STRUCTURE DESIGN: OUTLINE

I. Long Range Wakefield suppression.
   A. Dipole Modes (TM$_{11}$ like)

   B. Strong damping - Loss in Shunt Impedance
      1) Magnetic Field Coupling - Azimuthal Slots
      2) Electric Field Coupling - Longitudinal Slots

   C. Resonant Suppression
      1) Single Frequency: $f_{\text{dipole}} = (n/2)f_{\text{bunch}}$
      2) Beat note: $f_{\text{dip2}} - f_{\text{dip1}} = nf_{\text{bunch}}$
      3) Rectangular distribution of dipole frequencies:
         $\Delta f_{\text{dipole}} = nf_{\text{bunch}}$

   D. Non-resonant Suppression by detuning
      1) Rectangular Distribution: $W(t) \propto 1/t$
      2) Gaussian density distribution:
         $W(t) \approx \exp\{\left(\sigma_\omega\right)^2t^2/2\}$
            a) Truncation
            b) Effect of discrete modes
      3) Other smooth distributions

   E. Detuning combined with weak damping

   F. Design Procedure for Damped Detuned Structure
      1) Typical Dispersion Diagrams
II. Shunt Impedance Improvement

III. Tolerances
   A. Cell Frequency Tolerances: of the order of 1 MHz for both the monopole (fundamental) mode and the dipole mode - order of 1 μm tolerance on cell critical regions of cell contour.
   B. Alignment

IV. Fabrication Methods
   A. To Tune or Not To Tune??
   B. Diamond Turning
   C. Diffusion Bonding
A. Dipole Modes (TM$_{11}$ like)
GAUSSIAN DENSITY DISTRIBUTION

- \( \frac{K_{dn}}{df} \propto \exp\left\{ \frac{-(\omega-\omega_0)^2}{2\sigma_\omega^2} \right\} \), where \( K = \) kick factor \( \propto \omega R/Q \).

- Ideally then: \( W(t) \propto \exp\left\{ -\sigma_\omega^2 t^2/2 \right\} \)

- Advantages: 1) Non-resonant and therefore does not freeze collider operation to any particular bunch spacing other than some minimum spacing.

2) Wakefield decreases rapidly and monotonically

3) It permits error function interpolation of parameters with very sparse calculated data

- Disadvantages: 1) the gaussian frequency distribution is not limited, and so must be truncated. This causes a \( \sin(x)/x \) like wake to stop the rapid gaussian fall off at a level dependent on the truncation point.

2) The fact that there are a finite number of discrete modes causes a partial recoherence of the wakefield starting at a time \( t \approx 1/\delta f_{\text{max}} \) where \( \delta f_{\text{max}} \) is the widest frequency separation between
adjacent modes. With no damping the wakefield then increases until a time \( t \approx 1/\delta f_{\text{min}} \) where \( \delta f_{\text{min}} \) is the minimum spacing between modes at the center of the gaussian.

Thus the truncation and the finite number of discrete modes significantly degrade the wakefield envelope.
mode 49:
F = 14.381 K = 0.0468

mode 50:
F = 14.395 K = 0.0544

mode 51:
F = 14.408 K = 0.0628

mode 52:
F = 14.421 K = 0.0716

mode 53:
F = 14.434 K = 0.0803

mode 54:
F = 14.447 K = 0.0886

mode 55:
F = 14.459 K = 0.0958

mode 56:
F = 14.471 K = 0.1016

mode 57:
F = 14.482 K = 0.1059

mode 58:
F = 14.494 K = 0.1091

mode 59:
F = 14.505 K = 0.1113

mode 60:
F = 14.516 K = 0.1135

mode 61:
F = 14.527 K = 0.1156

mode 62:
F = 14.537 K = 0.1183

mode 63:
F = 14.548 K = 0.1212

mode 64:
F = 14.558 K = 0.1244
mode 161:  
F = 15.325  K = 0.3240

mode 162:  
F = 15.334  K = 0.3239

mode 163:  
F = 15.343  K = 0.3238

mode 164:  
F = 15.352  K = 0.3236

mode 165:  
F = 15.361  K = 0.3235

mode 166:  
F = 15.371  K = 0.3238

mode 167:  
F = 15.380  K = 0.3232

mode 168:  
F = 15.390  K = 0.3230

mode 169:  
F = 15.400  K = 0.3225

mode 170:  
F = 15.410  K = 0.3218

mode 171:  
F = 15.420  K = 0.3214

mode 172:  
F = 15.430  K = 0.3201

mode 173:  
F = 15.440  K = 0.3197

mode 174:  
F = 15.451  K = 0.3184

mode 175:  
F = 15.452  K = 0.3170

mode 176:  
F = 15.473  K = 0.3158
Figure A.1: NLC DS: line plots of $E_z$ along $\rho = 1.6\text{mm}$ for the 206 eigenmodes in the first dipole band. $F$ is the frequency in GHz while $K$ is the kick factor in $\text{V}/\mu \text{C}/\text{m}/\text{mm}$. 
Damped Detuned Structure

• A partial solution to the problem of having a finite number of discrete modes is to damp the modes to a place where the bandwidth of the mode is roughly equal to the mode separation. When this is done the frequency distribution of the dipole modes in the structure should approach a smooth curve. This is the approach we are taking.

• The light damping required is accomplished by coupling every cell (except 4 at each end) to a 4 waveguides, or damping manifolds, which run the length of the accelerator structure. These damping manifolds are positioned at 90 degree intervals in azimuth around the structure. They propagate the full frequency range of the lowest dipole band, but are cut off for the fundamental accelerating frequency of the structure (11.424 GHz). The coupling is Electric field coupling accomplished by longitudinal slots between the accelerator cells and the damping manifolds.

• The damping manifolds provide position monitor information for the structure. Since the dipole frequencies vary monotonically from about
14.3 GHz at the input end to about 16 GHz at the output, a frequency filter on the output from the damping manifolds can give good longitudinal resolution. The transverse resolution can be a few micrometers.

- The damping manifolds require a very good match. A VSWR as small as 1.05 produces a non-negligible degradation of the wake field. This is because the variation in the field strength in the damping manifold produces a variation in the coupling from mode to mode producing a rippling in the spectral function of the structure.

- The approach of combining detuning for the initial rapid decrease in wakefields with light damping costs only about 1% loss in shunt impedance, as opposed to strong damping which may reduce the shunt impedance by the order of 25%.
Design Procedure

- We pick a desired frequency distribution.

- Using Q2, a 2 D second order finite element field solver, we calculate about 5 cells whose synchronous frequencies in a periodic structure are uniformly distributed over the desired frequency range.

- Using a 3-D field solver (up to now, MAFIA) we add the coupling slots and damping manifolds and adjust the cavity diameters to give the same synchronous frequencies.

- We calculate the dispersion diagrams for each of these cells in a periodic structure including the manifold and the lowest two dipole bands.

- We fit the dispersion curves for each cell using 8 or 9 equivalent circuit parameters for the 3 periodic structures (2 dipole periodic structures (a TE and a TM mode) plus the manifold and the intercoupling constants
Next Linear Collider

\[
\alpha n \rightarrow 0.1186, \ \gamma \rightarrow 0.06249, \ f_0 \rightarrow 1.327, \ f_{\text{hat}} \rightarrow 1.332,
\]
\[
\eta \rightarrow 0.4597.
\]

Brillouin Diagram for RDDS1 Cell # 2
Double Band Model, 9 Par., KEWSLAC Data Points

Next Linear Collider

(alp -> 0.434, A -> 1.043, gamma -> 0.05829, fc -> 1.282, f0 -> 1.463, f0hat -> 1.386, eta1 -> 0.333, fm -> inf, eta1hat -> 0.09226, Gamma -> 0.02663)

Brillouin Diagram for RDDS1 Cell # 103
Double Band Model, 9 Par., KEK/SLAC Data Points

Next Linear Collider

\{ \alpha \rightarrow 0.1292, \ A \rightarrow 1.04, \ \gamma \rightarrow 0.07538, \ \phi_c \rightarrow 1.252, \ \phi_0 \rightarrow 1.639, \ \phi_0^{\hat{}} \rightarrow 1.437, \ \eta \rightarrow 0.2365, \ \eta^{\hat{}} \rightarrow 0.06554, \ \eta_m \rightarrow \infty, \ \gamma \rightarrow 0.02024 \}

Brillouin Diagram for RDDSI Cell # 204
Double Band Model, 9 Par., KEK/SLAC Data Points


2 (of 26), September 23, 1999 3:02 pm /u/apj/FrameMaker/RDDSI_6_99_Portrait.frame
• We then assume that these circuit parameters are appropriate for these same cells in an adiabatically tapered structure. The parameters of all the intermediate cells are determined by interpolation from the 5 calculated cells. For Gaussian distributions we use an error function for interpolation.

• The coupling between the damping manifolds and the cells are adjusted to optimize the wakefields.
Shunt Impedance Improvement

Although most travelling wave linear accelerators have been made with flat disks and cells that are right circular cylinders, it has long been known the Q of the cells and hence the shunt impedance could be improved by going to spheroidal shaped cavities. By doing so we found we could increase the Q by about 10%. We also improved the r/Q by 3% to 4% by reshaping the cavity and adding a circular bulge to the disks. Thus, a net improvement in shunt impedance of about 14% was achieved.
X-Band Round Detuned Structure (param-c), $a/\lambda=0.18$

Cell 001
\begin{align*}
a &= 5.65953 \text{mm} \\
Q &= 8300.38 \\
R &= 76.8596 \text{ M}\Omega/\text{m} \\
R/Q &= 9259.76 \\
V_g/c &= 0.1135 \\
E_s/E_a &= 3.00790
\end{align*}

Cell 052
\begin{align*}
a &= 4.97649 \text{mm} \\
Q &= 7970.96 \\
R &= 86.7337 \text{ M}\Omega/\text{m} \\
R/Q &= 10881.21 \\
V_g/c &= 0.0744 \\
E_s/E_a &= 2.51850
\end{align*}

Cell 103
\begin{align*}
a &= 4.70741 \text{mm} \\
Q &= 7846.88 \\
R &= 90.6774 \text{ M}\Omega/\text{m} \\
R/Q &= 11555.85 \\
V_g/c &= 0.0612 \\
E_s/E_a &= 2.41357
\end{align*}

Cell 154
\begin{align*}
a &= 4.45370 \text{mm} \\
Q &= 7733.49 \\
R &= 94.3869 \text{ M}\Omega/\text{m} \\
R/Q &= 12204.95 \\
V_g/c &= 0.0499 \\
E_s/E_a &= 2.32035
\end{align*}

Cell 206
\begin{align*}
a &= 3.81706 \text{mm} \\
Q &= 7462.76 \\
R &= 103.476 \text{ M}\Omega/\text{m} \\
R/Q &= 13865.69 \\
V_g/c &= 0.0272 \\
E_s/E_a &= 2.18890
\end{align*}
Fabrication Issues

!!! To Tune or Not To Tune !!!

• We have chosen not to tune even though it may be cheaper to achieve the fundamental mode frequency tolerances with tuning.

• The tolerances on the dipole mode frequencies are roughly the same as for the fundamental mode, but an error on the inner edge of the iris detunes the dipole mode by roughly the same amount but in the opposite direction from the monopole mode. If we correct the monopole mode by dimpling the outer surface of the cell (the only area accessible for dimpling) the error in the dipole mode will be roughly doubled. Because of this inability to tune both the monopole and the dipole independently, we decided to pursue fabrication that was accurate enough to not need tuning. This led us to diffusion bonding in order to avoid the detuning by braze alloy fillets. Single crystal diamond point machining seemed the natural way to get the surface finish required for optimum diffusion bonding and to achieve the ± 1 micron tolerance on the critical rf surfaces.

• Experience with diamond machining: KEK has demonstrated the ability to machine our cavity contours
X-Band RDS(c) AF Weighting Function (C102)

- $\omega^2 = \omega_0^2 (1 + W \Delta S \Delta d)$
- Positive $\Delta d$: Pushed IN

![Graph showing the X-Band RDS(c) AF Weighting Function](image)

```latex
\begin{align*}
\omega^2 &= \omega_0^2 (1 + W \Delta S \Delta d) \\
\text{Positive } \Delta d &\text{: Pushed IN}
\end{align*}
```
with 1 \( \mu \text{m} \) precision. We have shown that we can measure single cells with better than a 1 MHz accuracy in both the monopole and dipole modes and use this to direct sub-micron corrections to the contour.

- The concept for mass production is to microwave measure every cell within minutes of when it comes out of the diamond turning lathe and use the measurement of the monopole and dipole mode frequencies to feed forward on the machining of new cells. Sometimes this process will cause a few cells to be discarded, but the hope is to continually make minute corrections which keep the manufactured cells in the middle of the tolerance band. Since corrections can be made either in the outer region of the cell or on the iris, the monopole and dipole frequencies can be independently controlled, which cannot be done by tuning the completed accelerator structure. With automation the microwave measurements could be completed on a cell in less than a minute.

- The microwave measurement doesn't eliminate conventional mechanical measurement since it is insensitive to concentricity and to the outer diameter of the cell. The microwave measurement does measure exactly what we care about on the cavity contour - the dipole and monopole frequencies.
Deviation from smooth fit [MHz]