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Interactive Global Decoupling of the SSC Injection Lattice

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ABSTRACT

Global decoupling of the SSC 90° lattice, injection optics, has been simulated. The scheme consists of adjusting two families of skew quadrupoles (along with one normal trim quad circuit) to minimize the distance of closest approach of the tunes. It is important to note that this algorithm uses only quantities which can be measured in a real machine, thereby modeling a procedure commonly used on existing accelerators. The resulting coupling coefficient with tunes minimally separated, after one iteration, was always less than 0.0008 for the four random seeds studied. The skew quadrupole corrector strengths were more than an order of magnitude less than that of the cell quadrupoles.

1. Introduction.

It is well-known that reasonable first pass decoupling can be obtained by setting two families of judiciously placed skew quadrupoles.[1] The Tevatron is decoupled using this technique, as are CESR and the SPS. For the SSC, we envision this sort of global decoupling as a first pass correction after first turn orbit has been achieved and correcting the closed orbit. Further local decoupling will certainly be necessary as the interaction region quadrupoles are powered to their colliding-beam strengths.

2. Decoupling Algorithm

The following treatment is due to Peggs.[1] We write the normalized transfer matrix for the machine

$$T = \begin{pmatrix} M & m \\ n & N \end{pmatrix}. \tag{2.1}$$

The goal of decoupling is to make m and n small. We define the coupling matrix

$$H = m + n^{+} \tag{2.2}$$

Where the superscript + denotes the adjoint. According to Billing,[2] H can be written

$$H = H_{+} \sin \pi (Q_x + Q_y) + H_{-} \sin \pi (Q_x - Q_y). \tag{2.3}$$

Here Q_x and Q_y are the design tunes and

$$H_{\pm} = \sum_{SQ} q_m \begin{pmatrix} \cos \omega_{\pm} & \sin \omega_{\pm} \\ -\sin \omega_{\pm} & \cos \omega_{\pm} \end{pmatrix}, \tag{2.4}$$

where the sum is over skew quads, $q_m = \frac{\sqrt{\beta_x \beta_y}}{f}$ is the dimensionless skew quadrupole strength. In (2.4)

$$\omega_{\pm} = -(\phi_x(s_m) + \pi Q_x) \pm (\phi_y(s_m) + \pi Q_y) \tag{2.5}$$

where $\phi(s_m)$ is the phase advance at the skew quadrupole located at s_m. The eigenfrequencies of the motion, Q_1 and Q_2, are related by

$$(\cos\,(2\pi Q_1) - \cos\,(2\pi Q_2))^2 = (\frac{1}{2}\,\mathrm{Tr}\,(M - N))^2 + \det H. \tag{2.6}$$

Near the coupling resonance ($Q_x \approx Q_y$), the H_- term in (2.3) $\rightarrow 0$. In this case

$$H \approx H_+ = \begin{pmatrix} p & r \\ -r & p \end{pmatrix} \sin \pi(Q_x + Q_y). \tag{2.7}$$

where $p = \sum q_m \cos \omega_+$ and $r = \sum q_m \sin \omega_+$. On the coupling resonance $Q_x = Q_y$, thus Tr $(M - N) = 0$, so the distance of closest approach of the tunes is

$$\Delta Q = Q_1 - Q_2 \approx \frac{1}{2\pi}\sqrt{p^2 + r^2}. \tag{2.8}$$

The coupling coefficient, C, a measure of coupling defined by Chao and Month, [3] has magnitude equal to half the distance of closest approach of the perturbed tunes in a coupled machine near the coupling resonance. So, to minimize $|C|$, we minimize $Q_1 - Q_2$, minimizing p and r by setting skew quadrupole correctors to cancel contributions to p and r from errors in the lattice.

3. Lattice, Errors, and Requirements

The lattice used is dated August 6, 1987. It consists of two arcs, each composed of 144 cells, with cell phase advance of approximately 90°. The half cell length is 114.25 m, and the nominal dipole field is 6.6 Tesla. There are eight straight sections grouped into two clusters called Near and Far. The Near cluster has two low β IR's and two utility straights, and the Far cluster has two medium β IR's and two utilities. The nominal tunes of the machine are 98.285 in x, 98.265 in y.

The following random errors were introduced. All quadrupoles in the lattice were rotated, with $\sigma = 0.5$mr, and translated, with $\sigma = 0.5$mm. All dipoles were rotated, with $\sigma = 1.0$mr, translated, with $\sigma = 0.5$mm, and assigned random multipole errors $\sigma[a0] = 5.9 \times 10^{-4}$, $\sigma[b0] = 3.0 \times 10^{-4}$, $\sigma[a1] = 0.72 \times 10^{-2}$, $\sigma[b1] = 0.72 \times 10^{-2}$, $\sigma[a2] = 0.64$, $\sigma[b2] = 0.40$. All random multipole errors are in units used by the magnet errors group (parts per 10^4 at 1 cm), and the value for $\sigma[b2]$ assumes a 'binning' scheme [4] has been used to reduce the effective $\sigma[b2]$ by approximately a factor of five.

For the SSC we demand that the coupling coefficient after correction be less than 0.005.[5]

4. Placement of Skew Quadrupoles

One skew quadrupole from each family was placed in each straight section, for a total of sixteen skew quadrupoles, eight in each family. Figures 1 and 2 show the interaction region and utility layouts with the skew quadrupole locations indicated. The placement of the correctors, approximately that suggested by Jack Peterson and Walter Scandale, was chosen in an attempt to maximize $\cos\omega_+$ for one family and $\sin\omega_+$ for the other, keeping $\sqrt{\beta_x\beta_y}$ as large as possible. The following table shows the β functions and phases differences at the skew quadrupoles.

region	family	β_x	β_y	ϕ_x-ϕ_y
low β	sq1	180 m	1133 m	0.197
	sq2	369 m	73 m	0.236
medium β	sq1	146 m	869 m	0.182
	sq2	169 m	38 m	0.238
utility	sq1	73 m	363 m	0.013
	sq2	343 m	1058 m	−0.138

Table 1: β's and phases at skew quadrupole correctors, injection optics.

While these positions were satisfactory for studying the method, they are not ideal. In particular, the two circuits are not nearly independent at injection, and when the lattice is tuned to collision optics the beta functions at the sq2 correctors in the low and medium β IR's become small. The placement scheme of Peterson and Scandale, while acceptable for collision optics, has similar problems at injection. More work is needed to find a placement which is workable both at injection and collision. It should also be noted that the integer tunes will be split in the SSC to mitigate the effect of systematic skew quadrupole errors.

5. Correction techniques

The orbit was corrected using an algorithm based on overlapping localized bumps, which will be described in a future report. The resulting RMS orbit displacements at the beam position monitors varied between 0.20 and 0.30 mm in both planes.

The decoupling technique is interactive, much like that used in real accelerators. An interactive graphics program, running on a SUN Workstation, whose underlying physics model is Teapot,[6] plots the fractional parts of the tunes (obtained using a coupled Twiss analysis[7]) as a function of either one normal trim quadrupole circuit or one of the two skew quadrupole corrector circuits. In a real accelerator a spectrum analyser is used to obtain these tunes. Additional points on the plot are obtained via mouse and menu. Figure 3 illustrates the method. When the plot clearly shows a minimum in the separation between tunes, the value at which that minimum occurs is selected using the mouse, and the program sets the quadrupole strength to the chosen value. Another circuit can then be selected. In this fashion the tune split can be made smaller and smaller, until the user is satisfied. At any time the coupling coefficient can be computed.

6. Results

After one iteration,

seed	$2\|C\|$ initial	$2\|C\|$final	sq1(m^{-1})	sq2(m^{-1})
1	0.050	0.00005	0.14×10^{-3}	0.70×10^{-4}
2	0.013	0.00048	-0.87×10^{-5}	-0.36×10^{-4}
3	0.015	0.00044	-0.19×10^{-4}	-0.44×10^{-4}
4	0.017	0.00077	-0.30×10^{-4}	0.45×10^{-4}

Table 2: Results for four random seeds.

For reference, the strength of a normal cell quadrupole is $0.12 \times 10^{-1} m^{-1}$. All four machines were sufficiently decoupled after one iteration ($|C| < 0.005$). When the tunes were returned to their nominal values of 98.285, 98.265, $|C|$ increased due to contributions from H_- but was still less than 0.002 in all cases.

7. Conclusions and Acknowledgments.

I would like to acknowledge the work of my **Teapot** collaborators Ruth Hinkins, Tjet Sun, and Richard Talman. Thanks to Jack Peterson and Alex Chao for valuable discussions. Many thanks also to my oversight committee for its invaluable guidance.

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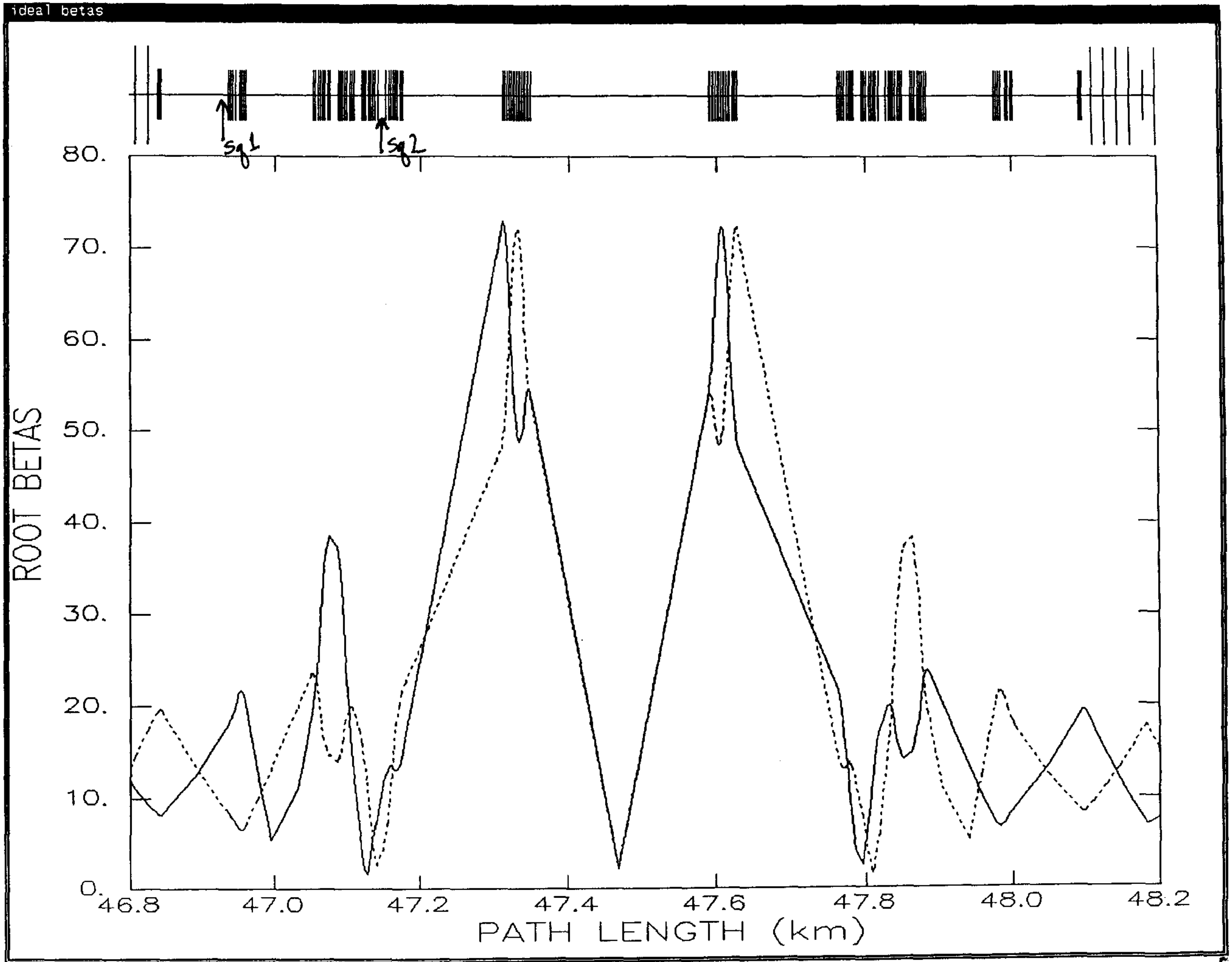
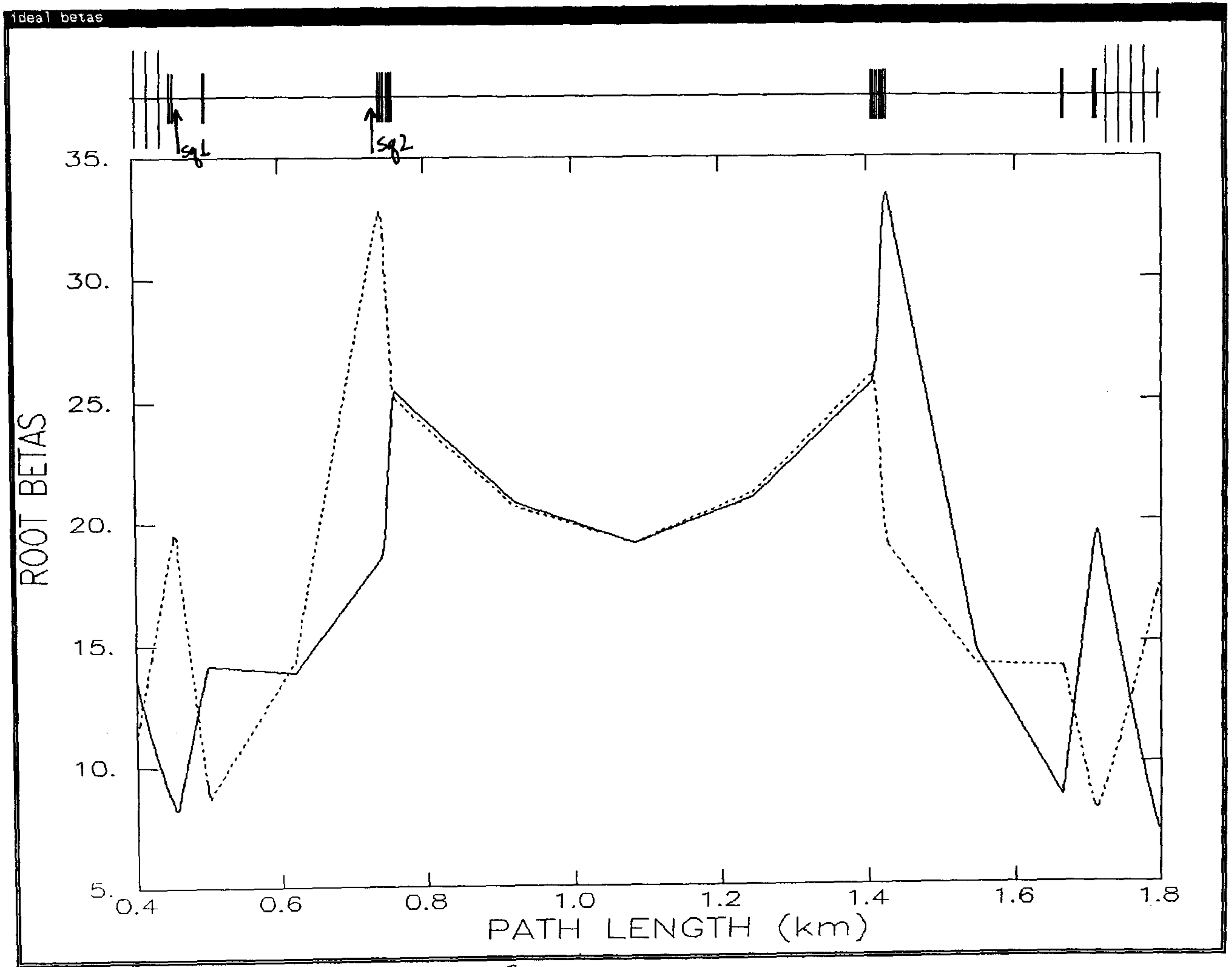

ideal betas
sq1
sq2
ROOT BETAS
0.
10.
20.
30.
40.
50.
60.
70.
80.
46.8
47.0
47.2
47.4
47.6
47.8
48.0
48.2
PATH LENGTH (km)



ideal betas
sq1
sq2
35.
30.
25.
20.
15.
10.
5.
ROOT BETAS
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
PATH LENGTH (km)

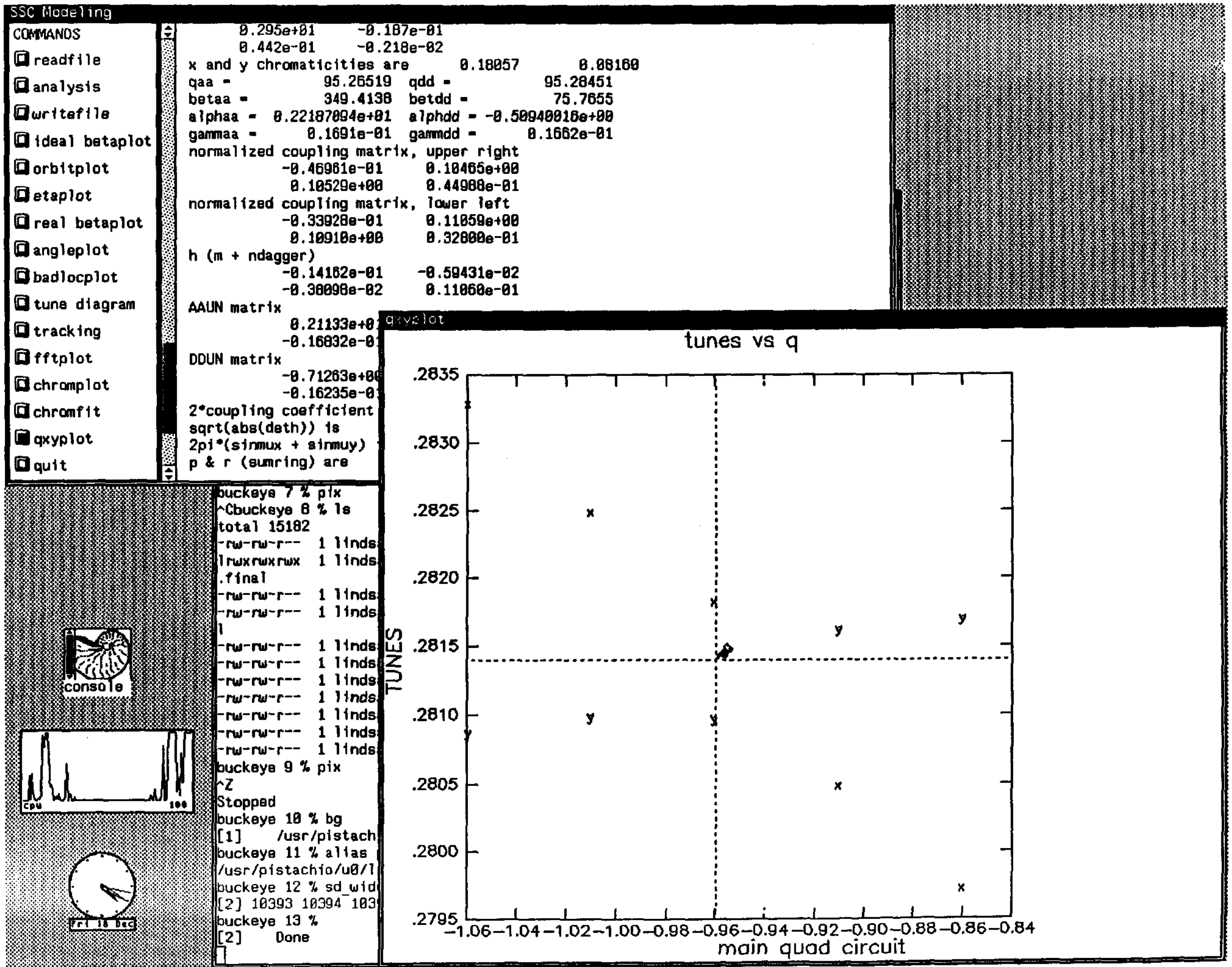

SSC Modeling
COMMANDS
readfile
analysis
writefile
ideal betaplot
orbitplot
etaplot
real betaplot
angleplot
badlocplot
tune diagram
tracking
fftplot
chromplot
chromfit
qxyplot
quit
0.295e+01 -0.187e-01
0.442e-01 -0.218e-02
x and y chromaticities are 0.18057 0.08160
qaa = 95.26519 qdd = 95.28451
betaa = 349.4138 betdd = 75.7655
alphaa = 0.22187094e+01 alphdd = -0.50940016e+00
gammaa = 0.1691e-01 gammdd = 0.1662e-01
normalized coupling matrix, upper right
-0.46961e-01 0.10465e+00
0.10529e+00 0.44988e-01
normalized coupling matrix, lower left
-0.33928e-01 0.11059e+00
0.10910e+00 0.32800e-01
h (m + ndagger)
-0.14162e-01 -0.59431e-02
-0.38098e-02 0.11060e-01
AAUN matrix
DDUN matrix
2*coupling coefficient
sqrt(abs(deth)) is
2pi*(sinmux + sinmuy)
p & r (sumring) are
buckeye 7 % pix
^Cbuckeye 8 % ls
total 15182
.final
buckeye 9 % pix
^Z
Stopped
buckeye 10 % bg
[1] /usr/pistach
buckeye 11 % alias
/usr/pistachio/u0/l
buckeye 12 % sd_wid
[2] 10393 10394 103
buckeye 13 %
[2] Done
console
qxyplot
tunes vs q
TUNES
.2835
.2830
.2825
.2820
.2815
.2810
.2805
.2800
.2795
-1.06 -1.04 -1.02 -1.00 -0.98 -0.96 -0.94 -0.92 -0.90 -0.88 -0.86 -0.84
main quad circuit

Figure 2