CMS ECAL Data Links

Sub-Project Specification

(Feasibility Study Report)

Version 1.0

Approval:

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1. Scope

In general, the goal of the project is to develop and provide a system to transfer data (data and trigger primitives) from the ECAL Front End boards in digital electronic parallel form to Off Detector boards in digital electronic serial form. This is to be accomplished making the maximum use of components and techniques chosen and developed for the CMS Tracker Data Links.

The Data Link system block diagram is shown in Figure 1. Approximately 9,000 such links will be needed for the transport of ECAL data and trigger information.

Specifically, the project encompasses the following:

Where relevant, the development, procurement, production, qualification, acceptance and integration into the link of all pieces of all physical objects, including:

1. The GOL Opto-hybrid (GOH), comprising:
    a. Gigabit Optical Link (GOL) [1] serialiser and laser driver chip
    b. Laser diode, including pigtail fiber terminated in a MU connector based on a 1.25 mm ferrule
    c. PCB, connector and passive components
2. The MU-SR adaptor employed at the distributed patch panel
3. The terminated ruggedized fiber ribbon, comprising:
    a. SM 12-fiber ruggedized ribbon
    b. Ribbon fan-out and termination in a MU-SR connector based on a 1.25 mm ferrule (distributed patch panel end)
    c. Ribbon termination in an MFS12 connector based on an MT12 ferrule (in-line patch panel end)
4. The MFS12 adaptor employed at the in-line patch panel
5. The terminated dense multi-ribbon cable, comprising:
    a. Dense 8-ribbon cable
    b. Ribbon break-out and termination in an MT12 ferrule at each end, housed in an MFS12 connector on the in-line patch panel end, and in an MPO12 connector in the receiver end
6. The 12-channel receiver module with its MPO12 connector shell

The following is a list of items which are **not** within the scope of the project (but which are essential to the success of the project), and the group which to our understanding is responsible, with advice and supervision from the Data Links group as necessary.

1. The specification of the levels of electromagnetic noise permissible (all groups)
2. The specification of ambient temperature near the GOH (Electronics Integration group)
3. The specification of the lengths of all types of fiber required in the supermodule or quadrant (Electronics Integration group)
4. The specification of the numbers of receiver modules needed per supermodule and quadrant (Off Detector group)

5. The choice of the deserializer and the related choice of protocol (Off Detector group)
6. The procurement, purchase and integration of the deserializer (Off Detector group)
7. The design, construction, installation, etc., of the patch panels themselves (Regional Center/Cabling Team)
8. The installation and post-installation test of all components of the Data Link (Regional Center & CMS Integration)
9. The providing of Front End and Off Detector electronics necessary to perform a test of the full readout chain, construction of the setup and performance of the tests (Front End, Data Links, Off Detector groups and Electronics Integration group where relevant)

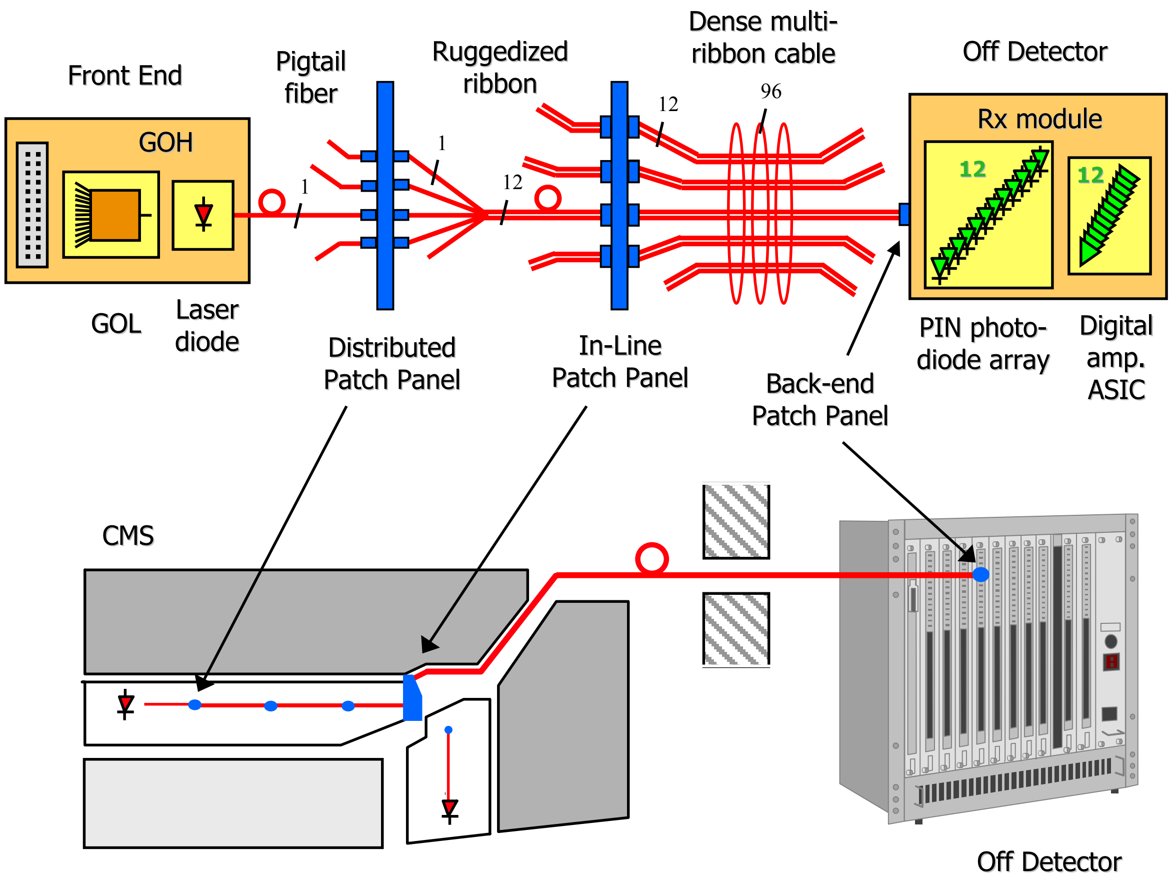

Figure 1. Data Link system block diagram.

2. Requirements

This section adds detail to the above scope.

2.1 Function

In general, the Data Link is required to transfer data from the ECAL Front End boards in digital electronic parallel form to Off Detector boards in digital electronic serial form. Optical technology is selected to perform this transfer, due to the large magnetic field, high radiation levels and potentially high levels of electromagnetic noise within the detector.

2.2 Performance

The performance parameters of the Data Link include the following. The Data Link must be able to:

1. accept 16-bit parallel data in electronic TTL form at a rate of 40 MHz (640 Mb/s overall), being provided the 40 MHz clock at the transmitter end
2. provide the data at the receiver output in serial electronic form at CML levels and with coding consistent with the deserializer chosen (and within the options provided for by the GOL)
3. provide the data at the receiver output in a sufficiently clean form in terms of jitter, amplitude and quality of eye diagram that it does not induce loss of data bits at the deserializer
4. when integrated with Front End and Off Detector electronics (including notably the deserializer), be characterized by a bit error rate (BER) of typically less than 10^{-12}

2.3 Environment and Ageing

In order to fulfill the above requirements, the Data Link must, among other considerations, be negligibly functionally affected by parameters of the operating environment where relevant, including:

1. magnetic field of 4 T
2. hadronic fluence of $3\times10^{14}/\text{cm}^2$
3. gamma dose of 1.5×10^5 Gy
4. electromagnetic noise levels to be determined
5. temperature range of 10°C - 35°C
6. operating life of 10 years

With respect to temperature, the Data Link must have access to sufficient cooling (both on and off detector) such that heat generated by its own components as well as components of neighboring systems does not affect its functioning.

2.4 Interfaces

In general, the Data Links must interface physically and electronically at the Front End boards and Off Detector boards, and in between must interface physically with other parts of the detector in a manner consistent with ECAL and CMS cabling and routing constraints.

2.4.1 Electronic Interfaces

The Data Link must receive from the Front End board 16-bit parallel data plus the 40 MHz clock in electronic TTL form, via a connector joining the Front End board and the opto-hybrid. The clock must have a sufficiently low level of jitter such that it does not induce loss of data bits at the deserializer.

The Data Link must deliver this data in serial electronic CML form as output from the receiver on the Off Detector board. The protocol by which the data is encoded is yet to be determined. G-Link and 8-bit/10-bit are the two candidates possible with the GOL. In 16-bit operation, both imply a data rate of 800 Mb/s output from the receiver (including encoding bits).

2.4.2 Mechanical Interfaces

The Data Link interfaces physically with other systems and structures in the following places:

1. At the Front End board, via an electrical connector and a mounting clip connecting the FE board to the opto-hybrid
2. At the Off Detector board, via soldered connections of a number of receiver modules surface mounted onto each board
3. Through the space that the pigtail fibers occupy, including any necessary support structures, such that the fibers are not excessively stressed
4. At the service trays or wall structure of the supermodule or dee, where the distributed patch panels will be installed
5. Through the space that the 12-fiber ruggedized ribbons will occupy, including any necessary support structures, such that the ribbons are not excessively stressed
6. At the outer end of the supermodule (barrel), or in suitable places to be defined (endcap), where the in-line patch panels will be installed
7. Through the space that the dense multi-ribbon cable will occupy, including any necessary support structures, such that the cable is not excessively stressed

In the above, “such that the object is not excessively stressed” means that the object must not be subjected to pressure, extension, bending or torsion beyond its specifications.

3. Data Link System Description

The Data Link system is illustrated in Figure 1. By nature it is a distributed system at the Front End, with two (Barrel) or six (Endcap) opto-hybrids connected to each Front End board. Pigtail fibers from the opto-hybrids are fanned in to 12-fiber ruggedized ribbon via an adaptor at the distributed patch panel, as soon as practical within the detector volume. Ruggedized ribbons are themselves fanned in to dense multi-ribbon cable containing eight 12-fiber ribbons via another adaptor at the in-line patch panel, located at the edge of ECAL. The cable carries the data to the counting room, where each of its ribbons is connected to a 12-channel receiver surface-mounted on the Off Detector board, via a connector at the back-end patch panel.

Ideally, the system implementation would result in a minimum of dark fiber and dark receiver channels. To some extent, this can be insured by combining the maximum number of channels possible into each ruggedized ribbon within a supermodule or dee. For reasons of modularity and reliability, it is not planned to route any ribbon or cable from any supermodule or dee to another, nor is it planned to carry the data from the detector in anything other than dense multi-ribbon cable[1], which affords it the maximum physical

[1] One provisional plan for the Endcap does indeed call for ruggedized ribbon to be routed through the end of the physical Endcap to in-line patch panels at the cable chain. The modularity of multi-ribbon cables within the Endcap is unlikely to be altered for this scheme, however.

protection. Therefore it will not be possible to achieve 100% fiber and receiver channel efficiency. As will be discussed later, dark fiber ribbon may serve as spares.

3.1 Components

In this section, the components of an individual data link are described.

3.1.1 Transmitter Opto-hybrid

The transmitter of the Data Link is the GOL Opto-hybrid (GOH), a single-channel opto-hybrid consisting of an electrical connector to the Front End board (Matsushita NAIS connector model no. CON50P-AXN450330S), a mounting clip, the GOL [1] serializer and laser driver chip and a laser diode, all mounted on a PCB incorporating the necessary circuitry. The layout of the front of the PCB is shown in Figure 2. The design and production of the PCB and the integration of all components into the GOH are part of the Data Links project.

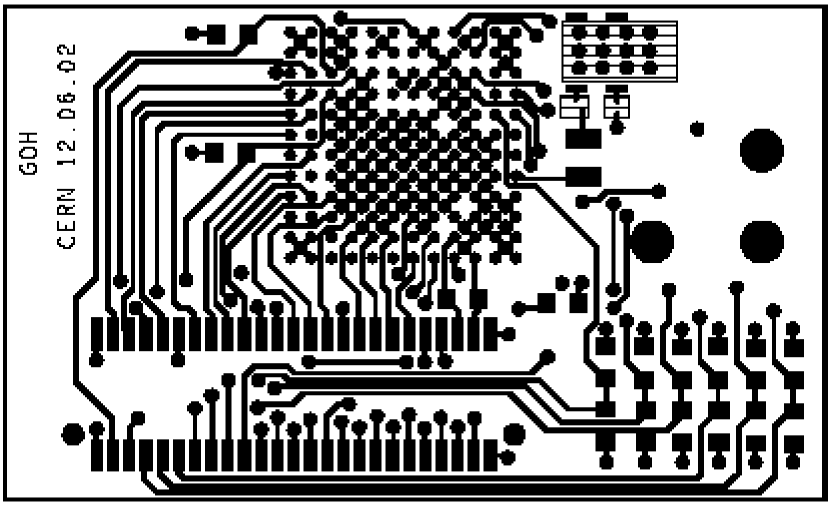

Figure 2. GOH PCB layout

The GOH will be oriented with the maximum possible number of components on the side facing the Front End board in order to protect the laser diode and its fiber. To provide electromagnetic shielding, a ground plane will be incorporated into the side of the GOH facing away from the Front End board. The schematic diagram of the GOH is shown in Figure 3.

The qualification of the effects of radiation damage on the GOL and the laser diode have been carried out by the CERN MIC group [1] and the Tracker Optical Links group [2], respectively.

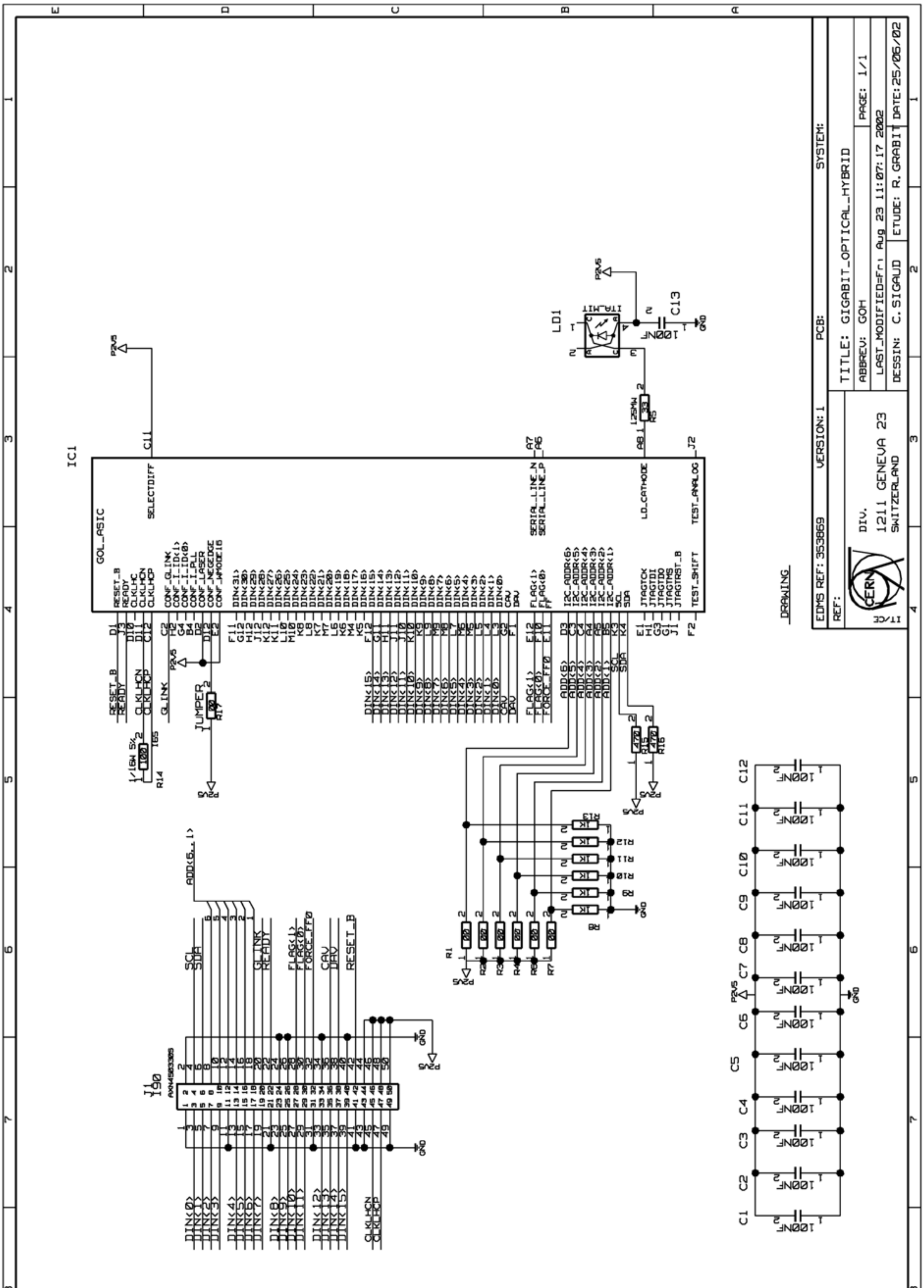

Figure 3. Schematic diagram of the GOH.

The radiation qualification of the assembled GOH, however, is part of the ECAL Data Links project. Different possible facilities for gamma and hadronic radiation tests are presently being investigated.

3.1.1.1 GOL

The GOL [1] chip was developed by the CERN Microelectronics Group specifically to operate reliably in the radiation conditions expected in the LHC experiments. It was implemented employing 0.25 μm CMOS technology and radiation tolerant layout practices. It is contained in a 12 × 12 BGA package. The GOL will be produced and tested under the supervision of the Microelectronics Group.

It has a user-selected data transmission rate of either 16 or 32 bits per cycle of the 40 MHz LHC clock. For each transmission rate, it supports both the G-Link and 8-bit/10-bit encoding protocols. Each of these protocols employs two bits for encoding per eight data bits, resulting in serial data transmission rates of 800 Mb/s and 1.6 Gb/s for 16- and 32-bit operation, respectively.

The maximum rated free-air operating temperature of the GOL is 75°C. The GOL itself dissipates 300 mW in operation. It is expected that air-cooling by unforced convection as well as thermal conduction via the GOH connector pins will be sufficient to satisfy this requirement.

3.1.1.2 Laser Diode

The laser diode employed was developed for the Tracker analog data links, as described in the Tracker Laser Transmitter specification document [3]. It is designed and produced by ST Microelectronics. It consists of an edge-emitting laser diode emitting light (λ = 1310 nm) into a single-mode optical fiber bonded to the transmitter package and exiting the package in pigtail form. The transmitter package is glued and wire-bonded to the GOH. The engineering drawing of the laser diode is shown in Figure 4.

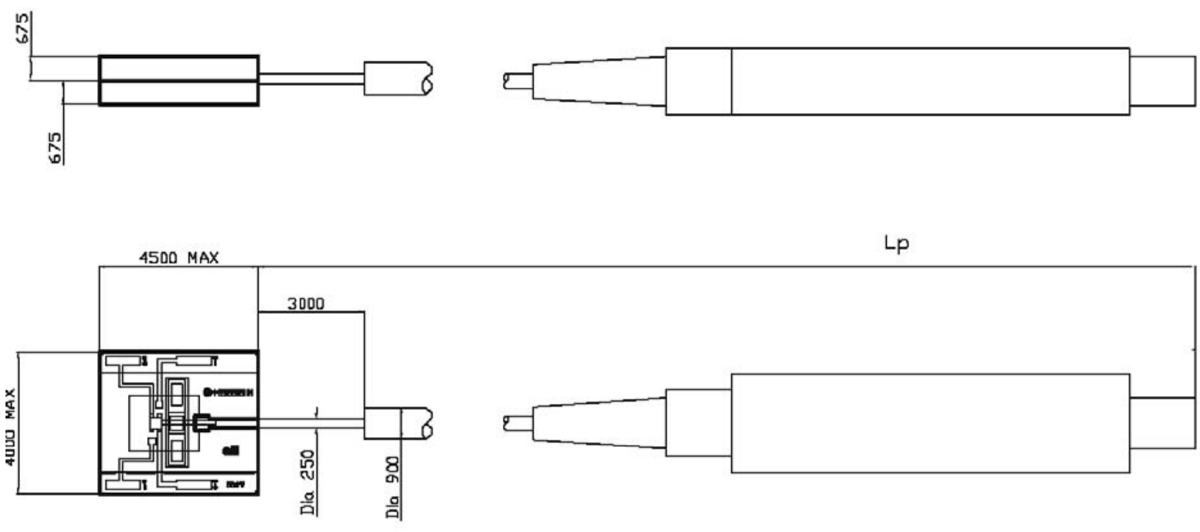

Figure 4. Laser diode engineering drawing.

The pigtail optical fiber is provided by Ericsson. The Tracker laser transmitter specifications [3] provide for 10 different possibilities of lengths of pigtail fiber between 0.3 m and 2.0 m, as shown in Table 1. It is believed that these will be sufficient for use throughout ECAL. The pigtail is terminated in a MU-type connector based on a 1.25 mm ferrule. This task is carried out by Sumitomo.

Pigtail fiber lengths
35 cm
56 cm
70 cm
80 cm
88 cm
100 cm
110 cm
120 cm
150 cm
200 cm

Table 1. Pigtail fiber lengths provided for in Tracker specifications

The laser diode has a maximum rise time specification of 0.5 ns and a typical rise time specification of 0.3 ns, consistent with operation at 800 Mb/s. Figure 8 shows the eye diagram of the laser diode mounted on the GOL evaluation board and driven at 800 Mb/s. A 20 Ω – 30 Ω series resistance is employed to improve the impedance match between GOL and laser diode. A more complex matching network could further improve the eye diagram.

The laser diode is compliant with a maximum magnetic field of 4 T, a maximum operating temperature of 70°C, hadronic fluence of up to $3\times10^{14}/cm^2$ and a maximum gamma dose of 1.5×10^5 Gy. All of these are consistent with the expected environmental conditions on the GOH and within ECAL in general.

3.1.2 Receiver

The receiver of the Data Link is the CML 12-channel NGK digital receiver module, POR10M12SFP. It employs the identical technology of the standard 8-channel 1.25 Gb/s POR10K08SFPA receiver of NGK. The 8-channel version has been used for all tests to present. An analog version of the 12-channel receiver, with the digital amplifying ASIC replaced by an analog ASIC, is the one used by Tracker for their analog data links.

The engineering drawing of the 12-channel NGK is shown in Figure 5. The pin assignments are shown in Table 2.

The optical interface is via an MPO12 connector. The receiver module is surface mounted on the Off Detector board (DCC and TCC). It is envisaged that up to seven such receiver modules will be contained in each Off Detector board [4].

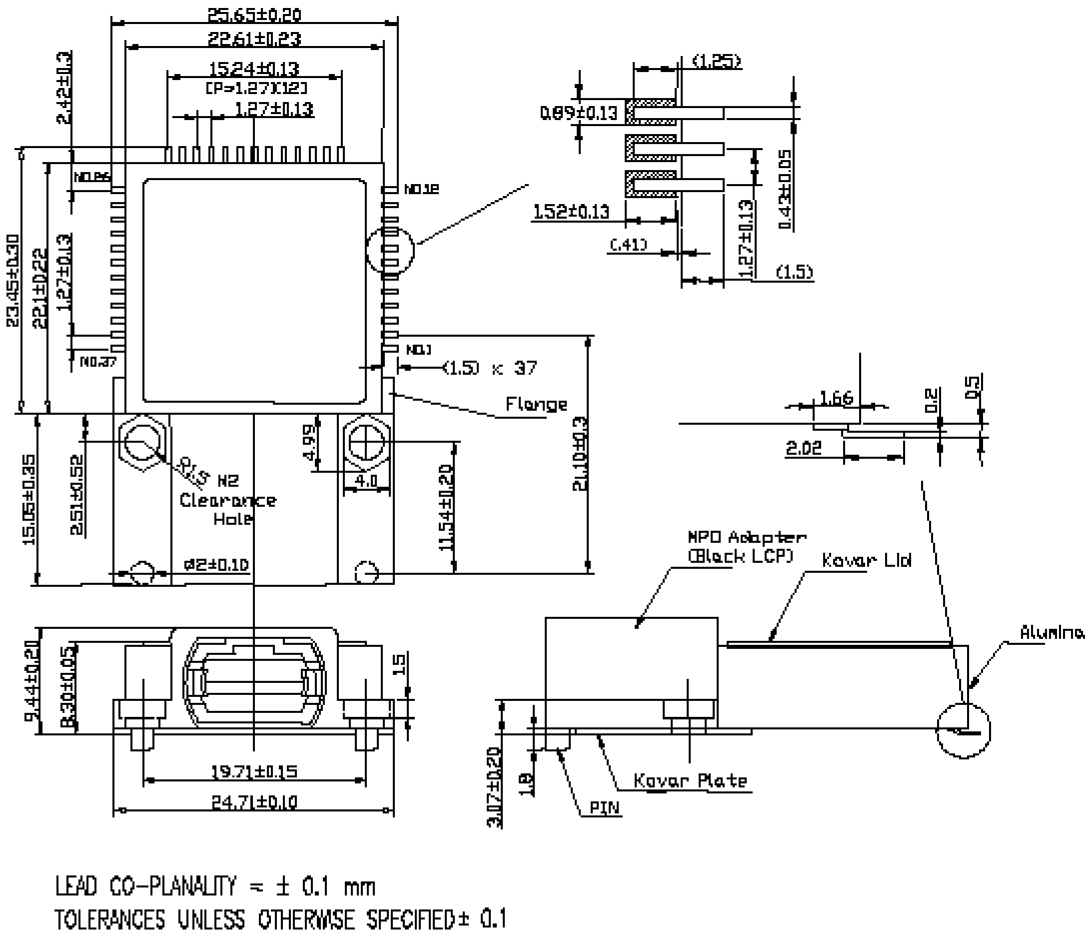

Figure 5. Engineering drawing of the 12-channel digital NGK receiver module.

12 Channel Rx – POR10M12SFP

Pin #	Name	Logic Level	Description
1	V_{CC1}	–	Power Supply (Vcc)
2	V_{CC2}	–	Power Supply (Vcc)
3	GND	–	Ground
4	N/C	–	Left Open
5	LOS	LVTTL out	Loss of signal
6	DO0P	–	Data output 0 non-inverted
7	DO0N	–	Data output 0 inverted
8	DO1P	–	Data output 1 non-inverted
9	DO1N	–	Data output 1 inverted
10	DO2P	–	Data output 2 non-inverted
11	DO2N	–	Data output 2 inverted
12	GND	–	Ground
13	DO3P	–	Data output 3 non-inverted
14	DO3N	–	Data output 3 inverted
15	DO4P	–	Data output 4 non-inverted
16	DO4N	–	Data output 4 inverted
17	DO5P	–	Data output 5 non-inverted
18	DO5N	–	Data output 5 inverted
19	GND	–	Ground
20	DO6P	–	Data output 6 non-inverted
21	DO6N	–	Data output 6 inverted
22	DO7P	–	Data output 7 non-inverted
23	DO7N	–	Data output 7 inverted
24	DO8P	–	Data output 8 non-inverted
25	DO8N	–	Data output 8 inverted
26	GND	–	Ground
27	DO9P	–	Data output 9 non-inverted
28	DO9N	–	Data output 9 inverted
29	DO10P	–	Data output 10 non-inverted
30	DO10N	–	Data output 10 inverted
31	DO11P	–	Data output 11 non-inverted
32	DO11N	–	Data output 11 inverted
33	N/C	–	Left Open
34	N/C	–	Left Open
35	GND	–	Ground
36	V_{CC2}	–	Power Supply (V_{CC})
37	V_{CC1}	–	Power Supply (V_{CC})
Case	GND	–	Ground

Table 2. Pin assignments for the 12-channel digital NGK receiver.

3.1.3 Fiber, Connectors and Adaptors

In this section, the fiber, connectors and adaptors employed in the data link are described.

3.1.3.1 Fiber

The optical fiber employed for all components is single-mode, 9/125/250/900 µm, tight-buffered jacket [3]. It is provided by Ericsson.

3.1.3.2 Distributed Patch Panel

The MU connector of the opto-hybrid pigtail plugs into a MU-SR (Simplified Receptacle) adaptor at the distributed patch panel. The adaptor is provided by Sumitomo. The design and installation of the patch panel itself will be carried out by the Regional Center/Cabling Team.

3.1.3.3 Ruggedized Ribbon

On the opposite side of the distributed patch panel is 12-fiber ruggedized ribbon. This ribbon consists of a 12-fiber ribbon protected by aramide yarn and sheathed with polyethylene [3]. It has a minimum bending radius of 3 cm in one plane. The upstream end of this ribbon is fanned out and each fiber is terminated with a MU-SR connector based on a 1.25 mm ferrule.

An engineering drawing of a ruggedized ribbon fanout is shown Figure 6.

3.1.3.4 In-Line Patch Panel

The downstream end of the ruggedized ribbon is terminated with an MFS12 connector housing an MT12 ferrule. This is connected to an MFS adaptor at the in-line patch panel. As for the distributed patch panel, the design and installation of the in-line patch panel itself will be carried out by the Regional Center/Cabling Team.

3.1.3.5 Dense Multi-Ribbon Cable

On the opposite side of the in-line patch panel is dense multi-ribbon cable. This cable contains a stack of eight 12-fiber ribbons encased in a rugged, halogen-free and flame-retardant sheath. It has a minimum bending radius of 8 cm in one plane. The ribbons are broken out of the cable on both ends. On the upstream end, they are terminated in an MFS12 connector housing an MT12 ferrule. On the downstream end, they are terminated in an MPO12 connector, also housing an MT12 ferrule.

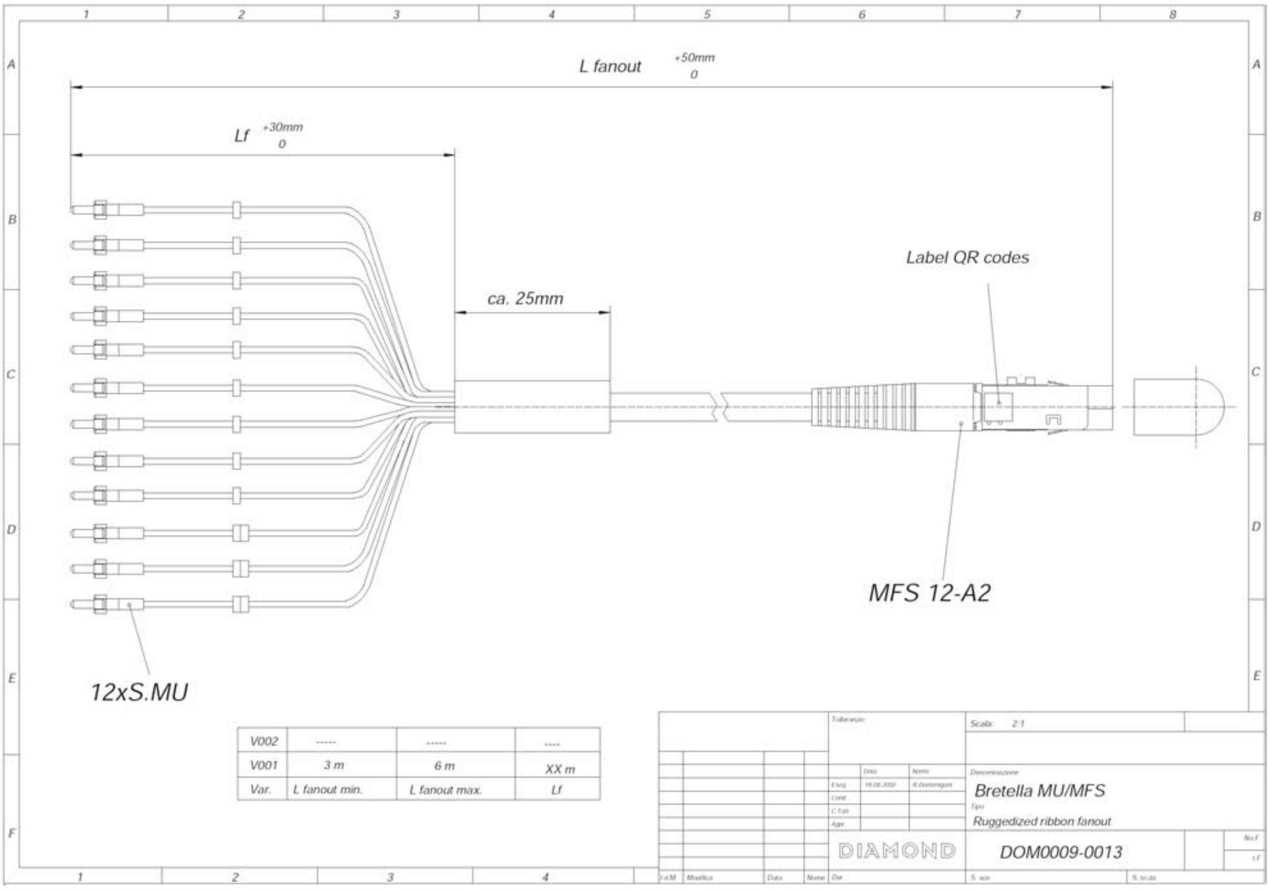

Figure 6. Engineering drawing of a ruggedized ribbon fanout.

3.1.3.6 Back-End Patch Panel

The MPO12 connector of each ribbon is connected to a 12-channel NGK digital receiver module at the back-end patch panel in the counting room. As for the other patch panels, the design and installation of the in-line patch panel itself will be carried out by the Regional Center/Cabling Team.

3.2 Fiber Modularity, Routing and Patch Panel Locations

The planned readout modularity for all of ECAL is one Front End board per submodule of 25 crystals. In the Barrel this corresponds to one data link plus one trigger link. In the Endcap it corresponds to one data link plus five trigger links.

In this section the fiber modularity, routing and patch panel locations are discussed separately for the Barrel and the Endcap.

3.2.1 Barrel

In the Barrel, a supermodule consists of one “long module” of 20 submodules and three “short modules” of 16 submodules each. Each module consists of two symmetric “half-modules”, each having access to a cable tray running the length of the supermodule.

As mentioned above, it is envisaged that all fibers arriving at a distributed patch panel in the Barrel will originate from within the same supermodule. A provisional scheme calls for pairs of patch panels (one data, one trigger) to be attached at six locations within each supermodule, as illustrated in Figure 7 by W. Lustermann.

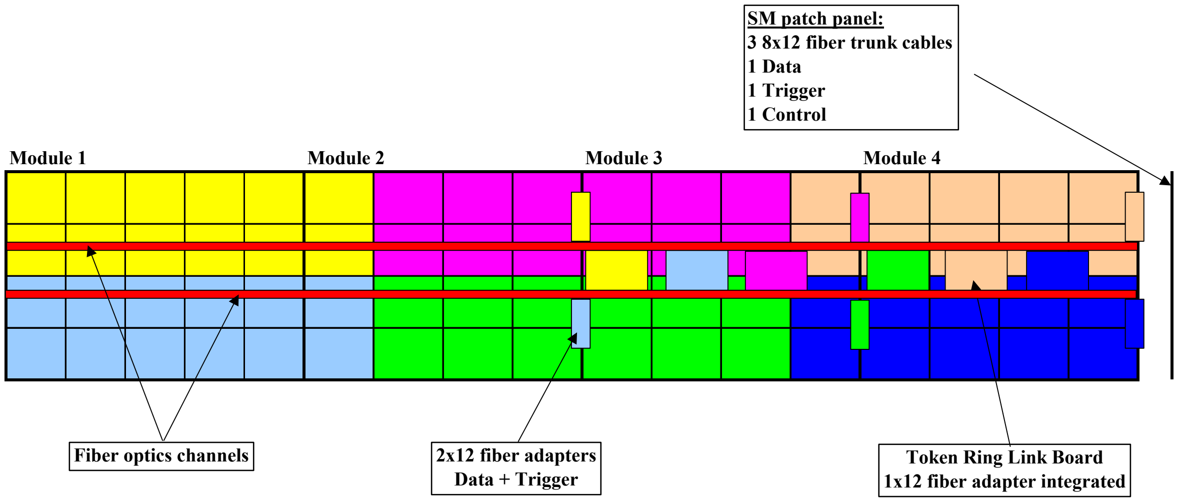

Figure 7. Provisional scheme for locations of patch panels within a supermodule.

Three pairs would serve the left half of the supermodule; the other three would serve the right half symmetrically. Within each half-supermodule, the locations proposed would be (laterally) near the supermodule service trays, and (lengthwise) at (a) the boundaries between modules 2 and 3, (b) between modules 3 and 4, and (c) at the outer edge of the supermodule. The service trays run the length of the supermodule, and would serve as the principle conduit for all pigtail fibers and ruggedized ribbons.

Each distributed patch panel would then include two MU-SR adaptors, serving up to 12 channels each of data and trigger. Patch panel adaptors at locations (a) and (b) would serve 12 fibers each, while patch panels at location (c) would serve 10 fibers. In this fashion the 68×2 channels of data + trigger needed for each supermodule could be completely served by 6×2 ruggedized ribbon cables. One dense multi-ribbon cable would be needed for data and another for trigger. Each would have two leftover ribbons. In the case of data, one of the leftover ribbons could be used to carry data for the monitoring system of the laser calibration system (which requires two channels). Both data and trigger would then have at least one spare multi-ribbon cable per supermodule.

In this scheme all ruggedized ribbons would arrive at the outer edge of the supermodule, where the in-line patch panel would be located.

3.2.2 Endcap

The locations of the distributed patch panels for the Endcap are yet to be determined. The numbers of fibers and cables are somewhat clearer. Each Endcap Front End board generates one channel of data and five channels of trigger primitives. This amounts to 78 data channels per quadrant, corresponding to one multi-ribbon cable and seven or eight ruggedized ribbon cables, depending on the number of receiver modules implemented on each Endcap DCC (one DCC of seven Rx or two DCC of four Rx each) [4]. The five channels of trigger primitives per Front End board give rise to 390 trigger channels per quadrant, corresponding to a minimum of 33 ribbon cables and five multi-ribbon cables.

Similarly to the Barrel, it is envisaged that the in-line patch panel will be located at the outer edge of the quadrant.

4. Deliverables

The types and quantities of the deliverables from the project are listed in Table 3. The quantities listed take into account the additional quantities needed to compensate for loss due to dark fiber and receiver channels, based on the modularity discussion in section 3.2.

Additional quantities needed for assembly yield inefficiency[2], spares, system and beam tests and detailed acceptance tests are described in Table 4 and taken into account in Table 7. Similarly to the plan for Tracker, spares are not initially planned to be ordered. If the assembly yield is better than the 90% estimated here, the excess produced may be considered spares. Otherwise, spares may be ordered via late purchase options in the contracts.

One additional deliverable is the GOH acceptance test setup to be developed within the project and provided to the manufacturer. The setup is described in section 5.2.

System Quantities	Barrel Data	Barrel Trigger	Total Barrel	Endcap Data min	Endcap Data max	Endcap Trigger min	Endcap Trigger max	Total Endcap min	Total Endcap max	Total ECAL min	Total ECAL max
GOH	36x68	36x68	4896	8x78	8x78	8x78x5	8x78x5	3744	3744	8640	8640
Distributed Patch Panel	Same as number of Receiver modules									796	852
Terminated Ruggedized Ribbon	Same as number of Receiver modules									796	852
In-Line Patch panel	Same as number of Multi-ribbon cables									120	120
Terminated Multi-ribbon Cable	36	36	72	8	8	8x5	8x5	48	48	120	120
Digital Receiver module	36x6	36x7	468	8x7	8x8	8x34	8x40	328	384	796	852

Significance of the quantities

36 = number of supermodules	68 = GOH per supermodule, data or trigger
8 = number of quadrants	78 = GOH per quadrant, data
	78x5 = GOH per quadrant, trigger
6 = Rx modules per supermodule, data	
7 = Rx modules per supermodule, trigger plus laser calibration	
7 = Rx modules per quadrant, data, scheme 1	8x34 = min Rx mods per quadrant, trigger plus laser calibration
8 = Rx modules per quadrant, data, scheme 2	8x40 = max Rx mods per quadrant, trigger plus laser calibration

Table 3. Types and quantities of deliverables

[2] We will in all cases begin with certified components. Some inefficiency may be expected in the assembly process, however, in particular due to the mounting of the GOL BGA and the wire-bonding of the laser diode.

Item	Additional quantity
Yield inefficiency[2]	0% - 10% of listed quantities
Spares	As needed (late purchase option in contract)
System/beam tests	Approximately 250 links
Acceptance tests	1% - 5% of listed quantities

Table 4. Additional quantities of deliverables needed.

5. Development Plan and Technical Progress

5.1 Initial Data Link Tests

The first setup has evolved from the existing GOL and ECAL Rose readout hardware. The Rose 12 readout board is driven by a Labview program running in a PC. The 40 MHz output clock from the Rose is connected to a GOL evaluation board with a pigtailed laser diode incorporated. The GOL is programmed to drive the laser diode at 800 Mb/s. The laser diode output is connected to an optical head and the output signal observed on a LeCroy oscilloscope, as shown in Figure 8.

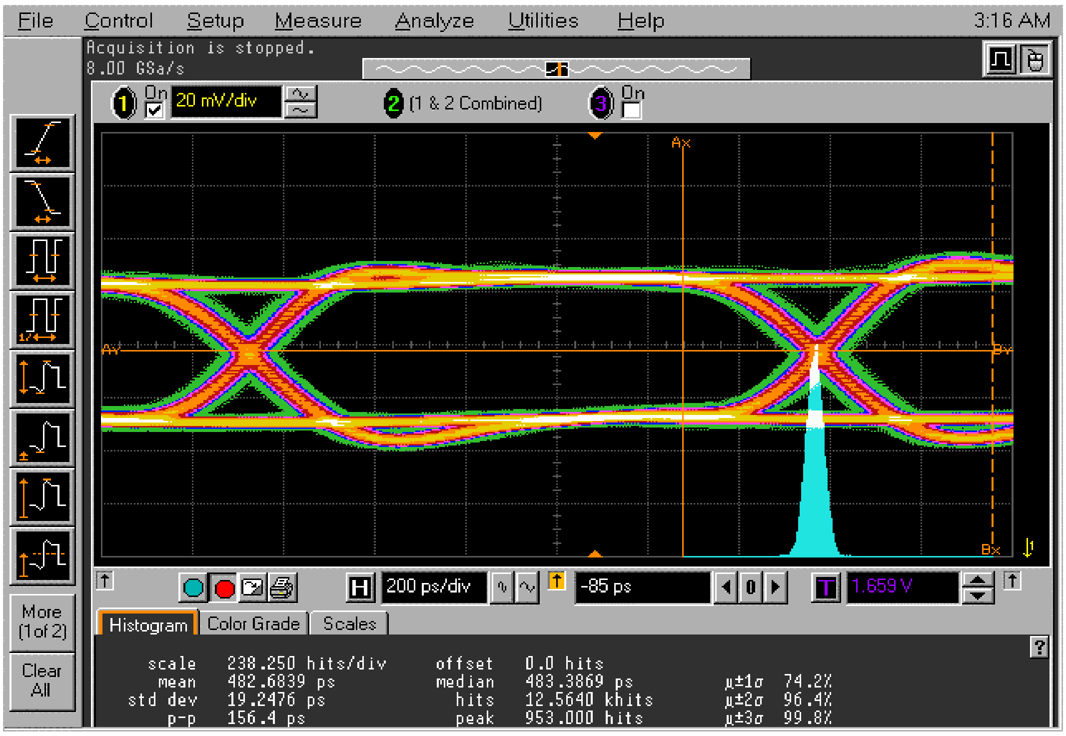

Figure 8. Eye diagram of laser diode mounted on GOL evaluation board and driven at 800 Mb/s.

The optical power measured for the two logic levels as a function of GOL I2C laser diode bias current setting is shown in Figure 9. The threshold current for the laser diode is seen near the I2C setting 16 for logic level 0.

The GOL generates a stream of bits representing a sawtooth pattern of sequential bit-packed words, and the laser diode output is connected to a receiver on a daughter board on the Rose board. The output bit stream from the receiver is compared to the expected sawtooth pattern by the Labview program and the resulting bit error rate is calculated.

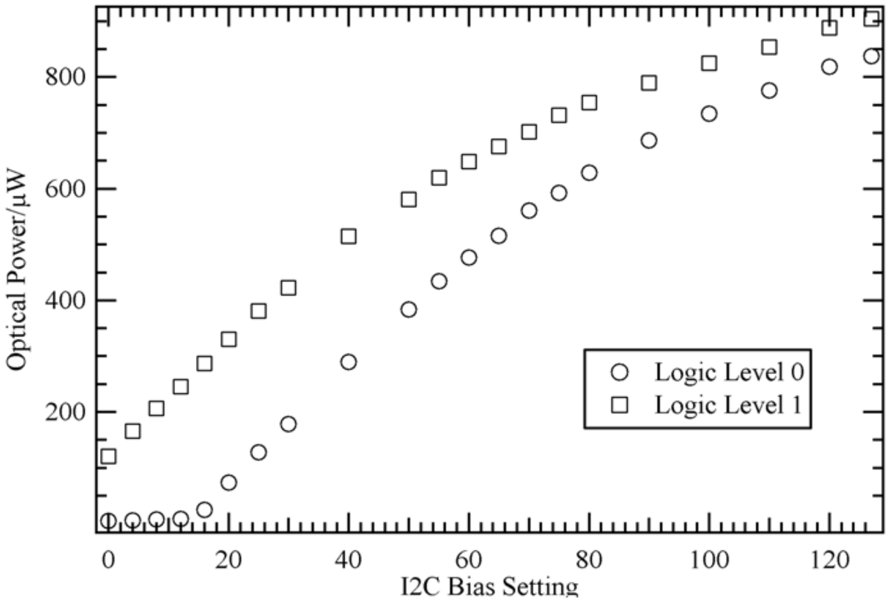

Figure 9. Optical power level vs. GOL I2C bias current setting for the two logic levels.

The first tests have been performed with the original Paroli receiver of the Rose system, on its daughter board on the Rose board. Subsequently a daughter board has been designed within the project for the 8-channel NGK receiver, using the Paroli daughter board as the starting point. The results shown here are for the NGK receiver.

The bit error rate has been measured for various levels of attenuation inserted between the laser diode and the receiver, for different GOL I2C settings of laser driver bias current. The results are shown in Figure 10. They show a wide operating margin of optical power with respect to the typical -6dBm operating point.

The principal disadvantage of this setup is its relatively low data-taking rate, due to the reset time of the Rose board between word readings. It is possible to compare only about 10^9 bits per day.

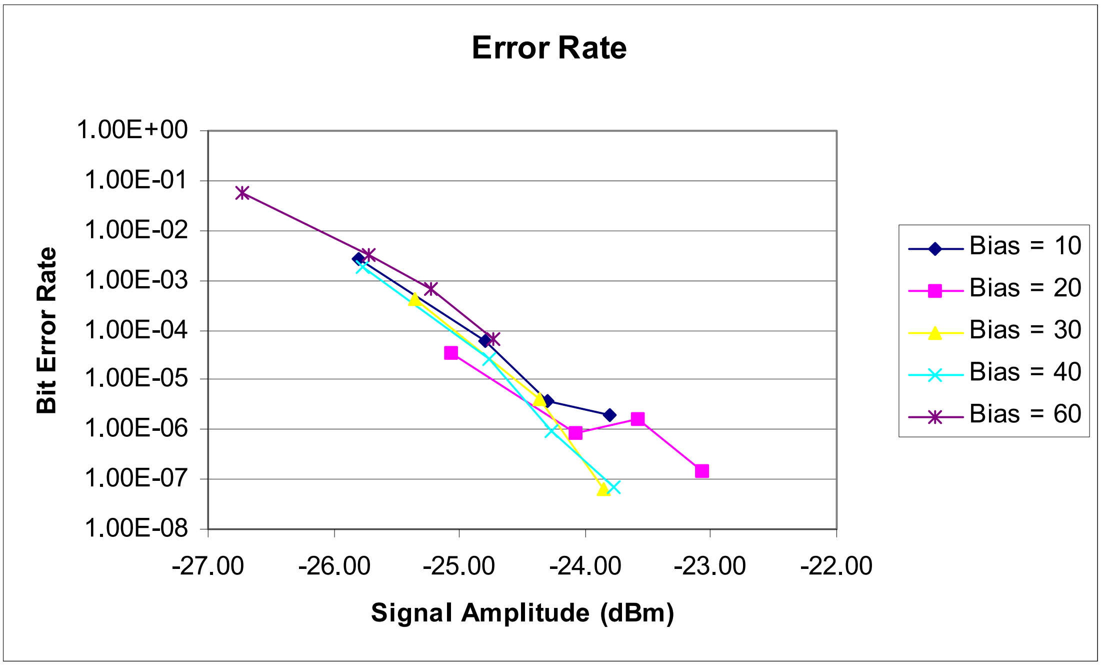

Figure 10. Observed bit error rate vs. signal amplitude, for different GOL I2C settings.

5.2 GOH

We have completed the GOH design and a prototype lot of 12 PCB's has been produced at CERN. The population of the prototypes is also taking place at CERN to take advantage of expertise already developed for the Tracker analog opto-hybrid, in particular for the wire-bonding of the laser diode. This is expected to be completed early in September.

We will use the BERT system described in section 5.4 to do the design validation and detailed qualification of the GOH prototype, as well as detailed tests of a small sub-sample of GOH during production.

Acceptance tests of the GOH will be performed by the manufacturer using a "standalone GOH test board" which we are developing. This is essentially a GOL evaluation board with the GOL itself replaced with the female part of the GOH connector. With the GOH connected, the combination will have essentially the same functionality as the GOL evaluation board with a laser diode attached, used in the initial link test. It will, however, have the advantage that it will be possible to quickly exchange the GOH connected. The board will be run without any external clock, trigger or other input besides DC power (therefore "standalone"). The laser diode output will be connected to an optical head and the output eye diagram observed on and recorded by an oscilloscope, which will apply a pass-fail mask test that we will develop. The resulting data will be uploaded to a dedicated PC and stored in a database program that we will develop and provide.

The task incumbent on the manufacturer will be, for each GOH, to mount it on the standalone test board, store and analyze the eye diagram, and record the results in the database. The process should require on the order of a few minutes per GOH.

We will develop, test, and deliver the acceptance test setup to the manufacturer, train the manufacturer's staff in its use, and perform on-site service as necessary. We plan to complete this task by the end of Q1 2003.

As mentioned in section 3.1.1, different possible facilities for gamma and hadronic radiation tests of the assembled GOH are presently being investigated.

5.3 12-Channel NGK Receiver

The 1.25 Gb/s 12-channel version of the digital NGK receiver is undergoing final tests by the manufacturer. The pin assignments and preliminary specifications documents already exist. It is expected that the modules and their evaluation board will be available in September. We plan to acquire them as soon as possible.

In the meantime, we have acquired the 1.25 Gb/s 8-channel version and two evaluation boards. As mentioned in section 3.1.2, the 8-channel and 12-channel employ identical technology. The Rose/Labview setup described above has been used to study the 8-channel receiver on its evaluation board, with the laser diode output connected to the evaluation board and the receiver output observed on the oscilloscope. Eye diagrams similar to that in Figure 8 are observed.

We plan to repeat this measurement with the 12-channel receiver and evaluation board as soon as we receive them.

In order to drive several channels of the receiver module simultaneously, we have ordered six additional GOL evaluation boards from the CERN MIC group. These will have pigtailed laser diodes incorporated as was done with the first board, as described in section 5.1. We will use them to characterize the receiver and look for possible crosstalk between receiver channels, by observing the eye diagram of one channel while transmitting data through several.

Such a setup may form the basis of a quick acceptance test to perform on all receiver modules if this is deemed necessary.

We will also construct a second BERT system as described in section 5.4 to perform detailed acceptance tests on a small sub-sample of receivers modules during production. We plan to begin construction of this setup once the first BERT setup is fully operational. We plan to complete this second BERT system by the end of the year.

5.4 BERT System

We are developing a Bit Error Rate Test (BERT) system, which should be the most complex and versatile test system of the project. The advantages of the previously-mentioned test systems are their simplicity and speed of development and therefore the time that could be gained on evaluating components. For this reason we plan to simultaneously develop the BERT along with the other systems.

We are developing the BERT based on the GIII data acquisition system developed by the CMS DAQ group. It involves 64-bit PCI-based transmitter and receiver cards. Each card sits in a PCI slot of an otherwise standard PC, and is controlled by a Linux program. Each card has an Altera Apex chip programmed to communicate with the PC via the PCI bus as well as through two 64-pin connectors. We will develop an adaptor to be able to connect one or more GOH to one of these connectors. The output of the GOH laser diode(s) will then be connected to a receiver module on its manufacturer evaluation board. Output from one or more of the receiver channels will be connected to deserializer module(s) on their manufacturer evaluation board(s). Output from each deserializer board will then be connected to a GIII receiver card via another adaptor that we will develop.

We will then write any additional control or user interface software necessary as well as the analysis software to compare the input and output signals and calculate and display the bit error rate.

A block diagram of the proposed BERT system is shown in Figure 11.

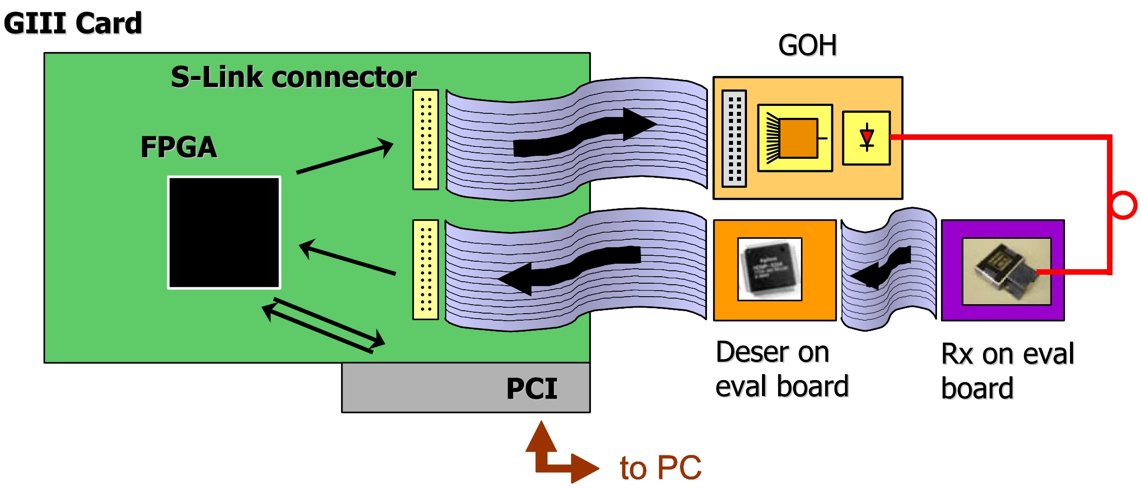

Figure 11. Block diagram of the proposed BERT System based on a GIII card.

We plan to test both the Agilent 1034A G-link and the TI TLK1501 8-bit/10-bit deserializers in the BERT system. As stated in section 1, we regard the final choice of deserializer and the related choice of protocol to be the responsibility of the Off Detector group, possibly with the benefit of knowledge and experience we acquire in the construction and testing of the BERT system.

We plan to complete the first BERT system by the end of October.

5.5 Full Readout Chain Test

We intend to participate in a test of the full readout chain, from Front End to Off Detector, using the final versions of all components when these become available. We consider it the responsibility of these groups to provide their corresponding electronics and that the responsibility to construct the setup and perform the tests will be shared by the three groups, with the assistance of the Electronics Integration group where relevant.

We recommend to complete this test prior to the installation of electronics in SM0 and SM1, ideally by the end of Q1 2003.

5.6 Summary of Development Setups

A summary showing the purpose of each test device or setup being developed is shown in Table 5. The hardware needed to complete each setup is described in the discussions above. In addition, we plan to develop a full chain test of the Data Link prior to the full readout chain test mentioned in section 5.5.

Device/setup	**Measurements**	**Purpose**
GOH:		
Standalone GOH test board	Eye diagram	Manufacturer acceptance test
GIII-based BERT	BER, eye diagram	Design validation, detailed qualification
12-channel receiver:		
N GOL evaluation boards	Eye diagram	Characterize Rx, look for crosstalk, possible quick acceptance test
GIII-based BERT	BER, eye diagram	Detailed qualification

Table 5. Summary of the development setups.

6. Prototype and Production Quality Plan

6.1 Manufacturing plan

The only deliverable component manufactured within the project is the GOH. At present, potential manufacturers are being investigated.

Other components are either off-the-shelf or are manufactured for Tracker and described in their specification documents.

6.2 Test plan

As mentioned in section 5.2, the GOH will be tested by the manufacturer using a test setup, which will be developed within the project and delivered to the manufacturer.

We may subject all receiver modules to a quick acceptance test based on a measurement of the eye diagram if this is deemed necessary, as described in section 5.3.
.

In addition, we plan to perform detailed tests on a small sub-sample of both GOH and receiver modules during production, as described in sections 5.2 and 5.3.

6.3 Installation plan

The installation and post-installation test of all components of the Data Link will be carried out by the Regional Center and CMS Integration Team, with advice and supervision from the Data Links group as necessary.

6.4 Maintenance plan

It is not foreseen to be necessary to perform maintenance on any component or aspect of the data link. However, should maintenance be necessary, the system is designed in such a way that faulty components can be easily replaced or spare fiber channels can be used.

7. Project Management

7.1 Personnel

The Project team members, in alphabetical order, are listed in Table 6.

Name	E-mail	Telephone
David Bailleux	david.bailleux@cern.ch	71674, 76172, 164241
Guy Dewhirst	guy.dewhirst@cern.ch	77546
Alexandre Dolgopolov	alexandre.dolgopolov@cern.ch	76737
James Grahl	james.grahl@cern.ch	78347
Paulo Moreira	paulo.moreira@cern.ch	77336
Margherita Obertino	obertino@fnal.gov	76737
Alexander Singovski	alexander.singovski@cern.ch	71674, 76143, 163369
François Vasey	francois.vasey@cern.ch	73885, 163707

Table 6. Project team members.

7.2 Project plan

The broad-brush project schedule and staffing plan is shown in Figure 12.

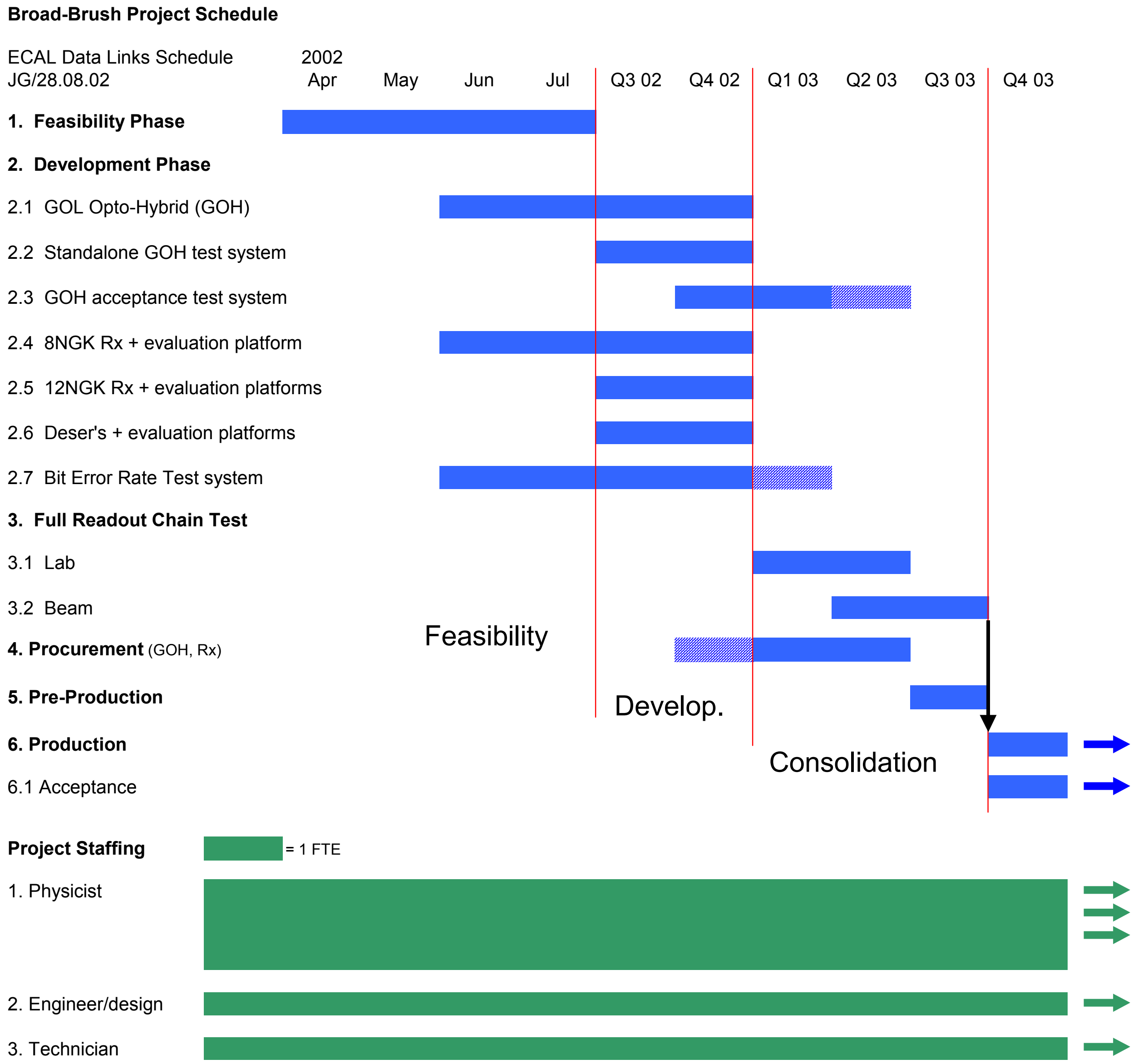

Figure 12. Broad-brush project schedule and staffing plan.

7.3 Costs

The baseline cost estimate of a single data link is shown in Figure 13. A calculation of the entire system cost, based on quantities described in Table 3 and Table 4, is shown in Table 7. The baseline entire system cost is therefore estimated at $1.73 M.

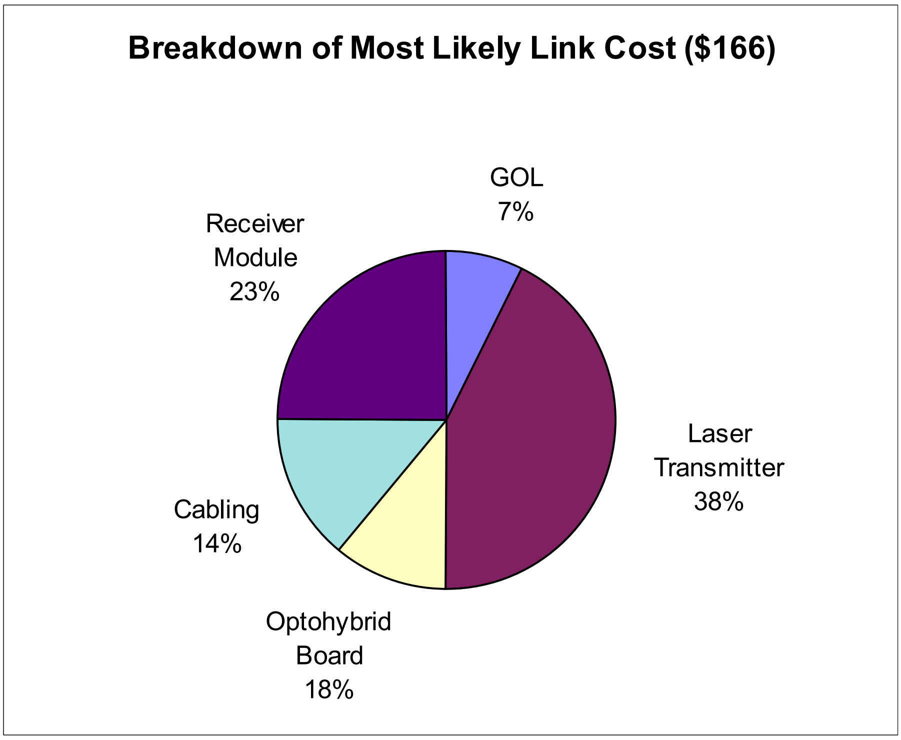

Figure 13. Breakdown of baseline cost of an individual data link.

System Costs	**Unit USD per item**	Quantity Sub-tot. min	max	Assembly Yield	Accept. Tests	Quantity Total min	max	**Total USD per item** min	max
GOH	101.20	8640	8640	1.10	1.05	9936	9936	1,005,573	1,005,573
Distributed Patch Panel	28.73	796	852	1.00	1.01	804	861	23,096	24,721
Terminated Ruggedized Ribbon	107.91	796	852	1.00	1.01	804	861	86,752	92,855
In-Line Patch panel	7.81	120	120	1.00	1.02	122	122	953	953
Terminated Multi-ribbon Cable	1161.01	120	120	1.00	1.02	122	122	141,644	141,644
Digital Receiver module	500.00	796	852	1.05	1.05	876	937	437,800	468,600
Total								1,695,818	1,734,346

Table 7. Baseline estimate of the entire Data Link system cost.

In addition, the cost of the development program is estimated to be $0.08 M. The cost of 250 data links intended for system/beam tests is estimated to be $0.07 M, where a factor of 1.5 has been applied due to the small quantities of the initial orders.

The total baseline project cost is therefore estimated to be about $1.88 M.

8. References

[1] P. Moreira et al., "GOL Reference Manual", preliminary v. 1.2, CERN EP/MIC (2002). http://proj-gol.web.cern.ch/proj-gol/

[2] K. Gill, et al., "CMS Tracker Optical Links Quality Assurance Manual", v. 1.2, CERN EP/CME (2001). EDMS CMS-TK-MA-0001

[3] F. Vasey, "CMS Tracker Optical Readout Link Specification, Part 2.2: Laser Transmitter", v. 3.5, CERN EP/CME (2002). EDMS CMS-TK-ES-0004

[4] J. Varela, "ECAL Off Detector Electronics", talk presented at the ECAL Electronics Feasibility Study Meeting at CERN (30 May 2002). http://cmsdoc.cern.ch/~jlfaure/OD_Web_Folder/June-02/ECAL-OD-JV-300502.PDF