BPM electrode and high power feedthrough
-Special topics in wideband feedthrough-

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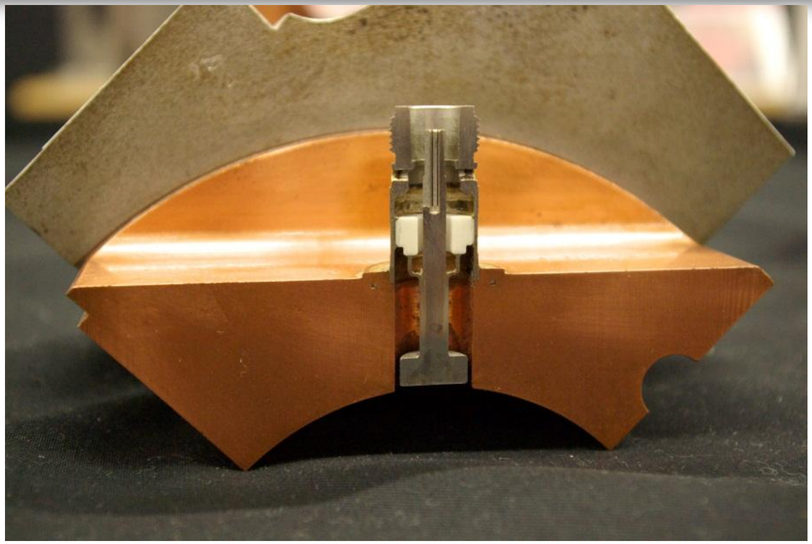
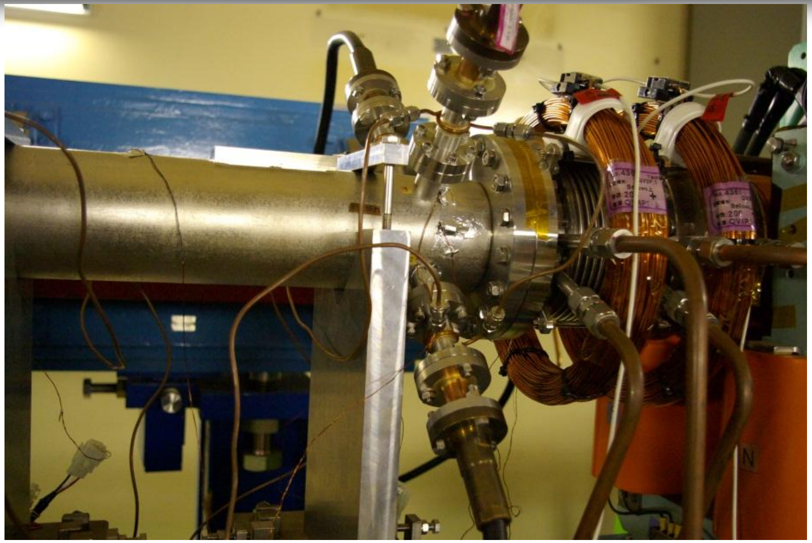
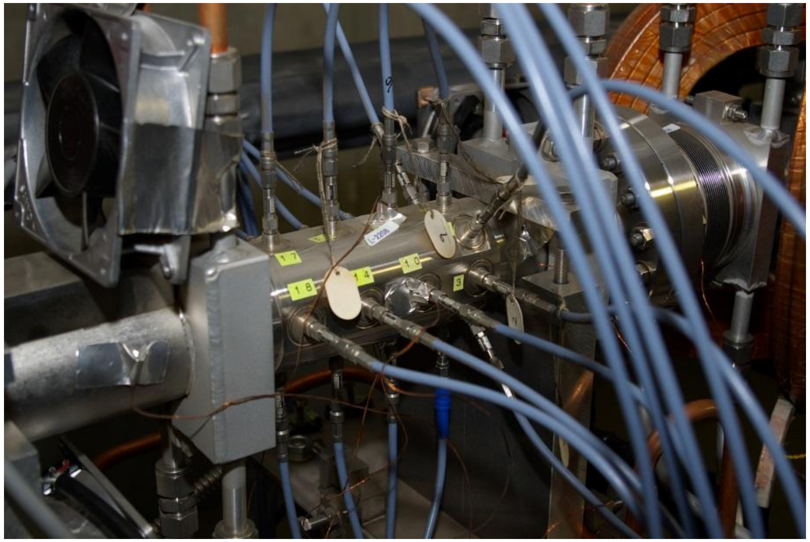
Introduction

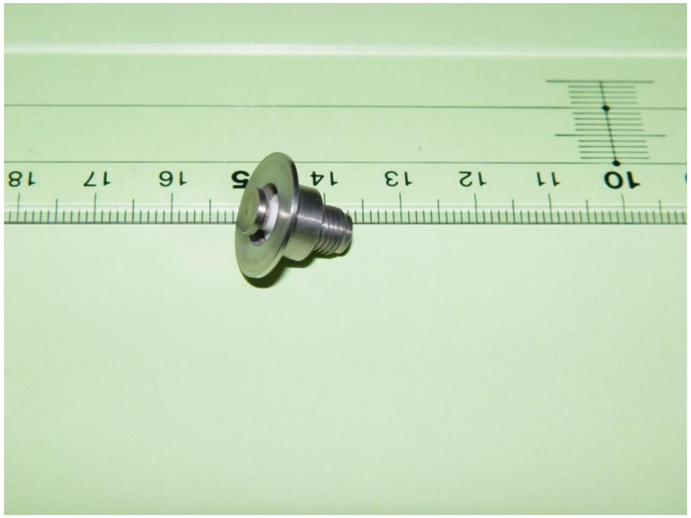
- **Beam runs in vacuum chambers (mostly) made of good-conducting metal.**
  - Vacuum chambers shield (fast) electro-magnetic wave from / to the beam.
  - Need some kind of "Feedthrough" to get / feed the electro-magnetic signal from / to beam.
- **Wideband coaxial feedthrough**
  - Button-type electrode
  - Stripline kicker / monitor
  - Plate-type position monitor
  - Ion (or electron cloud) clearing electrode

Feedthrough









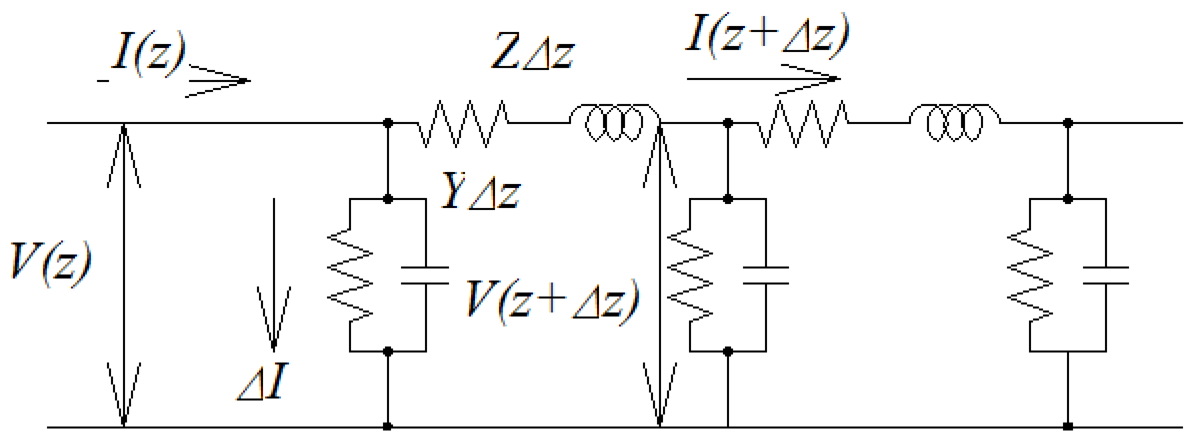
Need to consider..

- **Specification of the feedthrough**
  - Structure
    - Total size
    - Kind of RF connector, vacuum structure…
    - Mechanical (and heating) toughness
  - Frequency range, allowed SWR, reflection..
  - Power range
    - Beam induced power
    - Supplied power from outside
    - allowed (V)SWR

In this tutorial

- **Review of transmission line theory**
  - S-Parameter, (V)SWR
  - Time domain behavior (TDR)
- **Frequency-domain simulation**
  - Ansys HFSS
- **Time-domain simulation**
  - GdfidL
- **Design, evaluation of the button electrodes**
- **Design, evaluation of the high-power feedthroughs**
- **Summary**

Circuit representation of a uniform transmission line



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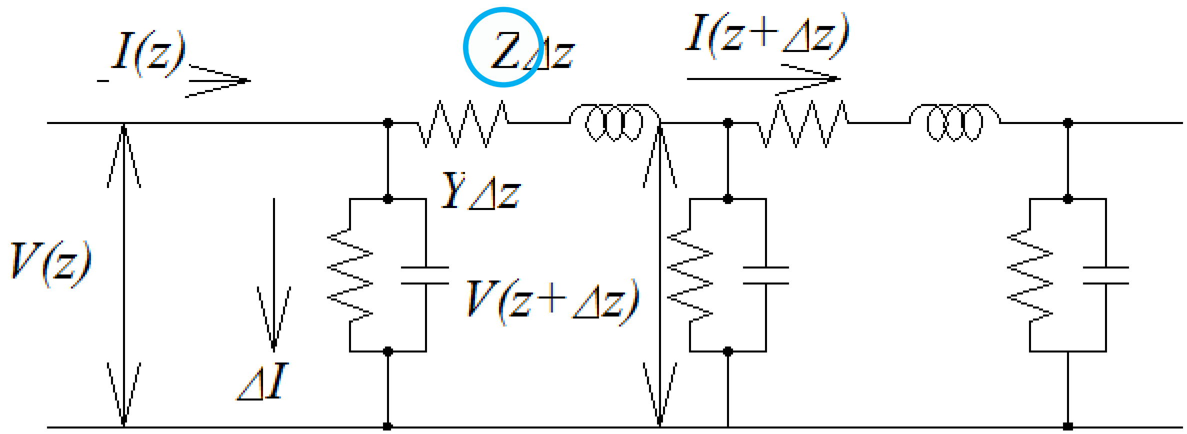
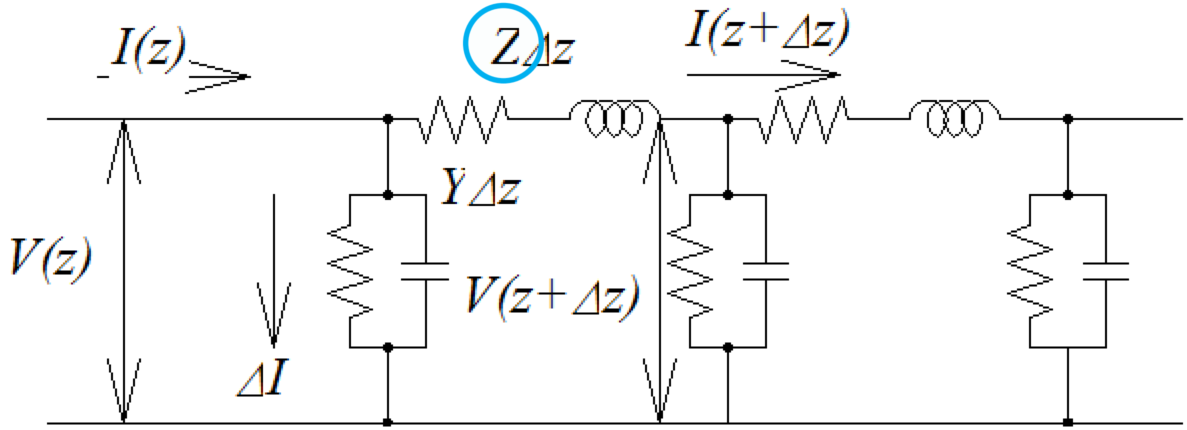


Circuit representation of a uniform transmission line

Unit impedance



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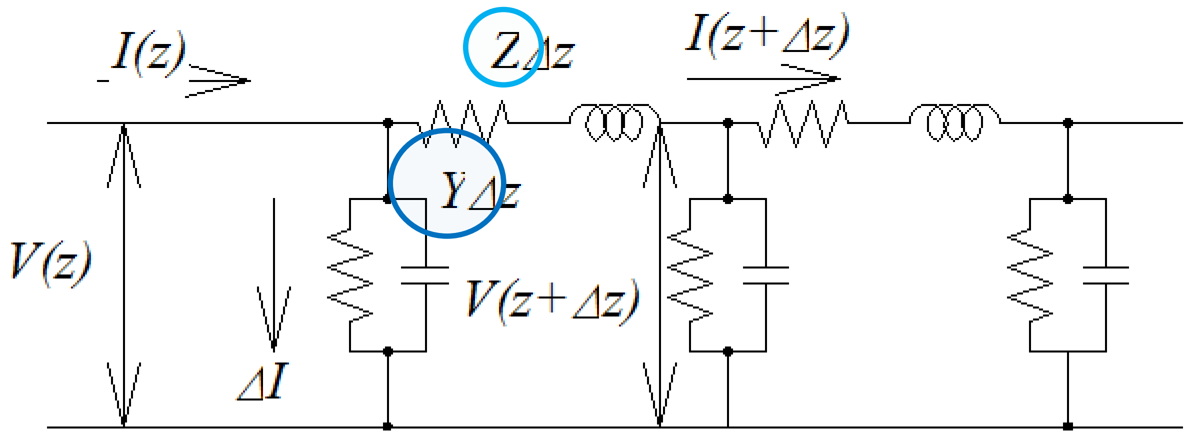

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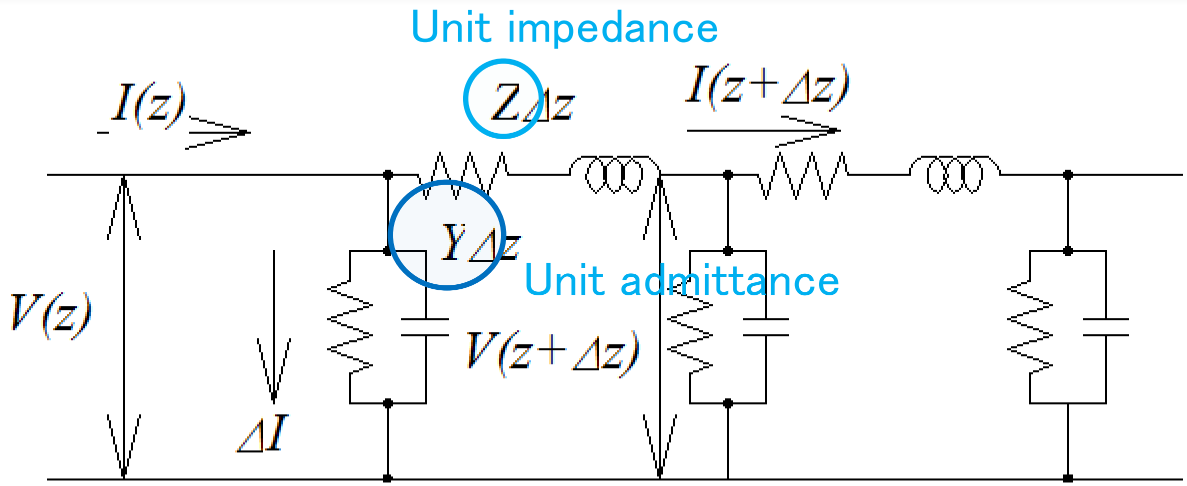

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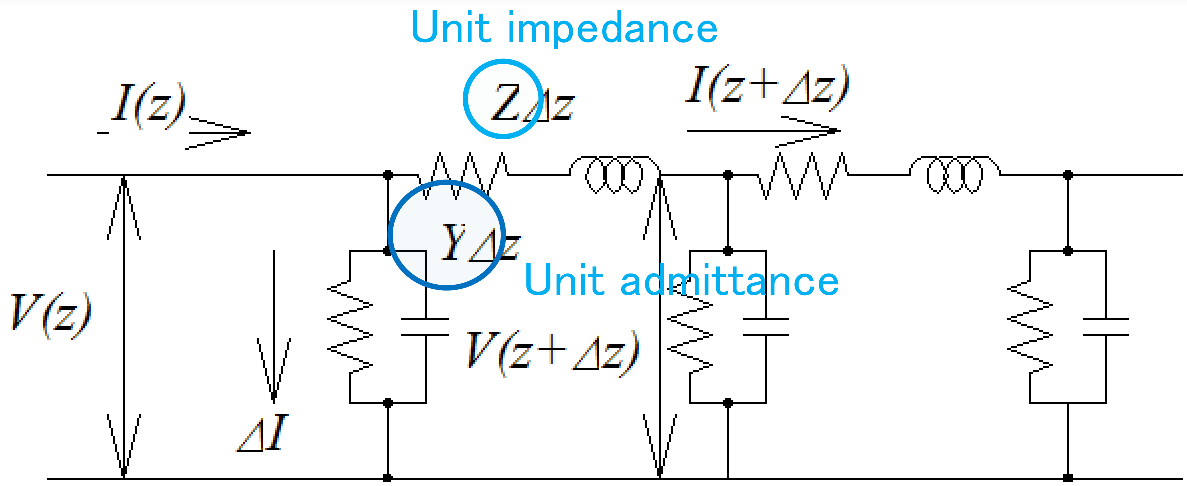

$$\Delta V = -IZ\Delta z$$

$$\Delta I = -VY\Delta z$$

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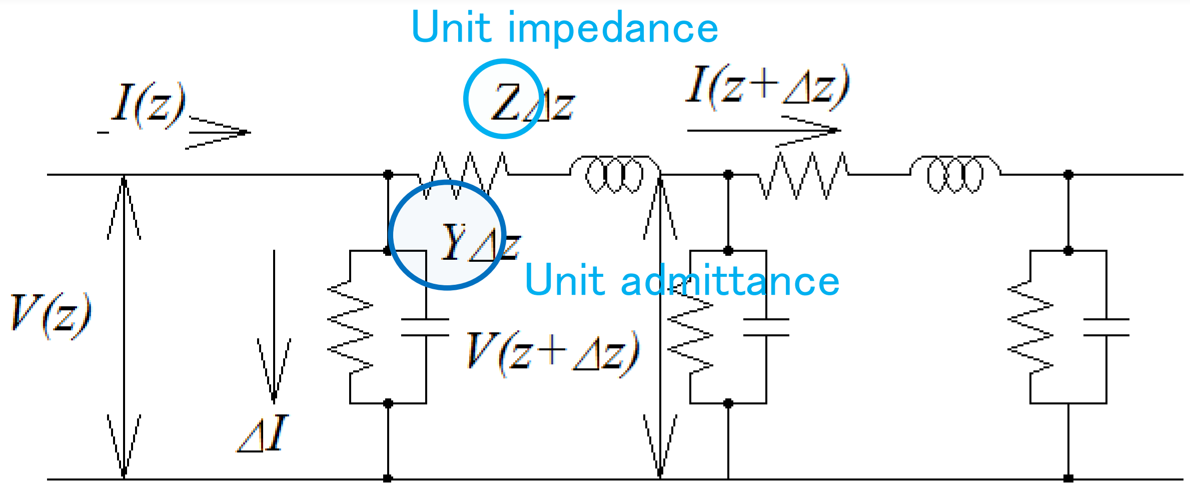

$$\Delta V = -IZ\Delta z$$

$$\Delta I = -VY\Delta z$$

$$\frac{dV}{dz} = -IZ$$

$$\frac{dI}{dz} = -VY$$

$$\frac{d^2V}{dz^2} = \gamma^2 V, \frac{d^2 I}{dz^2} = \gamma^2 I$$

$$\gamma^2 = ZY$$

Transmission line (cont.)

- **Solution**

$$V = V_1 e^{-\gamma z} + V_2 e^{\gamma z}$$
$$= V_1 e^{(j\omega t - \gamma z)} + V_2 e^{(j\omega t + \gamma z)}$$

- **Normal transmission line**

$$Z = R + jL\omega$$
$$Y = G + jC\omega$$

$$\gamma = \left(LC\omega^2\right)^{\frac{1}{2}}\left[1 - \frac{RG}{LC\omega^2} - j\left(\frac{G}{C\omega} + \frac{R}{L\omega}\right)\right]^{\frac{1}{2}}$$
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Resistance

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Parallel conductance

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$$R / L\omega << 1$$

- **Normal transmission line**

$$G / C\omega << 1$$

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Propagation constant

$$\gamma = \alpha + j\beta$$

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}}, \beta = \omega\sqrt{LC}$$

$$V = V_1 e^{j(\omega t - \beta z)} e^{-\alpha z} + V_2 e^{j(\omega t + \beta z)} e^{\alpha z}$$

- **Phase velocity**

$$v_p = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

$$\beta = \frac{2\pi f}{f\lambda} = \frac{2\pi}{\lambda}$$

Propagation constant

Attenuation constant

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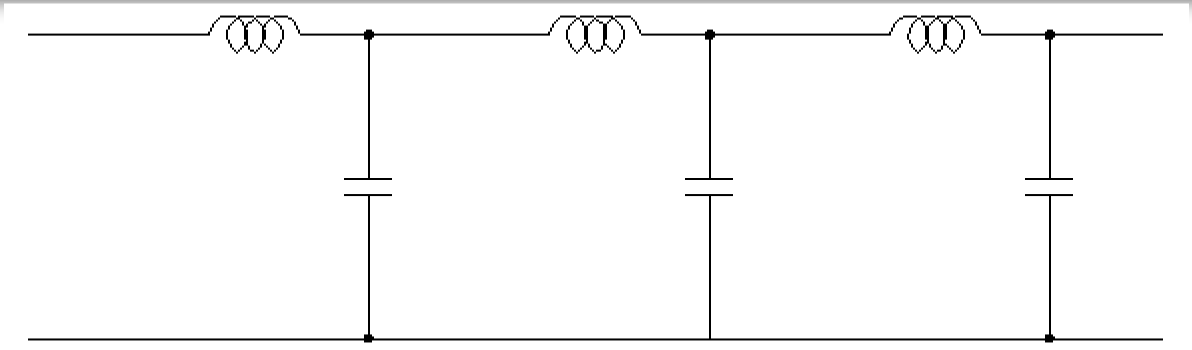
Loss less line



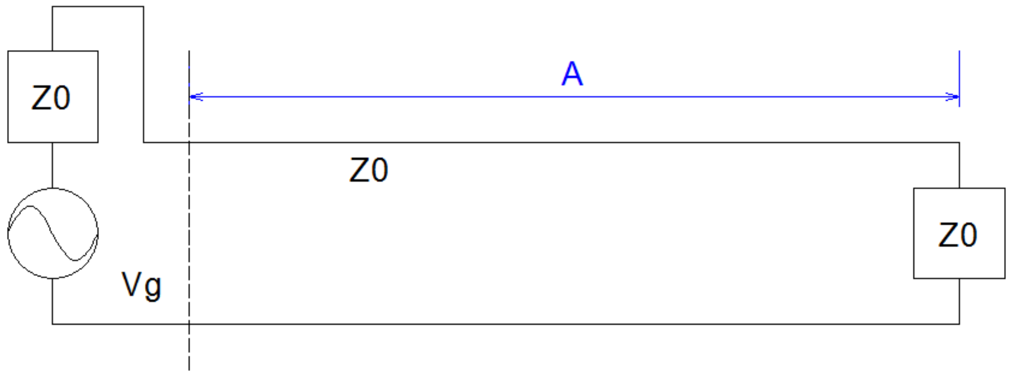
$$V = V_1 e^{-j\beta z} + V_2 e^{j\beta z}$$

$$I = \frac{1}{Z_0}\left(V_1 e^{-j\beta z} - V_2 e^{j\beta z}\right)$$

$$Z_0 = \frac{Z}{\gamma} = \sqrt{\frac{L}{C}}$$

$$\beta = \omega\sqrt{LC}$$

Impedance matched line



$$\frac{V(A)}{I(A)} = Z_0 = Z_0 \frac{V_1 e^{-j\beta A} + V_2 e^{j\beta A}}{V_1 e^{-j\beta A} - V_2 e^{j\beta A}}$$

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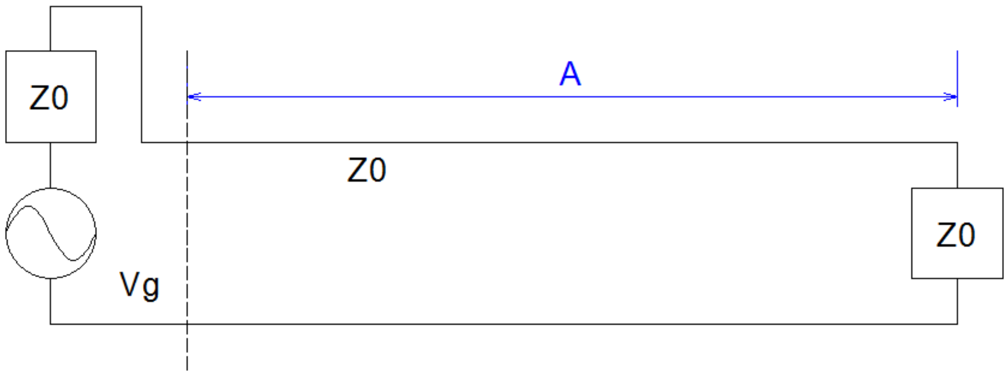

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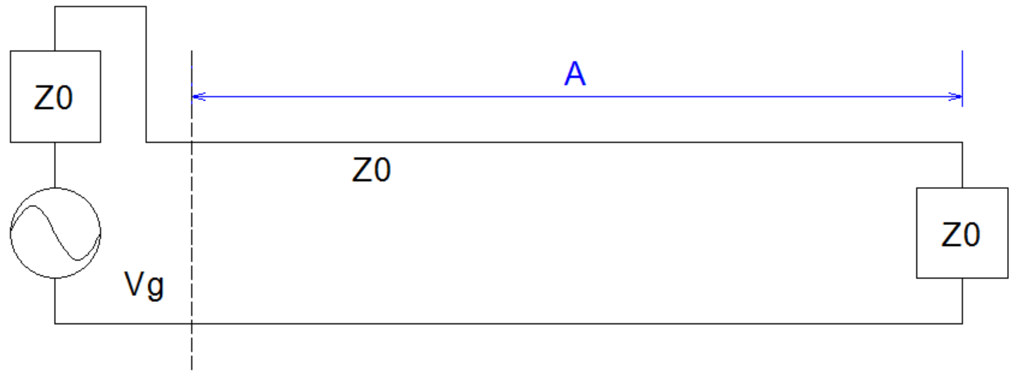

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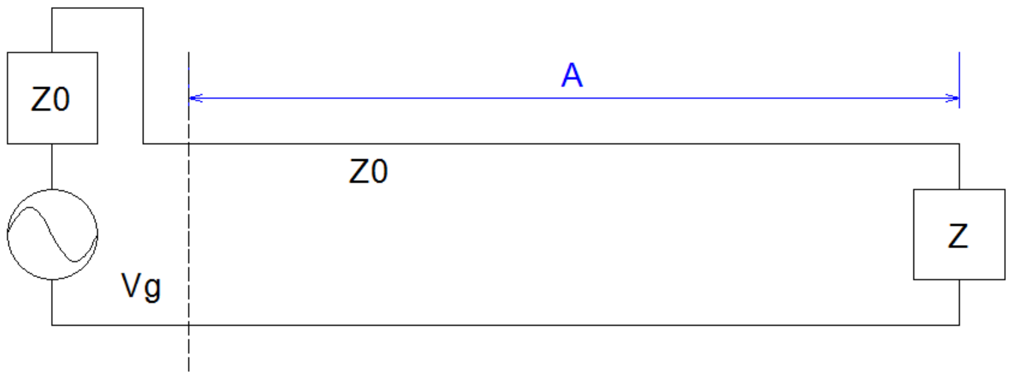
- **No reflection! (Only forwarding wave exist)**

Arbitrary termination

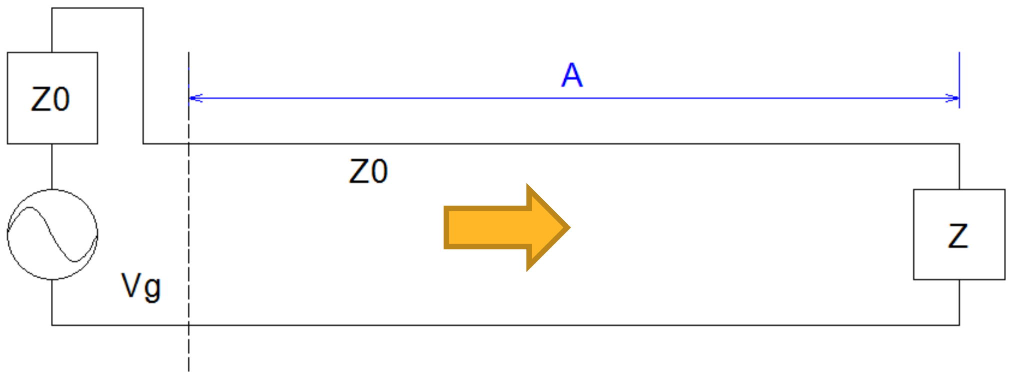


- **To satisfy V(A)/I(A)=Z, we need both forwarding and reflecting wave.**

$$V = V_1 e^{-j\beta z}\left(1+2\frac{|V_2|}{|V_1|}\cos\chi+\frac{|V_2|^2}{|V_1|^2}\right)^{\frac{1}{2}} \exp\left(j\tan^{-1}\frac{\frac{|V_2|}{|V_1|}\sin\chi}{1+\frac{|V_2|}{|V_1|}\cos\chi}\right)$$

$$\chi = 2\beta z+\theta_2-\theta_1$$

Arbitrary termination



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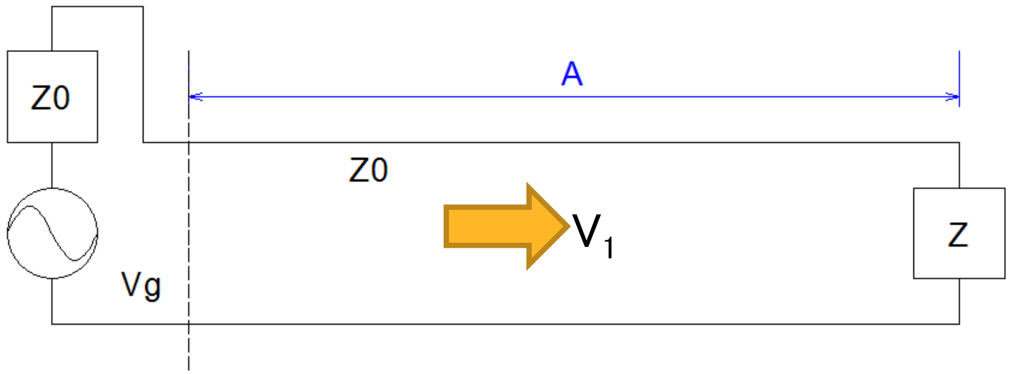

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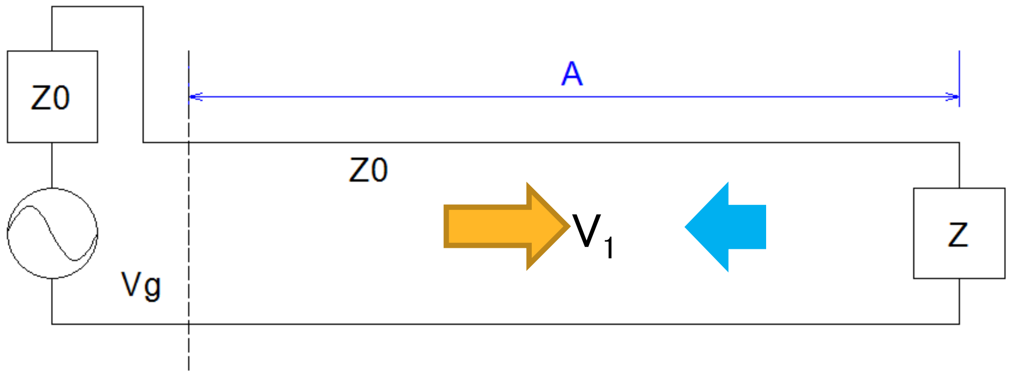

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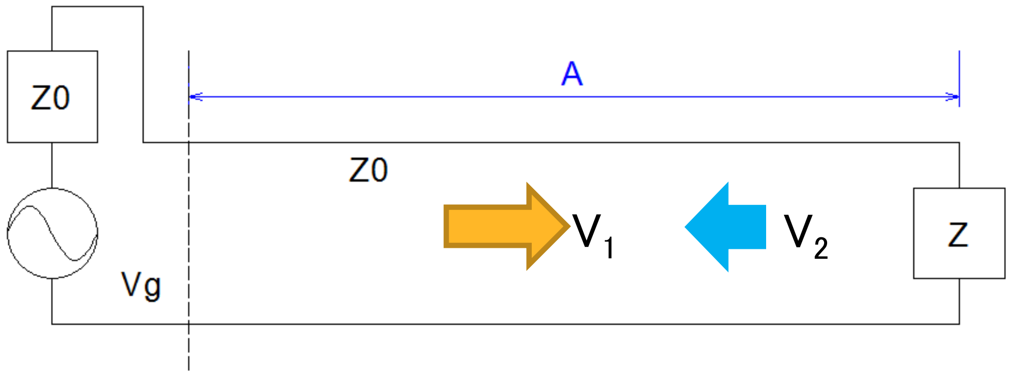

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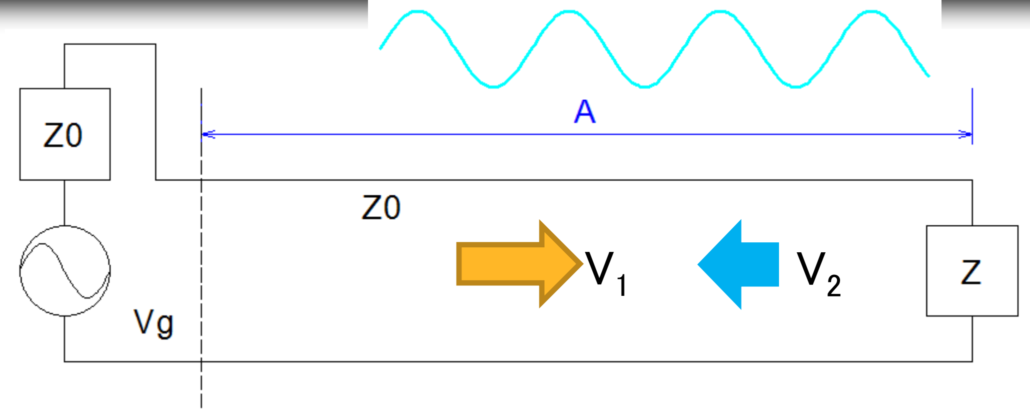

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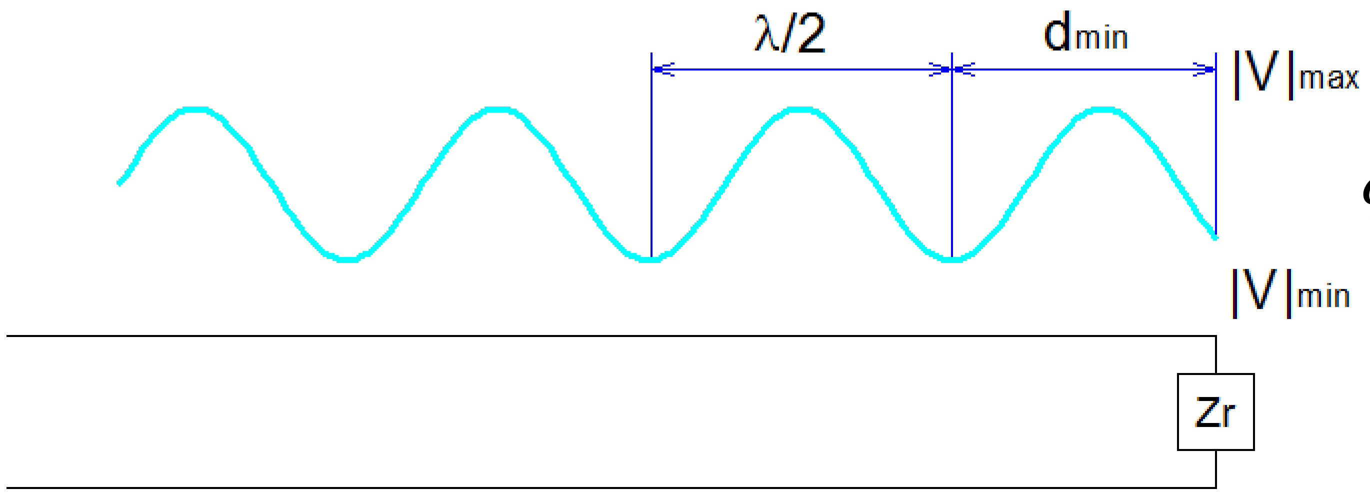
Standing wave ratio



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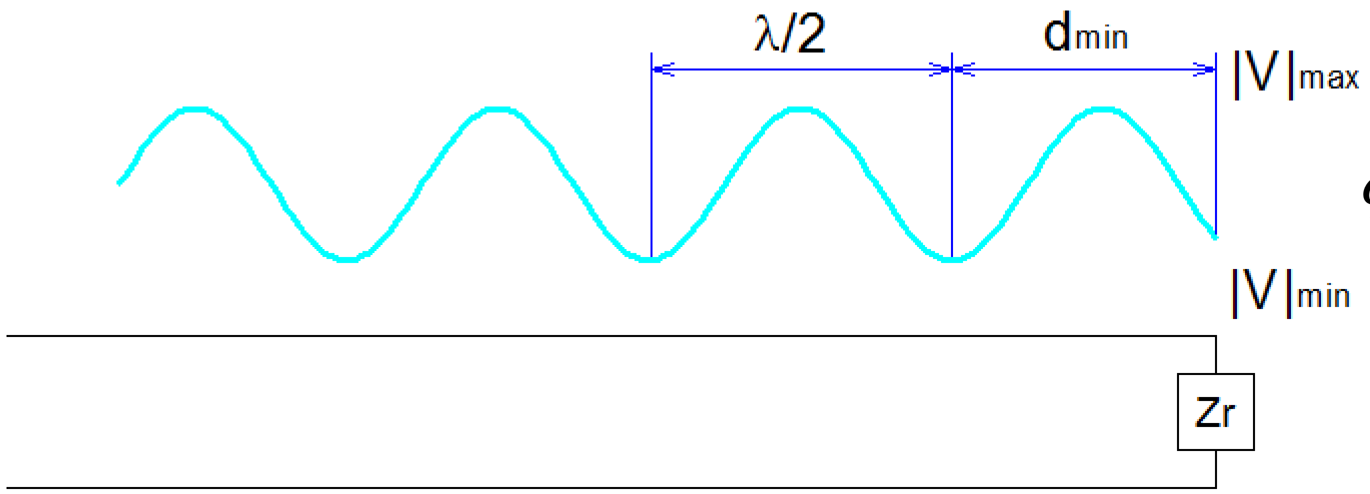

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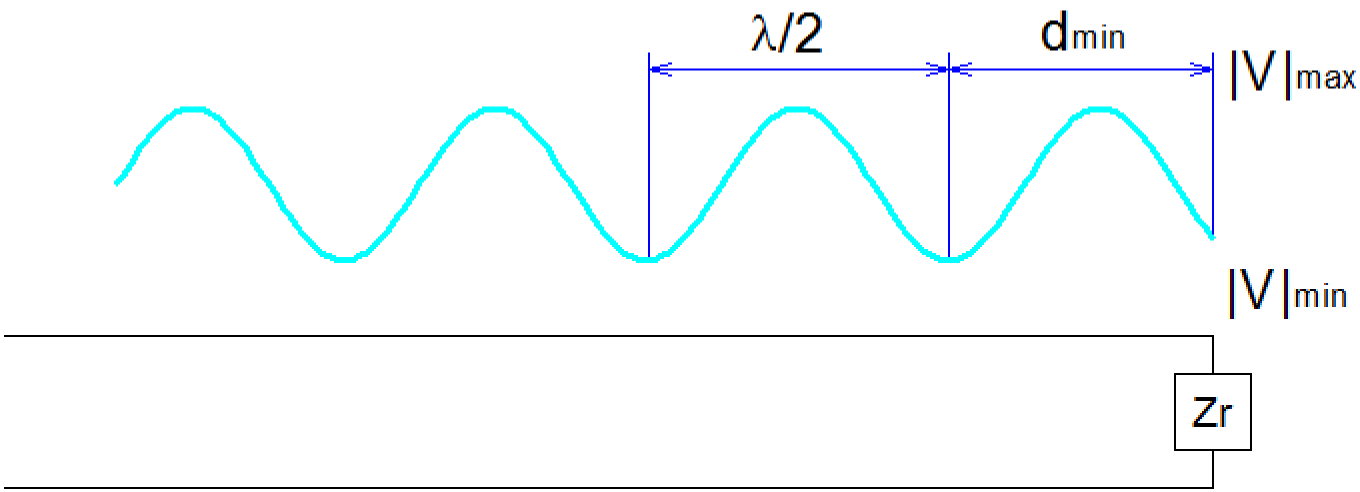
- **Standing wave ratio (SWR)**

Standing wave ratio



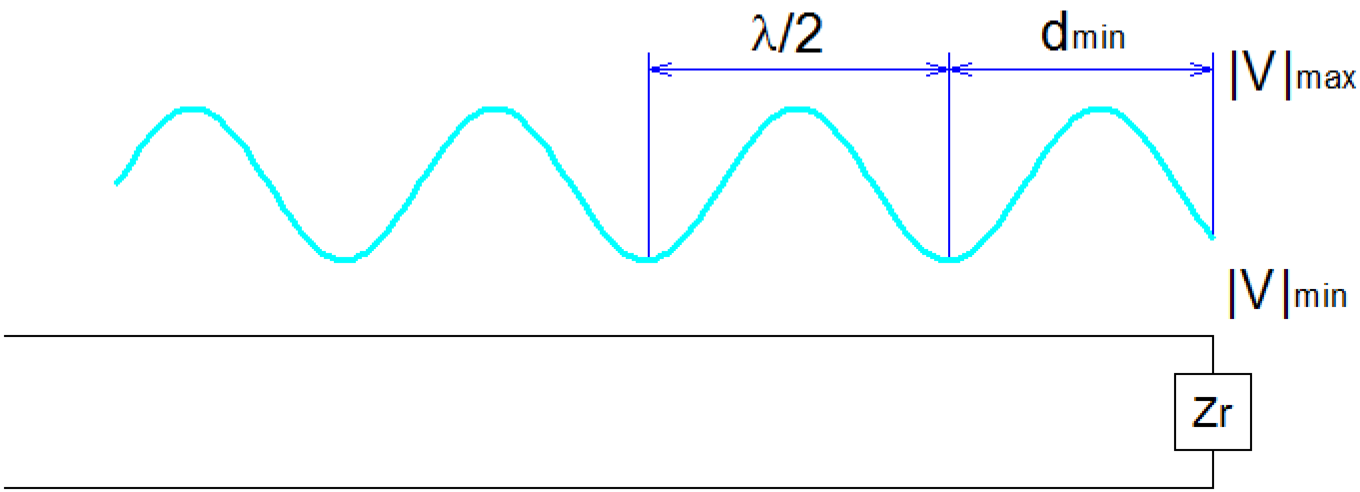
$$\varphi - 2\beta d_{\min} = \pi$$

- **Standing wave ratio (SWR)**

$$S = \frac{|V|_{\max}}{|V|_{\min}} = \frac{1+|\rho|}{1-|\rho|}$$

$$|\rho| = \frac{S-1}{S+1}$$

Standing wave ratio



$$\varphi - 2\beta d_{\min} = \pi$$

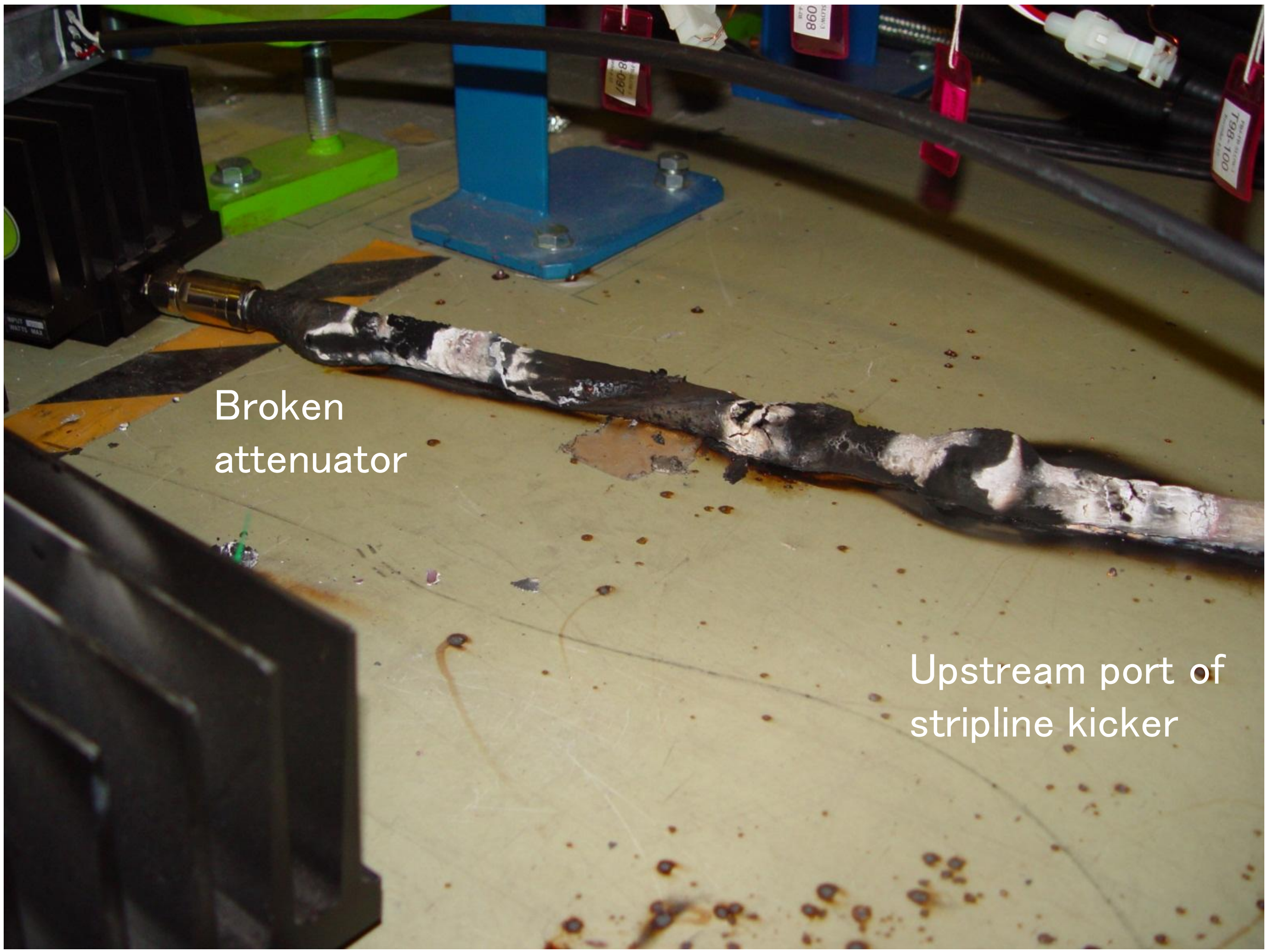
- **Standing wave ratio (SWR)**

$$S = \frac{|V|_{\max}}{|V|_{\min}} = \frac{1+|\rho|}{1-|\rho|}$$

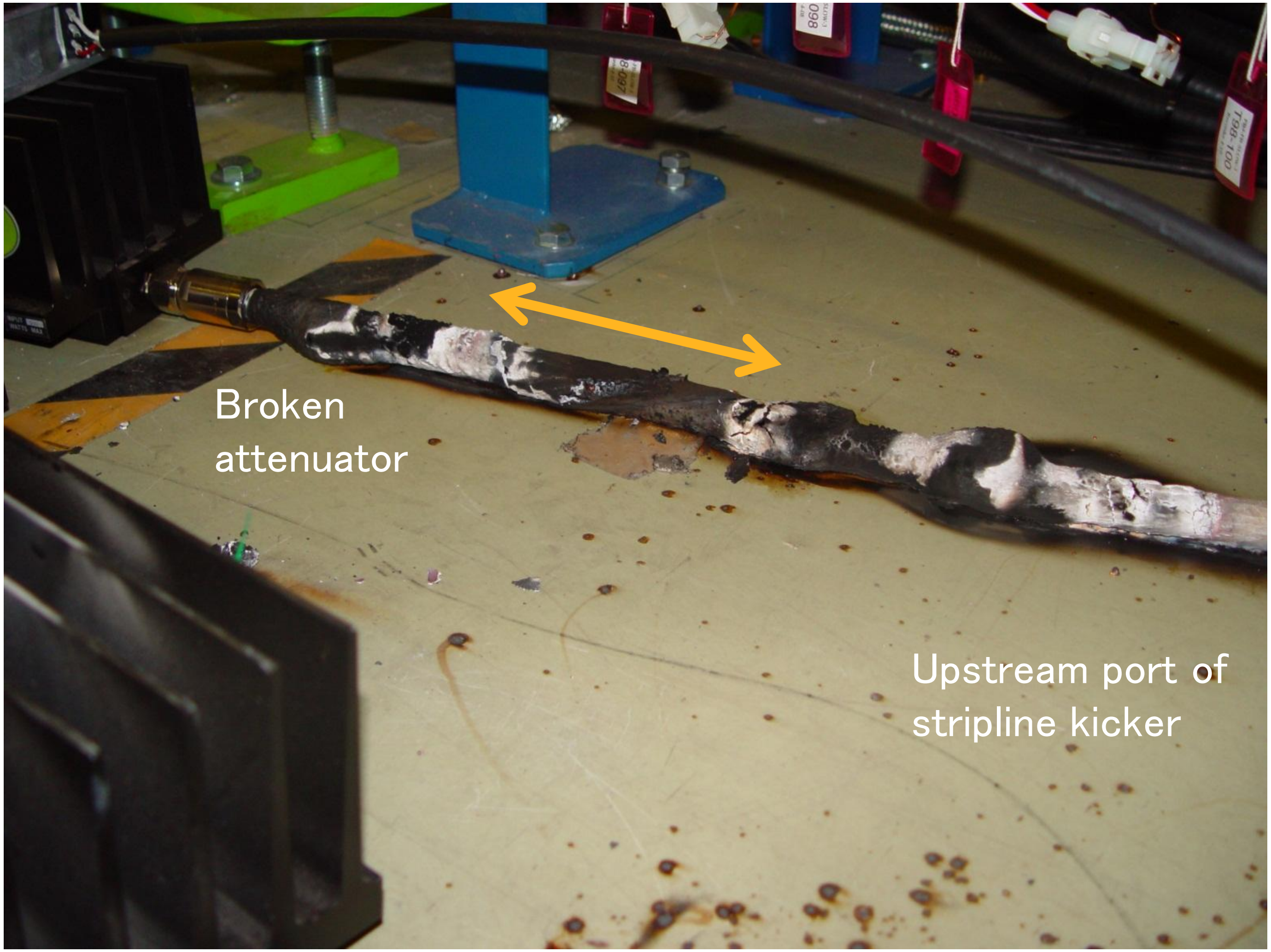
ρ: reflection constant

$$|\rho| = \frac{S-1}{S+1}$$

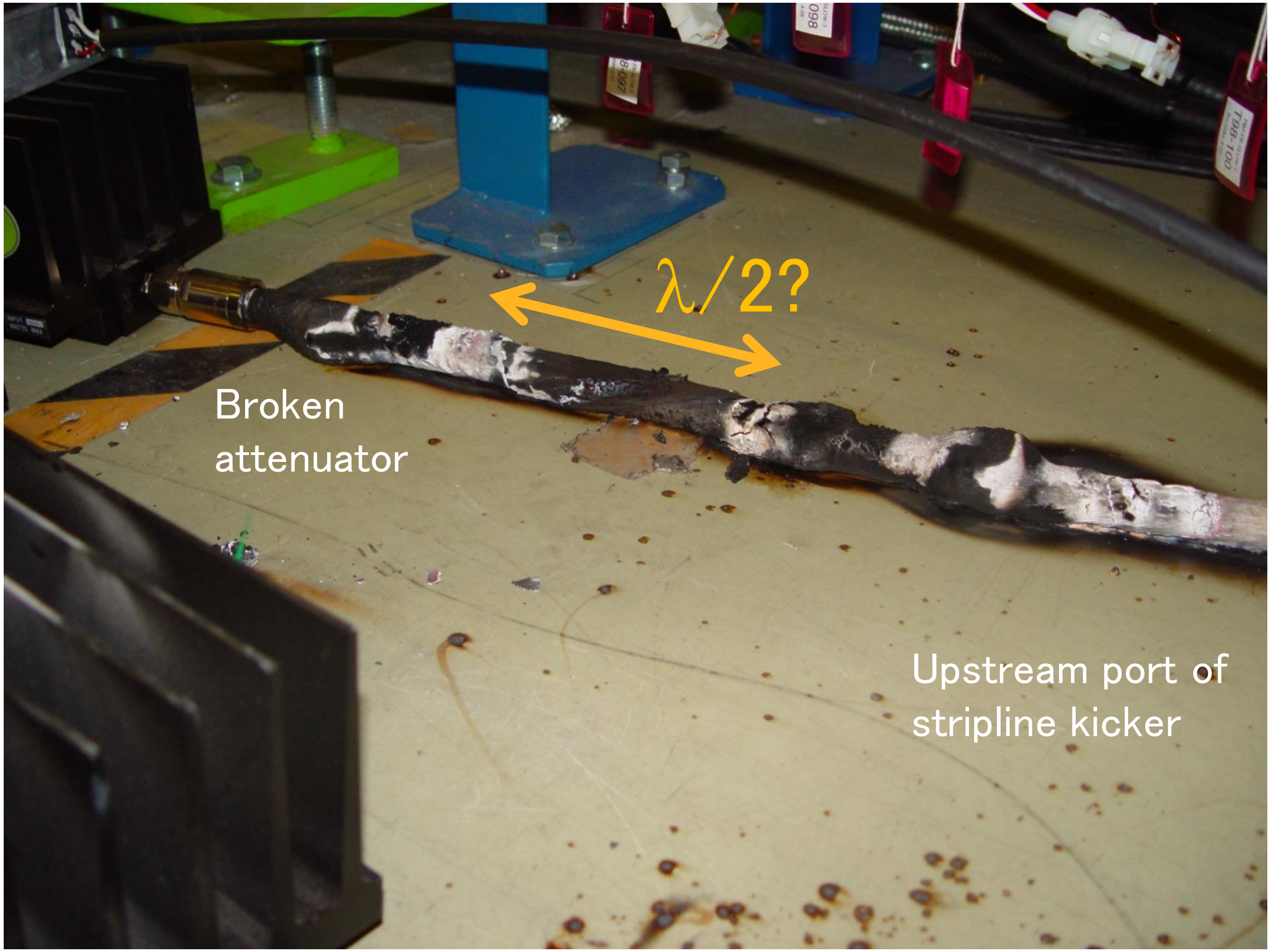
Example of standing wave!



Example of standing wave!



Example of standing wave!



Impedance of the load

- **We can estimate the load impedance using**

$$Z_r = Z_0 \frac{1+\rho}{1-\rho}$$

$$z_r = \frac{Z_r}{Z_0} = \frac{1+|\rho|e^{j\varphi}}{1-|\rho|e^{j\varphi}} = \frac{(S+1)+(S-1)e^{j(2\beta d_{\min}+\pi)}}{(S+1)-(S-1)e^{j(2\beta d_{\min}+\pi)}}$$

$$= \frac{1-jS\tan\beta d_{\min}}{S-j\tan\beta d_{\min}}$$

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SWR

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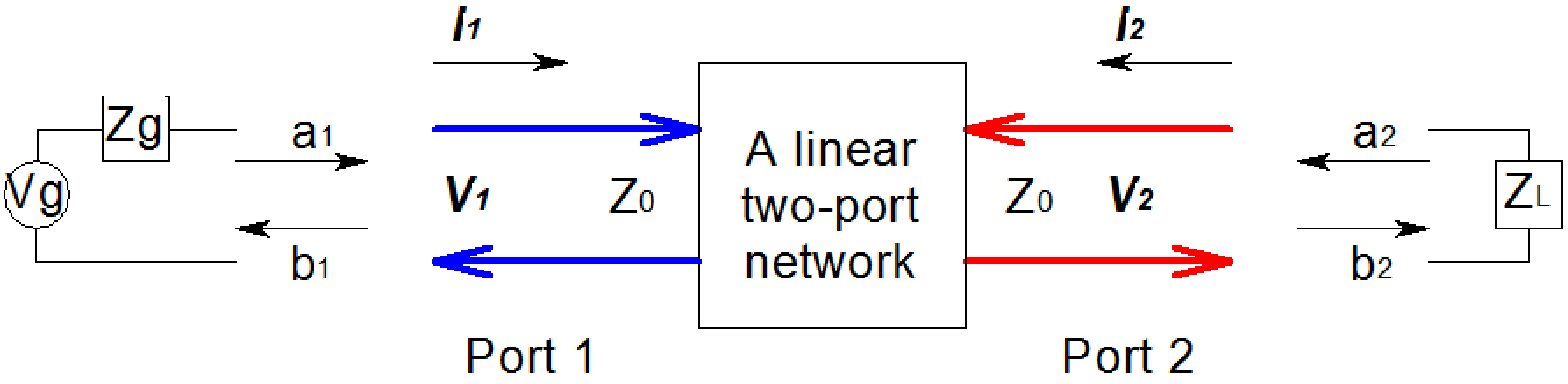
$$= \frac{1-jS\tan\beta d_{\min}}{S-j\tan\beta d_{\min}}$$

Scattering Matrix(S-Parameters)



$$\begin{pmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} \mathbf{a}_1 \\ \mathbf{a}_2 \end{pmatrix}$$

S-parameters

- Input Reflection Coefficient with Z_L=Z_0

$$S_{11} = \left.\frac{\mathbf{b}_1}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

- Output Reflection Coefficient with Z_G=Z_0 and V_G=0

$$S_{22} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_2}\right|_{\mathbf{a}_1=0}$$

- Forward Transmission Coefficient with Z_L=Z_0

$$S_{21} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

- Reverse Transmission Coefficient with Z_G=Z_0 and V_G=0

$$S_{12} = \left.\frac{\mathbf{b}_1}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

S-parameters

- Input Reflection Coefficient with $Z_L=Z_0$

$$S_{11} = \left.\frac{\mathbf{b}_1}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

Input match

- Output Reflection Coefficient with $Z_G=Z_0$ and $V_G=0$

$$S_{22} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_2}\right|_{\mathbf{a}_1=0}$$

- Forward Transmission Coefficient with $Z_L=Z_0$

$$S_{21} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

- Reverse Transmission Coefficient with $Z_G=Z_0$ and $V_G=0$

$$S_{12} = \left.\frac{\mathbf{b}_1}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

S-parameters

- Input Reflection Coefficient with $Z_L=Z_0$

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Input match

- Output Reflection Coefficient with $Z_G=Z_0$ and $V_G=0$

$$S_{22} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_2}\right|_{\mathbf{a}_1=0}$$

Output match

- Forward Transmission Coefficient with $Z_L=Z_0$

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- Reverse Transmission Coefficient with $Z_G=Z_0$ and $V_G=0$

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S-parameters

- Input Reflection Coefficient with $Z_L=Z_0$

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Input match

- Output Reflection Coefficient with $Z_G=Z_0$ and $V_G=0$

$$S_{22} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_2}\right|_{\mathbf{a}_1=0}$$

Output match

- Forward Transmission Coefficient with $Z_L=Z_0$

$$S_{21} = \left.\frac{\mathbf{b}_2}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

Gain or loss

- Reverse Transmission Coefficient with $Z_G=Z_0$ and $V_G=0$

$$S_{12} = \left.\frac{\mathbf{b}_1}{\mathbf{a}_1}\right|_{\mathbf{a}_2=0}$$

S-parameters

- Input Reflection Coefficient with $Z_L = Z_0$

$$S_{11} = \left. \frac{\mathbf{b}_1}{\mathbf{a}_1} \right|_{\mathbf{a}_2 = 0}$$

Input match

- Output Reflection Coefficient with $Z_G = Z_0$ and $V_G = 0$

$$S_{22} = \left. \frac{\mathbf{b}_2}{\mathbf{a}_2} \right|_{\mathbf{a}_1 = 0}$$

Output match

- Forward Transmission Coefficient with $Z_L = Z_0$

$$S_{21} = \left. \frac{\mathbf{b}_2}{\mathbf{a}_1} \right|_{\mathbf{a}_2 = 0}$$

Gain or loss

- Reverse Transmission Coefficient with $Z_G = Z_0$ and $V_G = 0$

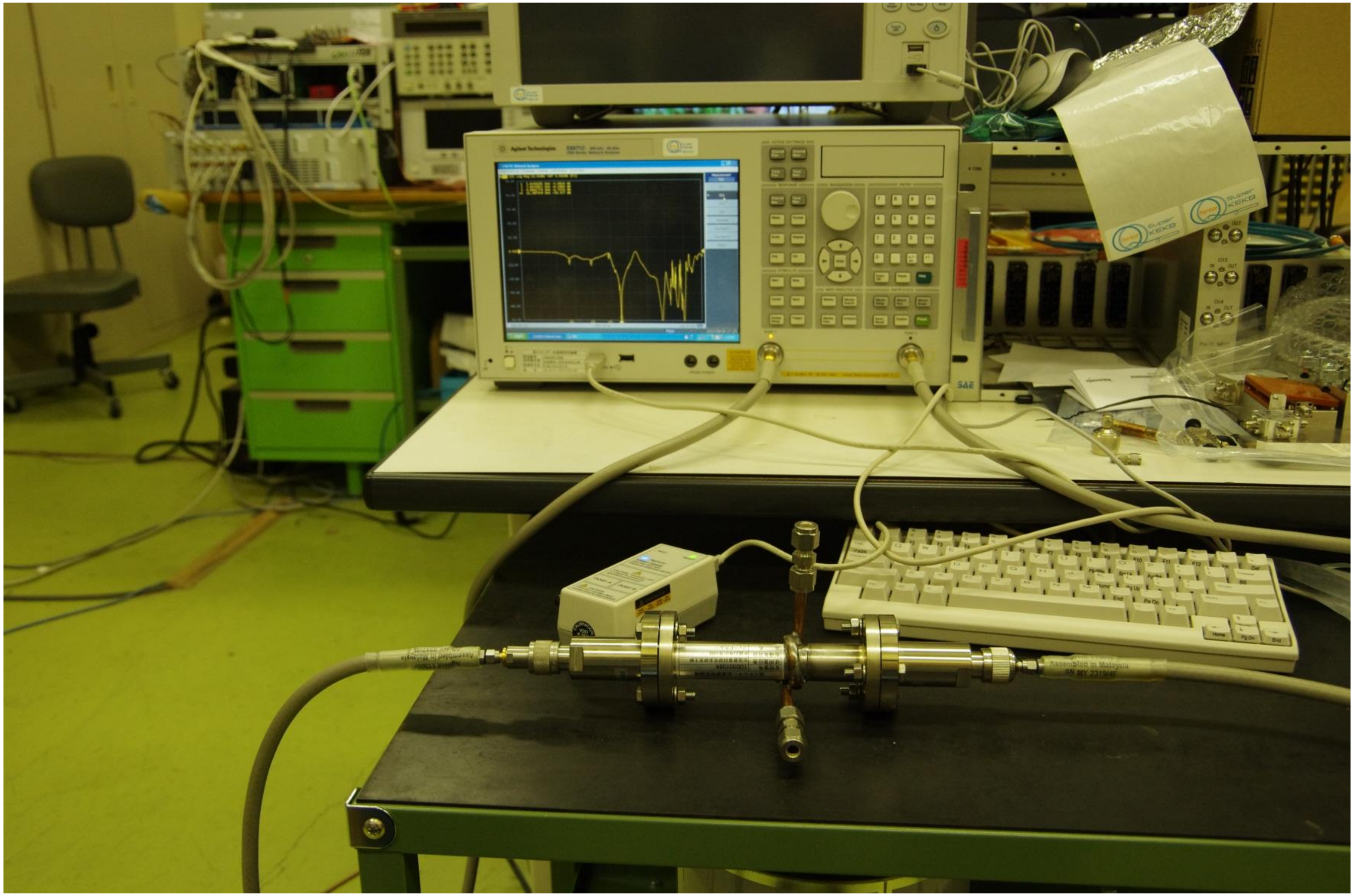
$$S_{12} = \left. \frac{\mathbf{b}_1}{\mathbf{a}_1} \right|_{\mathbf{a}_2 = 0}$$

Isolation

Why Use S-Parameters?

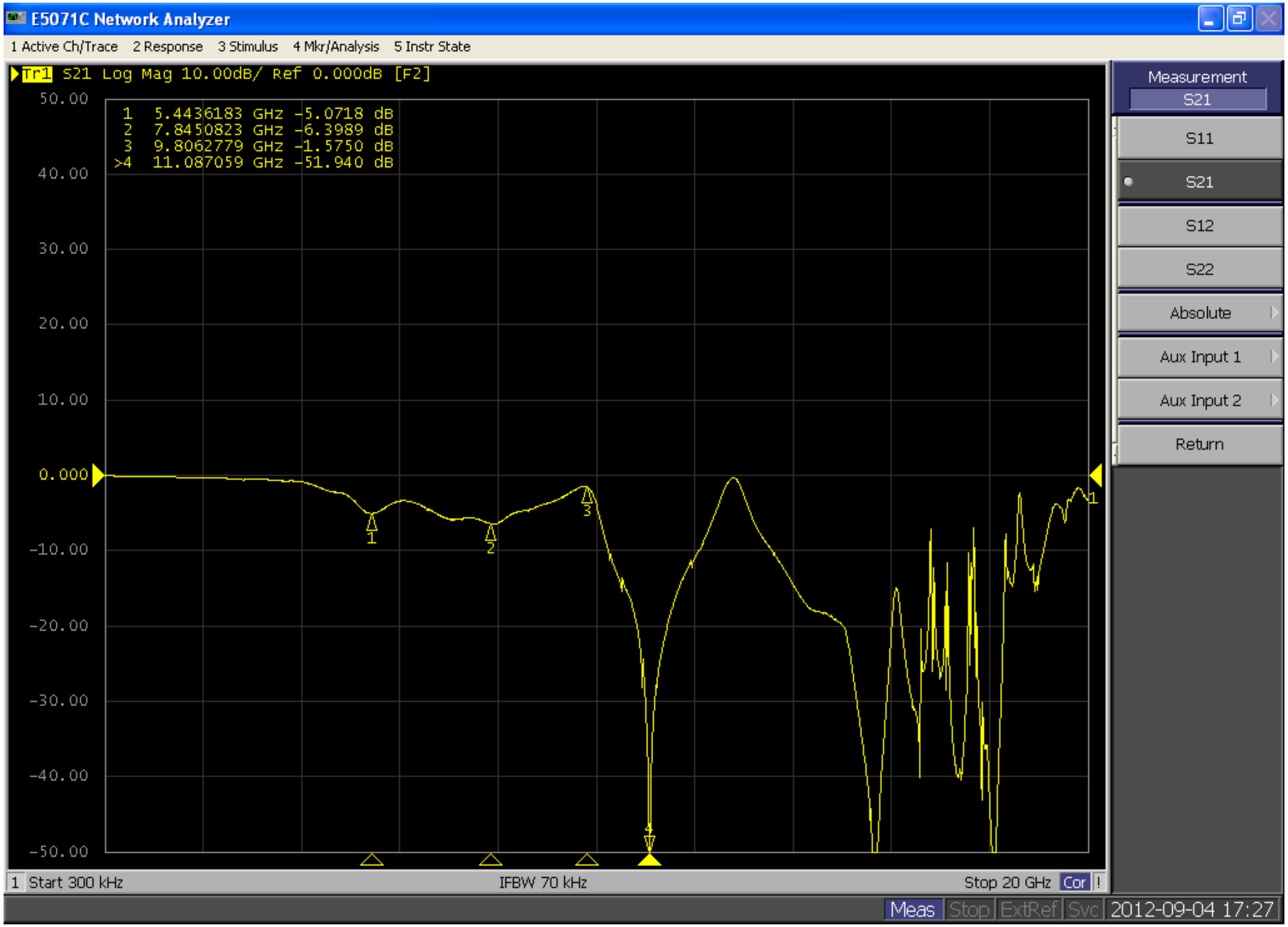
- relatively easy to obtain at high frequencies
  - measure voltage traveling waves with a vector network analyzer
  - don't need shorts/opens which can cause active devices to oscillate or self-destruct
- relate to familiar measurements (gain, loss, reflection coefficients...)
- can cascade S-parameters of multiple devices to predict system performance
- can compute H, Y or Z parameters from S-parameters if desired
- can easily import and use S-parameter files in electronic-simulation tools

RF Network Analyzer



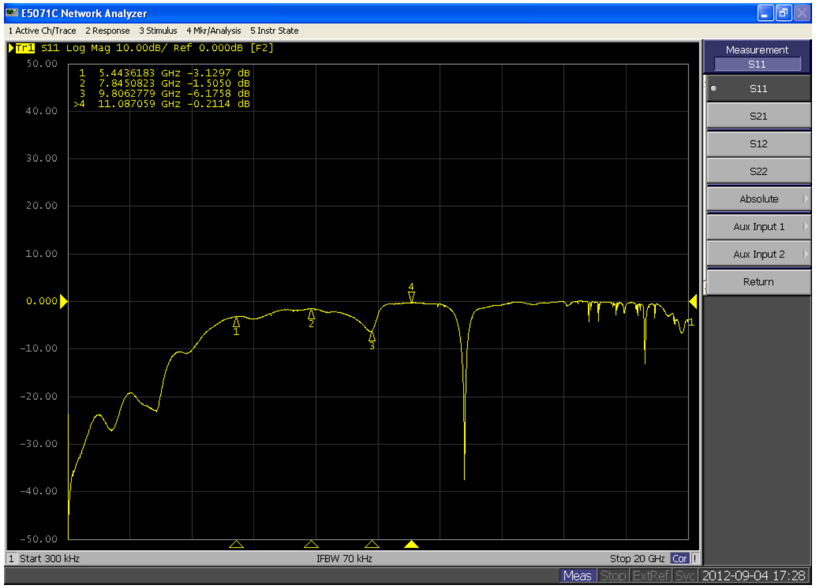
S21

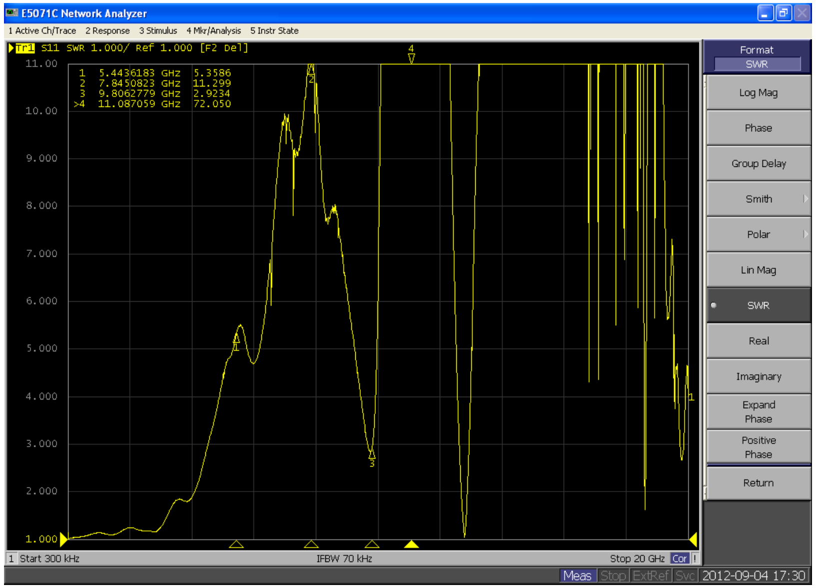
S21(in dB)



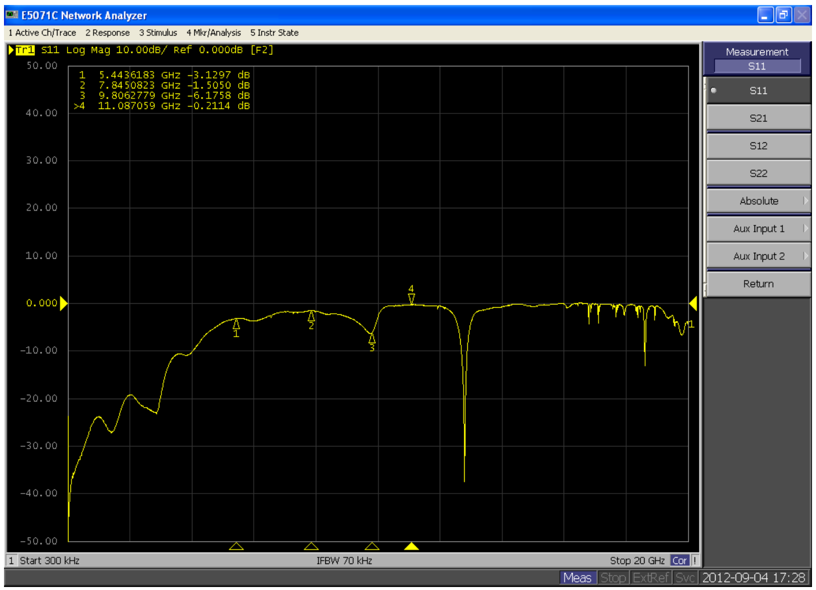
Frequency

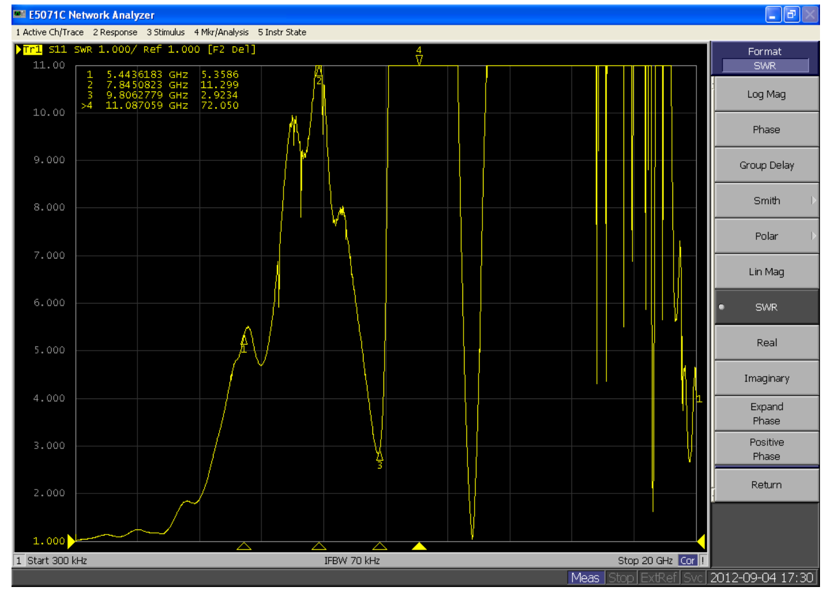
S11 and SWR(VSWR)





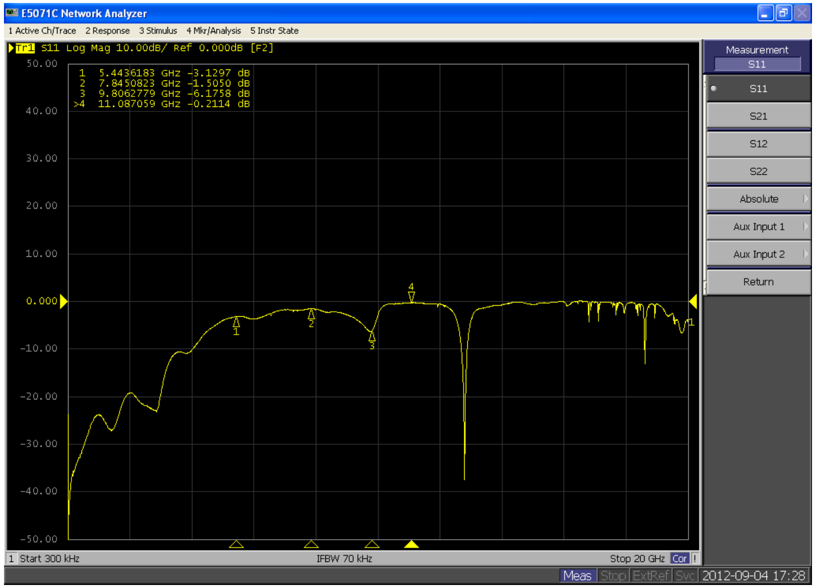
S11 and SWR(VSWR)

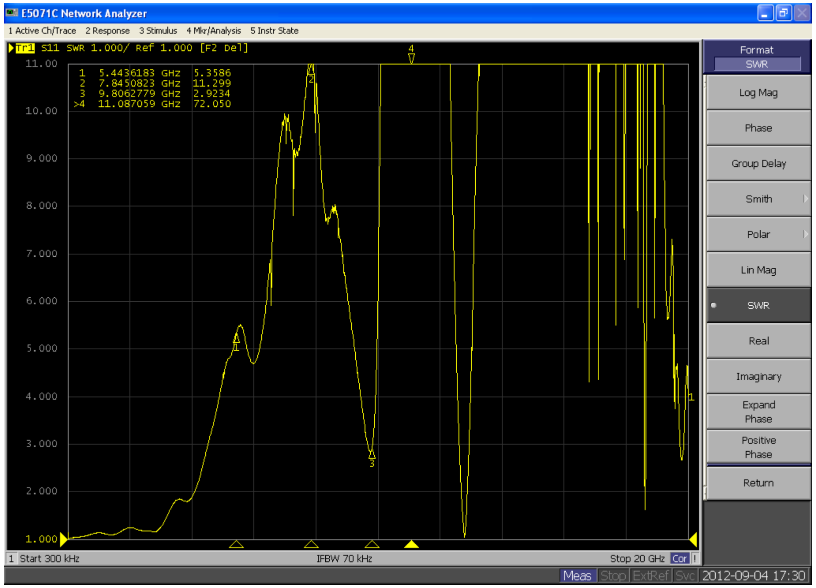




$$\left|20\log_{10}|S_{11}|\right|\mathrm{dB}$$

S11 and SWR(VSWR)

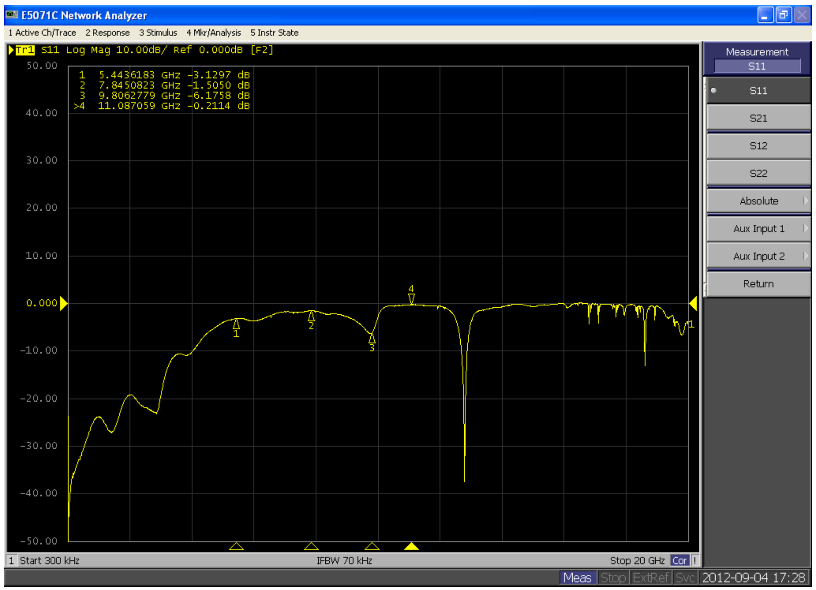


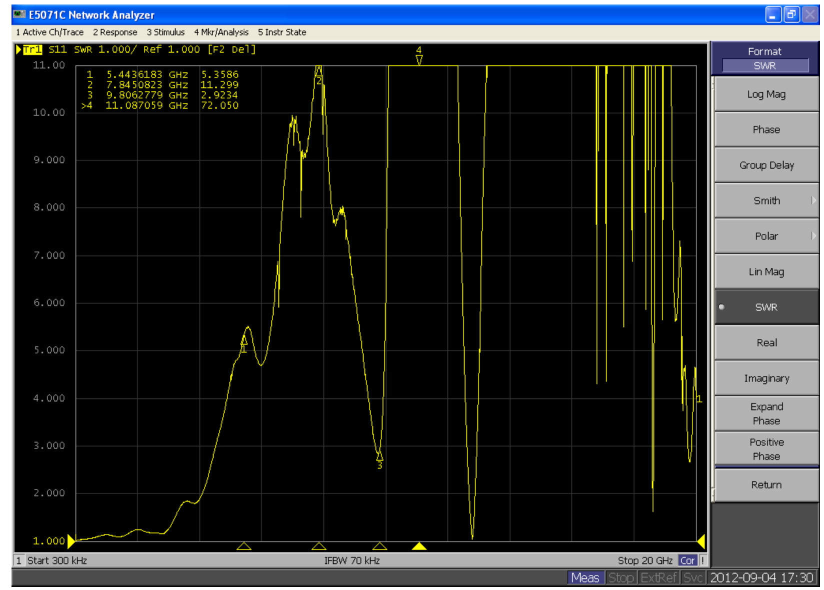


- **Return loss**

$$\left|20\log_{10}\left|S_{11}\right|\right|\mathrm{dB}$$

S11 and SWR(VSWR)



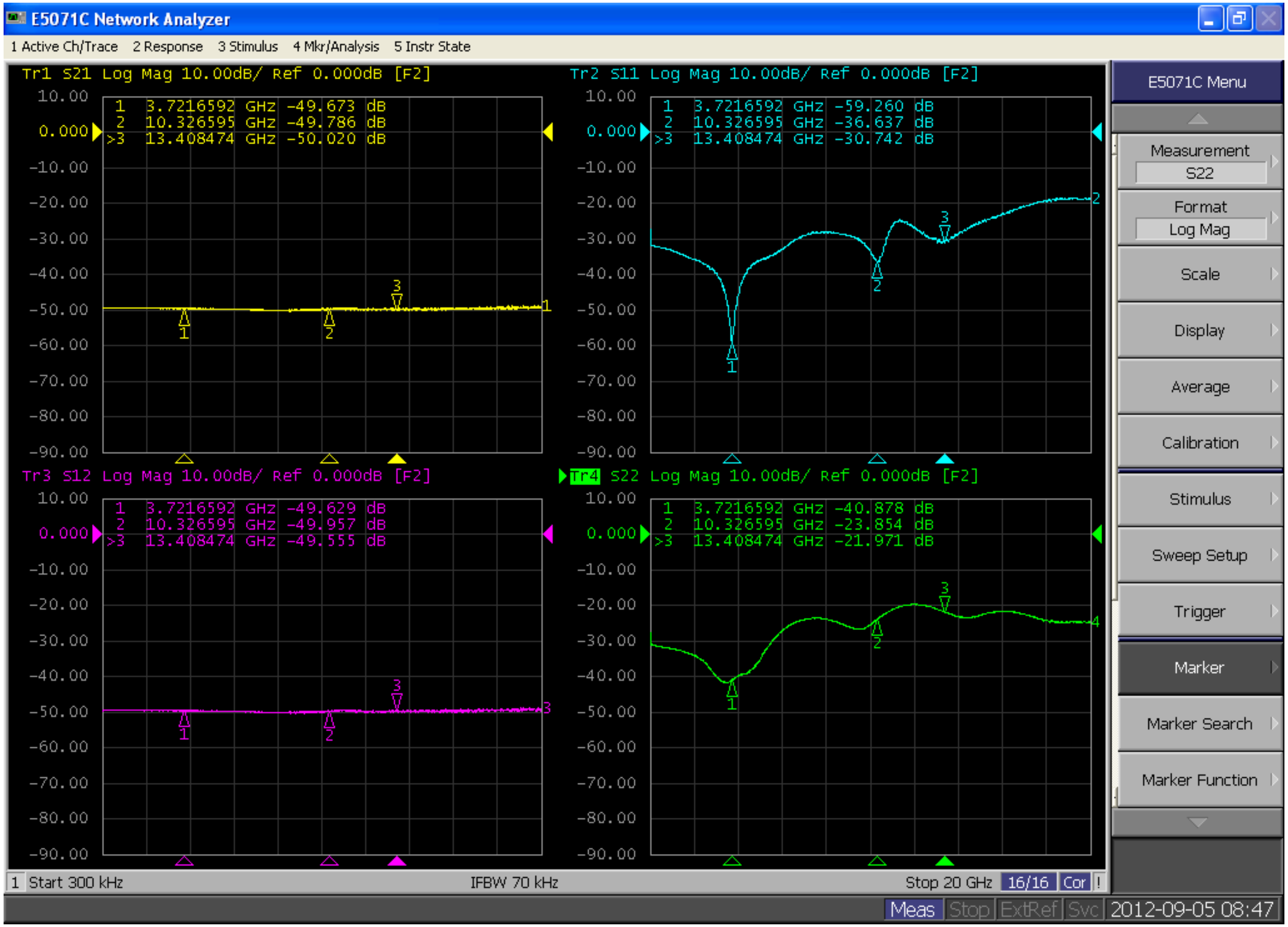


- **Return loss**

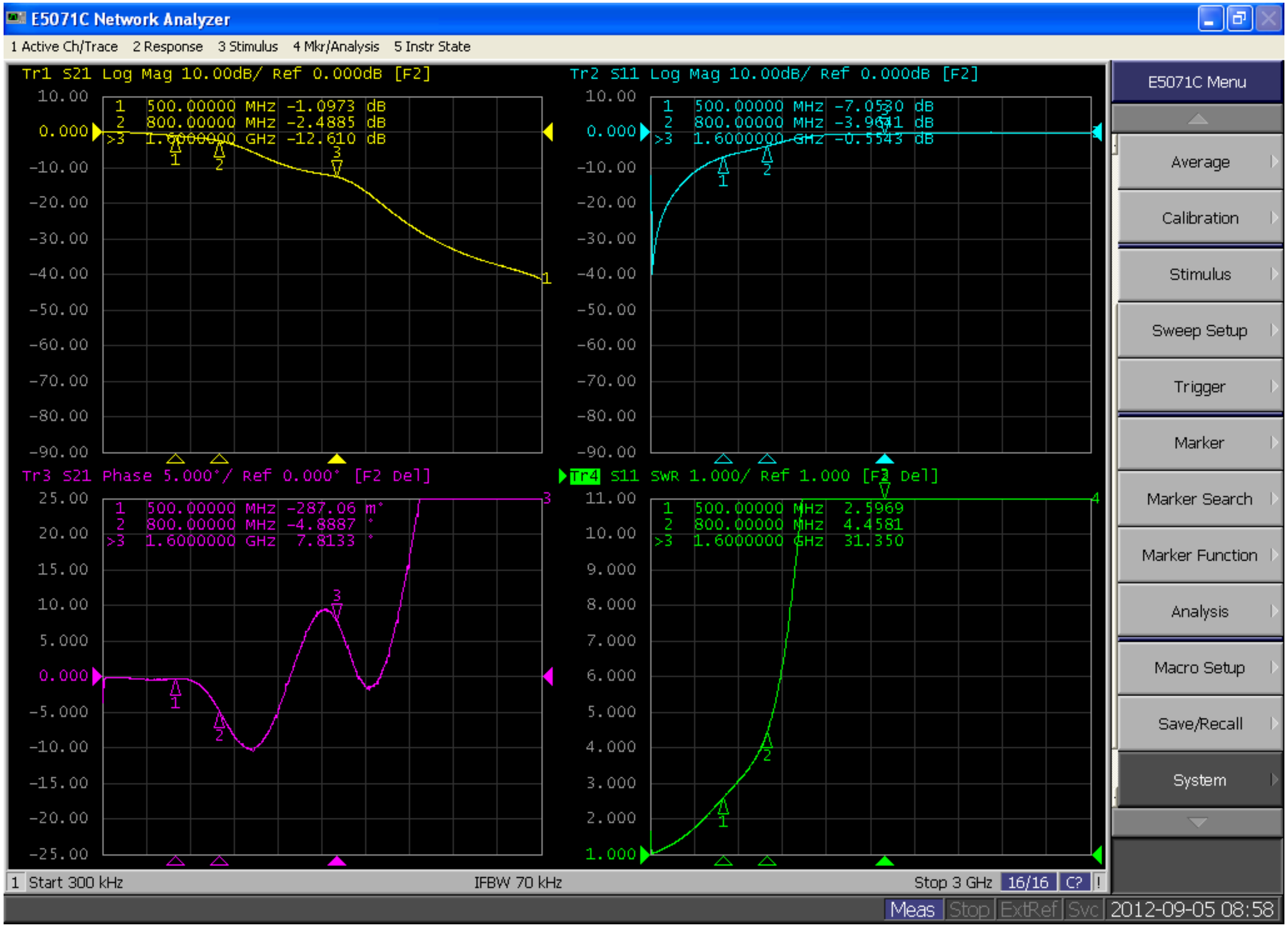
$$\left|20\log_{10}|S_{11}|\right|\mathrm{dB}$$

$$SWR_{input}=\frac{1+|S_{11}|}{1-|S_{11}|}$$

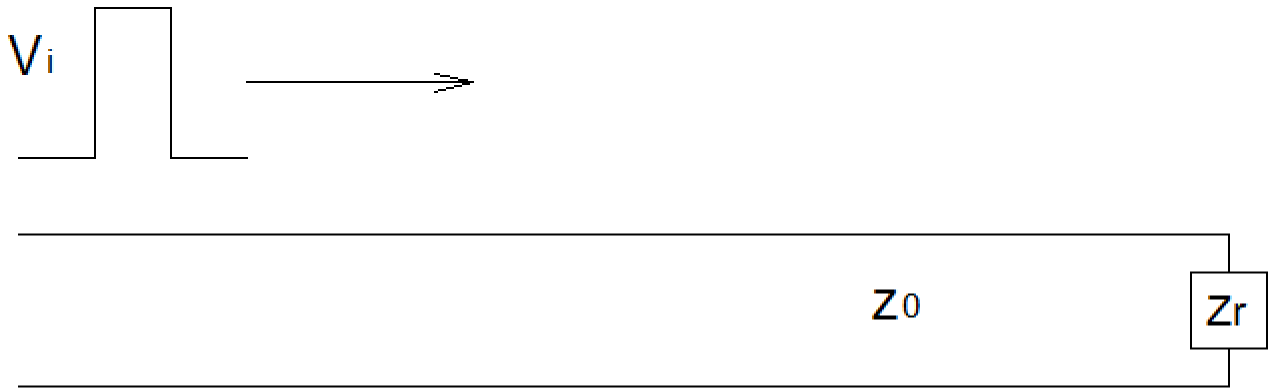
Example (50dB attenuator)



Example (800MHz Bessel LPF)



Time domain behavior--TDR

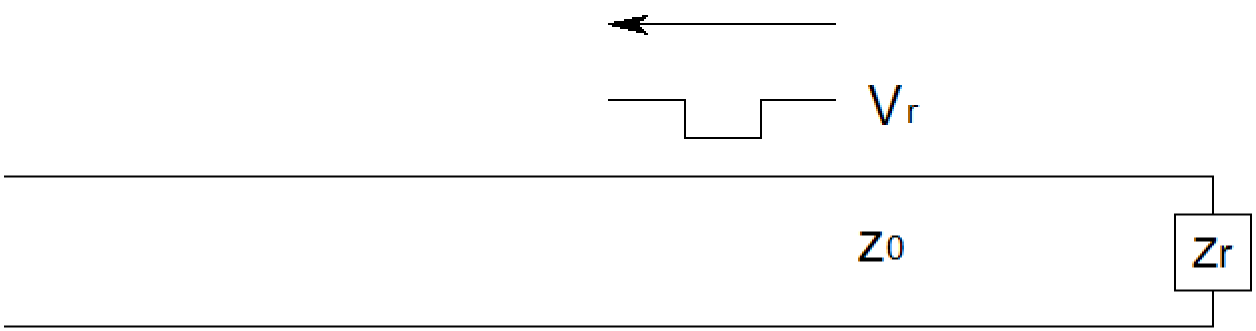


- **Using voltage ratio between forward and reflecting wave**

$$Z_r = \frac{1+\rho}{1-\rho} Z_0$$

$$\rho = \frac{V_r}{V_i}$$

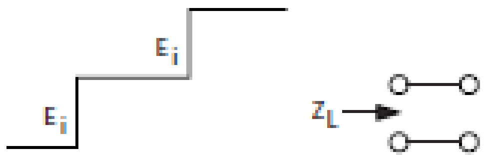
Time domain behavior--TDR



- **Using voltage ratio between forward and reflecting wave**

$$Z_r = \frac{1+\rho}{1-\rho} Z_0$$

$$\rho = \frac{V_r}{V_i}$$



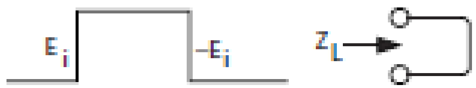
(A) Open Circuit Termination ($Z_L = \infty$)

(A) $E_r = E_i$

Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = +1$

Which is true as $Z_L \rightarrow \infty$

$\therefore Z =$ Open Circuit



(B) Short Circuit Termination ($Z_L = 0$)

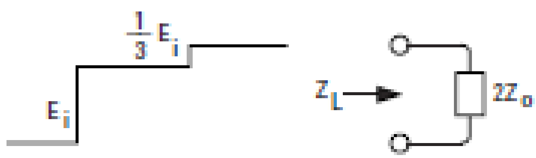
(B) $E_r = E_i$

Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = -1$

Which is only true for finite Z

When $Z_L = 0$

$\therefore Z =$ Short Circuit

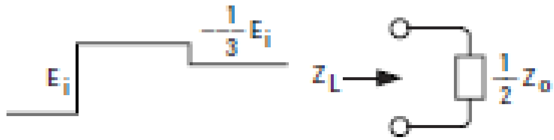


(C) Line Terminated in $Z_L = 2Z_o$

(C) $E_r = +\frac{1}{3} E_i$

Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = +\frac{1}{3}$

and $Z_L = 2Z_o$



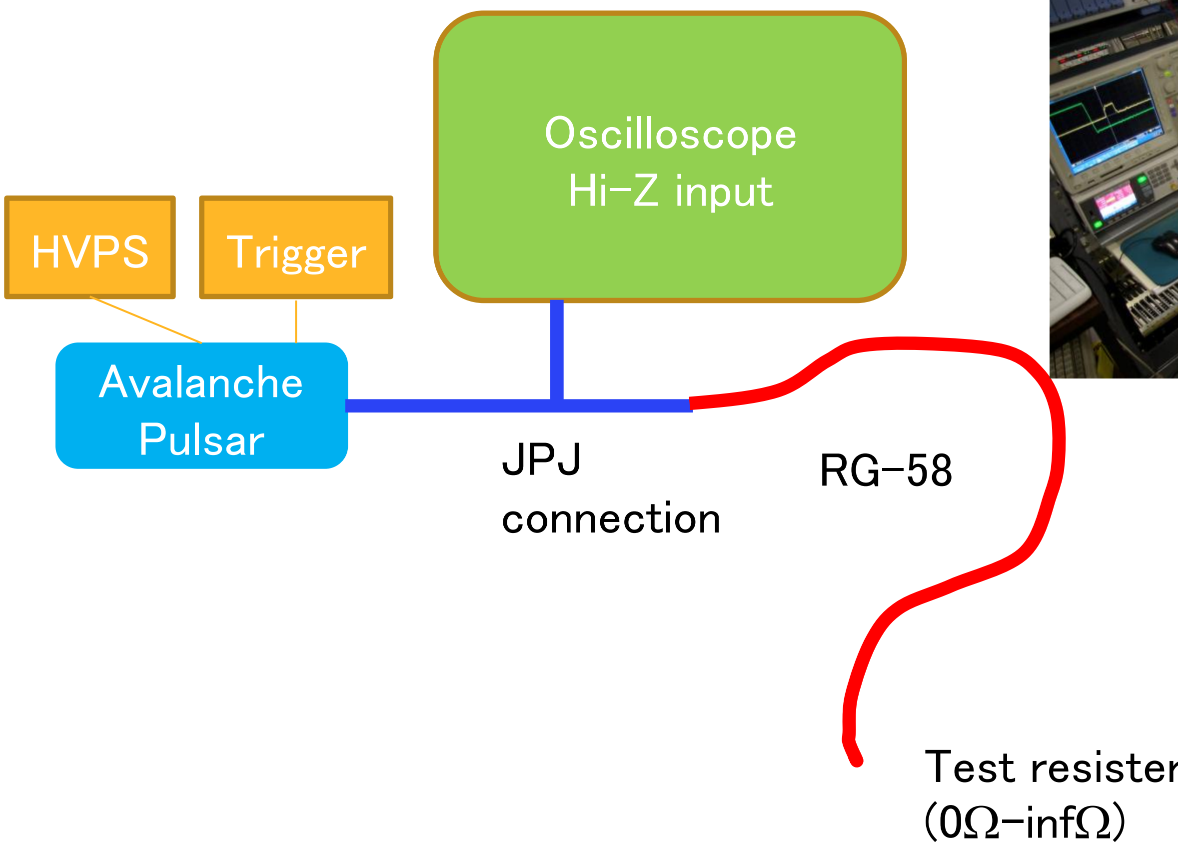
(D) Line Terminated in $Z_L = \frac{1}{2} Z_o$

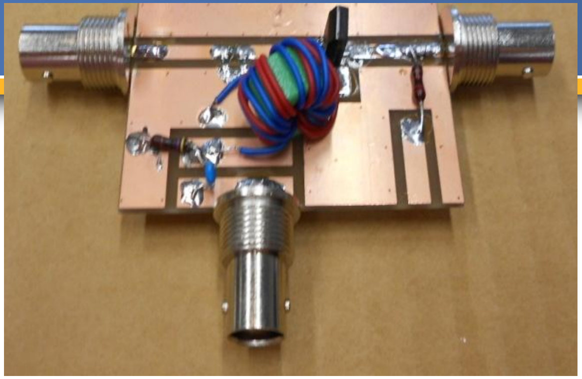
(D) $E_r = -\frac{1}{3} E_i$

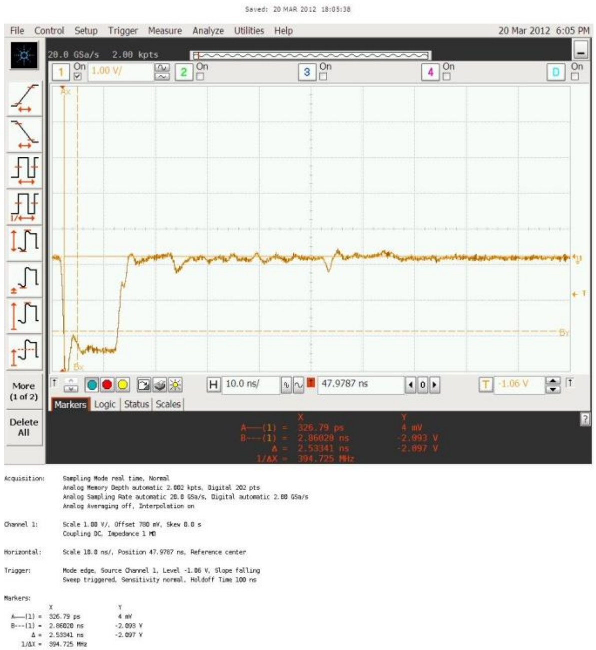
Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = -\frac{1}{3}$

and $Z_L = \frac{1}{2} Z_o$

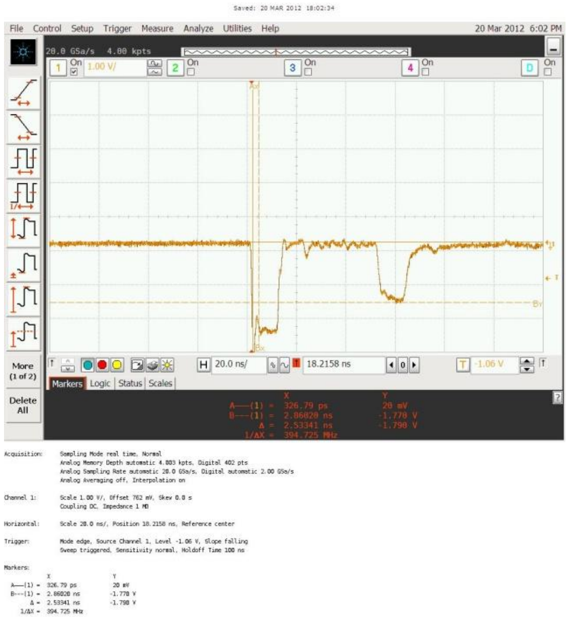
Science Camp 2011 (for High School students)


Oscilloscope
Hi-Z input
HVPS
Trigger
Avalanche
Pulsar
JPJ
connection
RG-58
Test resister
(0Ω-infΩ)

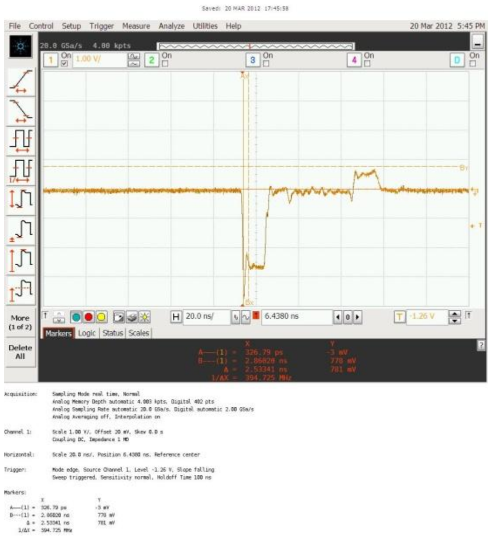



Saved: 20 MAR 2012 18:05:38
20 Mar 2012 6:05 PM
Acquisition: Sampling Mode real time, Normal
Analog Memory Depth automatic 2.002 kpts, Digital 202 pts
Analog Sampling Rate automatic 20.0 GSa/s, Digital automatic 2.00 GSa/s
Analog Averaging off, Interpolation on
Channel 1: Scale 1.00 V/, Offset 700 mV, Skew 0.0 s
Coupling DC, Impedance 1 MΩ
Horizontal: Scale 10.0 ns/, Position 47.9787 ns, Reference center
Trigger: Mode edge, Source Channel 1, Level -1.06 V, Slope falling
Sweep triggered, Sensitivity normal, Holdoff Time 100 ns
Markers:
A—(1) = 326.79 ps 4 mV
B---(1) = 2.86020 ns -2.093 V
Δ = 2.53341 ns -2.097 V
1/ΔX = 394.725 MHz

51Ω

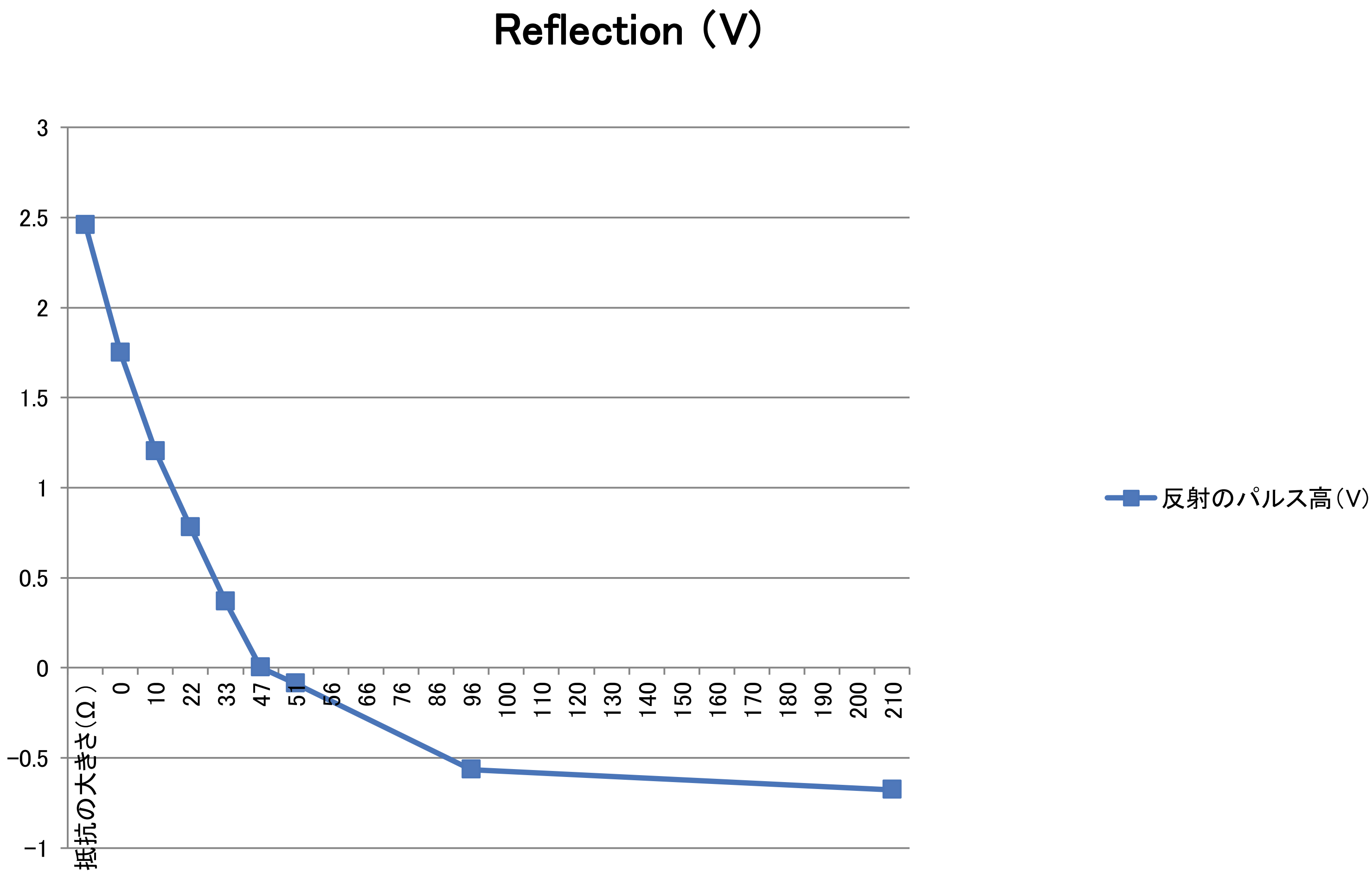

Saved: 20 MAR 2012 18:02:34
20 Mar 2012 6:02 PM
Acquisition: Sampling Mode real time, Normal
Analog Memory Depth automatic 4.003 kpts, Digital 402 pts
Analog Sampling Rate automatic 20.0 GSa/s, Digital automatic 2.00 GSa/s
Analog Averaging off, Interpolation on
Channel 1: Scale 1.00 V/, Offset 762 mV, Skew 0.0 s
Coupling DC, Impedance 1 MΩ
Horizontal: Scale 20.0 ns/, Position 18.2158 ns, Reference center
Trigger: Mode edge, Source Channel 1, Level -1.06 V, Slope falling
Sweep triggered, Sensitivity normal, Holdoff Time 100 ns
Markers:
A—(1) = 326.79 ps 20 mV
B---(1) = 2.86020 ns -1.778 V
Δ = 2.53341 ns -1.798 V
1/ΔX = 394.725 MHz

470Ω

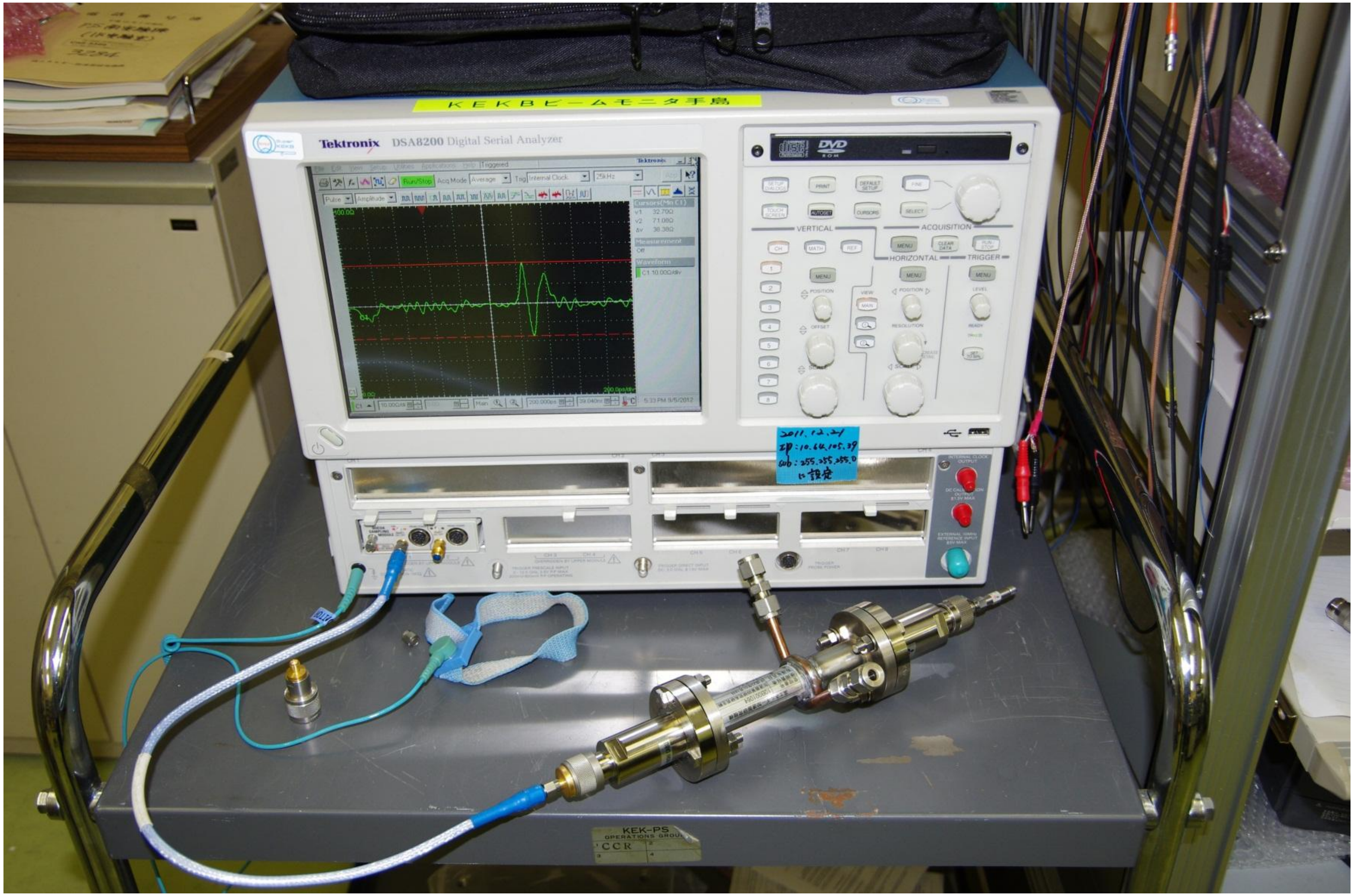

20 Mar 2012 5:45 PM
Acquisition: Sampling Mode real time, Normal
Analog Memory Depth automatic 4.003 kpts, Digital 402 pts
Analog Sampling Rate automatic 20.0 GSa/s, Digital automatic 2.00 GSa/s
Analog Averaging off, Interpolation on
Channel 1: Scale 1.00 V/, Offset 20 mV, Skew 0.0 s
Coupling DC, Impedance 1 MΩ
Horizontal: Scale 20.0 ns/, Position 6.4380 ns, Reference center
Trigger: Mode edge, Source Channel 1, Level -1.26 V, Slope falling
Sweep triggered, Sensitivity normal, Holdoff Time 100 ns
Markers:
A—(1) = 326.79 ps -3 mV
B---(1) = 2.86020 ns 778 mV
Δ = 2.53341 ns 781 mV
1/ΔX = 394.725 MHz

33Ω

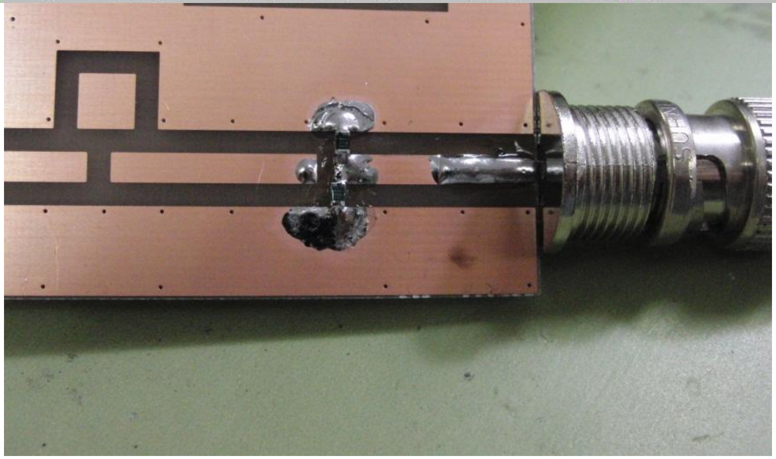
Matching of 50-ohm line



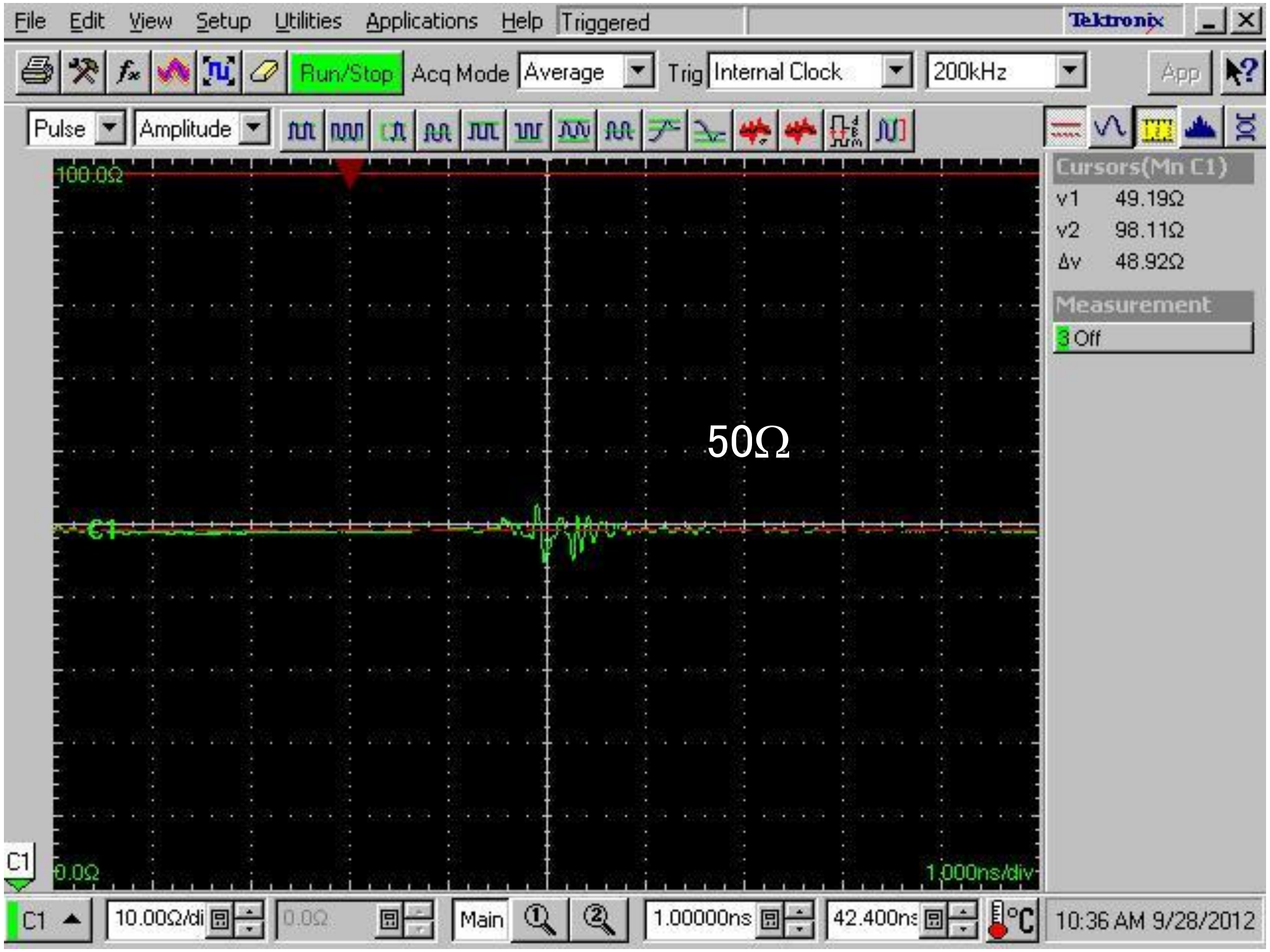
Real TDR


KEKBビームモニタ手島
Tektronix DSA8200 Digital Serial Analyzer
VERTICAL
ACQUISITION
HORIZONTAL
TRIGGER
KEK-PS
OPERATIONS GROUP
CCR

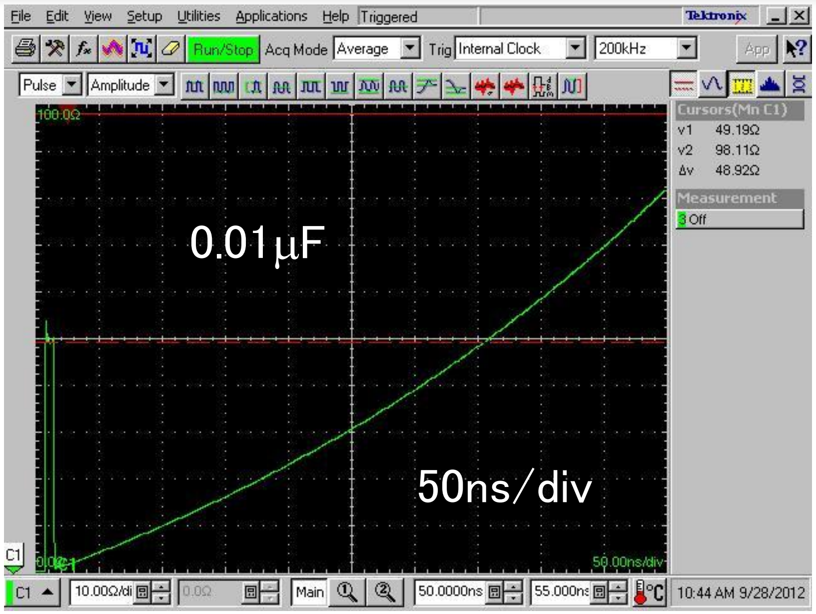
TDR (chip resister)

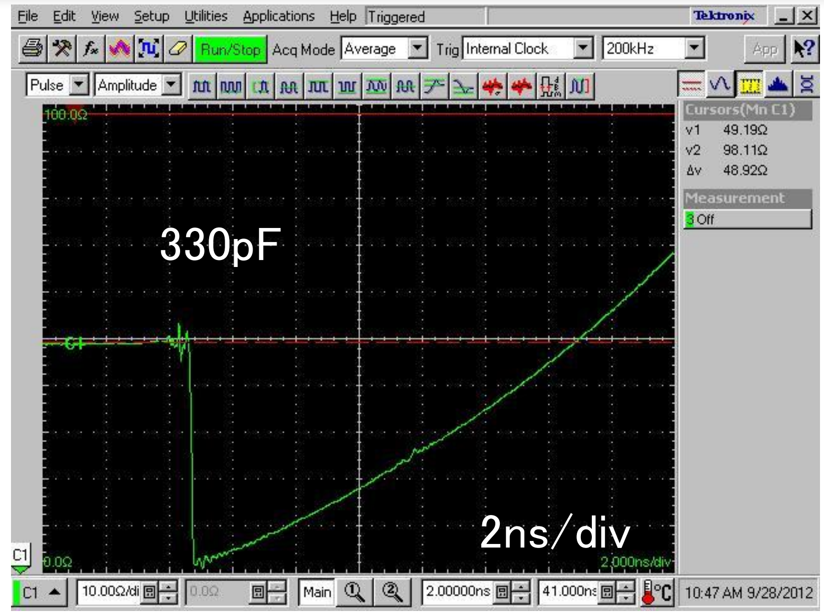


TDR

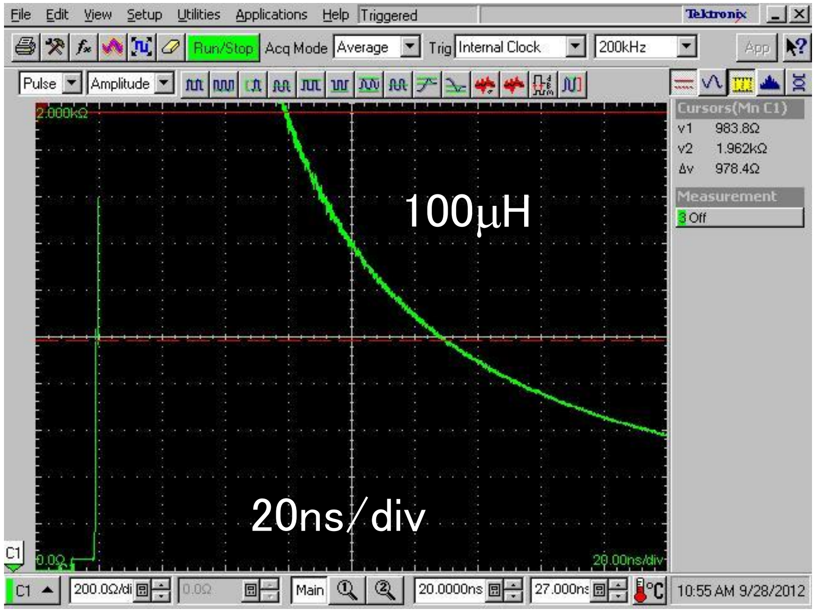

File Edit View Setup Utilities Applications Help Triggered
Tektronix
Run/Stop
Acq Mode Average
Trig Internal Clock
200kHz
App
Pulse
Amplitude
100.0Ω
C1
0.0Ω
1.000ns/div
Cursors(Mn C1)
v1 49.19Ω
v2 98.11Ω
Δv 48.92Ω
Measurement
3 Off
C1
10.00Ω/di
0.0Ω
Main
1.00000ns
42.400ns
°C
10:36 AM 9/28/2012
50Ω

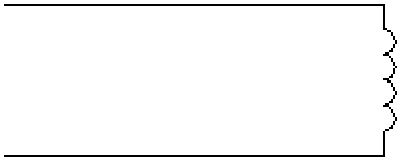
Capacitor

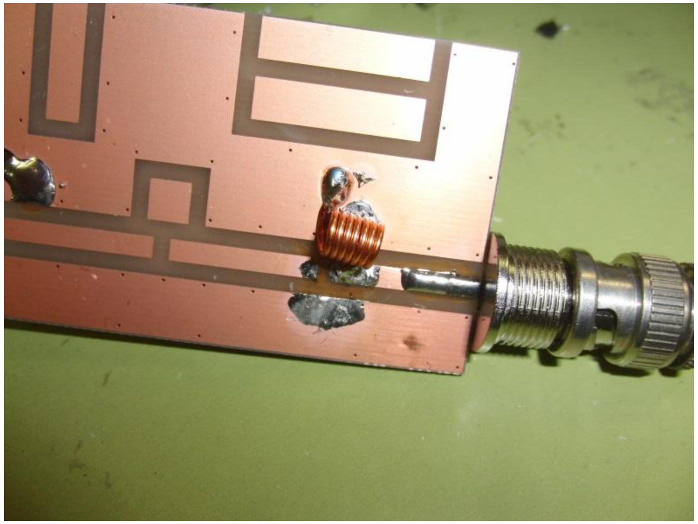




Inductance







Tips

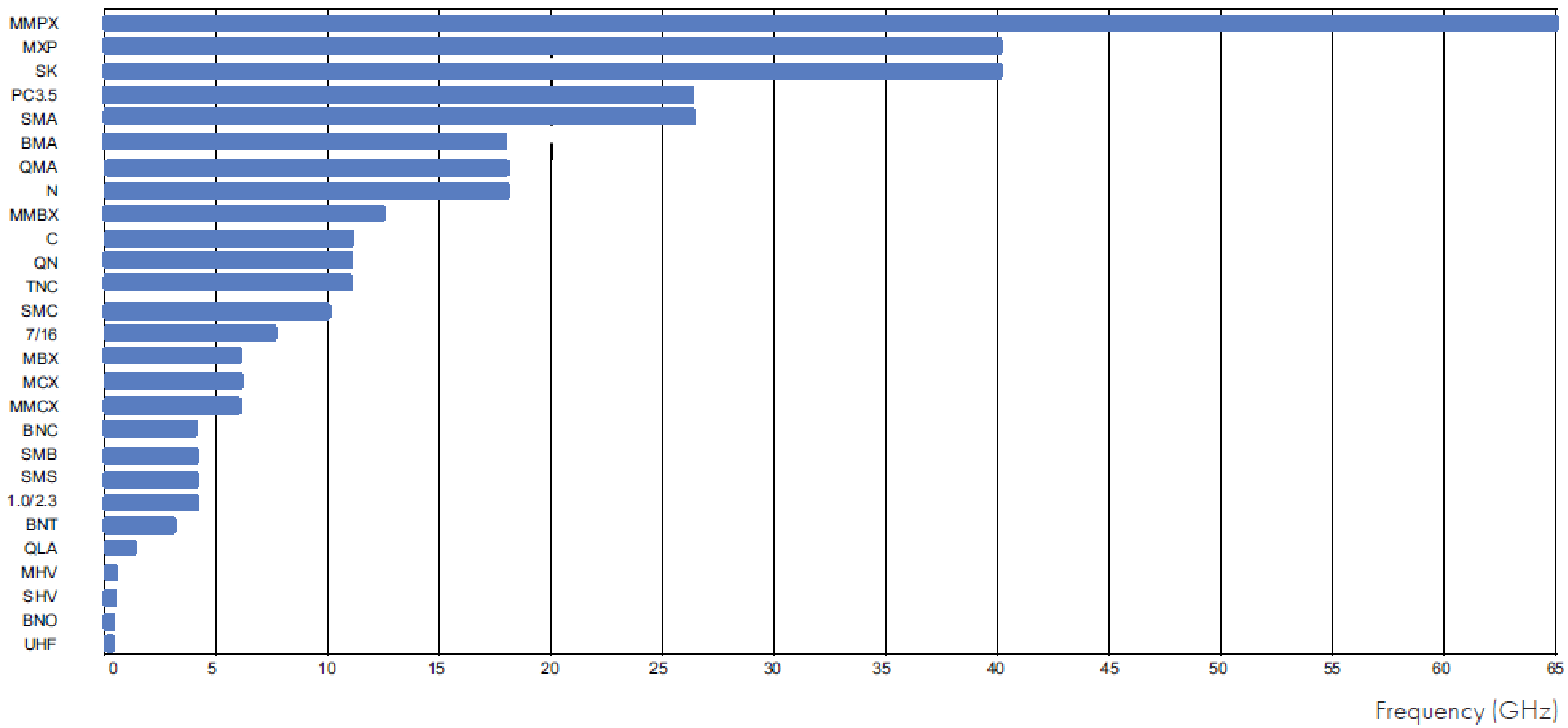
- **Good matched two-ports (such as J-J structure) is needed to measure the S-parameters of the feedthrough structure.**
  - For the TDR measurements, open structure (button or rod on vacuum side) might usually be OK

Ideal feedthrough?

- **Mechanical**
  - Completely satisfy required mechanical toughness
  - Satisfy vacuum requirements

- **Frequency domain**
  - S21 (and S12) ~1 (0dB)
  - S11 (and S22)~ −inf dB
- **Time domain**
  - Impedance=50 Ohm, completely matched structure

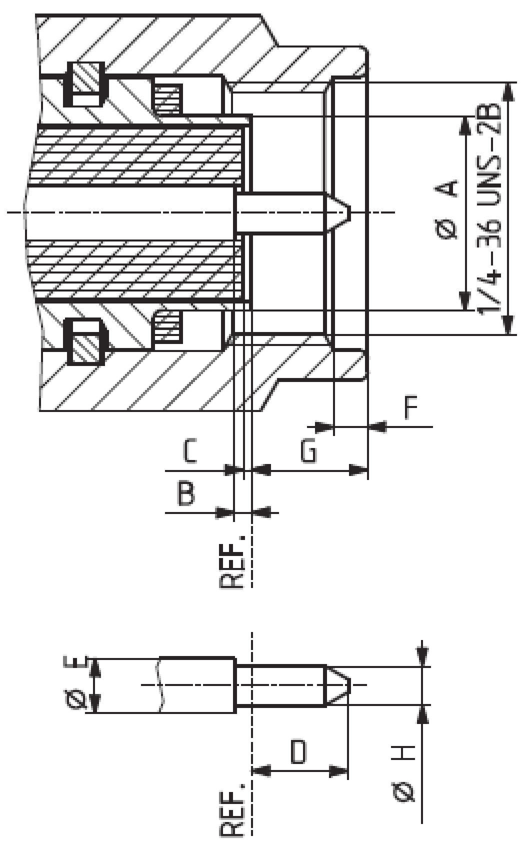
RF connector



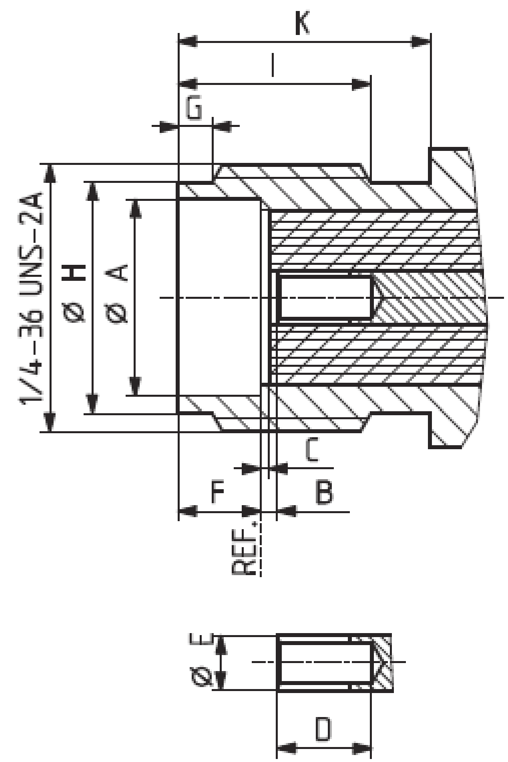
Frequency range of connector series.

Plug(male) and Jack(female)

Plug (male)

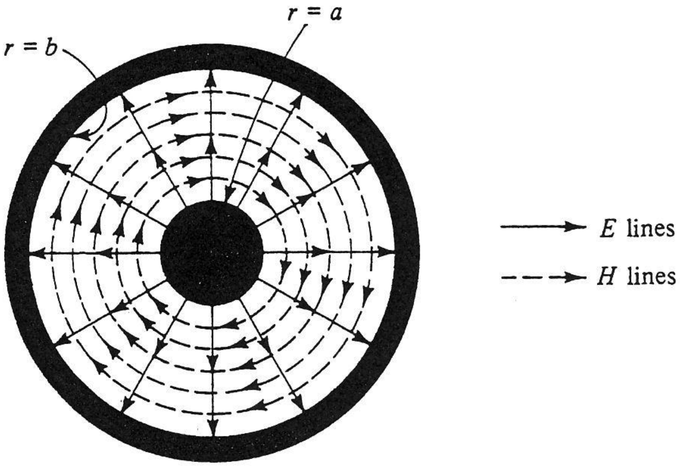


Jack (female)



Size of the feedthrough

- **Which connectors do you want to use?**
  - N?,SMA?,BNC?,7/16-DIN?,7/8-EIA?



$$Z_0 = 60\sqrt{\frac{\mu_R}{\varepsilon_R}}\ln\frac{b}{a}$$

Attenuation Length (dB/m)

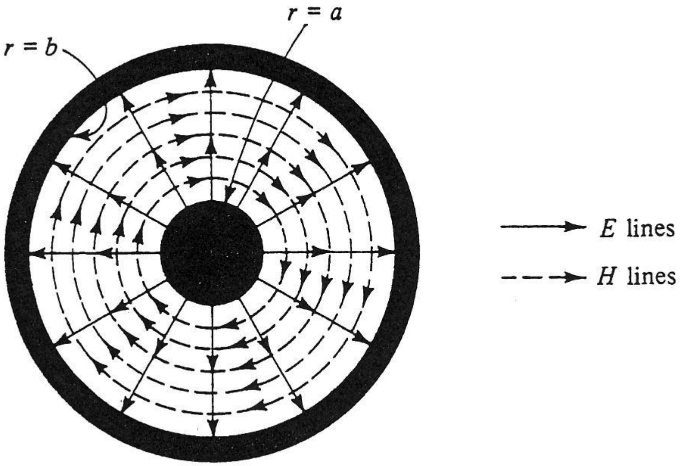
$$\alpha \approx \alpha_c + \alpha_d$$

$$\alpha_c = 13.6\frac{\delta_s\sqrt{\varepsilon_R}\{1+(b/a)\}}{\lambda_0 b\ln(b/a)},$$

$$\alpha_d = 27.3\frac{\sqrt{\varepsilon_R}}{\lambda_0}\tan\delta$$

Size of the feedthrough

- **Which connectors do you want to use?**
  - N?,SMA?,BNC?,7/16-DIN?,7/8-EIA?



$$Z_0 = 60\sqrt{\frac{\mu_R}{\varepsilon_R}}\ln\frac{b}{a}$$

Attenuation Length (dB/m)

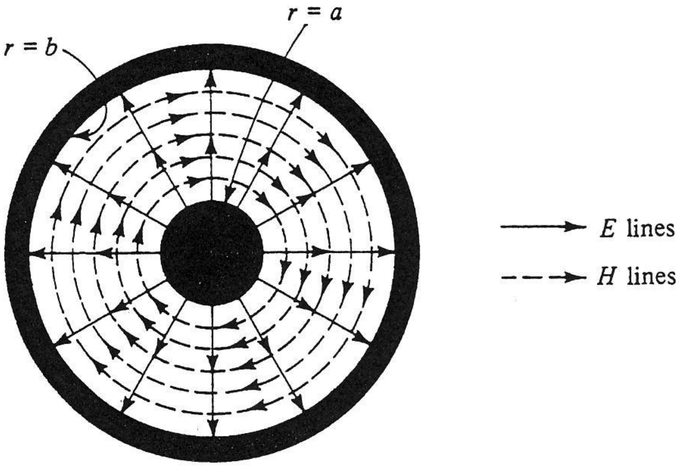
$$\alpha \approx \alpha_c + \alpha_d$$

$$\alpha_c = 13.6\frac{\delta_s\sqrt{\varepsilon_R}\{1+(b/a)\}}{\lambda_0 b\ln(b/a)},$$

$$\alpha_d = 27.3\frac{\sqrt{\varepsilon_R}}{\lambda_0}\tan\delta$$

Size of the feedthrough

- **Which connectors do you want to use?**
  - N?,SMA?,BNC?,7/16-DIN?,7/8-EIA?



$$Z_0 = 60\sqrt{\frac{\mu_R}{\varepsilon_R}}\ln\frac{b}{a}$$

Attenuation Length (dB/m)

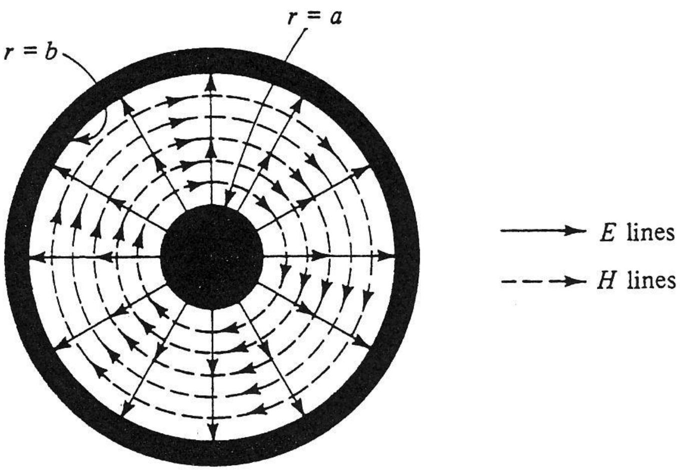
$$\alpha \approx \alpha_c + \alpha_d$$

$$\alpha_c = 13.6\frac{\delta_s\sqrt{\varepsilon_R}\{1+(b/a)\}}{\lambda_0 b\ln(b/a)},$$

$$\alpha_d = 27.3\frac{\sqrt{\varepsilon_R}}{\lambda_0}\tan\delta$$

Size of the feedthrough

- **Which connectors do you want to use?**
  - N?,SMA?,BNC?,7/16-DIN?,7/8-EIA?



$$Z_0 = 60\sqrt{\frac{\mu_R}{\varepsilon_R}}\ln\frac{b}{a}$$

Attenuation Length (dB/m)

$$\alpha \approx \alpha_c + \alpha_d$$

$$\alpha_c = 13.6\frac{\delta_s\sqrt{\varepsilon_R}\{1+(b/a)\}}{\lambda_0 b\ln(b/a)},$$

$$\alpha_d = 27.3\frac{\sqrt{\varepsilon_R}}{\lambda_0}\tan\delta$$

Higher-mode propagation in coaxial lines.

- **TE11mode**

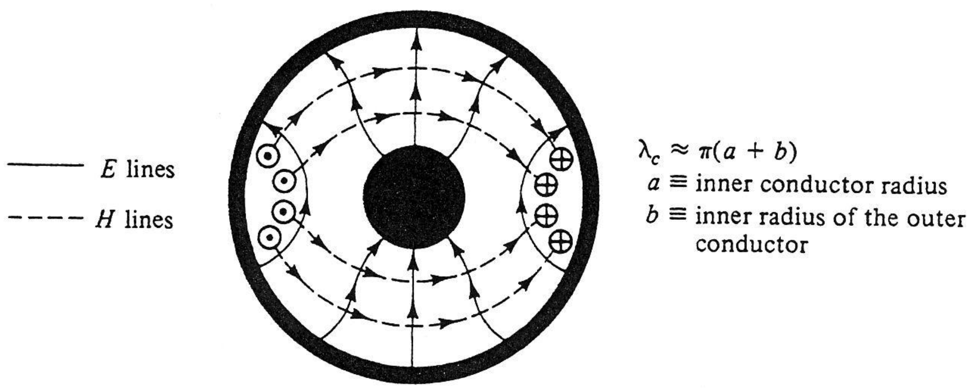
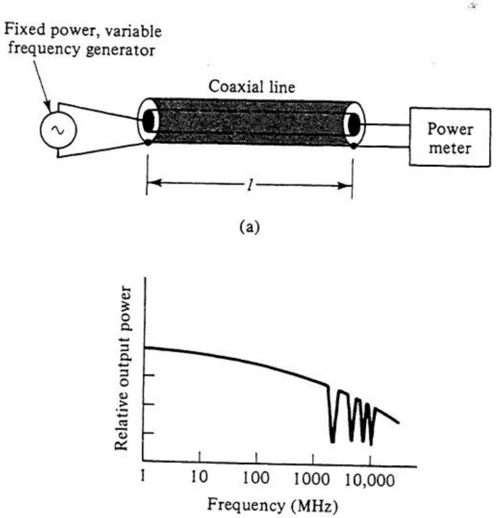


Figure 5-3 The electromagnetic field pattern for the TE_{11} mode in a coaxial line.

$$\lambda_c \approx \pi(a+b)$$

$$f_c \approx \frac{c}{\pi(a+b)\sqrt{\varepsilon_R}}$$



- Type-N:18GHz
- SMA: 34GHz

- RG-223:~30GHz
- EIA 7/8":~6.8GHz

Connectors in the air

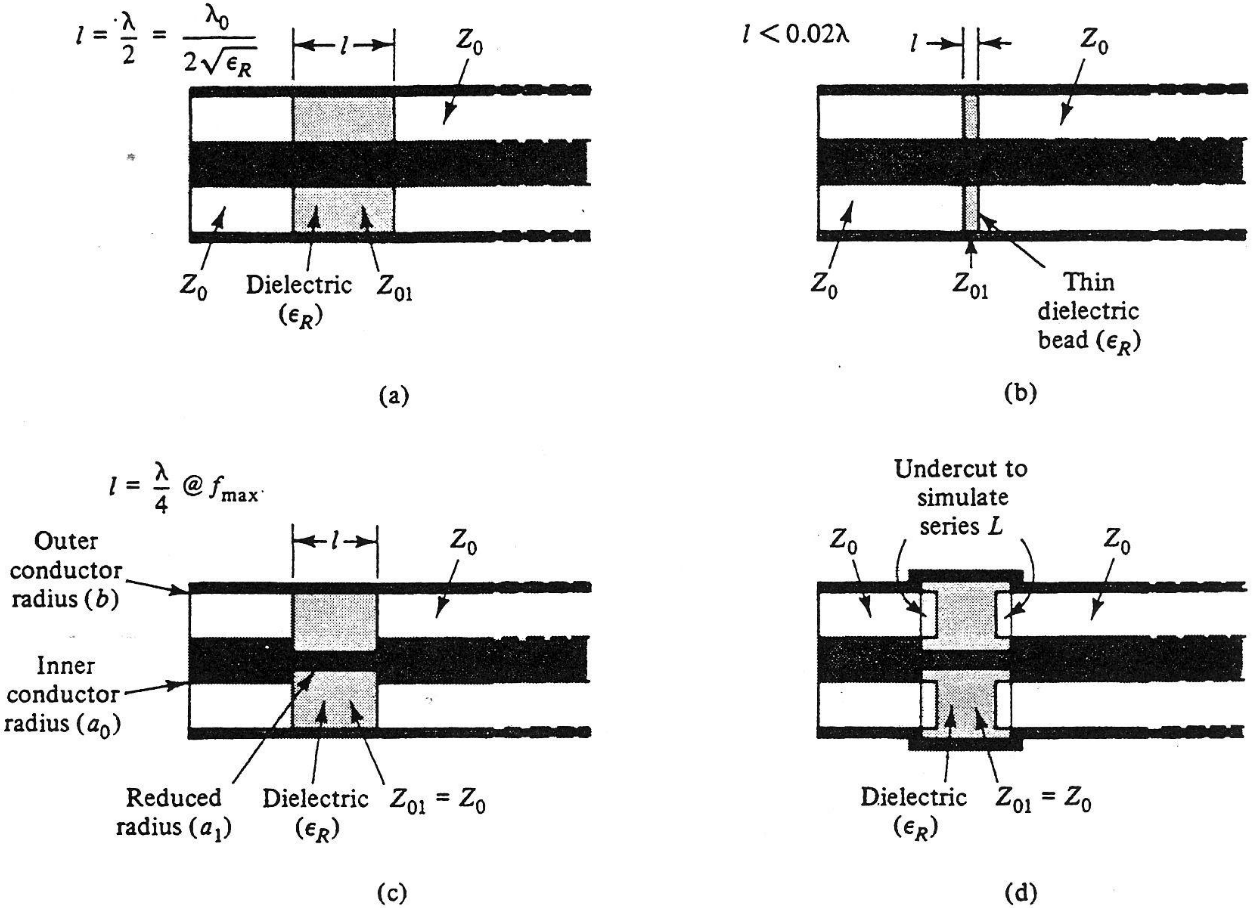


Figure 6–8 Four types of dielectric bead supports for coaxial lines.

$$Z_{01} = \frac{Z_0}{\sqrt{\varepsilon_R}}$$

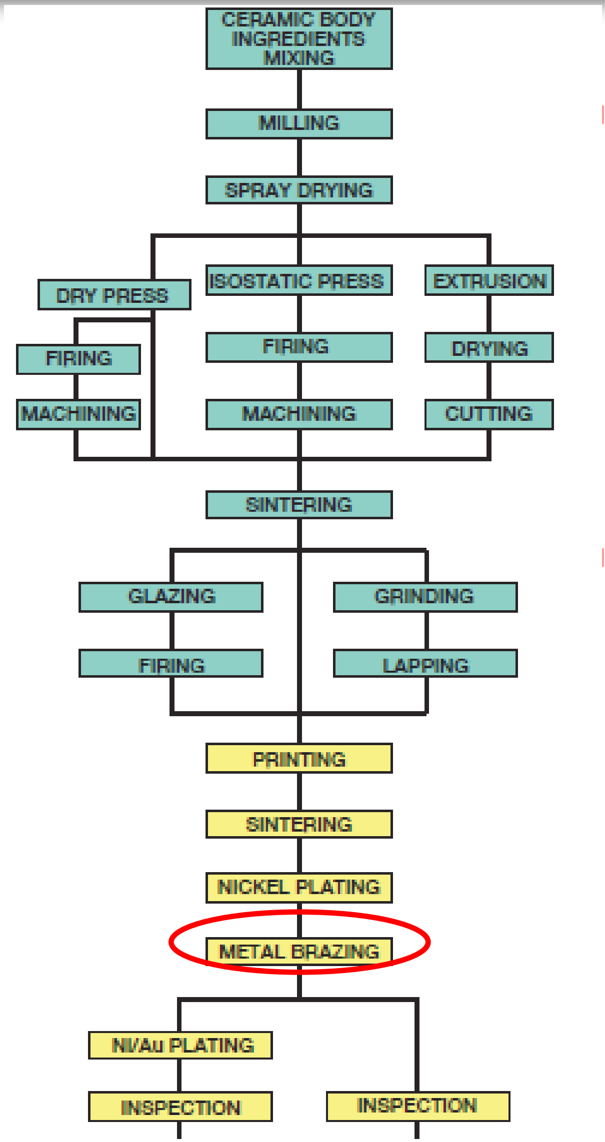
Feedthrough for vacuum

- **Vacuum seal (and support for inner conductor)**
  - Alumina ceramic (ε_R~10), Si_3N_4(~8)
  - Glass (ε_R~4–5)
    - Much larger than the support used in the air (~2)
- **Need to stand mechanical stress coming from**
  - Vacuum pressure
  - (huge) pressure when connecting the cable (or attenuator) to the feedthrough
  - Thermal stress
    - Baking
    - Heating by the beam power
- **Need to keep good RF contact under severe condition**
  - Heat cycle
  - Radiation, active gas

Outer/inner conductor

- **Kovar (Nickel-cobalt ferrous alloy)**
    - Trademark of Carpenter Technology Corporation
  - Designed to be compatible with the thermal expansion characteristics of borosilicate glass
  - Ferromagnetics: Not so good for use near strong magnet.
  - Thermal conductivity : Low
- **Ti**
  - Non-magnetic material
- **Cu, Al, Stainless steel..**
  - Also be usable. Consult your ceramic company.

Feedthrough process



Brazing temperature

- ~800 degC
- After brazing process, metal parts will be well annealed – original characteristics might be changed.
  - No spring action at all!

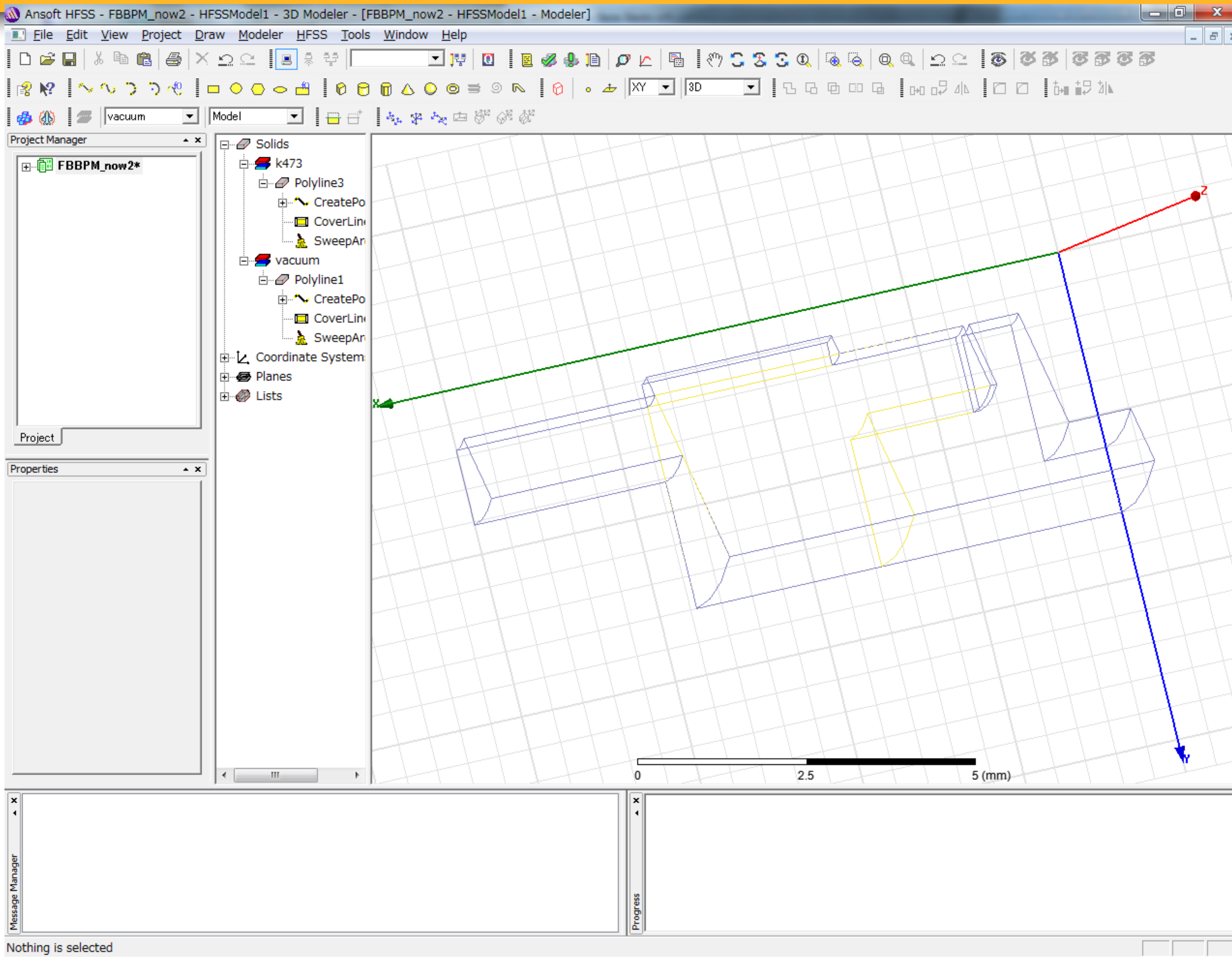
Braze to vacuum chamber OK?

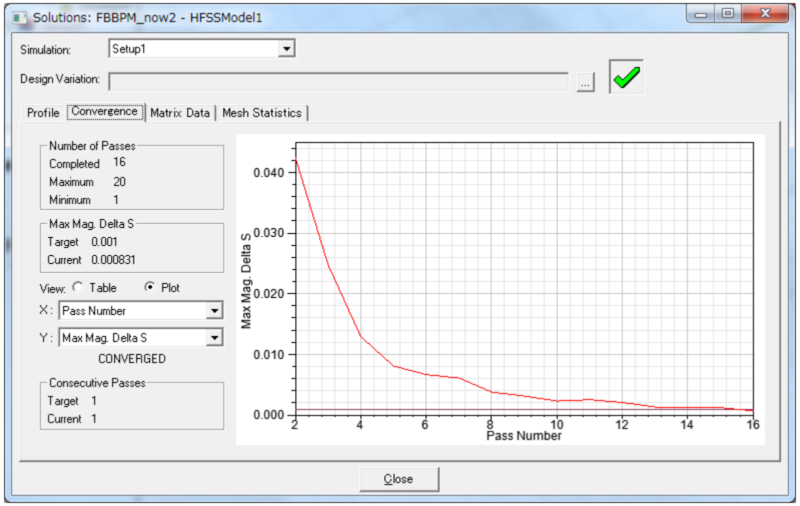
- Second (third?) brazing process
- There exist brazing materials with lower temperature
  - Not so easy to control the temperature

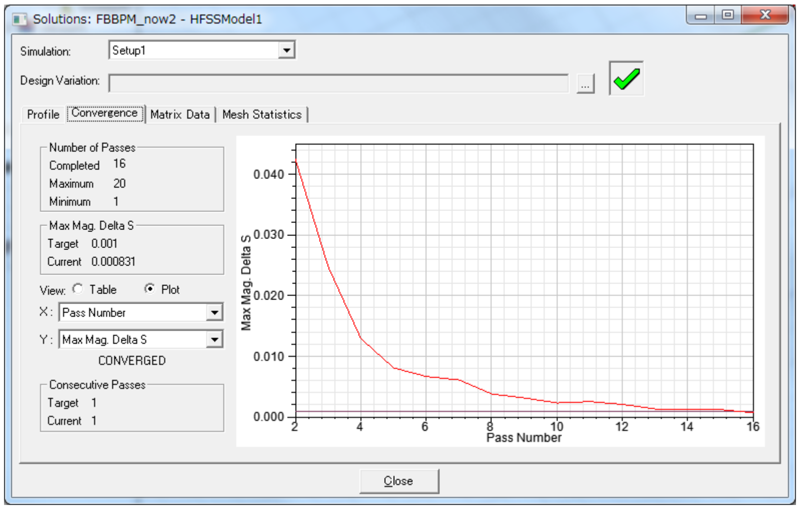
Frequency domain design

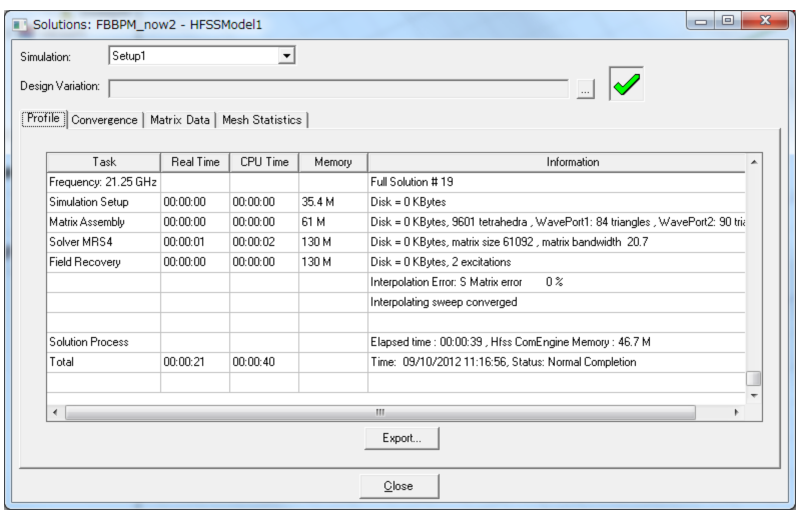
- **ANSYS (Ansoft) HFSS**
  - 3D full-wave electromagnetic field simulator
  - Multiple state-of the-art solver (finite element method or integral equation method)
  - calculate S-parameters, field patterns, eigen values, impedances..
  - Good user interface, Good interface to other tools such as ANSYS, etc.
  - Automatic mesh handing
  - (Very) Fast simulation speed

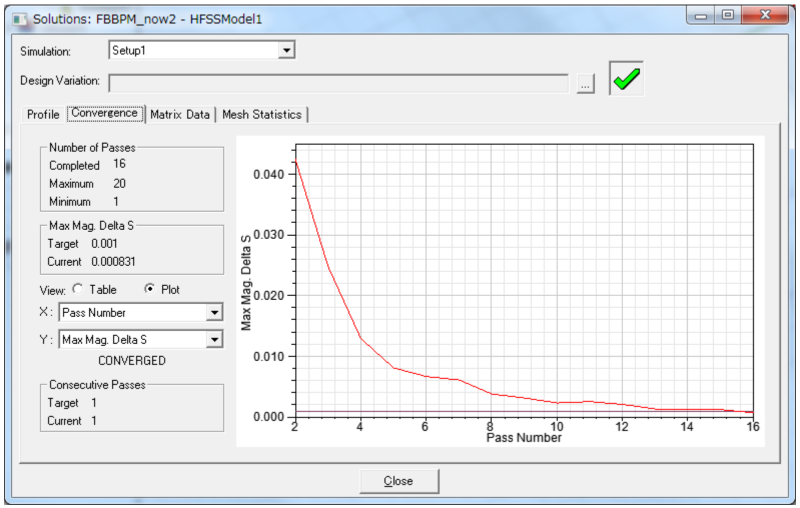
Example

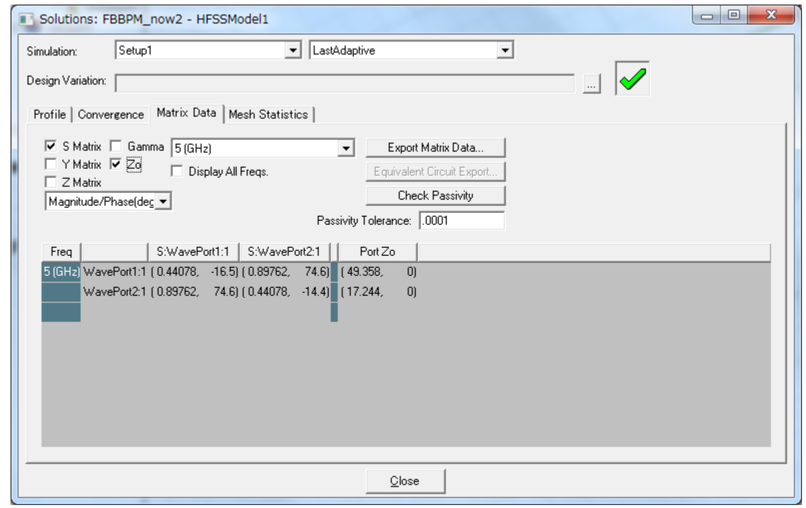

Ansoft HFSS - FBBPM_now2 - HFSSModel1 - 3D Modeler - [FBBPM_now2 - HFSSModel1 - Modeler]
File Edit View Project Draw Modeler HFSS Tools Window Help
vacuum
Model
XY
3D
Project Manager
FBBPM_now2*
Project
Properties
Solids
k473
Polyline3
CreatePo
CoverLin
SweepAr
vacuum
Polyline1
CreatePo
CoverLin
SweepAr
Coordinate System
Planes
Lists
0
2.5
5 (mm)
Message Manager
Progress
Nothing is selected

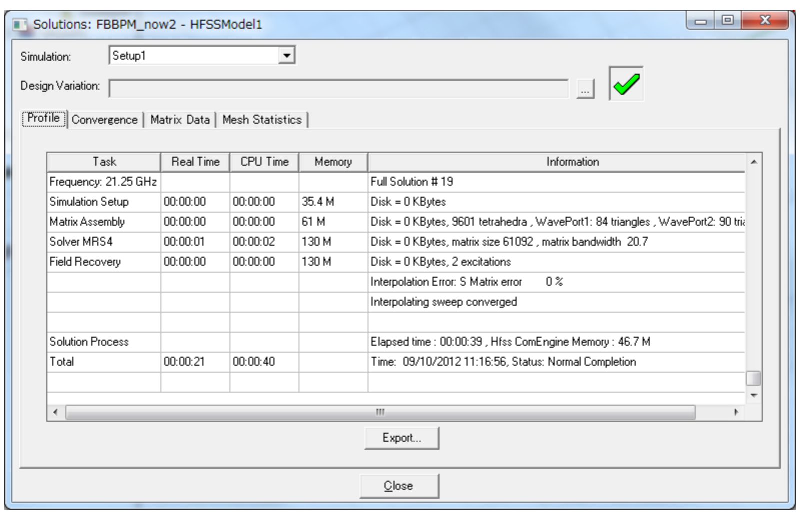

Solutions: FBBPM_now2 - HFSSModel1
Simulation:
Setup1
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
Number of Passes
Completed 16
Maximum 20
Minimum 1
Max Mag. Delta S
Target 0.001
Current 0.000831
View: Table Plot
X: Pass Number
Y: Max Mag. Delta S
CONVERGED
Consecutive Passes
Target 1
Current 1
Max Mag. Delta S
Pass Number
Close


Solutions: FBBPM_now2 - HFSSModel1
Simulation: Setup1
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
Number of Passes
Completed 16
Maximum 20
Minimum 1
Max Mag. Delta S
Target 0.001
Current 0.000831
View: Table Plot
X: Pass Number
Y: Max Mag. Delta S
CONVERGED
Consecutive Passes
Target 1
Current 1
Max Mag. Delta S
0.040
0.030
0.020
0.010
0.000
2
4
6
8
10
12
14
16
Pass Number
Close

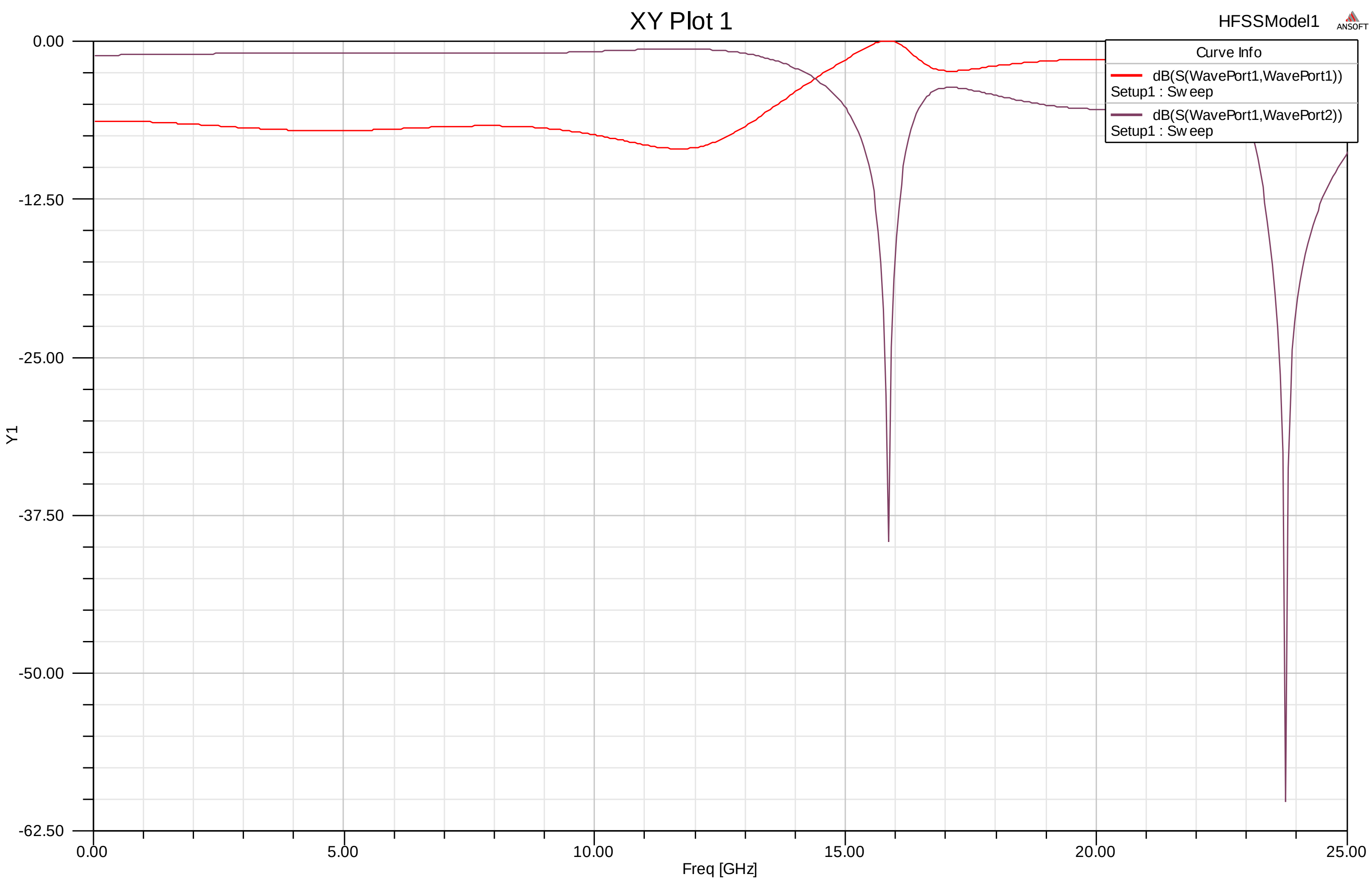

Solutions: FBBPM_now2 - HFSSModel1
Simulation: Setup1
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
Task
Real Time
CPU Time
Memory
Information
Frequency: 21.25 GHz
Full Solution # 19
Simulation Setup 00:00:00 00:00:00 35.4 M Disk = 0 KBytes
Matrix Assembly 00:00:00 00:00:00 61 M Disk = 0 KBytes, 9601 tetrahedra , WavePort1: 84 triangles , WavePort2: 90 tri
Solver MRS4 00:00:01 00:00:02 130 M Disk = 0 KBytes, matrix size 61092 , matrix bandwidth 20.7
Field Recovery 00:00:00 00:00:00 130 M Disk = 0 KBytes, 2 excitations
Interpolation Error: S Matrix error 0 %
Interpolating sweep converged
Solution Process
Elapsed time : 00:00:39 , Hfss ComEngine Memory : 46.7 M
Total 00:00:21 00:00:40
Time: 09/10/2012 11:16:56, Status: Normal Completion
Export...
Close


Solutions: FBBPM_now2 - HFSSModel1
Simulation: Setup1
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
Number of Passes
Completed 16
Maximum 20
Minimum 1
Max Mag. Delta S
Target 0.001
Current 0.000831
View: Table Plot
X: Pass Number
Y: Max Mag. Delta S
CONVERGED
Consecutive Passes
Target 1
Current 1
Max Mag. Delta S
0.040
0.030
0.020
0.010
0.000
2
4
6
8
10
12
14
16
Pass Number
Close

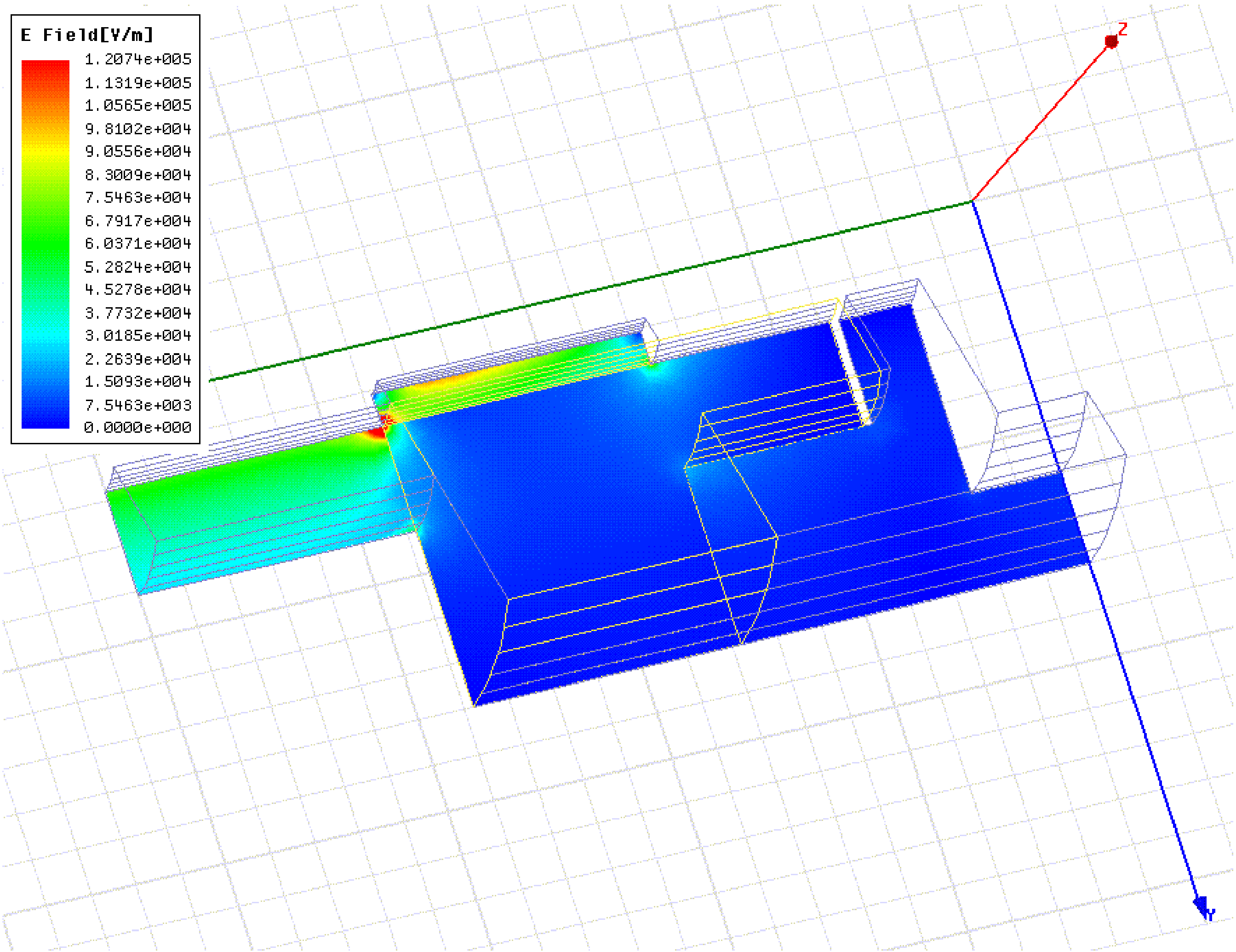

Solutions: FBBPM_now2 - HFSSModel1
Simulation: Setup1
LastAdaptive
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
S Matrix
Gamma
5 (GHz)
Export Matrix Data...
Y Matrix
Zo
Display All Freqs.
Equivalent Circuit Export...
Z Matrix
Magnitude/Phase(deg
Check Passivity
Passivity Tolerance: .0001
Freq
S:WavePort1:1
S:WavePort2:1
Port Zo
5 (GHz) WavePort1:1 (0.44078, -16.5) (0.89762, 74.6) (49.358, 0)
WavePort2:1 (0.89762, 74.6) (0.44078, -14.4) (17.244, 0)
Close


Solutions: FBBPM_now2 - HFSSModel1
Simulation: Setup1
Design Variation:
Profile
Convergence
Matrix Data
Mesh Statistics
Task
Real Time
CPU Time
Memory
Information
Frequency: 21.25 GHz Full Solution # 19
Simulation Setup 00:00:00 00:00:00 35.4 M Disk = 0 KBytes
Matrix Assembly 00:00:00 00:00:00 61 M Disk = 0 KBytes, 9601 tetrahedra , WavePort1: 84 triangles , WavePort2: 90 tri
Solver MRS4 00:00:01 00:00:02 130 M Disk = 0 KBytes, matrix size 61092 , matrix bandwidth 20.7
Field Recovery 00:00:00 00:00:00 130 M Disk = 0 KBytes, 2 excitations
Interpolation Error: S Matrix error 0 %
Interpolating sweep converged
Solution Process Elapsed time : 00:00:39 , Hfss ComEngine Memory : 46.7 M
Total 00:00:21 00:00:40 Time: 09/10/2012 11:16:56, Status: Normal Completion
Export...
Close

(Fast) Frequency sweep



E-Field pattern



Time domain simulation

- **GdfidL Electromagnetic Field simulator**
  - Time dependent Fields in loss-free or lossy structure
  - Fields may be excited by port mode or relativistic line charge
  - Resonant fields in loss-free or lossy structure
- **Calculated result**
  - S-parameters, including power (voltage) value
  - Wake potentials including loss factor, impedance etc.
  - Q values and Shunt impedance
- **Need (some)large-scale parallel computing resources**
  - KEKB: 256 cores, 512GB Linux cluster
  - Text-base user interface, longer simulation time

Example of GdfidL input(1)

```
define(EL,1) define(MAG,2)
define(INF, 1000)

define(PipeRadius, 25.40e-3/2)
define(PipeStart, 100.0e-3)
define(PipeEnd,100.0e-3)
define(BpmAdd,13.5e-3)
define(STPSZE,0.1e-3)

-general
   outfile= /users/tobiyama/GD/bpm-CL22/temp/
   scratchbase =/users/tobiyama/GD/scratch/
-material
 material=10
 type=electric
 material=15
 type=normal, epsr=9.7, muer=1, kappa=0, mkappa=0
```

```
-mesh
  spacing=0.1e-3
  pxlow= 0
  pxhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pylow= 0
  pyhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pzlow=-PipeStart+5*STPSZE
  pzhigh=PipeEnd-5*STPSZE

  cxlow=magnetic, cxhigh=electric
  cylow=magnetic, cyhigh=electric
  czlow=electric, czhigh=electric

-brick
 material=EL
 xlow= -INF, xhigh=INF
 ylow= -INF, yhigh=INF
 zlow= -INF, zhigh=INF
 doit
```

Example of GdfidL input(1)

```
define(EL,1) define(MAG,2)
define(INF, 1000)

define(PipeRadius, 25.40e-3/2)
define(PipeStart, 100.0e-3)
define(PipeEnd,100.0e-3)
define(BpmAdd,13.5e-3)
define(STPSZE,0.1e-3)

-general
   outfile= /users/tobiyama/GD/bpm-CL22/temp/
   scratchbase =/users/tobiyama/GD/scratch/
-material
 material=10
 type=electric
 material=15
 type=normal, epsr=9.7, muer=1, kappa=0, mkappa=0
```

```
-mesh
  spacing=0.1e-3
  pxlow= 0
  pxhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pylow= 0
  pyhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pzlow=-PipeStart+5*STPSZE
  pzhigh=PipeEnd-5*STPSZE

  cxlow=magnetic, cxhigh=electric
  cylow=magnetic, cyhigh=electric
  czlow=electric, czhigh=electric

-brick
 material=EL
 xlow= -INF, xhigh=INF
 ylow= -INF, yhigh=INF
 zlow= -INF, zhigh=INF
 doit
```

Example of GdfidL input(1)

```
define(EL,1) define(MAG,2)
define(INF, 1000)

define(PipeRadius, 25.40e-3/2)
define(PipeStart, 100.0e-3)
define(PipeEnd,100.0e-3)
define(BpmAdd,13.5e-3)
define(STPSZE,0.1e-3)

-general
   outfile= /users/tobiyama/GD/bpm-CL22/temp/
   scratchbase =/users/tobiyama/GD/scratch/
-material
 material=10
 type=electric
 material=15
 type=normal, epsr=9.7, muer=1, kappa=0, mkappa=0
```

```
-mesh
  spacing=0.1e-3
  pxlow= 0
  pxhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pylow= 0
  pyhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pzlow=-PipeStart+5*STPSZE
  pzhigh=PipeEnd-5*STPSZE

  cxlow=magnetic, cxhigh=electric
  cylow=magnetic, cyhigh=electric
  czlow=electric, czhigh=electric

-brick
 material=EL
 xlow= -INF, xhigh=INF
 ylow= -INF, yhigh=INF
 zlow= -INF, zhigh=INF
 doit
```

Example of GdfidL input(1)

```
define(EL,1) define(MAG,2)
define(INF, 1000)

define(PipeRadius, 25.40e-3/2)
define(PipeStart, 100.0e-3)
define(PipeEnd,100.0e-3)
define(BpmAdd,13.5e-3)
define(STPSZE,0.1e-3)

-general
   outfile= /users/tobiyama/GD/bpm-CL22/temp/
   scratchbase =/users/tobiyama/GD/scratch/
-material
 material=10
 type=electric
 material=15
 type=normal, epsr=9.7, muer=1, kappa=0, mkappa=0
```

```
-mesh
  spacing=0.1e-3
  pxlow= 0
  pxhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pylow= 0
  pyhigh=(PipeRadius+BpmAdd-5*STPSZE)
  pzlow=-PipeStart+5*STPSZE
  pzhigh=PipeEnd-5*STPSZE

  cxlow=magnetic, cxhigh=electric
  cylow=magnetic, cyhigh=electric
  czlow=electric, czhigh=electric

-brick
 material=EL
 xlow= -INF, xhigh=INF
 ylow= -INF, yhigh=INF
 zlow= -INF, zhigh=INF
 doit
```

Example of GdfidL input(2)

```
#
# cave beam pipe
#
-gbor
  material=0
  origin=(0,0,0)
  zprimedirection= (0,0,1)
  rprimedirection= (1,0,0)
  range= (0,360)

  clear

  point(-PipeStart,0)
  point(-PipeStart,PipeRadius)
  point(PipeEnd,PipeRadius)
  point(PipeEnd,0)
  point(-PipeStart,0)
  show=all
  doit
```

```
#
# bpm block
#
macro BpmBlock
define(Dist, @arg1)
define(Angle, (@arg2)*@pi/180)

define(BpmDiskRadius, 6e-3/2)
define(BpmRodRadius,1.8e-3/2)
define(BpmairRadius,1.1e-3/2)
define(BpmOutRadius1, 8e-3/2)
define(BpmOutRadius2, 4.1e-3/2)
define(BpmCera1Radius,4.1e-3/2)
define(BpmCera2Radius,8e-3/2)
define(BpmDiskLength,1e-3)
define(BpmRod1Length,2.9e-3)
define(BpmRod2Length,3e-3)
define(BpmRod3Length,6.1e-3)

define(Cerastart,1.9e-3)
define(Cera1Length,2e-3)
define(Cera2Length,3e-3)

define(DP1, (5e-
3+BpmDiskLength+BpmRod1Length+BpmRod2Length))
define(DP2, (DP1+Dist - 5e-3))
```

Example of GdfidL input(2)

```
#
# cave beam pipe
#
-gbor
  material=0
  origin=(0,0,0)
  zprimedirection= (0,0,1)
  rprimedirection= (1,0,0)
  range= (0,360)

  clear

  point(-PipeStart,0)
  point(-PipeStart,PipeRadius)
  point(PipeEnd,PipeRadius)
  point(PipeEnd,0)
  point(-PipeStart,0)
  show=all
  doit
```

```
#
# bpm block
#
macro BpmBlock
define(Dist, @arg1)
define(Angle, (@arg2)*@pi/180)

define(BpmDiskRadius, 6e-3/2)
define(BpmRodRadius,1.8e-3/2)
define(BpmairRadius,1.1e-3/2)
define(BpmOutRadius1, 8e-3/2)
define(BpmOutRadius2, 4.1e-3/2)
define(BpmCera1Radius,4.1e-3/2)
define(BpmCera2Radius,8e-3/2)
define(BpmDiskLength,1e-3)
define(BpmRod1Length,2.9e-3)
define(BpmRod2Length,3e-3)
define(BpmRod3Length,6.1e-3)

define(Cerastart,1.9e-3)
define(Cera1Length,2e-3)
define(Cera2Length,3e-3)

define(DP1, (5e-
3+BpmDiskLength+BpmRod1Length+BpmRod2Length))
define(DP2, (DP1+Dist - 5e-3))
```

Example of GdfidL input(2)

```
#
# cave beam pipe
#
-gbor
  material=0
  origin=(0,0,0)
  zprimedirection= (0,0,1)
  rprimedirection= (1,0,0)
  range= (0,360)

  clear

  point(-PipeStart,0)
  point(-PipeStart,PipeRadius)
  point(PipeEnd,PipeRadius)
  point(PipeEnd,0)
  point(-PipeStart,0)
  show=all
  doit
```

```
#
# bpm block
#
macro BpmBlock
define(Dist, @arg1)
define(Angle, (@arg2)*@pi/180)

define(BpmDiskRadius, 6e-3/2)
define(BpmRodRadius,1.8e-3/2)
define(BpmairRadius,1.1e-3/2)
define(BpmOutRadius1, 8e-3/2)
define(BpmOutRadius2, 4.1e-3/2)
define(BpmCera1Radius,4.1e-3/2)
define(BpmCera2Radius,8e-3/2)
define(BpmDiskLength,1e-3)
define(BpmRod1Length,2.9e-3)
define(BpmRod2Length,3e-3)
define(BpmRod3Length,6.1e-3)

define(Cerastart,1.9e-3)
define(Cera1Length,2e-3)
define(Cera2Length,3e-3)

define(DP1, (5e-
3+BpmDiskLength+BpmRod1Length+BpmRod2Length))
define(DP2, (DP1+Dist - 5e-3))
```

Example of GdfidL input(3)

```
#
-gccylinder
 material=0, radius=BpmOutRadius1,length = DP1
 origin=(cos(Angle)*(Dist - 5e-3), sin(Angle)*(Dist - 5e-3),  0)
 direction=(cos(Angle),sin(Angle),0)
 doit
-gccylinder
 material=0, radius=BpmOutRadius2
 length= BpmRod3Length
 origin=(cos(Angle)*(DP2),sin(Angle)*(DP2),  0)
 direction=(cos(Angle),sin(Angle),0)
 doit
#
# ceramic
#
-gccylinder
 material=15, radius=BpmCera1Radius,length=Cera1Length
 origin=(cos(Angle)*(Dist+Cerastart), sin(Angle)*(Dist+Cerastart),  0)
 direction=(cos(Angle),sin(Angle),0)
 doit
-gccylinder
 material=15, radius=BpmCera2Radius,length=Cera2Length
 origin=(cos(Angle)*(Dist+Cerastart+Cera1Length),¥
        sin(Angle)*(Dist+Cerastart+Cera1Length),  0)
 direction=(cos(Angle),sin(Angle),0)
 doit
```

```
# air again
-gccylinder
 material=0, radius=BpmRodRadius,length =
(Cera1Length+Cera2Length)
 origin=(cos(Angle)*(Dist+Cerastart),sin(Angle)*(Dist-Cerastart)  0)
 direction=(cos(Angle),sin(Angle),0)
 doit
# bpm disk
-gccylinder
 material=10, radius=BpmDiskRadius,length=BpmDiskLength
 origin=(cos(Angle)*(Dist), sin(Angle)*(Dist), 0)
 direction=(cos(Angle),sin(Angle),0)
 doit
-gccylinder
 material=10, radius=BpmRodRadius, length=BpmRod1Length
 origin=(cos(Angle)*(Dist+BpmDiskLength),¥
 sin(Angle)*(Dist+BpmDiskLength),    0)
 direction=(cos(Angle),sin(Angle),0)
 doit


 ....still many definitions...

endmacro #BpmBlock
```

Example of GdfidL input(4)

```
call BpmBlock(13.2e-3,90)
call BpmBlock(13.2e-3,0)
call BpmBlock(13.2e-3,-90)
call BpmBlock(13.2e-3,180)

-fdtd
 -lcharge
    charge=1e-12
    sigma=6e-3
    xposition=0, yposition=0
    shigh=5
    showdata=no
 -ports
    name=beamlow, plane=zlow, modes=0, npml=40, doit
    name=beamhigh, plane=zhigh, modes=0, npml=40, doit
    name=bpmyp, plane=yhigh, modes=1, npml=15, doit
    name=bpmxp, plane=xhigh, modes=1, npml=15, doit

-fdtd
  doit
```

- **mesh 0.1mm**
- **bunch length 6mm**
- **beam=(0,0) [center]**
- **wake up to 5m**

Example of GdfidL input(4)

```
call BpmBlock(13.2e-3,90)
call BpmBlock(13.2e-3,0)
call BpmBlock(13.2e-3,-90)
call BpmBlock(13.2e-3,180)

-fdtd
 -lcharge
    charge=1e-12
    sigma=6e-3
    xposition=0, yposition=0
    shigh=5
    showdata=no
 -ports
    name=beamlow, plane=zlow, modes=0, npml=40, doit
    name=beamhigh, plane=zhigh, modes=0, npml=40, doit
    name=bpmyp, plane=yhigh, modes=1, npml=15, doit
    name=bpmxp, plane=xhigh, modes=1, npml=15, doit

-fdtd
  doit
```

- **mesh 0.1mm**
- **bunch length 6mm**
- **beam=(0,0) [center]**
- **wake up to 5m**

Example of GdfidL input(4)

```
call BpmBlock(13.2e-3,90)
call BpmBlock(13.2e-3,0)
call BpmBlock(13.2e-3,-90)
call BpmBlock(13.2e-3,180)

-fdtd
 -lcharge
    charge=1e-12
    sigma=6e-3
    xposition=0, yposition=0
    shigh=5
    showdata=no
 -ports
    name=beamlow, plane=zlow, modes=0, npml=40, doit
    name=beamhigh, plane=zhigh, modes=0, npml=40, doit
    name=bpmyp, plane=yhigh, modes=1, npml=15, doit
    name=bpmxp, plane=xhigh, modes=1, npml=15, doit

-fdtd
  doit
```

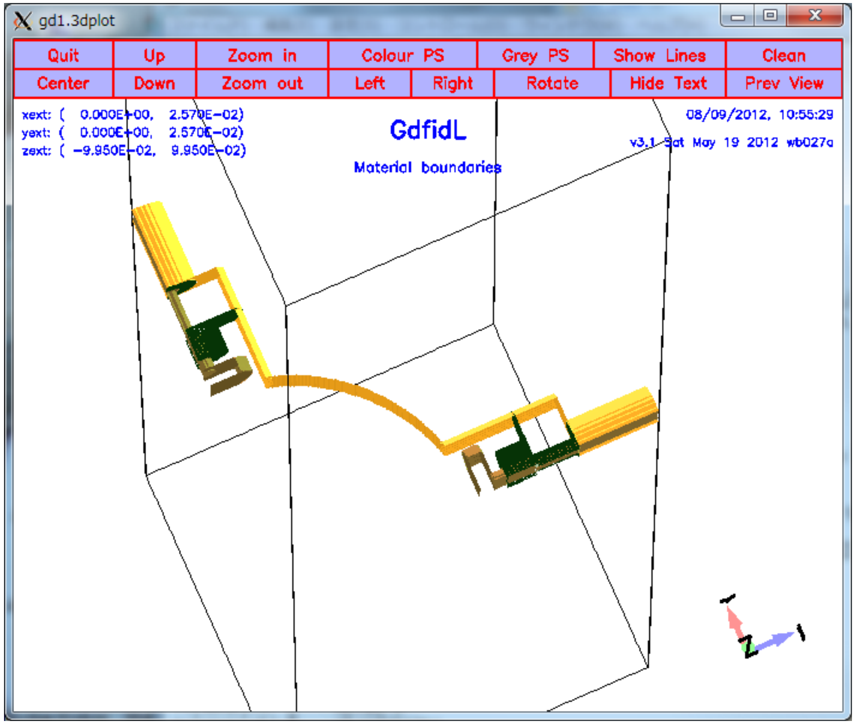
- mesh 0.1mm
- bunch length 6mm
- beam=(0,0) [center]
- wake up to 5m

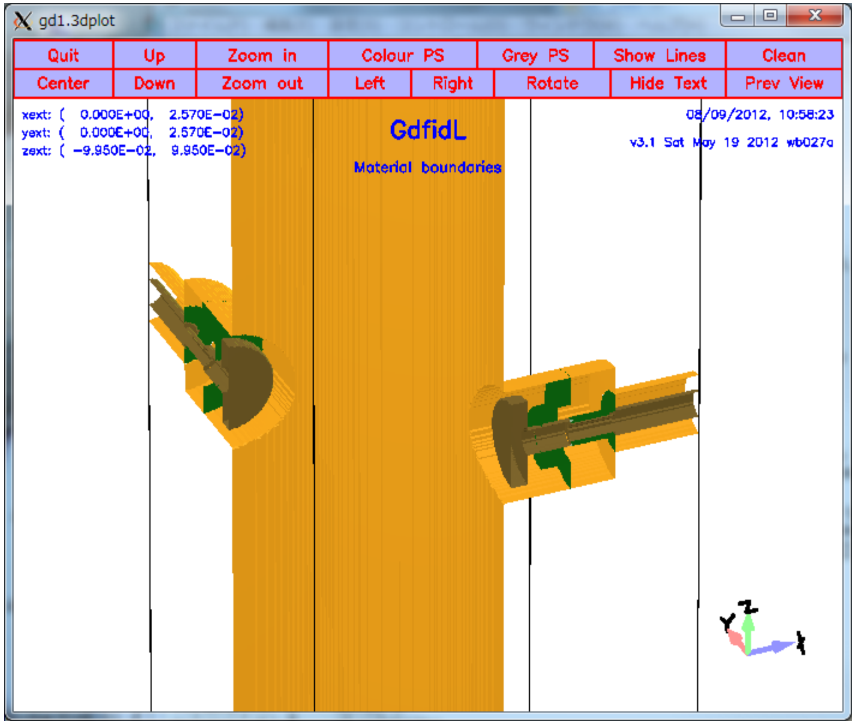
Example of GdfidL input(4)

```
call BpmBlock(13.2e-3,90)
call BpmBlock(13.2e-3,0)
call BpmBlock(13.2e-3,-90)
call BpmBlock(13.2e-3,180)

-fdtd
 -lcharge
    charge=1e-12
    sigma=6e-3
    xposition=0, yposition=0
    shigh=5
    showdata=no
 -ports
    name=beamlow, plane=zlow, modes=0, npml=40, doit
    name=beamhigh, plane=zhigh, modes=0, npml=40, doit
    name=bpmyp, plane=yhigh, modes=1, npml=15, doit
    name=bpmxp, plane=xhigh, modes=1, npml=15, doit

-fdtd
  doit
```

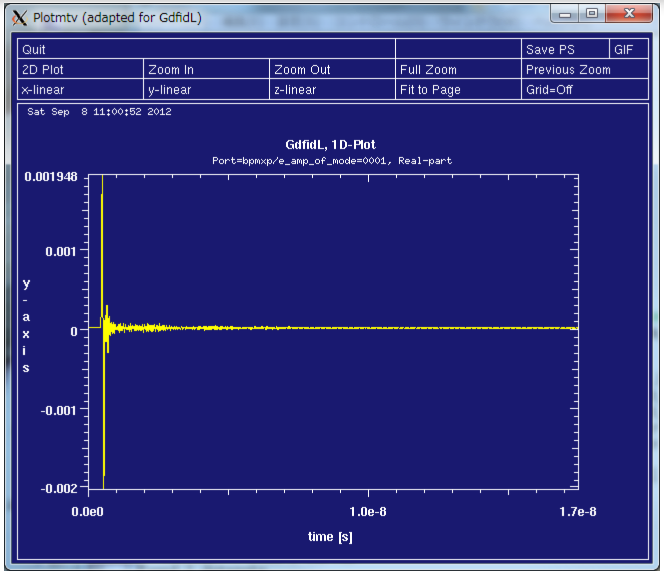
- **mesh 0.1mm**
- **bunch length 6mm**
- **beam=(0,0) [center]**
- **wake up to 5m**

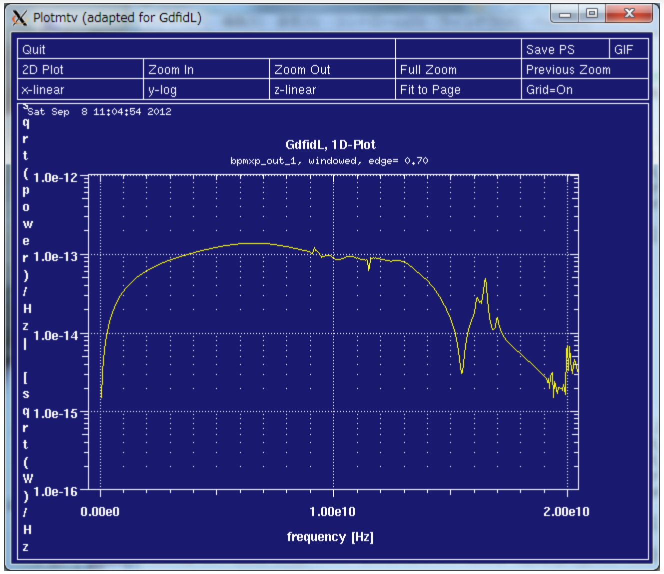
Model view

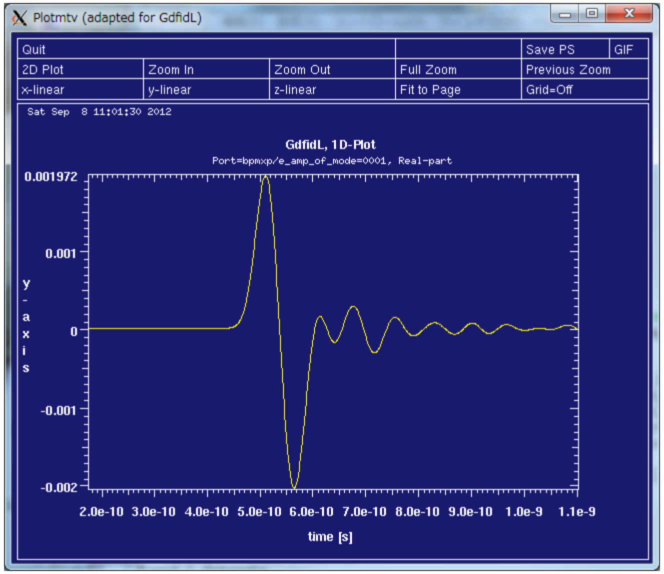

gd1.3dplot
Quit
Up
Zoom in
Colour PS
Grey PS
Show Lines
Clean
Center
Down
Zoom out
Left
Right
Rotate
Hide Text
Prev View
xext: (0.000E+00, 2.570E-02)
yext: (0.000E+00, 2.570E-02)
zext: (-9.950E-02, 9.950E-02)
GdfidL
Material boundaries
08/09/2012, 10:55:29
v3.1 Sat May 19 2012 wb027a


gd1.3dplot
Quit
Up
Zoom in
Colour PS
Grey PS
Show Lines
Clean
Center
Down
Zoom out
Left
Right
Rotate
Hide Text
Prev View
xext: (0.000E+00, 2.570E-02)
yext: (0.000E+00, 2.570E-02)
zext: (-9.950E-02, 9.950E-02)
GdfidL
Material boundaries
08/09/2012, 10:58:23
v3.1 Sat May 19 2012 wb027a

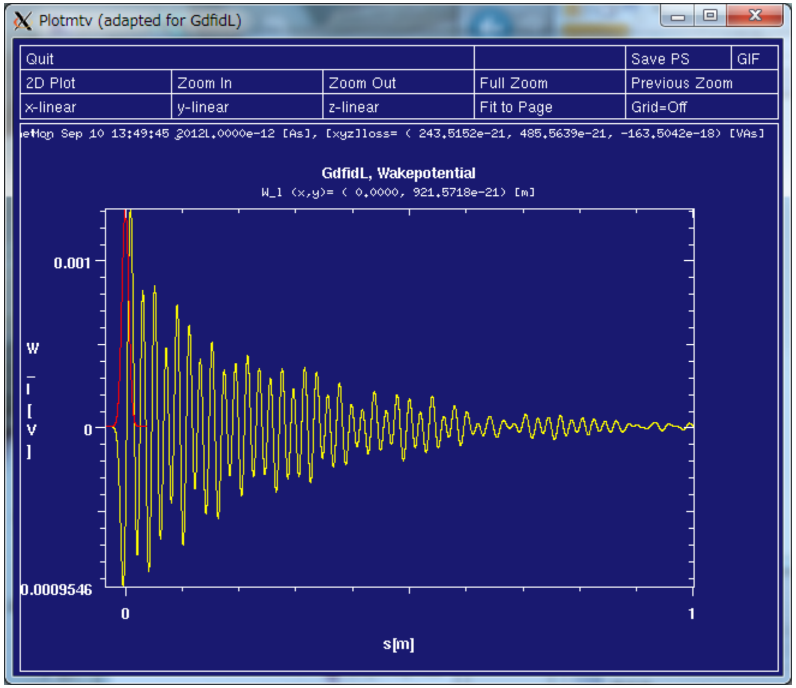
Post processing (using gd1.pp)

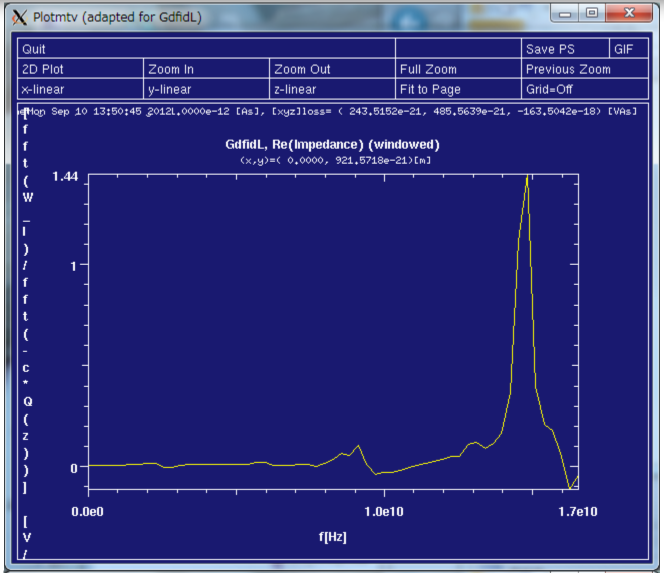


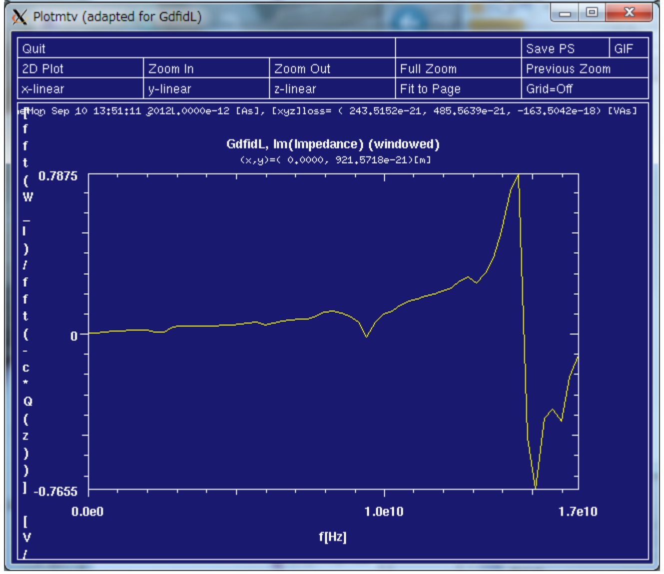




wakes, impedances

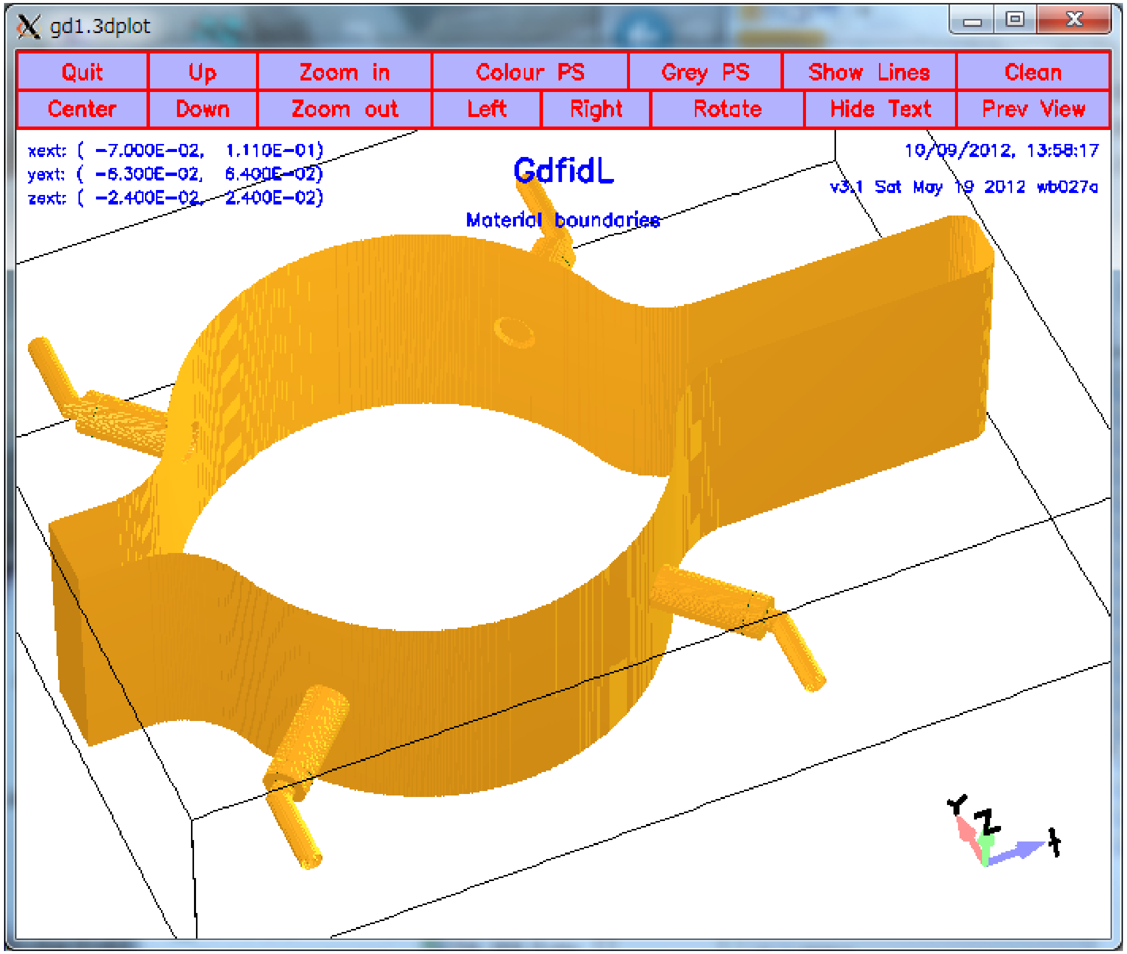




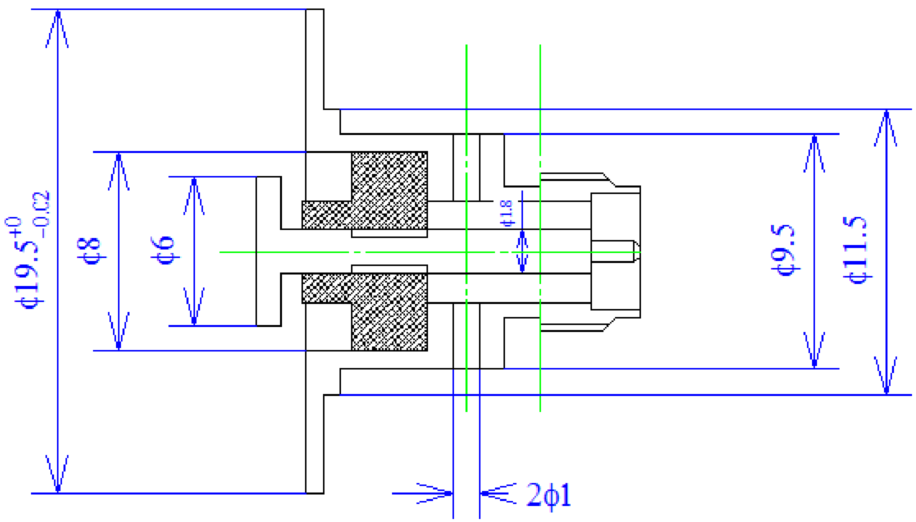


Tips

- Ports must be placed orthogonally to the boundaries.



Button electrode (KEKB-FB)



Feedback用SMAフィードスルーC型概略図

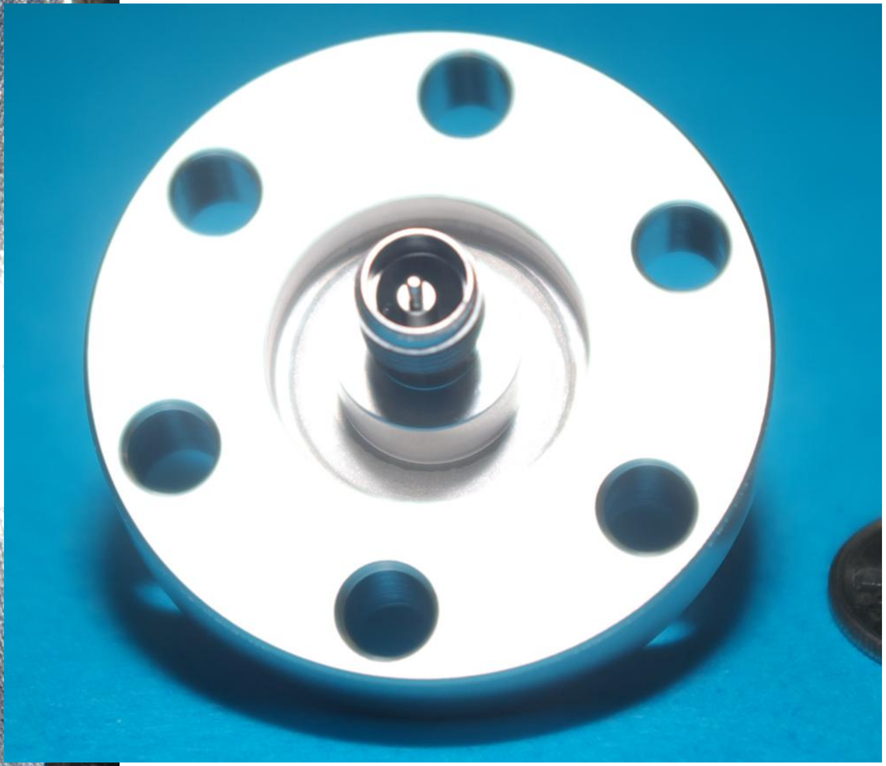
作図：飛山真理 19/Mar/2004

縮尺4:1

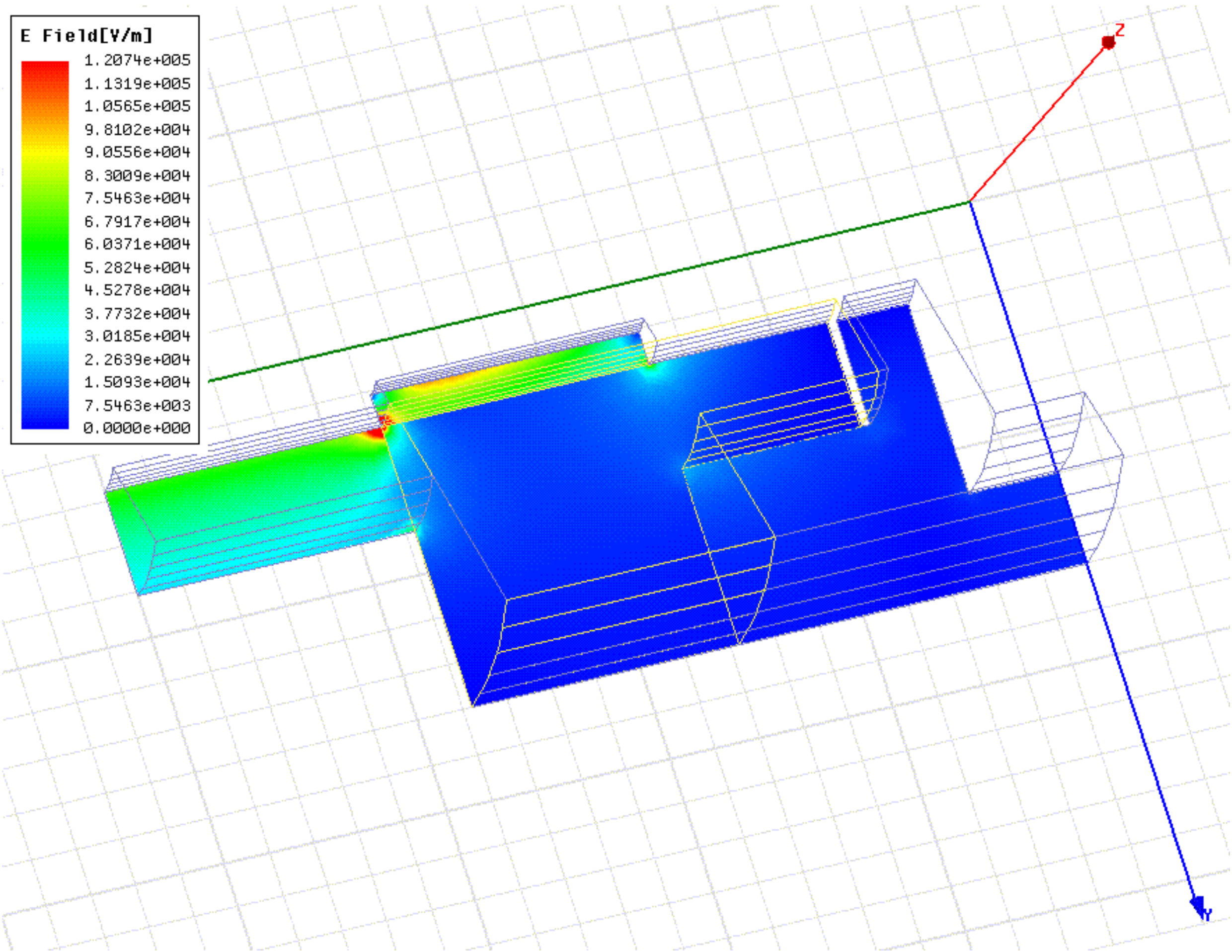
Tips

- **Using normal SMA-J connector (or N-J, too) usually encounter difficulty in RF contact at the split-pin of the center conductor due to brazing process – No spring action might be expected after the process.**
  - Using P-structure.. not easy to handle..
  - Use pin on the J-structure ("Reverse type J")
- **Gold-plating of at the RF connector is desirable**
  - Not easy to maintain the thickness of the gold during brazing process (Gold will be diffused into the bulk metal..)

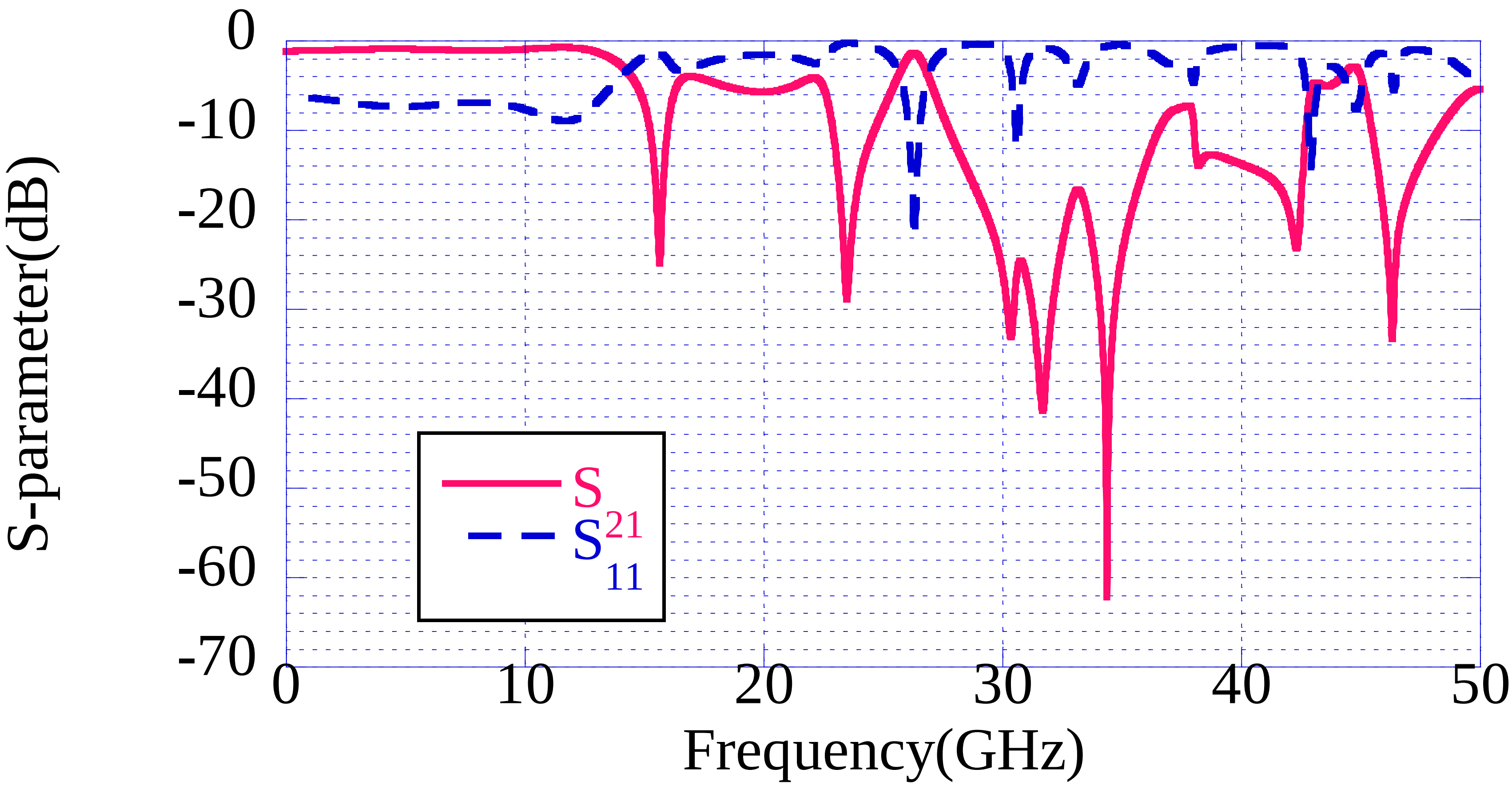
SMA-J and SMA-J(R)



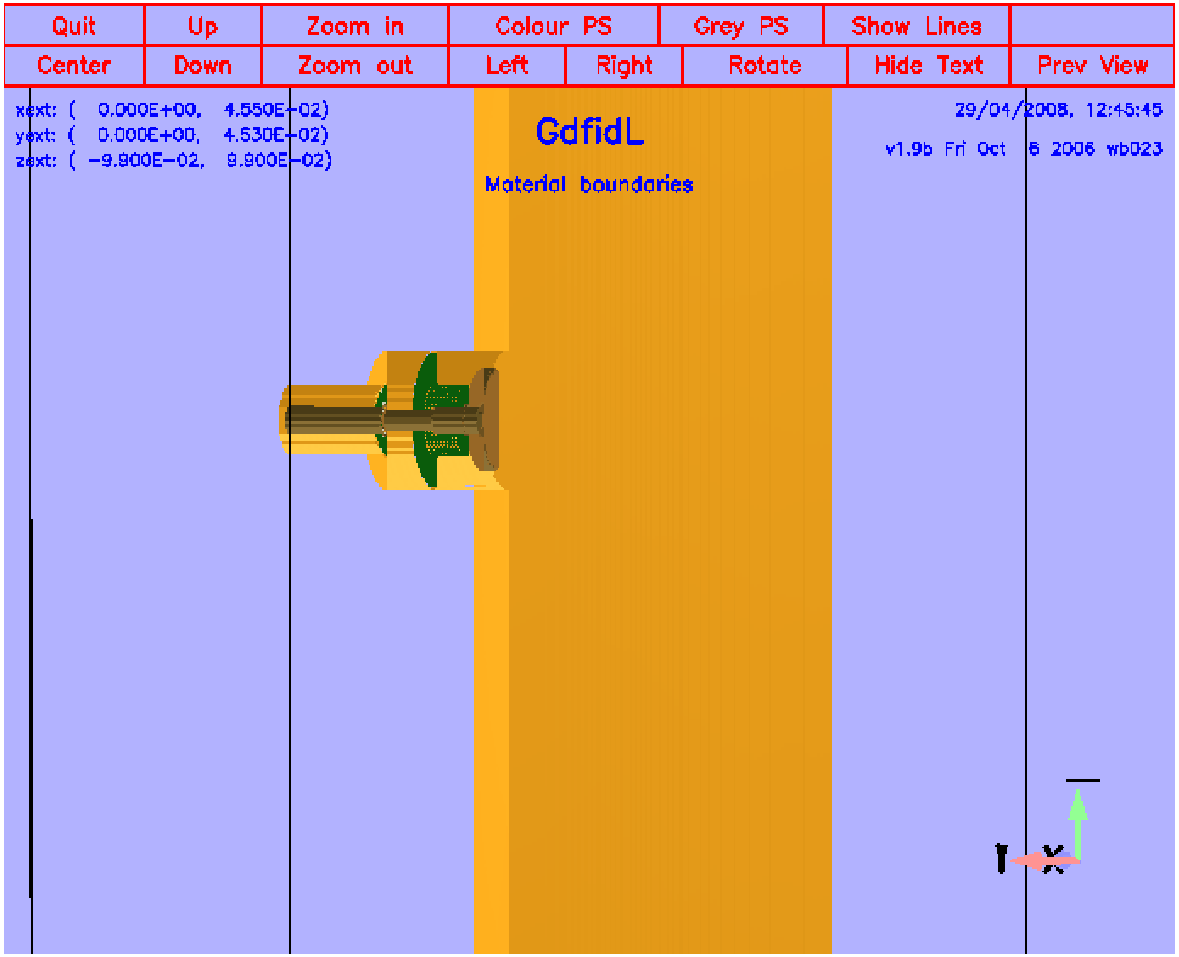
HFSS model


E Field[V/m]
1.2074e+005
1.1319e+005
1.0565e+005
9.8102e+004
9.0556e+004
8.3009e+004
7.5463e+004
6.7917e+004
6.0371e+004
5.2824e+004
4.5278e+004
3.7732e+004
3.0185e+004
2.2639e+004
1.5093e+004
7.5463e+003
0.0000e+000
Z
Y

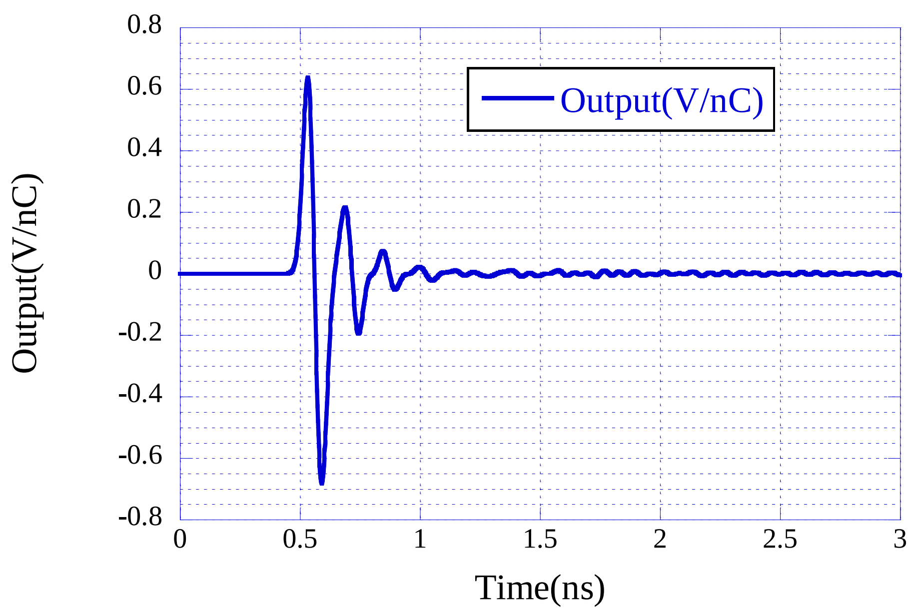
Simulated S-Parameters

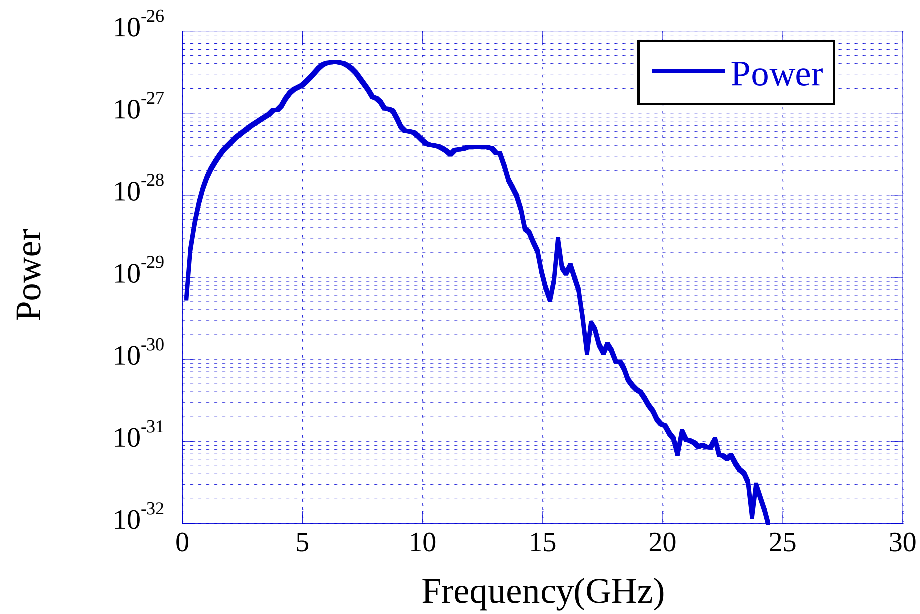


GdfidL model



Simulated Port output

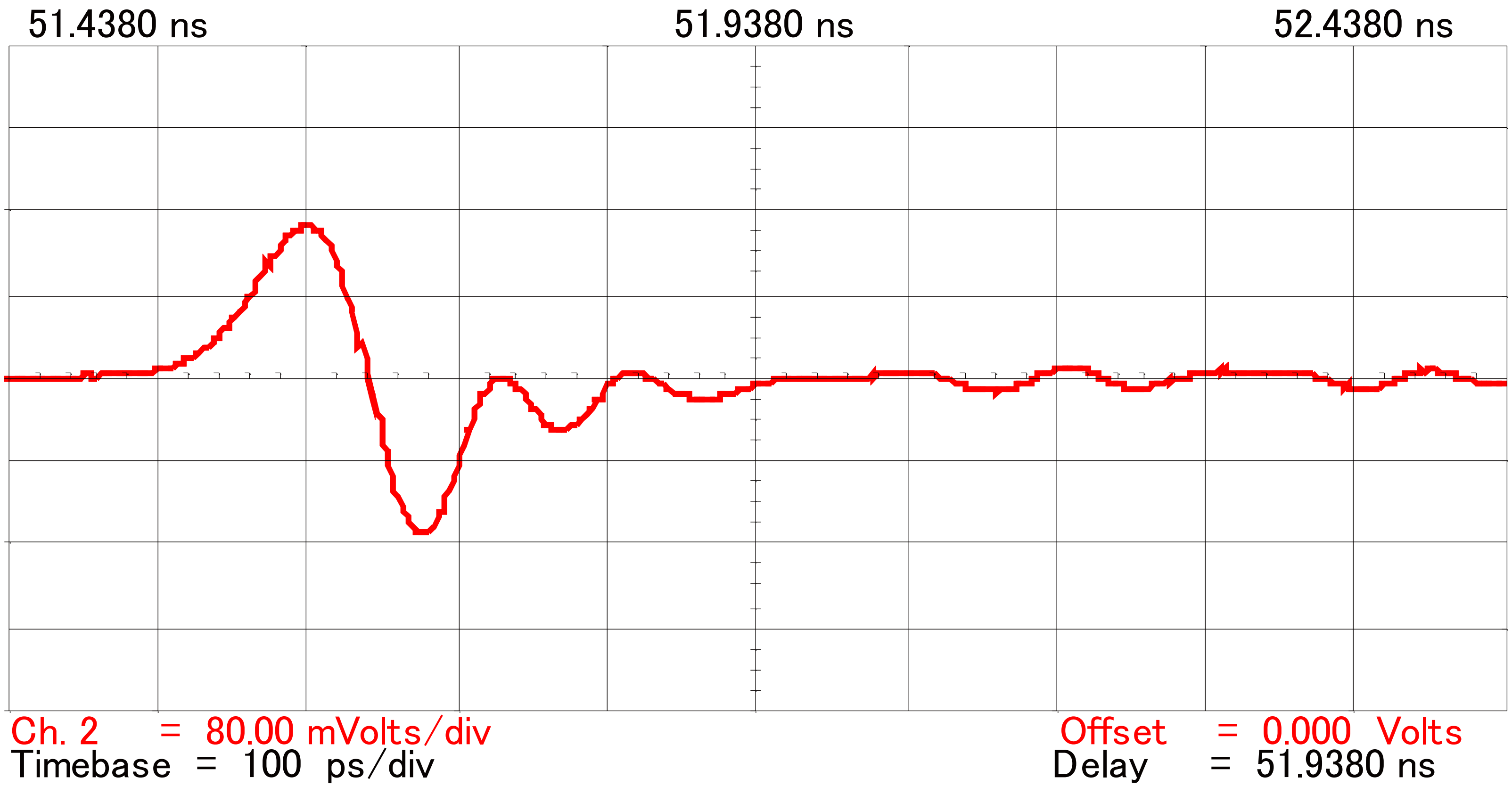




Tips

- **Need to pay attention to the possible trapped modes in the sealing structure, which may damage the seal on high beam current operation.**
  - Use Eigen-mode solver to estimate the frequency of the trapped mode.
  - Fine frequency sweep to find dip structure in S11
  - Coupling to coaxial mode might be difficult.
- **Need to pay attention to the multipactoring around the button gap, especially for high single-bunch current machine.**
- **Longitudinal beam coupling impedance might not be negligible on large circumference, high beam current machine.**

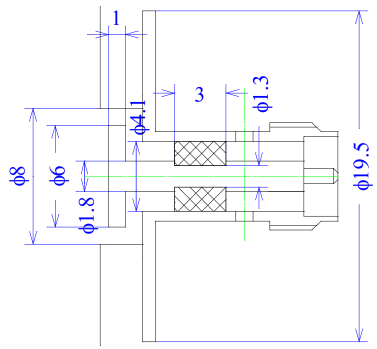
Measured signal (20GHz scope)

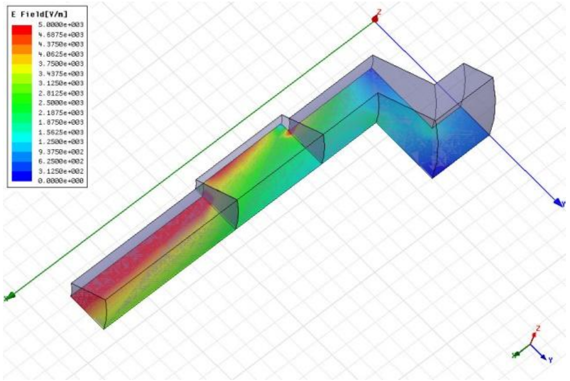


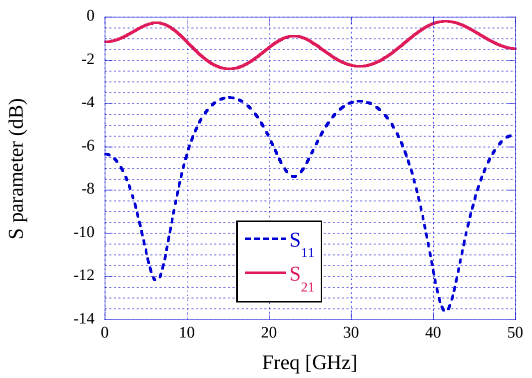
9nC/bunch LER 43dB attenuation, LER upstream

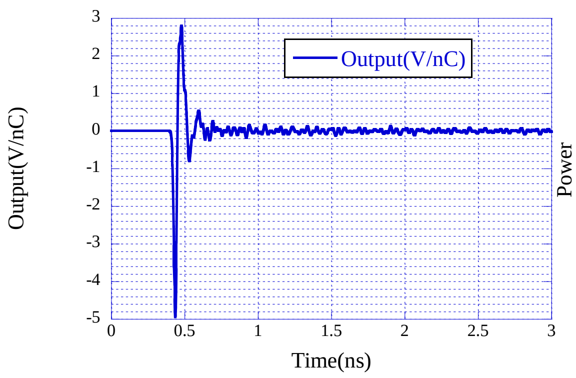
Maximum beam current at KEKB: 2A+1.3A=3.3A with large horizontal offset

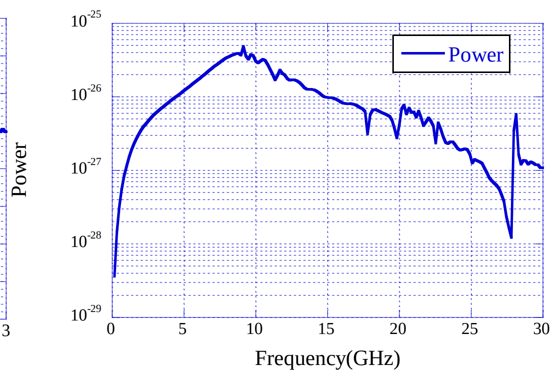
Feedthrough with low εr(~4) sealing



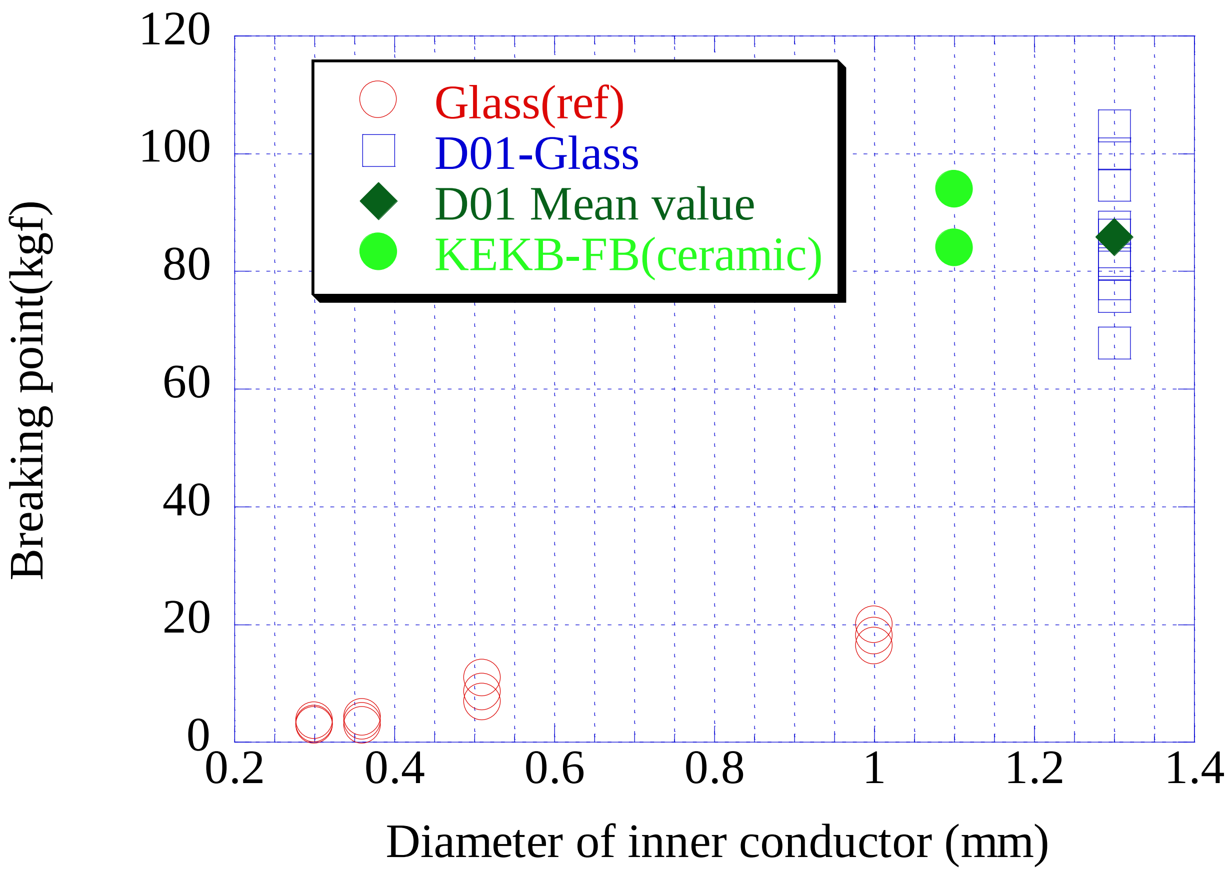




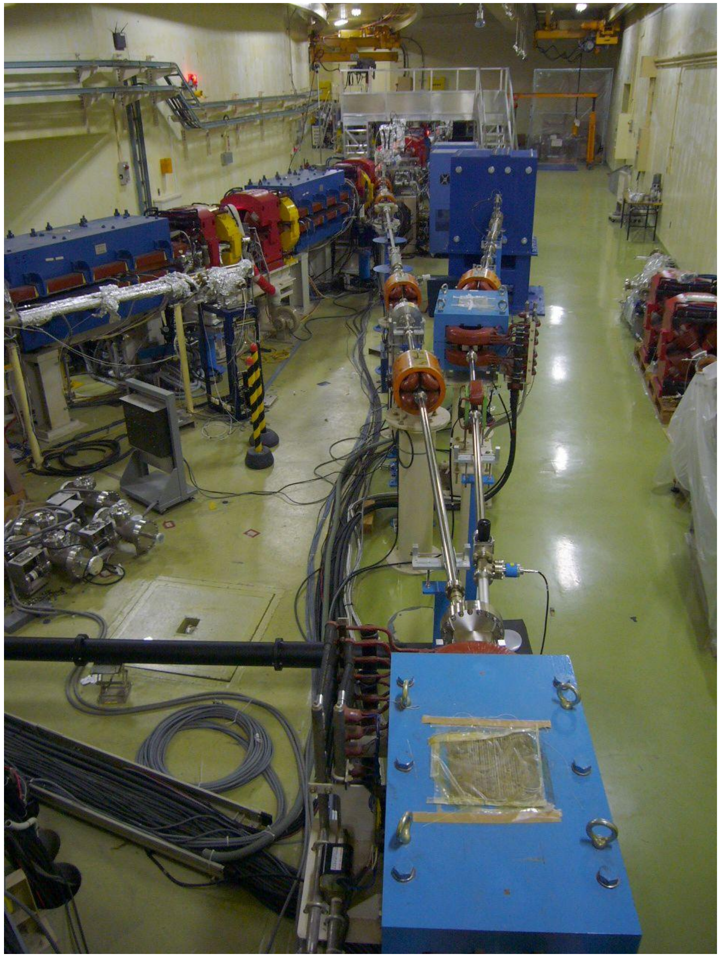


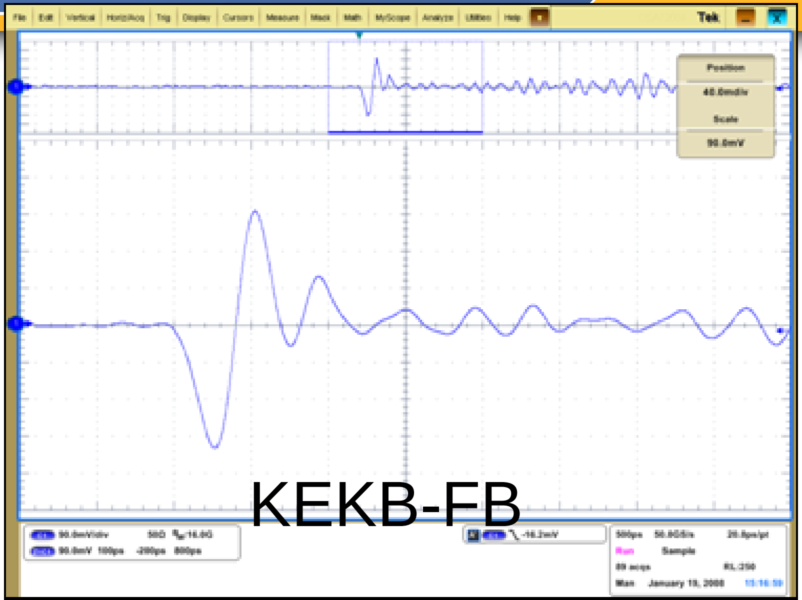


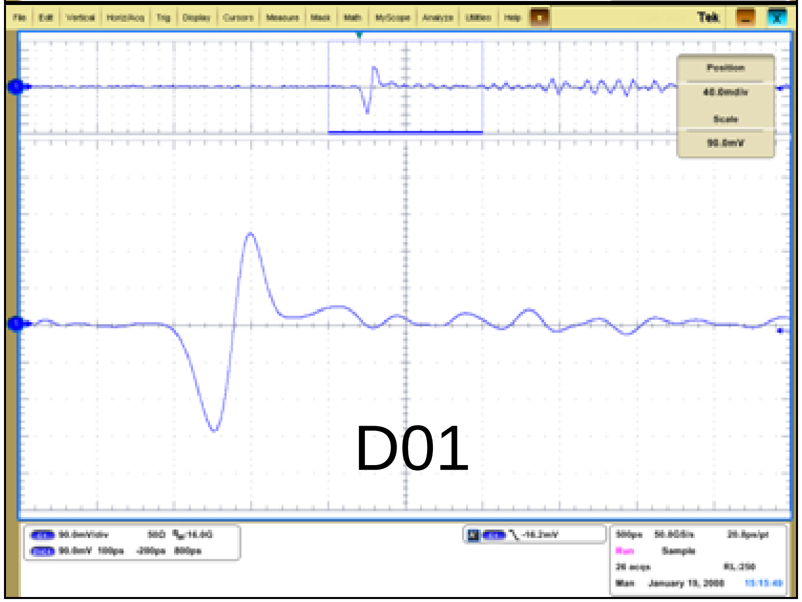
Center pin pulling-out test



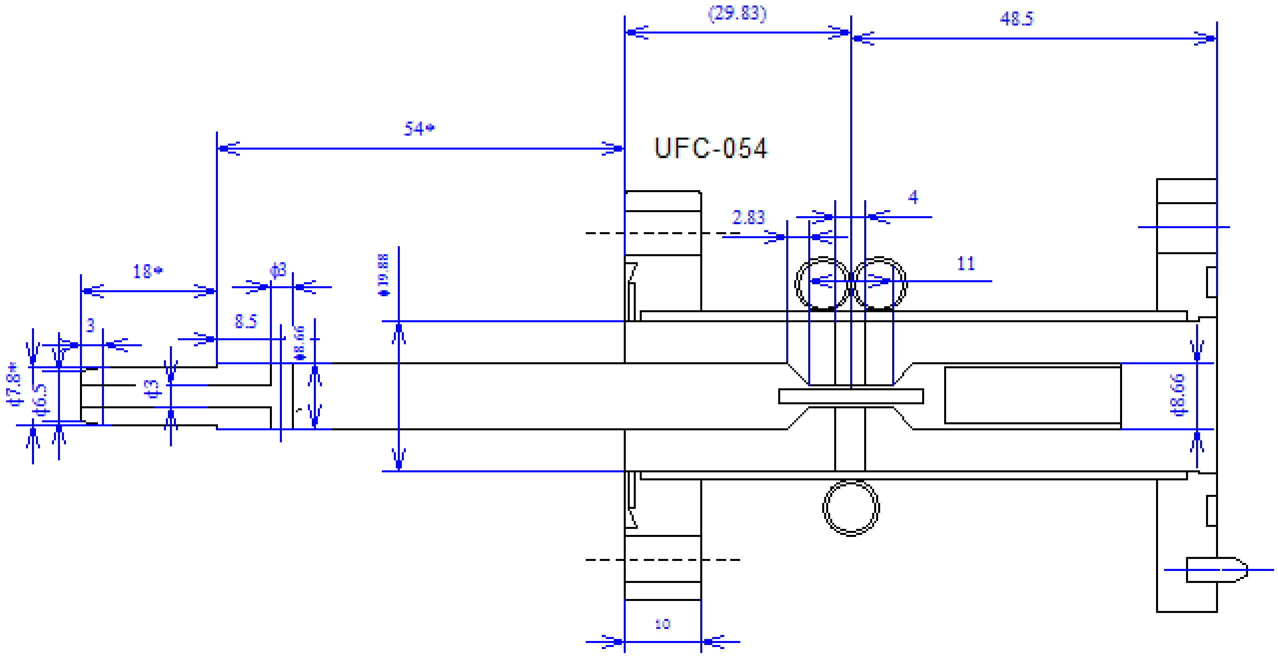
Beam test using Linac short pulse







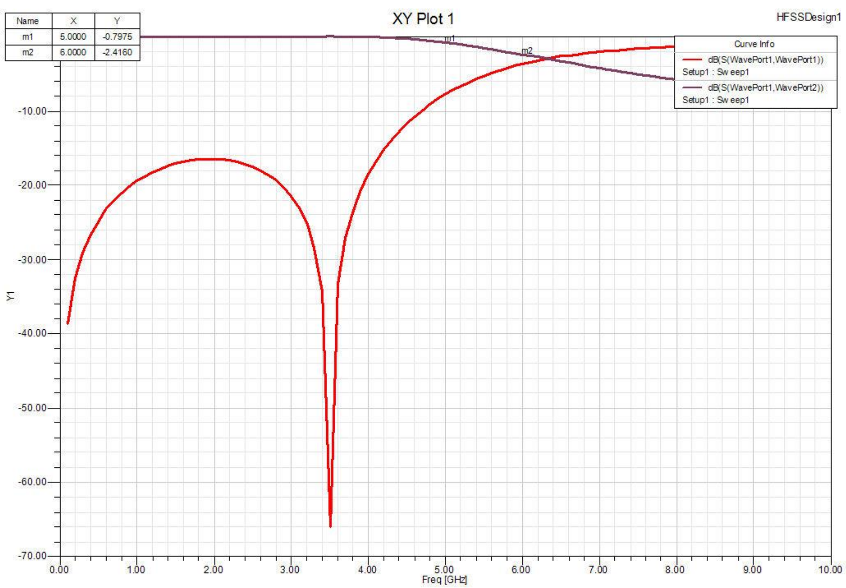
High power feedthrough



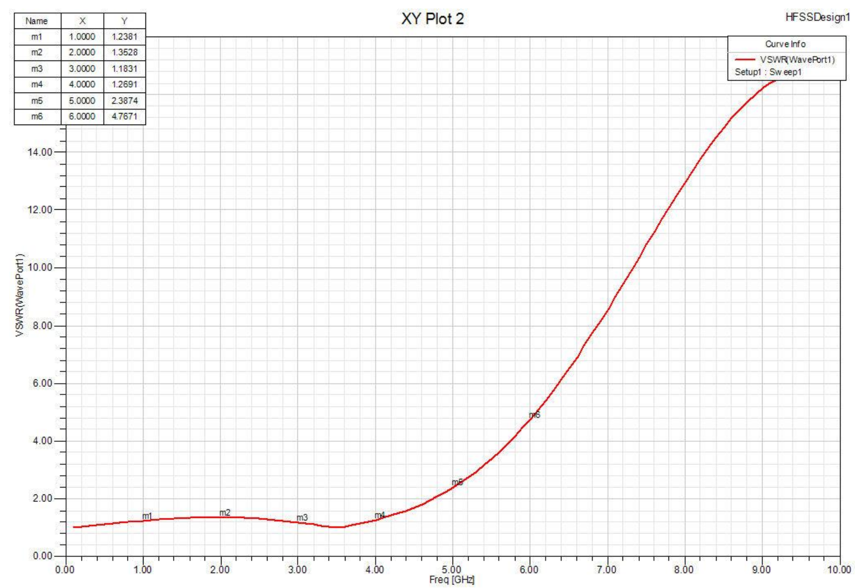
- Max CW power ~ 5kW
- Not so wideband (DC-3GHz)
- SWR through pass band <1.1

Simulated S-Parameters

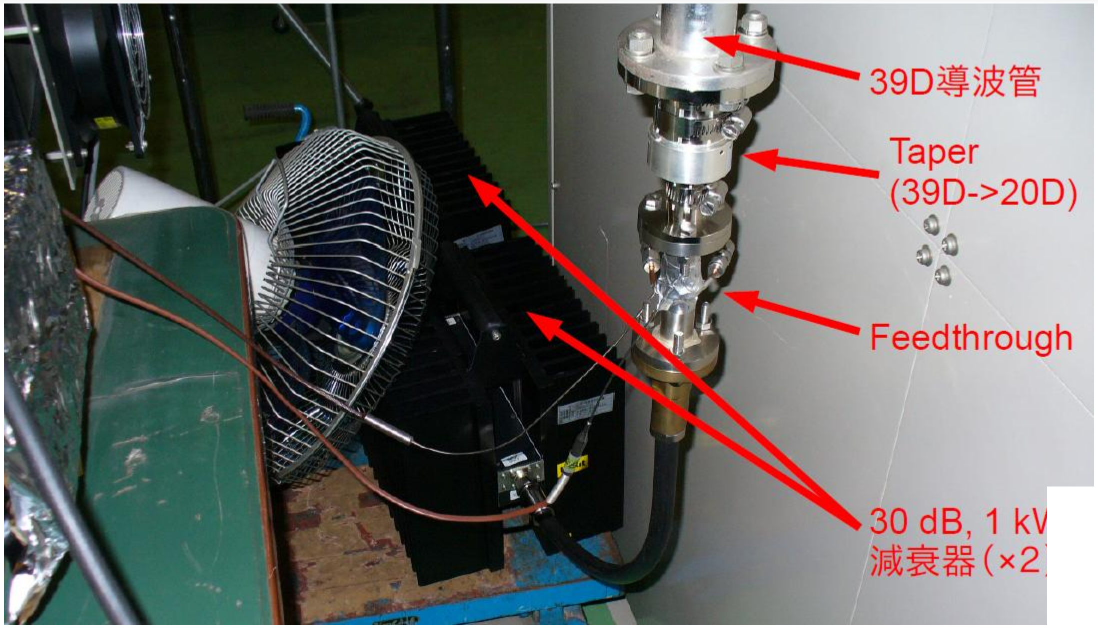
S21 and S11



VSWR(S11)

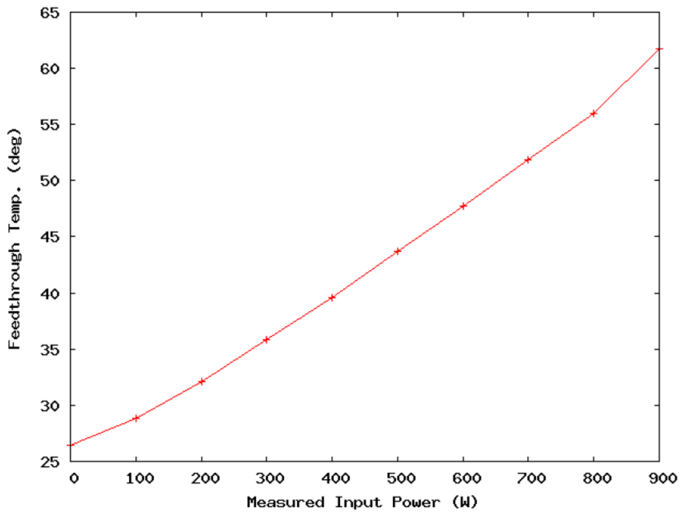


High power test



1.3GHz power source

Feedthrough温度対入力パワー



冷却水がなくても900 Wまでは異常無し。

- **Temperature rise :4 deg/100W**

  (without water cooling)

Tips

- To enhance thermal conductivity between the center conductor and the outer wall, it might be considered to fill BN (ε_R~4) at the air side.
- Si_3N_4 has lower ε_R and has better (lower) loss tangent
  - Expensive
  - Mechanically weaker than alumina-ceramic

Summary

- **Briefly reviewed the transmission-line theory**
  - S-Parameters, SWR, Time-domain response
- **Introduced E-M simulation software**
  - HFSS (Frequency domain)
  - GdfidL (Time domain)
- **Shown several examples**
  - KEKB-FB button electrode
  - SuperKEKB-FB button electrode
  - High power feedthrough for SuperKEKB longitudinal kicker.

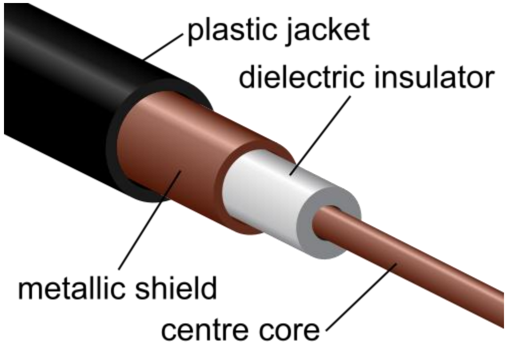
Reference

- “Microwave Engineering Passive Circuits”,
  by Peter A. Rizzi, ISBN 0135867029
- “Introduction to Microwave Theory”,
  by Harry A. Atwater, ISBN 0898741920
- Ansys HFSS,
  - http://www.ansys.com/Products/Simulation+Technology/Electromagnetics/High-Performance+Electronic+Design/ANSYS+HFSS
- GdfidL, http://www.gdfidl.de/
- Kyocera Corporation
  - http://global.kyocera.com/prdct/fc/product/usage/vacuum/index.html
- Orient Microwave Corp.
  - http://www.orient-microwave.com/english/index.html
- SUHNER
  - http://ipaper.ipapercms.dk/HUBERSUHNER/Technologies/Radiofrequency/RFConnectorsEN/

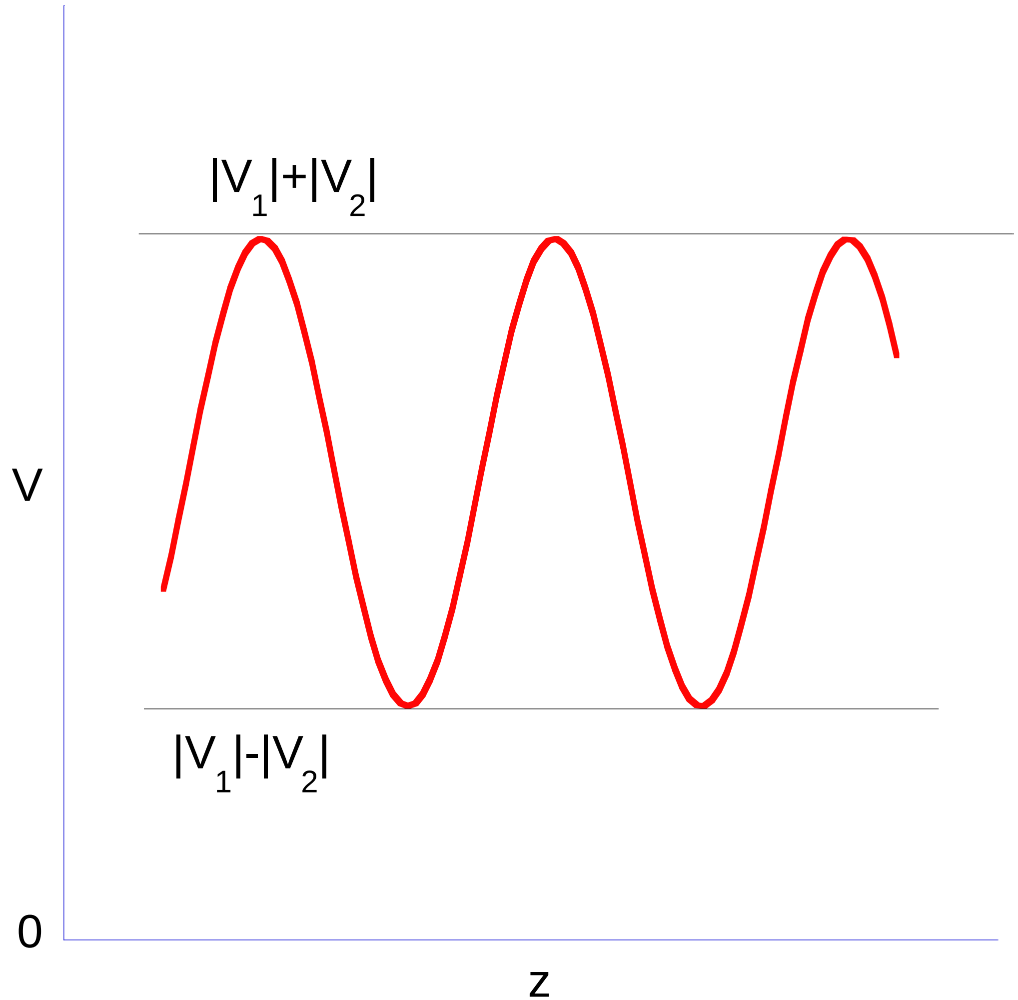
backup

Transmission line

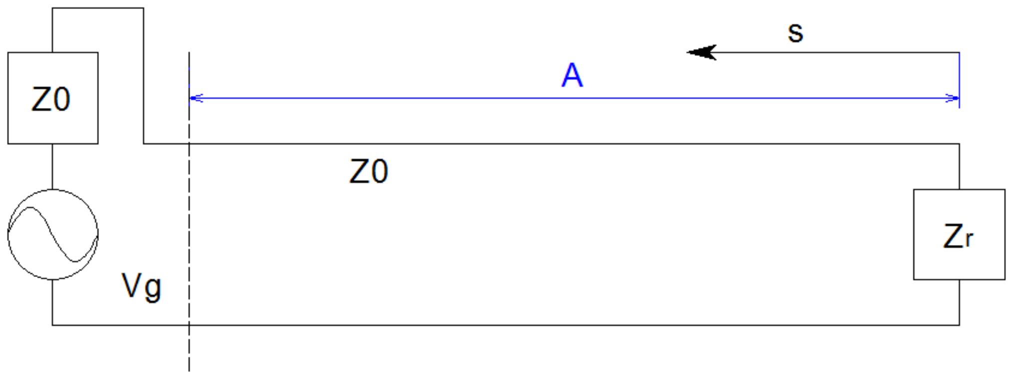
- **Coaxial cable**



Standing wave



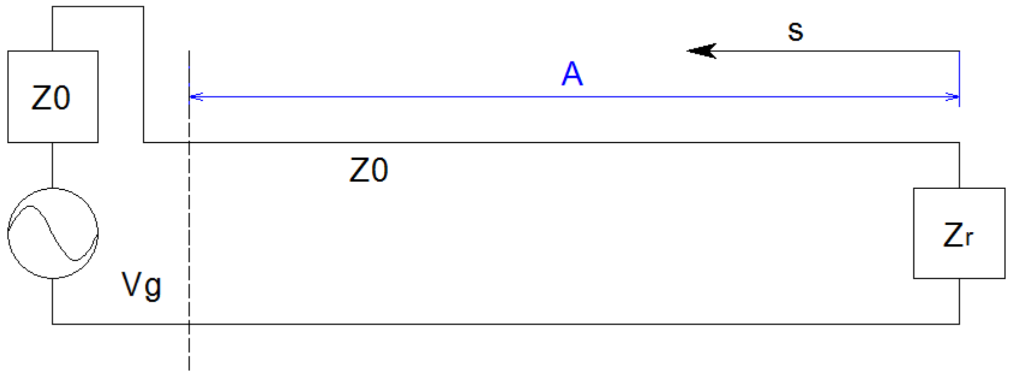
Standing wave



$$V = V_1 e^{-j\beta(A-s)} + V_2 e^{j\beta(A-s)} = V_1' e^{j\beta s} + V_2' e^{-j\beta s}$$

$$= V_1' e^{j\beta s}\left(1 + \rho e^{-2j\beta s}\right)$$

Standing wave

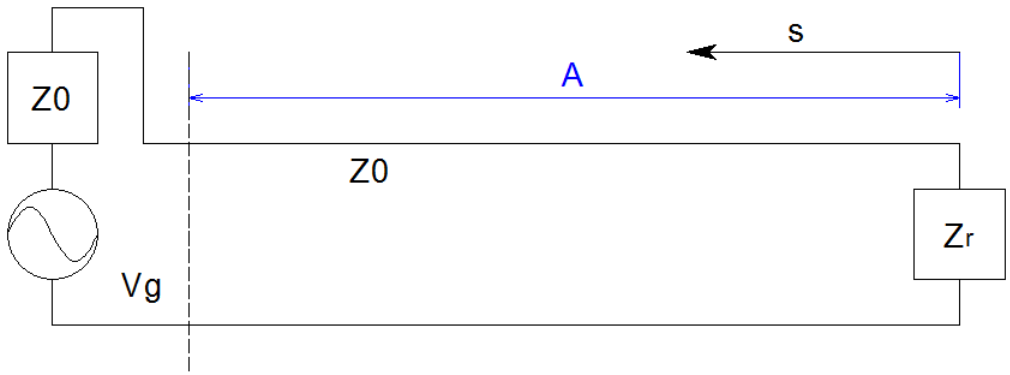


$$V = V_1 e^{-j\beta(A-s)} + V_2 e^{j\beta(A-s)} = V_1' e^{j\beta s} + V_2' e^{-j\beta s}$$

$$= V_1' e^{j\beta s}\left(1 + \rho e^{-2j\beta s}\right)$$

- **ρ: reflection constant**

Standing wave

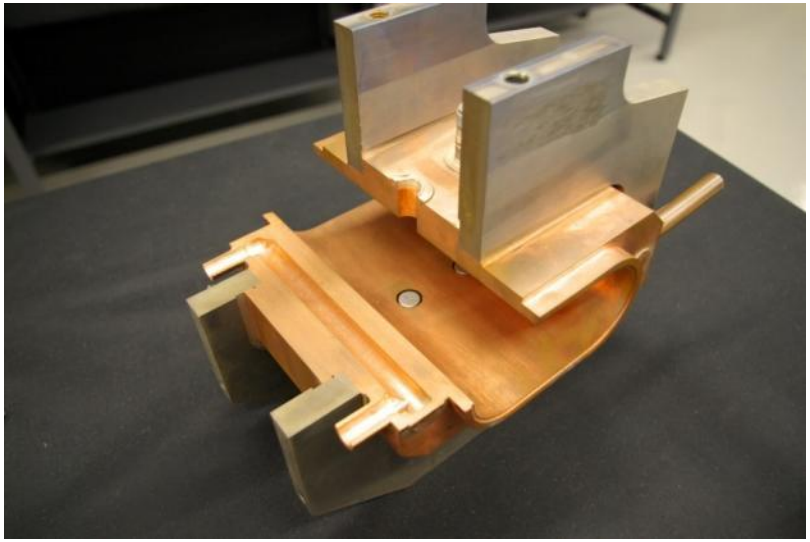


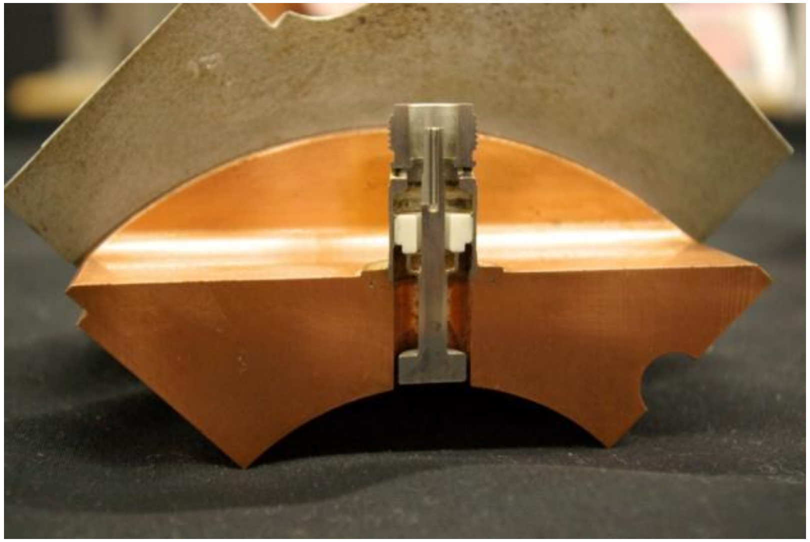
$$V = V_1 e^{-j\beta(A-s)} + V_2 e^{j\beta(A-s)} = V_1' e^{j\beta s} + V_2' e^{-j\beta s}$$
$$= V_1' e^{j\beta s}\left(1 + \rho e^{-2j\beta s}\right)$$

- ρ: reflection constant

$$\rho = \frac{V_2'}{V_1'} = |\rho| e^{j\varphi}$$
$$V = V_1' e^{j\beta s}\left(1 + |\rho| e^{j(\varphi - 2\beta s)}\right)$$

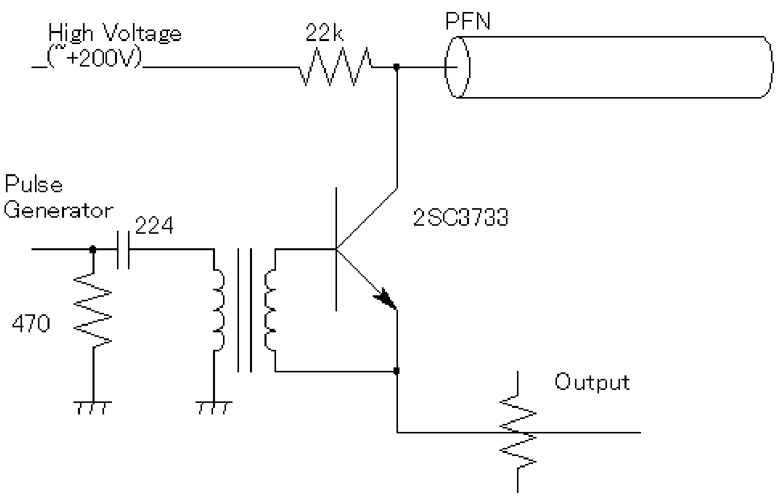
例:ボタン電極型ビーム位置モニタ

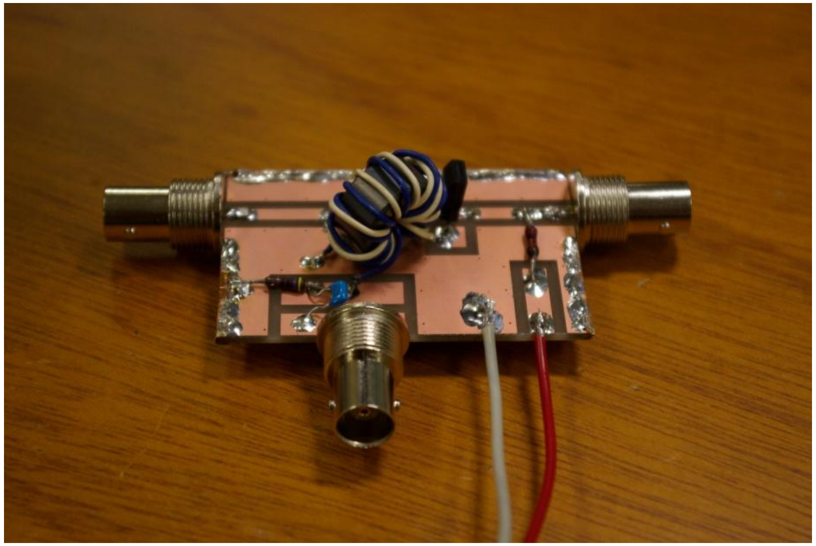




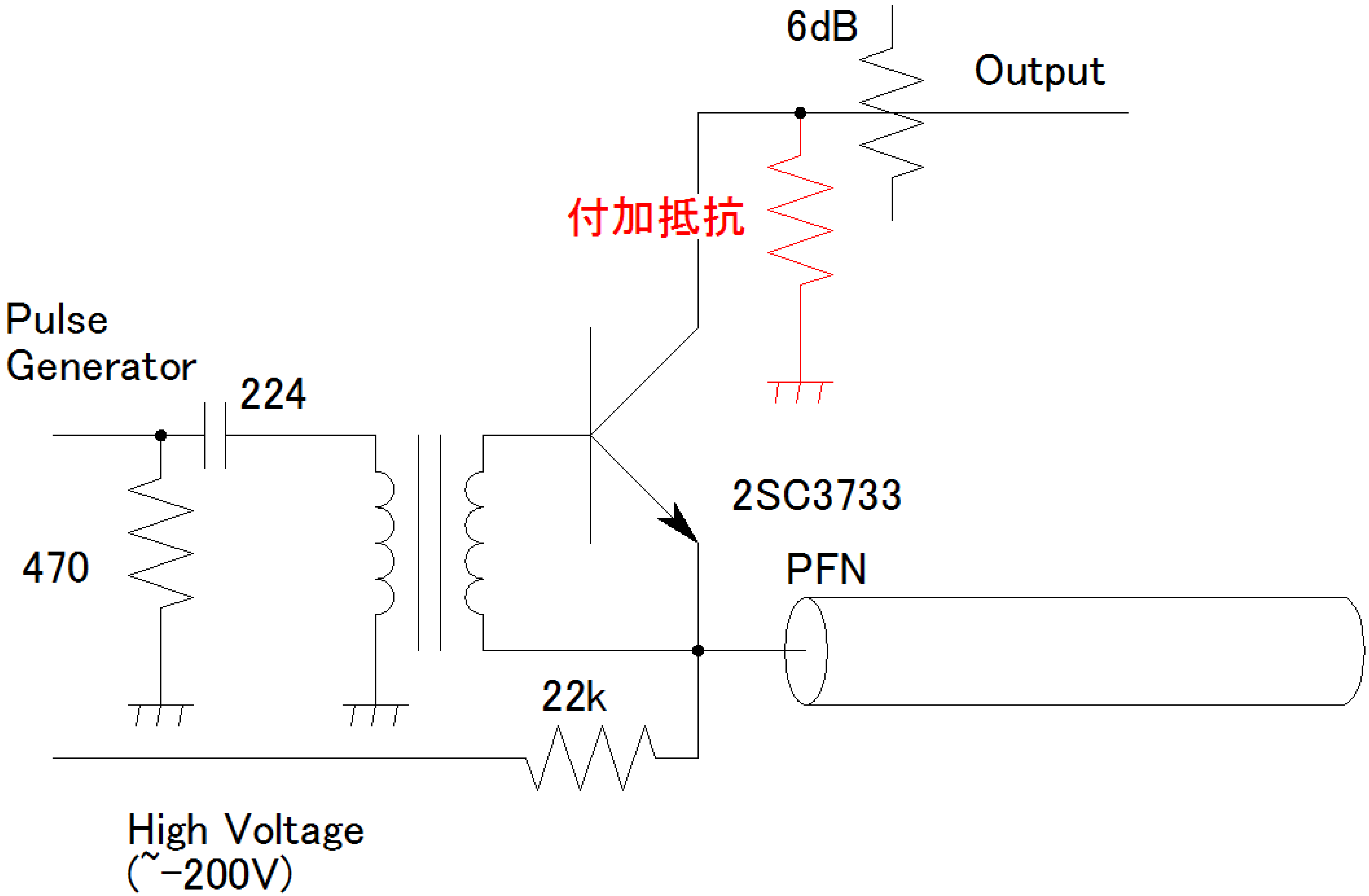
四つの電極に出てきた電荷の差から、バンチの重心位置を求めるためのモニターです。レンズの働きをする四極電磁石に固定してあります。

アバランシェトランジスタパルサー(正極性)

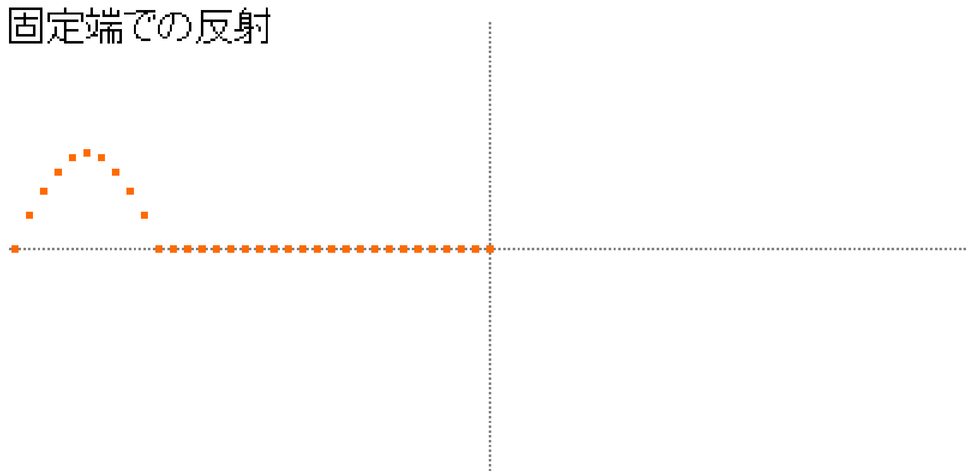


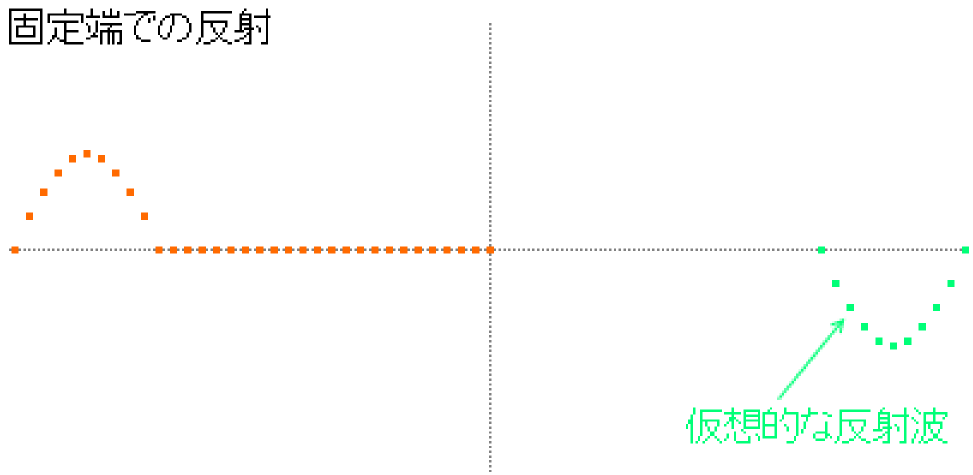


アバランシェパルサー(負極性)



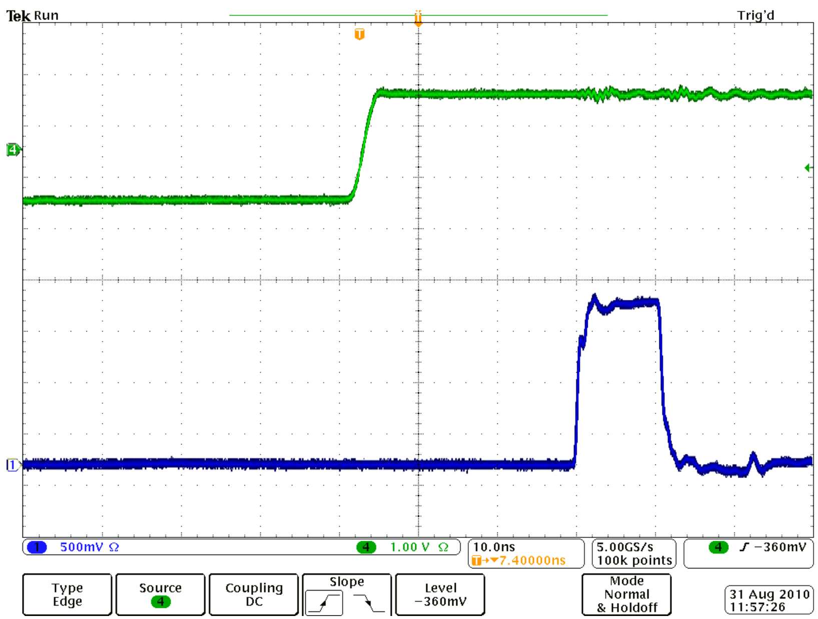
固定端での反射





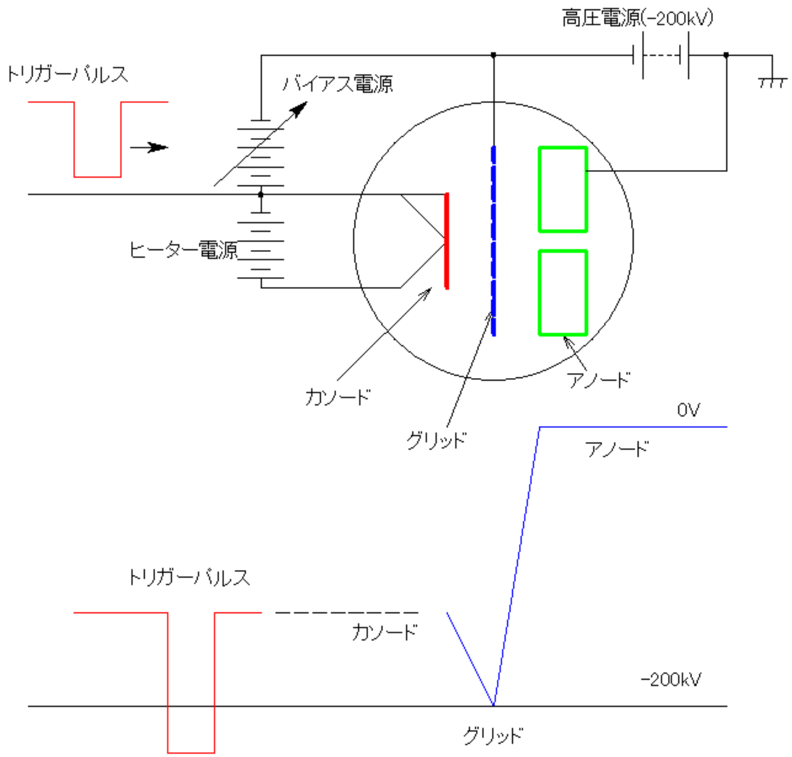
http://www.wakariyasui.sakura.ne.jp/2-1-0-0/2-1-2-4koteitannjiyuutann.html

出力は

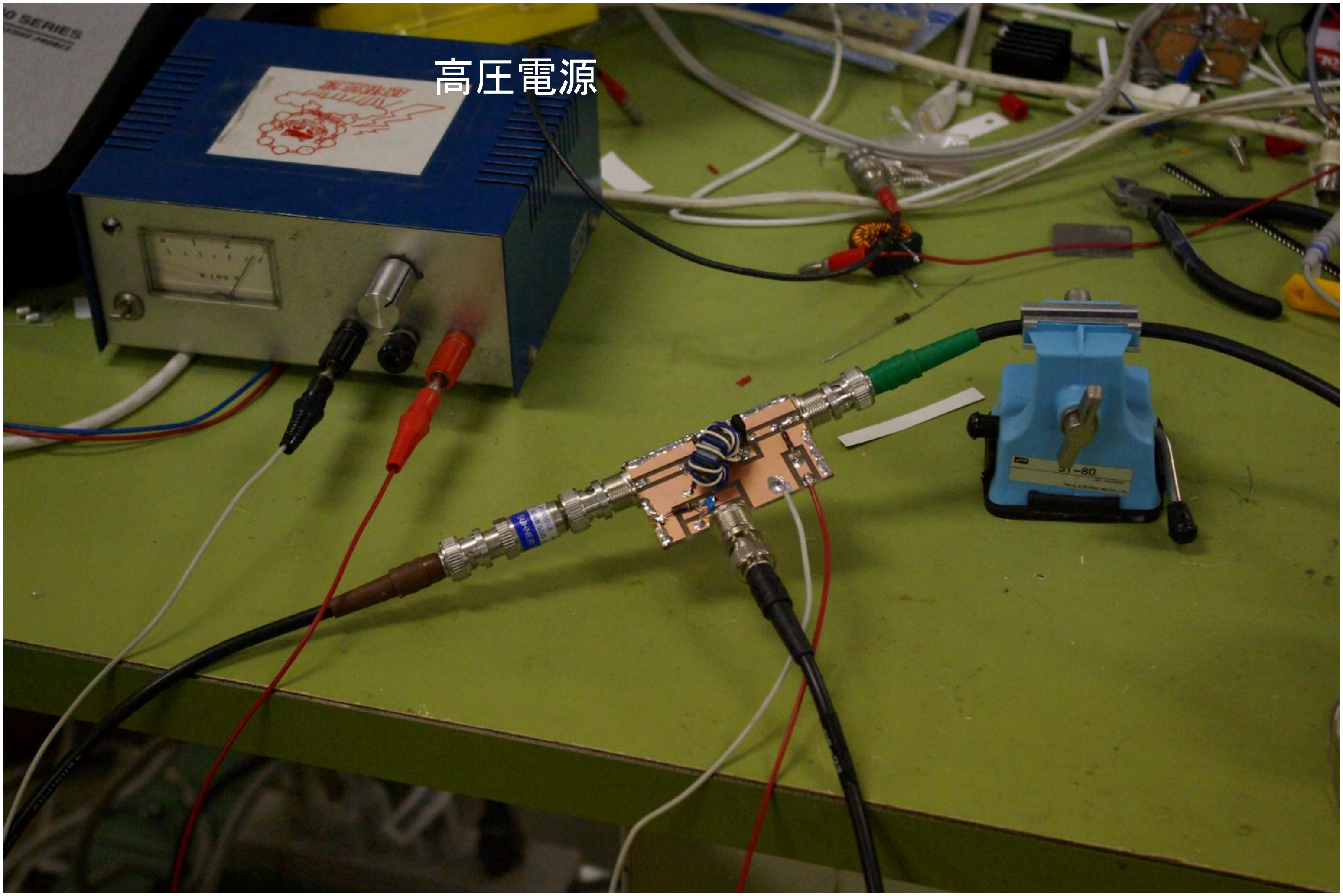


- トリガーが入ってトランジスタがONになり、約10ns後にOFFになっている。
- このとき、PFNには1mの同軸線をつけていた。ここにたまっていた高電圧が抜けて、パルス高が0に戻った。

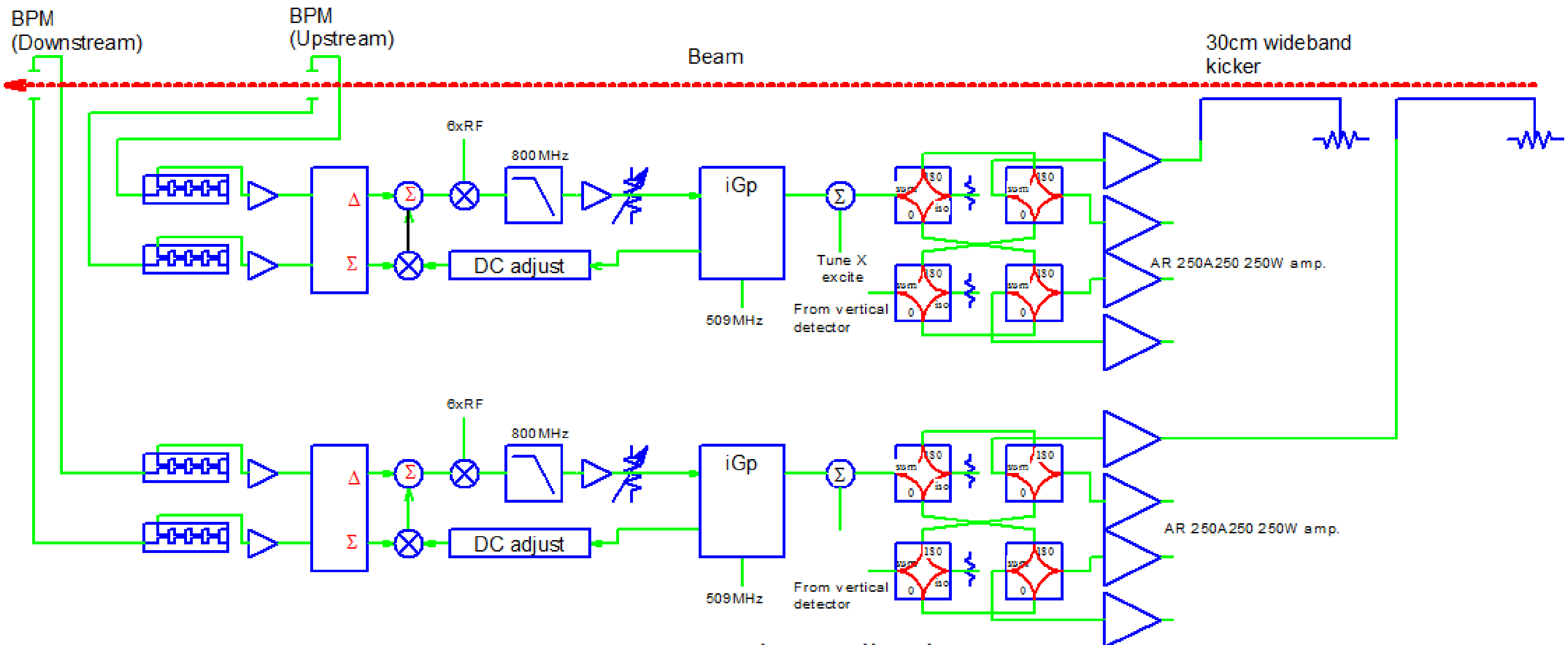
アバランシェパルサーの使用例



- 線形加速器の熱電子銃から出る電子ビームの長さを非常に狭く(1ns以下とか)したいとき、アバランシェパルサーを使ってビームが出るタイミングを制御します

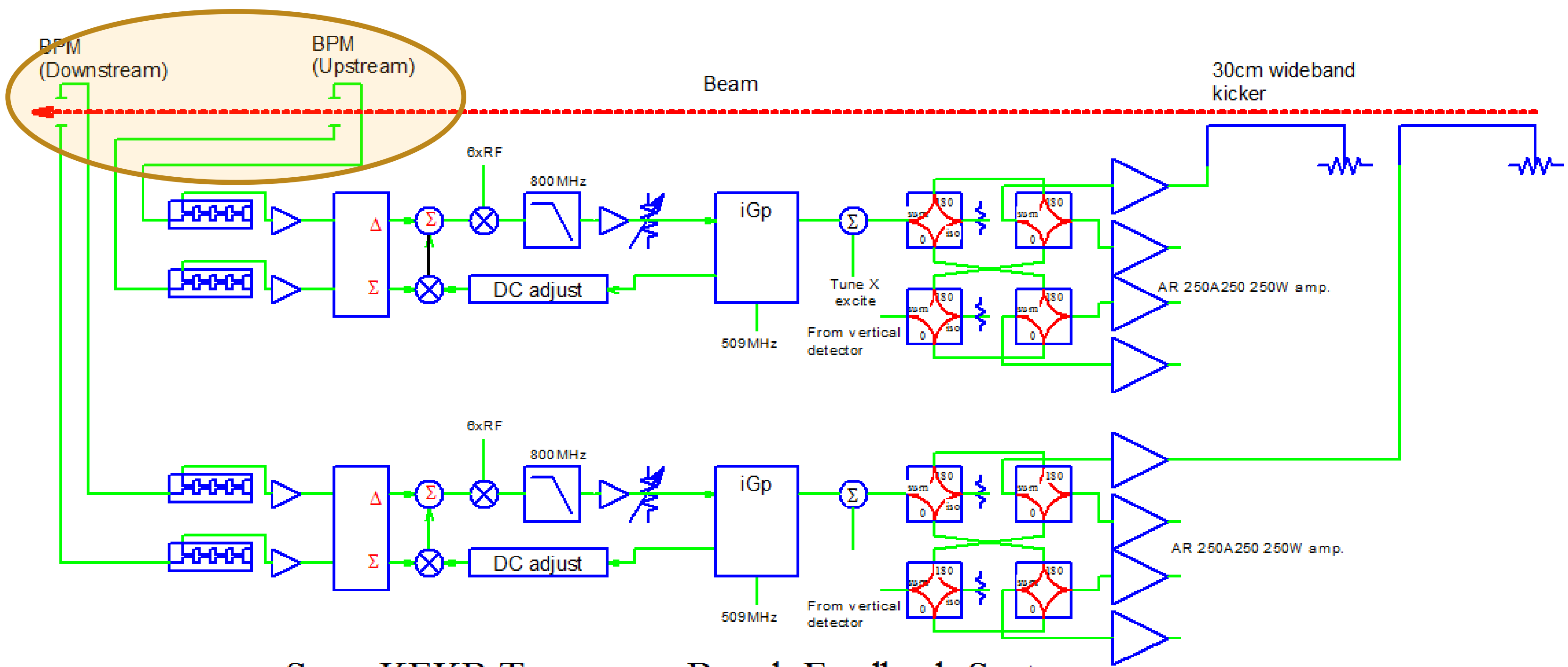

高圧電源

SuperKEKB Transverse FB plan



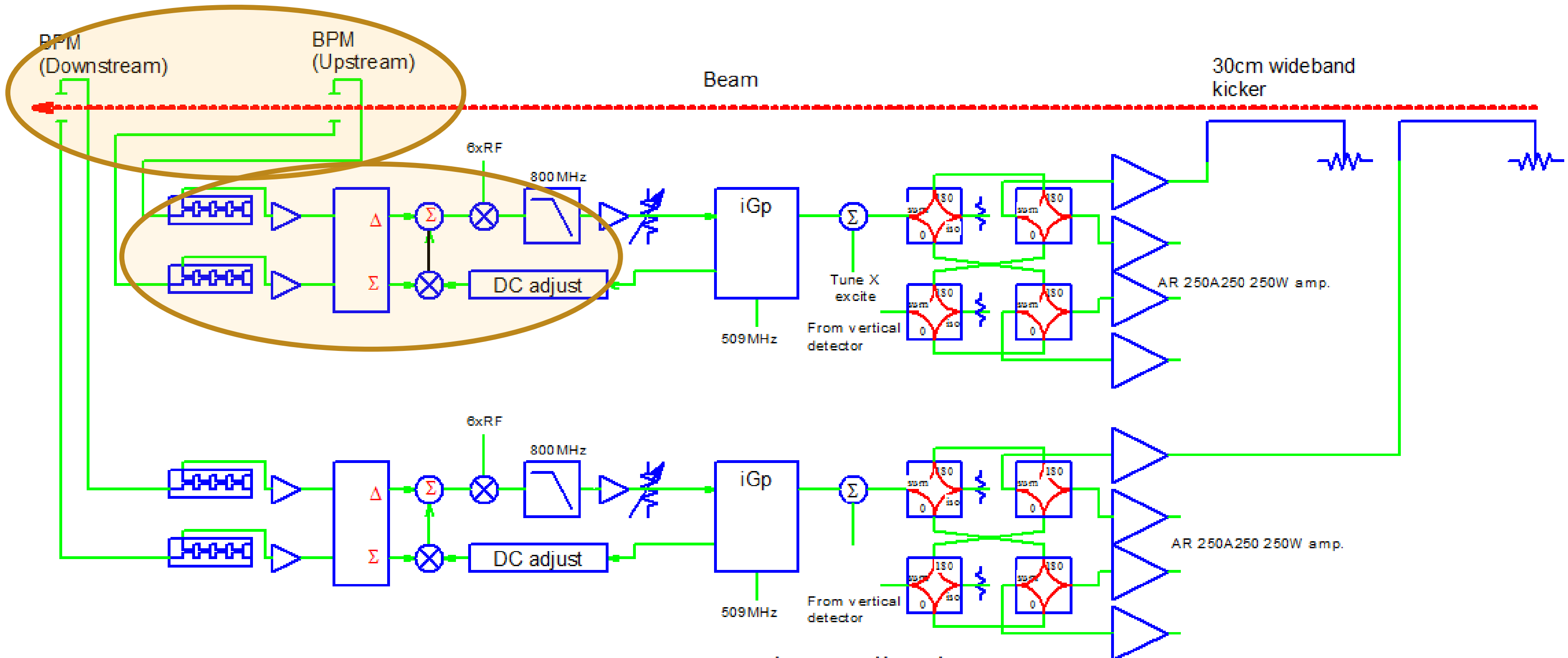
SuperKEKB Transverse Bunch Feedback System

SuperKEKB Transverse FB plan



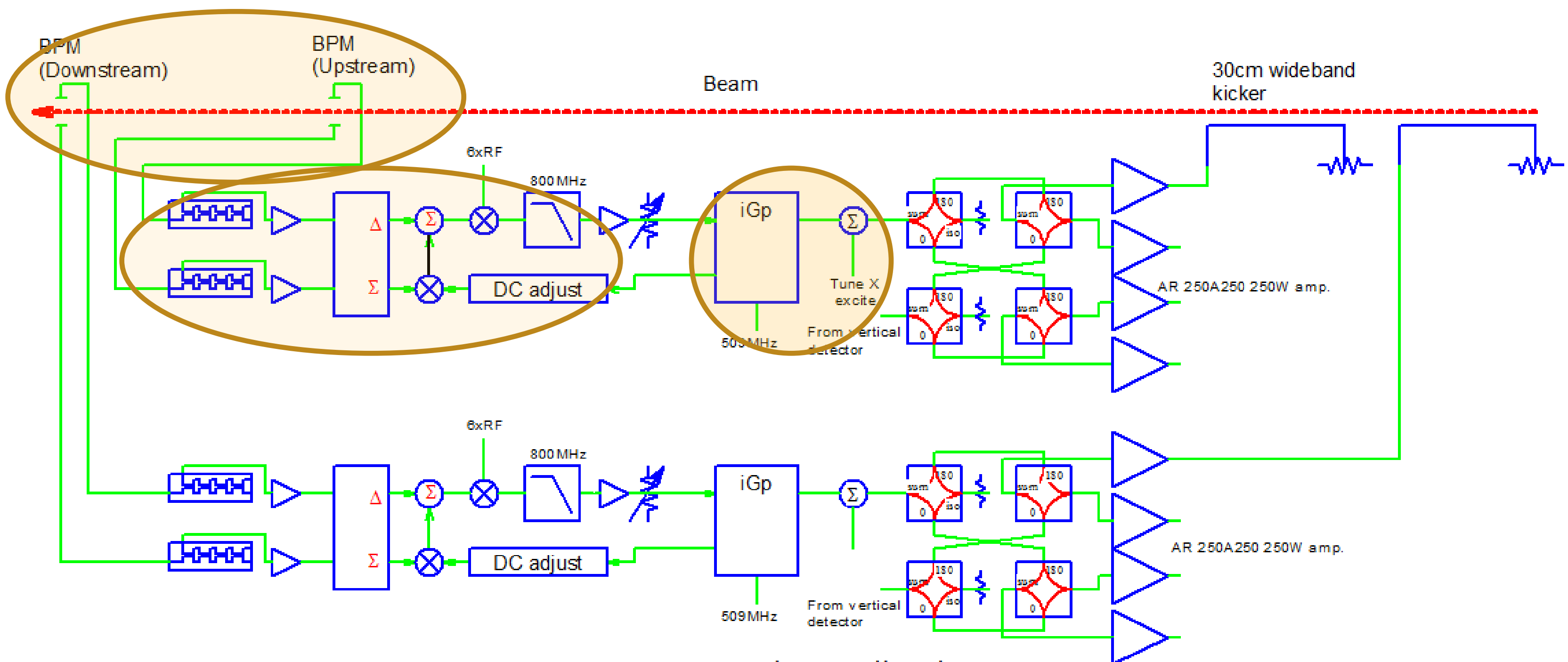
SuperKEKB Transverse Bunch Feedback System

SuperKEKB Transverse FB plan



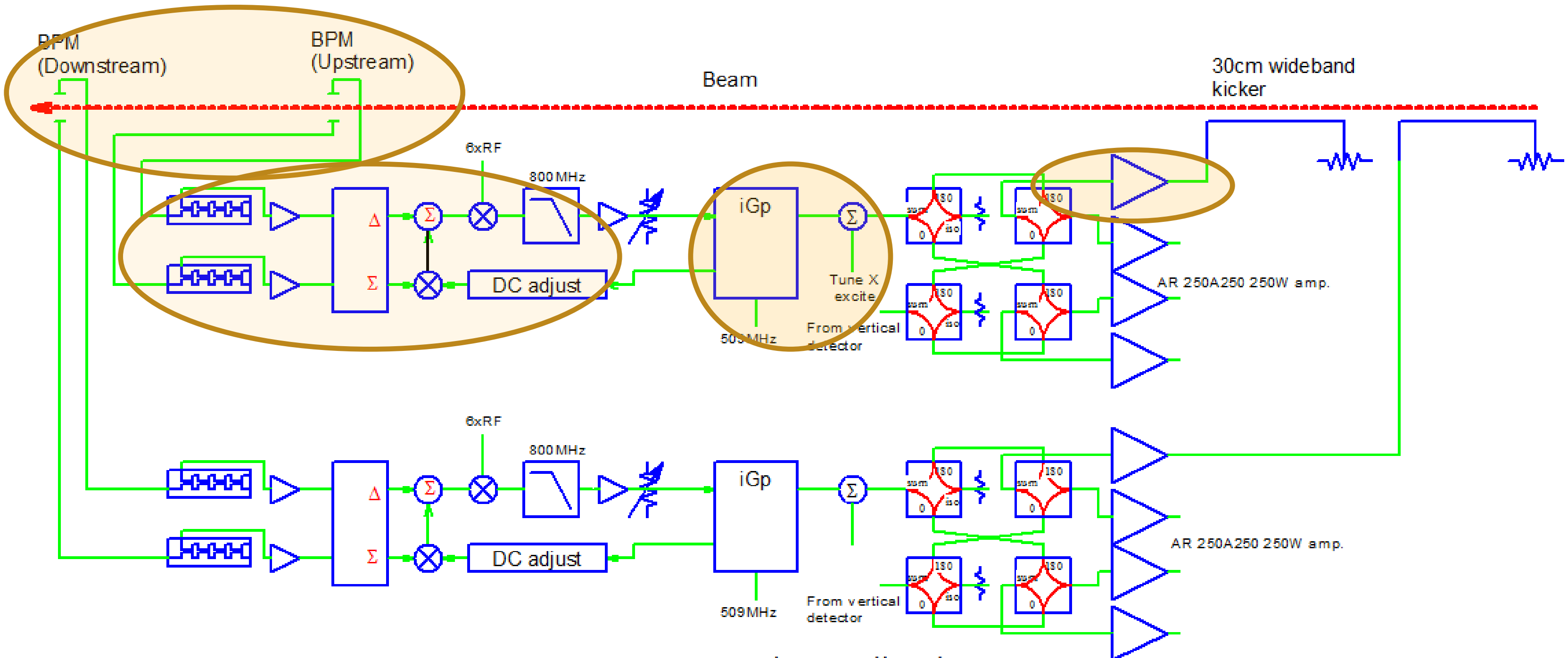
SuperKEKB Transverse Bunch Feedback System

SuperKEKB Transverse FB plan



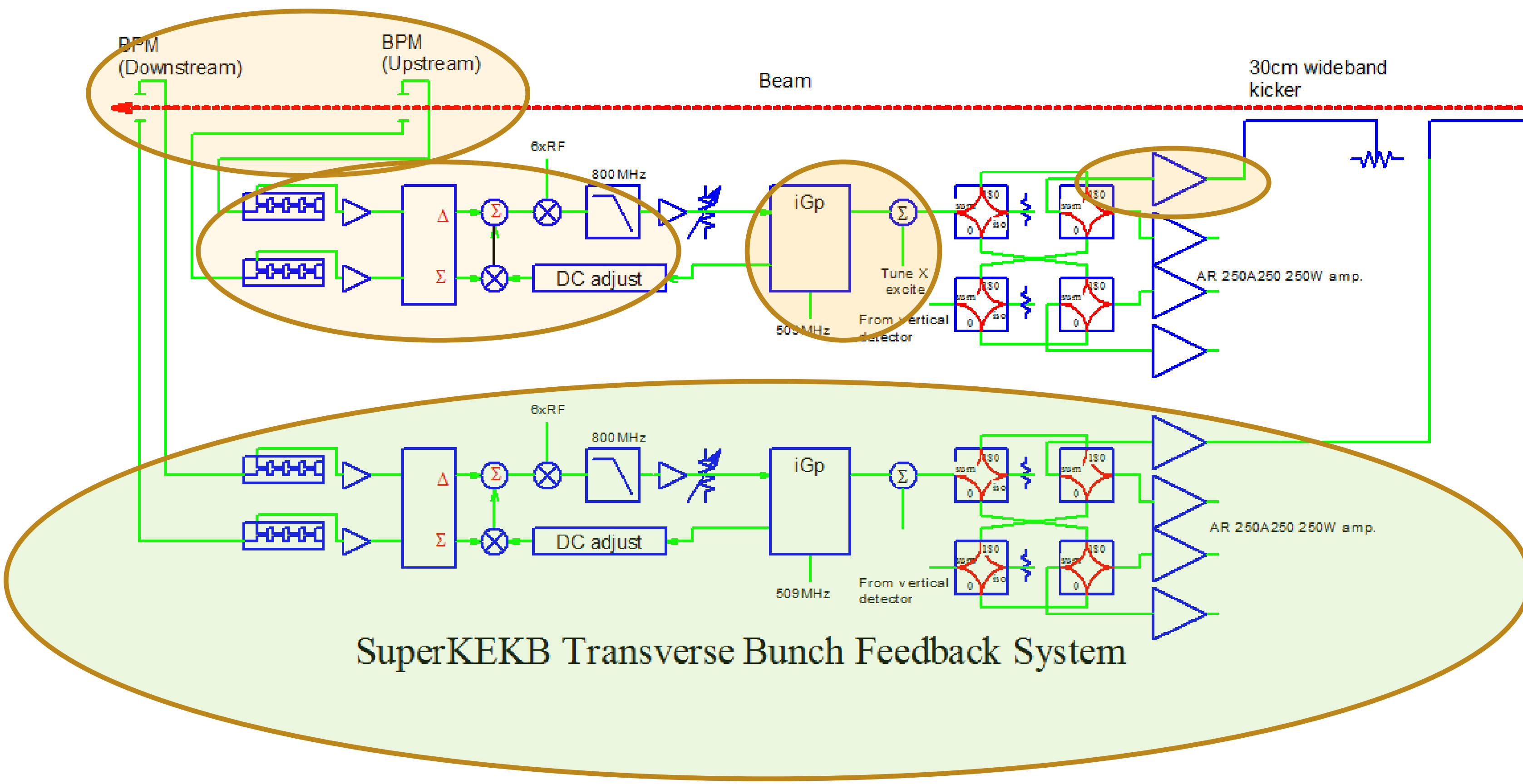
SuperKEKB Transverse Bunch Feedback System

SuperKEKB Transverse FB plan

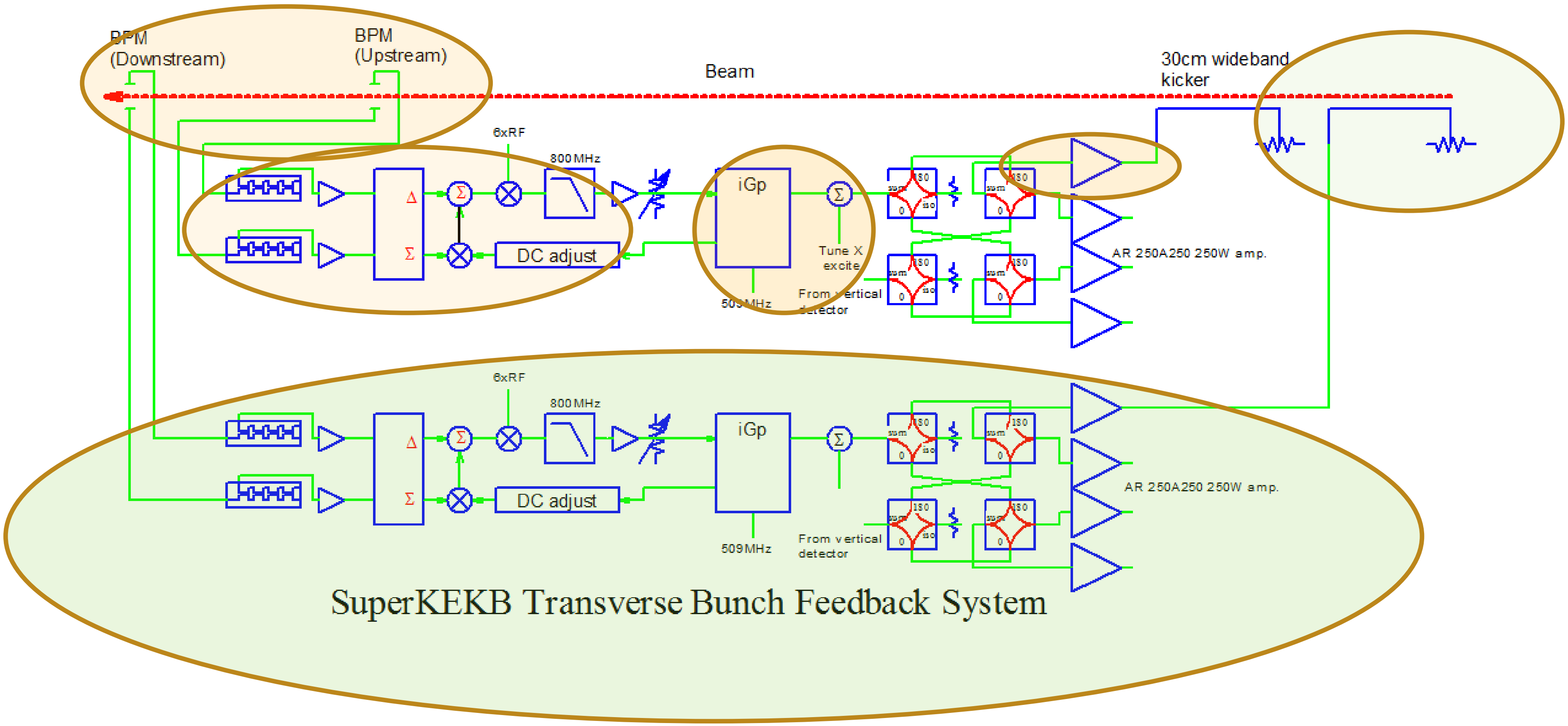


SuperKEKB Transverse Bunch Feedback System

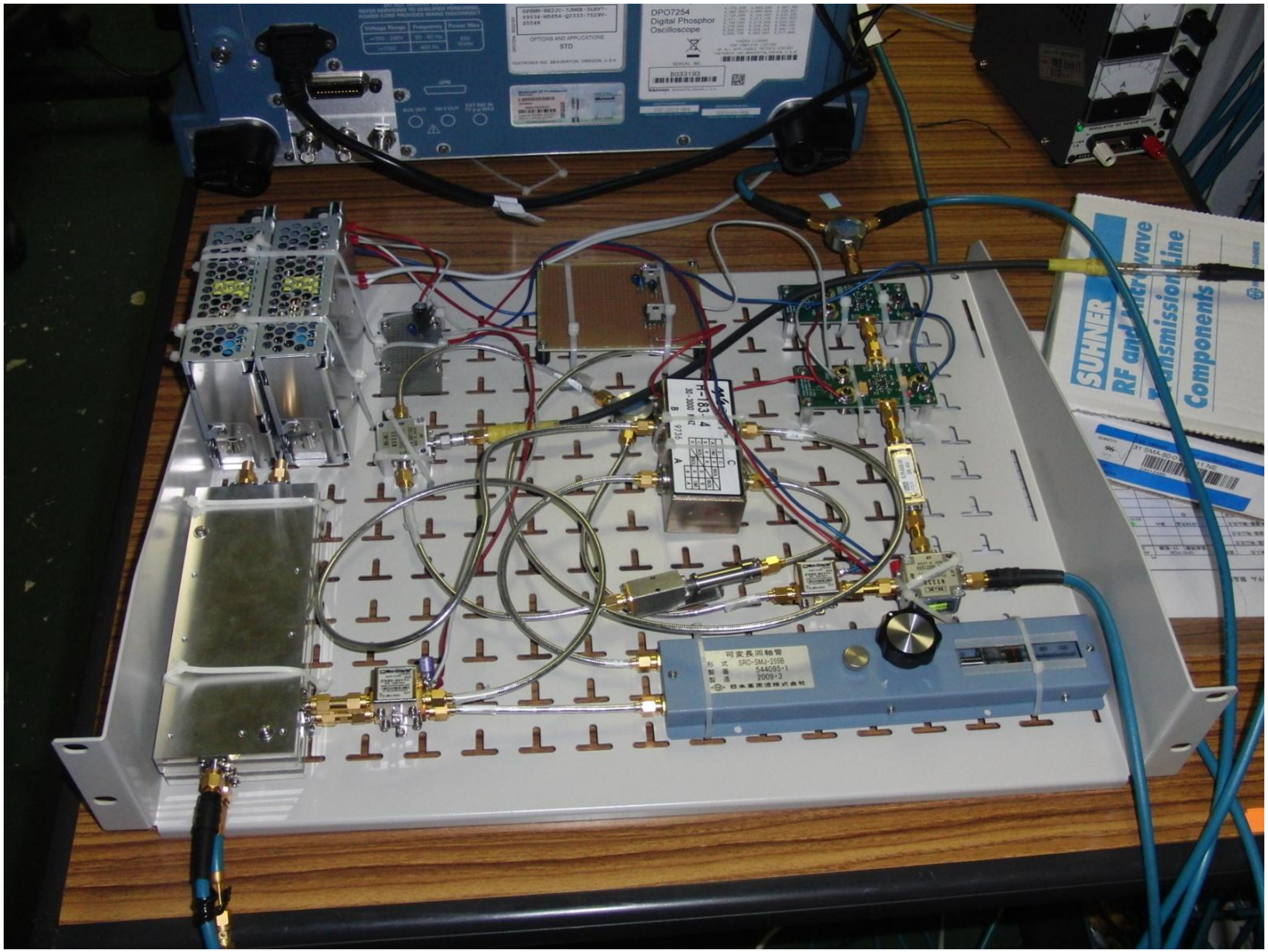
SuperKEKB Transverse FB plan



SuperKEKB Transverse FB plan



Bunch position detector prototype



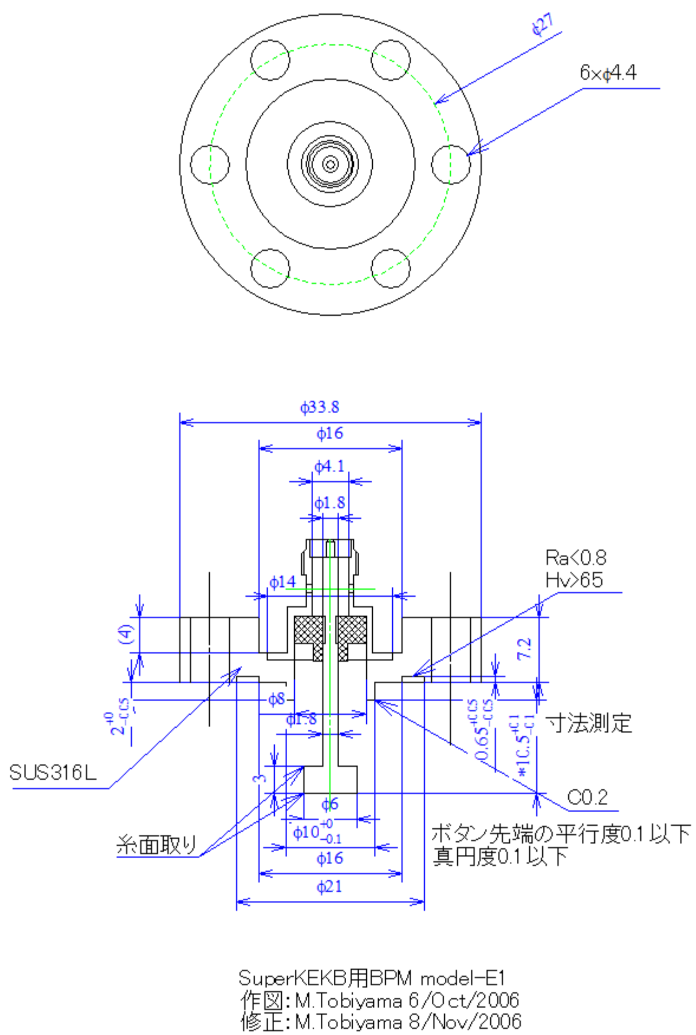
Vacuum chamber

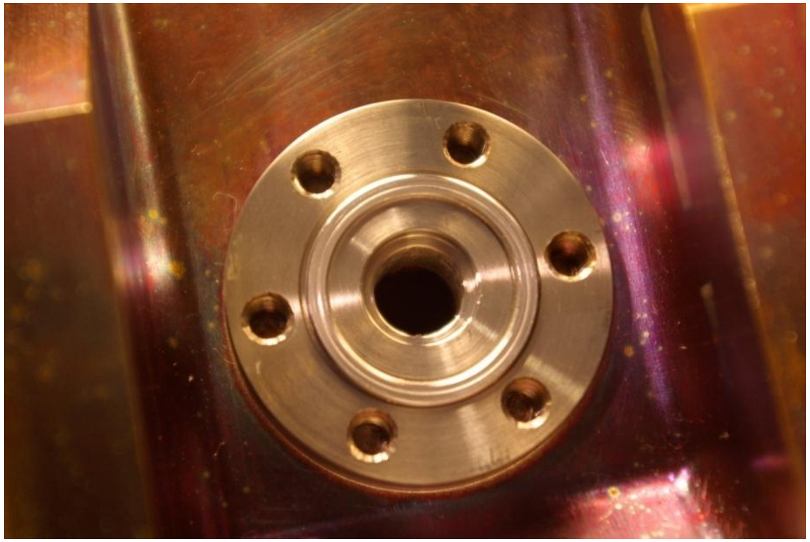
- Aluminum alloy antechamber
- cutoff frequency <1 GHz

Aluminum-alloy duct

Aluminum-alloy duct

BPM head


φ27
6×φ4.4
φ33.8
φ16
φ4.1
φ1.8
φ14
Ra<0.8
Hv>65
7.2
(4)
φ8
寸法測定
SUS316L
C0.2
φ6
糸面取り
ボタン先端の平行度0.1以下
真円度0.1以下
φ16
φ21
SuperKEKB用BPM model-E1
作図:M.Tobiyama 6/Oct/2006
修正:M.Tobiyama 8/Nov/2006



Impedance/button output simulation