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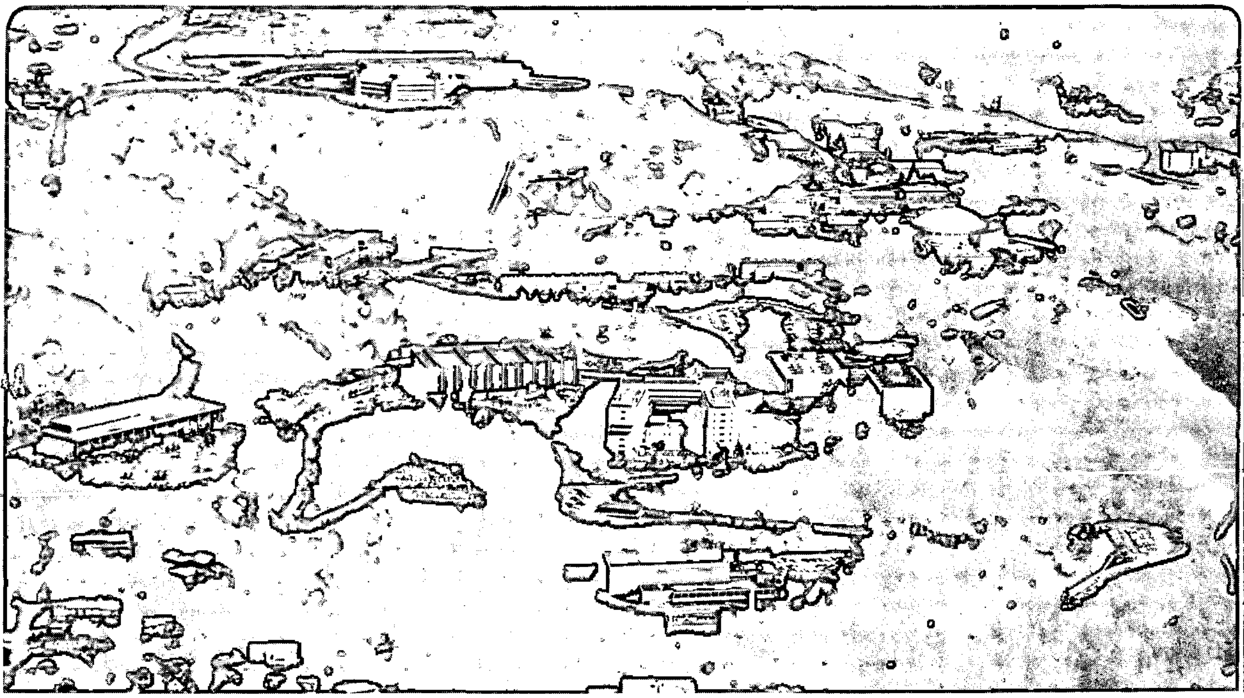

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HIGH SPEED DATA TRANSMISSION AT THE SUPERCONDUCTING SUPER COLLIDER

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ABSTRACT

High speed data transmission using fiber optics in the data acquisition system of the Superconducting Super Collider has been investigated. Emphasis is placed on the high speed data transmission system overview, the local data network and on subassemblies, such as optical transmitters and receivers. Also, the performance of candidate subassemblies having a low power dissipation for the data acquisition system is discussed.

I. INTRODUCTION

The Superconducting Super Collider Detector System should be capable of operating with luminosity corresponding to an interaction rate of the order of 10^8 events per second. The detector system will involve more than 10^6 channels of readout electronics. Consequently, a new high performance data acquisition system will be needed to process the large quantities of data from detector elements. Also, extensive online processing will be required to reduce the amount of data per interaction and data rates to amounts that can be handled by present storage techniques and computing capacity.

Recently, the concept of guided lightwave communication along optical fibers profoundly impacts communication and instrumentation systems as well as computer interconnections and system architecture. Fiber optic links provide several major advantages over conventional electronic systems. These include immunity to electromagnetic interference, and low transmission losses for very high data rates. It also makes possible thinner and lighter cables and has a strong potential for long data transmission link capabilities extending to the gigahertz region. Losses of approximately 0.20 dB/km at 1300 nm have been achieved for single mode fibers with minimum dispersion wavelengths near 1300 nm. At the present time practical high data rate optical transmission systems are operating between 45 Mbit/s and 1.7 Gbit/s. Figure 1 shows relative component cost/performance ratio of fiber optics data transmission system, expressed as cost per bit per km, as a function of time, [1]. There has been approximately a hundred-fold decrease in the cost per unit capacity every seven years.

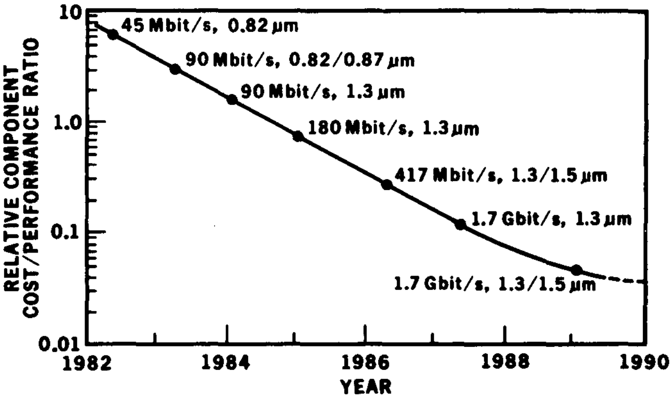

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Fig. 1. Relative component cost/performance ratio for fiber optics data transmission system.

II. SYSTEM OVERVIEW

A simplified block diagram of the new data acquisition system architecture incorporating optical fiber networks is given in Fig. 2. The architecture of the system is based on a number of earlier workshops on triggering and data acquisition organized by the SSC Central Design Group, [2, 3]. The system will consist of the following subsystems: detector front-end electronics using custom integrated circuits, an efficient high speed data collection and transmission system using fiber optics, a parallel event building network, special purpose processors for prompt triggers, calibration, and data compression, online processing units and a large data storage. Using an open system architecture, the data acquisition system will be capable of processing data rates of several thousand Gbit/s from detector elements to the online processing subsystem.

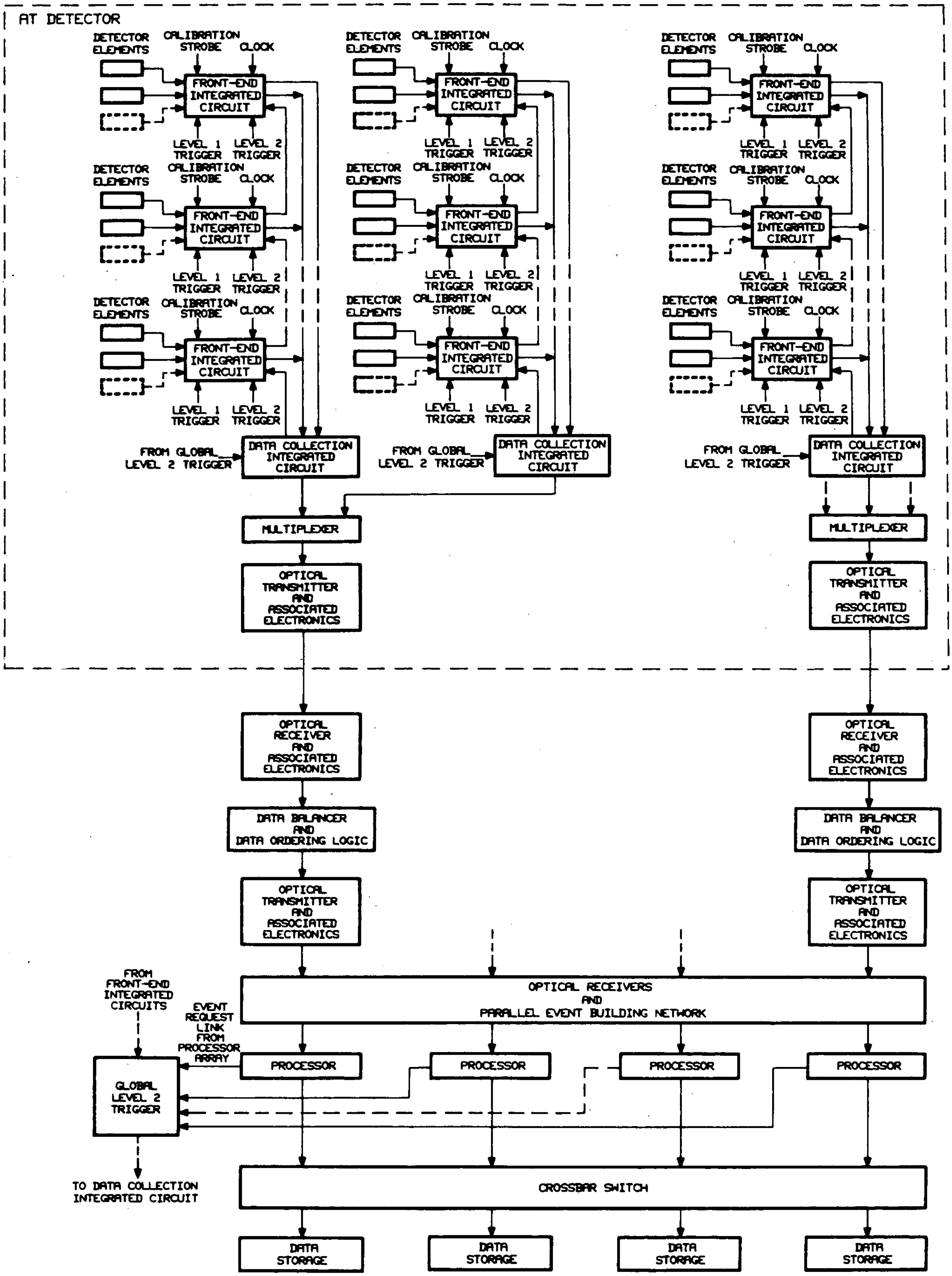

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Fig. 2. Data Acquisition architecture for the SSC detector.

The front-end integrated circuits accept signals from the detector elements and store these signals during the time necessary to process level 1 and level 2 triggers. Data collection integrated circuits collect the data from a set of front-end integrated circuits and prepare them for multiplexing, [4]. High speed data transmission will be implemented by optical fiber networks consisting of optical transmitters, receivers and associated electronics. The data balancer shifts multiplexed data to different fiber optic links and into the parallel event building network. This network simultaneously collects its input information from several detector channels. Also, the network simultaneously transmits totally built events to its multiple output ports.

It has been shown earlier that the application of optical data transmission in the SSC data acquisition system can significantly increase its data rate capability. Furthermore, it has also been shown that optical transmission will significantly reduce electromagnetic interference and eliminate ground currents with their attendant problems. Also, wide band optical transmission improves the maintainability, hermeticity and reliability because of the reduction of the cable plant size and simplification of the overall architecture of the detector systems, [5-10].

At previous workshops relating to the SSC data acquisition it was also shown that the system will be partially imbedded within the structure of the detector. Consequently, the power dissipation, system reliability, and radiation hardness will be of prime importance.

During the full operation of the data collection system of the detector front-end electronics, the digital data and fast timing signals will be present on the local data networks at the same time as the front-end electronics is receiving low-level analog signals. Consequently, there is a strong possibility for cross coupling between signal channels if electrical transmission is used. Therefore, the optical data transmission should be integrated in the data collection system to minimize cross-coupling effects. Also, the overall architecture of the collection system can be simplified by signal multiplexing and optical data transmission. Specifically, optical fiber networks will be applied in the following areas of the detector electronics subsystem:

(1) Distribution of Timing Signals

Fast timing signals, such as the 60 MHz clock, the level 1 and level 2 triggers, as well as calibration strobes, will be distributed by fiber waveguides or guided-wave optical interconnections with a timing precision significantly better than 1 ns and the bit error rate smaller than 10^{-9}.

The optical interconnecting circuits would consist of a semiconductor-based guided-wave circuit, laser diodes and photodiodes. These laser diodes and photodiodes will be integrated with the guided-wave circuit. Such monolithic integration of electronic and photonic devices on a single chip has become the focus of considerable research effort during the last several years, [11].

(2) Transmission of Digital Data

The undirectional data from front-end IC's to digital data collection IC's, the handshake and interconnecting signals, as well as the output event data will be distributed, in a number of cases, by optical fibers. Furthermore, the handshake signals between front-end IC's and data collection IC's can be implemented by bidirectional data transmission systems using IC optical transmitters and receivers, [11].

Outside the detector, optical fiber networks, incorporating subassemblies having low power dissipation, can be used in certain areas of the data acquisition system. These areas are the high speed data transmission for point to point links, the optoelectronic integrated circuits of the detector subsystem, the high speed data transmission for data and control signals, interconnection of special purpose devices in trigger systems and high data rate transmission into an on line multiprocessor subsystem.

For example, in the system shown in Fig. 1 the data can be transmitted from multiplexers to data balancers by means of 1000 parallel high speed fiber links. At present, a single optical fiber data transmitting channel can operate with a data rate of 1.7 Gbit/s with a high reliability. Consequently, the combined data rate capability of the system is 1.7×10^3 Gbit/s.

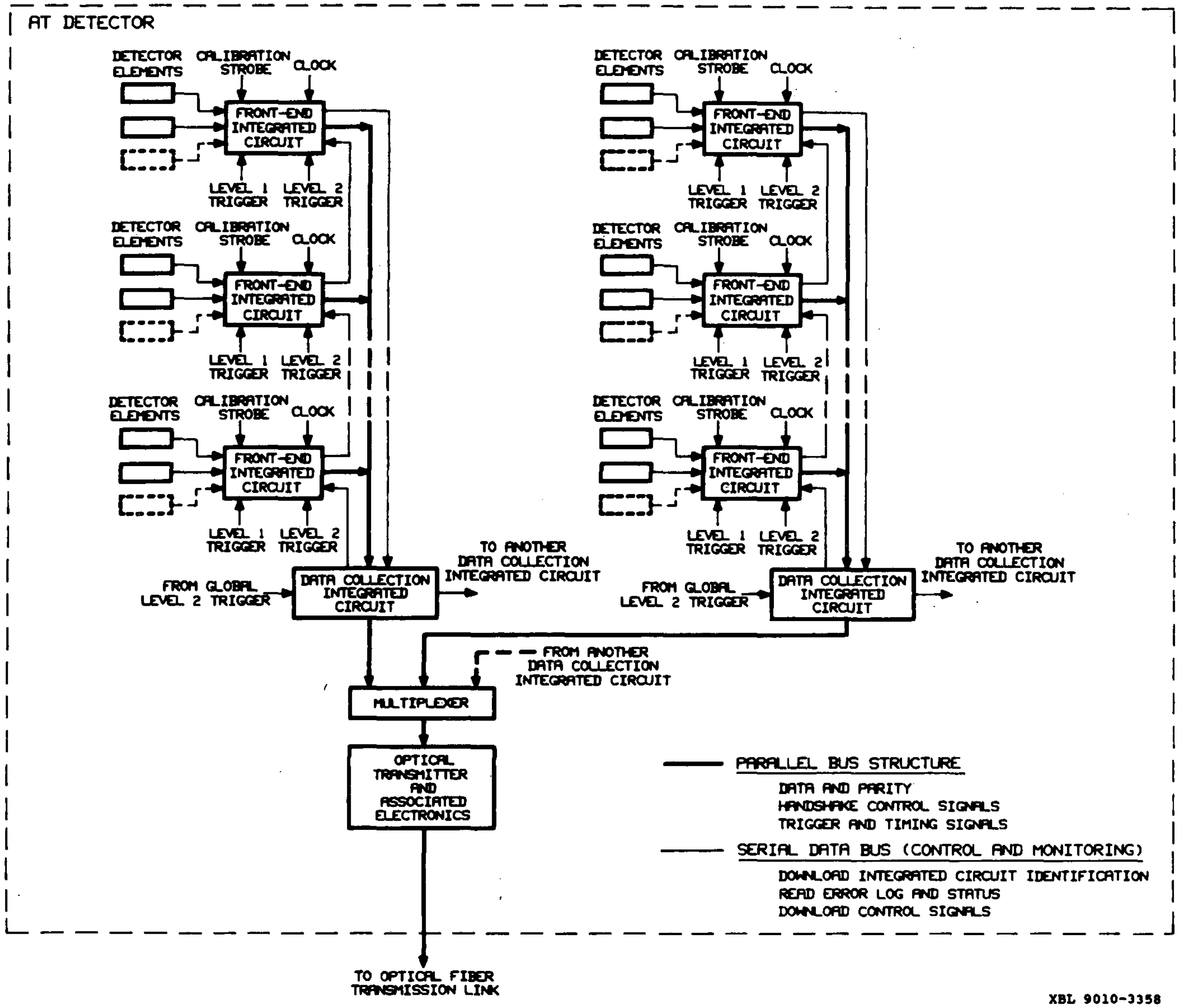

Fig. 3. The bus structure for control and readout of front-end integrated circuits.

III. DESIGN CONSIDERATIONS

A. *Local Data Network*

The process of moving data from the front-end integrated circuits to optical transmitter is controlled by a handshaking protocol between front-end IC's and data collection IC's, [4]. Data are organized in packets which include additional information such as time and location. The readout of data from front-end IC's is accomplished by connecting a group of these circuits to a single data collection IC using a local data network. As shown in Fig. 3 groups of data collection IC's can be assembled in a tree structure. The local data network consists of parallel and serial data bus structures. The parallel bus structure will be employed for moving event data packets, handshake control signals, and triggering/timing signals. The serial bus provides control information to front-end IC's. Furthermore, this bus also carries status information from the front-end IC's back to the control computer.

B. *Optical Transmitter*

Functional block diagram of the optical transmitter is shown in Fig. 4, [10]. The transmitter accepts input data and using 4B/5B coding format converts them into a serial stream. Also, the transmitter performs a non-return to zero (NRZ) to non-return to zero, invert on ones (NRZI) format conversion and transmits the data through an interface and a light source to the optical fiber transmission link. The combination of 4B/5B encoding and application of NRZI data format results in frequent transitions on the transmitter serial data output and a duty cycle of 60%/40% in the worst case. This is important for fiber optic transmission because it limits the DC offset voltage of the transmitter output. The frequent transitions on the incoming data stream to the optical receiver aid its phase-locked loop circuitry in maintaining synchronization with the transmitter.

The transmitter requires a reference clock of a specified frequency, typically 20 MHz, for its phase-locked loop. This clock signal may be obtained from the host system or generated by in-built crystal oscillator. The phase-locked loop circuit multiplies the reference clock and provides the timing reference for all interval clocking and control operations.

The clocking and control circuit determines the operating frequency and controls synchronization frame insertion. The synchronization frame is inserted into the data path whenever there are no input data.

The input control circuit controls the input latch of the transmitter. The input data are latched in the transmitter on the rising edge of the strobe signal. The light source interface translates logic level at the NRZI converter output into the drive current for the light source.

Light emitting diodes and semiconductor lasers are the most frequently employed as light sources in optical systems. Light emitting diodes (LED's) offer the advantages of simple fabrication and operation as well as low cost, high reliability and good linearity and small temperature dependence of the light output. Semiconductor index-guided injection laser diodes offer high output power level, efficiency and bit rate modulation capability as well as extremely narrow spectra and excellent mode stability of the emitted light, [10].

Using a light emitting diode as the light source the optical transmitter has the following characteristics: emission wavelength = 1300 nm, maximum data rate capability = 100 Mbit/s, average optical output power, while transmitting square wave = 32 μW(-15 dbm), rise and fall time of the light pulse from 1 to 4 ns, and total power dissipation = 3.15 W. The optical signal is coupled to a 62.5 μm-diameter core multimode fiber.

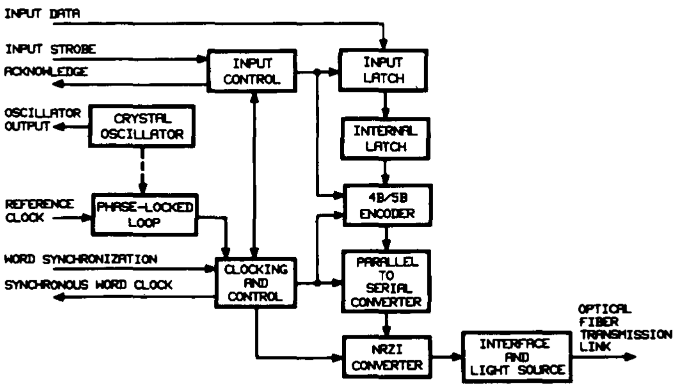

Fig. 4. Optical transmitter block diagram.

Using an index-guided injection InGaAsP laser the optical transmitter has the following characteristics: emission wavelength = 1300 nm, maximum data rate capability = 1.0 Gbit/s, CW optical power = 1 mW(OdBm), rise and fall time smaller than 330 ps, RMS spectral width smaller than 3 nm, and total power dissipation=8.5 W. The optical signal is coupled to a 8 μm-diameter core single mode fiber.

C. *Optical Receiver*

The optical receiver accepts serial optical input data from the optical fiber transmission link, detects the optical signal, recovers clock and data, and performs an NRZI to NRZ conversion, [8]. Also, the receiver translate the resulting 5B symbols into 4B data, assembles parallel words and transmits them to the data balancer circuitry.

Photodetector and detector interface detects the input data from the optical fiber transmission link. The phase-locked loop circuit multiplies the input reference clock signal by an appropriate factor to generate the timing reference signal for the receiver operation. This multiplied signal provides the reference for deriving clock and data information from the incoming signals. The receiver can be operated with or without a local crystal oscillator. With a local oscillator the reference signal is obtained from a clock recovery circuit. Without the local oscillator the reference signal is obtained from the host system.

The clocking and control circuits coordinate the reconstruction of a parallel data word in the serial code word. However, it is necessary to acquire a synchronization signal before any data can be read. This is accomplished by providing a reference clock signal having the same frequency as the transmitter. Once the synchronization is achieved the data information is recovered from the serial input stream. Data are serially converted back to the NRZ format.

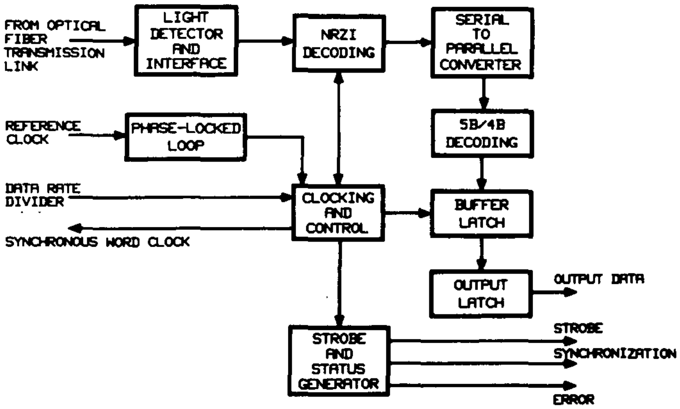

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Fig. 5. Optical receiver block diagram.

The strobe and status circuitry generates the following interface status signals: strobe, synchronization and error. Strobe pulses indicate when a new data word is present at the output latch. Synchronization indicates reception of the synchronization frame. Error is activated when the current output word is decoded from one or more 5B invalid symbols. It remains activated until a new data word, decoded from ten valid 5B symbols, is recorded on the output bus.

IV. CONCLUSIONS

With respect to the detailed design of high-speed optical fiber networks for SSC detector some subassemblies, for point-to-point communication, are presently commercially available. These subassemblies are transmitter-receiver pairs, based on gallium arsenide technology, and capable of operating up to 1 Gbit/s data rates, [12]. In general, such pairs do not incorporate a fast light source, the photodetector and associated electronics. They would require interfacing with light emitters and photodetectors having an appropriate data rate capability, [13]. Meanwhile, for data rates up to 100 Mbit/s the optical transmitter-receiver pairs have recently become available with incorporated light sources and photodetectors, [14].

However, the detailed design of optical fiber networks for specific SSC detectors and the choice of technology used for their implementation requires further study. Some of these are the high-speed low power dissipation fiber optic subassemblies, wavelength division multiplexers and demultiplexers, radiation sensitivity of components and subassemblies and network reliability and failure modes.

High performance fiber optic subassemblies, such as time division multiplexers and demultiplexers, clock and data recovery circuits, multiple crosspoint switches, and optical transmitters and receivers typically require a significant amount of power for their operation. Design studies must be made of subassembly configurations and of integrated circuit technologies giving minimum power dissipation. In particular, studies are required on the design of these subassemblies based on the application of specific integrated circuits.

Multiplexing increases the information capacity of optical fibers by simultaneously transmitting two or more different signals at different wavelengths on the same channel. The technique requires a separate source for each desired wavelength and multiplexing devices to couple all the signals into the fiber and to separate them at the other end of the fiber. Since the transmitted signals are completely independent, information with different formats and data rates can be transmitted on the same fiber waveguide without requiring any synchronization between the channels. Further studies should be carried out on the implementation of this technique for bidirectional data transmission using very low power dissipation IC optical transmitters, single mode fibers and wide-band IC optical receivers.

Most of the optical and mechanical characteristics of silica-based optical fibers are well understood. Other problems, such as radiation effects on optical sources, fiber waveguides, optical receivers and associated electronic circuits are presently being investigated in the Generic SSC R&D program, [9]. However, further studies are needed on the reliability and failure modes of low power dissipation fiber optic networks.

V. ACKNOWLEDGMENTS

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