Infrared Data Association
Serial Infrared
Physical Layer Specification

Version 1.3

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Authors

Many people contributed to this physical layer document, primarily from Hewlett-Packard, IBM and Sharp.
Editor of version 1.3 and author of appendices (Test Methods and Examples):
John Petrilla of HP, (408)435-6608, (408)435-6286 (fax), john_petrilla@hp.com
Author of low power option extension to 0.576 Mb/s, 1.152 Mb/s and 4.0 Mb/s data rates:
Raymond Quek of HP, (65) 2798871, (65) 2780791 (fax), raymond_quek@hp.com
The primary author and editor of versions 1.0 through 1.2:
Joe Tajnai of HP, (408)435-6331, (408)435-6286 (fax), joe_tajnai@hp.com.

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Minor edits were made after the meeting

NOTE: Version 1.3 Obsoletes and Replaces Version 1.2

Current Changes

(Changes from Version 1.2, Errata approved Oct. 15, '98, Document edits completed Nov. 20 '98)
Low power option extended to 0.576 Mb/s, 1.152 Mb/s and 4.0 Mb/s data rates.
Recommendation added of higher EMI test ambient for operation with or near mobile phone or pager.
Appendix B.4. revised to include examples for standard, low power and mixed operation at 1.152 Mb/s and 4.0 Mb/s and tables reformatted for consistency. Noise calculations revised for better match with model.
Various typographical errors corrected.

Prior Changes

(Changes from Version 1.1)
Low power option added.
Information regarding eye safety standards and compliance added.
Examples added for low power option and low power option/standard combination.
All examples, except 1.152Mb/s, recalculated and reformatted for consistency.

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1. Introduction

1.1. Scope

This physical specification is intended to facilitate the point-to-point communication between electronic devices (e.g., computers and peripherals) using directed half duplex serial infrared communications links through free space. This document specifies the optical media interfaces, and 0.576 Mb/s, 1.152 Mb/s and 4.0 Mb/s modulation and demodulation. It contains specifications for the Active Output Interface and the Active Input Interface, and for the overall link. It also contains Appendices covering test methods and implementation examples.

Over the past several years several optical link specifications have been developed. This activity has established the advantages of optical interface specifications to define optical link parameters needed to support the defined link performance. Optical interface specifications are independent of technology, apply over the life of the link and are readily testable for conformance. The IrDA serial infrared link specification supports low cost optoelectronic technology and is designed to support a link between two nodes from 0 to at least 1 meter apart as shown in Figure 1 (the two ports need not be perfectly aligned).

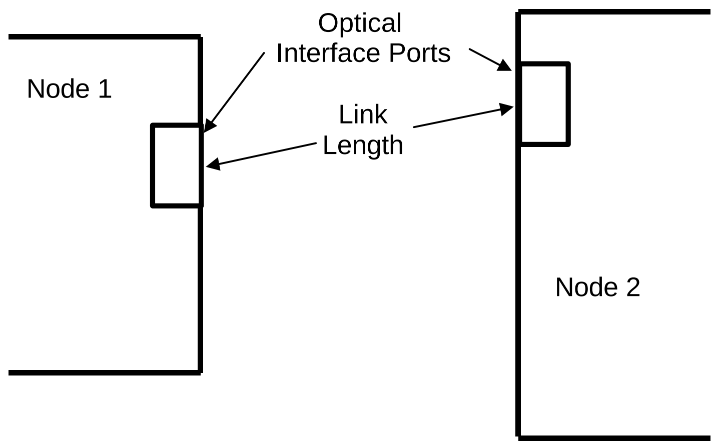


Figure 1. Schematic View of the Optical Interface Port Geometry

1.2. References

The following standards either contain provisions that, through reference in this text, constitute provisions of this proposed standard, or provide background information. At the time of publication of this document, the editions and dates of the referenced documents indicated were valid. However, all standards are subject to revision, and parties to agreements based on this proposed standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

IrDA (Infrared Data Association) Serial Infrared Link Access Protocol (IrLAP), Version 1.1, June 16, 1996.

IrDA (Infrared Data Association) Serial Infrared Link Management Protocol, IrLMP), Version 1.1, January 23, 1996.

IrDA (Infrared Data Association) Serial Infrared Physical Layer Measurement Guidelines, Version 1.0, January 16, 1998.

IrDA (Infrared Data Association) IrMC Specification, Version 1.0.1, January 10, 1998.

IEC Standard Publication 61000-4-3: Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment, Part 3: Radiated Electromagnetic Field Measurements.

IEC 60825-1:(1993) Safety of laser products-Part 1: Equipment classification, requirements and user's guide, as amended (reported at TC 76 Meeting, Frankfurt, Germany, October 31, 1997).

CENELEC EN 60825-1/A11 (October 1996) (amendment to CENELEC version of IEC 60825-1:(1993)

1.3. Abbreviations & Acronyms

4PPM = Four Pulse Position Modulation
A = Address field
Base = Number of pulse positions (chips) in each data symbol
BER = Bit Error Ratio
Bwr = Receiver Bandwidth
Bwrl = Receiver Band Lower Cutoff Frequency
Bwru = Receiver Band Upper Cutoff Frequency
C = Control field
CCITT = International Consultative Committee for Telephone and Telegraph; now ITU-T (CCITT is obsolete term). CCITT used in CRC codes.
CENELEC = European Committee for Electrotechnical Standardization
Chip = One time slice in a PPM symbol
cm = centimeter(s)
CRC32 = 32 bit IEEE 802.x Cyclic Redundancy Check Field
Ct = Duration of one chip
dB = decibel(s)
DBP = Data Bit Pair
DD = PPM encoded data symbol
Dt = Duration of one data symbol
EIA = Electronic Industries Association
FCS = Frame Check Sequence
FIR = Fast (Serial) Infrared (obsolete term)
HDLC = High level Data Link Control
I = Information field
IEC = International Electrotechnical Commission
IR = Infrared
IRLAP = Infrared Link Access Protocol (document), also IrLAP
IRLMP = Infrared Link Management Protocol (document), also IrLMP
ITU-T = International Technical Union - Telecommunication (new name of old CCITT)
kBd = kilobaud
kb/s = kilobits per second
kHz = kilohertz
LSB = Least Significant Bit
m = meter(s)
mA = milliampere(s)
Mbd = Megabaud
Mb/s = Megabits per second
MHz = MegaHertz
mW = milliwatt(s)
ms = millisecond(s)
MSB = Most Significant Bit
nA = nanoampere(s)
ns = nanosecond(s)
pA = picoampere(s)
PA = Preamble
Payload Data = Real, unencoded data bytes transmitted in any packet
PLL = Phase Locked Loop
PPM = Pulse Position Modulation
RZ = Return-to-Zero

RZI = Return-to-Zero-Inverted
SCC = Serial Communication Controller
SIP = Serial Infrared Interaction Pulse
SIR = Serial Infrared
Sr = Steradian
STA = Start Flag
STO = Stop Flag
Tf = Fall Time
Tr = Rise Time
uA = microampere(s)
UART = Universal Asynchronous Receiver/Transmitter
Up = Peak Wavelength
uA = microampere(s)
us = microsecond(s)
uW = microwatt(s)
V = volt(s)

1.4. Definitions

1.4.1. Link Definitions

BER. Bit Error Ratio is the number of errors divided by the total number of bits. It is a probability, generally very small, and is often expressed as a negative power of 10 (e.g., 10^-8).

Angular Range is described by a spherical coordinate system (radial distance and angular coordinate relative to the z axis; the angular coordinate in the plane orthogonal to the z axis is usually ignored, and symmetry about the z axis is assumed) whose axis is normal to the emitting and receiving surface of the optical port and intersects the optical port at the center. The angular range is a cone whose apex is at the intersection of the optical axis and the optical interface plane.

Half-Angle (degrees) is the half angle of the cone whose apex is at the center of the optical port and whose axis is normal to the surface of the port (see Angular Range above). The half angle value is determined by the minimum angle from the normal to the surface where the Minimum Intensity In Angular Range is encountered.

Angular subtense is the angle (in degrees or radians) which an object, such as an emitter or detector or aperture covers at a specified distance (e.g., the sun, viewed from the Earth, subtends and angle of approximately 0.5°).

1.4.2. Active Output Interface Definitions

Maximum Intensity In Angular Range, power per unit solid angle (milliwatts per steradian), is the maximum allowable source radiant intensity within the defined angular range (See Angular Range definition in Section 1.4.1.).

Minimum Intensity In Angular Range, power per unit solid angle (milliwatts or microwatts per steradian), is the minimum allowable source radiant intensity within the defined angular range (See Angular Range definition in Section 1.4.1.).

Rise Time Tr, 10-90%, and Fall Time Tf, 90-10% (microseconds or nanoseconds). These are the time intervals for the pulse to rise from 10% to 90% of the 100% value (not the overshoot value), and to fall from 90% to 10% of the 100% value.

Optical Over Shoot, % of Full (or 100%), is the peak optical signal level above the steady state maximum, less the steady state maximum, expressed as a % of the steady state maximum.

Signaling Rate, (kilobits per second or megabits per second). The rate at which information (data and protocol information) is sent or received.

Pulse Duration, % of bit period. This is the duration of the optical pulse, measured between 50% amplitude points (relative to the 100% value, not the overshoot value), divided by the duration of the bit or symbol period (depending on the modulation scheme), expressed as a percentage. This parameter is used in the duty factor conversion between average and peak power measurements.

Edge Jitter, %. For rates up to and including 115.2 kb/s, this is the maximum deviation within a frame of an actual leading edge time from the expected value. The expected value is an integer number of bit durations (reciprocal of the signaling rate) after the reference or start pulse leading edge. The jitter is expressed as a percentage of the bit duration.

For 0.576 Mb/s and 1.152 Mb/s rates, the jitter is defined as one half of the worst case deviation in time delay between any 2 edges within 32 bit durations of one another, from the nearest integer multiple of the average bit duration. In other words, at 1.151 Mbps (valid deviation from 1.152 Mbps), if two pulses can be found in a transmitted frame whose edges are separated by 25.10 microseconds, this would be out of spec., since the nearest integer multiple of the bit duration is 25.195 microseconds, so the observed delay is more than twice 2.9% of a bit period (50.3 nanoseconds) different from the expected delay.

For 4.0 Mb/s, both leading and trailing edges are considered. From an eye diagram (see measurements section-Appendix A), the edge jitter is the spread of the 50% leading and trailing times. The jitter is expressed as a percentage of the symbol duration.

Peak Wavelength (nanometers). Wavelength at which the optical output source intensity is a maximum.

1.4.3. Active Input Interface Definitions

Maximum Irradiance In Angular Range, power per unit area (milliwatts per square centimeter). The optical power delivered to the detector by a source operating at the Maximum Intensity In Angular Range at **Minimum Link Length** must not cause receiver overdrive distortion and possible related link errors. If placed at the Active Output Interface reference plane of the transmitter, the receiver must meet its bit error ratio (BER) specification.

Minimum Irradiance In Angular Range, power per unit area (milliwatts or microwatts per square centimeter). The receiver must meet the BER specification while operating at the Minimum Intensity in Angular Range into the minimum Half-Angle Range at the maximum Link Length.

Half-Angle (degrees) is the half angle of the cone whose apex is at the center of the optical port and whose axis is normal to the surface of the port. The receiver must operate at the Minimum Irradiance In Angular Range from 0 angular degrees (normal to the optical port) to at least the minimum angular range value.

Receiver Latency Allowance (milliseconds or microseconds) is the maximum time after a node ceases transmitting before the node’s receiver recovers its specified sensitivity.

Edge Jitter, %. The receiver must allow the link to operate within the specified BER for all possible combinations of output interface specs, except for non-allowed codes. No separate input interface jitter parameters are specified. The actual definitions for the various data rates are given in Section 1.4.2.

2. General Description

2.1. Point-to-Point Link Overview

The serial infrared link supports optical link lengths from zero to at least 1 meter for accurate (within specified bit error ratio), free space communication between two independent nodes (such as a calculator and a printer, or two computers).

2.2. Environment

The Optical Interface Specifications apply over the life of the product and over the applicable temperature range for the product. Background light and electric field test conditions are presented in Appendix A.

2.3. Modulation Schemes

For data rates up to and including 1.152 Mb/s, RZI modulation scheme is used, and a “0” is represented by a light pulse. For rates up to and including 115.2 kb/s, the optical pulse duration is nominally 3/16 of a bit duration (or 3/16 of a 115.2 kb/s bit duration). For 0.576 Mb/s and 1.152 Mb/s, the optical pulse duration is nominally 1/4 of a bit duration.

For 4.0 Mb/s, the modulation scheme is 4PPM. In it, a pair of bits is taken together and called a data symbol. It is divided into 4 “chips”, only one of which contains an optical pulse. For 4.0 Mb/s, the nominal pulse duration (chip duration) is 125 ns. A “1” is represented by a light pulse.

2.4. Eye Safety Standards

In the October 1993 edition of IEC 60825-1, LEDs were included along with lasers. The standard requires classification of the Allowable Emission Level of all final products. Allowable emission level refers to the level of ultraviolet, visible or infrared electromagnetic radiation emitted from a product to which a person could be exposed. The IEC standard is being amended as of June 1997; however, the technical portion of the amendment is identical with CENELEC’s Amendment A11 to its standard EN 60825-1.

While it is the CENELEC standard which requires regulatory compliance in CENELEC’s European member countries, its standard is based on the IEC standard. Because of delays, the CENELEC amendment was approved and is in effect before the IEC amendment. At this time, regulation of LED output is only in effect in the CENELEC countries (most of Europe).

Any product which emits radiation in excess of AEL Class 1 must be labeled (a hazard symbol and an explanatory label would be required). Class 1 products must only be declared as such in the product literature.

Compliance with the IrDA specification does not imply compliance with the IEC and CENELEC standards. Two issues must be addressed. First, the allowed output radiant intensity is a strong function of apparent emitter size (see Appendix A for measurement information). A sufficiently small source could be above Class 1 and still be below the maximum radiant intensity allowed by the specification. Second, the classification must be done under the worst reasonable single fault condition.

3. Media Interface Description

3.1. Physical Representation

A block diagram of one end of a serial infrared link is shown in Figure 2. Additional signal paths may exist. Because there are many implementation alternatives, this specification only defines the serially encoded optical output and input signals at [3].

In the diagram, the electrical signals to the left of the Encoder/Decoder at [1] are serial bit streams. For data rates up to and including 1.152 Mb/s, the optical signals at [3] are bit streams with a "0" being a pulse, and a "1" is a bit period with no pulse. For 4.0 Mb/s, a 4PPM encoding scheme is used, with a “1” being a pulse and a “0” being no a chip with no pulse.. A summary of pulse durations for all supported data rates appears in Table 2 in Section 4.1.

The electrical signals at [2] are the electrical analogs of the optical signals at [3]. For data rates up to and including 115.2 kb/s, in addition to encoding, the signal at [2] is organized into frames, each byte asynchronous, with a start bit, 8 data bits, and a stop bit. An implementation of this (up to 115.2 kb/s) is described in Appendix B. For data rates above 115.2 kb/s, data is sent in synchronous frames consisting of many data bytes. Detail of the frame format is found in Section 5.

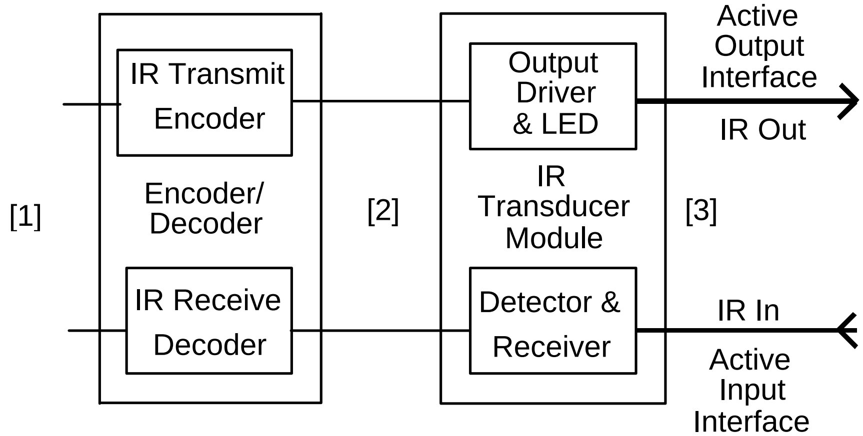


Figure 2. IR Transducer Module

3.2. Optical Angle Definitions

The optical axis is assumed to be normal to the surface of the node's face that contains the optical port (See Figure 3). For convenience, the center of the optical port is taken as the reference point where the optical axis exits the port. If there is asymmetry, as long as the maximum half angle of the distribution is not greater than the allowable Half-Angle Range maximum, and the minimum half angle of the distribution is not less than the Half-Angle Range minimum, the Half-Angle Range specification is met.

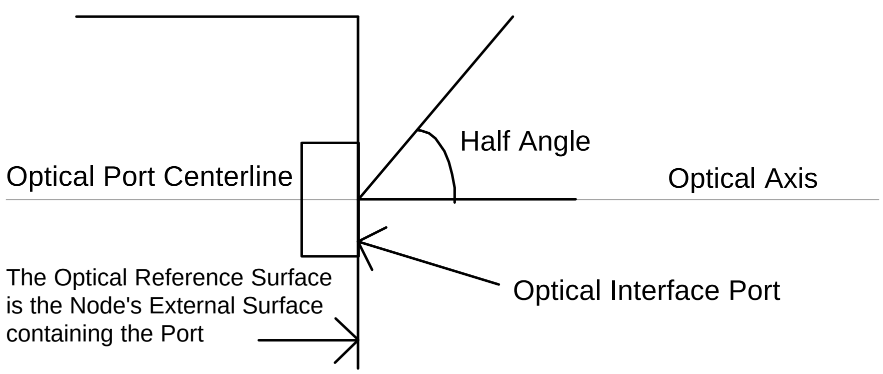


Figure 3. Optical Port Geometry

4. Media Interface Specifications

4.1. Overall Links

There are two different sets of transmitter/receiver specifications. The first, referred to as Standard, is for a link which operates from 0 to at least 1 meter. The second, referred to as the Low Power Option, has a shorter operating range. There are three possible links (See Table 1 below): Low Power Option to Low Power Option, Standard to Low Power Option; Standard to Standard. The distance is measured between the optical reference surfaces.

	Low Power - Low Power	Standard - Low Power	Standard - Standard
Link Distance Lower Limit, meters	0	0	0
Minimum Link Distance Upper Limit, meters	0.2	0.3	1.0

Table 1. Link Distance Specifications

The **Bit Error Ratio** (BER) shall be no greater than 10^-8. The link shall operate and meet the BER specification over its range.

Signaling Rate and Pulse Duration: An IrDA serial infrared interface must operate at 9.6 kb/second. Additional allowable rates listed below are optional. Signaling rate and pulse duration specifications are shown in Table 2.

For all signaling rates up to and including 115.2 kb/s the minimum pulse duration is the same (the specification allows both a 3/16 of bit duration pulse and a minimum pulse duration for the 115.2 kb/s signal (1.63 microseconds minus the 0.22 microsecond tolerance)). The maximum pulse duration is 3/16 of the bit duration, plus the greater of the tolerance of 2.5% of the bit duration, or 0.60 microseconds.

For 0.576 Mb/s and 1.152 Mb/s, the maximum and minimum pulse durations are the nominal 25% of the bit duration plus 5% (tolerance) and minus 8% (tolerance) of the bit duration.

For 4.0 Mb/s, the maximum and minimum single pulse durations are the nominal 25% of the symbol duration plus and minus a tolerance of 2% of the symbol duration. For 4.0 Mb/s, the maximum and minimum double pulse durations are 50% of the symbol plus and minus a tolerance of 2% of the symbol duration. Double pulses may occur whenever two adjacent chips require a pulse.

The link must meet the BER specification over the link length range and meet the optical pulse constraints.

Signaling Rate	Modulation	Rate Tolerance % of Rate	Pulse Duration Minimum	Pulse Duration Nominal	Pulse Duration Maximum
2.4 kb/s	RZI	+/- 0.87	1.41 us	78.13 us	88.55 us
9.6 kb/s	RZI	+/- 0.87	1.41 us	19.53 us	22.13 us
19.2 kb/s	RZI	+/- 0.87	1.41 us	9.77 us	11.07 us
38.4 kb/s	RZI	+/- 0.87	1.41 us	4.88 us	5.96 us
57.6 kb/s	RZI	+/- 0.87	1.41 us	3.26 us	4.34 us
115.2 kb/s	RZI	+/- 0.87	1.41 us	1.63 us	2.23 us
0.576 Mb/s	RZI	+/- 0.1	295.2 ns	434.0 ns	520.8 ns
1.152 Mb/s	RZI	+/-0.1	147.6 ns	217.0 ns	260.4 ns
4.0 Mb/s (single pulse) (double pulse)	 4PPM 4PPM	 +/-0.01 +/-0.01	 115.0 ns 240.0 ns	 125.0 ns 250.0 ns	 135.0 ns 260.0 ns

Table 2. Signaling Rate and Pulse Duration Specifications

In order to guarantee non-disruptive coexistence with slower (115.2 kb/s and below) systems, once a higher speed (above 115.2 kb/s) connection has been established, the higher speed system must emit a

Serial Infrared Interaction Pulse (SIP) at least once every 500 ms as long as the connection lasts to quiet slower systems that might interfere with the link. A SIP is defined as a 1.6 us optical pulse of the transmitter followed by a 7.1 us off time of the transmitter. It simulates a start pulse, causing the potentially interfering system to listen for at least 500 ms. See Section 5.2.

The specified values for **Rise Time Tr**, **Fall Time Tf**, and **Jitter** are listed in Table 3.

Receiver Latency Allowance and Conditioning: The receiver electronics can become biased (or even saturated) from optical power coupled from the adjacent transmitter LED in the node. If the link is operating near the minimum optical irradiance condition (see Table 4), there may be a significant period of time before the receiver relaxes to its specified sensitivity. This duration includes all aspects of a node changing from transmit to receive. See IrDA (Infrared Data Association) Serial Infrared Link Access Protocol (IrLAP) for negotiation of shorter latency times.

For latency critical applications, such as voice transmission as specified in (IrDA IrMC Specification Version 1.0.1), a low power option module will not interoperate at the maximum link distance with a standard module whose minimum latency is greater than 0.50 milliseconds. For applications where latency is not critical (where latency may be negotiated to a value greater than 0.50 ms), interoperation is possible within the appropriate distance specification.

Receivers with gain control or other adaptive circuitry may require conditioning after durations of no optical input. The protocol allows for additional start flags (STAs) to be used for conditioning.

Link Access and Management Control protocols are covered in separate specification documents (see Section 1.2., References).

4.2. Active Output Interface

At the Active Output Interface, an infrared signal is emitted. The specified Active Output Interface parameters appearing in Table 3 are defined in section 1.4 and the associated test methods are found in Appendix A. Std refers to the standard 0 to 1 meter link; LowPwr refers to the Low Power Option; Both refers to both.

SPECIFICATION	Data Rates	Type	Minimum	Maximum
Peak Wavelength, Up, um	All	Both	0.85	0.90
Maximum Intensity In Angular Range, mW/Sr	All	Std	-	500*
" " " " " "		LowPwr	-	72*
Minimum Intensity In Angular Range, mW/Sr	115.2 kb/s & below	Std	40	-
" " " " " "	115.2 kb/s & below	LowPwr	3.6	-
" " " " " "	Above 115.2 kb/s	Std	100	-
" " " " " "	Above 115.2 kb/s	LowPwr	9	-
Half-Angle, degrees	All	Both	15	30
Signaling Rate (also called Clock Accuracy)	All	Both	See Table 2	See Table 2
Rise Time Tr, 10-90%, Fall Time Tf, 90-10% , ns	115.2 kb/s & below	Both	-	600
' " " " " " " " "	Above 115.2 kb/s	Std	-	40
Pulse Duration	All	Both	See Table 2	See Table 2
Optical Over Shoot, %	All	Both	-	25
Edge Jitter, % of nominal pulse duration	115.2 kb/s & below	Both	-	+/-6.5
Edge Jitter Relative to Reference Clock, % of nominal bit duration	0.576 & 1.152 Mb/s	Std	-	+/-2.9
Edge Jitter, % of nominal chip duration	4.0 Mb/s	Std	-	+/-4.0

* For a given transmitter implementation, the IEC 60825-1 AEL Class 1 limit may be less than this. See section 2.4 above and Appendix A.

Table 3. Active Output Specifications

4.3. Active Input Interface

If a suitable infrared optical signal impinges upon the Active Input Interface, the signal is detected, conditioned by the receiver circuitry, and output to the IR Receive Decoder. The specified Active Input Interface parameters appearing in Table 4 are defined in section 1.4. The test methods for determining the values for a particular serial infrared interface are found in Appendix A.

SPECIFICATION	Data Rates	Type	Minimum	Maximum
Maximum Irradiance In Angular Range, mW/cm^2	All	Both	-	500
Minimum Irradiance In Angular Range, uW/cm^2	115.2 kb/s & below	LowPwr	9.0	-
" " " " " "	115.2 kb/s & below	Std	4.0	-
" " " " " "	Above 115.2 kb/s	LowPwr	22.5	-
" " " " " "	Above 115.2 kb/s	Std	10.0	-
Half-Angle, degrees	All	Both	15	-
Receiver Latency Allowance, ms	All	Std	-	10
" " " "	All	LowPwr	-	0.5

Table 4. Active Input Specifications

There is no Half-Angle maximum value for the Active Input Interface. The link must operate at angles from 0 to at least 15 degrees.

There are no Active Input Interface Jitter specifications, beyond that implied in the Active Output Requirements. The link must meet the BER specification for all negotiated and allowable combinations of Active Output Interface specifications, except for non-allowed codes. For rates up to and including 115.2 kb/s, the allowed codes are described in Infrared Data Association Serial Infrared Link Access Protocol (IrLAP), and Infrared Data Association Link Management Protocol. See Section 1.2, References. For 0.576 Mb/s and 1.152 Mb/s and 4.0 Mb/s, see Section 5 of this document.

5. 0.576, 1.152 and 4.0 Mb/s Modulation and Demodulation

5.1. Scope

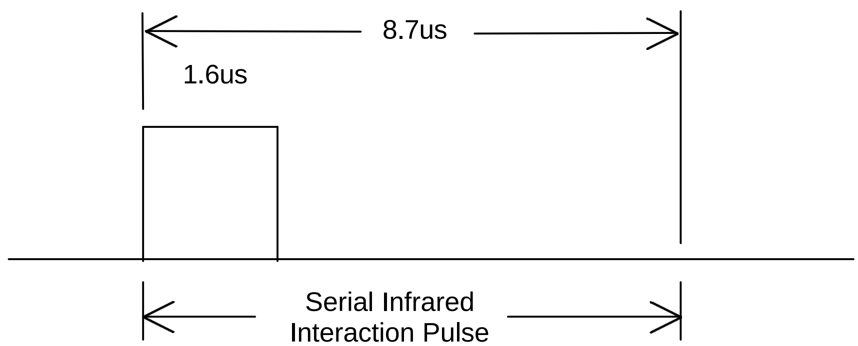
This section covers data modulation and demodulation at 0.576, 1.152 and 4.0 Mb/s data rates. The 0.576 and 1.152 Mb/s rates use an encoding scheme similar to 115.2 kb/s; the 4.0 Mb/s rate uses a pulse position modulation (PPM) scheme. Both cases specify packet format, data encoding, cyclic redundancy check, and frame format for use in communications systems based on the optical interface specification.

Systems operating at these higher rates are transparent to IrLAP and IrLMP as it is defined for the lower rates. Architecturally, it appears as an alternate modulation/demodulation (modem) path for data from IrLAP bound for the IR medium. These higher rates are negotiated during normal IrLAP discovery processes. For these and specific discovery bit field definitions of the higher rates, see documents referenced in Section 1.2.

The Low Power Option is only defined up to 115.2 kb/s, so this section only applies to the standard link.

5.2. Serial Infrared Interaction Pulses

In order to guarantee non-disruptive coexistence with slower (up to 115.2 kb/s) systems, once a higher speed (above 115.2 kb/s) connection has been established, the higher speed system must emit a **Serial infrared Interaction Pulse (SIP)** at least once every 500 ms as long as the connection lasts to quiet slower systems that might interfere with the link (see Section 4.1). The pulse can be transmitted immediately after a packet has been transmitted. The pulse is shown below:



5.3. 0.576 and 1.152 Mb/s Rates

5.3.1. Encoding

The 0.576 and 1.152 Mb/s encoding scheme is similar to that of the lower rates except that it uses one quarter pulse duration of a bit cell instead of 3/16, and uses HDLC bit stuffing after five consecutive ones instead of byte insertion. The following illustrates the order of encoding.

1) The raw transmitted data is scanned from the least significant to the most significant bit of each byte sent and a 16 bit CRC-CCITT is computed for the whole frame except flags and appended at the end of data.

The CRC-CCITT polynomial is defined as follows:

$$CRC(x) = x^{16} + x^{12} + x^{5} + 1$$

(For an example refer to the 32 bit CRC calculation in section 5.4.2.5 and adjust the polynomial for the one indicated above and note the size will be 16 bits (2 bytes) instead of 32 bits (4 bytes) , note preset to all 1’s and inversion of the outgoing CRC value)

(The address and control field are considered as part of data in this example.) For example, say four bytes, ‘CC’hex, ’F5’hex, ’F1’hex, and ’A7’hex, are data to be sent out in sequence, then ‘51DF’hex is the CRC-CCITT.

LSB MSB
Raw Data 00110011 10101111 10001111 11100101

LSB MSB
Data/CRC 00110011 10101111 10001111 11100101 11111011 10001010

2) A ‘Zero’ is inserted after five consecutive ones are transmitted in order to distinguish the flag from data. Zero insertion is done on every field except the flags. Using the same data as an example;

LSB MSB
Data/CRC 00110011 10101111 10001111 11100101 11111011 10001010

First bit to be transmitted Last bit to be transmitted
Transmit Data 001100111010111110000111110110010111110101110001010

(Note: Underlined zeros are inserted bits.)

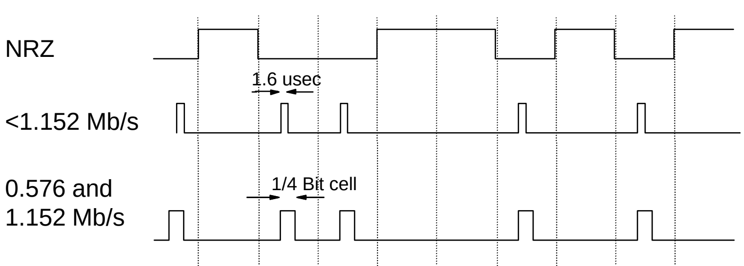
3) The beginning and ending flags, ‘7E’hex, are appended at the beginning and end. Using the same example;

First bit to be transmitted Last bit to be transmitted
Transmit Data 0111111000110011101011111000011111011001011111010111000101001111110

4) An additional beginning flag is added at the beginning. Finally the whole frame to be sent out is:

First bit to be transmitted Last bit to be transmitted
Tx Frame 011111100111111000110011101011111000011111011001011111010111000101001111110

5) The transmitter sends out 1/4-bit-cell-length pulse of infrared signal whenever data is zero. For example, the frame to be sent out is 0100110101 in binary in the order of being transmitted, then the following figure illustrates the actually transmitted signal for lower data rates and also for 0.576 and 1.152 Mb/s.



5.3.2. Frame Format

5.3.2.1. Frame Overview

The 0.576 and 1.152 Mb/s frame format follows the standard HDLC format except that it requires two beginning flags and consists of two beginning flags, an address field, a control field, an information field, a frame check sequence field and minimum of one ending flag. ‘7E’hex is used for the beginning flag as well as for the ending flag. The frame format is the same as for the lower rate-IrLAP frame with STA changed from ‘C0’hex to ‘7E’hex and STO changed from ‘C1’hex to ‘7E’hex.

S T A	S T A	A D D R	DATA	16b FCS	S T O

STA:	Beginning Flag, 01111110 binary
ADDR:	8 bit Address Field
DATA:	8 bit Control Field plus up to 2045 = (2048 - 3) bytes Information Field
FCS:	CCITT 16 bit CRC
STO:	Ending Flag, 01111110 binary

Note 1: Minimum of three STO fields between back to back frames is required.
Note 2: Zero insertion after five consecutive 1's is used. CRC is computed before zero insertion is performed.
Note 3: Least significant bit is transmitted first.
Note 4: Abort sequence requires minimum of seven consecutive 1's.
Note 5: 8 bits are used per character before zero insertion.

5.3.2.2. Beginning Flag (STA) and Ending Flag (STO) Definition

The 0.576 and 1.152 Mb/s links use the same physical layer flag, 01111110, for both STA and STO. It is required to have a minimum of two STAs and a minimum of one STO. The receiver treats multiple STAs or STOs as a single flag even if it receives more than one.

5.3.2.3. Address Field (ADDR) Definition

The 0.576 and 1.152 Mb/s links expect the first byte after STA to be the 8 bit address field. This address field should be used as specified in the IrLAP.

5.3.2.4. Data Field (DATA) Definition

The data field consists of Control field and optional information field as defined in the IrLAP.

5.3.2.5. Frame Check Sequence Field (FCS) Definition

The 0.576 and 1.152 Mb/s links use a 16 bit CRC-CCITT cyclic redundancy check to check received frames for errors that may have been introduced during frame transmission. The CRC is computed from the ADDR and Data fields using the same algorithm as specified in the IrLAP.

5.3.2.6. Frame Abort

A prematurely terminated frame is called an aborted frame. The frame can be aborted by blocking the IR transmission path in the middle of the frame, a random introduction of infrared noise, or intentional termination by the transmitter. Regardless what caused the aborted frame, the receiver treats a frame as an aborted frame when seven or more consecutive ones (no optical signal) are received. The abort terminates the frame immediately without the FCS field or an ending flag.

5.3.2.7. Frame Transmission Order

All fields are transmitted the least significant bit of each byte first.

5.3.2.8. Back to Back Frame Transmission

Back to back, or "brick-walled" frames are allowed with three or more flags, '01111110'b, in between. If two consecutive frames are not back to back, the gap between the last ending flag of the first frame and the STA of the second frame should be separated by at least seven bit durations (abort sequence).

5.4. 4 Mb/s Rate

5.4.1. 4PPM Data Encoding Definition

Pulse Position Modulation (PPM) encoding is achieved by defining a data symbol duration (Dt) and subsequently subdividing Dt into a set of equal time slices called "chips." In PPM schemes, each chip position within a data symbol represents one of the possible bit combinations. Each chip has a duration of Ct given by:

$$Ct = Dt/Base$$

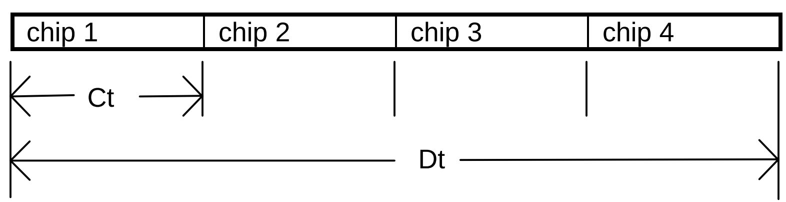
In this formula "Base" refers to the number of pulse positions, or chips, in each data symbol. The Base for IrDA PPM 4.0 Mb/s systems is defined as four, and the resulting modulation scheme is called "four pulse position modulation (4PPM)." The data rate of the IrDA PPM system is defined to be 4.0 Mb/s. The resulting values for Ct and Dt are as follows:

$$Dt = 500 \text{ ns}$$

$$Ct = 125 \text{ ns}$$

The figure below describes a data symbol field and its enclosed chip durations for the 4PPM scheme.

ONE COMPLETE SYMBOL



Because there are four unique chip positions within each symbol in 4PPM, four independent symbols exist in which only one chip is logically a "one" while all other chips are logically a "zero." We define these four unique symbols to be the only legal data symbols (DD) allowed in 4PPM. Each DD represents two bits of payload data, or a single "data bit pair (DBP)", so that a byte of payload data can be represented by four DDs in sequence. The following table defines the chip pattern representation of the four unique DDs defined for 4PPM.

Data Bit Pair (DBP)	4PPM Data Symbol (DD)
00	1000
01	0100
10	0010
11	0001

Logical “1” represents a chip duration when the transmitting LED is emitting light, while logical “0” represents a chip duration when the LED is off.

Data encoding for transmission is done LSB first. The following examples show how various data bytes would be represented after encoding for transmission. In these examples transmission time increases from left to right so that chips and symbols farthest to the left are transmitted first.

Data Byte	Resulting DBPs	Resulting DD Stream (chips and symbols transmitted from left to right for LSB first reception)
X’1B’	00 01 10 11	
		0001
		0010
		0100
		1000
		0001 0010 0100 1000
X’0B’	00 00 10 11	0001 0010 1000 1000
X’A4’	10 10 01 00	1000 0100 0010 0010

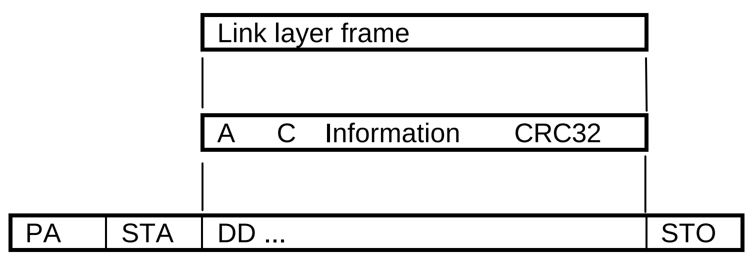
First chip delivered to/received by physical layer.

Last chip delivered to/received by physical layer.

5.4.2. PPM Packet Format

5.4.2.1. Packet Overview

For 4.0 Mb/s PPM packets the following packet format is defined:

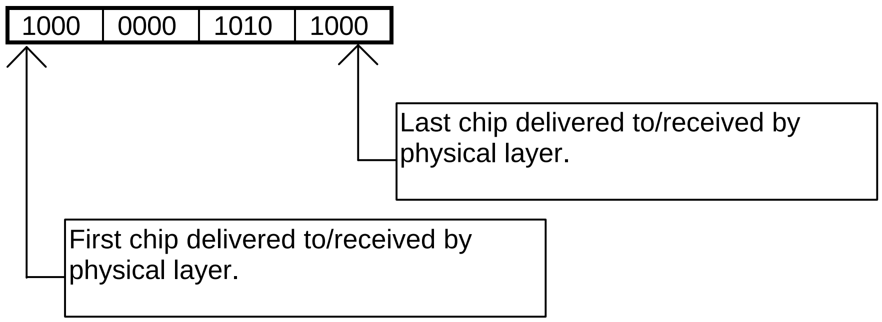


In this packet format, the payload data is encoded as described in the 4PPM encoding above, and the encoded symbols reside in the DD field. Maximum packet length is negotiated by the same mechanism as for the slower rates. The preamble field (PA) is used by the receiver to establish phase lock. During PA, the receiver begins to search for the start flag (STA) to establish symbol synchronization. If STA is received correctly, the receiver can begin to interpret the data symbols in the DD field. The receiver continues to receive and interpret data until the stop flag (STO) is recognized. STO indicates the end of a frame. The chip patterns and symbols for PA, STA, FCS field, and STO are defined below. Only complete packets that contain the entire format defined above are guaranteed to be decoded at the receiver (note that, as for the lower rates, the information field, I, may be of zero length).

The 4PPM data encoding described above defines only the legal encoded payload data symbols. All other 4 chip combinations are by definition illegal symbols for encoded payload data. Some of these illegal symbols are used in the definition of the preamble, start flag, and stop flag fields because they are unambiguously not data.

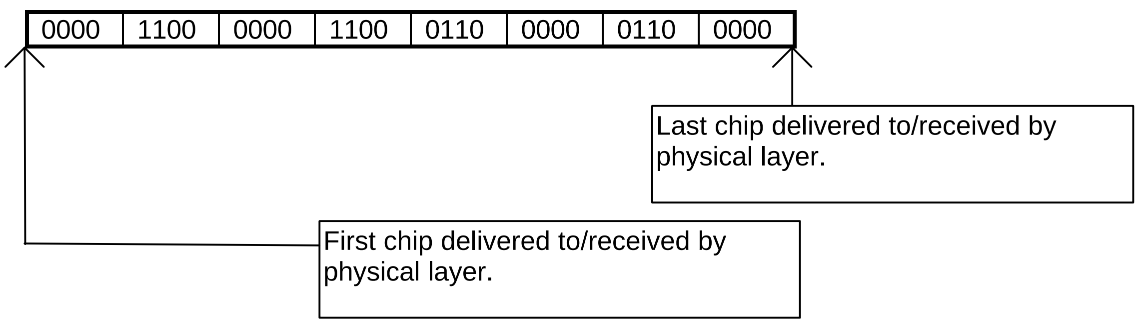
5.4.2.2. Preamble Field Definition

The preamble field (PA) consists of exactly sixteen repeated transmissions of the following stream of symbols. In the PA field, transmission time increases from left to right so that chips and symbols on the left are transmitted first.



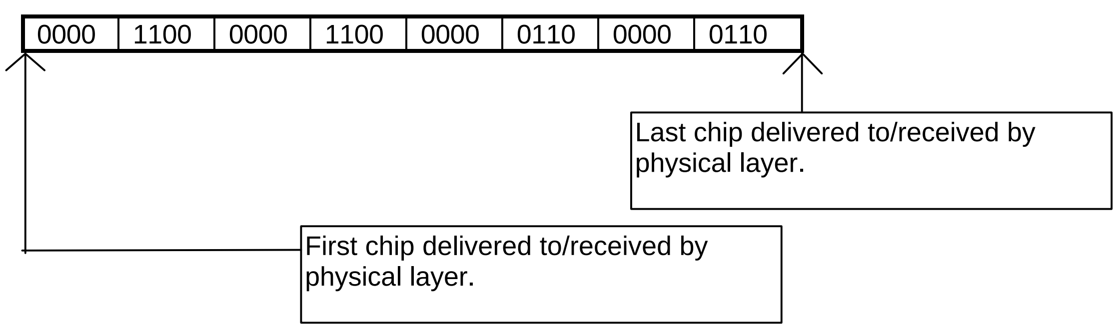
5.4.2.3. Start Flag Definition

The start flag (STA) consists of exactly one transmission of the following stream of symbols. In the STA field, transmission time increases from left to right so that chips and symbols on the left are transmitted first.



5.4.2.4. Stop Flag Definition

The stop flag (STO) consists of exactly one transmission of the following stream of symbols. In the STO field, transmission time increases from left to right so that chips and symbols on the left are transmitted first.



5.4.2.5. Frame Check Sequence Field Definition

Frame check sequence (FCS) field is a 32 bit field that contains a cyclic redundancy check (CRC) value. The CRC is a calculated, payload data dependent field, calculated before 4 PPM encoding. It consists of the 4PPM encoded data resulting from the IEEE 802 CRC32 algorithm for cyclic redundancy check as applied to the payload data contained in the packet. The CRC32 polynomial is defined as follows:

$$CRC(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{2} + x + 1$$

The CRC32 calculated result for each packet is treated as four data bytes, and each byte is encoded in the same fashion as is payload data. Payload data bytes are input to this calculation in LSB first format.

The 32 bit CRC register is preset to all "1's" prior to calculation of the CRC on the transmit data stream. When data has ended and the CRC is being shifted for transmission at the end of the packet, a "0" should
be shifted in so that the CRC register becomes a virtual shift register. Note: the inverse of the CRC register is what is shifted as defined in the polynomial. An example of a verilog implementation follows to describe the process.

```
module txcrc32(clrcrc,clk,txdin,nreset,crcndata,txdout,bdcrc);
/* ************************************************************************** */
// compute 802.X CRC x32 x26 x23 x22 x16 x12 x11 x10 x8 x7 x5 x4 x2 x + 1
// on serial bit stream.
/* ************************************************************************** */
/* bdcrc is input signal used to send a bad crc for test purposes */
/* note ^ is exclusive or function */

input clrcrc,clk,txdin,nreset,crcndata,bdcrc;
output txdout;
reg [31:0] nxtxcrc,txcrc;

/* ************************************************************************** */
// XOR data stream with output of CRC register and create input stream
// if crcndata is low, feed a 0 into input to create virtual shift reg
/* ************************************************************************** */

wire crcshin = (txcrc[31] ^ txdin) & ~crcndata;

/* ************************************************************************** */
// combinatorial logic to implement polynomial
/* ************************************************************************** */

always @ (txcrc or clrcrc or crcshin)
begin
if (clrcrc)
nxtxcrc <= 32'hffffffff;
else
begin
nxtxcrc[31:27] <= txcrc[30:26];
nxtxcrc[26] <= txcrc[25] ^ crcshin; // x26
nxtxcrc[25:24] <= txcrc[24:23];
nxtxcrc[23] <= txcrc[22] ^ crcshin; // x23
nxtxcrc[22] <= txcrc[21] ^ crcshin; // x22
nxtxcrc[21:17] <= txcrc[20:16];
nxtxcrc[16] <= txcrc[15] ^ crcshin; // x16
nxtxcrc[15:13] <= txcrc[14:12];
nxtxcrc[12] <= txcrc[11] ^ crcshin; // x12
nxtxcrc[11] <= txcrc[10] ^ crcshin; // x11
nxtxcrc[10] <= txcrc[9] ^ crcshin; // x10
nxtxcrc[9] <= txcrc[8];
nxtxcrc[8] <= txcrc[7] ^ crcshin; // x8
```

```
nxtxcrc[7] <= txcrc[6] ^ crcshin; // x7
nxtxcrc[6] <= txcrc[5];
nxtxcrc[5] <= txcrc[4] ^ crcshin; // x5
nxtxcrc[4] <= txcrc[3] ^ crcshin; // x4
nxtxcrc[3] <= txcrc[2];
nxtxcrc[2] <= txcrc[1] ^ crcshin; // x2
nxtxcrc[1] <= txcrc[0] ^ crcshin; // x1
nxtxcrc[0] <= crcshin; // +1
end

end

/* ********************************************************************** */
// infer 32 flops for strorage, include async reset asserted low
/* ********************************************************************** */
always @ (posedge clk or negedge nreset)
begin
if (!nreset)
txcrc <= 32'hffffffff;
else
txcrc <= nxtxcrc;     // load D input (nxtxcrc) into flops
end

/* ********************************************************************** */
// normally crc is inverted as it is sent out
// input signal badcrc is asserted to append bad CRC to packet for
// testing, this is an implied mux with control signal crcndata
// if crcndata = 0 , the data is passed by unchanged, if = 1 then
// the crc register is inverted and transmitted.
/* ********************************************************************** */

wire txdout = (crcndata) ? (~txcrc[31] ^ bdcrc) : txdin; // don't invert
                                        // if bdcrc is 1
endmodule
/* ********************************************************************** */
```

The following shows a CRC calculation and how the results would be represented after encoding for transmission. The results of the CRC calculation (txcrc[31 - 0]) is shown in the next table when the contents of the DD field is X’1B’ and X’A4’, where X’1B’ is the first byte of the DD field. If the four bytes of CRC are counted as received data, then the resultant 6 bytes in order would be X’1B’, X’A4’, X’94’, X’BE’, X’54’ and X’39’.

	[31] [0]
txcrc[31-0]	1101 0110 1000 0010 1101 0101 0110 0011
~txcrc[31-0]	0010 1001 0111 1101 0010 1010 1001 1100

CRC Value	Resulting DBPs	Resulting DD Stream (chips and symbols transmitted from left to right for LSB first reception)
~txcrc[24-31]	10 01 01 00	
		1000
		0100
		0100
		0010
		1000 0100 0010 0001
~txcrc[16-23]	10 11 11 10	0010 0001 0001 0010
~txcrc[8-15]	01 01 01 00	1000 0100 0100 0100
~txcrc[0-7]	00 11 10 01	0100 0010 0001 1000

First chip delivered to/received by physical layer.

Last chip delivered to/received by physical layer.

5.4.3. Aborted Packets

Receivers may only accept packets that have valid STA, DD, FCS, and STO fields as defined in the PPM Packet Format section. The PA field need not be valid in the received packet. All other packets are aborted and ignored.

Any packet may be aborted at any time after a valid STA but before transmission of a complete STO flag by two or more repeated transmissions of the illegal symbol "0000." Also, any packet may be aborted at any time after a valid STA by reception of any illegal symbol which is not part of a valid STO field.

5.4.4. Back to Back Packet Transmission

Back to back, or "brick-walled" packets are allowed, but each packet must be complete (i.e., containing PA, STA, DD and STO fields). Brick-walled packets are illustrated below.

Packet 1				Packet 2			
PA	**STA**	**DD**	**STO**	**PA**	**STA**	**DD**	**STO**

Appendix A. Test Methods

Note- A.1 is Normative unless otherwise noted. The rest of Appendix A and all of Appendix B are Informative, not Normative {i.e., it does not contain requirements, but is for information only}. Examples of measurement test circuits and calibration are provided in IrDA Serial Infrared Physical Layer Measurement Guidelines.

A.1. Background Light and Electromagnetic Field

There are four ambient interference conditions in which the receiver is to operate correctly. The conditions are to be applied separately.

1. Electromagnetic field: 3 V/m maximum
   Refer to IEC 61000-4-3 test level 2 for details.
   (For devices that intend to connect with or operate in the vicinity of a mobile phone or pager, a field of 30 V/m with frequency ranges from 800 Mhz to 960 Mhz and 1.4 GHz to 2.0 GHz including 80% amplitude modulation with a 1 kHz sine wave is recommended. Refer to IEC 61000-4-3 test level 4 for details. The 30 V/m condition is a recommendation; 3 V/m is the normative condition.)

2. Sunlight: 10 kilolux maximum at the optical port
   This is simulated with an IR source having a peak wavelength within the range 850 nm to 900 nm and a spectral width less than 50 nm biased to provide 490 uW/cm^2 (with no modulation) at the optical port. The light source faces the optical port.

   This simulates sunlight within the IrDA spectral range. The effect of longer wavelength radiation is covered by the incandescent condition.

3. Incandescent Lighting: 1000 lux maximum
   This is produced with general service, tungsten-filament, gas-filled, inside-frosted lamps in the 60 Watt to 150 Watt range to generate 1000 lux over the horizontal surface on which the equipment under test rests. The light sources are above the test area. The source is expected to have a filament temperature in the 2700 to 3050 degrees Kelvin range and a spectral peak in the 850 nm to 1050 nm range.

4. Fluorescent Lighting : 1000 lux maximum
   This is simulated with an IR source having a peak wavelength within the range 850 nm to 900 nm and a spectral width of less than 50 nm biased and modulated to provide an optical square wave signal (0 uW/cm^2 minimum and 0.3 uW/cm^2 peak amplitude with 10% to 90% rise and fall times less than or equal to 100 ns) over the horizontal surface on which the equipment under test rests. The light sources are above the test area. The frequency of the optical signal is swept over the frequency range from 20 kHz to 200 kHz.

   Due to the variety of fluorescent lamps and the range of IR emissions, this condition is not expected to cover all circumstances. It will provide a common floor for IrDA operation.

A.2. Active Output Specifications

A.2.1. Peak Wavelength

The peak wavelength (Peak Wavelength, Up, um) is the wavelength of peak intensity and can be measured using an optical spectrum analyzer. The pulse shape and sequence can be the same as that used for the power measurements below and the measurement can be made on the optical axis.

A.2.2. Intensity and Angle

The following three specifications form a set that can be measured concurrently:

- Maximum Intensity In Angular Range, mW/Sr
- Minimum Intensity In Angular Range, mW/Sr
- Half-Angle, degrees

This intensity measurement requires means to measure optical power as well as the distance and angle from a reference point. Power measured in milliwatts (mW) or microwatts (uW) is converted to intensity in mW/Sr (or uW/Sr) or irradiance in mW/cm^2 (or uW/cm^2). In addition, if there are any cosmetic windows or filters that are part of the interface, they must be in place for all intensity and spatial distribution optical measurements

The primary reference point is the center point of the surface of the IrDA optical port and the port's optical axis is the line through the reference point and normal to the port surface. Link specifications are based on the assumption that the maximum intensity at the port surface is 500 mW/cm^2 due to a point source of 500 mW/Sr maximum intensity placed one centimeter behind the reference surface. Distance is measured radially from the reference point to the test head. Half-Angle is the angular deviation from the optical axis as shown in Figure 4. The plane of the detector at the Test Head is normal to the radial vector from the center of the optical port to the detector.

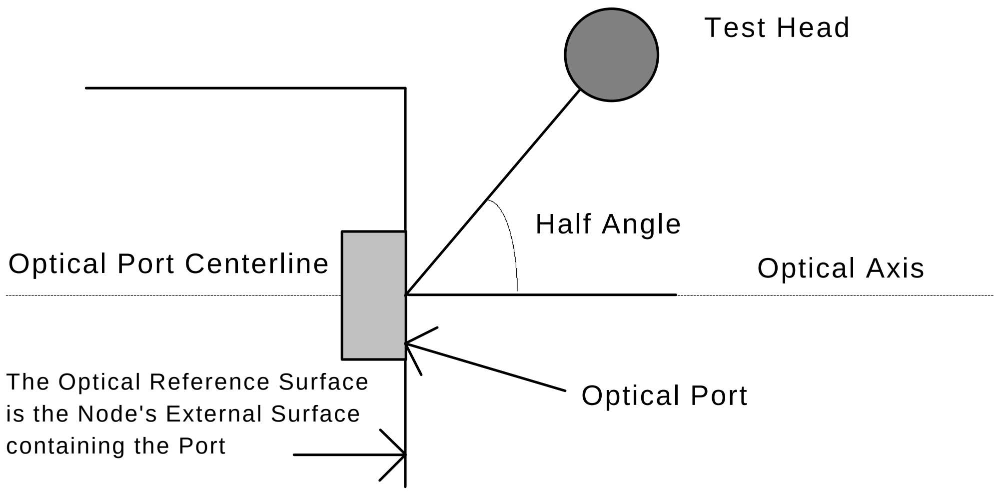


Figure 4. Optical Port Angle Measurement Geometry

The IrDA link specification is based on peak optical power levels. Power measurement can be made on a single pulse or by averaging a sequence of pulses and converting to peak levels. Averaging methods require knowledge of the pulse sequence and/or duty factor in order to calculate the peak power from the reported average. In addition, for short pulse durations, attention must be paid to the effect of the rise and fall times of the optical signal on the effective optical pulse duration.

The test head is to be calibrated to provide accurate results for signals within the appropriate ranges of wavelength, pulse and pulse sequence characteristics. The size of the photodetector in the test head must be known in order to translate the results from power (mW or uW) to irradiance (mW/cm^2 or uW/cm^2) and intensity (mW/Sr or uW/Sr). Finally, the test head should be aimed directly at the reference point, i.e., the test detector should be normal to the vector from the center of the optical port to the center of the test detector.

The power measurement should be made at a distance large enough to avoid near field optical effects but close enough to receive a robust signal. To test for an appropriate distance, make power measurements at half and double the chosen distance and check that the results are consistent with an inverse square relationship.

Resolution of spatial intensity variation should be as fine as the smallest detector. Unfortunately, because the detected signal intensity is averaged over the size of the test head, resolution becomes a tradeoff with signal strength. However, there is no size constraint in the Active Input Interface specification for the detector in the IrDA receiver. It is impractical to test with an infinitesimal detector. A suggested test setup employs a 1 cm^2 area photodiode at a distance of 30 cm from the emitter. For a circular photodiode, the diameter is 1.13 mm, which subtends an angle of 1.08°, or 0.00111 steradians. Any measurement setup should have at least this angular resolution.

Figure 5 contains a graphical representation of the serial infrared Active Output Interface specifications. The measured intensity must be less than or equal to "Maximum Intensity In Angular Range" in the angular region less than or equal to 30 degrees and less than or equal to "Minimum Intensity In Angular Range" in the angular region greater than 30 degrees. The measured intensity must be greater than or equal to "Minimum Intensity In Angular Range" in the angular region less than or equal to 15 degrees. The minimum allowable intensity value is indicated by “min” in Figure 5, since the actual specified value is dependent upon data rate.

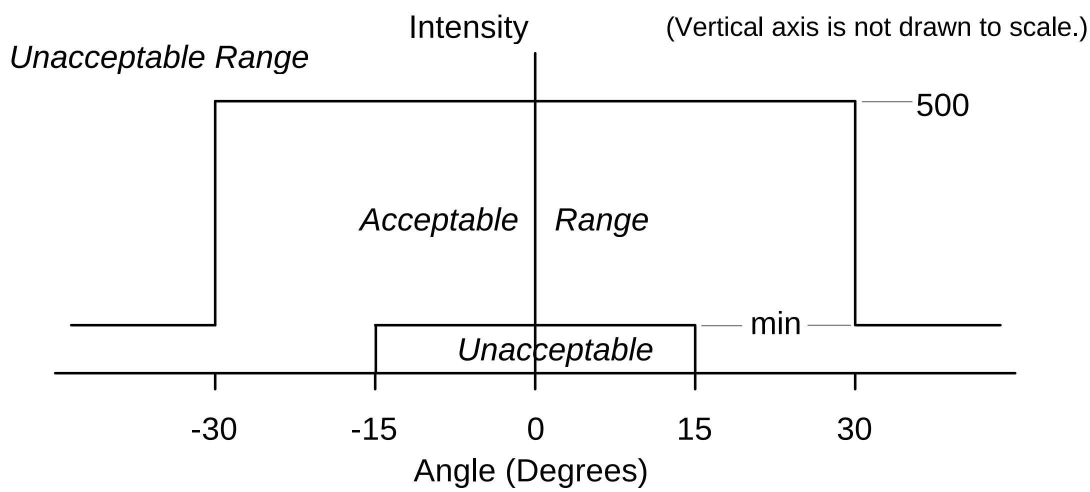


Figure 5. Acceptable Optical Output Intensity Range

The optical power measurements are converted to optical intensity across the +/- 30 degree region to verify both the maximum and minimum intensity specifications and sufficiently beyond +/- 30 degrees to verify the specification. Optical power is converted to intensity by the relationship

Intensity(mW/Sr) = [Power(mW)]/[Detector Solid Angle(Sr)].

The Detector Solid Angle in steradians is given by the relationship

Detector Solid Angle (Sr) = 2pi[1-cos(Half-Angle)],

where the Half-Angle is half the angle subtended by the detector, viewed from the reference point.

The Detector Solid Angle can be approximated with the relationship

Detector Solid Angle (Sr) ~ [Area of Detector]/[r^2],

where r is the distance between the test head and the reference point.

A.2.3. Pulse Parameters and Signaling Rate

The following six specifications form a set that can be measured with the same set-up:

- Rise Time Tr, 10-90%, us or ns
- Fall Time Tf, 90-10%, us or ns
- Pulse Duration, % of Bit or Symbol Period
- Optical Over Shoot, %
- Edge Jitter, us or ns
- Signaling Rate, kb/s or Mb/s

These measurements require means to measure optical power and an oscilloscope (or equivalent) with sufficient bandwidth to resolve jitter to better than 0.2 us (for data rates up to and including 115.2 kb/s). For the data rates up to 4.0 Mb/s, jitter down to 10 ns must be resolved.

Definitions of the reference point, etc., are the same as for the Active Output Interface power measurements and the same considerations for test distance and signal strength apply. The test head should be positioned within +/- 15 degrees of the optical axis and aimed directly at the reference point.

Rise Time, Fall Time, Pulse Duration and Overshoot can be measured for a single optical pulse. Since overshoot is referenced to the pulse amplitude at the end of the pulse, the maximum duration pulses should be used in this test. For Rise Time, Fall Time, Pulse Duration and Overshoot, refer to Figure 6. It is critical to determine the 100% level, since all four of these parameters are dependent upon it. If there is uncertainty concerning the existence of the flat region that defines the 100% level (is there over shoot, or does the pulse have a long, rounded top?), measurements at a longer drive pulse duration will resolve this, and allow easier determination of the 100% level.

Jitter and Signaling Rate require a sequence of pulses for determination. For data rates up to and including 115.2 kb/s, the signal is asynchronous at the byte; therefore Jitter and Signal Rate are only relevant within a byte. For 0.576 Mb/s, 1.152 Mb/s and 4.0 Mb/s, however, the optical bit stream is synchronous for up to 500 ms, though typically less than 20 ms (window = 7, packet size = 2k). Thus, the measurement requires the accumulation of data over a longer time interval.

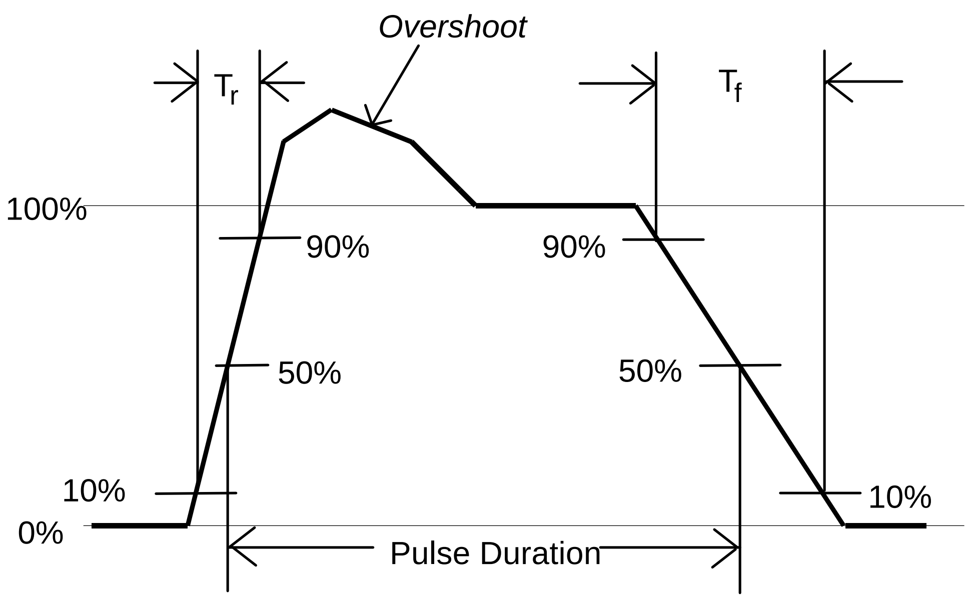


Figure 6. Pulse Parameter Definitions

The reciprocal of the mean of the absolute delay times between optical pulses is the data rate. Although some accuracy should be gained by the averaging, for only 1 asynchronous byte the tolerance requirement may be difficult to achieve with an oscilloscope. If UART frames are back to back (synchronous across bytes), use of an oscilloscope may be adequate. If access to an internal clock signal is available, a counter may be used.

For rates up to and including 115.2 kb/s, we can consider jitter to be the range of deviation between the leading edge of the optical pulse and a reference signal edge. Refer to Figure 7. For simplicity, the reference signal can be taken to be the leading edge of the first pulse in the byte (the "Start" pulse). Using the nominal data rate, the arrival time of each pulse in the byte can be predicted. The jitter (in time units) is the maximum departure from predicted arrival time of the actual arrival time. Since jitter may be pattern dependent, various data should be used in the test signal.

For 0.576 and 1.152 Mb/s RZI and 4.0 Mb/s 4PPM, an entire packet can be used to determine jitter. The optical signal should be detected using a high speed optical detector (e.g., a reverse-biased, small silicon p-i-n diode). The detector output signal is displayed using a storage oscilloscope set to trigger as often as possible during a packet, the stored image displaying an eye diagram. Care should be taken to use time constants in any ac coupling which are much, much longer than the symbol times.. The jitter (in time units) is half of the horizontal "smear" of the eye signal at the 50% level, where the leading and trailing edges of the signal cross (see Figure 8). To determine data rate, a counter may be used at 4.0 Mb/s if a sufficiently long data transmission is available. For 0.576 and 1.152 Mb/s, an oscilloscope and back to back packets are recommended to determine data rate.

For 0.576 and 1.152 Mb/s, there may be some implementations which use a digital synthesizer to generate the transmitter clock. In this case, there may be jitter of up to +/- 25 ns relative to an idealized reference clock. Typically, with a 40 MHz primary clock, the jitter would be +/- 12.5 ns from the synthesizer, and another 5 ns or so from the driver and LED.

The jitter may be measured indirectly by using a high speed photodiode and a digitizing oscilloscope to measure the variance in edge to edge delay. Configure the transmitter to repetitively send large (2kb) packets of data (approximately 2 ms), and trigger the oscilloscope on any rising optical edge. Capture a section of the waveform delayed from the reference edge by 1 to 31 times the bit period. Capture several hundred repetitions at each delay, and measure the spread in the edge locations. It is necessary to measure at several delays since any one delay might be a multiple of the clock synthesis cycle, and show artificially small jitter. Measurements at several prime intervals should be sufficient, e.g., at 3, 7, 13 ,19, and 31 times the bit period. The jitter relative to a "reference" clock is one half of the worst case spread in the rising edges at each delay.

The jitter may also be measured relative to a reference clock generated with an analog phase locked loop with a tracking bandwidth of about 10 kHz, locked to the optical signal edges. In this case, the oscilloscope should be triggered on the reference clock edge, and several hundred optical signal edges should be collected. Adequate time must be allowed for the PLL to settle before collecting edges, so the oscilloscope trigger should be gated for several PLL time constants after the beginning of a packet.

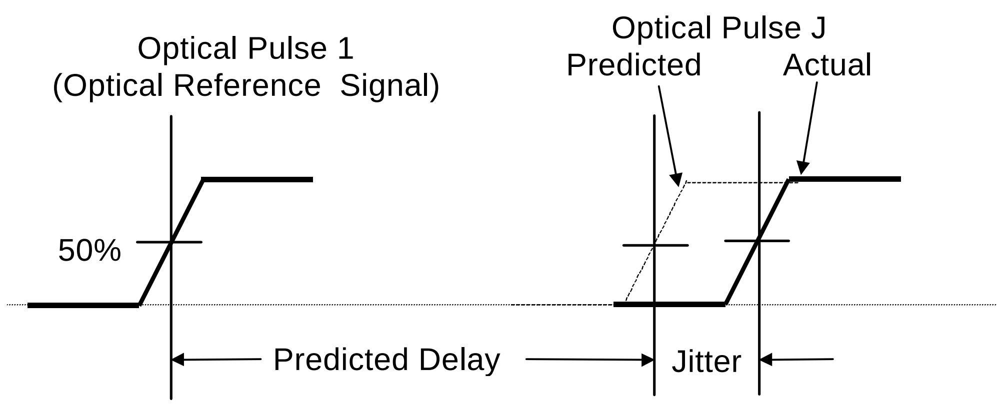


Figure 7. Pulse Delay and Jitter Definitions

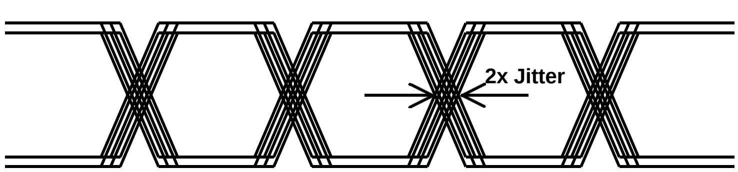


Figure 8. 4.0 Mb/s Jitter Definitions

A.2.4. Eye Safety Standard

The apparent source size is a parameter used in determining the power or energy Accessible Emission Level Class limits and the measurement conditions of IEC 60825-1 and CENELEC EN60825-1.

The apparent source size is how large the source appears (how tightly the power or energy is concentrated). One method to determine apparent source size is to form an image of the source with a relay lens, as shown in Figure 9. By placing the emitter at a distance of twice the focal length of the lens, an image of size equal to the source will form at the same distance on the other side of the lens. The image can then be scanned with a small photodiode to determine the distribution of emitted light. Alternatively, a CCD camera system can be used; several of these systems on the market include software for analyzing the image.

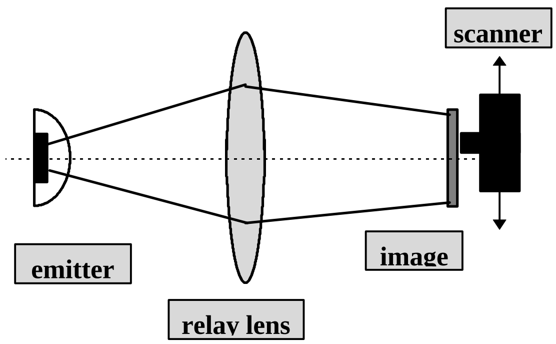


Figure 9. Apparent Source Size Measurement

The apparent source size, s, is deemed to be the diameter of the smallest circular aperture containing approximately 63.2% of the incident light.

Measurements of source output power must be made at the correct distance, r, and with the correct aperture diameter, d. Under the new amendment to IEC 60825-1 (and CENELEC EN60825-1) the measurement conditions for measuring output power, source to measurement aperture distance, r, and aperture diameter, d, are functions of apparent source size, s. The measurement distance, r, measurement aperture diameter, d, are derived from apparent source size, s, as follows:

Aperture Diameter (d)	Measurement Distance (r)
Fixed at 7.0 millimetres	$100 (s / 10 + 0.0046)^{0.5}$ millimetres
$7 (s / 10 + 0.0046)^{-0.5}$ millimetres	Fixed at 100 millimetres

Table 5. Measurement Parameters

These relationships apply for s between 0.15 mm and 10 mm, which probably includes all IrDA compliant emitters.

A fixed aperture of 7.0 mm can be easier to implement, and then adjust the measurement distance according to the calculation. Whether the aperture is fixed at 7.0 mm or the distance is fixed at 100 mm, only light output power passing through the aperture is measured for comparison to the AEL Class limits.

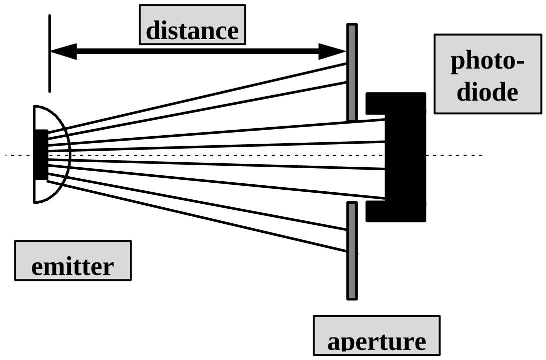


Figure 10. IEC 60825-1 AEL Classification Power Measurement

Source output power can be derived from measured photocurrent resulting from light collected on a calibrated photodiode detector. Measured photocurrent in amps can be converted to detected power in watts, using the calibration factor in amps/watt.

For source wavelength λ = 700-1050 nm, the AEL Class 1 limit is calculated as:

Limit = [0.0007 $t^{0.75}$ $C_4 C_6$ Joules] [1000 / t] milliwatts

t = exposure duration in seconds (100 seconds is the default value)

C4 = $10^{.002(\lambda - 700)}$

C6 = 1 for $\alpha < \alpha_{min}$

C6 = α/α_{min} for $\alpha_{min} < \alpha < \alpha_{max}$

C6 = $100/\alpha_{min}$ for $\alpha > \alpha_{max}$

where α = 1000 x [2 x $\tan^{-1}$((s/2)/100 mm] (milliradians)
s = apparent source size (millimeters)

It is convenient to express both the AEL Class limit and the measured AEL of the system in terms of watts/steradian. System source radiant intensity is often specified in milliwatts per steradian.

Apparent source angular subtense, α, is the 2-dimensional angle subtended by the source's radiated light image at a distance of 100 mm. A 3-dimensional angle (solid angle) subtended by the source's radiated light image can be expressed in units of steradians. A hemisphere (1/2 of a sphere) subtends a solid angle of 2π steradians. The solid angle, Ω, subtended by a cone of full angle, θ, is given by:

$$\Omega = 2\pi (1 - \cos(\theta/2))$$

Given the measurement distance, r, and the aperture diameter, d, the solid angle given by:

$$\Omega = 2\pi (1 - \cos(\tan^{-1}(d/2r)))$$

The measured AEL and AEL Class limits can now be expressed in watts/steradian:

AEL (watts/steradian) = AEL (watts) / Ω (steradians)

Given the measurement distance, r, and the aperture diameter, d, the AEL is:

AEL (mW/sr) = AEL (mW)/ (2π (1 - cos($\tan^{-1}$(d/2r))))

Once the source radiant intensity in milliwatts/steradian has been determined, it can be compared with the AEL Class limits for classification. If the output does not exceed the Class 1 limit, the operation is Class 1. If it exceeds the Class 1 limit but is less than 5 times the limit, operation is Class 3A. It is anticipated no IrDA compliant sources will produce output above the Class 3A.

The classification must be done under the worst reasonable single fault condition. For more information, refer to IEC 60825-1 or CENELEC EN 60825-1 and their amendments.

A.3. Active Input Specifications

The following five specifications form a set which can be measured concurrently:

- Maximum Irradiance in Angular Range, mW/cm^2
- Minimum Irradiance in Angular Range, uW/cm^2
- Half-Angle, degrees
- Bit Error Ratio, (BER)
- Receiver Latency Allowance, ms

These measurements require an optical power source and means to measure angles and BERs. Since the optical power source must provide the specified characteristics of the Active Output, calibration and control of this source can use the same equipment as that required to measure the intensity and timing characteristics. BER measurements require some method to determine errors in the received and decoded signal. The latency test requires exercise of the node's transmitter to condition the receiver.

Definitions of the reference point, etc., are the same as for the Active Output Interface optical power measurements except that the test head is now an optical power source with the in-band characteristics (Peak Wavelength, Rise and Fall Times, Pulse Duration, Signaling Rate and Jitter) of the Active Output Interface. The optical power source also must be able to provide the maximum power levels listed in the Active Output Specifications. It is expected that the minimum levels can be attained by appropriately spacing the optical source from the reference point.

Figure 11 illustrates the region over which the Optical High State is defined. The receiver is operated throughout this region and BER measurements are made to verify the maximum and minimum requirements. The ambient conditions of A.1 apply during BER tests; BER measurements can be done with worst case signal patterns. Unless otherwise known, the test signal pattern should include maximum length sequences of "1"s (no light) to test noise and ambient, and maximum length sequences of "0"s (light) to test for latency and other overload conditions.

The minimum allowable intensity value is indicated by “minimum” in Figure 11, since the actual specified value is dependent upon data rate.

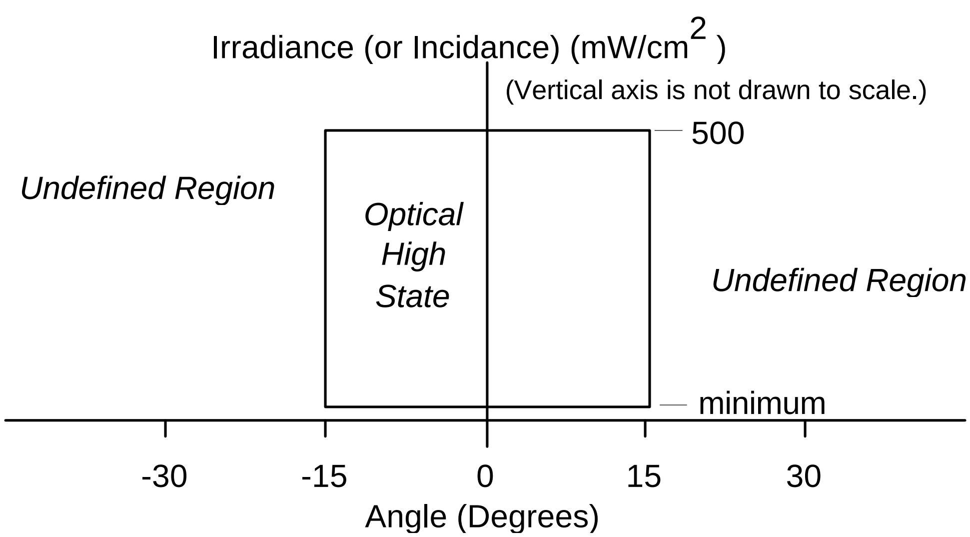


Figure 11. Optical High State Acceptable Range

Latency is tested at the Minimum Irradiance in Angular Range conditions. The receiver is conditioned by the exercise of its associated transmitter. For rates up to and including 1.152 Mb/s, the conditioning signal should include maximum length sequences of "0"s (light) permitted for this equipment. For 4.0 Mb/s 4PPM operation, various data strings should be used; the latency may be pattern dependent. The receiver is operated with the minimum irradiance levels and BER measurements are made after the specified latency period for this equipment to verify irradiance, half-angle, BER and latency requirements.

Appendix B. An Example of One End of a Link Implementation

Appendix B is Informative, not Normative {i.e., it does not contain requirements, but is for information only}. Specifications in Table 6 are derived from tables earlier in the document.

The link implementations in this appendix are examples only. All links must operate at 9.6 kb/s. Specifications are used as constraints, but all other parameters' values are calculated for the purpose of providing a more complete example.

B.1. Definitions

UART - Universal Asynchronous Receiver/Transmitter: an electronic device/module that interfaces with a serial data channel.

B.2. Physical Representations

A block diagram of one end of an overall serial infrared link for data rates up to and including 115.2 kb/s is shown in Figure 12a. Figure 12b shows on overall configuration for a link supporting the lower speeds as well as 0.576 Mb/s, 1.152 Mb/s and 4.0 Mb/s.

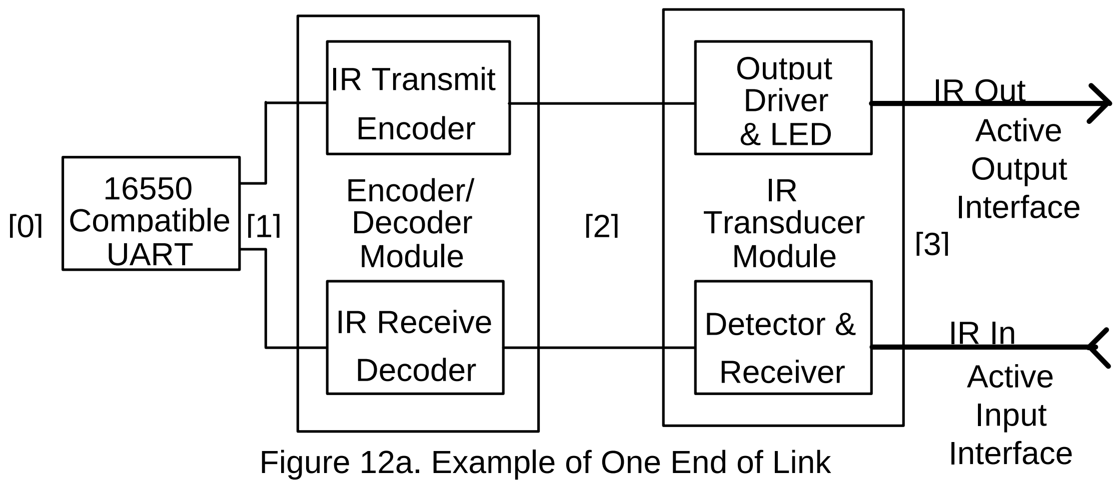


Figure 12a. Example of One End of Link
For Signaling Rates Up to & Including 115.2 kb/s

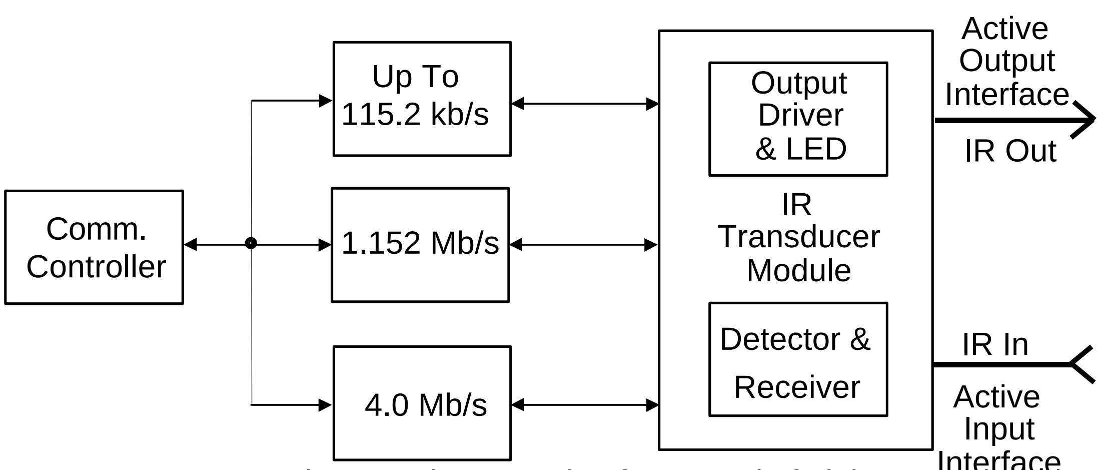


Figure 12 b. Example of One End of Link
For Signaling Rates Up to 4.0 Mb/s

B.3. Functionality & Electrical Waveforms - Data Rates Up to & Including 115.2 kb/s

In Figure 12a, the signal to the left of the UART [0] will not be discussed. The signal between the UART and the Encoder/Decoder [1] is a bit stream of pulses in a frame comprised a Start Bit, 8 Data Bits, no Parity Bit and ending with a Stop Bit, as shown in Figure 13a.

The signal at [2], between the Encoder/Decoder Module and the IR Transducer Module is shown in Figure 13b. The electrical pulses between the IR Transmit Encoder and the Output Driver & LED are 3/16 of a bit period in duration (or, for the slower signaling rates, as short as 3/16 of the bit period for 115.2 kb/s). Note that the IR Transmit Encoder and the Output Driver and LED pulses begin at the center of the bit period. The electrical pulses between the Detector & Receiver and the IR Receive Decoder are nominally of the same duration as those between the IR Transmit Encoder and the Output Driver & LED, but may be longer in some implementations. Thus, the electrical signals at [2] are analogs of the optical signals at [3]; an example of a nominal waveform is shown in Figure 13b. A "0" is represented by a pulse and a "1" is represented by no pulse.

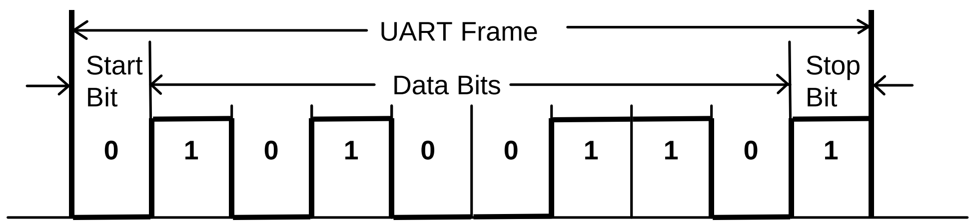


Figure 13a. UART Frame

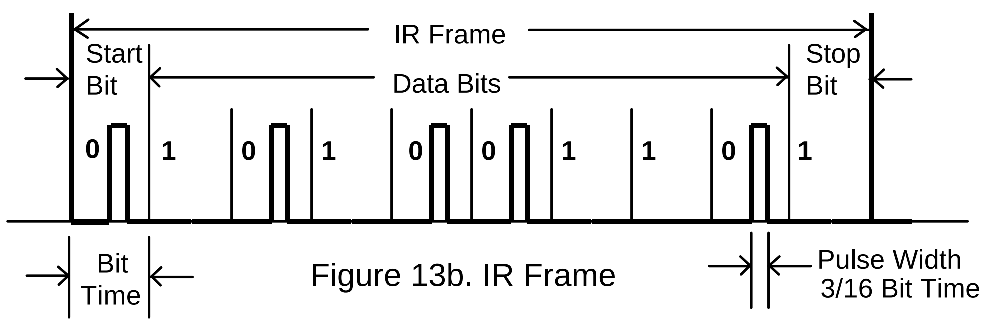


Figure 13b. IR Frame

B.4. Receiver Data and Calculated Performance

Examples in this section are provided to show receiver implementations which are sufficient to meet the BER requirements called for in section 4 for minimum irradiance conditions. The highest signaling rate for each of the encoding formats is used due to the bandwidth and noise consequences. The sunlight ambient is also used for its noise impact.

Photodiode currents are calculated for the minimum signal and sunlight conditions. Different effective optically receptive areas are assumed for the standard and low power options. Noise and eye loss calculations are based on an assumed high input impedance preamplifier model with a single high frequency pole and a single low frequency pole forming a bandpass filter where the only noise sources are thermal noise due to the input impedance and shot noise due to sunlight generated photodiode current. The high frequency pole is set by the impedance and capacitance at the input of the preamplifier.

Preamplifier output rise time (Channel Response Time) is calculated combining preamplifier and Active Output characteristics. Eye loss due to minimum pulse width and channel response time limiting the amplitude to less than 100% of pulse magnitude is calculated. Eye loss due to jitter is not calculated and margin is provided for this and other considerations.

The three segments of Table 6 appear in specifications in section 4 of the main body of this document and are repeated here for convenient reference. Tables 7, 8 and 9 present examples of 115.2 kb/s receiver implementations for standard, low power and mixed operation. Tables 10, 11 and 12 present similar examples for 1.152 Mb/s implementations as do Tables 13, 14 and 15 for 4.0 Mb/s operation. Tables 7 through 15 also repeat specifications for convenient reference.

TERMS:

Detector Responsivity (µA/(mW/cm^2) is a photodiode characteristic combining sensitivity (A/W) and effective area.

Channel Response Time is the 10% to 90% rise time produced by the rms combination of the Active Output rise time and step response rise time of the preamplifier.

Receiver Noise Current is the thermal noise associated with the impedance at the input of the preamplifier and the associated bandwidth.

Sunlight Ambient Noise Current is the shot noise associated with the sunlight induced photodiode current and the associated bandwidth.

Receiver Noise Current is the rms combination of the receiver and sunlight ambient noise currents.

Comparator Threshold is assumed to be at 50% of the minimum signal condition to yield optimum signal to noise ratios for both high and low states.

Specified Signal/Noise ratio for BER is the SNR calculated to achieve the required BER for a static signal level where the threshold is at 50% of the high state and noise is gaussian.

Receiver Margin is the ratio of the actual SNR to the Specified SNR for BER expressed in dB(optical).

Penalty: Eye Loss for Bandwidth Limits is the additional signal required for the minimum pulse width to reach 100% of the eye opening height expressed in dB(optical).

Margin for Edge Jitter, EMI, other is the signal margin above the Specified SNR for BER remaining after accounting for Eye Loss for Bandwidth Limits expressed in dB(optical).

LINK INTERFACE SPECIFICATIONS	Data Rates	Type	Minimum	Maximum
Signaling Rate	All	Both	See Table 2	See Table 2
Link Distance Lower Limit, m	All	Both	-	0
Minimum Link Distance Upper Limit, m	See Table 1	Both	See Table 1	-
Ambient Sunlight Irradiance**, µW/cm^2		Both	-	490
Bit Error Ratio, BER	All	Both		10^-8
ACTIVE OUTPUT SPECIFICATIONS				
Peak Wavelength, Up, µm	All	Both	0.85	0.90
Maximum Intensity In Angular Range, mW/Sr	All	Std	-	500*
“ “ “ “ “ “		LowPwr	-	72*
Minimum Intensity In Angular Range, mW/Sr	≤ 115.2 kb/s	Std	40	-
“ “ “ “ “ “	≤ 115.2 kb/s	LowPwr	3.6	-
“ “ “ “ “ “	> 115.2 kb/s	Std	100	-
“ “ “ “ “ “	> 115.2 kb/s	LowPwr	9	-
Half-Angle, degrees	All	Both	15	30
Rise Time Tr, 10-90%, Fall Time Tf, 90-10% , ns	≤ 115.2 kb/s	Both	-	600
´ “ “ “ “ “ “ “ “	> 115.2 kb/s	Both	-	40
Pulse Duration	All	Both	See Table 2	See Table 2
Edge Jitter, % of nominal pulse duration	≤ 115.2 kb/s	Both	-	+/-6.5
Edge Jitter Relative to Reference Clock, % of nominal bit duration	0.576 Mb/s & 1.152 Mb/s	Both	-	+/-2.9
Edge Jitter, % of nominal chip duration	4.0 Mb/s	Both	-	+/-4.0
ACTIVE INPUT SPECIFICATIONS				
Maximum Irradiance in Angular Range,mW/cm^2	All	Both	-	500
Minimum Irradiance In Angular Range, uW/cm^2	≤ 115.2 kb/s	LowPwr	9.0	-
“ “ “ “ “ “	≤ 115.2 kb/s	Std	4.0	-
“ “ “ “ “ “	> 115.2 kb/s	LowPwr	22.5	-
“ “ “ “ “ “	> 115.2 kb/s	Std	10.0	-
Half-Angle, degrees	All	Both	15	-
Receiver Latency Allowance, ms	All	Std	-	10
“ “ “ “	All	LowPwr	-	0.5

* For a given transmitter implementation, the IEC 60825-1 AEL Class 1 limit may be less than this. See section 2.4 above and Appendix A.

** Used for an example of ambient conditions. Allowance must be made for fluorescent and incandescent radiation as well as EMI.

Table 6. Serial Infrared Specifications

B.4.1. 115.2 kb/s Standard Implementation Example

(Standard transmitter to standard receiver for 115.2 kb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, kb/s	114.2	116.2
Minimum Link Distance Upper Limit, m	1.0	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	4.0	
Min. Eff. Receiver Signal Detected Current, nA	175.8	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0015	
Receiver Upper 3 dB Bandwidth Limit, MHz		0.250
Receiver Input Noise Current, A	3.95E-10	-
Receiver Input Noise Current, A/(Hz)^0.5	7.93E-13	-
Sunlight Ambient Noise Current, A	1.64E-09	-
Total Receiver Input rms Noise Current, A	1.69E-09	-
Comparator Threshold = 0.5(Signal), nA	87.9	-
Receiver Signal Detected/Input Noise Current	104.2	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	9.68	-
Single Bit Pulse Width, Tb, ns	1410	-
Channel Response Time, Tc, ns	-	1523
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.93
Margin for Edge Jitter, EMI, other, dB	8.8	-

Table 7. Receiver Data and Calculated Performance for Standard Operation at 115.2 kb/s

B.4.2. 115.2 kb/s Low Power Option Implementation Example

(Low power transmitter to low power receiver for 115.2 kb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, kb/s	114.2	116.2
Minimum Link Distance Upper Limit, m	0.20	
Detector Responsivity, µA/(mW/cm^2)	17.2	
Minimum Irradiance In Angular Range, µW/cm^2	9.0	
Min. Eff. Receiver Signal Detected Current, nA	154.5	-
Sunlight In-Band Photocurrent, A	8.41E-06	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0015	
Receiver Upper 3 dB Bandwidth Limit, MHz		0.250
Receiver Input Noise Current, A	2.44E-10	-
Receiver Input Noise Current, A/(Hz)^0.5	4.89E-13	-
Sunlight Ambient Noise Current, A	1.02E-09	-
Total Receiver Input rms Noise Current, A	1.05E-09	-
Comparator Threshold = 0.5(Signal), nA	77.2	-
Receiver Signal Detected/Input Noise Current	146.6	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	11.17	-
Single Bit Pulse Width, Tb, ns	1410	-
Channel Response Time, Tc, ns	-	1523
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.93
Margin for Edge Jitter, EMI, other, dB	10.2	-

Table 8. Receiver Data and Calculated Performance for Low Power Operation at 115.2 kb/s

B.4.3. 115.2 kb/s Low Power Option/Standard Implementation Example

(Low power transmitter to standard receiver for 115.2 kb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, kb/s	114.2	116.2
Minimum Link Distance Upper Limit, m	0.30	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	4.0	
Min. Eff. Receiver Signal Detected Current, nA	175.8	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0015	
Receiver Upper 3 dB Bandwidth Limit, MHz		0.250
Receiver Input Noise Current, A	3.95E-10	-
Receiver Input Noise Current, A/(Hz)^0.5	7.93E-13	-
Sunlight Ambient Noise Current, A	1.64E-09	-
Total Receiver Input rms Noise Current, A	1.69E-09	-
Comparator Threshold = 0.5(Signal), nA	87.9	-
Receiver Signal Detected/Input Noise Current	104.2	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	9.68	-
Single Bit Pulse Width, Tb, ns	1410	-
Channel Response Time, Tc, ns	-	1523
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.93
Margin for Edge Jitter, EMI, other, dB	8.8	-

Table 9. Receiver Data and Calculated Performance for Standard Receiver & Low Power Transmitter Operation at 115.2 kb/s

B.4.4. 1.152 Mb/s Standard Implementation Example

(Standard transmitter to standard receiver for 1.152 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, Mb/s	1.1508	1.1532
Minimum Link Distance Upper Limit, m	1.0	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	10.0	
Min. Eff. Receiver Signal Detected Current, nA	439.4	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0151	
Receiver Upper 3 dB Bandwidth Limit, MHz		2.48
Receiver Input Noise Current, A	3.92E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	2.50E-12	-
Sunlight Ambient Noise Current, A	5.17E-09	-
Total Receiver Input rms Noise Current, A	6.49E-09	-
Comparator Threshold = 0.5(Signal), nA	219.7	-
Receiver Signal Detected/Input Noise Current	67.8	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	7.81	-
Single Bit Pulse Width, Tb, ns	147.6	-
Channel Response Time, Tc, ns	-	146.7
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.69
Margin for Edge Jitter, EMI, other, dB	7.1	-

Table 10. Receiver Data and Calculated Performance for Standard Operation at 1.152 Mb/s

B.4.5. 1.152 Mb/s Low Power Option Implementation Example

(Low power transmitter to low power receiver for 1.152 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, Mb/s	1.1508	1.1532
Minimum Link Distance Upper Limit, m	0.20	
Detector Responsivity, μA/(mW/cm^2)	17.2	
Minimum Irradiance In Angular Range, μW/cm^2	22.5	
Min. Eff. Receiver Signal Detected Current, nA	386.2	-
Sunlight In-Band Photocurrent, A	8.41E-06	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0151	
Receiver Upper 3 dB Bandwidth Limit, MHz		2.48
Receiver Input Noise Current, A	2.42E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	1.54E-12	-
Sunlight Ambient Noise Current, A	3.23E-09	-
Total Receiver Input rms Noise Current, A	4.03E-09	-
Comparator Threshold = 0.5(Signal), nA	193.1	-
Receiver Signal Detected/Input Noise Current	95.8	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	9.32	-
Single Bit Pulse Width, Tb, ns	147.6	-
Channel Response Time, Tc, ns	-	146.7
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.69
Margin for Edge Jitter, EMI, other, dB	8.6	-

Table 11. Receiver Data and Calculated Performance for Low Power Operation at 1.152 Mb/s

B.4.6. 1.152 Mb/s Lower Power/Standard Implementation Example

(Low power transmitter to standard receiver for 1.152 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Signal Pulse Rate, Mb/s	1.1508	1.1532
Minimum Link Distance Upper Limit, m	0.30	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	10	
Min. Eff. Receiver Signal Detected Current, nA	439.4	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.0151	
Receiver Upper 3 dB Bandwidth Limit, MHz		2.48
Receiver Input Noise Current, A	3.92E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	2.50E-12	-
Sunlight Ambient Noise Current, A	5.17E-09	-
Total Receiver Input rms Noise Current, A	6.49E-09	-
Comparator Threshold = 0.5(Signal), nA	219.7	-
Receiver Signal Detected/Input Noise Current	67.8	-
Specified Signal/Noise Ratio For BER	11.2	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	7.81	-
Single Bit Pulse Width, Tb, ns	147.6	-
Channel Response Time, Tc, ns	-	146.7
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.69
Margin for Edge Jitter, EMI, other, dB	7.1	-

Table 12. Receiver Data and Calculated Performance for Standard Receiver & Low Power Transmitter Operation at 1.152 Mb/s

B.4.7. 4.0 Mb/s Standard Implementation Example

(Standard transmitter to standard receiver for 4.0 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Chip Rate, Mb/s	7.9992	8.0008
Minimum Link Distance Upper Limit, m	1.0	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	10.0	
Min. Eff. Receiver Signal Detected Current, nA	439.4	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.040	
Receiver Upper 3 dB Bandwidth Limit, MHz		6.04
Receiver Input Noise Current, A	4.87E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	1.99E-12	-
Sunlight Ambient Noise Current, A	8.06E-09	-
Total Receiver Input rms Noise Current, A	9.42E-09	-
Comparator Threshold = 0.5(Signal), nA	219.7	-
Receiver Signal Detected/Input Noise Current	46.7	-
Specified Signal/Noise Ratio For BER	11.5	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	6.10	-
Single Bit Pulse Width, Tb, ns	115	-
Channel Response Time, Tc, ns	-	70.4
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.51
Margin for Edge Jitter, EMI, other, dB	5.6	-

Table 13. Receiver Data and Calculated Performance for Standard Operation at 4.0 Mb/s

B.4.8. 4.0 Mb/s Low Power Option Implementation Example

(Low power transmitter to low power receiver for 4.0 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Chip Rate, Mb/s	7.9992	8.0008
Minimum Link Distance Upper Limit, m	0.20	
Detector Responsivity, μA/(mW/cm^2)	17.2	
Minimum Irradiance In Angular Range, μW/cm^2	22.5	
Min. Eff. Receiver Signal Detected Current, nA	386.2	-
Sunlight In-Band Photocurrent, A	8.41E-06	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.040	
Receiver Upper 3 dB Bandwidth Limit, MHz		6.04
Receiver Input Noise Current, A	3.00E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	1.23E-12	-
Sunlight Ambient Noise Current, A	5.04E-09	-
Total Receiver Input rms Noise Current, A	5.86E-09	-
Comparator Threshold = 0.5(Signal), nA	193.1	-
Receiver Signal Detected/Input Noise Current	65.9	-
Specified Signal/Noise Ratio For BER	11.5	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	7.60	-
Single Bit Pulse Width, Tb, ns	115	-
Channel Response Time, Tc, ns	-	70.4
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.51
Margin for Edge Jitter, EMI, other, dB	7.1	-

Table 14. Receiver Data and Calculated Performance for Low Power Operation at 4.0 Mb/s

B.4.9. 4.0 Mb/s Low Power/Standard Implementation Example

(Low power transmitter to standard receiver for 4.0 Mb/s)

RECEIVER REQUIREMENTS & CALCULATED PERFORMANCE (Not Interface Specifications)	**Minimum**	**Maximum**
Chip Rate, Mb/s	7.9992	8.0008
Minimum Link Distance Upper Limit, m	0.30	
Detector Responsivity, µA/(mW/cm^2)	44	
Minimum Irradiance In Angular Range, µW/cm^2	10.0	
Min. Eff. Receiver Signal Detected Current, nA	439.4	-
Sunlight In-Band Photocurrent, A	2.15E-05	-
Receiver Lower 3 dB Bandwidth Limit, MHz	0.040	
Receiver Upper 3 dB Bandwidth Limit, MHz		6.04
Receiver Input Noise Current, A	4.87E-09	-
Receiver Input Noise Current, A/(Hz)^0.5	1.99E-12	-
Sunlight Ambient Noise Current, A	8.06E-09	-
Total Receiver Input rms Noise Current, A	9.42E-09	-
Comparator Threshold = 0.5(Signal), nA	219.7	-
Receiver Signal Detected/Input Noise Current	46.7	-
Specified Signal/Noise Ratio For BER	11.5	-
Receiver Margin (Min. S/N)/(Spec. S/N), dB	6.10	-
Single Bit Pulse Width, Tb, ns	115	-
Channel Response Time, Tc, ns	-	70.4
Penalty: Eye Loss for Bandwidth Limits, dB	-	0.51
Margin for Edge Jitter, EMI, other, dB	5.6	-

Table 15. Receiver Data and Calculated Performance for Standard Receiver & Low Power Transmitter Operation at 4.0 Mb/s