Temperature Variation Effects in a Reflective Electroabsorption Modulator-Based Network Architecture for Particle Physics Applications

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Abstract: We describe a network architecture for bidirectional transfer of information in the upgraded design of the Large Hadron Collider at CERN. The highly asymmetric, upstream-intensive traffic and the requirement for low mass, low power and radiation hard front-end components lead to a non-conventional network design compared to commercial telecommunication networks. Following the description of the network architecture we focus on the temperature sensitivity of the selected front-end component and its impact on system performance.

1 Introduction.

The evolution of experimental physics has always been coupled with technological advances. Optical fiber communication technologies are prominent examples as they enable transfer of the large volumes of data generated by particle physics experiments. The Large Hadron Collider (LHC), the world's largest and most powerful particle accelerator, started routine operation in 2009. Two counter-rotating beams of particles are brought into collision at four points around its 27 km circumference. Each collision point is surrounded by special detectors, called "experiments", designed to detect and reconstruct what happens during the collisions [1]. The planned luminosity upgrade of the LHC to high-luminosity LHC (HL-LHC) will result in increased rate of data production, as well as higher radiation levels. Such increases bring new design requirements for the data links and their components.

Many types of optical links are in use in the LHC experiments, as currently different types of information are carried over different physical links. The forthcoming upgrade provides an excellent opportunity to upgrade and consolidate the current network infrastructure to a more efficient and flexible single one that can transport all types of data [2].

Electroabsorption modulators (EAMs) are seen to be of interest in the particle physics community due to their potential radiation hardness, as well as their low mass and power consumption [3]. Their use was suggested and investigated for the LHC [3], but technological difficulties at the time led to a different solution being chosen. Here the concept of using the EAM for high-energy physics experiments is revisited with a proposal for a new network architecture, based on the use of Reflective EAMs (REAMs). The impact of temperature variation on system performance is discussed. This will be important in this application where both the bulk and power consumption must be limited, which in turn precludes the usual approach of using a thermoelectric element to stabilize the REAM temperature.

This paper is structured as follows; Section 2 briefly describes the proposed network architecture. Section 3 provides the background on operating principles of an EAM that is required to appreciate aspects related to its impact on network performance. Finally, Section 4 explores the impact of temperature variation on REAM operation and the way this affects system performance.

2. Network Architecture.

Table I shows the expected requirements for the upgraded optical links of the HL-LHC. Although different experiments and subdetectors have different networking requirements and although upgrade plans may change, the figures in the table are judged to be sufficient to accommodate transfer of all types of traffic required for the operation of the experiments. The system comprises a high number of nodes (the equivalent of nodes are "users" in a telecommunications network) and therefore it is not feasible to multiplex traffic to all users on the same fiber. It is important to note the strongly asymmetrical nature of this network with the downstream rate being only 10% of that of the upstream.

In the downstream direction most of the information need to be broadcasted, hence resources - fiber and transceivers - can be shared. In the upstream direction, however, the high data rate requirement per user makes multiplexing much more challenging. Such “unusual” network requirements led to the design of the architecture depicted in Figure 1. The downstream transmitter as well as the optical seed, which provides the light to be modulated by the REAM for upstream transmission, are shared. These two components are located in the “counting room”, which is an environment set away from the highly radioactive detector space and is shielded from radiation. An upstream/downstream pair use the same fiber with information being separated using different wavelengths as illustrated in Figure 1. The wavelength used for upstream transmission, may be in the 1520-1560 nm window, where REAMs, optical transmitters and receivers are commercially available. The downstream wavelength in this example is chosen to be 1490 nm mainly to explore the possibility of extending the work presented in [2].

Table 1 Requirements for the upgraded optical links

Quantity	Value
Upstream Data Rate	10Gbps (per user)
Downstream Data Rate	1Gbps (overall)
Link Length	<1km
Number of users	~10^4

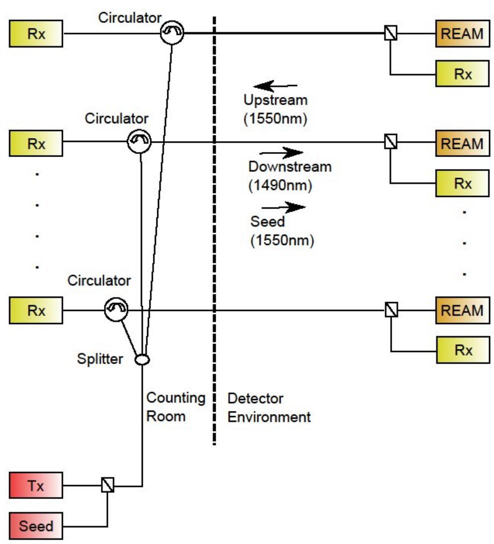

Figure 1 Network Architecture

3. Electroabsorption Modulator.

In order to evaluate the impact of different factors affecting the upstream performance, some understanding of the operation of the EAM is required. An EAM modulates light using the variation of the absorption of semiconductor material when an external electric field is applied, caused either by the Franz-Keldysh Effect (FKE) or by the Quantum Confined Stark Effect (QCSE) [4]. The EAM used in this work, a 10Gbps Reflective Electroabsorption Modulator made available by CIP Photonics [5], is based on QCSE.

One of the main metrics used to characterize EAMs is their static or electrooptic response - also known as transmission characteristics or switching curve [4]. The static response is defined as the ratio of the output light intensity over the input light intensity as a function of voltage [4] and has a significant impact on system performance, as it determines the maximum achievable extinction ratio.

The generic shape of static response of a QSCE-based EAM is depicted in Figure 2. The static response – which is the inverse of the induced attenuation – initially decreases with increasing reverse bias voltage until reaching a minimum and then starts increasing. The shape of the static response and its minimum transmission point depend on the structure of the particular device, as well as its operating conditions, including temperature. As figure 2 shows, the extinction ratio at DC is given by $ER_{dB} = T(V_L)_{dB}$-$T(V_H)_{dB}$. Therefore the shape of the static response as well as the choice of the operating voltages V_H and V_L can have a significant effect on system performance, as they determine the extinction ratio and the associated power penalty [6].

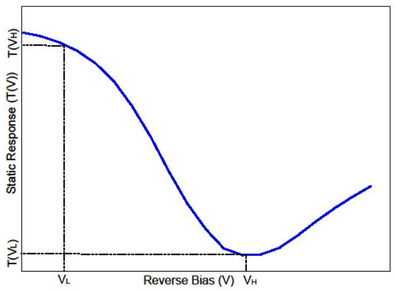

Figure 2 EAM static response and selection of operating voltage (based on measurements)

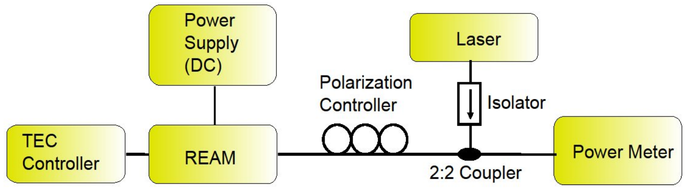

Figure 3 Measurement Setup

4. Impact of Temperature Variation.

The selection of the modulation voltage levels becomes more challenging in a temperature-varying environment, as the static response is temperature-dependent. Typically the effects of temperature variation are compensated using a thermo-electric cooler (TEC), but for our application this is not acceptable, as it would increase the mass and the power consumption of the front-end component.

The setup that was used to measure the static response of the REAM at different temperatures is shown in Figure 3. A 1550 nm distributed feedback (DFB) laser diode was used to seed light to the modulator. The output power of the laser was set to 0 dBm and the overall attenuation induced by all components apart from the REAM was measured to be 11 dB. As QCSE-induced absorption is polarization dependent [4], a polarization controller was used to modify the input light polarization to produce the worst case scenario resulting in the minimum extinction ratio. The static response was measured by varying the applied reverse bias voltage from -0.8 V to 3.8 V, using a step of 0.2 V. The thermoelectric cooler controller was used to tune the temperature of the device.

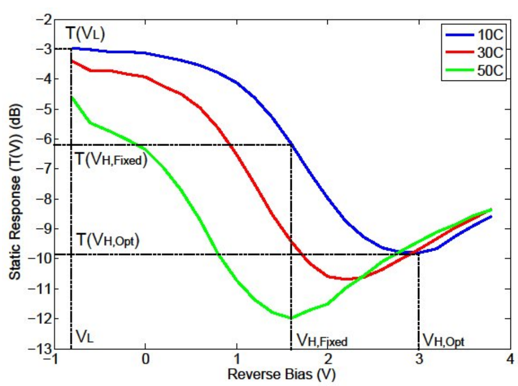

Figure 4 Temperature Dependence of Static Response

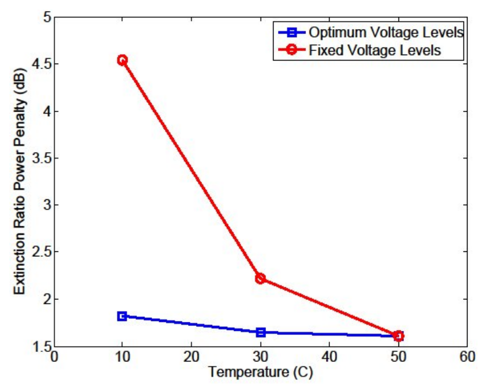

Figure 5 Extinction Ratio Power Penalty vs. Temperature

The results of the measurements at three different temperatures (10^o C, 30^o C and 50^o C) are shown in Figure 4. The temperature range of 40^o C has been selected to approximate the maximum temperature difference inside the detector [1]. Figure 4 reveals a number of important trends with increasing temperature, namely increase of the insertion loss, decrease of the reverse bias voltage level at which the static response minimum occurs and a slight increase of the maximum extinction ratio.

In order to estimate the impact of temperature it has been assumed that the modulation voltage levels are determined by the static response at the highest operating temperature. The reason is that the static response minimum occurs at low voltage levels when the operating temperature is high. Operation at higher voltages would require the use of both the decreasing and the increasing parts of the static response, leading to significant non-linear effects. The modulation voltage levels were thus set to V_L =

-0.8 V, $V_{H,Fixed}$ =1.6 V to maximize the extinction ratio at the highest temperature, as shown in Figure 4. The obvious problem encountered in this case is the sub-optimum choice of voltage levels at lower temperatures - the optimum at 10^oC, $V_{H,Opt}$ =3 V is also shown in Figure 4 - leading to a decrease of the extinction ratio. Figure 5 shows the extinction ratio power penalty calculated for different temperatures [6] both when the modulation voltage levels are fixed and when optimum voltage levels are used.

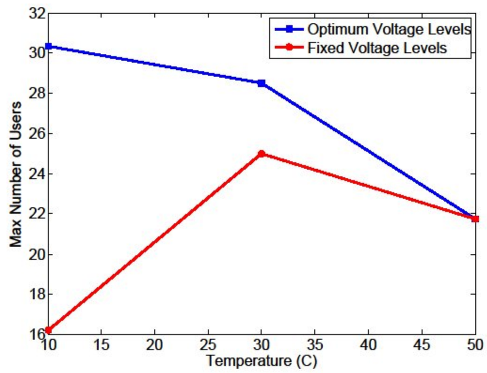

Figure 6 Max number of users vs. Temperature

At the system level, as Figure 6 shows, this corresponds to a decrease of the maximum achievable splitting ratio by a factor of ~1.8 (at 10^o C). Moreover, the extinction ratio at this temperature when the voltage is fixed is just 3.2 dB, a prohibitively low value. This indicates that some voltage adaptation mechanism is required to avoid significant performance degradation.

5. Summary and Conclusion.

We propose a new network architecture for the bidirectional transportation of information in high-energy physics experiments. The architecture is based on the use of REAMs seeded remotely by a DFB laser. System performance studies are carried out with particular emphasis on the impact of the temperature-dependent behaviour of the REAM on system dimensioning. Our studies show that maximizing the number of user nodes could be achieved through variation of the REAM modulation voltage levels.

Acknowledgments.

This work was supported in part by ACEOLE, a Marie Curie mobility action at CERN, funded by the European Commission under the 7th Framework Programme.

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