedures and results, and explains how the component- level performance affects the performance of the complete fiber-optic data communication network.

EMC problems worsen as the data rate increases. This application note details some of the practices that the equipment designers can observe to help avoid being affected by EMC when using Agilent's new high data rate HFBR-510X/520X products.

2.0 Elements of Electromagnetic Compatibility (EMC)

2.1a What is Radiated Emission?

The first EMC area is radiated emissions, sometimes called electromagnetic interference or EMI. A radio or TV broadcast is an example of intentionally radiated electromagnetic energy. A computing device also radiates electromagnetic emissions, although it is not intended to. (The radiation is an inherent by-product of the switching currents flowing in its conductors). Electromagnetic radiation occurs when a changing current flows in a conductor. At the area near the conductor (antenna), we usually see either the electric or the magnetic field dominate the total radiated field. This area near the antenna is called the near field. The antenna formed by taking one long wire and breaking it at the center to form two separate wires, is known as an electric dipole antenna. The dipole antenna is usually driven by a varying voltage source, with the positive source node connected to one wire and the negative source node connected to the other wire. The dipole antenna near-field radiation is predominately an electric field. If a varying current flows in a loop of wire, it creates predominately magnetic field radiation. This antenna is known as a (magnetic) loop antenna. At a point far away from this antenna, neither the electric nor the magnetic fields dominate. These areas are known as the far-field region. In this region, the radiation (or equivalently the electromagnetic wave) becomes what is known as a transverse electromagnetic wave (TEM). A TEM wave behaves the same as all the other radio/TV waves that travel through the air. The characteristics of the air determine the electric-to-magnetic field strengths or, equivalently, the characteristic impedance of the radiation. An actual communication system contains various antennas formed by the circuit interconnections and by the other metal bodies in the circuitry. These antennas are then driven by various energy sources within the system circuitry. One example is the loop form by V_{CC} to Data output to Ground, through the V_{CC} decoupling capacitor, then back to V_{CC}. Additional examples are the LED current loop in a fiber-optic transmitter, and ground wires (PCB traces) driven by voltage noise sources that act as dipole antennas, and so forth.

Government agencies around the world regulate the amount of radiated electromagnetic energy emitted by various sources. Their intent is to allow any purposely transmitted radiated energy to be received without being interfered with by some other radiation source at around the same frequency. Equipment that radiates emissions could interfere with radios in the same building or even with other electronic equipment that is sensitive to that radiation. Electromagnetic interference (EMI) describes the effect of unwanted radiation interfering with another (intentional or unintentional receiver) circuit's operation.

The government agencies usually set their radiated emissions regulations to distinguish between two types of applications. The first is a factory or office (Class A) where a higher level of radiation can be tolerated; the second is the home (Class B) where there are more TVs and radios and therefore less electromagnetic radiation can be tolerated. Most manufacturers want their systems to meet all of the home environment radiated emissions specifications used around the world so that they can be sold in the US, in Europe or in Japan, with no restrictions. In Europe, computer systems must meet CENLEC EN55022 (Class B). In Japan, it is the VCCI Class 2 specification which is equal to the CISPR 22B specification. The EN55022 specification limits are identical to the CISPR 22B specification limits. In the USA, all equipment that could be used in the home must meet FCC Class B. (If the equipment can meet CISPR 22B, it will almost certainly meet FCC Class B.) All equipment not for use in the home must meet FCC Class A. In the USA, the separation between factory/office environments and the home environment is such that there is a large market for systems that meet FCC Class A only. In Europe and Japan, the Class A market is very limited since almost all environments could be considered home environments because offices and homes are often in the same building. Also, most manufacturers, in general, do not want to limit their products by making them FCC Class A only.

Any product that does not meet the pertinent emissions requirement for a particular country cannot be legally sold in that country. Any manufacturer who sells equipment that is found to violate the regulations can, if caught, face large fines and penalties. Also the manufacturer may be forced to withdraw the product from the market until the regulating government agency (FCC in the U.S.) is convinced that the radiated emissions of the modified product meet the required specification limits. Also note that for the FCC, if the system contains a clock with a frequency above 108 MHz, it must meet the FCC limits for radiated emission frequencies up to 2 GHz. Most ATM (contains a 155 MHz clock) and FDDI (contains a 125 MHz clock) systems will therefore need to be tested to FCC B up to 2 GHz. Europe and Japan currently do not regulate radiated emissions above 1 GHz, although they are expected to follow the FCC example in the near future.

Most manufacturers want their equipment to pass FCC B by at least 6 dB because the equipment will be much more easily accepted by the FCC and other agencies. If they don't pass by 6 dB, then various worst-case products with different hookup configurations must usually be tested to convince the FCC that they will pass FCC B in the worst case. If they do pass by 6 dB, the FCC will usually certify that the product passed, as long as the manufacturer can show that their test setup with a typical product was reasonably close to worst case. Thus a 6 dB margin at an FCC-approved test site operated by a manufacturer or by an independent test agency implies that any one production unit of the product that is tested at a FCC certified test site will pass the FCC limits (by at least 0 dB margin).

2.1b How System Design Affects Radiated Emissions.

System design can affect radiated emissions in three main ways. The first way is in the choice of circuit components. Some generate more high-frequency energy than others do. The second way relates to the effect of the antennas (that is, the circuit interconnections) that the high-frequency energy sources are connected to. The third way is by the shielding that the chassis box provides and by the cable shields that effectively reduce the amount of radiation that the antennas leak to the outside world.

Circuit components are seldom specified in terms of how much energy they can radiate. But, as a general rule, don't use components that are much faster than you need. The faster the edge speed and the faster the clock rate, the more radiated noise the circuit generates. Also, circuits that limit Vcc noise spikes such as the differential current switches used in ECL logic can help reduce radiated noise. Totem pole/CMOS outputs that draw large Vcc current spikes when the output switches can generate lots of noise. Circuits which internally limit edge rates and Vcc spikes while still giving adequate input/output speeds are sometimes available (such as the "quiet" CMOS family). Also, trying to keep transmission lines short will prevent ringing. (Ringing translates into more high-frequency energy and therefore more radiation.) Short Vcc-to-ground decoupling loops will often help reduce Vcc spikes. (Sometimes it will make the spikes worse, but the antenna smaller, so overall it is usually better). Ferrites can also reduce ringing by adding high-frequency damping resistance.

The antennas are formed by the circuit interconnections and by the V_{CC}-to-ground current loops. Keep these as small as possible. If they are long enough to be treated as transmission lines, then it is important that the line is terminated in its characteristic impedance. Antennas can also be formed by long traces that are driven by ground voltage noise and therefore radiate. Even a ground plane, when driven by a ground noise source can radiate. Often, cables can radiate energy when high-frequency currents flow through them. Since cables are often the largest antenna around, they are usually the dominant source of radiation. Chassis and cable shields can also radiate if ground noise current or voltage drives them. Fiber-optic cables do not, however, radiate energy as wire cables do. Therefore, fiber-optic cables can help reduce radiated emissions if using wire cables is a problem. At FDDI and

ATM data rates, the encoding/decoding schemes, and the consequent additional circuitry, needed to reduce the bandwidth and the emissions on a twisted pair wire cable, are not needed if a fiber-optic cable is used.

If an antenna is completely enclosed in a sufficiently thick metal box, then no radiation will escape. If the box has an aperture, then some radiation will escape through it. The bigger the opening and the higher the frequency, the more radiation that escapes. If the antenna is sufficiently far enough away from the opening, then the theoretical far-field attenuation by a rectangular opening (slot) in a shield is:

$$20\log_{10}\frac{\lambda}{2l} \qquad \text{Eq. 1}$$

where λ is the wavelength and l is the largest linear slot dimension.

For example, at 875 MHz the wavelength is:

$$\frac{(3*10^{10})}{875*10^{6}} = 34.3 \text{ cm/13.5 inches}$$

A slot big enough for an FDDI MIC connector fiber-optic module (4.06 cm / 1.6 inches) would provide 12.5 dB of shielding at 875 MHz. At 875 MHz, a slot big enough for a duplex SC connector fiber-optic module (3.05 cm / 1.2 inches) would provide 15.0 dB of shielding. At 875 MHz, a slot big enough for a simplex ST connector fiber-optic module (1.27 cm / 0.5 inches) would provide 22.6 dB of shielding. Thus the 1x9 module duplex SC hole provides 2.5 dB more shielding than the MIC FDDI connector hole does. If the radiation were at 437.5 MHz instead of 875 MHz, then each slot would provide an extra 6 dB of shielding. (The wavelength at 437.5 MHz is twice that at 875 MHz. This doubling of λ gives a 6 dB increase in shielding (Eq 1). If there are multiple identical openings in a shield, then the total radiation is increased by: This formula assumes the openings are close together (within 1/2 wavelength). Thus two ST connector openings would allow 3 dB more radiation to escape than one opening would. This is the reason why a duplex SC connector opening has 22.6-15-3=4.6 dB less shielding than two ST connector openings do (if the ST openings are not too close to each other).

$$20\log_{10}\sqrt{n} \text{ dB} \quad \text{where n is the number of openings.}$$

These shielding formulas are invalid if the source is too close to the opening, if the openings are so close together that they appear as one big hole, or if there is any conductor sticking through the opening (in which case it really should not be called an opening). The shielding is determined by the longest linear dimension of the opening. Thus, even a very thin, but long hole could leak quite a lot of radiation. This often happens at box joints and seams, and care must be taken to prevent radiation in these areas. EMI gaskets are often used in seams and joints to make sure that the electrical contact across the seam and joint is continuous. In this manner, long radiation holes, which otherwise might form between the screw/bolt locations that hold the seam or joint together, if no gasket were present, are prevented. Good conduction is necessary for good shielding. Metal works the best. Some conductive spray paints or metal coatings can help and may be able to approach a metal wall in the best case. Very-low-frequency magnetic fields often need exotic high-permittivity materials such as mu-metal to attenuate these magnetic fields. A conductive wire sticking through an opening can pick up radiation inside the box, conduct the noise to the outside of the box, then reradiate the energy, completely defeating the shielding provided by the opening, were it empty. A fiber-optic module with a metal nose can often conduct radiation outside a chassis if it has a section of the metal housing that sticks out of the chassis and if that metal housing is not tied to the chassis. The HFBR-510X/520X fiber-optic transceivers have plastic housings and do not conduct radiation outside of the chassis in this manner.

External shields can be added to provide additional shielding. An example of this would be an external conductive vanity cover over the fiber-optic ports to allow all the fibers to escape in a bundle through a relatively small exit access hole. This hole provides additional shielding. If the hole is a tube with the length longer than the diameter, a waveguide effect occurs and the radiation is drastically reduced as it travels through this tube. See Reference (3) for details. The waveguide phenomenon, for example, can be quite effective, but it is sometimes difficult to implement such a structure in practice. (Such structures can, while reducing the radiated emissions, make it so much more difficult to remove the fiber-optic cable connections in the field as to make their overall product contribution questionable. For example, a door may have to be opened up, the fiber connector disconnected, and then slid through a waveguide tube in order to disconnect the fiber from the communication system. This is much more difficult than merely unplugging a fiber from a module port that is accessible directly through a hole in the chassis back panel. The HFBR-510X/520X fiber-optic transceivers' low-radiated emissions make the need for elaborate structures, such as waveguides, to reduce emissions much less necessary.)

If noise is induced in the shield, it can radiate. This problem is usually avoided by the "skin effect" which keeps most shield noise currents on the inside of the box, close to their sources, while no noise current flows on the outside of the box. If the shield is directly connected to some noise source, there will be problems. Also resonances can occur inside a box; and depending on the dimensions of the box, a standing wave can form. Radiation at this standing wave frequency can be amplified inside the enclosure. The dominant frequency of the radiation from a chassis can often be at its resonant frequency.
Since there are so many factors that affect radiation and since many of these factors interact with each other, radiated emissions can be the most tricky EMC problem and should be considered as early in the design as possible. It is often difficult to fix a radiated emissions problem once the system design has been completed and is near production. Using good shielding, good high frequency PC board layouts, good cabling, and good low-emission circuit components, such as the HFBR-510X/520X fiber-optic transceivers, will help ensure the radiated emissions compliance of the final product. Additionally, if the EMC performance is considered early in the product design and if low radiated emission components are used, then the designer may find that less stringent shielding can be used in the final product. Less stringent shielding is often easier to manufacture and is lower in cost. Thus, less stringent shielding can lower the overall product cost. For example, a conductively coated plastic chassis that needs no extensive EMI gasketing can be cheaper to make than a metal chassis with many EMI gaskets. Thus, low radiated emission components, such as the HFBR-510X/520X fiber-optic transceivers, can allow the product designer to make a lower-cost product that still has good radiated emissions performance.

2.2a What is Susceptibility (Immunity)?

Electromagnetic susceptibility of a product (or immunity) is defined as the effect of external electromagnetic fields on the performance of that product. The performance is measured in the presence of an external electromagnetic field relative to the performance with the electromagnetic field absent. The measurements must be made over a variety of electromagnetic field strengths and frequencies. Then the same product performance is measured with the electromagnetic field turned off.

Immunity and susceptibility refer to the same characteristics (immunity is the inverse of susceptibility). From a measurement point of view, however, what is measured is the performance penalty due to the electromagnetic fields and this penalty is the susceptibility. The goal is to have zero performance penalty or zero susceptibility, i.e. totally immune.

At the system level, only a few written specifications address susceptibility (immunity). The authors of the IEC 801-3 specification (see Reference (7)) have stated that the computer system product under test should be immune to 1 to 10 V/m external fields. They define three classes of devices. Class 1 is a 1 V/m susceptibility test for devices that are expected to be used in low level electromagnetic field environments. Class 2 is a 3 V/m susceptibility test for moderate environments. Class 3 is a 10 V/m susceptibility test for environments with severe electromagnetic radiation present. What is meant by immune (i.e. how much penalty is allowed) however, is left unclear and is said to be negotiable between vendor and customer. Based on some of Agilent Technologies' customer inputs, Agilent has standardized on a 10 V/m field strength to test fiber-optic transceivers. Thus Agilent modules are tested to the Class 3 IEC 801-3 severe environment test level. This is a large field strength and would be difficult to generate inside a computer system unless the source is within inches (or centimeters) of the circuit in question. Or it could be generated by a very large ESD or by a very-high-power radio transmitter (walkie-talkie) that is held very close to the system.

As an example of how large a 10 V/m field is, consider that the FCC B radiated emissions limit is 46 dB μV/m at 500 MHz at a test distance 3 meters from the source. This is a $1\mu V/m*10^{(46/20)} = 199\mu V/m$ field strength. The far field strength varies as a function of 1/r, where r is the distance from the source. Thus, at a distance of 1 cm (0.39 inches) from the source, the field strength would be 300*199 µV/m = 0.06 V/m . This is still $20\log_{10}(10/0.06) = 44$ dB less field strength than a 10 V/m field. Therefore, to generate a 10 V/m field at the fiber-optic receiver would require a source, which on its own would fail FCC B by 44 dB, to be placed within 0.4 inches (1 cm) of the receiver. Clearly not too many such sources can be present in a computer system which must pass FCC B limits. So, practically, a 10 V/m field can be generated only by a large high-frequency current pulse, such as an ESD pulse, or by a high power nearby radio/TV transmitter. The example in the IEC 801-3 specification indicates that a 10-watt walkie-talkie held at 1 meter from the Agilent module (with no shielding provided by the system chassis) would generate a 5 V/m field. This is the largest field strength indicated on the IEC 801-3 Figure A.3 curve, (so one would assume that in reality a 5 V/m field might be the most that would be seen from a walkie-talkie).

Usually an antenna in the circuit will pick up the external field and then couple it into a critical circuit node where it appears as a noise signal. The susceptibility will depend on the frequency of the field because the receiving antenna gain varies with frequency and because the circuit noise rejection varies with frequency. The noise can be picked up directly at the sensitive node itself or can be conducted from another node (such as V_{CC}) that has a larger gain antenna connected to it.

Performance degradations due to incident electromagnetic fields can occur as lines appearing on CRT displays, noise/other channels appearing on a radio broadcast reception, larger than normal bit error rates in digital networks, or state machines getting mixed up and the whole system becoming locked or just behaving strangely. Susceptibility problems are bothersome to the end users because it is often difficult for them to fix the problem (or even to get it to occur often enough in order to try to fix it). Many systems have built in error correction and error trapping routines so that if some strange error does occur at least the only thing the user might experience is the extra delay caused by the time it took the system to catch and recover from the error (and possibly retransmit the data).

Obviously, the less often these susceptibility problems occur, the better. When components with low-radiated emissions are used inside the system, such that the system can pass the radiated emissions requirements easily, then there are fewer possible large sources of radiation that could conceivably cause susceptibility problems. And, of course, components with high immunity (or low susceptibility) should be used whenever possible.

Generally speaking, a 10 V/m field strength will not occur very often but is a reference level to use for susceptibility testing. Components that can withstand a 10 V/m fields and maintain their designed performance should not create any susceptibility problems when used in a communication system. The system designer can be confident that the other components in his/her system, most external radiated field sources, and most ESD strikes (that do not conduct current directly through the component itself), are not likely to affect the performance of these 10 V/m immune components in any significant manner. The HFBR-510X/520X fiber-optic transceivers are a good example of such a 10 V/m immune component.

2.2b How System design Affects Susceptibility (Immunity).

For this discussion we will concentrate only on the effects of the external electromagnetic field on the fiber-optic module circuitry although other circuitry can also be affected by an external field. The effects will vary from circuit to circuit. But this susceptibility discussion, concentrating on fiber-optic receivers, will hold true, in general, for other circuits as well.

The usual effect of an external field on a fiber-optic receiver is to degrade the received bit error rate. The fiber-optic receiver (Rx) is usually the most sensitive analog circuit in the entire communication network product. An external field can induce a signal on the antennas formed by the interconnections in the fiber-optic Rx circuitry. Antennas are bi-directional devices. The same phenomenon that causes an antenna to radiate an electromagnetic field when a voltage/current signal is applied to its inputs, will generate the same voltage/current signal at those inputs, (now really the outputs), if the same antenna is placed within an identical, but externally generated, electromagnetic field. The antenna, formed by the Rx circuit interconnections, picks up the external field and generates a signal. If the generated noise signal is conducted to a sensitive circuit node, the node then experiences a lower signal-to-noise ratio, which increases the bit error rate. (In a perfect fiber-optic Rx, the signal-to-noise ratio and the bit error rate are directly related). So the external electromagnetic field can inject noise into the fiber-optic Rx and thus degrade the bit-error rate (BER).

Obviously, the larger the field strength is, the bigger (higher gain) the antenna is, the better the coupling to the sensitive node is, and the more sensitive that node is to noise, the worse the overall susceptibility of the Rx will be. The HFBR-510X/520X fiber-optic receivers have been designed with these concepts in mind to ensure that the Rx can operate under a large electromagnetic field strength with only a negligible effect on the BER. But, at the equipment level containing many components, how can the system design affect the overall system performance (BER etc.) for a certain end-use environment known to contain electromagnetic fields of certain frequencies and field strengths?

The first thing to consider is where this external field comes from. The field could be caused by an ESD. The ESD currents flowing in the antennas formed by the chassis and/or other circuitry generate the field. The external fields could be generated by other equipment outside the chassis, but nearby, such as radio or TV transmitters. The external fields could also be caused by other circuitry inside the system chassis, if that circuitry is located nearby the fiber-optic Rx.

Fields which must pass from outside the chassis to the inside are attenuated by the chassis shielding. The shielding by the chassis, to a field external to the chassis, is the same as the shielding provided by the chassis to exiting radiation as was discussed in section 2.1b. So if the field has to pass through only one 1.2 inch (3.05 cm) hole in the chassis to get inside, then it will be attenuated by 26.4 dB at 237 MHz relative to the outside field strength. So, in this example, a 10 V/m outside field strength would be equivalent to a 0.5 V/m field strength inside the chassis. Many chassis, however, do not provide that much shielding. Also, if the circuit is very close to the hole, the shielding will be less than the 26.4 dB at 237 MHz value that is calculated, based on the assumption that the receiver is far away (in the far field) from the hole (that is, the source). In addition, the farther the component is from the hole in the shield, the lower the external field will be at the component because the field strength rolls off (at 1/r) as the distance, r, from the source increases.

As we have said earlier, ESD can generate fields. The shorter the path (from the strike contact point in the system to earth ground) that the ESD current flows through, the lower the strength of the field that the ESD strike will generate. The lower the peak ESD current is (if it can be limited somehow), the lower the field strength that will be generated. Also, if the frequency characteristics of the ESD strike can be lowered in frequency (by limiting the ESD current pulse rise and falling edges), then the strength and the frequency of the ESD generated field can be lowered. If, in addition, the ESD current does not flow inside the chassis, it will generate a larger field on the outside of the chassis than on the inside of the chassis. Thus, in the case where the ESD current flows only on the outside of the chassis, the chassis shielding will help shield the circuit inside from the ESD-generated field. Most designs try to prevent ESD current flow through the printed circuit board grounds inside the system in order to reduce both the ESD generated fields inside the chassis, and the chance of component damage due to ESD current flow.

Any noisy components near the sensitive Rx could cause problems. The fiber-optic Tx is shielded, but it is still the closest high-current circuit to the Rx. When the transmitter in a transceiver operates, it is possible that it could affect the BER of the receiver that is located next to it inside the transceiver. The Tx could conductively couple or radiatively couple noise into the Rx. The Tx-to-Rx crosstalk is defined as the change in receiver sensitivity (in dB of optical input power) with constant BER, when the transmitter is operating versus when the transmitter is off (data inputs held at constant dc levels). Agilent Technologies has tested the HFBR-510X/520X fiber-optic transceiver Tx to Rx crosstalk and found that it is negligible (it is typically 0.0 dB and easily less than 0.1 dB worst case). This result makes sense because the Rx susceptibility is practically zero, the Tx radiation level is very small, and therefore, the radiated coupling between the Tx and Rx is extremely low. Agilent Technologies has also designed the Tx and Rx to prevent crosstalk due to conducted (V_{CC} and ground) paths.

If there is a sensitive circuit in the system, precautionary steps can be taken to make it less sensitive to electromagnetic fields. One step is to add an additional shield over the sensitive circuit. Since the fiber-optic Rx in the HFBR-510X/520X already has a very good shield built in, this will not be necessary. Another step is to make sure that the Vcc and ground and I/O lines are short to prevent noise from coupling in. Agilent tests the susceptibility of the HFBR-510X/520X Rx in a test breadboard that has the typical data sheet (Reference (1) and (2)) Vcc power supply filtering circuit and also has typical input/output line lengths. So, any possible effect on the Rx due to the coupling of the field into the I/O lines or the Vcc or ground lines in a real application circuit is accounted for in the susceptibility test.

Another way to make a system more immune to external fields is to make the system respond elegantly to any noise that is picked up. Approaches such as error detection and correction hardware and/or software, or merely a request for retransmission, in case the received errors are not correctable, are possible ways to be more immune to the effects of noise. The other thing to consider is that systems can have additional guardbands for noise by using large amplitude signals. Most logic-level signals (like ECL outputs) are large enough in amplitude that the noise generated by the external field will have negligible effect on the circuit operation. Any fiber-optic Rx, if operated at optical input power levels a few dB above its sensitivity limit, can withstand more noise without degrading the BER above its specified limit, than it can if the optical input power is at the sensitivity limit.

2.3a What is ESD?

Certain non-conductive materials can either donate charge (electrons) or acquire charge when in contact with other materials. A material with a net charge can then transfer it to a conductive material either by direct contact or by inducing the opposite charge in the conductor. If this charged conductor contacts an earth ground (or any conductive body with a very large amount of stored charged available), a current will flow until that conductor's net charge becomes zero. For example, if your skin is charged from walking across the carpet on a cold dry day and you then touch a grounded or large conductor, you may see a spark as your skin discharges, and feel a tingle in your finger, as the current flows. The characteristics of the ESD current depend on the amount of charge stored and on the impedance of the circuit that discharges it (to ground).

Products are usually specified in terms of how much electrostatic discharge they can withstand without damage. Usually two types of discharging conductors are modelled. Each conductor is modelled as a capacitor (C) at a certain voltage, which implies a certain amount of stored charge, in series with a resistor (R) and an inductor in order to model the conductor DC and AC discharging impedance. The human body is modelled relatively well by a small C and a large R. The machine or metal body model is under more debate within the industry but usually has a large C and low R (and thus has a higher discharge current than the human body).

2.3b How System design Affects ESD.

As mentioned above, ESD can affect a product during its manufacturing or during its operating lifetime. Usually, during manufacturing, the various components in the equipment are less protected from ESD than when they are installed in a fully assembled system. The use of ESD reduction techniques can help minimize ESD damage to the exposed components. Workers reduce the chance and amount of ESD by wearing grounding straps on wrists, by wearing conductive smocks, by using conductive mats on surfaces, by using anti-static packaging to keep ESD off sensitive components, and by using anti-static devices or equipment that reduce the static in the air or on surfaces.

Since a system usually consists of various components and subassemblies, each with different ESD tolerance, the ESD capacity of each item in each stage of the manufacturing process must be known in order to guarantee that each item can be handled safely during the manufacturing process. If all the ESD events are controlled during manufacturing so that they lie safely within the limits of the most ESD-sensitive components, then the system can be manufactured without ESD damage.

In a finished system, ESD can still cause permanent product damage. Often, however, a more important problem is ESD disturbances to the system performance. An ESD performance disturbance could include things such as lines on a CRT display, logic getting stuck in a locked state, or a larger number of bit errors than usual. These ESD disturbances can be accounted for in the system design in order to ensure that the product's end user does not notice any drastic performance differences when an ESD event does occur.

The HFBR-510X/520X fiber-optic transceivers are shipped in a low-cost anti-static shipping tube to prevent ESD during shipping and handling. The tubes protect the transceivers until they are removed and assembled onto the PC boards. The end-use application PC boards often provide additional protection to the module from ESD after the module is soldered onto the PC board. This additional protection comes about from the terminating impedances found on most of the transceiver input and output lines on the PC board. These terminating impedances divert some of the ESD current that would otherwise flow into an unprotected module pin. Furthermore, PCB can be designed with guard rings around the edge of the board. The guard rings are connected to chassis ground when the board is installed in the system. The guard rings divert currents to the chassis-ground in the event of an ESD, thus reducing the chance of damage.

If the components are enclosed inside a conductive or static-dissipating chassis box in the end product, then ESD is more likely to go to the conductive box than to some other non-conductive component. For example, if a plastic-nose, fiber-optic module is protruding from the chassis box, then ESD is more likely to be conducted to the section of the chassis box that is near the module nose than it is to be conducted to the insulating transceiver's plastic-nose itself. If the chassis grounding is such that the ESD currents to ground flow on the chassis and do not flow inside the PCB component grounds, then ESD damage or ESD problems due to radiated fields caused by the ESD pulse will be reduced. One such scheme to keep ESD currents only on the chassis is referred to as a single-point grounding scheme because the chassis and the circuit grounds connect at only one point.

2.4a What is Conducted Noise?

The fourth EMC area is conducted noise. Ideally a conductor will carry only the desired signal. Practically, however, there is always some component of the actual signal on the conductor that is undesirable. This component is defined as noise. Conducted noise emanates from one section of the product's circuitry, and is conducted to the section of the circuitry being observed. A good example is the switching noise in the power supply line (V_{CC}) of a digital (logic gates) circuit being conducted over to a sensitive analog (amplifier) power supply line and adversely affecting the analog-circuit's performance.

There are three main components of conducted noise. First is the conducted noise generator. Second is the path that the noise takes to conduct from the generator circuit to the receiving circuit. Third is the sensitivity of the receiving circuit to this noise. So, conducted noise problems could be eliminated by eliminating the noise source, removing the conductive path, or by using circuitry that is insensitive to the effects of conductive noise.

Since an actual fiber-optic communication network has many different types of circuitry, all operating at once, it is important that potential conducted noise problems be minimized to allow all the circuitry to operate without any section of it being adversely affected. In addition, most computing products have limits on how much conducted noise they are allowed to generate on the 120 Vac power lines to prevent them from disturbing other devices connected to the same ac power line. Since this ac power-line-conducted noise problem is determined more by the overall product's power supply circuitry and filtering and is not very much affected by the fiber-optic transceiver that might be operating in the product, the ac power line conducted noise will not be discussed in this application note. Agilent Technologies has taken steps in the design to minimize the noise that is generated by the HFBR-510X/520X modules. Therefore the probability of any possible disturbance from these modules on the ac power line has also been minimized.

2.4b How System design Affects Conducted Noise.

Conducted noise can be generated by switching power supplies, digital logic gates, lightning transients, and other noise on the ac power lines. Usually the low-frequency noise is handled by filters and transient absorbers in the power supply. Switching power supplies can be designed to have as low a noise output as is possible. Digital logic gate noise can be reduced by having good decoupling capacitors with short lead lengths between Vcc and ground near the logic gates. Vcc and ground planes in a multilayer printed circuit board reduce the Vcc and ground effective lead lengths and thus reduce the amount of Vcc and ground noise.

Sensitive circuits can have additional power supply filtering circuits that reduce the noise before it gets to the sensitive circuit. Depending on the noise frequencies, different values of filter capacitance can be tried to eliminate the noise frequency over a wide bandwidth. Usually, for a group of ICs on a PC board, some 0.1 μF and 10 μF V_{CC} filtering capacitors will help reduce Vcc noise over a reasonably wide bandwidth. For low frequencies, some resistance in the power supply line, plus a large capacitance, low frequency bypass capacitor can act as an effective low-pass power supply filter. Inductors and ferrites can also be used in power supply filters to add additional filtering if needed.

Some digital logic families generate more noise than others. Within a given logic gate family, usually the faster the logic gate, the more noise it will generate. Logic families with totem pole outputs, such as TTL and CMOS, can draw large spikes of Vcc current during switching, thus creating Vcc noise. There are newer families of CMOS available that have been designed to be quieter. ECL is designed with differential current sources that tend to maintain a more constant power supply current during switching. The HFBR-510X/520X fiber-optic transceiver uses extensively differential current switches and ECL output stages, similar to those used in the ECL family. Thus the HFBR-510X/520X fiber-optic transceiver generates low amounts of Vcc noise due to its almost "dc" power supply current.

Besides filtering and reducing the noise sources, sometimes problems can occur from shared V_{CC}s or grounds. If a sensitive circuit is upstream from a digital logic gate generating V_{CC} noise, its power supply voltage will bounce when the digital logic gate switches and draws current. If the sensitive circuit has its own separate V_{CC} or ground line or plane it won't detect this noise due to the other digital logic gate. But, if two circuits need to talk to each other, often their V_{CC}s and grounds should be common so that there are no noise differences in V_{CC} or ground between the two circuits that can act as equivalent noise sources.

An additional approach is to try circuits that are not too sensitive to V_{CC} or ground noise. Digital logic gates are a good example of this because they have a good deal of noise margin. Therefore, they can tolerate a fair amount of noise before it causes them to misread a logic state. Differential outputs also help because the follow-on logic switches when the two data outputs cross. This crossing point is first-order independent of V_{CC} and ground noise. Differential outputs reject noise better than single-ended outputs do because the V_{CC} and ground noise is effectively reduced. The V_{CC} and ground noise is common to both of the differential digital outputs. Therefore, when the two outputs are subtracted from each other, to find the differential output voltage that determines the output logic state, the common-mode noise on each output, to first order, is canceled out. Hence, the common-mode Vcc and ground noise does not appear in the final differential output signal. Analog circuits can be designed to reject noise by adding filters and by trying to use differential signal techniques where possible.

3.0 Summary of HFBR-510X/520X Component Level EMC Performance

The results show that the EMC performance of the HFBR-510X/520X is excellent and should therefore make the customer's EMC design easier.

A. The module typically passes worldwide emissions limits for class B by more than 10 dB. Therefore, one unit in a computer system will not cause the system to fail radiated emissions to the worldwide B test limits no matter how poor the shielding is.

B. The susceptibility is basically zero for 10 V/m fields. Because of the module's high immunity, the customers need not worry about the effects of nearby circuits on the receiver (Rx). Fields external to the system are also not an issue. Only very large ESDs could generate a 10 V/m field, so the concern about ESDs causing bit-error rate problems is minimized.

C. The module is a Class 1 ESD component and so should be handled in a Class 1 ESD environment. It withstood 1800 volts and therefore missed the Class 2 classification limit by only 200 volts. Using the machine model EIAJ test it withstood 100 volts. When the transceiver is installed in the application circuit, it can withstand a 25 kV zap to anywhere on the module without permanent damage.

D. In a real application circuit, 50 mVp-p of V_{CC} noise should cause no more than a 0.3-dB sensitivity penalty, no matter what the V_{CC} noise frequency is. Most V_{CC} noise frequencies will cause zero penalty.

E. The transmitter (Tx) to receiver (Rx) crosstalk is also basically zero. Thus the Tx in the transceiver can operate with any data pattern and not disturb the BER of its neighboring receiver under any conditions.

4.0 HFBR-510X/520X Component-Level EMC Testing

The electronics industry EMC standards are often not defined and are sometimes non-existent at the component level. Most EMC specifications apply to system-level products only. Therefore, Agilent Technologies has tried to generate its own component-level EMC specifications. A good component level EMC specification must accomplish two goals. First, the specification must be relatively easy to measure, and the measurement must be repeatable and accurate. Second, the component performance measured must have a clear relationship to the performance of the component, and its consequent effect on the overall finished-product performance, when that component is used as intended in the finished product. Since the actual end-usage EMC performance is determined by many factors in the overall system, the usual approach is to use some conceivable worst-case condition to determine the component-level EMC test conditions. Then either guarantee that the component will never experience such a worst-case condition in the end environment or use that worst case plus known facts about how the actual end environment differs from the worst case to predict the actual system performance.

4.1a Radiated Emissions Testing Procedure

The HFBR-510X/520X fiber-optic modules under test were placed in an electrical-loopback test breadboard and were tested to find their radiated emission spectrum using the FCC certified semi-anechoic test chamber at Agilent Technologies' Cupertino site (CA). This test chamber is used by various Agilent divisions to test their products to FCC and other emissions limits. The tests are mostly automated and are conducted by qualified personnel.

For the FCC Class-B tests, the test antenna was placed at a 3-meter test distance from the module. For the FCC Class-A, CISPR 22, VCCI, or EN 55022 tests, the test antenna was placed at a 10-meter test distance from the module. The worst-case peak field strength radiated emissions were found by moving the antenna up and down from 0.1 to 4 meters in height, by changing from vertical to horizontal antenna polarizations, and by rotating, in 45-degree increments, the turntable on which the module was placed. The entire radiated emissions frequency range, as determined by the particular test antenna in use, was observed during these tests so that the worst-case peak at each frequency could be found. The antenna and test system calibration factors were then used to derive the peak radiated electrical field strength being emitted, at each frequency, from that module at that test distance. Each radiation frequency was then quasi-peaked for those frequencies below 1 GHz.

These final worst-case field strengths were then compared to the relevant specification limit. The worst-case margin to the specification limit is the smallest difference between a worst-case final radiation level and the specification limit, over the entire specified frequency range. Note that because both the radiation levels and the limits vary with frequency, the highest radiation level will not necessarily give the worst-case margin. A log periodic antenna is used from 200 to 1000 MHz. A biconical antenna is used from 30 to 250 MHz. Above 1 GHz a horn antenna is used. Note that the FCC and other regulatory agencies do not regulate radiated emissions below 30 MHz.

A standard HFBR-510X/520X transceiver module outside the test chamber provided a 125 Mbaud or 155 Mbaud 1010 pattern optical signal. This optical signal was used to drive the Rx of the HFBR-510X/520X transceiver module in the loopback test breadboard inside the test chamber. The loopback test board uses the power supply decoupling circuit recommended in the data sheet . The Rx drives the Tx using a 2.7 inch (6.86 cm) long connection between the Tx and Rx *data* and *data* * pins. (The actual Rx to Tx lines go 1 inch (2.54 cm) up and back, and go 0.7 inch (1.78 cm) across.) This connection length was believed to reflect the approximate length of a connection, from the Rx to a PHY circuit, and then back from the PHY circuit to the Tx, in a real application printed circuit board. The 50 ohm to V_{CC}-2 Volt equivalent (split load) terminations were placed at the Tx inputs. The board has a 2.5 by 2.9 inch (6.35x7.37 cm) ground plane with through-hole components and hand wiring. Coaxial cable with ferrites (plus a coiled section) brings in dc power. The shield of this dc power supply cable keeps any radiation from adding to the test result. Thus, any radiation seen in this test is due exclusively to the fiber-optic transceiver module and to any interaction it might have with the test board.

The final margin to the FCC and other regulatory agencies specification below 1 GHz was obtained by quasi-peaking each emission peak at each frequency according to the FCC requirements. Quasi-peaking allows devices such as printers, which put out radiation only in short bursts (when a print head turns on), a break by averaging the radiation energy over a specified period of time. For a fiber-optic module with a 1010 pattern that puts out continuous radiated energy, quasi-peaking drops the peak radiation level by a small fixed amount. Since quasi-peak testing takes more time, only the worst radiation peaks are quasi-peaked. Some of the lower-level radiation data is approximated to an equivalent final quasi-peak result from the peak result by taking the actual peak emission result and subtracting a fixed 1.5 dB value to get an approximate final quasi-peak result. Above 1 GHz, no quasi peak detectors exist. Therefore, the FCC B test above 1 GHz uses the peak radiation value directly and adjusts its specification limit accordingly. The radiation frequencies seen for this test consist of harmonics of the fundamental frequency of the 1010 data pattern. The fundamental frequency of a 1010 pattern is equal to one-half the data rate. Thus the 125 Mbaud radiation test has radiation frequencies that occur in integer multiples of 62.5 MHz.

The worst-case quasi-peak radiated field strengths for each frequency are compared with the FCC and other regulatory agencies specified limits. These test limits vary with frequency. The margin (positive if pass, negative if fail) by which the final worst-case, quasi-peaked if necessary, field strength passes the test specification is the test margin of the component to the FCC and other regulatory agencies limit at that frequency. The final overall FCC and other regulatory agencies test margin for that component is the worst-case (smallest) margin, over the entire specified frequency range. It is this final test margin that is used by the FCC and other regulatory agencies to determine whether the product passes the specification or not. So the final FCC and other regulatory agencies test margin is the worst-case (quasi-peaked below 1 GHz) margin of the detected field strength to the limit for any radiation frequency in the specified range, any module orientation, any antenna height and any antenna orientation.

Use of a calibrated semi-anechoic chamber ensures results that can be used directly to determine FCC qualification. Problems due to resonances in TEM cells are eliminated. (A resonance can give large radiation test errors by amplifying the radiation at the resonant frequency.) Since the test facility is automated, we can test modules and conduct experiments relatively quickly. We have also tested modules inside a simulated metal chassis box and have verified that our plastic nose modules do indeed get close to the theoretical shielding limit predicted from the size of the hole in the shield.

Agilent Technologies radiated emissions tests are designed to be as close to real life as is possible, so that the results can be correlated to final customer results. An attempt was made to design a test board that realistically mimics a typical best-case customer layout. Agilent would like the results of the radiated emission tests to be such that even if a customer provides no shielding, one of the Agilent HFBR-510X/520X transceiver modules will not cause the customer to have typically less than 6 dB margin to any of the worldwide B limits. Most customers want their system to pass worldwide B by 6 dB. Agilent's goal was therefore to pass FCC B by 10 dB. Since CISPR 22B, EN 55022, and VCCI Class 2 Europe and Japan B limits are roughly 3 dB tougher for our fiber-optic modules to meet than FCC B is, meeting FCC B by 10 dB ensures 7 dB to worldwide B.

In an actual system, the chassis shielding will often greatly reduce emission. So, in a well-shielded system, many modules could be used (in a FDDI concentrator or ATM switch, for example). If we get 21 dB of shielding at 437.5 MHz from a 1.2 inch (3.05 cm) duplex SC hole in a chassis, then we have 21 dB more margin to work with. In a concentrator, if all the modules' energy were in phase and therefore directly added together, 21 dB would be enough for n modules, where n is found from:
Or perhaps the energy is not correlated; in which case, even more modules could be used.

We have never tested a concentrator or switch so we do not know exactly how the radiation from all the modules in a concentrator would add up. If any of our customers have insight in this area that they would like to share with us, our applications department would be most interested. We have seen FDDI concentrators with many MIC connector modules. These concentrators have supposedly passed FCC classification for office equipment (Class B) and therefore the previous analysis may be too conservative. No matter what the real limit on the number of units in concentrators is, we feel that we have done our best to ensure that our radiation is as low as possible to ensure that the largest number of modules can be used in concentrator or switch applications. Very large concentrators can, if necessary, add additional shielding, by the use of vanity covers etc. to lower their radiation. A 1010 pattern is the worst-case data pattern for radiated emissions. A psudo-random bit sequence (PRBS) or varying pulse-width data pattern tends to spread out the energy and lower the radiated emissions. We use a 1010 pattern to be conservative and because a 1010 is an FDDI IDLE pattern which could be sent rather frequently in a real FDDI system.

$$21 = 20\log_{10}\sqrt{n} + 20\log_{10} n$$

$$= 30\log_{10} n$$

This formula is derived from the shielding formula for multiple holes in a chassis plus the increase in radiation for multiple modules adding in phase. An equivalent way of expressing this formula is:

$$n = 10^{(21/30)} = 5$$

If the modules' phase is uncorrected due to each concentrator having its own clock source, then perhaps the modules radiation would r.m.s add. In this case we would have:

$$21 = 20\log_{10}\sqrt{n} + 20\log_{10}\sqrt{n}$$

$$= 20\log_{10} n$$

$$n = 10(21/20) = 11$$

4.1b Radiated Emissions Testing Results

The following results show that the typical 820 nm and 1300 nm HFBR-510X/520X transceivers pass all the worldwide B limits by better than 10 dB margin below 1 GHz. Above 1 GHz, a test board ground plane resonance causes the unit to pass FCC B by 7 dB above 1 GHz. Thus, one unit will not cause a computer system to have less than 6 dB margin to any worldwide B-radiated emissions test limit, even if no shielding is provided by the customer chassis. (Remember that the FCC radiated emissions specification is currently the only one that requires testing above 1 GHz.) The final emissions data is quasi peaked below 1 GHz and is just the peak data above 1 GHz. Table 1 shows a summary of the radiated emissions results. NA means that actual test data was not available. Based on other data, however, the NA results have been approximated and those estimates are listed in parenthesis with an approximate sign.

Figure 1 shows the final emissions data for the HFBR-5103/5105/5204/5205 1300 nm transceiver relative to FCC B limits at 125 Mbaud. Figure 2 shows the final emissions data for the HFBR-5103/5105/5204/5205 1300 nm transceiver relative to FCC B limits at 155 Mbaud. Figure 3 shows the final emissions data for the HFBR-5103/5105/5204/5205 1300 nm transceiver relative to the rest of world B (CISPR 22B, EN55022, VCCI Class 2) limits at 125 Mbaud. Figure 4 shows the final emissions data for the HFBR-5103/5105/5204/5205 1300 nm transceiver relative to the rest of world B (CISPR 22B, EN55022, VCCI Class 2) limits at 155 Mbaud. Figure 5 shows the final emissions data for the HFBR-5104/5203 820 nm transceiver relative to FCC B limits at 125 Mbaud. Figure 6 shows the final emissions data for the HFBR-5104/5203 820 nm transceiver relative to FCC B limits at 155 Mbaud. The bars on the plots in these figures show the tested final (quasi peak below 1 GHz) radiated field strength. The squiggly lines on the plots show the test system noise floor. The test limit is shown as a solid line labeled with the test limit name.

The radiation is usually a little worse at 155 Mbaud than 125 Mbaud. This is because there is more high-frequency energy existing in (the fourier spectrum of) the higher data rate signal. Also, sometimes, a 155 Mbaud harmonic will be closer to a resonant frequency than a 125 Mbaud harmonic will be and this can cause the radiation to increase. The 155 Mbaud radiation peak at 232.5 MHz is just past the frequency where the FCC B and other limits suddenly increase. (FCC B increases 2.5 dB at 216 MHz and CISPR 22B, EN55022, and VCCI Class 2 go up 7 dB at 230 MHz.) Below 1 GHz, the 820 nm unit is slightly worse than the 1300 nm unit by 1.3 to 1.8 dB. This increase in the 820 nm module radiation is due to a known design difference in the 820 nm modules versus the 1300 nm modules. This difference is still small enough to allow any wavelength HFBR-510X/520X transceiver module to still meet the data sheet claim of typically passing worldwide B limits by 10 dB margin.

Above 1 GHz, the radiation drastically increases. This is due to a ground plane resonance effect on the Agilent test board. The board has a 2.5 by 2.9 inch (6.35x7.37 cm) ground plane with through-hole wiring. Energy from the module, probably conducted through the Vcc and ground connections, excites the ground plane as an electric (dipole/monopole) antenna. Since the ground plane is acting as a resonant antenna, the actual

Table 1: HFBR-510X/520X Radiated Emissions Test Result Summary

Optical Wavelength	Data Rate Mbaud	Worst case margin to FCC B (below 1 GHz)	Worst case margin to FCC A (below 1 GHz)	Worst case margin to World B (CISPR 22 B, VCCI 2, EN55022B Below 1 GHz)	Worst case margin to FCC B (above 1 GHz)	Frequency in MHz where worst case margin to below 1 GHz FCC B limit occurred
1300 nm	125	16.7	27.2	13.7	7.8	187.5
1300 nm	155	14.4	23.1	13.6	7.3	232.5
820 nm	125	14.9	NA (~25.4)	NA (~11.9)	NA (~7.8)	187.5
820 nm	155	13.1	NA (~21.8)	NA (~12.3)	NA (~7.3)	232.5

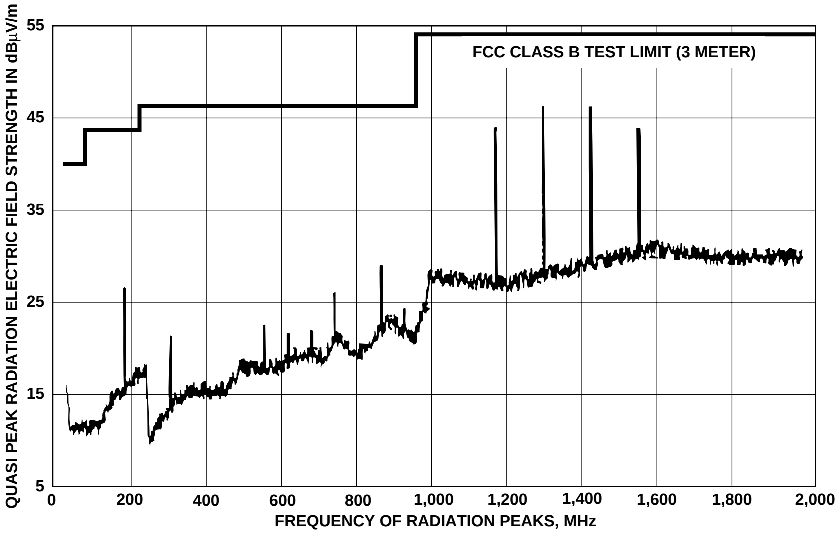

Figure 1. HFBR-510X/520X 1300 nm radiated emissions at 125 Mbaud to FCC B limits.

amount of energy exciting it has only a small effect on the amount of the radiation. The frequency of the radiation peak is right around 1.3 to 1.4 GHz and a quarter wavelength at those frequencies is 2.3 to 2.5 inches (5.84 to 6.35 cm). This is just the size of the test board ground plane. Therefore, the ground plane is acting as a one-quarter wavelength resonant antenna. We have tried experiments in which we changed the size of the test board ground plane, and found that the resonant frequency of the radiation changes just as we would have expected, based on the ground plane size differences. We have also tried various fiber-optic modules in the test board and have measured their radiation above 1 GHz. The results are almost the same no matter what module is being tested. So, any fiber-optic module seems to be able to excite the ground plane resonance. And once the ground plane resonates, it dominates the overall radiation. We are planning additional experiments to make observations regarding this ground plane resonance issue. Our applications and R&D department is interested in any customer experiences that may help us understand how this ground plane resonance phenomenon affects our customer's radiated emissions.

How would it affect our customer's radiated emissions? We have tested a customer's multilayer FDDI PCB. It reduced the radiation above 1 GHz by 3.5 dB but it increased the radiation below 1 GHz (in the 750 MHz area) by 5 dB. Thus, for the 1300 nm module tested at 125 Mbaud, the worst-case margin to FCC B was 12.1 dB (at 750 MHz) below 1 GHz and 11.4 dB above 1 GHz. Even with this different test board, we still pass worldwide B by 9 dB. The multilayer PCB helped the radiation above 1 GHz, but the larger PCB size (6" vs 3") caused the ground plane resonance to occur at 750 MHz. Our HFBR-510X/520X modules have low enough radiation levels so that we can see this ground plane resonance occur without having this phenomenon masked by some other radiation source. Figure 7 shows the final emissions data for

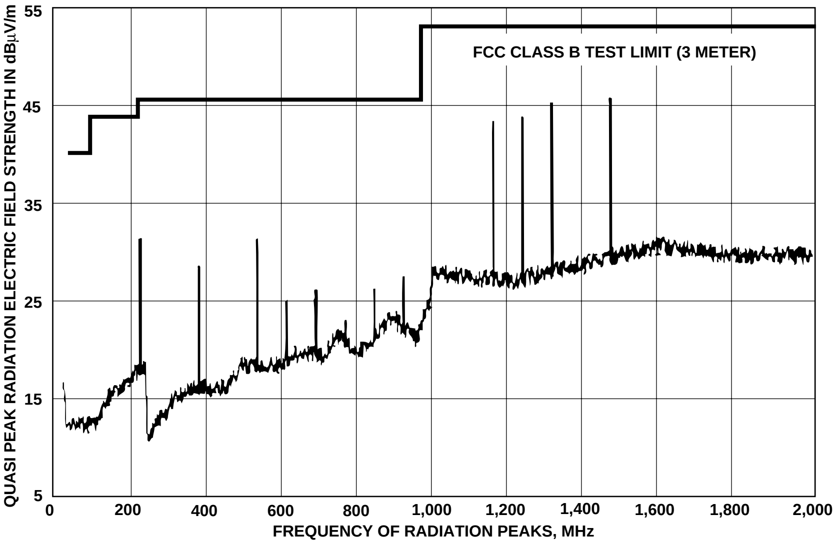

Figure 2. HFBR-510X/520X 1300 nm radiated emissions at 155 Mbaud to FCC B limits.

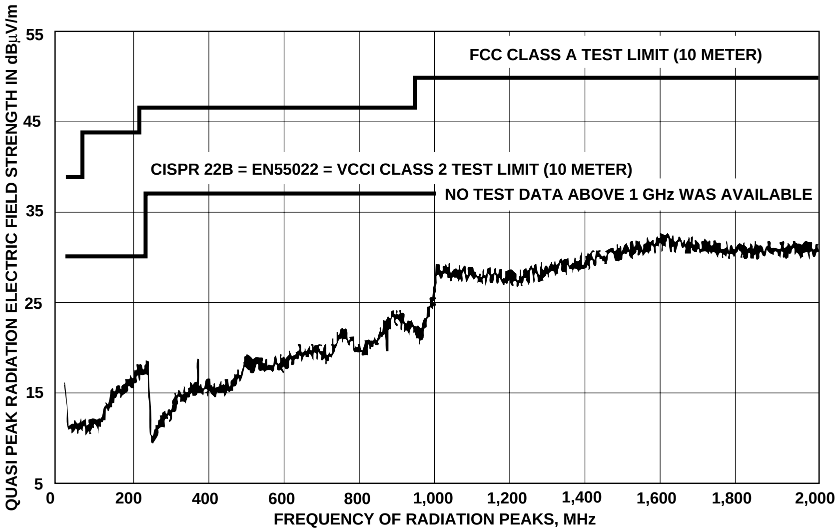

Figure 3. HFBR-510X/520X 1300 nm radiated emissions at 125 Mbaud to 10 meter test limits, (FCC A, CISPR 22B, EN55022, VCCI class 2).

the HFBR-5103/5105/5204/5205 1300 nm transceiver relative to FCC B limits at 125 Mbaud using this 3x6" customer multilayer FDDI PCB. More experiments need to be done to further understand this problem and how it affects our customers.

The typical customer PC board is inserted into a backplane in a chassis. Therefore the ground antenna structure, formed by the entire computer system ground network, could by itself be effectively much bigger than the board ground plane. Therefore, any resonances that may occur would be at a much lower frequency than the frequency calculated from the board size alone. If the frequency is low, the resonance may not occur at all, may occur at frequencies that do not radiate efficiently, or may occur below the 30-MHz lower-frequency limit for the radiated emissions test. So, most systems will be safe from a ground plane resonance effect (ground plane resonance could be excited by other ECL or other circuitry in the system, in addition to the excitement provided by our module. We therefore, have decided to hold to our standard test board results and those results are quoted in this report.

4.2a Susceptibility (Immunity) Testing Procedure

To measure the susceptibility, an external field must be generated and the link BER must be measured. A field can be generated by an antenna in a semi-anechoic chamber but this test is slow and cumbersome. We use a TEM cell. The TEM cell is situated in our R&D lab, close to all the BER measuring equipment. An automated test program measures the BER and sets up the correct field strength and frequency inside the TEM cell. The TEM cell is a large rectangular metal cell that can be thought of as an expanded coaxial waveguide. The voltage measured at the output of the cell corresponds to a certain electromagnetic field strength inside the cell. A module and test board can be placed inside the cell between the center and the outer cell conducting planes. As long as the module and the test board are not too large, the cell will still generate a TEM wave and the cell will still maintain its calibrated field strength to output voltage correlation. Our cell is specified to 450 MHz, which is adequate for our susceptibility test because we see zero susceptibility penalty above 350 MHz for any of our HFBR-510X/520X transceivers. Above 450 MHz, the TEM cell can resonate (i.e. standing electromagnetic waves can form). Thus it cannot be used to test for radiation. Therefore we use the semi-anechoic chamber for radiation testing.

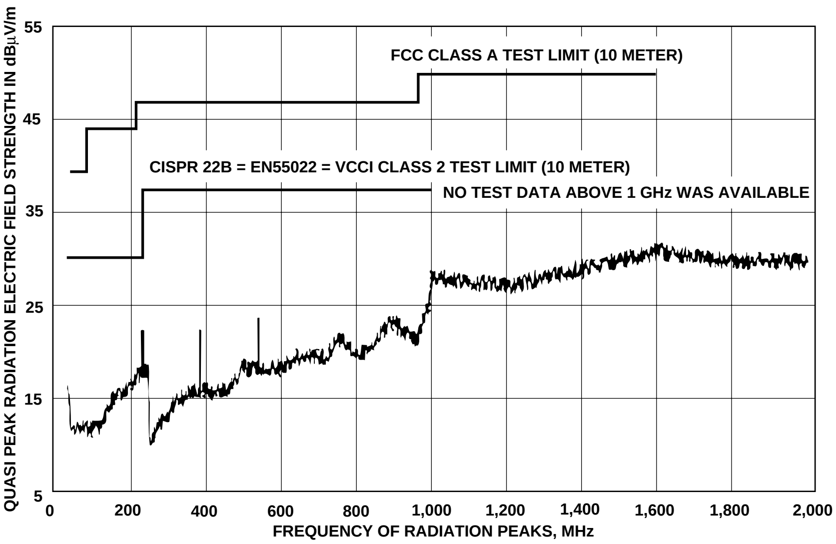

Figure 4. HFBR-510X/520X 1300 nm radiated emissions at 155 Mbaud to 10 meter test limits, (FCC A, CISPR 22B, EN55022, VCCI class 2).

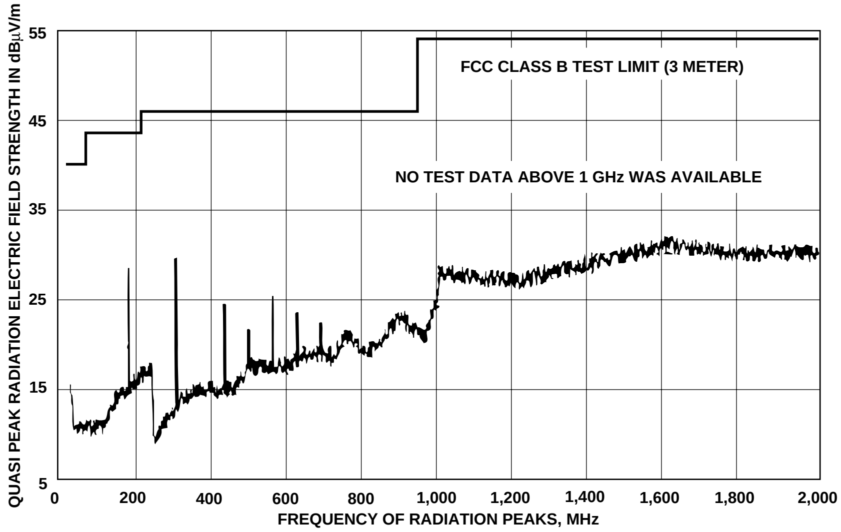

Figure 5. HFBR-5104/5203 820 nm radiated emissions at 125 Mbaud to FCC B limits.

A sine wave generator and a RF amplifier provide the TEM cell input drive voltage. A spectrum analyzer detects the output power from which the electric field strength can be derived. Sine wave generators from 10 MHz to 450 MHz are used to see how the susceptibility varies over frequency. A pure, unmodulated sine wave is used. Modulating the field, as is sometimes used in some product susceptibility tests, does not make sense for our fiber-optic receivers. The fact that the entire susceptibility test is automated allows us to quickly measure the susceptibility of any fiber-optic module.

The BER pattern generator drives a HFBR-510X/520X transmitter that is located outside the TEM cell. This transmitter optically drives (via a fiber-optic cable) a HFBR-510X/520X receiver inside the TEM cell. The transceiver Rx inside the cell drives its neighboring Tx via the electrical Rx to Tx data line loopback connection on the test board. The Tx inside the cell drives (via another fiber-optic cable) a HFBR-510X/520X receiver outside the TEM cell whose outputs are connected to the BER detector input. Thus a link consisting of two transceivers is bit error-rate tested.

The TEM cell test uses the same loopback test breadboard that is used in the radiation test. The loopback board dc power is brought in via a coaxial Vcc cable. The coaxial Vcc cable has a coiled section plus ferrites to prevent noise pickup on the Vcc cable. The coaxial Vcc cable is a large antenna. It is important to prevent it from picking up noise and injecting that noise into the transceiver power supply because we want to measure the susceptibility of the module and not its Vcc noise rejection. Thus, the susceptibility test measures only the effects of the external field on the module in its application test board and therefore includes any possible coupling or interactions between the module and its application test board.

The overall sensitivity in the susceptibility test, derived from the two fiber-optic transceivers in the link, is determined by the errors produced by the loopback board Rx which, using an optical attenuator, is run near the sensitivity optical input power level. There are no errors produced by the regular breadboard Rx outside the TEM cell because it runs at high optical input power levels due to the short fiber directly connecting the inside cell Tx to the outside Rx.

The $1*10^{(-6)}$ bit error rate (BER) sensitivity at the left eye edge for a $2^{(7)}$-1 PRBS pattern is measured in exactly the same fashion as is described in the conducted noise tests. The sensitivity is first measured with no field present in the TEM cell. Then a field is

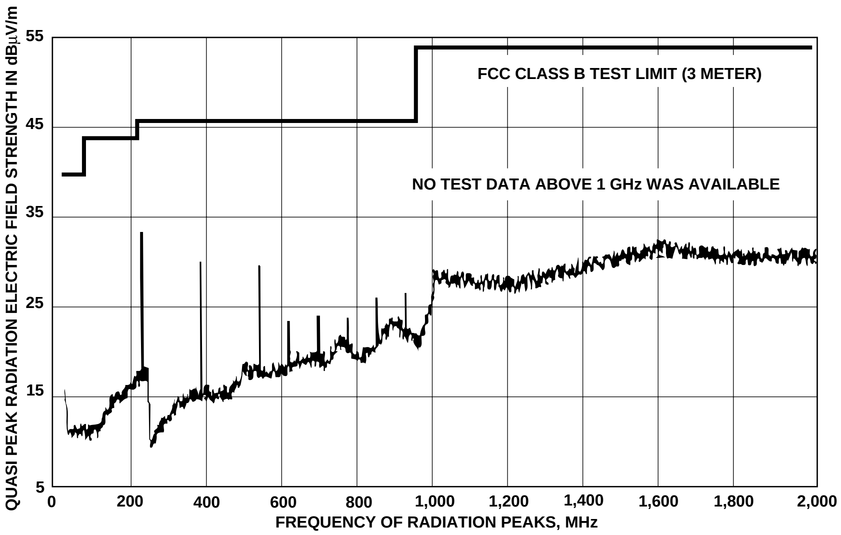

Figure 6. HFBR-5104/5203 820 nm radiated emissions at 155 Mbaud to FCC B limits.

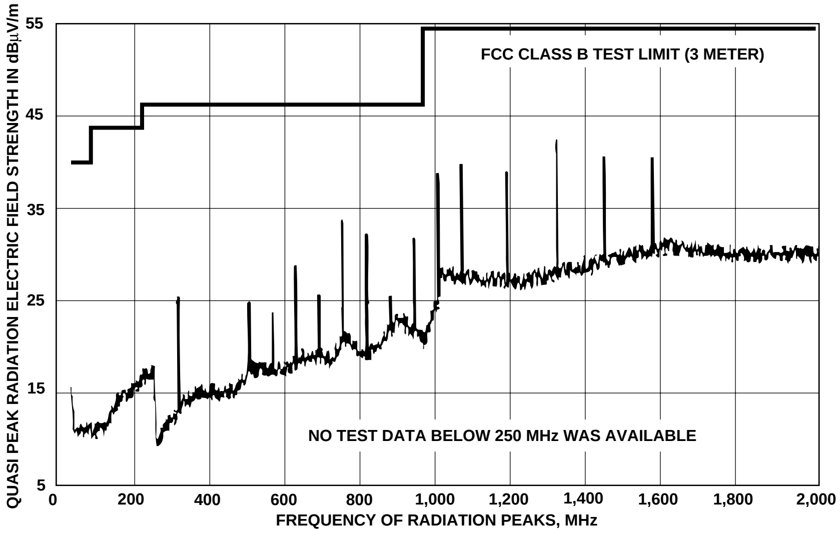

Figure 7. HFBR-510X/520X 1300 nm radiated emissions at 125 Mbaud to FCC B limits using customer 3 x 6 inch multilayer FDDI PCB.

applied and the sensitivity is remeasured. The optical dB change in the left eye edge with $2^{(7)}$ - 1 PRBS pattern and $1*10^{(-6)}$ BER sensitivity, from adding an electric field of a known field strength and frequency, is equal to the susceptibility penalty at that field strength and frequency. The susceptibility penalty is therefore calculated by subtracting the sensitivity with the field present from the sensitivity with no field present. 10 V/m is the usual field strength to use in susceptibility tests. We also measure the susceptibility at 3 V/m and 20 V/m in to see how the susceptibility varies over field strength.

4.2b Susceptibility (Immunity) Testing Results

Figure 8 shows the susceptibility results for a 1300 nm HFBR-510X/520X transceiver for 10.33 and 20.37 V/m field strengths. The 10 V/m worst-case susceptibility is 0.05 dB, which is practically zero. You can see a slightly bigger penalty of 0.13 dB at 20.37 V/m which tells you that the test is indeed working. The 3.27 V/m susceptibility test shows less penalty than does the 10.33 V/m test. The 3 V/m test result was not printed because the plot was too difficult to read. The data was taken at 125 Mbaud for a 1300 nm transceiver. The results do not change at 155 Mbaud and are not dependent on data rate. The 820 nm HFBR-5104/5203 transceiver susceptibility data was taken at 155 Mbaud. The 820 nm susceptibility is just as good as the 1300 nm susceptibility. The actual data plot is not included in this report because the result is slightly better than the 1300 nm result, but is, at the same time, within the measurement noise of the 1300 nm result. Both the 820 nm and 1300 nm module susceptibility results are so good that measurement noise dominates in some of the plotted data. (Maximum measurement noise for the susceptibility test is roughly 0.05 dB.)

The negligible penalties to the sensitivity for a 10-V/m external electromagnetic field give us confidence that most applications will see no performance degradation in the fiber-optic link due to other nearby circuitry or to external EMI sources (such as radio transmitters) that are located outside the system chassis. Only an extremely large ESD has even a chance of creating a large enough field that could cause a noticeable, but even then probably very small, disturbance in the HFBR-510X/520X fiber-optic link.

4.3a ESD Testing Procedure

The ESD component level tests are the most standardized of any of the component level EMC tests. Many

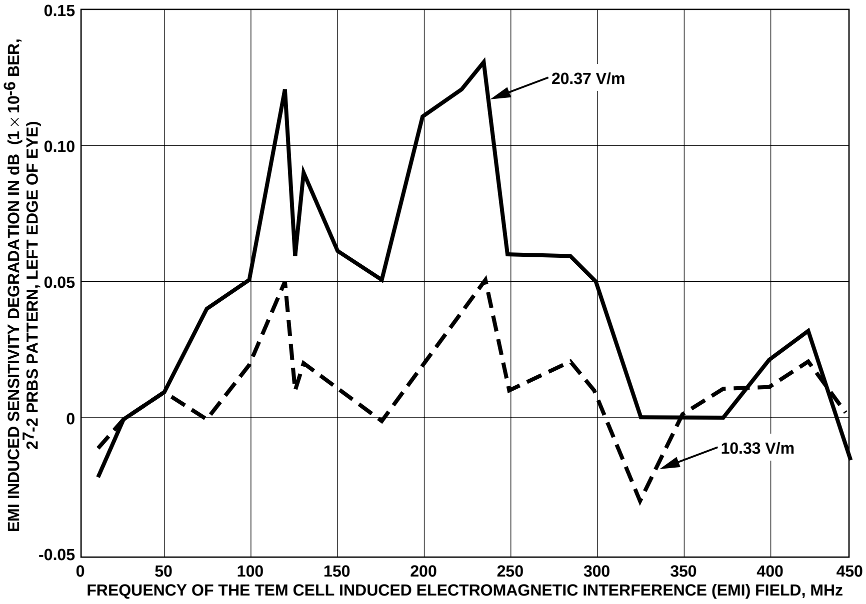

Figure 8. HFBR-510X/520X 1300 nm susceptibility for ≈ 10 and ≈ 20 V/m fields. 820 nm HFBR-5104/5203 susceptibility plots are not included here, but are as good or better than 1300 nm to within measurement noise (max noise ≈ 0.05dB).

industry standard ESD tests were developed for integrated circuits (ICs) such as CMOS and TTL gates. One such standard is the MIL-STD-883D Method 3015.7 (see Reference (5)). It classifies components into categories based on how much ESD voltage they can withstand. A human body model ESD test circuit consisting of R = 1500 ohms and C = 75 pF is charged up to a certain voltage and is then directly discharged to various combinations of the component pins. Five discharges to the pins are made. Next the module is tested for permanent performance degradation. The largest voltage at which no permanent performance degradation is found is the ESD withstand voltage. The ESD withstand voltage is then used to determine the ESD class of the component per the table in the MIL-STD-883D Method 3015.7 specification. In the HFBR-510X/520X module the data input and output pins are the most sensitive to ESD. These pins are therefore internally protected by ESD protection devices.

There is also a Japanese variation of the MIL-STD test which models a machine body model electrostatic discharge. The test is essentially similar to the MIL-STD specification, but applies the discharge between each pin and ground. The ESD test circuit resistance, R, is zero ohms and the capacitance, C, is 200 pF. The low resistance models the low resistance of a metal body. The specification is called EIAJ#1988.3.2B Version.2. Machine Model.

Another ESD specification is based on the IEC 801-2 standard (see Reference (6)). This is actually a box-level ESD test and specifies that the box product will not be "damaged" by an ESD that contacts it anywhere on the exposed outside areas of the product. Exactly what is meant by damage is left to the manufacturer and to the customer to decide. We have defined "damage" as permanent product performance degradation. A temporary increase in BER during an ESD does not count as damage for this test. Our susceptibility test, however, guarantees good BER performance as long as the ESD does not cause an electrostatic discharge current to flow directly through the component and does not produce electromagnetic fields above 10 V/m in strength. In any case, as soon as the ESD is over, the fiber-optic module immediately returns to normal operation.

The module was zapped on its exterior surface with an electrostatic discharge simulator wand (zap). At first we zapped only the nose section (where the SC connectors are attached, about the first 0.5 inch (1.27 cm) or so). We discharged to the top, bottom, left, right and front of the module nose. Since this did not cause any permanent performance degradation at 25 kV, which was the limit of our test equipment, we tried discharging to any point on the top, left, right or front of the module. We used a EDS-200 Electrostatic Discharge Simulator Wand. The wand simulates the human body and has a capacitance of 300 pF and a resistance of 150 ohms. The module was self oscillating in an electrical and optical loopback board. The status detect output drove an LED which indicated whether the link was up or not. After each set of ESD, the module was placed on the manufacturing tester to check for any module performance degradation.

4.3b ESD Testing Results

The HFBR-510X/520X modules

sustained no damage with 5 discharges at 1800 Volts, using the MIL-STD human body model test circuit to simulate an electrostatic discharge that goes directly to the 1x9 module pins. Above 1800 volts some permanent module damage did occur. This test was done according to MIL-STD-883D Method 3015.7 using a 1.5 k ohm resistor and 100 pF capacitor human body model. Therefore, according to MIL-STD-883D Method 3015.7, this is a Class 1 device and appropriate Class 1 ESD precautions during handling should be taken. During assembly ESD wrist straps and other industry-standard ESD reduction techniques should be used to ensure an ESD environment that is safe for Class 1 device handling. The HFBR-510X/520X fiber-optic transceivers are therefore shipped in a low-cost anti-static shipping tube to prevent ESDs during shipping and handling. The module did pass at 1800 volts however, and this is only 200 volts away from the Class 2 MIL-STD ESD classification of 2000 volts. Therefore the HFBR-510X/520X transceiver may not be as sensitive to ESD damage as most MIL-STD Class 1 rated components.

The Japanese EIAJ#1988.3.2B Version.2 Machine Model ESD test showed that our module could withstand a 100 Volt level.

Once the module is installed in its application board, it can withstand more ESD energy. The 25 kV zap test had no problems. There was no permanent ESD damage to the module, when in its application circuit, no matter where the zap occurred on the module surface. In the loopback board test setup, the link monitor light might blink briefly during the ESD zap, implying a momentary bit error rate burst, but the light immediately came back on once the discharge ended. Thus, the ESD to the module could produce some bit errors but the module recovers completely once the discharge ends (in a few millisecond). Therefore a 25 kV discharge directly to a HFBR-510X/520X transceiver module installed in a computer system will cause no permanent damage and worst case could cause only some bit errors. Keeping in mind the modules' good susceptibility results, provides confidence that those bit errors will be the absolute minimum possible for a fiber-optic module of this type. If good ESD design is used in the computer system, it is probable that only a very large ESD would make even a noticeable difference in the fiber-optic link performance.

4.4a Conducted Noise Testing Procedure

A known amount of noise is coupled onto the fiber-optic test circuit V_{CC}. The degradation in the receiver sensitivity due to this noise is then measured. Sinusoidal noise signals of different frequencies are used to check how the sensitivity degradation varies over noise frequency. 50 mV peak-to-peak (p-p) of sinusoidal noise is applied via an ac coupling bias tee to a 1-ohm resistor, which is directly connected to the Rx test board V_{CC} connection. The peak-to-peak noise level is measured at the 1-ohm resistor on the side away from the module Vcc connection. The $1x10^{(-6)}$ bit error rate (BER) sensitivity at the left eye edge for a $2^{(7)}$ - 1 PRBS pattern * is measured with no V_{CC} noise present and with 50 mV p-p of V_{CC} noise present. The difference in sensitivity is the V_{CC} noise sensitivity penalty. This value is recorded.

The noise sensitivity penalty is first tested with no external Vcc filter present on the test breadboard. This tells us how well the module's internal V_{CC} decoupling network can reject noise on its own. Then a portion of the recommended data sheet power supply filter is added in. (See Figure 11 of the HFBR-5100 data sheet or Figure 7 of the HFBR-5200 data sheet). The external Vcc filter tested contained a 0.1-µF capacitor at the module pin, a 1-µH inductor in series with the V_{CC} line, and a 0.1-µF capacitor on the other side of the inductor. (These components are labeled C1, L1 and C3 in the data sheets). This test filter does not contain the 10-µF, low-frequency capacitor recommended on the data sheet (C4) because our ac coupling network and the pulse generator cannot generate enough signal to drive the V_{CC} node to a 50 mV p-p level when the 10-µF capacitor is present. The effect on the sensitivity with the 0.1-µF, 1-µH, 0.1-µF test filter in place is then measured. Finally, the effects of the filter if the entire recommended data sheet V_{CC} filter, including the 10-µF capacitor, are estimated (but not measured).

4.4b Conducted Noise Testing Results

The sensitivity degradation to a 50 mV p-p noise signal at the V_{CC} connection was measured. In summary, the results are that with no V_{CC} filter present on the test board there is less than a 1 dB penalty below 15 MHz and less than a 0.2 dB penalty above 15 MHz. With the external V_{CC}

filter of a 0.1-µF capacitor at the module pin, a 1-µH inductor in series with the V_{CC} line, and a 0.1-µF capacitor on the other side of inductor, large amounts of sensitivity degradation are confined to a small frequency range around 440 kHz where the filter resonates. Even in this small frequency range, the penalty does not exceed 1.4 dB. Estimates of the V_{CC} noise performance using the real data sheet V_{CC} filter, including the 10 uF recommended capacitor, show less than a 0.3 dB penalty for a 50 mV p-p noise signal in a real application circuit.

In a real application, if it turns out that very low frequency noise is present, and needs to be filtered, a 10-µF capacitor in parallel with the 0.1-µF C1 at the Rx module V_{CC} pin would provide this additional low-frequency filtering. We are fairly certain that this extra 10 µF will never be needed in the vast majority of the HFBR-510X/520X transceiver applications. (Therefore this extra 10-µF capacitor is not shown in the recommended data sheet power supply Vcc filter.) Most applications, using the recommended data sheet Vcc power supply filtering, should never experience any problems in the fiber-optic link operation due to V_{CC} noise.

Figure 9 shows the Rx Vcc noise sensitivity penalty without the external V_{CC} noise filter recommended in Figure 11 of the HFBR-510X or Figure 7 of the HFBR-520X data sheet. The noise is conducted, via the 1-ohm resistor, directly into the module Rx V_{CC} pin. The plot shows that the transceiver module Rx internal V_{CC} filtering network filters out almost all of the noise above 15 MHz on its own. Therefore, the Rx has less than a 0.2 dB V_{CC} noise sensitivity penalty above 15 MHz. Figure 10 shows that less than a 1 dB penalty below 15 MHz is present, even without any external V_{CC} filter.

Figure 11 shows that an external V_{CC} filter can really move any noise problems that might be present down to much lower frequencies. For this plot, the external V_{CC} filter tested contained a 0.1-µF capacitor at the module pin, a 1-µH inductor in series with the V_{CC} line, and a 0.1-µF capacitor on the other side of the inductor. (These components are labeled C1, L1, C3 in the data sheet). This filter does not contain the 10-µF low-frequency filter capacitor, C4, present in Figure 11 (or 7)! Figure 12 shows that the Vcc noise problem areas are confined to the frequencies where the external V_{CC} filter resonates, at around 440 kHz. Even this worst-case point has less than a 1.4 dB sensitivity penalty.

In a real application circuit, C4 will be present. This 10-µF capacitor will greatly attenuate any low-frequency noise conducted from the system V_{CC} power supply circuitry. If the resistance from the Vcc supply to the module V_{CC} filter is 0.2 ohm for example, the 10-µF capacitor will form a filter with a 79 kHz bandwidth. At 440 kHz, the 50 mV noise, from the system V_{CC} power supply, will be attenuated to a 9 mV noise signal at the module V_{CC} filter connection. An educated guess indicates that the sensitivity penalty will probably be less than 0.3 dB at 440 kHz. So the conclusion is that unfiltered low-frequency noise can affect the receiver if it reaches the module pin. Still, even the worst possible scenario has less than a 1.4 dB penalty for a 50 mV p-p noise signal.

With good Vcc noise filtering on the Rx V_{CC} connection per the data sheet recommendation of figure 11 (or 7), the real system should have less than a 0.3 dB penalty to a 50 mVp-p V_{CC} noise signal. (Such a V_{CC} noise signal could be generated somewhere else in the customer's system and then conducted over to the fiber-optic module V_{CC} via the V_{CC} power supply bus). Note that it is impossible to perform the V_{CC} noise immunity test with C4 (10 µF) present because the low ac impedance makes it difficult to apply 50 mVp-p of noise on V_{CC} with conventional sine wave generators and AC coupling. Also, at this point, the test does not really determine what would happen in an actual customer application due to the uncertainty of what the Vcc line impedance would be and how much filtering the 10-µF capacitor would really provide. The general conclusion for now is that the HFBR-510X/520X Vcc

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* There are different sensitivity test windows defined for each product in the product data sheets. These windows are derived from the link jitter allocations to ensure that the Rx does not add more jitter to the overall link jitter than is allowed by the link specification. The sensitivity over the window is always worse than the center of the eye sensitivity. For Vcc noise and susceptibility measurement sensitivity testing, the bit error rate detector clock is aligned with the data eye so that the clock is at the left edge of the test window in the data eye. Then the optical input power is adjusted to get a 1x10$^{(-6)}$ bit error rate. This optical input power is then the left eye edge 1x10$^{(-6)}$ BER sensitivity level for the data pattern under test. See the notes in the data sheets (Reference (1) and (2)) for the HFBR-510X/520X products that describe the receiver section "Input Optical Power Minimum at Window Edge" specifications. (For example, note 20 for the HFBR-5103 Rx.)

noise rejection, in the real application circuit, will be good enough so that most applications will not suffer any noticeable degradations in the fiber-optic link performance due to V_{CC} noise.

5.0 Conclusions

It is no surprise that the HFBR-510X/520X transceiver modules have excellent electromagnetic compatibility because it was taken into account early in their design. Over the years, we have learned a lot about EMC and made a great deal of improvements in the design of fiber-optic modules to satisfy our customers' needs to meet global EMC requirements. The integrated circuits used in the modules are designed to reject V_{CC} noise. The circuits are also designed to be as differential as is possible in order to help reduce V_{CC} noise generation and to help improve the V_{CC} noise and susceptibility noise rejection. The internal edge rates inside the ICs have been carefully limited to help reduce the radiated emissions. Special module packaging techniques, including internal shielding, are used to reduce the emissions from the transmitter and to improve the susceptibility of the receiver. The modular printed circuit board uses good high-frequency layout techniques that reduce loop sizes to improve emissions, susceptibility and V_{CC} noise.

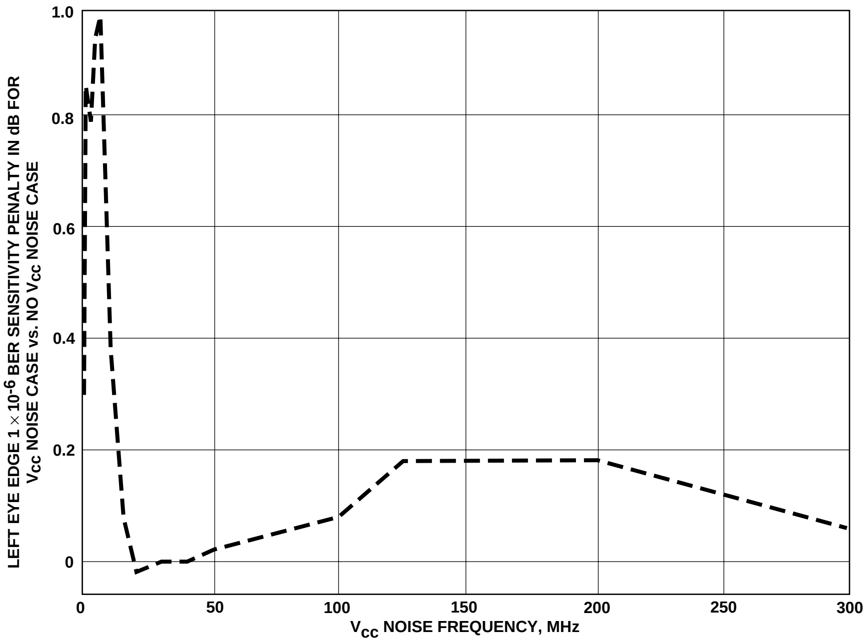

Figure 9. HFBR-510X/520X V_{CC} noise performance with no external V_{CC} filter.

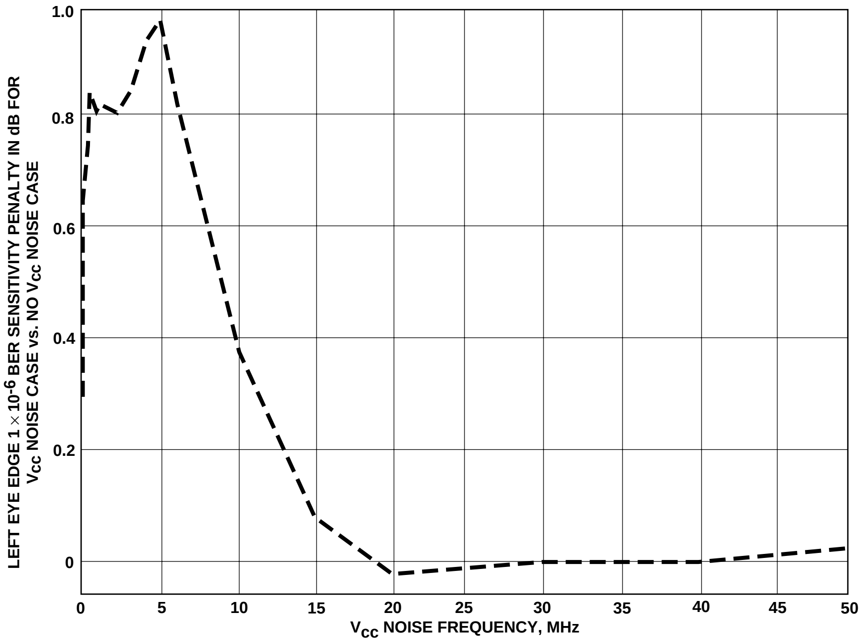

Figure 10. HFBR-510X/520X V_{CC} noise performance with no external V_{CC} filter 0 to 50 MHz.

All these improvements were made while keeping the module cost low. The cost of the EMC improvements is a small percentage of the overall module cost and we think customers will find it well worth it when they consider the money and time it saves them in their final product design and manufacturing cost. The HFBR-510X/520X transceiver modules will make the final product easier to meet EMC compliance, will make it less likely for the final product to experience strange intermittent internal EMC-related performance problems and, if the HFBR-510X/520X transceiver module EMC performance is taken advantage of, will allow cheaper lower-cost shielding to be used in the final product.

The HFBR-510X/520X transceiver module EMC performance is summarized below.

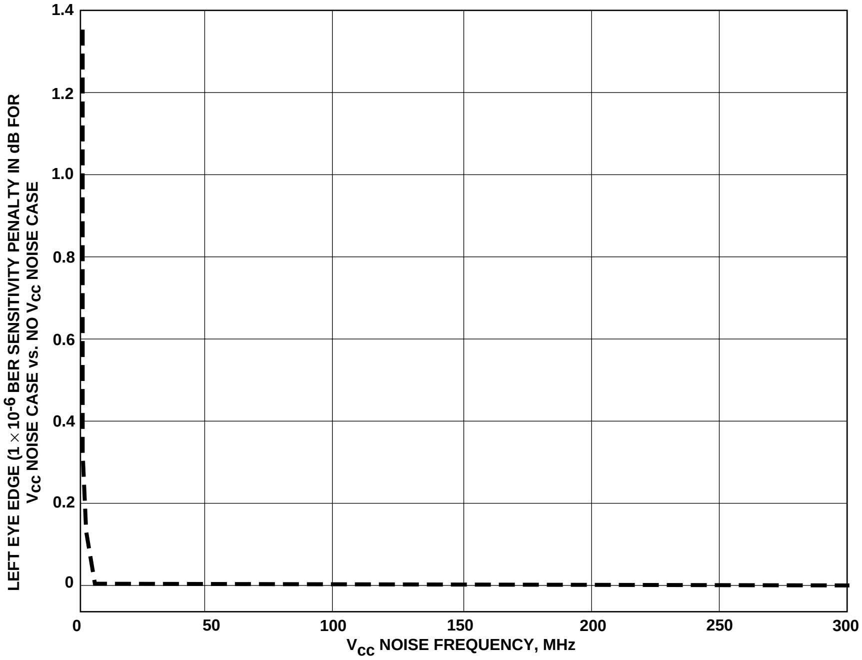

Figure 11. HFBR-510X/520X V_{CC} noise performance with 0.1 µF, 1 µH, 0.1 µF external V_{CC} filter (C1, L1, C3 in the data sheet).

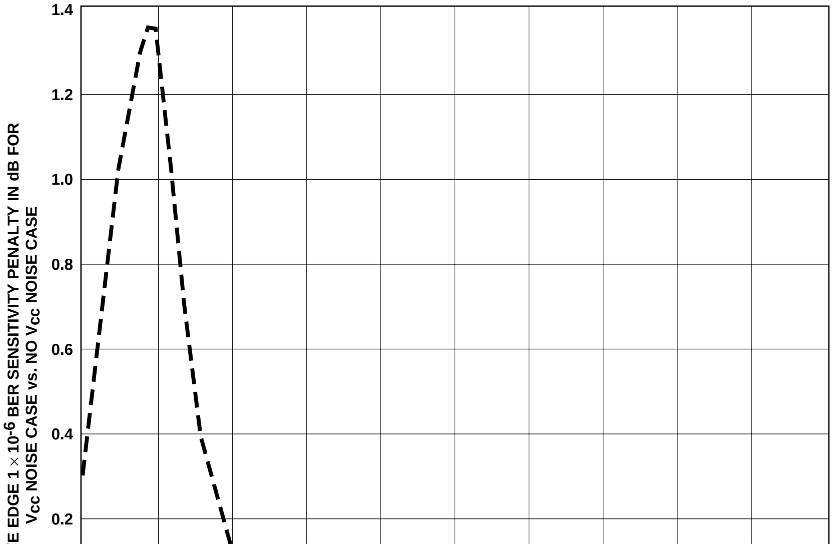

Figure 12. HFBR-510X/520X 1300 nm sesceptibility for ≈ 20 V/m fields. 820 nm HFBR-5104/5203 susceptibility plots are not included here, but are as good or better than 1300 nm to within measurement noise (max noise ≈ 0.05dB).

The module's radiated emissions typically passes worldwide B limits (FCC B, CISPR 22B, EN 55022, and VCCI Class 2) by more than 10 dB. One unit in a computer system will not cause this system to fail the worldwide radiated emissions limits, for either the home or office usage environments, no matter how poor the shielding is. The excellent module emissions level allows the best attempt at using a large number of modules in concentrator applications while still allowing the concentrators to pass radiated emission limits.

The susceptibility is basically zero for 10 V/m fields. Because of the module's high immunity, the customers need not worry about the effects of nearby circuits on the receiver. Fields generated external to the computer system are also not a worry. Only very large ESD events could generate a 10 V/m field, so the concern about ESD zaps causing bit errors is minimized. This unit is suitable for use in Class 3 severe electromagnetic radiated field environments as described in the IEC 801-3 specification.

The crosstalk from the transmitter to the receiver in the transceiver module is virtually zero. Thus the operation of the Tx in the transceiver will not affect the operation of its neighboring Rx in the same transceiver under any circumstances.

The ESD test is conducted per the MIL-STD-883D Method 3015.7 specification. The HFBR-510X/520X transceiver modules withstand 1800 V human-body model electrostatic discharge to any combination of pins with no permanent damage. The modules are classified as MIL-STD Class 1 ESD components, but are close to the 2000 Volt Class 2 minimum limit.

These transceivers also withstand a 100 Volt level to the Japanese EIAJ#1988.3.2B Version.2 Machine Model ESD test.

When the transceiver is installed in the application circuit, the module withstands a 25 kV ESD zap to anywhere on the module with no permanent damage. It should not be damaged by any 25 kV human body zap in any computer system application. This is a variation of the IEC 801-2 test. A rare ESD directly to the module that conducts current through the module can cause some bit errors but the module recovers very quickly.

In the real application circuit, with the data sheet recommended power supply filter, 50 mVp-p of V_{CC} noise should cause no more than a 0.3 dB sensitivity penalty, no matter what the V_{CC} noise frequency is. Most V_{CC} noise frequencies will cause zero penalty. In most applications there should be no noticeable effect on the fiber-optic link performance due to V_{CC} noise.

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