Tuning of CLIC Accelerating Structure Prototypes at CERN

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Introduction

Tuning Purpose

- Phase velocity = beam velocity (Phase advance per cell ~ frequency)
- Matching cell (Output matching cell→ standing-wave)

Where are we?

- Estimation of fabrication error 2~3μm?
- (for X-band, v_g=0.01c, 120),
- 1μm of radius → 1MHz → 1 phase error/cell or 0.02 (-34dB) reflection from matching

Tuning Method

Reflection of a single cell due to frequency detuning

$\beta = Q_0/Q_e$

Γ ⟷ C, R_C, L

Q_{ext} Q_0, f_0

$$\Gamma = \frac{(\beta-1)(\beta+1)-Q_0^2(\Delta F)^2}{(\beta+1)^2+Q_0^2(\Delta F)^2} - j\frac{2\beta Q_0 \Delta F}{(\beta+1)^2+Q_0^2(\Delta F)^2}$$

$$\Delta F = \frac{f}{f_0} - \frac{f_0}{f}$$

$\Delta F = -2\Delta f_0/f_0$ if $\Delta f_0 << f_0$

Frequency detuning →Imaginary part

$$\Gamma \approx -j\frac{2\beta Q_0' \Delta F}{(\beta+1)^2+{Q_0'}^2(\Delta F)^2} \approx j\frac{Q_0'\Delta f_0}{f_0} \qquad Q_0' = \frac{\omega U}{P_w+P_f} \approx \frac{\omega U}{P_f} = \frac{\omega W D}{W v_g} = \frac{c\varphi}{v_g}$$

The field, the waves and the local reflection

- The waves

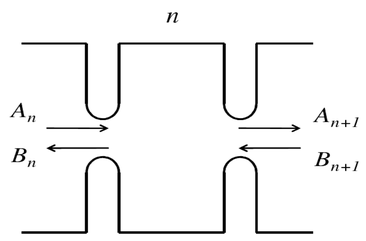
$A_n = Ae^{j(\omega t-\varphi n)}$

$B_n = Be^{j(\omega t+\varphi n)}$

- The field

$I_{n-1} = A_n e^{j\varphi_{n-1}} + B_n e^{-j\varphi_{n-1}}$

$I_n = A_n + B_n$



$$A_n = \frac{I_{n-1}+I_n e^{-j\varphi_{n-1}}}{-2j\sin\varphi_{n-1}} \qquad B_n = \frac{I_{n-1}+I_n e^{j\varphi_{n-1}}}{2j\sin\varphi_{n-1}}$$

$$\Gamma_{\text{local}}|_N = \frac{B_N}{A_N}$$

$$\Gamma_{\text{local}} = \frac{B_n - B_{n+1}e^{-j\varphi}}{A_n}, (2 \le n \le N-1)$$

$$\Gamma_{\text{local}}|_1 = \frac{\left[-j|\Delta S_{11}^{(1)}|/\Delta S_{11}^{(1)}\right] S_{11}A_1 - B_2 e^{-j\varphi}}{A_1}$$

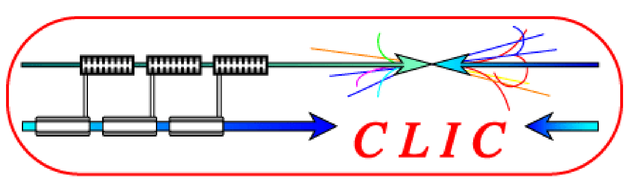
Reflection seen from VNA (relationship between global/local reflection)

$$|\Delta\Gamma_{\text{global}}| = e^{\alpha(n)}\,|\Delta\Gamma_{\text{local}}(n)| \qquad \alpha(n) = -\sum_{m=1}^{n-1}\frac{c\varphi}{Q_0(m)v_g(m)}.$$

Γ_{global} ⟷ $\frac{dP}{dz} = -\frac{\omega}{Q_0}\frac{1}{v_g}P$ Γ_{local}

Procedure

1. "bead-pull" measurement
2. Calculate forward and backward wave along the structure
3. Calculate local reflection of each cell
4. Calculate global reflection change due to local reflection correction
5. Tuning each cell while monitoring the global reflection
   1. Start from output side
   2. Several iteration

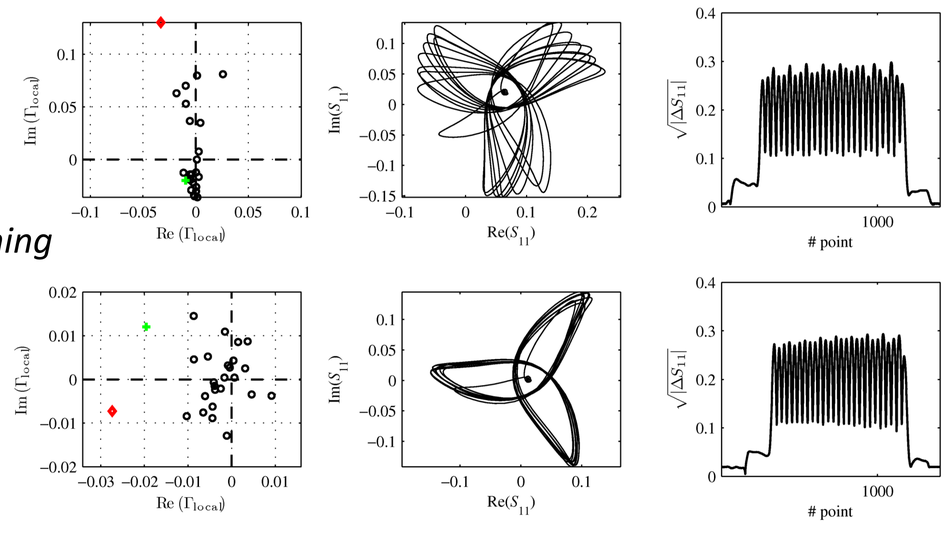


Tuning Example

Photo of a CLIC-G prototype Structure

Before tuning

After tuning



RF measurement results of a CLIC-G (TD24) structure before (TOP) and after (BOTTOM) tuning

- left: Calculated local reflection;
  - red-diamond: output cell,
  - green-cross: input cell,
  - black-circles: regular cells;
- middle: bead-pull results showing the RF phase;
- right: bead-pull results showing field amplitude

Tuning Results

- Average phase shift error is 0.07 degree.
- The local reflection of the output matching cell had an imaginary part of "j0.13", (←6MHz frequency error at vg=0.8%c)→a standing-wave pattern (figure up-right). corrected after tuning.
- a small residual reflection (real part) from the output matching cell still exists, which is due to the matching iris error

TD18 after High Power test