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Injector S-band linac for linear colliders

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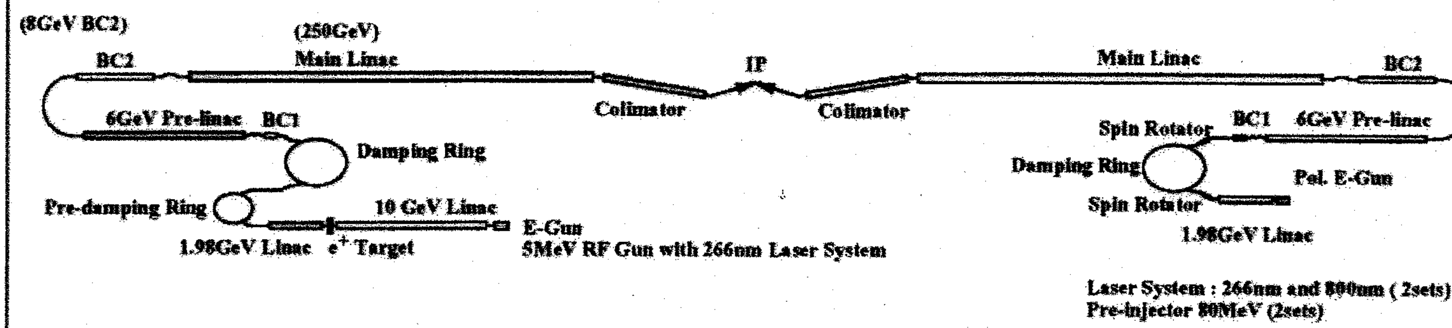
S-band Linac

Layout of JLC



1. *Electron*
   - *1.98GeV electron injector linac for DR*
   - *6GeV Pre-linac*
2. *Positron*
   - *10GeV electron linac for e+ production*
   - *1.98GeV positron injector linac for Pre-DR*
   - *6GeV Pre-linac*

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Beam parameter & requirement

Beam parameter (@final focus)

- *Bunch charge : 7.5 x 10^9 e-/bunch*
- *Bunch number : 192*
- *Bunch spacing : 1.4 ns*

High current !
Long-pulse train !

Electron injector linac for DR

- *Energy : 1.98 GeV,* [redacted]
- *Energy spread (full width): +-1% (90% beam)*
- *Normalized emittace: 1.0E-4 (1σ)*

Electron linac for Positron production

- *Energy : 10 GeV*
- *Bunch charge : 1.0 x 10^{10} e-/bunch (High charge)*
- *Energy spread (full width):* [redacted] *+-1% (90% beam)*

Positron linac

- *Energy : 1.98 GeV*
- *Energy spread (full width): ~+-1% (90% beam)*
- *Normalized emittace: 3.0E-3 (1σ)*

Beam loading

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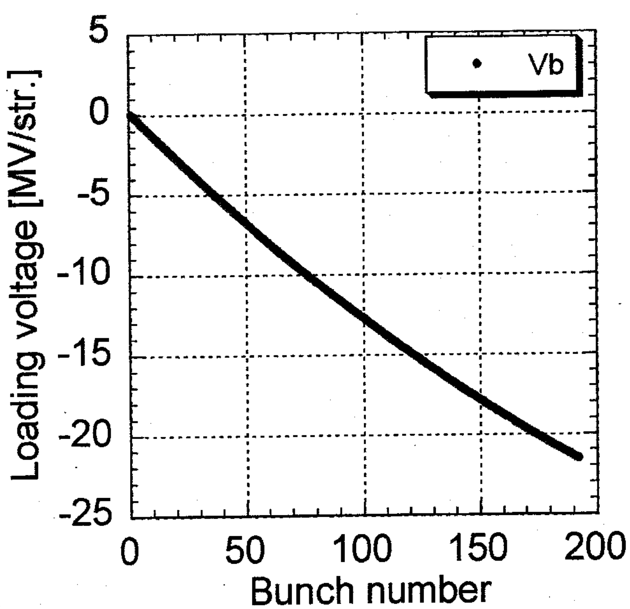
•*Single bunch*

minimized energy spread adjusting accelerating phase

1nC bunch ~ 0.5 % (3σ)

•*Multi-bunch*



Tf = 830ns, r = 60 MΩ

Heavy beam loading
(Pulse width ; 267.4 ns, Beam current ; 0.857A)

Energy acceptance of DR ; ~ +-1.0 % (3σ)

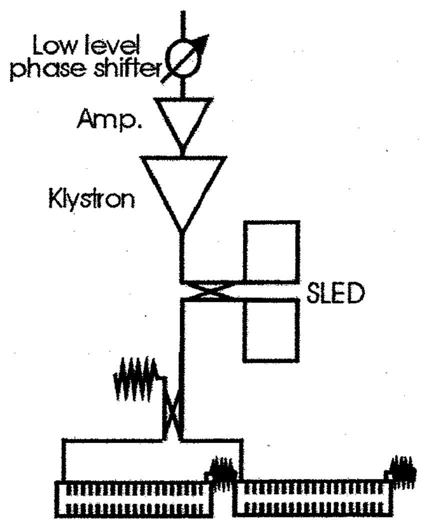
Necessarily
Energy Compensation System (ECS)

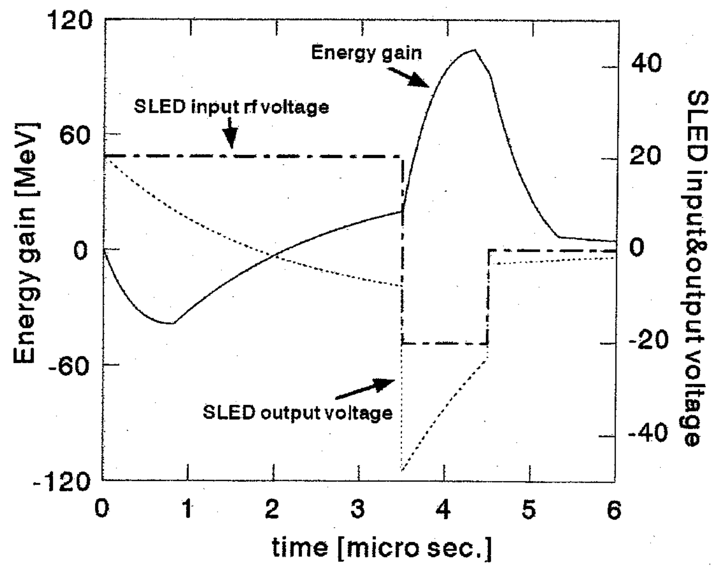
for injection to DR
emittance preservation

S-band linac

- *SLED system*
- *S-band accelerating structure*
  - *Short-range longitudinal wake --- single bunch beam loading*
  - *Long-range longitudinal wake --- transient beam loading → (ECS)*
  - *Transverse wake --- beam brow-up*

    (long-range → 6 GeV pre-linac Structure design)





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Energy compensation system

<u>*ΔT ECS*</u>

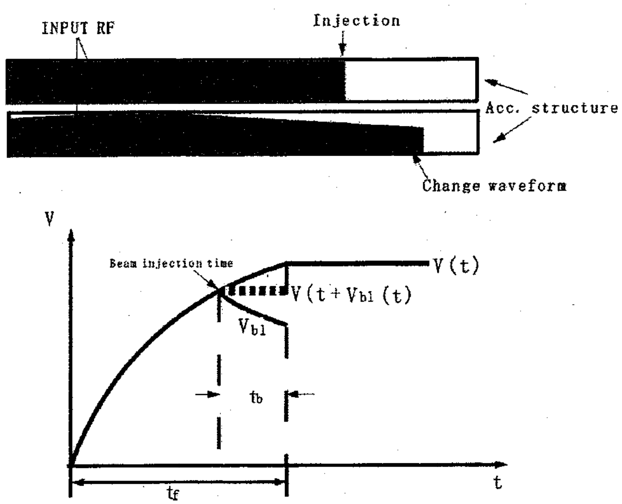
**Injection timing*
**Amplitude modulation of rf pulse*

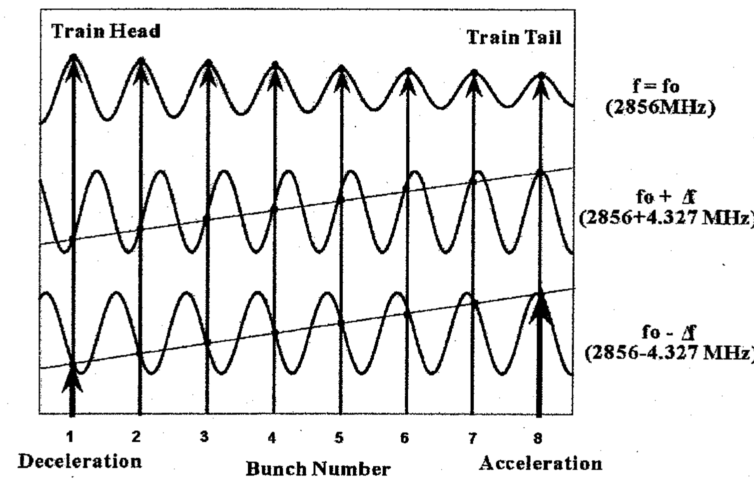
Local energy compensation
(Good for lattice)

<u>*ΔF ECS*</u>

**Using +dF & -dF structures*

High gradient acceleration in Reg. Section





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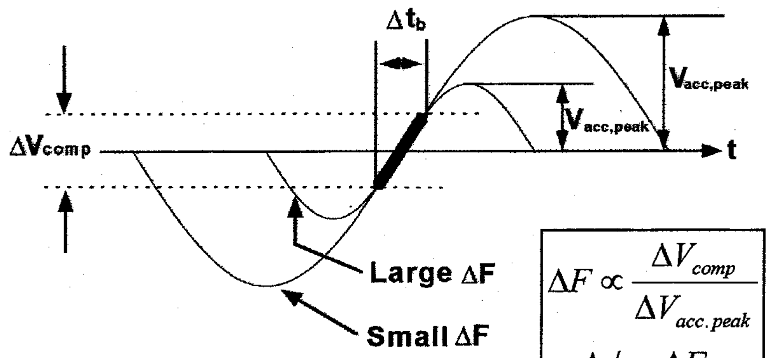
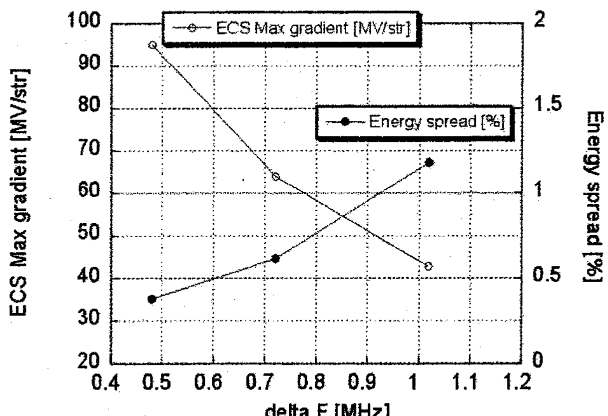
ΔF ECS （1）



$$\Delta F \propto \frac{\Delta V_{comp}}{\Delta V_{acc.peak}}$$

$$\Delta\phi \propto \Delta F$$

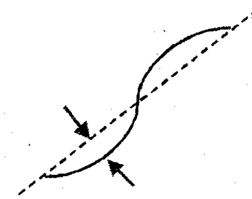
$$\frac{\Delta E_{final}}{E} \leq 1\% \text{ (DR Energy acceptance)}$$



Tf = 830ns, r= 60 MΩ

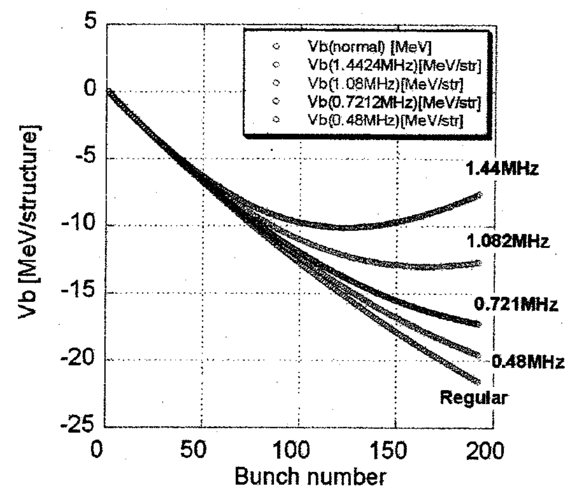
Residual energy spread

In case of linear beam loading



$$\frac{\Delta E_{final}}{E} \propto \Delta F^2$$

Beam loading in ECS structure



Tf = 830ns, tb= 267ns, Qb=7.5E+9

ΔF ECS (2)

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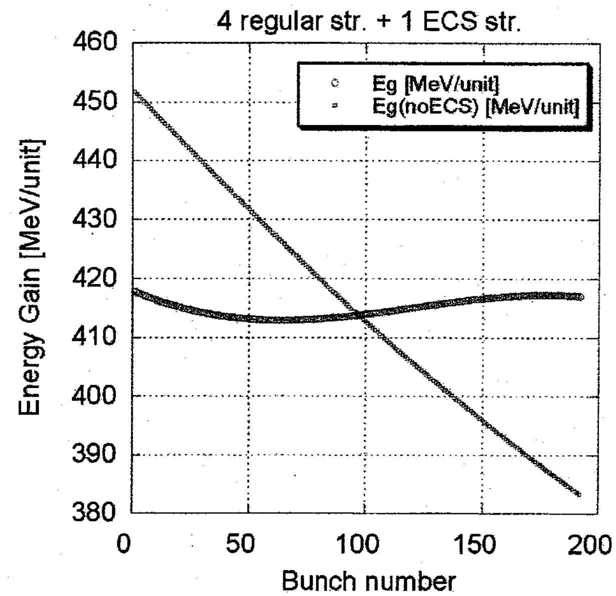
Accelerating efficiency depends on ΔF ECS unit size

$$Acc_{eff} = \frac{N_{Reg} \cdot E_{g-Reg.}[\text{MeV/str.}]}{N_{Reg} + N_{ECS}}$$

Acc. Efficiency of large unit is high,
but it generate large energy spread along the linac



Average gradient = 27 MV/m, L_{Reg}=L_{ECS}= 3 m,
Unit active length = 15 m

ΔF = 1.018MHz, $\Delta E/E$ = 1.18%

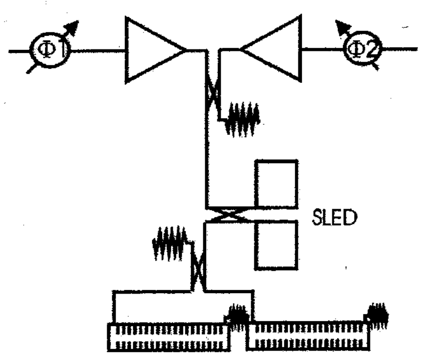
Emittance growth due to quads misalignment

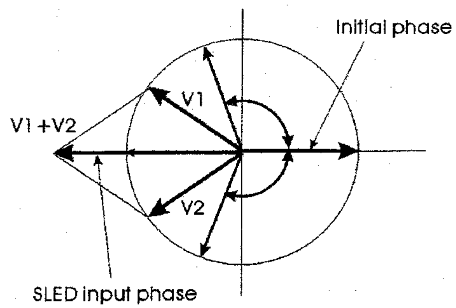
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{A_{rms}^2}{2\gamma_0\varepsilon_0}\sum_i \gamma_i\beta_i k_i^2 \left(\frac{\Delta E}{E}\right)_i^2$$

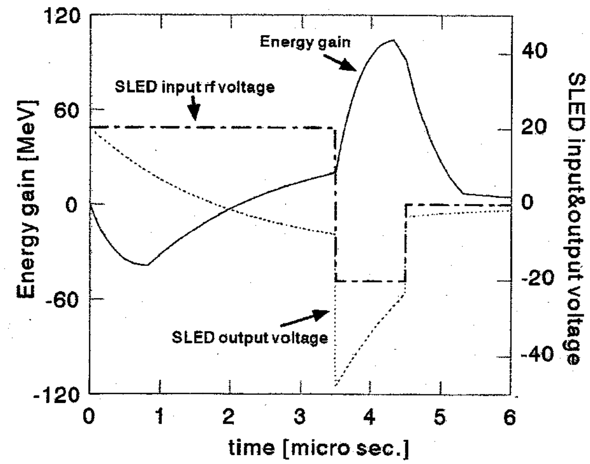
ΔT ECS (1)

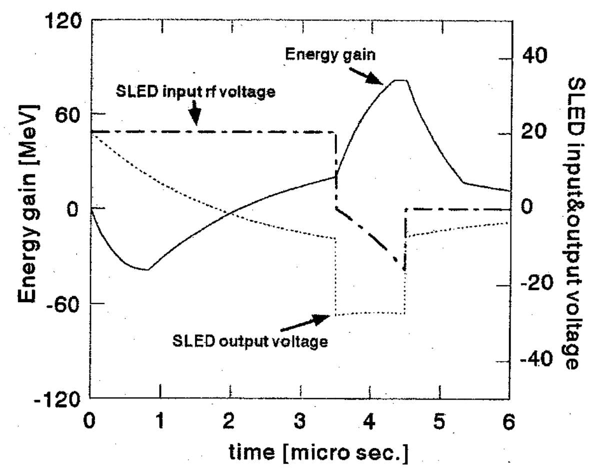
Phase to Amplitude modulation

- *Combine two klystrons*
- *Input rf for SLED cavity with constant phase*
- *Klystron runs in saturation : Stable*









ΔT ECS (2)

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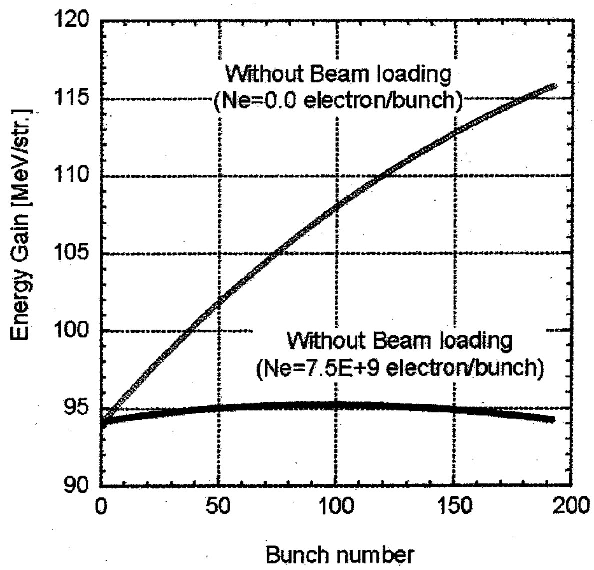
Only injection timing adjustment

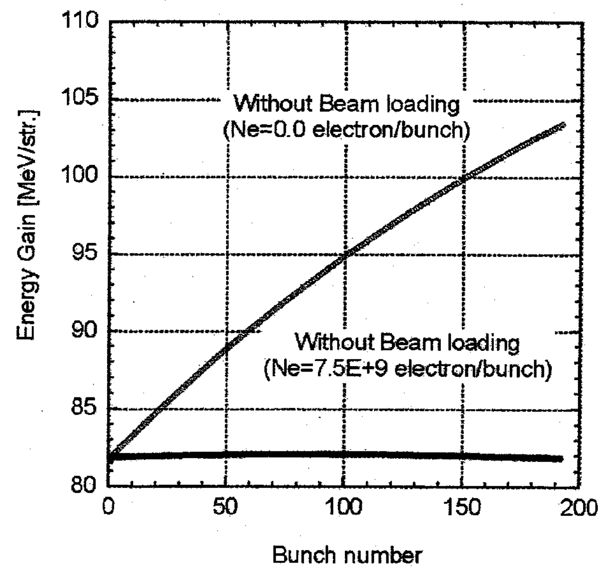


Acc. Gradient ; 31.5 MV/m

(Kly output power; 80 MW)

Energy spread ; 1.1 %

Injection timing & amplitude modulation

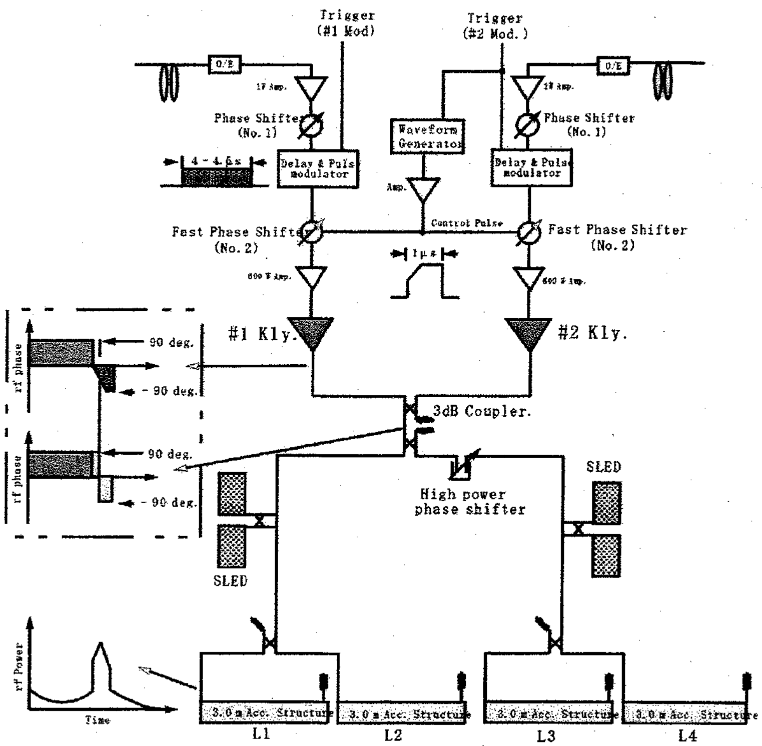


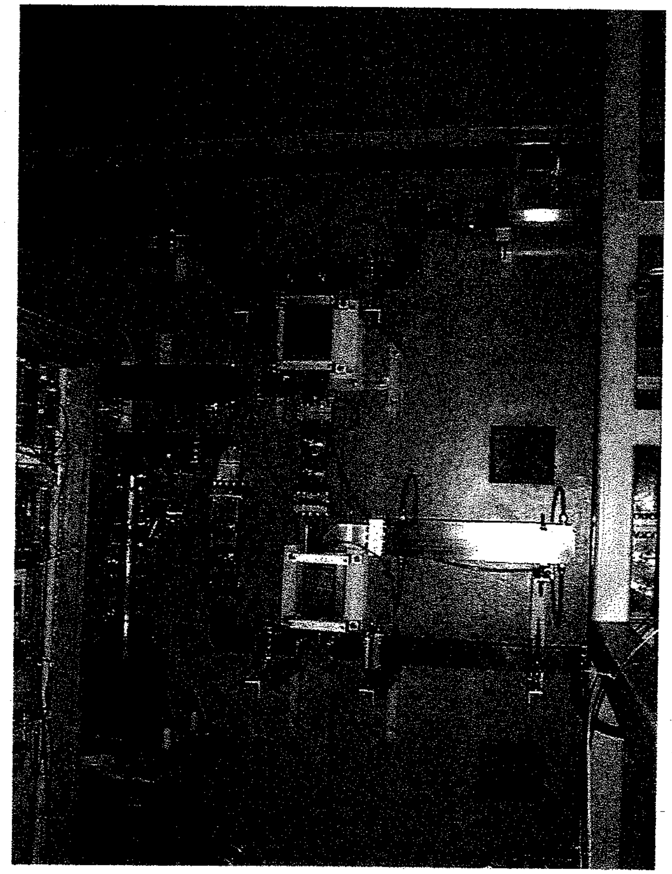
Acc. Gradient ; 27.5 MV/m

(Kly output power; 80 MW)

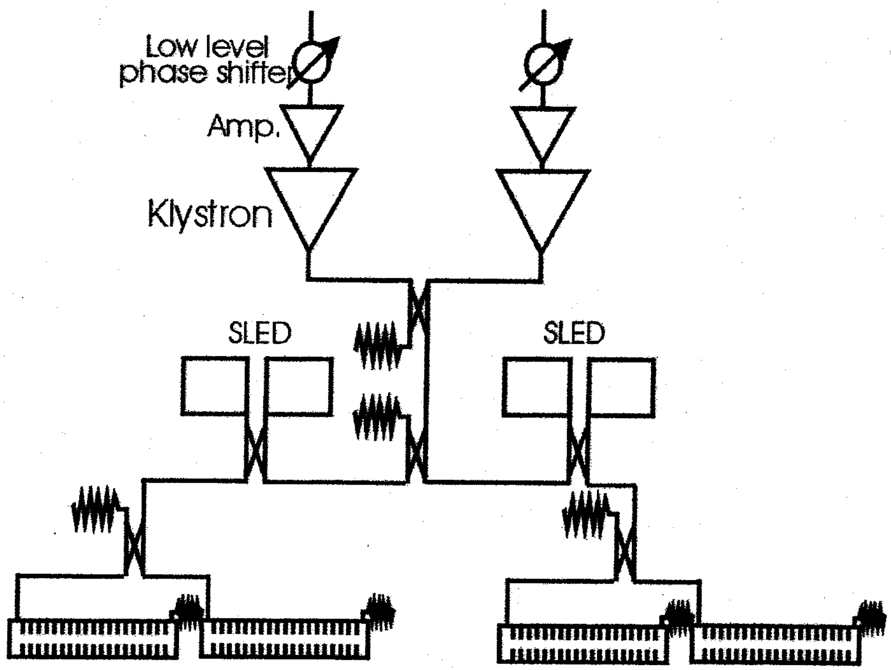
Energy spread ; 0.27 %

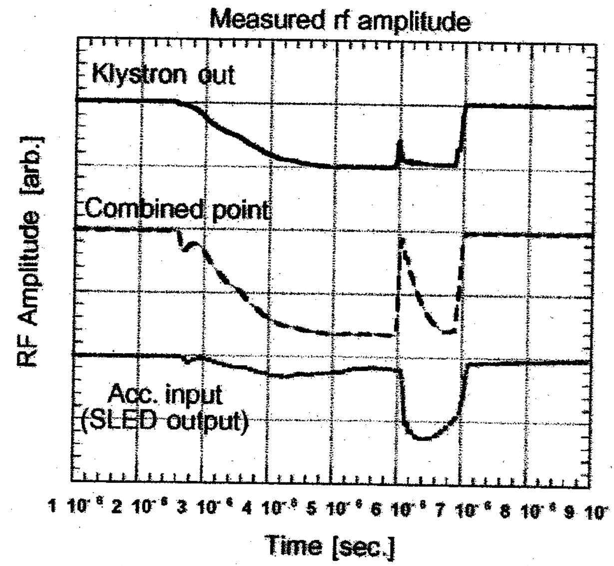
Phase to amplitude modulation (1)

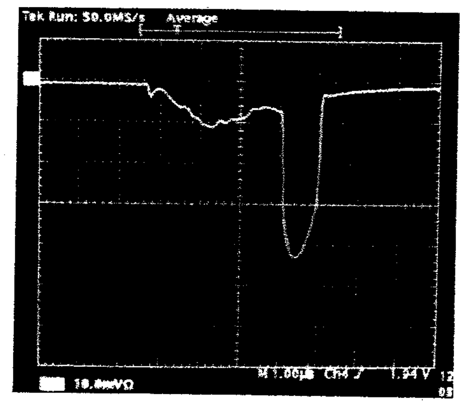




Phase to amplitude modulation (2)







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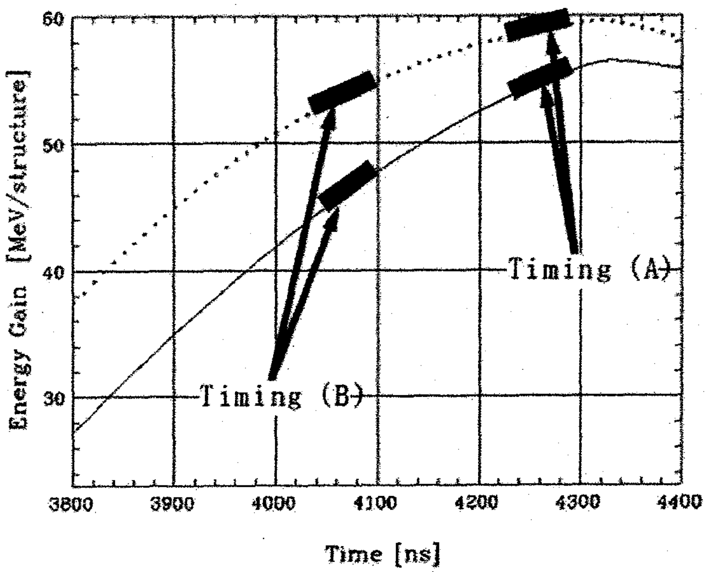
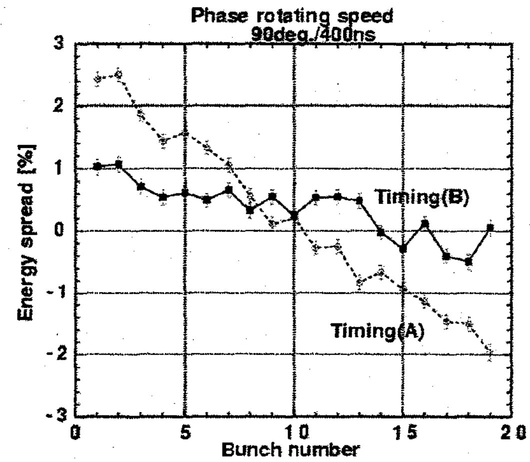
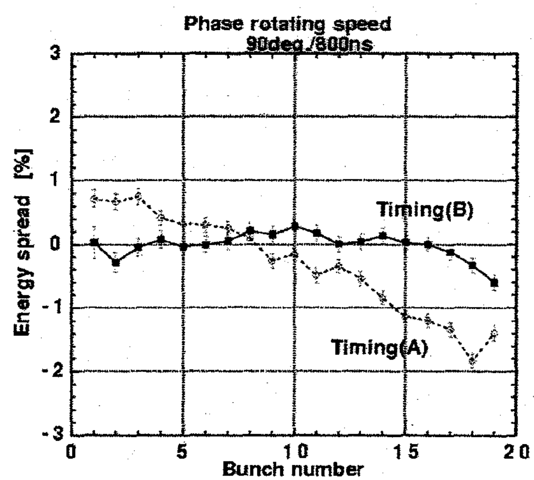
Phase to amplitude modulation (3)







ΔF , ΔT ECS

• ΔF and ΔT (injection timing & amplitude modulation) can be compensate the multi-bunch energy spread within the injection energy acceptance of DR. ΔT ECS can compensate non-uniform multi-bunch beam making arbitrary waveform for SLED cavities.

•Accelerating gradient

$$E_{\Delta T(regular)} \leq E_{\Delta F(regular)} \Longrightarrow E_{\Delta T(net)} \approx E_{\Delta F(net)}$$

• ΔT (injection timing & amplitude modulation) is local energy compensation system, Emittance growth due to chromatic effect can be minimized. Optical design for ΔT ECS is will be easy.

ΔT (injection timing & amplitude modulation) is applied to S-band injector linac

<u>1.9 GeV injector linac</u>

Number of unit	: 8	16 klystrons, 32 accelerating structures 16 SLED cavities
Maximum energy gain :	2.64 GeV (35% energy margin → 17% saved kly output power)	