RF Technology for a 2 TeV Collider
Based on Copper Structures

We examine the technology needed for a 1.6–2.0 TeV linear collider with an active structure length of 22 km. Our starting point is the existing technology base already established for the NLC. Extensions in technology required to reach an energy of 1.6 TeV with a luminosity of $2.4 \times 10^{34}$ are examined for three rf sub-systems:

- Accelerator structures
- Klystrons
- Pulse compression system

An energy of 2.0 TeV can be reached at a reduced luminosity of about $1 \times 10^{33}$.
Accelerator Structures

Present Technology
In tests at NLCTA, 0.6m traveling-wave structures have achieved an unloaded gradient of about 60 MV/m at a pulse length of 400ns and a breakdown rate of less than 0.1/hr.

Improvements needed
To meet the requirements of the proposed 2 TeV collider design, the unloaded gradient must be increased to about 100 MV/m. While not impossible, this will be extremely difficult to do in a traveling-wave (TW) structure. However, as noted below, short standing-wave (SW) structures employed for rf guns are already operating at close to this gradient.

Standing-wave structure technology
The physics underlying rf breakdown is at present poorly understood. However, some experimental evidence indicates that it is helpful to reduce the local power available to produce surface damage. This points the way toward reducing the number of cells fed from a single rf feed.
It is very difficult to design a TW structure with a small number of cells (say a dozen) because this implies a low group velocity and, in general, a small beam aperture and unacceptable wakefields. A SW structure, however, can be built with any number of cells up to about 20 per feed. The maximum number of cells for a SW structure that can meet the 100MV/m gradient requirement must be determined by experiment. As a guide, we note that a six-cell structure for an rf gun operating in the ASTA facility area at SLAC has achieved a gradient of about 80 MV/m at a pulse length of 200ns with no evidence of breakdown (Arnold Vlieks).
Standing-wave structure
Klystrons

Present Technology

An NLC klystron has achieved the design peak power of 75 MW at the design pulse width of 1.6 µs. The efficiency is about 50%.

Improvements needed

Extend pulse width to 3.2 µs and improve the efficiency. In addition to improving the performance of the existing klystron design, a multi-beam klystron should be considered. The lower current per beam for such a tube would increase the pulse length threshold for the excitation of parasitic modes in the gun and rf structure. In addition, the lower perveance per beam would increase the efficiency. An efficiency of 60% or more should be possible.
**Pulse Compression System**

*System Description*

The pulse compression system enhances the peak power delivered by the klystrons at the expense of a reduced pulse length. The NLC design uses a so-called SLED-II pulse compression system in which power from a pair of klystrons is fed into a pair of resonant delay lines. The klystron pulse length is an integral number N times the round-trip delay time, termed a time bin—400ns for the NLC design. Energy from the klystrons is stored in the delay lines over the first N–1 time bins. At the beginning of the N\(^{th}\) time bin, the input phase to the klystrons is shifted by 180°. This causes the energy stored in the lines to empty out through a somewhat subtle process based on the superposition principle for rf fields. This process is not 100\% efficient, even if all of the rf components are lossless. For the NLC design with a compression ratio of 4, this intrinsic efficiency is 86\%.

To sustain the very high peak rf power (on the order of 500 MW) and to reduce losses, all rf components are overmoded. It is a difficult design challenge to produce highly overmoded components with negligible mode conversion losses.

To achieve the higher peak power required for a 2 TeV collider, it is proposed to double the compression ratio to 8 by adding a stage of so-called binary pulse compression, or BPC. The intrinsic efficiency of this BPC stage is 100\%. The overall efficiency of the pulse compression and power transmission system, from the klystrons to the input of the accelerator structures, is estimated to be about 70\%.
Basic SLED-II / BPC Module
(Cr = 8)

2 x 75MW
3.2\mu s

2 x 516MW
400ns

800ns resonant delay lines

400ns delay lines

2 x 258MW
800ns

klystrons

2 x SLED-II
Cr=4

BPC
Cr=2

to eight 0.6m structures

NOTE: Losses not included.

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### X-Collider Parameters

<table>
<thead>
<tr>
<th>System</th>
<th>Unloaded Gradient (MV/m)</th>
<th>Bunch Charge ($10^{16}$)</th>
<th>Loaded Gradient (MV/m)</th>
<th>Energy (TeV)</th>
<th>Number of Bunches</th>
<th>Repetition Rate</th>
<th>Luminosity $(10^{33})$</th>
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</thead>
<tbody>
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<td>73</td>
<td>0.75</td>
<td>56</td>
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<td>Add BPC Afterburner. Compression Ratio: 8</td>
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<td>96.5</td>
<td>2.0</td>
<td>105</td>
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<td>≈ 1</td>
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Active structure length: 22 km
RF system efficiency: about 35%
AC power for rf: about 250 MW