LA-UR -90-3587

CONF-9010212--8

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

LA-UR--90-3587

DE91 001848

TITLE: CABLING FOR AN SSC SILICON TRACKING SYSTEM

AUTHOR(S): Hans Ziock, Jan Boissevain, Bradly Cooke and William Miller

SUBMITTED TO: Symposium on Detector Research and Development for the Superconducting Super Collider, Fort Worth, Texas, on October 15-18, 1990

Received by OSTI

NOV 05 1990

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

MASTER

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CABLING FOR AN SSC SILICON TRACKING SYSTEM

Hans Ziock, Jan Boissevain, Bradly Cooke, and William Miller
Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

As part of the Superconducting Super Collider Laboratory (SSCL) funded silicon tracking subsystem R&D program, we examine the problems associated with cabling such a system. Different options for the cabling plant are discussed.

Introduction

A silicon microstrip tracking detector for an SSC experiment is an extremely complex system. The system consists of approximately 10^7 detector channels, each of which requires a communication link with the outside world and connections to the detector bias voltage supply, to a DC power supply for the onboard electronics, and to an adjustable discrimination level. The large number of channels and the short time between beam interactions (16 nanoseconds) dictates the need for high speed and large bandwidth communication channels, and a power distribution system that can handle the high current draw of the electronics including the large AC component due to their switching. At the same time the constraints imposed by the physics measurements require that the cable plant have absolutely minimal mass and radiation length.

Considerations for DC Power Cabling

The cross section of a quadrant of such a detector system is shown in Fig. 1. The system is cylindrically symmetric about the z-axis. Therefore in the central region the system consists of a series of cylindrical shells, while in the forward region it consists of sets of annular rings. The system being investigated for the subsystem work is approximately 1 meter in diameter and 6 meters in length. It is estimated to use 20,000 watts of power, although one hopes to reduce this value. If the electronics operate at 5 volts, the main power bus must carry 4,000 amps. The power distribution is assumed to be independent for each half ($\pm z$) of the system so that each bus carries 2000 amps. It is further assumed that each power bus, including the associated secondary lines and the ground lines (a factor of 2), is 2x2.5m long on average and has a total voltage drop of $\Delta V = 2\times0.1$ volts.

Using Ohm's law its resistance is $R = \Delta V/I = 0.2V / 2000A\ 1.0\times10^{-4}\Omega$. Therefore the cross-sectional area of the power bus is $500\text{cm}\times\rho/R = 13.25\text{cm}^2$, where $\rho \equiv$ resistivity $= 2.65\times10^{-6}\Omega$-cm for aluminum. Accounting for both the supply and ground lines, the total cross section of the cable is 26.5 cm^2. The power dissipated in the cable is $\Delta V\times I=400\text{W}$. To minimize the path length of any particle through the power bus, it is clearly advantageous for the power bus to have the same cylindrical symmetry as the system and to be at as large a radius as possible. For a power bus in the form of a cylindrical shell, area $\equiv A = 26.5\ \text{cm}^2 = 2\pi rt$, or the thickness $\equiv t = A/2\pi r$. (Note the 1/r dependence.) Assuming that the bus is at the inner face of the vessel that encloses the silicon system at say r = 55cm, one finds $t = 0.077\text{cm} = .0086X_0$ (radiation lengths) for aluminum. Using the values given in Table 1, one finds $t=0.0337X_0$ for copper and $t=0.0033X_0$ for beryllium.

TABLE 1

Metal	resistivity @20°C [ρ] (Ω-cm)	radiation length [X_0] (cm)	figure of merit $\rho/X_0/\{\rho/X_0\}_{Al}$
Cu	1.67×10^{-6}	1.43	3.92
Al	2.65×10^{-6}	8.90	1.00
Be	4.0×10^{-6}	35.30	0.38

In addition to the metal, the cables will require insulating layers. A likely candidate is Kapton, which has a radiation length of 28.6 cm, a dielectric constant of 3.5, and a dielectric strength of ~ 200V/micron. It will therefore be a negligible contributor to the total number of radiation lengths. However, the total X_0 values for the cable are not insignificant. The copper option would seem to be immediately ruled out. Furthermore, due to constraints on the cable routing imposed by the geometry, some particles

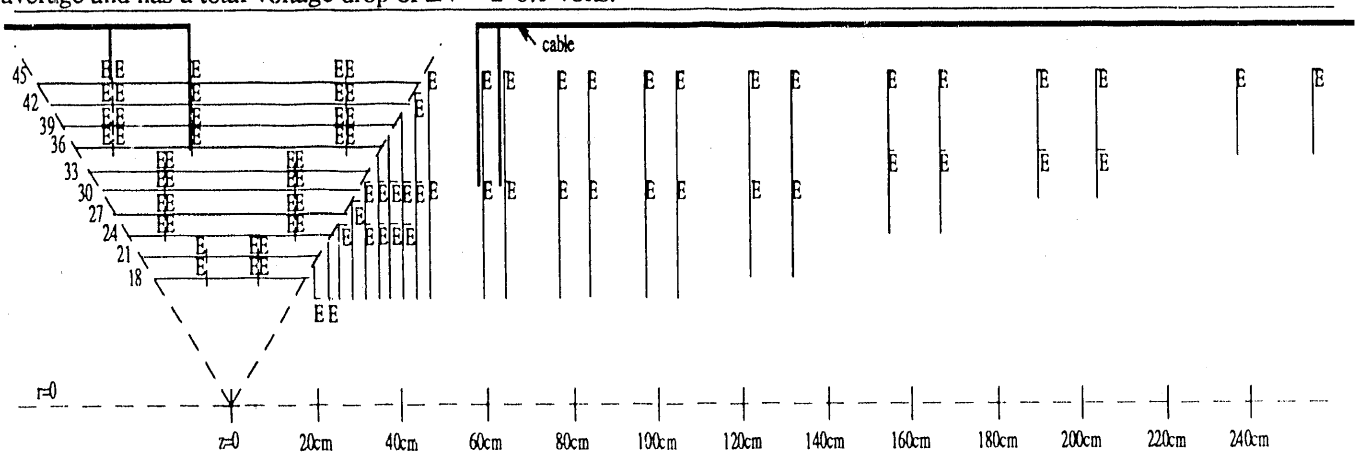

Figure 1. Layout of the silicon microstrip tracker system. The system is a cylinder of revolution about the z-axis and is symmetric about z=0. The exception is the position of the electronic packages (E) in the central region, of which both halves are shown. The positions of the electronic packages are not yet finalized. The routes of a few sample cables are shown.

will have multiple crossings of parts of the power bus. The only options available to further reduce the total material in a particle's path are to use thinner conductors, and to combine the electrical distribution job with that of mechanical support, using some existing structure in the system. The first option increases the already large power dissipation in cable itself, possibly necessitating active cooling for the conductor. The second option is equally untenable. The only structures available in the present design that could double in the role of power distribution are the enclosure vessel and the space frame[1]. As the secondary power lines must continually branch off of the main power bus to feed the individual layers of detector electronics, the transition region from main to secondary lines would probably be very complex, and negate any potential material savings. The requirement of spatially closely coupled ground and supply lines makes the integrated approach even more difficult if not impossible. The close coupling minimizes any magnetic forces and torques on conductors that run perpendicular to the magnetic field, and minimizes induced voltages and forces caused by a quench (see the next section).

The most reasonable power distribution scheme (see Fig. 1 and 2) would have a cylindrical power bus shell, which consists of a series of supply and ground conductors (S&G lines) running along its length. Three layers of conductor (ground, supply, ground), would form a single S&G line, and would be separated by insulating layers. In essence one has a stripline with segmented ground planes. At the z position of a layer of detectors, an appropriate number of S&G lines would run radially inward to supply and ground planes on the cooling ring[1] for that layer. The electronics would be mounted directly on the cooling ring. The bias supply voltage could be supplied in an analogous manner. As several orders of magnitude less current is required for that job, the amount of metal in that bus is likewise reduced.

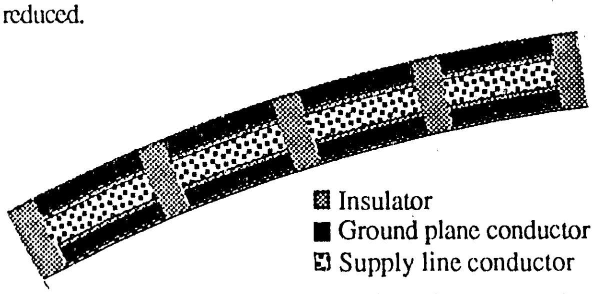

Figure 2. A cross section of a section of the power bus.

Magnetic Forces and Quench Effects

In the worst case, the cable layout is such that a single S&G line supplies a ring of electronics at r=50cm. Assuming the system properties given below in Table 2, one has a current of 50 amps in such a cable. The force on a wire of length l, which carries a current I orthogonal to a uniform magnetic field is $F = lIB$. A 0.1m long radial supply wire, which is carrying the current of 50A, feels a force of $50A \times .1m \times 2T = 10$ newtons. That is clearly not negligible. By running the supply and ground lines back to back, and mechanically coupling them, the net force is 0, although a torque can be induced. By keeping the distance between the supply and ground lines small, or orienting the cables such that the vector between them is parallel to the magnetic field lines, the torque goes to zero.

TABLE 2

Total power consumption	20,000 W	
Channels	10,000,000	
Power/channel	2.0 mW	
Pitch	50μm ≡	200 channels/cm
Strips on both faces	→	400 channels/cm
Power/cm width	0.8 W/cm	
Power for r=50cm ring	250 W	
DC supply voltage	5 V	
Supply current (ring)	250 W / 5V ≡50A	
Magnetic field (B_0)	2.0 Tesla	
B field decay (quench)	$B_0 \exp(-t/\tau)$, $\tau > 20$ seconds	

The emf induced during a quench is $d\phi/dt = (dB/dt)_{max}A$, where ϕ (= $B_0 A$) is the flux and A is the area of the conducting loop threaded by the flux. During a quench, dB/dt is largest at t=0 and has a value of $-B_0/\tau$. By keeping the ground and supply lines back to back $A \approx 0$. If the supply and ground lines are separated by say 1 mm over a 50 cm length and are oriented so that the maximum number of field lines pass through this area (worst case), then the maximum induced emf is 5×10^{-5} volts, which is negligible. Eddy currents will be further reduced by the circumferential subdivision we propose for the power bus. Therefore, any induced current and force resulting from the quench will also be negligible.

Considerations for AC Power Cabling

An estimate of the spectral components of the power fluctuation seen at the supply line interconnect to a dynamically switching logic or amplifier circuit can be made as follows. An outflowing digital pulse will produce an approximately equivalent inflowing pulse from the power supply interconnect. For a pulse with a 50% duty cycle and 10% rise and fall time (this is a typical digital pulse), the DC and first 6 AC components of its normalized, power spectral-distribution are:

$$DC \rightarrow 0.4363,\ f_o \rightarrow 0.4837,\ 2f_o \rightarrow 0.0418,\ 3f_o \rightarrow 0.0156,$$
$$4f_o \rightarrow 0.0179,\ 5f_o \rightarrow 0.0000,\ 6f_o \rightarrow 0.0035,$$

where $f_o = 1/T$ and T = clock frequency.

What the above results illustrate, is that greater than 50% of the power required to generate a pulse is AC power. Somehow the main power bus to wafer level interconnects must be able to neutralize and contain these AC components. Failure to do so could lead to wafer to wafer coupling through the power bus and through electromagnetic radiation, and pulse-shape deterioration due to a band-limited power supply interconnect or inadequate localized power supply filtering. (Note: detector strips with high gain amplifiers make good E&M receivers and with sufficient coupling, excellent oscillators.)

Cylinder to Wafer Interconnects

Based on preliminary work we have conducted on metallic transmission lines for SSC high speed communication channels[2], the stripline configuration shown in Fig. 2 provides a good compromise between bandwidth, radiation length and shielding. The structure allows for multiple power leads and, if applicable, communication channels in a flat tape package. One of its main advantages is that the width, w, of the metal conductor can be made wider to decrease both DC and AC resistance. In addition, the characteristic impedance of the line can be decreased, providing a lower dynamic AC impedance.

The utility of providing multiple, uncoupled power-supply leads to a single wafer should not be underestimated, especially for wafers that consume large amounts of power and contain a large number of digital circuits that switch simultaneously. In order to filter out most of the spectral components f_o and higher, capacitors will need to be placed at the wafer/power cable interface. Tantalum capacitors are relatively small and quite radiation resistant. The exact amount of metal ribbon cable and capacitance needed per wafer will depend on such factors as power dissipation, clock frequency, wafer geometry and layout rules.

Communication Links

The design of the communication link from the silicon system to the external world will be driven by the required bandwidth. That bandwidth will be determined in part by how many communication channels there are (namely how finely the system is segmented). For a given channel, the data rate has two components: 1) the average rate caused by isolated particles randomly striking a detector, and 2) the rarely occurring peak rate which is caused by a large number of correlated particles passing through the small part of the system read out by a single communication channel. The data transfer rate for component 1) can be estimated as follows: The η coverage for a 1 cm wide section of the central wafer which extends from z=-6cm to z=6cm at r=18cm is given by

$\tan\theta_{start}$	= 18cm/-6cm	→ 108.435 deg,
$\tan\theta_{stop}$	= 18cm/6cm	→ 71.565 deg,
η_{start}	$= -\ln(\tan(.5\theta_{start}))$	= - 0.327,
η_{stop}	$= -\ln(\tan(.5\theta_{stop}))$	= 0.327,
$d\eta$	$= \eta_{stop} - \eta_{start}$	= 0.655.
circum. of ring	$= 2\pi \times 18$cm	= 113.097 cm

ASSUME:

1) $dN/d\eta$/event = 7.5, where N is the # of charged particles,
2) An added factor of 2.2 for interactions and loopers for N,
3) At L=10^{33}/cm^2, 1.6x60MHz = 9.6×10^7 events/sec }

Then the rate of particles through a 1 cm wide section of the central wafer which extends from z=-6cm to z=6cm at r=18cm: $= 2.2\,(dN/d\eta)\times d\eta\times 9.6\times10^7 / 113.097$
$= 9.17\times10^6$/sec.

If on average a typical particle causes two adjacent strips to be above threshold, and the detector has strips on both its sides, then the number of hit strips is four times the rate or 3.67×10^7/sec/cm width. Assuming that one communication channel services a 5cm wide section, then the number of hit strips is a factor of 5 larger. Eleven bits are needed to uniquely identify any one of the 2000 strips in the 5cm segment. The corresponding data transfer rate is 2 Gbit/sec to get all the information off. Assuming an event reduction factor of 1000 given by the level 1 trigger, the rate drops to 2 Mbit/sec.

The data transfer rate for component 2) follows: A 2TeV p_t jet can contain as many as 50 charged particle tracks that pass through the detector region covered by one readout channel[3]. Assume that 5 μsec are available to transmit the hit information for use in the level 2 trigger. Once again we multiply by a factor of 2 for the average number of hit adjacent strips per track, a factor of 2 for strips on both sides of the detector, and a factor of 11 for the number of bits. The required bandwidth is then $50\times2\times2\times11 / 5\times10^{-6}$/sec = 440 Mbit/sec. Clearly if one uses the level one trigger rate reduction, it is component 2) that determines the needed bandwidth. Note also that while component 1) is directly proportional to the luminosity (L), component 2) is independent of L. The required bandwidth and considerations, such as attenuation, power, crosstalk, and material-mass[2],[4], would argue for fiber optic communication links. A typical fiber optic cable is 100 microns in diameter, is made of SiO_2, and is sufficiently radiation resistant. Even for 1 fiber per wafer (~10,000 overall), the total cross-sectional area of all the fibers is only 1cm^2. Two way communication will at most double that area.

Short Strips

Although the preceding arguments have been made in the context of long strip double-sided detectors, the results apply equally well to the short single-sided strip detector option. The power consumption is approximately equivalent for both. Overall the communication channel bandwidth is also almost the same for the two options as the number of tracks is independent of the detector type. The number of hits is therefore the same for the two options within a factor of 2. (Single-sided: only 1 hit/track, double-sided: 2 hits/track). There are approximately 8 times as many short strip detectors overall. That will require an additional 3 bits for the strip specification.

Conclusion

The constraints imposed by the requirements of minimal mass and large bandwidth drive one in the direction of optical communication channels, and power buses that are in the form of stripline like ribbon cables at large radii. The conductors will have to be low Z metals such as aluminum or beryllium, and the cable plant design and routing must be carefully considered in the mechanical design of the system. Any reductions in the total power consumption will be very helpful. Furthermore, issues such as crosstalk between individual detector channels and power supply isolation will have to be carefully addressed. With sufficient effort, a functional design can be achieved.

References

[1] W. Miller *et al.*, "Mechanical Engineering and Design of Silicon-Based Particle Tracking Systems", these proceedings
[2] B. Cooke *et al.*, "SSC High Speed Communication Channel and Interconnects", these proceedings.
[3] A. Palounek, LBL, private communication.
[4] J . Ogle *et al.*, "Applications of Electro-optic Modulators for Wide Bandwidth Recording of Transient Signals", these proceedings.

END

DATE FILMED

11 / 26 / 90