Prototype Measurements of Coupler Cavities for L-band Traveling-wave Accelerating Structure*

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POSTECH
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Introduction

- L-band traveling-wave electron accelerator
- Irradiation Application
- 1.3 GHz, 10 MeV and 30 kW
- Design by SUPERFISH and PARMELA code
- Prototype measurements of coupler cavities
- Kyhl's method

Accelerator Parameters

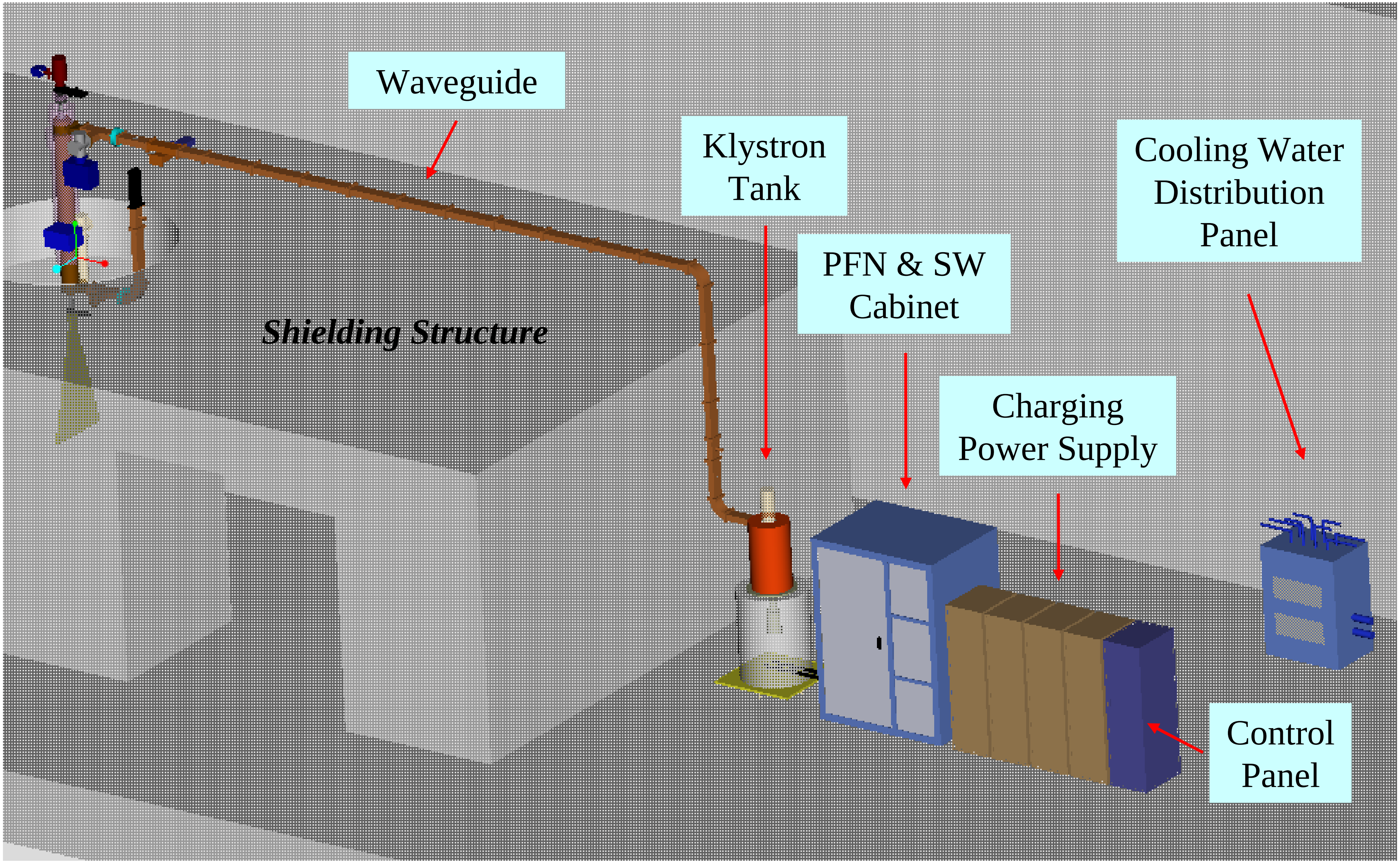
Beam	
Beam Species	Electron
Beam Energy	10.3 MeV
Pulsed Beam Current	1.45 A
Beam Transmission Rate	91%
Beam Duty Factor	2.1×10^{-3}
Averaged Beam Power	31.4 kW
No Loaded Beam Energy	17 MeV
Beam Loading Factor	-4.62 MeV/A

E-gun	
High Voltage	80 kV
Pulsed Beam Current	1.6 A
Beam Duty Factor	2.1×10^{-3}
RF	
Operating Frequency	1300 MHz
Pulsed RF Power	25 MW
RF Duty Factor	2.38×10^{-3}
Averaged RF Power	60 kW

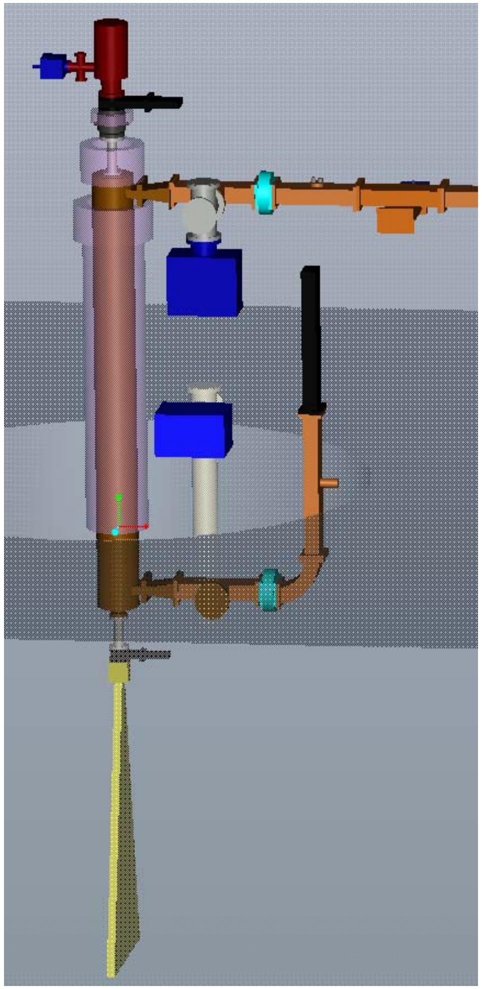
Accelerator Parameters

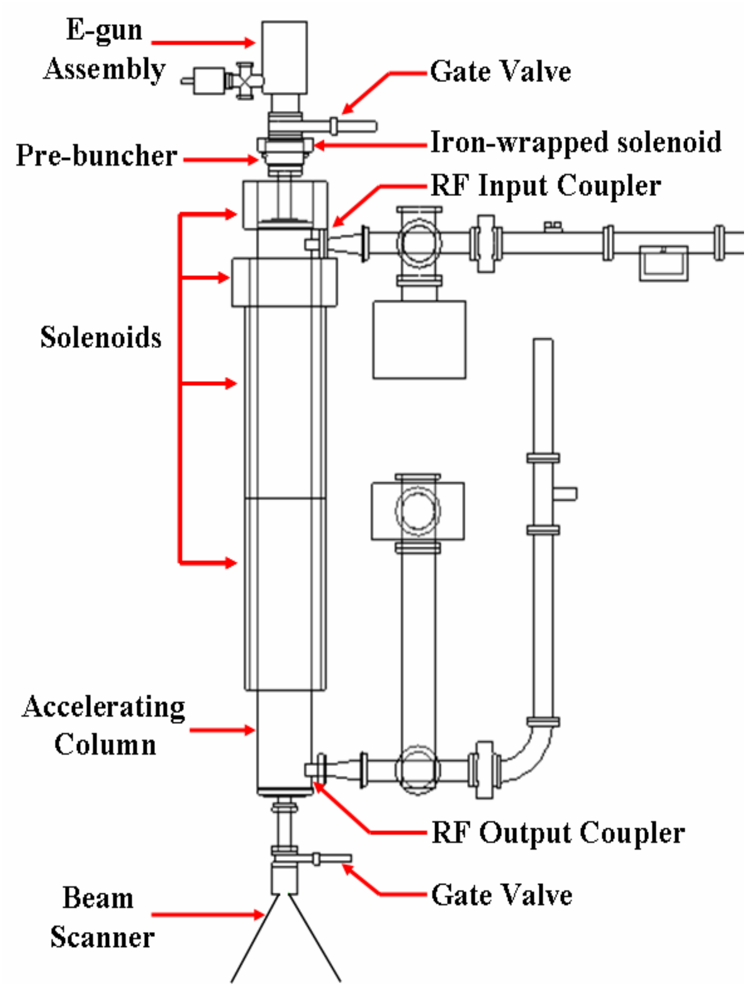
Accelerator Structure	
Number of Bunching Cells	5
Number of Accelerating Cells	26
Total Length	2.4 m
Operating Mode	$2\pi/3$
Operating Temperature	40°C ± 1°C
Averaged Accelerating Gradients	4.2 MV/m
Shunt Impedance*	43 MΩ/m
Quality Factor*	20000

Layout of Accelerator System

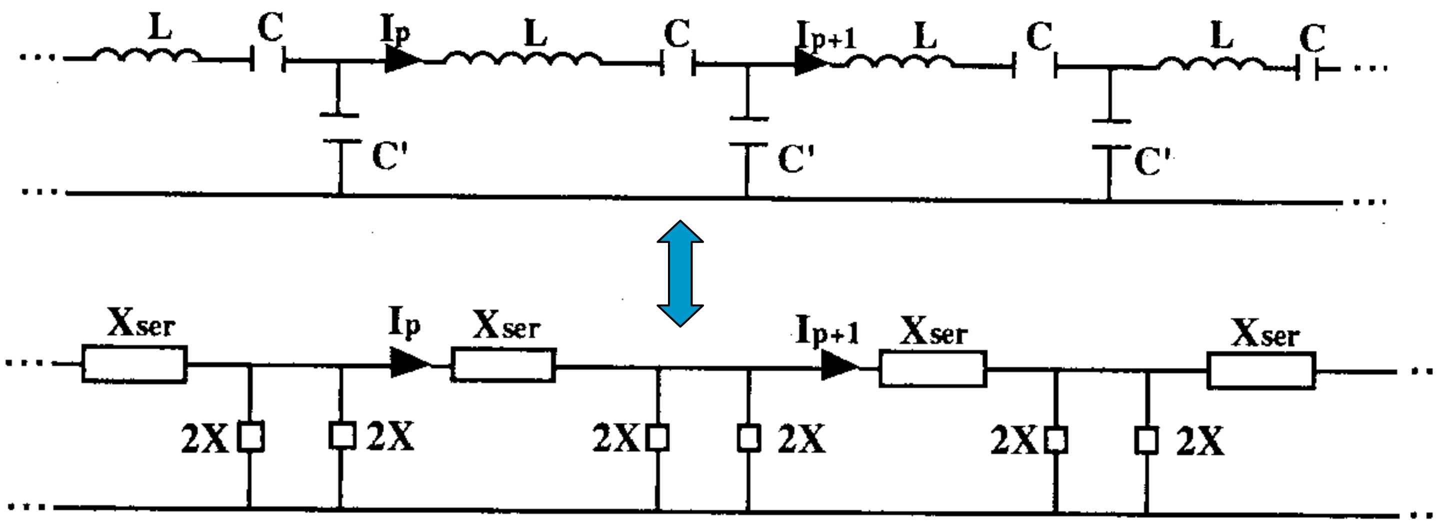


Layout of Beamline





Input Impedance for Traveling-wave Accelerating Structure



For no reflected wave and the phase advance of ϴ per cell

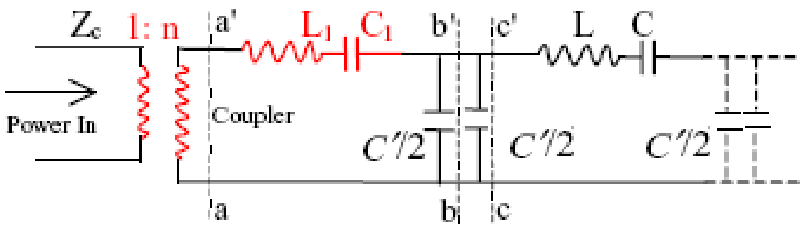
$$Z_e^2 = \frac{X \cdot X_{ser}}{1 + \frac{X_{ser}}{4X}}, \quad \cos\theta = 1 + \frac{X_{ser}(\omega_\theta)}{2X(\omega_\theta)} \quad \Rightarrow \quad Z_e^2(\omega_\theta) = -4X^2(\omega_\theta)\tan^2\frac{\theta}{2}$$

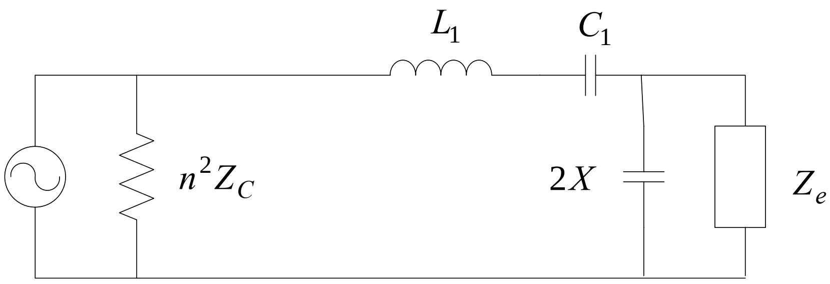
$$Z_e(\omega_\theta) = 2\left|X(\omega_\theta)\right|\tan\frac{\theta}{2}$$

Z_e : Input impedance of periodic array of traveling-wave accelerating cells

$$X_{ser} = j\omega L + \frac{1}{j\omega C}, \quad X = \frac{1}{j\omega C'}$$

Matching Condition for Traveling-wave Accelerating Structure





$$Z_L = n^2 Z_C$$

$$Z_R(\omega_\theta) = j\omega_\theta L_1 + \frac{1}{j\omega_\theta C_1} + \frac{2X \cdot 2|X|\tan(\theta/2)}{2X + 2|X|\tan(\theta/2)} = |X|\sin\theta + j|X|(\frac{4\delta}{k} + \cos\theta)$$

where $\delta = \frac{\omega_C}{\omega_{\pi/2}} - 1$, $\omega_C = \sqrt{\frac{1}{L_1 \nu}}$, $\frac{1}{\nu} = \frac{1}{C_1} + \frac{1}{C'}$

Matching condition: $Z_L = Z_R$

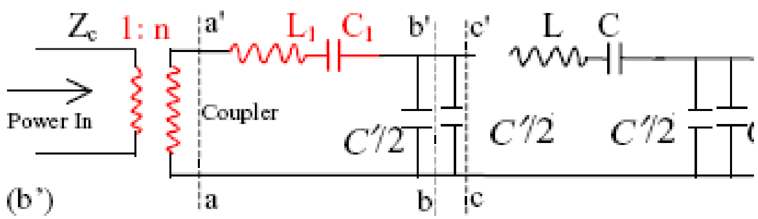
$$\beta \equiv \frac{n^2 Z_C}{|X(\omega_\theta)|\sin\theta} = 1$$

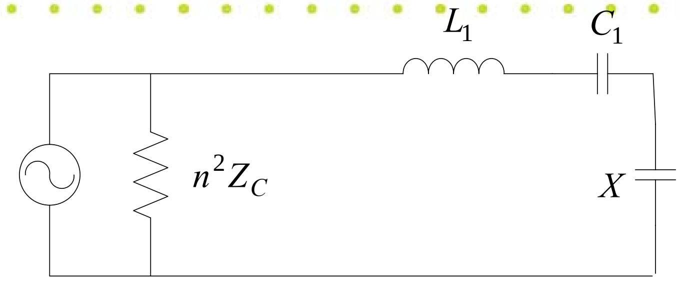
$$\omega_C = \omega_{\pi/2}(1 - \frac{k}{4}\cos\theta) \cong \frac{\omega_{\pi/2} + \omega_\theta}{2}$$

Dispersion relation

$$\omega_\theta = \frac{\omega_{\pi/2}}{\sqrt{1 + k\cos\theta}}$$

Analysis of Kyhl's Method





$$\tan\frac{\varphi}{2} \cong \frac{n^2 Z_C}{\omega L_1 - \dfrac{1}{\omega \nu}} = \frac{n^2 \omega Z_C}{L_1(\omega^2 - \omega_C^2)} \quad \text{, when } |\Gamma| \to 1$$

$$\beta = \frac{1}{\dfrac{k}{2}\omega_{\pi/2}\sin\theta} \cdot \frac{\tan\dfrac{\varphi_1}{2}\tan\dfrac{\varphi_2}{2}(\omega_1^2 - \omega_2^2)}{\omega_1 \tan\dfrac{\varphi_2}{2} - \omega_2 \tan\dfrac{\varphi_1}{2}}$$

ω_1 , ω_2 are arbitrary frequencies and

φ_1, φ_2 are corresponding reflection angles.

For matched condition, the resonant frequency of this circuit should be as following.

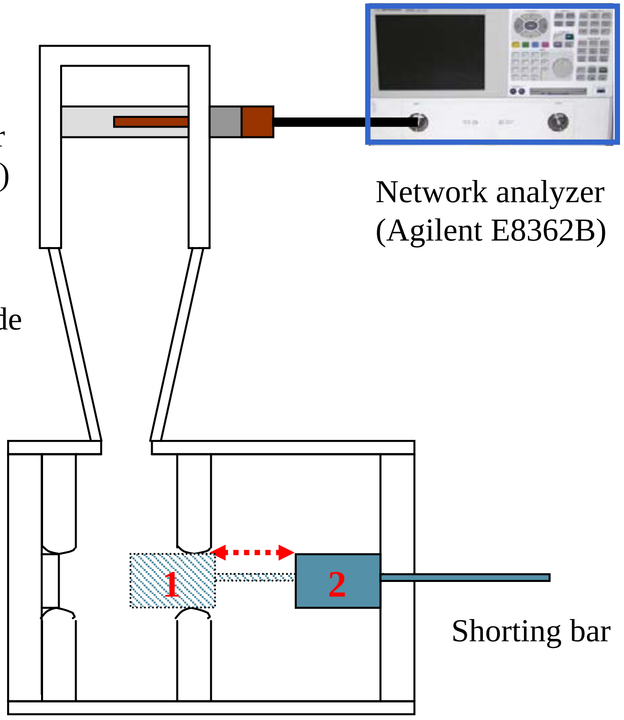
$$\omega_C \cong \frac{\omega_{\pi/2} + \omega_\theta}{2}$$

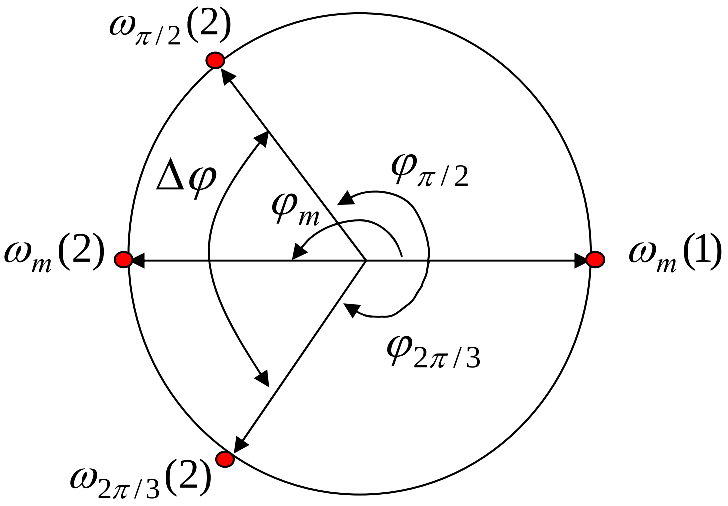
If we choose frequencies as $\omega_1 = \omega_{\pi/2}$, $\omega_2 = \omega_{2\pi/3}$ then $\varphi_1 = -\varphi_2$ and

$$\beta \cong \frac{\tan(\varphi_1/2)}{\sqrt{3}} = 1.$$

Equivalent to Khyl's method

Impedance Matching for coupler cavities





$\omega_m(1)$: mean frequency of $\omega_{\pi/2}$ and $\omega_{2\pi/3}$ at position 1

$\omega_{\pi/2}(2)$: $\pi/2$-mode frequency at position 2

$\omega_{2\pi/3}(2)$: $2\pi/3$-mode frequency at position 2

$\omega_m(2)$: mean frequency of $\omega_{\pi/2}$ and $\omega_{2\pi/3}$ at position 2

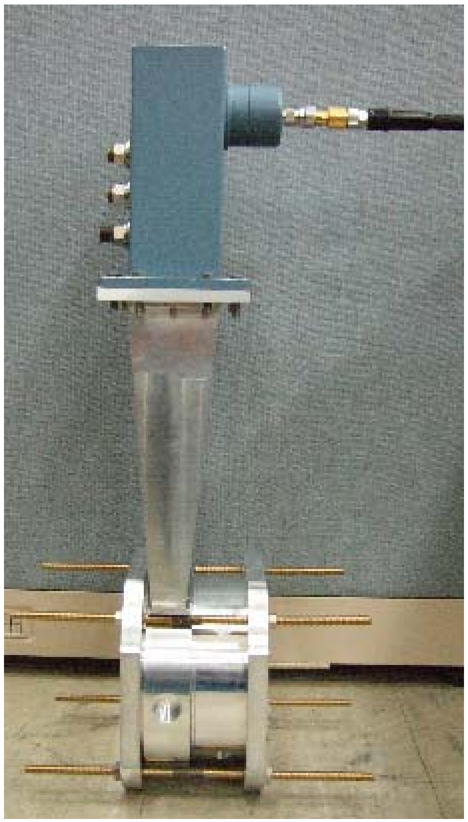
For critical coupling to traveling-wave accelerating column

$$\varphi_m = 180^\circ \qquad \varphi_{\pi/2} = \varphi_{2\pi/3} = 120^\circ$$

Under-coupled: $\varphi_{\pi/2} = \varphi_{2\pi/3} < 120^\circ$

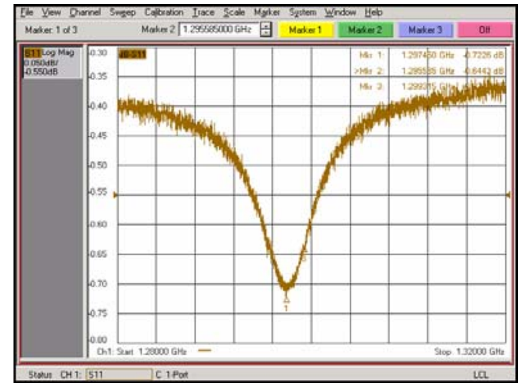
Over-coupled: $\varphi_{\pi/2} = \varphi_{2\pi/3} > 120^\circ$

Prototype Test of Coupler Cavities



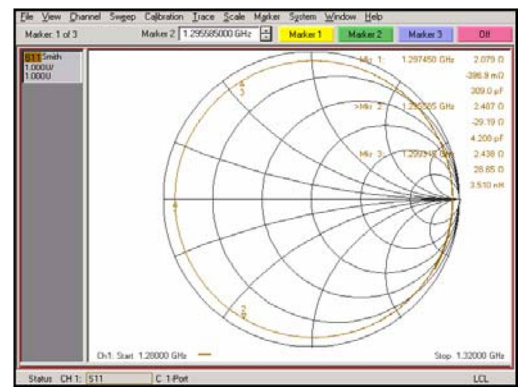
Setup for Prototype Test

Network Analyzer



S11 Parameter

Phase



Smith Chart

Measurement Procedure

Expand the coupling aperture length

↓

Find the resonant frequency ω_c of 1st cavity by shorting 2nd cavity

↓

Calculate ω_1 and ω_2

$$\omega_1 = \omega_c - \delta\omega, \omega_2 = \omega_c + \delta\omega$$

$$\delta\omega = \frac{\omega_{2\pi/3} - \omega_{\pi/2}}{2}$$

↓

Measure the reflected angle ϕ_1 and ϕ_2 of ω_1 and ω_2

↓

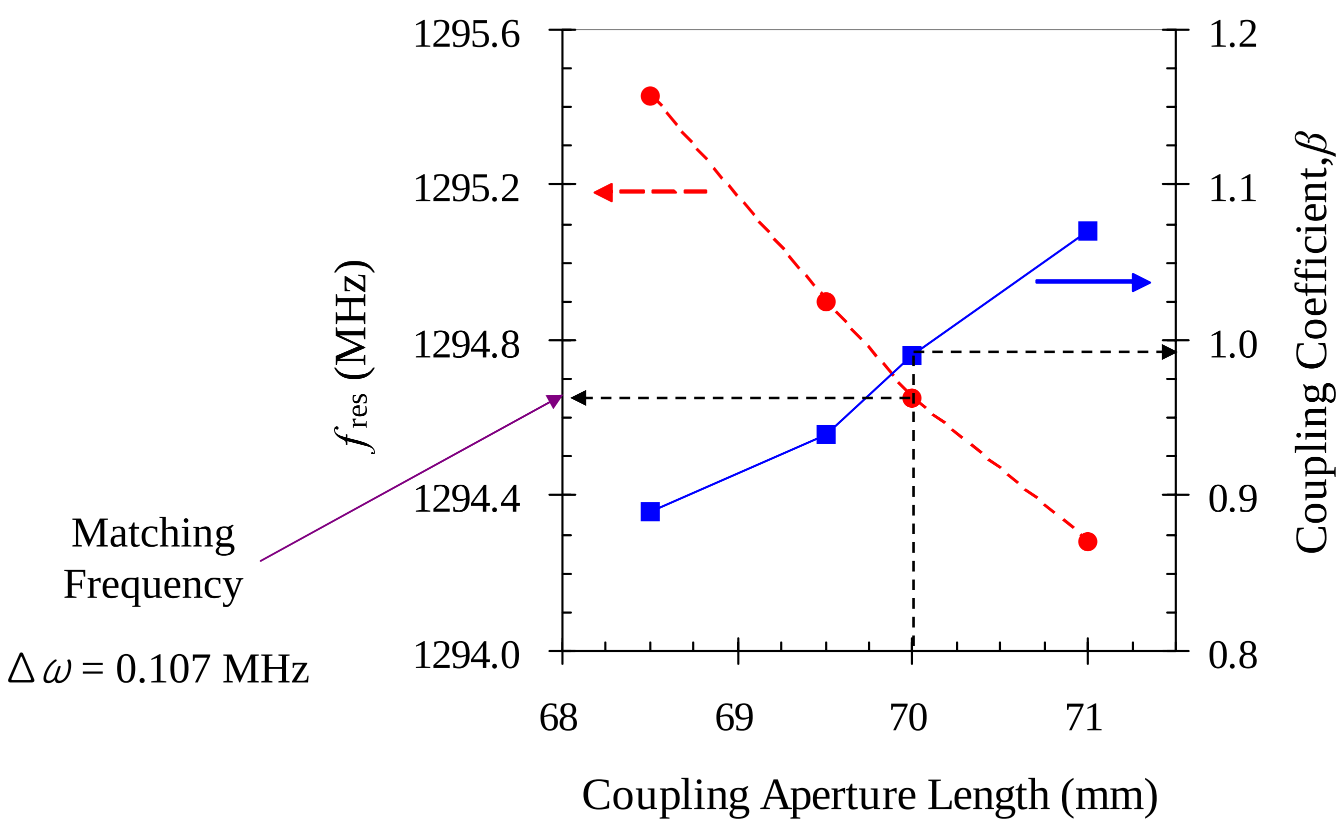
Calculate β

(If $\beta < 1$ → back to "Expand the coupling aperture length")

↓

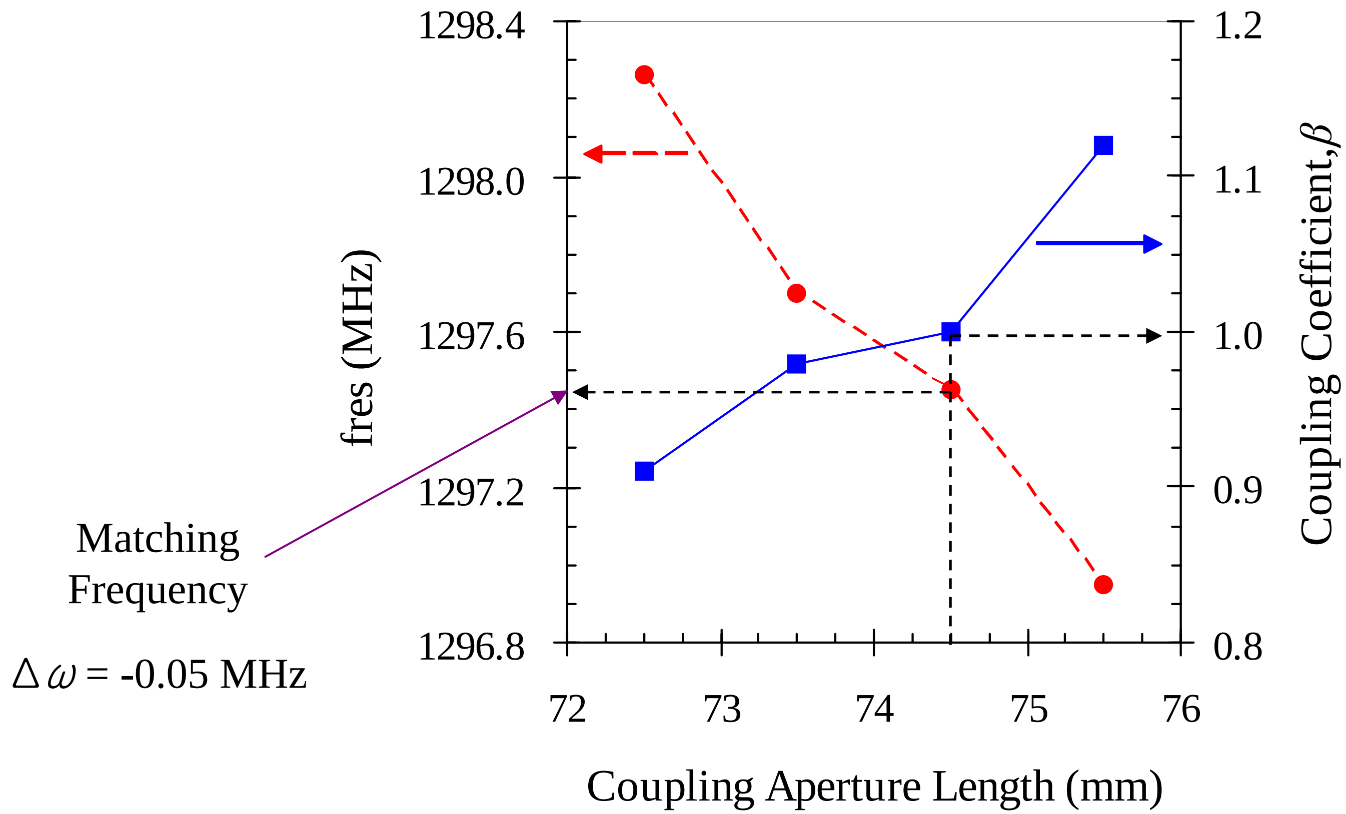
Impedance matching : $\beta = 1$, $\omega_c = \omega_m$

Experimental Results of Input Coupler



Cavity radius and coupling aperture width are fixed.

Experimental Results for Output Coupler



Cavity radius and coupling aperture width are fixed.

Summary

- Intense L-band traveling-wave linac of 10 MeV and 30 kW is designed for the sterilizing industrial application.

- Impedance matching for input and output coupler cavities are tested by the Khyl's method.

- With cold tests of model cavities, detailed dimensions are confirmed for the fabrication drawings.