Modifications to the SSC Lattice

A. A. Garren and D. E. Johnson
SSC Central Design Group*
c/o Lawrence Berkeley Laboratory, Berkeley, California 94720

Summary

Possible modifications of the lattice described in the Superconducting Super Collider Conceptual Design Report of March 1986 have been considered and are presented below. One potential modification to the lattice is to change the arc cells in betatron phase advance from 60° to 90°, and to lengthen them to include six rather than five dipoles per half cell. Another related change is to make the dispersion suppressors shorter, and to include longer drift spaces for scrapers and detectors.

A study of the basic cell structure for the SSC was recently carried out which concluded that the lattice presented in the CDR[1] could be somewhat improved by increasing the half-cell length so as to include six dipoles instead of five, and by changing the cell phase advance from 60° to 90°.[2] This study indicated several points of significant, but not overwhelming, improvement in the basic machine design derived from the higher phase advance, such as larger linear and dynamic apertures for both on- and off-momentum beams, more relaxed requirements on dipole and quadrupole multipole field errors, and higher tolerance to persistent current effects. The overall cost of the machine in either case is comparable. A lattice design based upon a 90° cell is presented below. The general structure is very similar to that described in the CDR with two notable exceptions:

1. The dispersion-suppressing sections for the 90° case are different in design from those in the CDR and are shorter; and,
2. The Interaction Regions have been made longer than those of the CDR without increasing the cluster length, due to the shorter dispersion suppressors, thus allowing more available free space for experimental apparatus. In particular, the free space in the medium-beta straight section has been increased from ±102 m to ±120 m.

Global Structure

As in the CDR, the lattice consists of two nearly semicircular arcs connected by two clusters of experimental and utility regions. Each cluster is composed of four straight sections separated by horizontally bending sections which serve to ensure that the muon shower from one experimental area is not directly aimed at the neighboring experiment, and also provide areas in which one may scrape the beam to reduce beam halo or emittance, while each arc contains 143 normal cells.

As in the CDR, one cluster contains two sections intended to become experimental regions in the future, which are presently configured as utility sections, and two medium-beta sections, while the other cluster has two utility modules and two low-beta modules.

The main parameters of the lattice are given in Table I.

Table I – Parameters of 90° Cell SSC Lattice

Circumference	83.631		km
Structure: two arcs, two clusters			
Near cluster: 2 utility, 2 low-β			
Far cluster: 2 utility, 2 medium-β			
Cell phase advance	90°		
Betatron tunes ν_x, ν_y	94.42	94.40	
Short IR, long IR tunes	3.75	3.25	
Utility tune	2.25		
$\beta_{\max}$, $\beta_{\min}$ in arcs	388	67	m
$\eta_{\max}$, $\eta_{\min}$ in arcs	3.03	1.46	m
β^* in short IR	0.5		m
$\beta_{\max}$ in short IR	7.95		km
β^* in long IR	10.0		m
$\beta_{\max}$ in long IR	4503		m
Free space, short IR	±20		m
Free space, long IR	±120		m
Utility center, end drifts	904	118	m
IP–IP distance, bend angle	2285	82	m, mrad
Cells/arc, modules/cluster	143	4	
Cell, cluster module length	228.5	2285	m
Number of dipoles/half cell	6		
Number of dipoles/ring	3832		
Magnetic field, gradient	6.61	229.3	T, T/m
Average, magnetic radius	13.310	10.087	km
Dipole, quadrupole lengths	16.54	3.64	m
Vertical separation	0.70		m

Normal Cell

A layout of the 90° half cell is shown in Fig. 1. Each half cell contains six 16.54 m, 6.61 T dipoles (at 20 TeV) separated by 0.8 m, one 3.64 m, 229.3 T/m quadrupole, and a 6.57 m correction spool slot length.

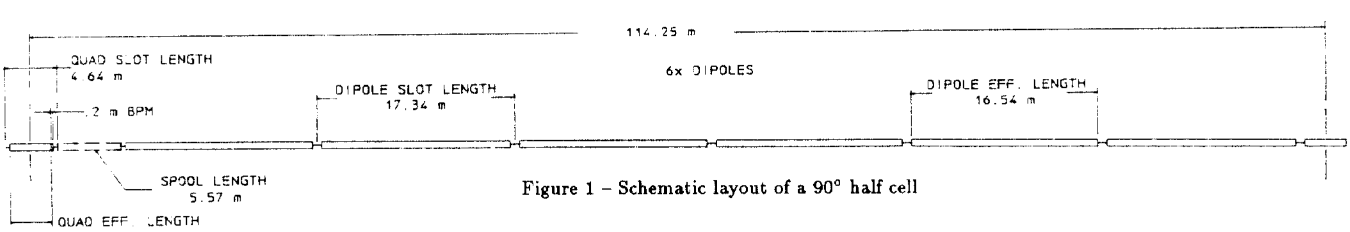

Figure 1 – Schematic layout of a 90° half cell

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Due to the lower values of the dispersion function, these cells yield significantly better linear and dynamic apertures.

Cluster Modules

The structure of the clusters is illustrated in Fig. 2.

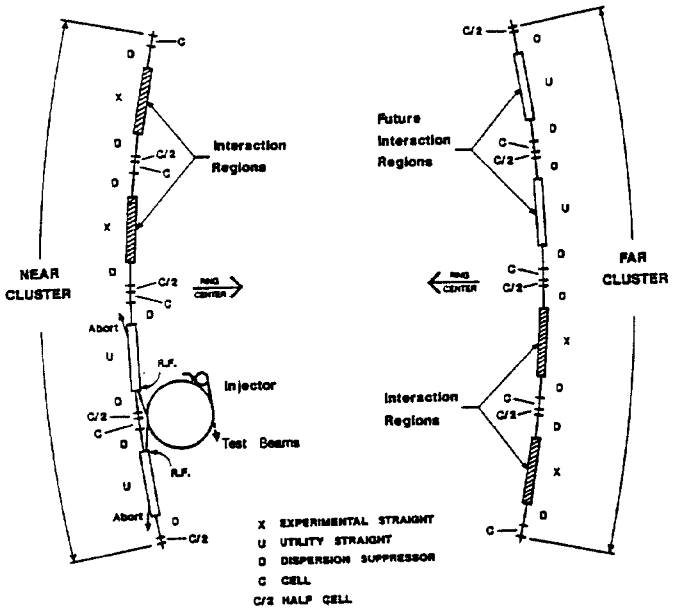

Figure 2 – Lattice structure of the clusters

Each module consists of a half cell, a dispersion suppressor, a straight section free of horizontal bends, a dispersion suppressor, and a full cell. All of the dispersion suppressors are identical and each straight section is 1257 m long as opposed to 1152 m in the CDR, with the total module length being 2285 m, compared to 2400 m.

The essential advantage of the 90° cells, insofar as insertions are concerned, is that the dispersion-suppression region can be made using fewer cells that in the 60° case, so that the IR regions can be increased in length without increasing the IP–IP separation. This leads to improved optics in the IR regions, additional space for detectors, and an increased "free space" in the medium-beta IR of ±120 m instead of ±102 m as given in the CDR.

Dispersion Suppressors

As stated above, the bending section between two IP's consists of a dispersion suppressor, three half cells, and another dispersion suppressor. The layout and lattice functions of the bending section are shown in Fig. 3. Each suppressor consists of two, 3/4 length, 90° cells containing four rather than six dipoles per half cell.

The length and bending of these cells is such that their dispersion is half that of a normal cell. As a result, the dispersion in them makes half a betatron oscillation about the proper value $\eta_C/2$, from η_C to zero.

In a thin lens approximation, $\eta = L\theta$, so in the suppressor cells, one should have $L\theta = (L\theta)_C/2$. With the choices of $L = 3/4 \times L_C$ and $\theta = 2/3 \times \theta_C$, the suppressor cells are less densely packed than the arc cells so that there are enlarged drift spaces next to the quadrupoles for scrapers, collimators,

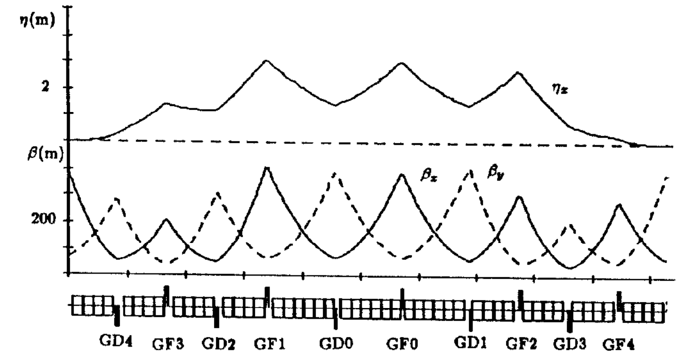

Figure 3 – Dispersion suppressors between IR's.
Bottom scale is 100 m between tick marks

beam diagnostic equipment, *etc.* Since the SSC magnets are far from thin lenses, this approximation does not quite hold and so would not entirely control the dispersion. By judiciously moving the blocks of dipoles within the half cells and adjusting the lengths of the intervening quadrupoles, however, true dispersion-suppressing sections have been produced while maintaining the same lower overall length of the suppressors.

Straight Sections

The straight sections in this lattice design consist of a utility section for beam injection, abort, *etc.*, and low- and medium-beta experimental areas. The basic designs are very similar to those given in the CDR, the major difference being the increased length. A plot of the lattice functions for the utility section is shown in Fig. 4. Because of the large beta-function values in the utility section, the innermost quadrupoles have a coil winding diameter of 5 cm as opposed to 4 cm elsewhere, and hence have a lower gradient. This is shown in Table II, which lists the fixed-value magnets in the utility module as well as those used in the normal cells, the dispersion suppressors. Table II also includes the vertical dipoles required in order to bring the two beams into collision in the experimental areas.

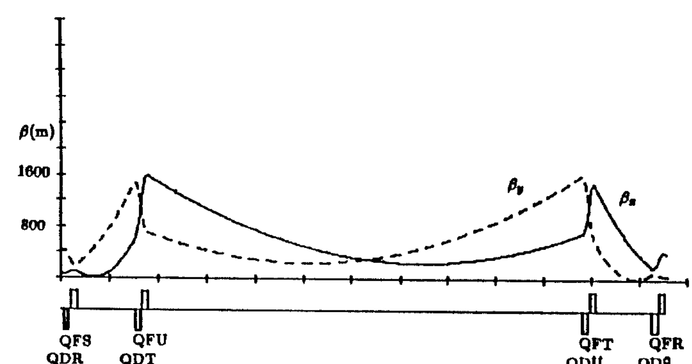

Figure 4 – Lattice functions for the utility straight section
Bottom scale is 100 m between tick marks

The experimental modules need to be tunable as the collision optics have maximum beta values which are too large for injection at 1 TeV. Both the medium-beta and the low-beta sections can be continuously tuned over a large range of β^* by adjusting the six different quadrupole circuits. Lattice functions showing half of each of the experimental sections tuned to the collision optics are plotted in Figs. 5 and 6. Table III lists the different quadrupoles used in these sections and their qradients for a few steps in the tune curves.

Table II – 90° Lattice Magnet Requirements excluding Experimental Sections

Type	Name	Length	Field
Dipoles			
Horizontal	B	16.5400m	6.613T
Vertical	BV1	5.0000	5.081
	BV2	16.5400	6.613
	BV3	8.0000	5.212
Quadrupoles			
Normal Cell	QF,QD	3.6400	±229.3T/m
Dispersion Suppressor	G4	4.8700	229.3
	G3	4.8476	229.3
	G2	4.9100	229.3
	G1	4.2537	229.3
	G0	3.6669	229.3
Utility	QR	9.8408	229.3
	QS	14.2204	229.3
	QT	11.3288	169.6
	QU	11.3288	169.6
Sextupoles	SF		768.7T/m
	SD		−1543.2

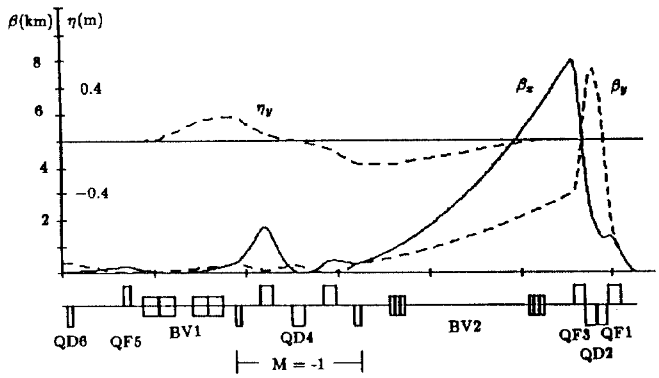

Figure 5 – Lattice functions for the low–β straight section
Bottom scale is 100 m between tick marks

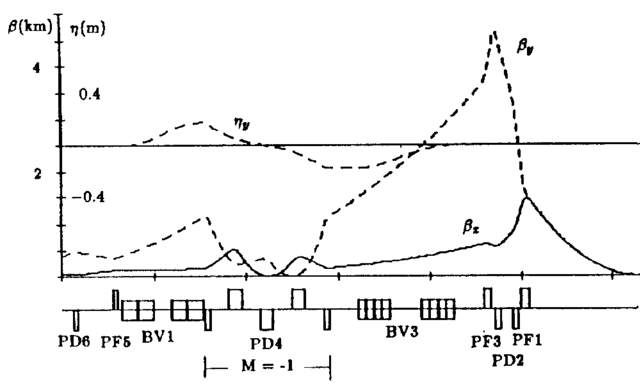

Figure 6 – Lattice functions for the medium–β straight section
Bottom scale is 100 m between tick marks

Table III
Tune Tables for the Low- and Medium-β Insertions

Low – β

Quad	Length	$\beta^* = 0.5$m	2.0m	4.0m
QF1	14.0471m	229.3T/m	229.3T/m	233.2T/m
QD2	11.5000	−222.1	−226.9	−234.3
QF3	12.6000	223.5	228.7	233.4
QD4	14.2170	−229.3	−155.0	−129.3
QF5	8.3037	229.3	159.5	136.0
QD6	6.0000	−223.7	223.8	231.8
$\hat{\beta}(M=-1)$		1733m	335m	1030m
$\hat{\beta}$(Triplet)		7947	2069	1050
$\Delta\nu(IP-IP)$		3.75	3.75	3.73

Medium - β

Quad	Length	$\beta^* = 10.0$m	30.0m	50.0m
PF1	9.5000m	225.9T/m	193.2T/m	177.3T/m
PD2	6.8000	−186.7	−228.0	−228.4
PF3	7.4000	80.7	202.5	220.5
PD4	14.2170	−229.3	−222.5	−184.3
PF5	4.2000	182.8	181.6	219.8
PD6	4.7000	−156.9	212.6	230.8
$\hat{\beta}(M=-1)$		1132m	438m	347m
$\hat{\beta}$(Triplet)		4503	193	710
$\Delta\nu(IP-IP)$		3.25	3.25	3.25

References

1. *Superconducting Super Collider Conceptual Design*, **SSC–SR–2020** (1986).
2. *Optimization of the Cell Lattice Parameters for the SSC*, Cell Lattice Study Group, SSC Central Design Group, **SSC–SR–1024** (1986).