Triangle and Concave Pentagon Electrodes for an Improved Broadband Frequency Response of Stripline Beam Position Monitors*

Yong Ho Chin (KEK)

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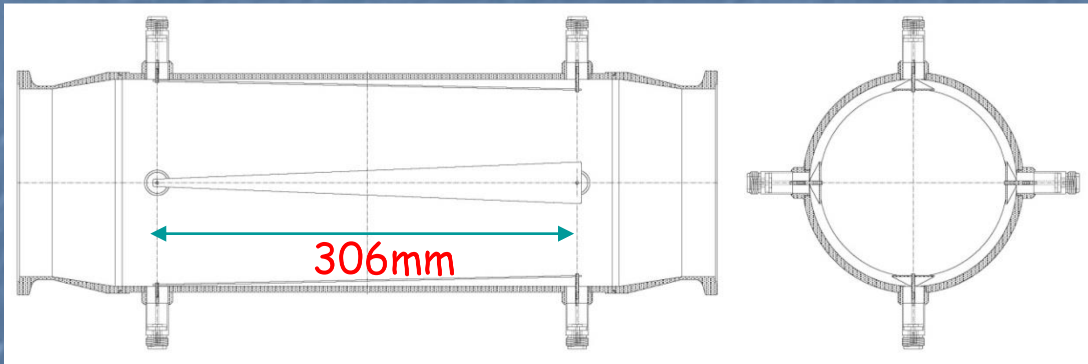
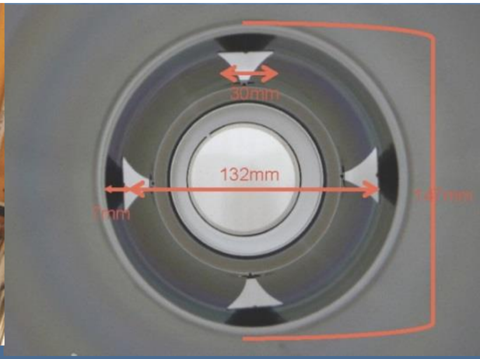
Exponentially Tapered Electrodes

- A new stripline BPM is under development at J-PARC MR for both the intra-bunch feedback system (~100MHz) and e-clould detection (~several GHz).
- It has exponentially tapered electrodes for an improved frequency response, compared to rectangular ones.





Exponential Electrode: Prototype and Measurement at SPS

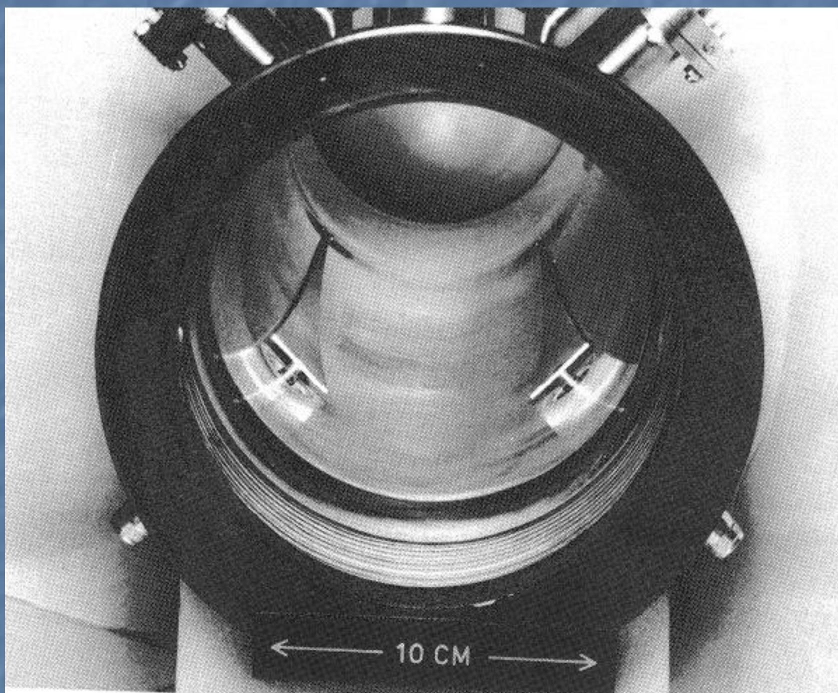


Fig. 31b - Interior of directional coupler pick-up

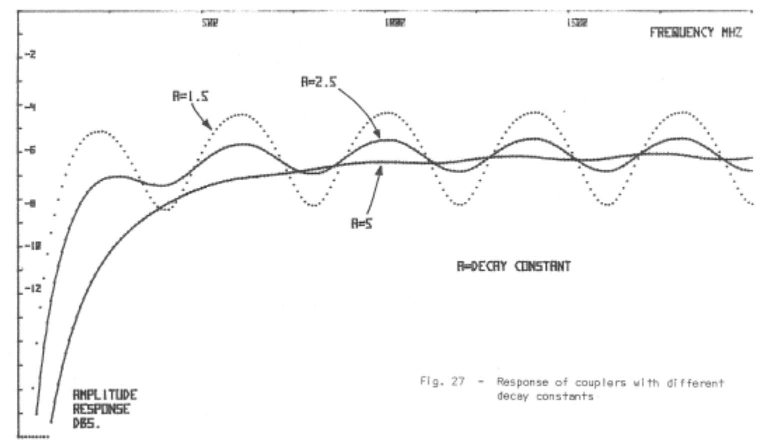


Fig. 27 - Response of couplers with different decay constants

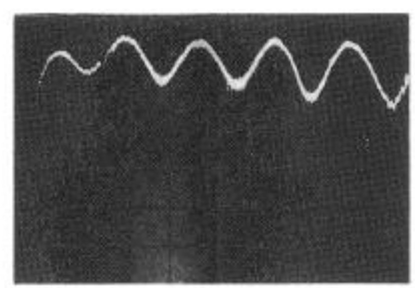
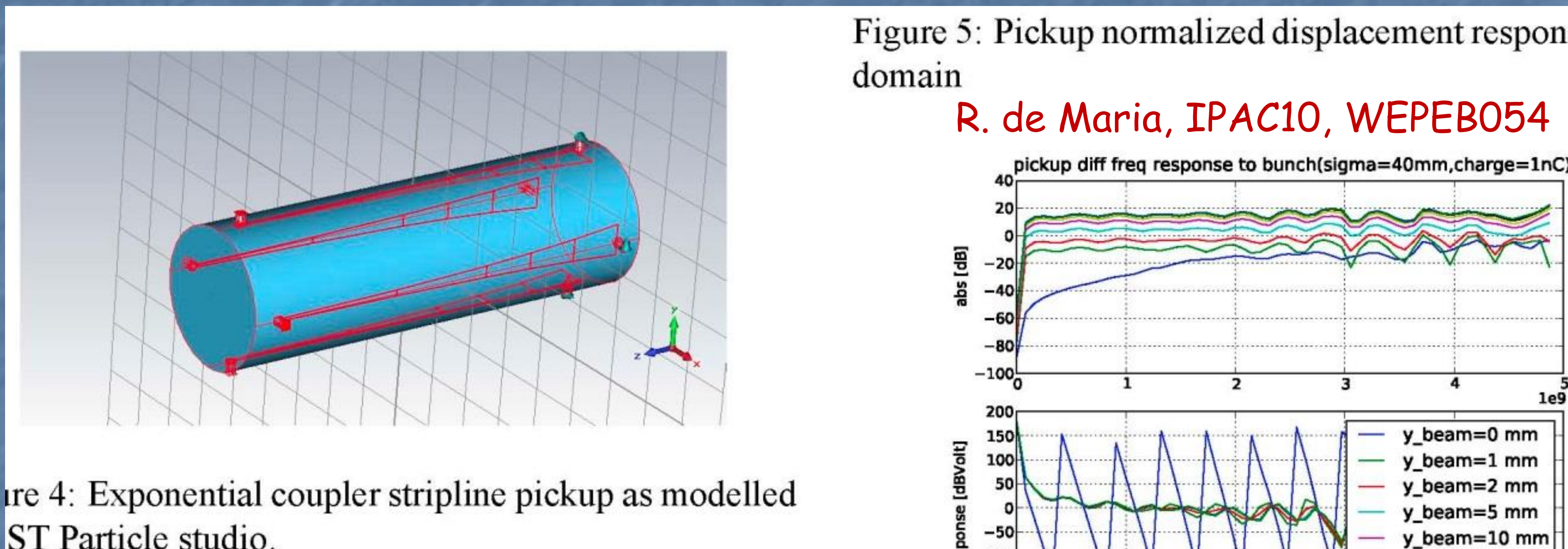


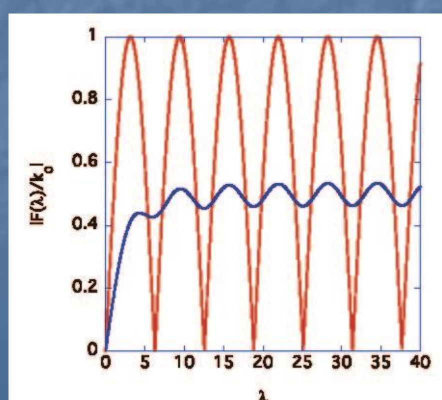
Fig. 37 - Frequency response of sum signal from directional coupler pick-up
200 MHz/div 2.5 dB/div

(Linnecar, CERN-SPS-ARF-SPS/78/17)

Exponential Electrode CST Model @CERN, SPS



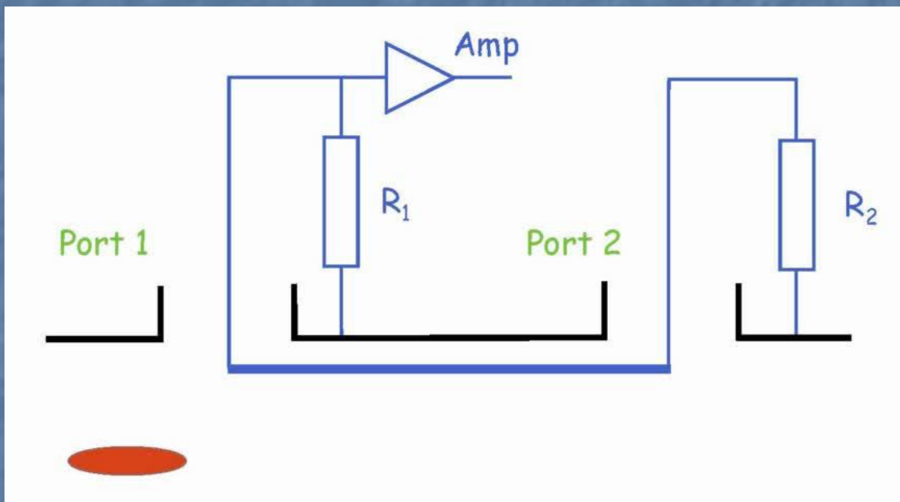
R. de Maria, IPAC10, WEPEB054



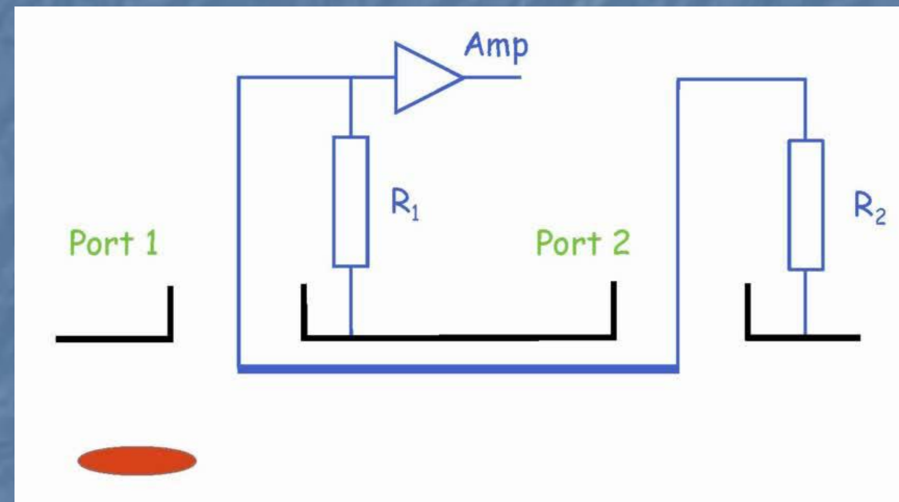
Theory: $\lambda = \frac{2\omega l}{v}$

Red: Rectangular electrode
Blue: Exponential electrode

Frequency Response of a Rectangular Electrode (Length=L)



$Z_{strip}=R_1=R_2=50\Omega$



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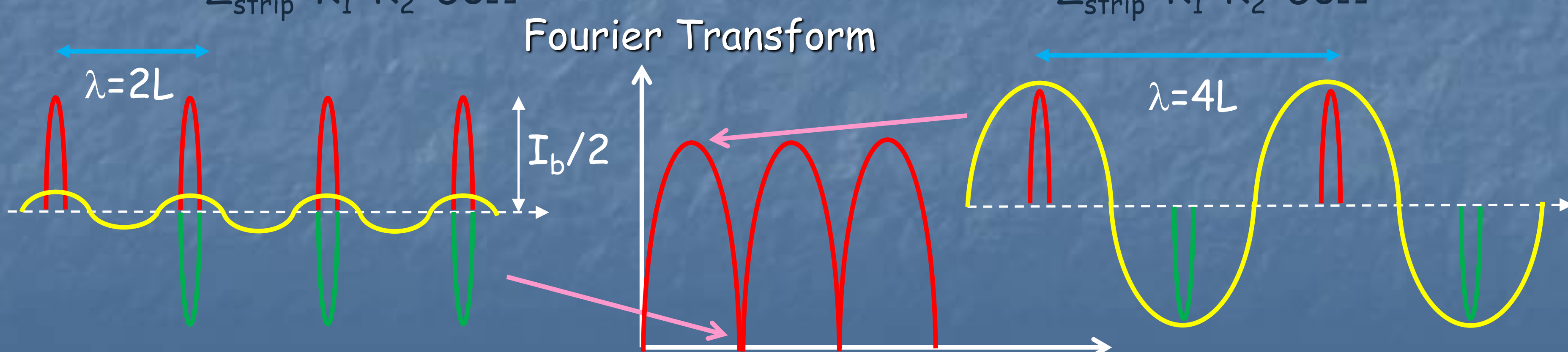
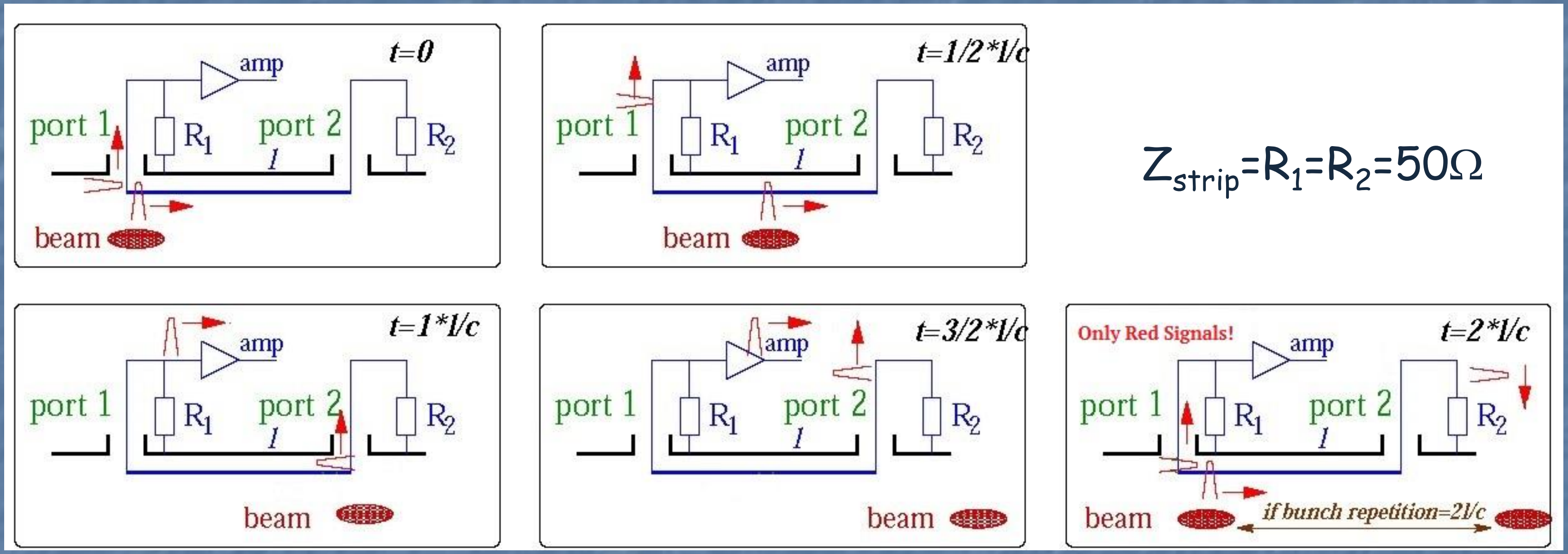
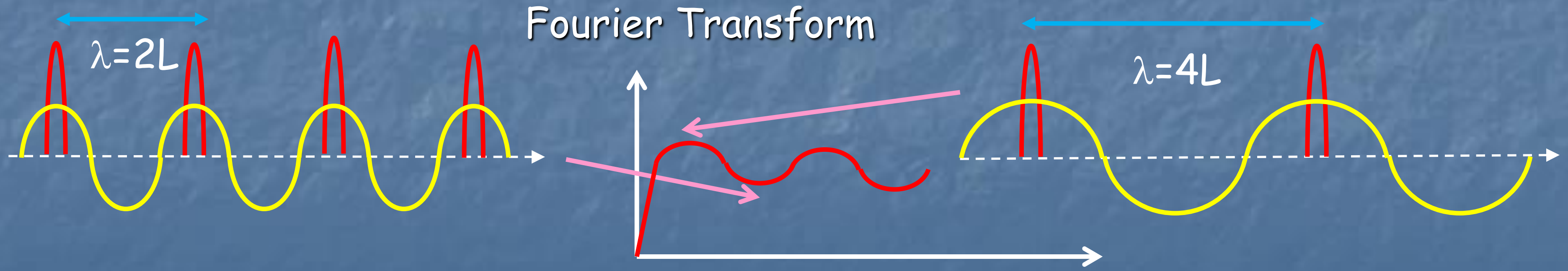


The Key for a Flatter Frequency Response is Generation of No Green Pulse

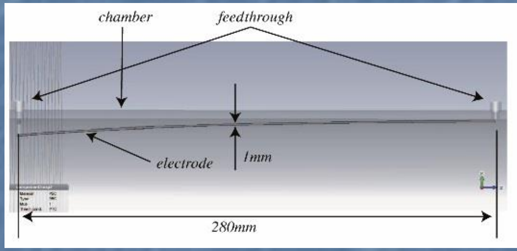


$Z_{strip}=R_1=R_2=50\Omega$

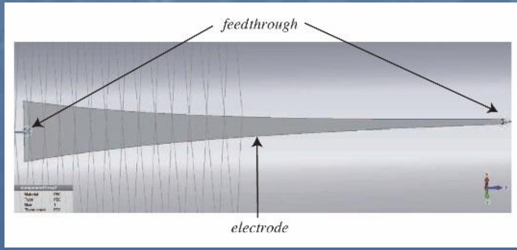


Two Conditions for No Green Pulse

- Bring down the electrode toward downstream to the same level as the beam chamber so that it has the same coupling with a beam as the beam chamber.

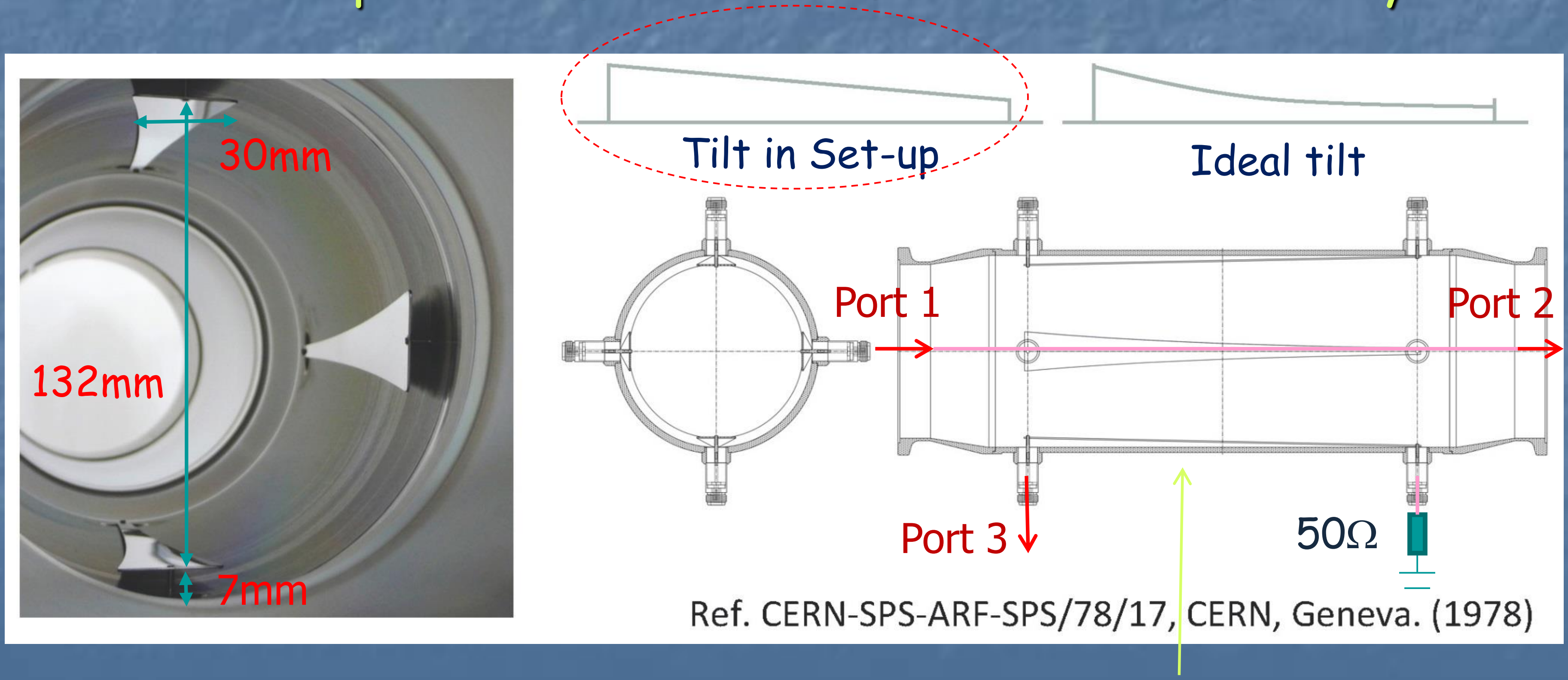


  - The electrode looks like a part of the beam chamber now.
- Make the electrode narrower toward downstream.
  - Area-wise, the image current excited on the electrode becomes negligible compared to that on the beam chamber.

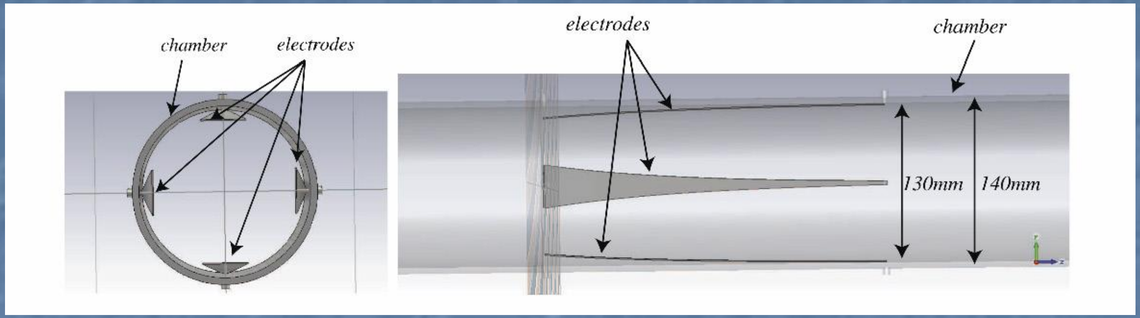


Exponential Electrode at J-PARC: Prototype and Measurement

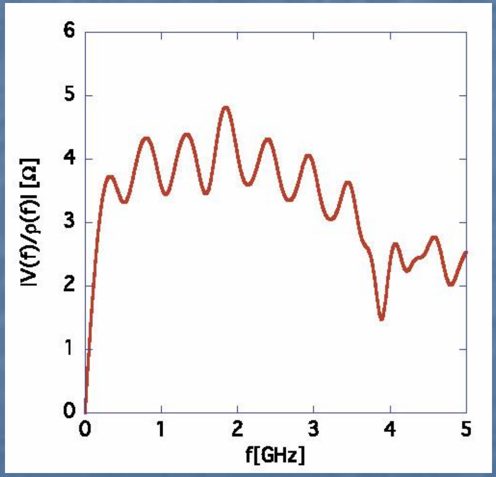
- The electrodes need be bent down toward the tip in proportion to its width for a good impedance matching, but we kept them flat due to fabrication difficulty.



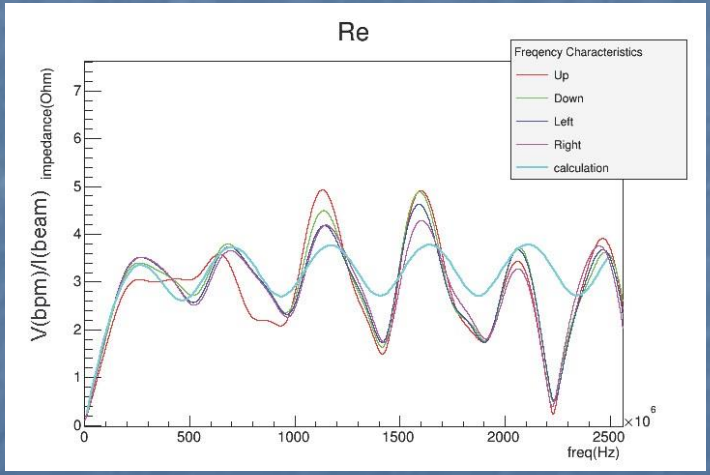
Frequency Response at J-PARC: Simulations and Measurements



CST Studio simulation configuration for exponential electrodes



Simulation result for ideally bent exponential electrode



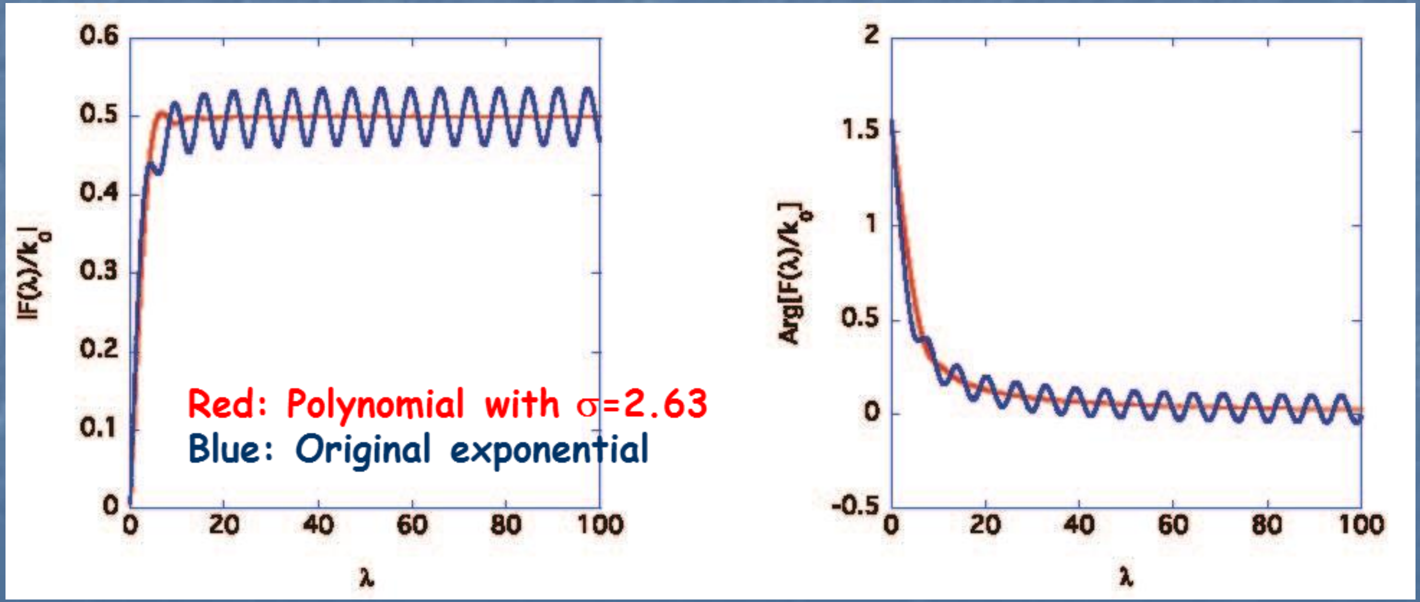
Measurements for flat exponential electrode

Rather poor performance, seemingly due to impedance mismatching.

Quest for Theoretically Better Shape

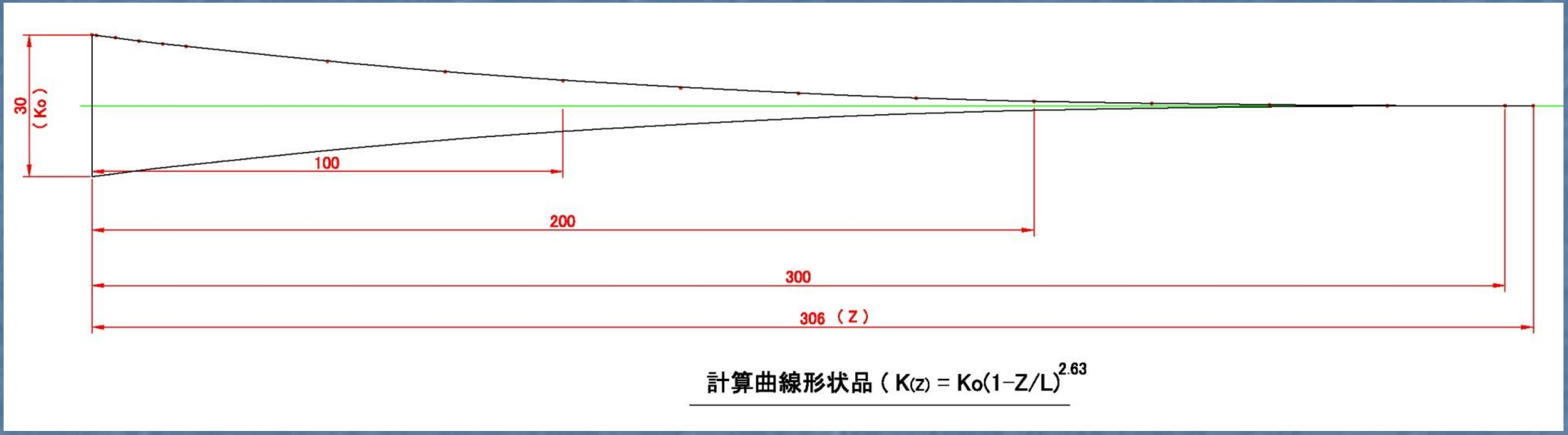
- We reported at the Erice workshop that the following polynomial electrode has a much flatter frequency response, theoretically.

$$k(z) = k_0 \frac{(l-z)^\sigma}{l^\sigma},$$



Prototyping of Polynomial Electrode

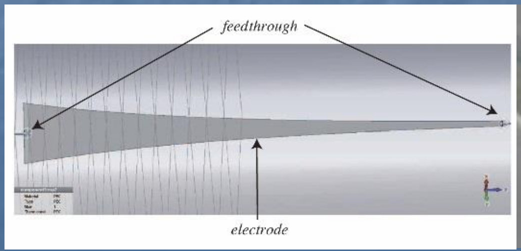
- Mechanical Problems
  - It becomes so narrow toward the tip that it is practically impossible to fabricate it by cutting a metal plate.
  - The narrow part can hardly stand by itself.

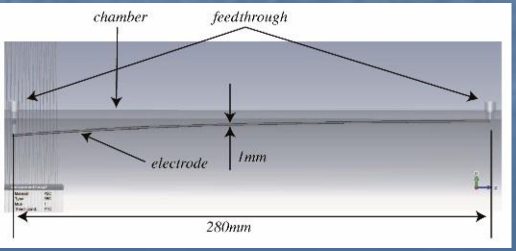


- Measurement Results.
  - Total failure.

Two Conflicting Requirements for a Good Impedance Matching

- Theoretician's idealism
  - The electrode shape needs to be smoothly tailored toward its tip, though it may become a quite complicated shape.
- Engineering reality
  - The electrode needs to be precisely bent down toward its tip, in proportion to its width, which is difficult in practice.
- Failure to comply with the engineering requirement can easily make void of the merit of the idealism.
  - After all, "Reality Bites".



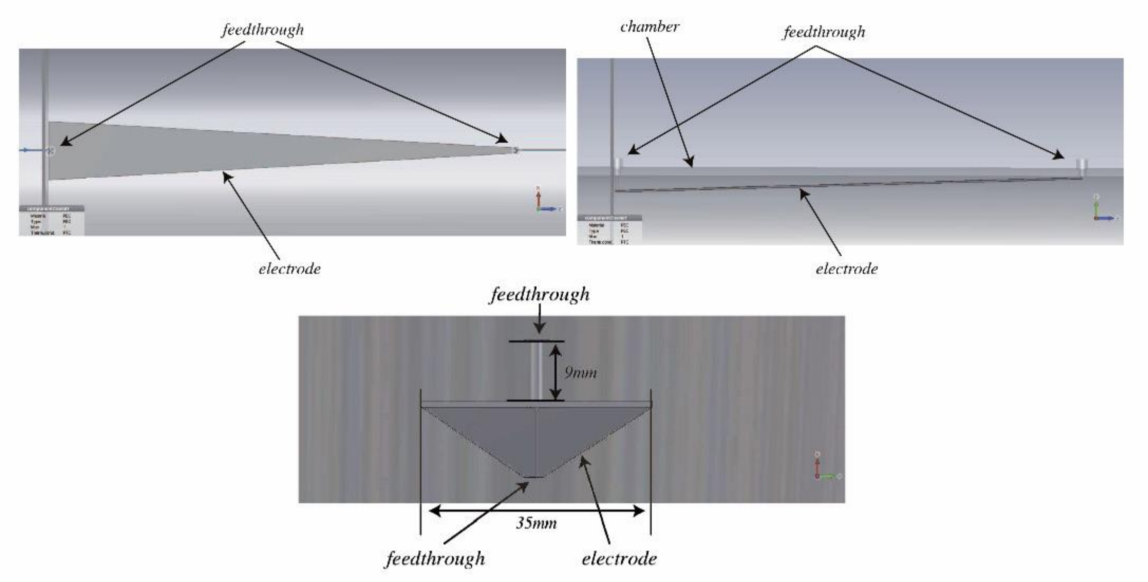



Rethinking for a Better Approach

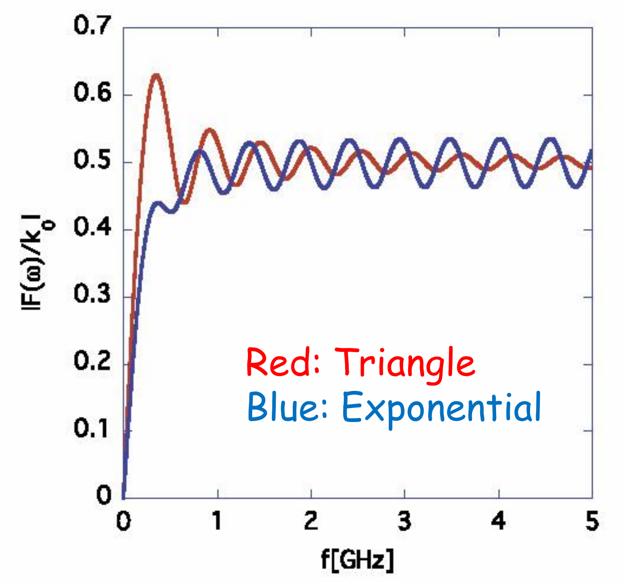
- During the bus tour to the Sicilian Pantheon in the Erice workshop, I thought
  - We should better take a 180 degree opposite approach instead.
    - Start with a simple shape, easy to fabricate and set up, and gradually increase its complexity to improve the frequency performance.
    - The frequency performance will be saturated quickly as the complexity of the shape is increased, since the potential merit by a sophisticated shape (idealism) will be offset by the difficulty in compliance of the engineering requirement (reality).

Triangle Electrode

- The simplest shape next to the rectangle is a triangle.
  - It requires no bending to attain a good impedance matching: just place a flat triangle plate with tilt toward downstream.



CST Studio Simulation Configuration



Theoretical frequency response

CST Studio Results for Triangle

- In the theoretical result, only TEM modes are excited, while all modes are included in the simulations.
- The phase follows the ideal linear line.
- A large overshoot is still visible at low frequency.
- The frequency response starts to decline from ~2GHz.

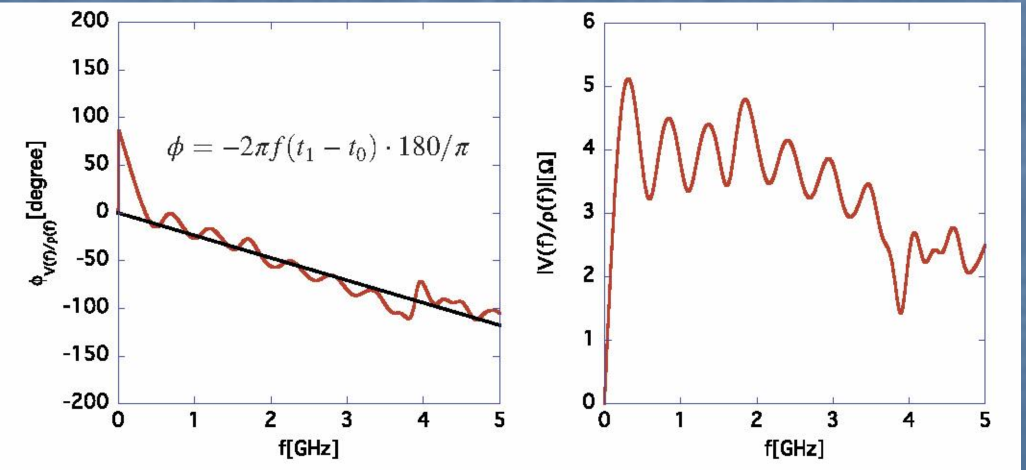
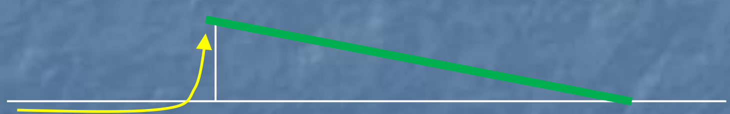


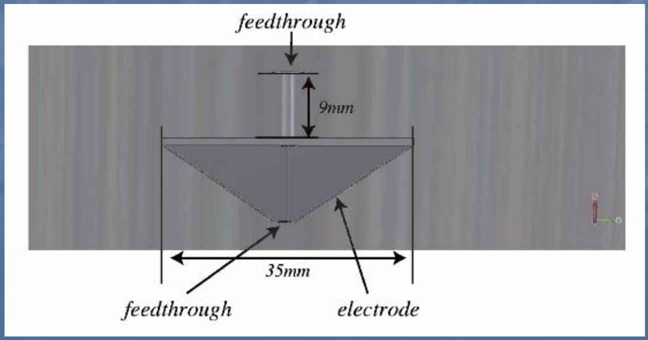
FIG. 9. Fourier transform of the beam induced-voltage divided by that of the beam current.

Why Decline at High Frequency?

- There is a 9 mm-high gap between the chamber wall and the upstream edge of the electrode.
  - A part of the image current running on the chamber prior to the electrode jumps to it as the displacement current.
- For short wavelength, this gap prevents a smooth flow of the displacement current and thus high frequency components of the image current are reduced on the electrode.

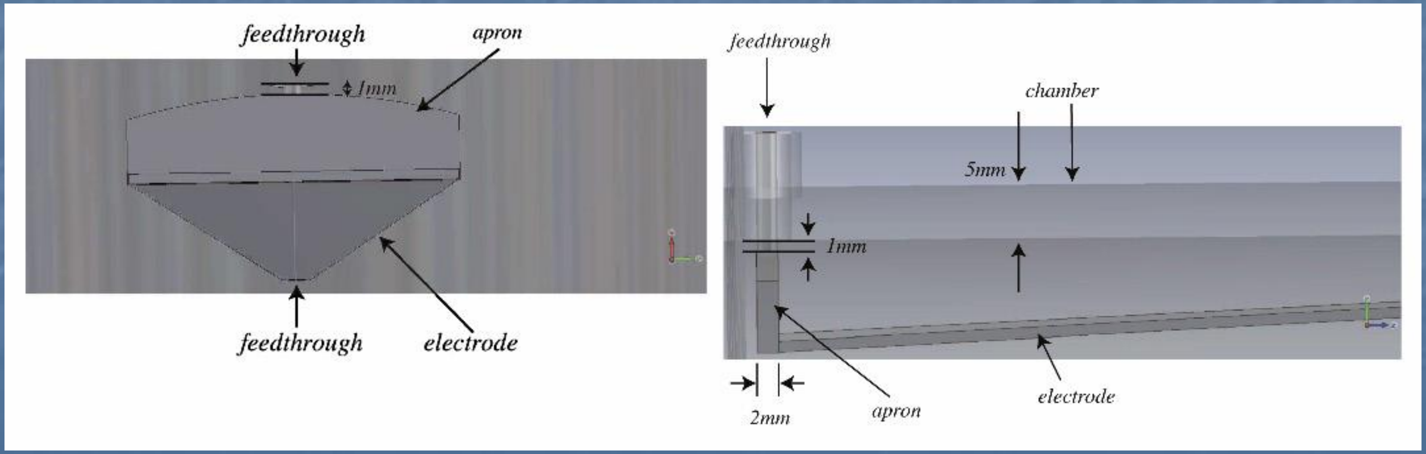


For short wavelength, the gap looks taller.



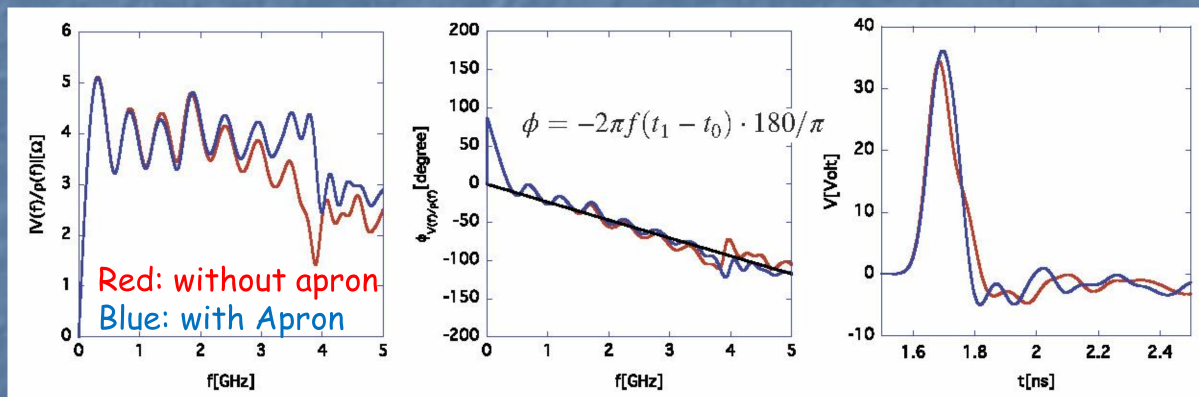
Solution: Fill the Gap with an Apron

- To reduce this gap for the image current, and thus to enable its smooth transition to the electrode, we attach a plate perpendicular to the upstream edge of the electrode, called "an apron".
- With the apron, the gap between the electrode and the chamber is reduced from 9 mm to 1 mm.

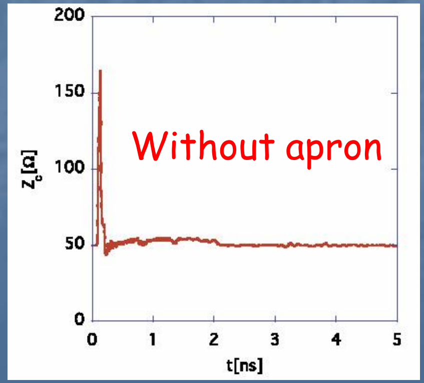


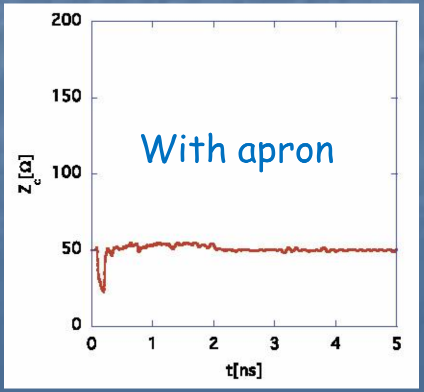
CST Studio Results with Apron

- The apron improves the frequency response up to 4GHz.



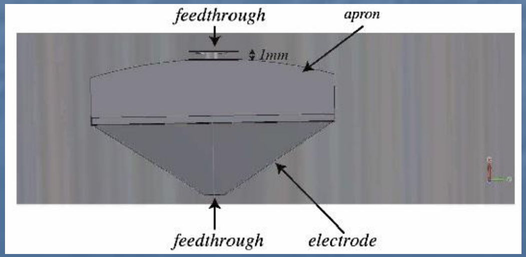
- The impedance distribution along the electrode shows that impedance mismatch is significantly reduced.



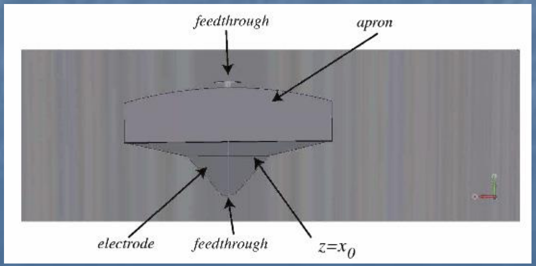


How about the Overshoot at Low Frequency

- The mitigation of the overshoot can be done by introducing one more complexity in the shape.
  - But the final shape must be simple and easy enough for fabrication and setup.
- One solution is to replace the long, straight sides of the triangle by a three-point polyline.
  - The triangle is transformed to a concave pentagon.
  - The pentagon electrode needs to be bent only once at the middle point of the polylines for a good impedance matching.
  - Its fabrication and setup remain easy.



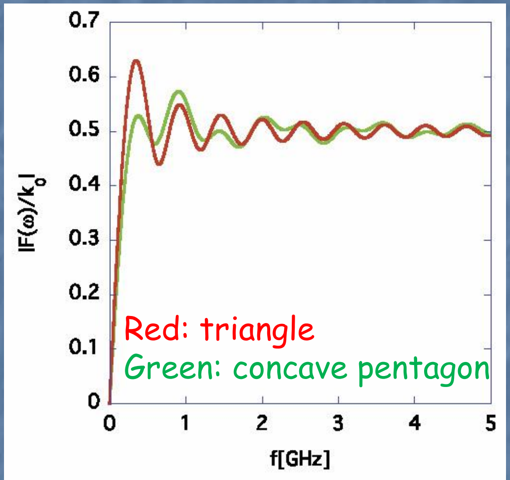
Triangle with Apron



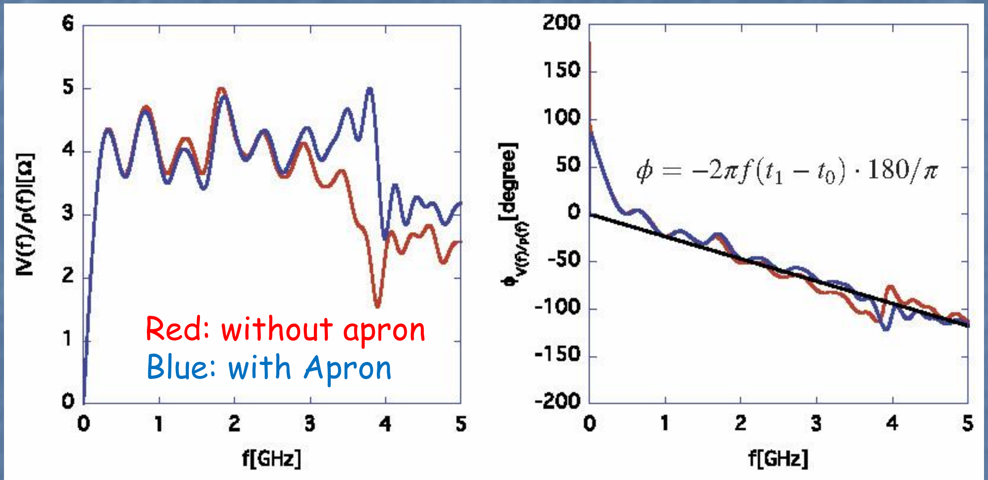
Concave Pentagon with Apron

Theoretical and Simulation Results

- Both results show that the overshoot problem of the triangle electrode at low frequency is significantly mitigated in the concave pentagon electrode.



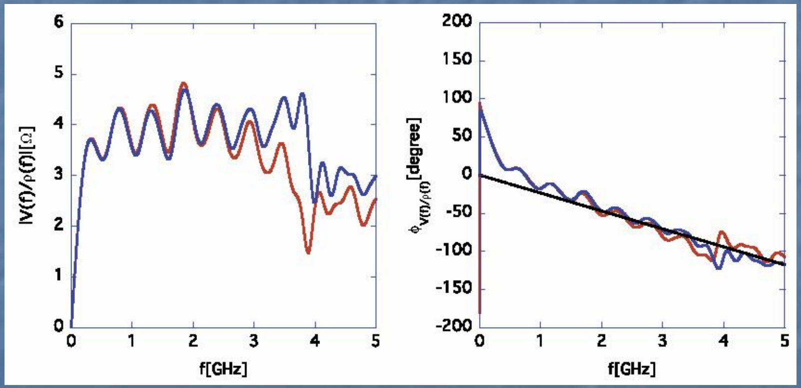
Theory



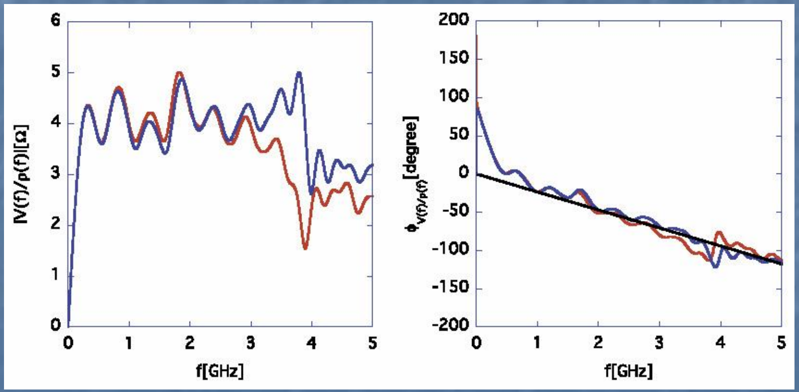
CST Studio Simulation Results

Comparison between Exponential and Concave Pentagon with Aprons

- In the exponential electrode, we assume that it is perfectly bent in proportion to its width, which is quite difficult in practice.
- No significant difference is observable.
  - Though, the ideal exponential electrode is much more difficult to fabricate and setup correctly.



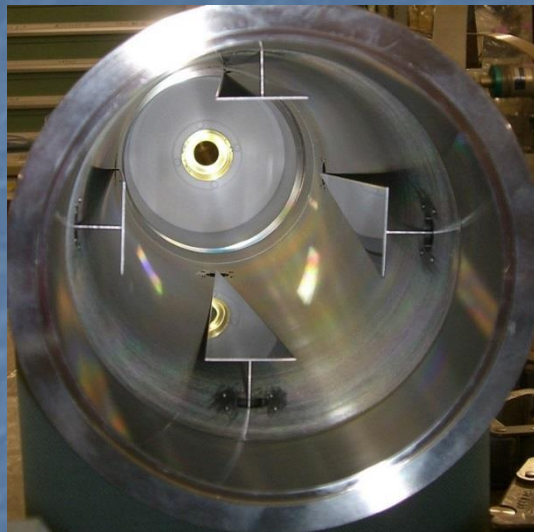
Ideal exponential electrode



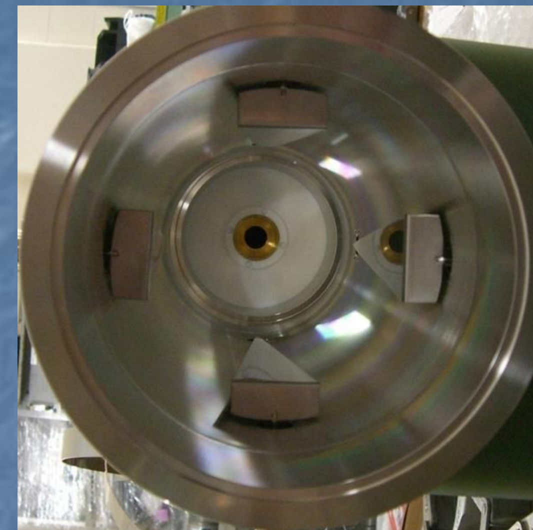
Concave pentagon electrode

Prototypes

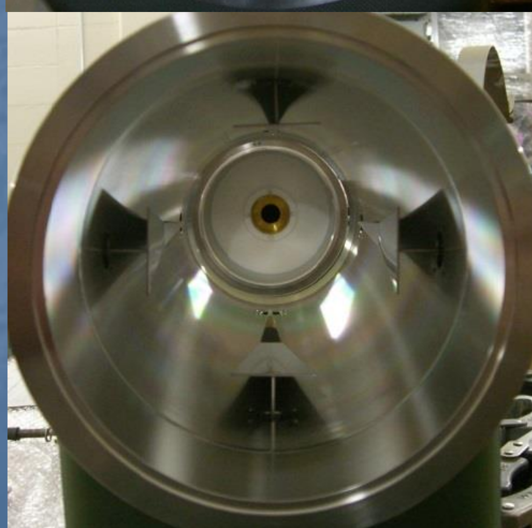
Triangle
w/o apron



Triangle
with apron



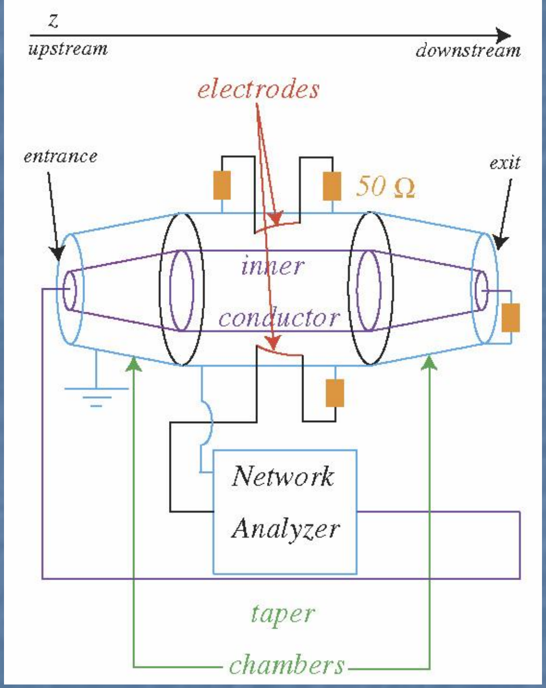
Pentagon
w/o apron



Pentagon
with apron

Measurement Set-up

- Schematic



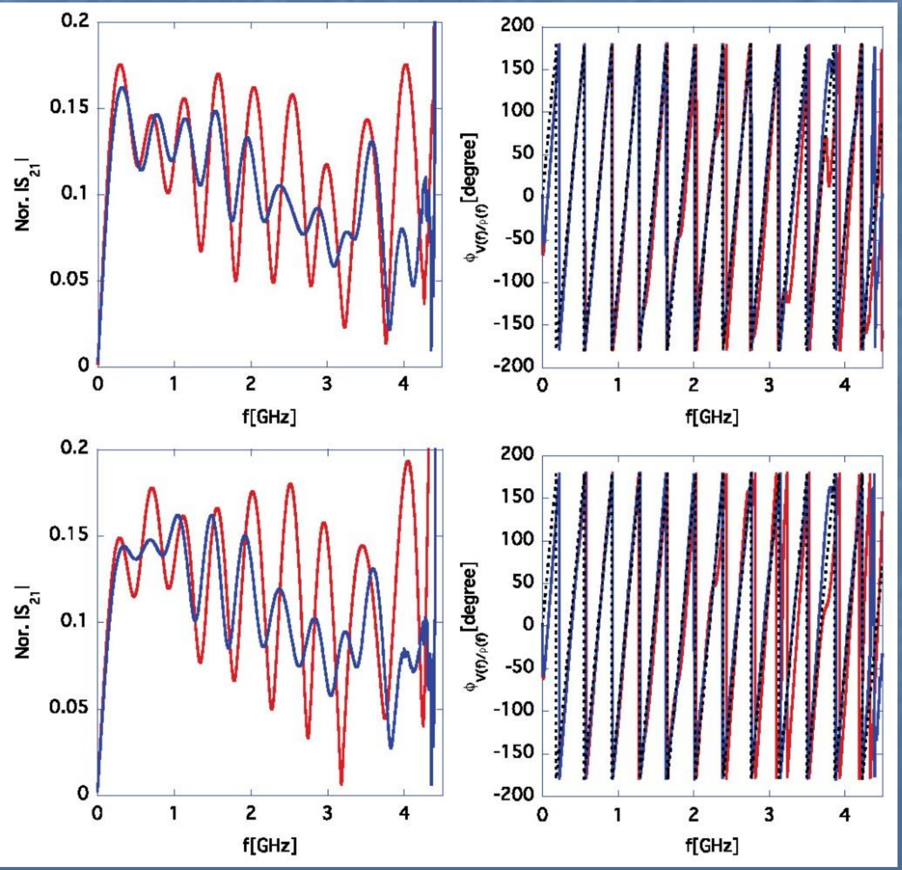
- The transfer function is estimated by measuring the transmission coefficient S21.
- The calibration is done by 2-port electric calibration module 85092b.
- The measurement is done by sweeping the frequency of the input signal (the sinusoidal function with single-frequency).

Measurement Results

- Not as good as the simulations, but the frequency response of the concave pentagon is good up to 4GHz.

Triangle
Red: w/o apron
Blue: with apron

Concave pentagon
Red: w/o apron
Blue: with apron



Dotted lines

$$\phi = 2\pi f t_2 \cdot 180/\pi$$

Conclusions 1

- We suspected that once we replace the conventional rectangle electrode by a triangle or its alike, a further increase of the complexity of the shape will hardly improve the frequency response.
  - In fact, the concave pentagon can produce the frequency response as good as one for the ideal exponential electrode.
  - Nevertheless, the concave pentagon is much easier to fabricate and setup, since a concave-pentagon shaped flat plate needs to be slightly bent only once at the middle concave point.
- The both simulation and measurements results demonstrate that the apron attached on the upstream end of the electrode helps to maintain the high signal strength up to 4 GHz .

Conclusions 2

- We expect that the gradual decline of the frequency response at high frequency in measurements can be mitigated by improving the impedance matching in the fabrication process.