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On The Use Of Three-Dimensional TEM Cells For Total Radiated Power Measurements

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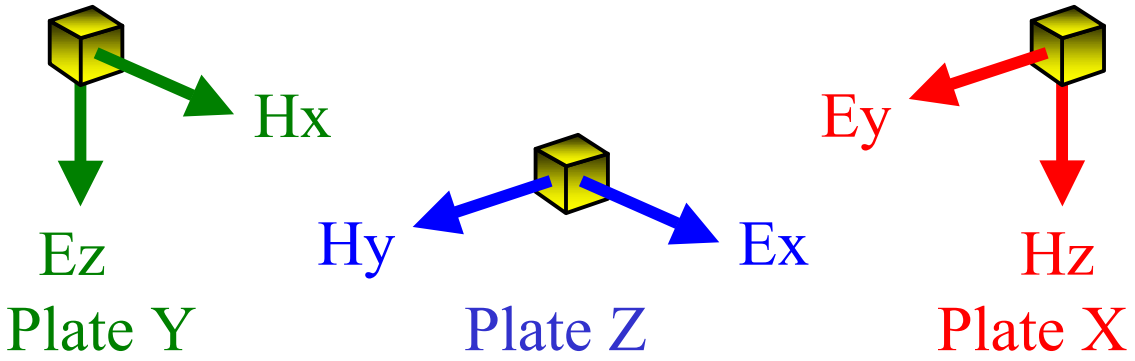
Overview

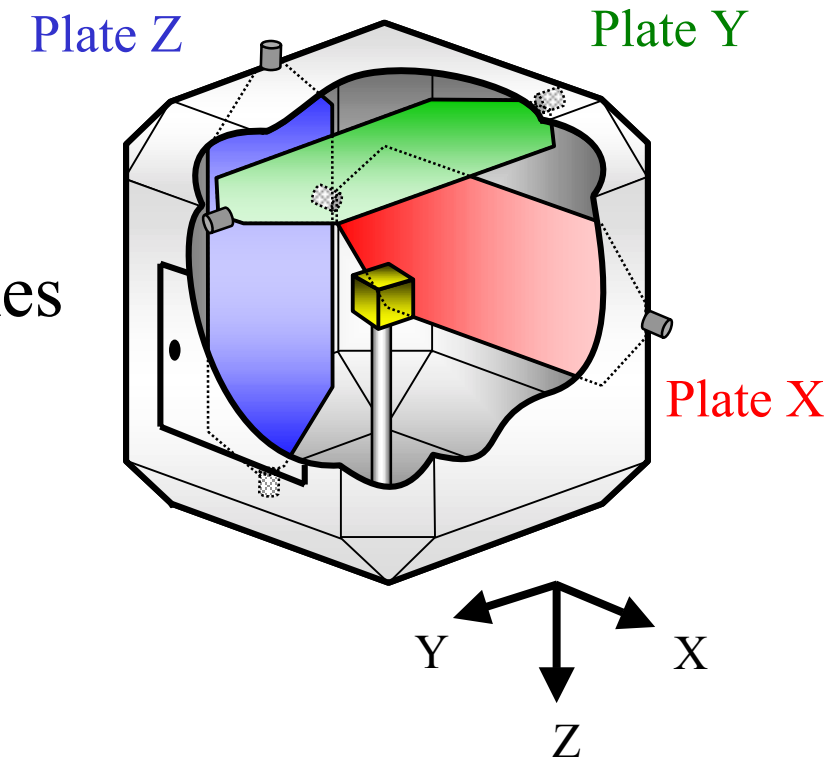
- Introduction on 3D-TEM cells and hybrid structures
- Radiation measurements in TEM cells
- First results with the generic prototype, comments…
- New 6-plate balanced 3D-TEM cell
- Measurement results in balanced and unbalanced mode
- Conclusions and perspectives

3-Dimensional TEM cells (and hybrids)

At low frequencies :

- 3 TEM cells in 1
- 3 Orthogonal TEM coupling planes

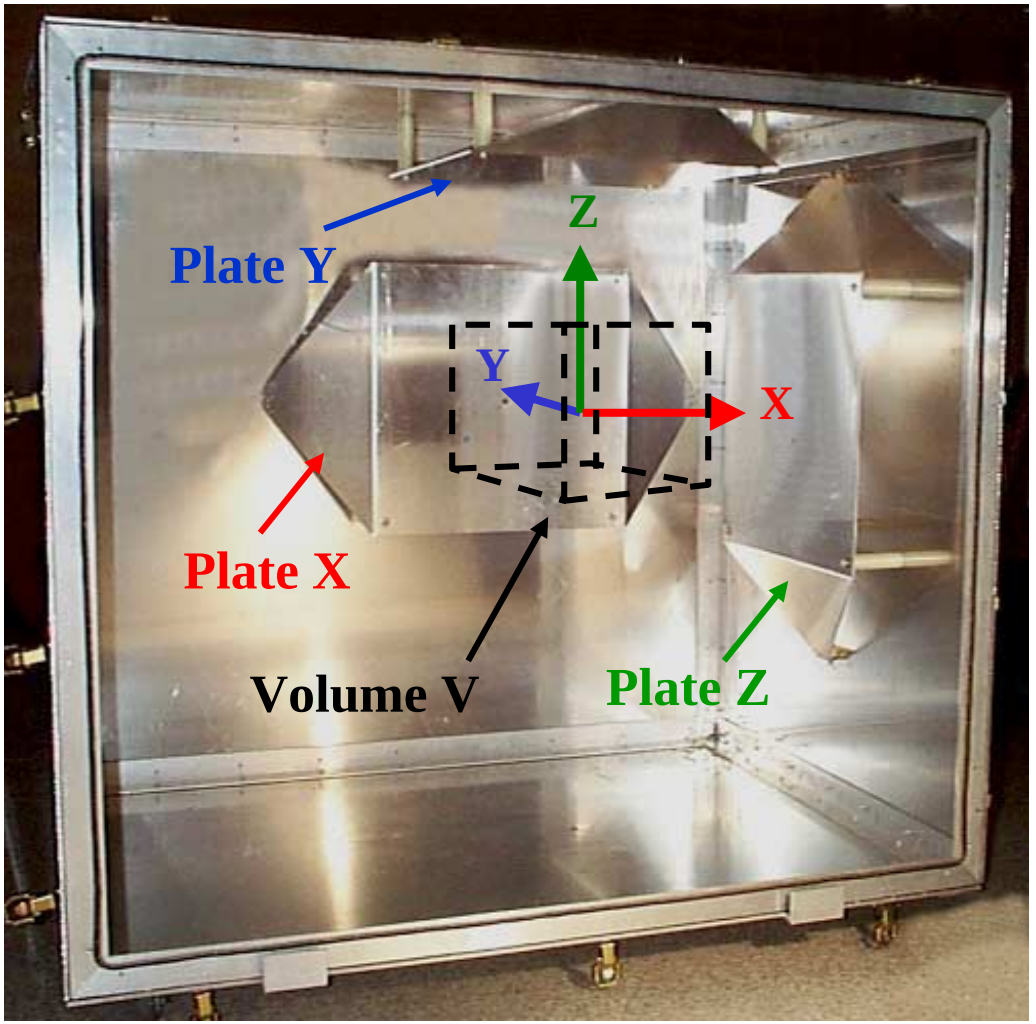




- Balanced or unbalanced structure

At high frequencies : resonant cavity

Prototype of a generic 3-D hybrid cell

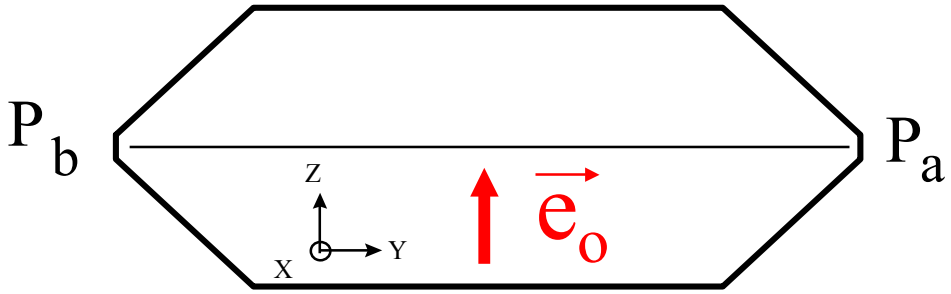


Radiation in a TEM cell

Electric and magnetic moments of an *electrically small source*

$$\begin{cases} \vec{M}_e = m_{ex} e^{j\psi_{ex}} \vec{x} + m_{ey} e^{j\psi_{ey}} \vec{y} + m_{ez} e^{j\psi_{ez}} \vec{z} \\ \vec{M}_m = m_{mx} e^{j\psi_{mx}} \vec{x} + m_{my} e^{j\psi_{my}} \vec{y} + m_{mz} e^{j\psi_{mz}} \vec{z} \end{cases}$$

Dominant TEM mode and *field uniformity in test volume*



$$P_{\substack{a \\ b}} = \frac{e_o^2}{4}\left[m_{ez}^2 + k^2 m_{mx}^2 \pm 2\, k\, m_{ez} m_{mx} \sin(\psi_{ez} - \psi_{mx}) \right]$$

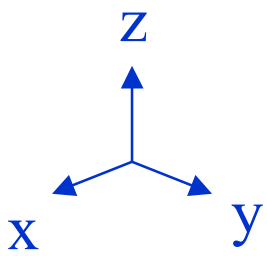
Unknown phases

Obtaining the total radiated power

Knowing

$$P_t = \frac{\pi\, Z_o}{3\,\lambda^2}\left[m_{ex}^{\,2} + m_{ey}^{\,2} + m_{ez}^{\,2} + k^2\left(m_{mx}^{\,2} + m_{my}^{\,2} + m_{mz}^{\,2}\right)\right]$$

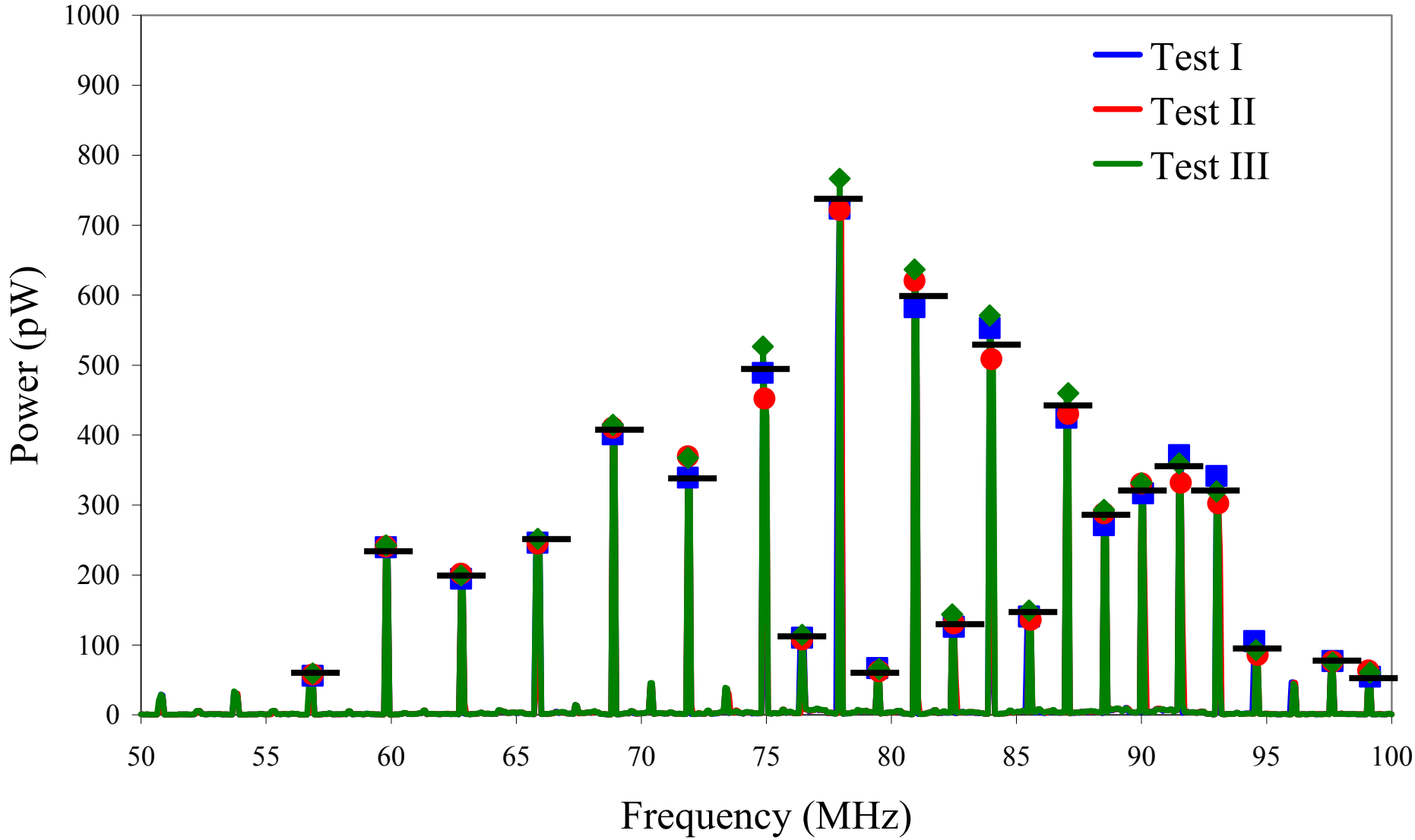
Using three orthogonal orientations



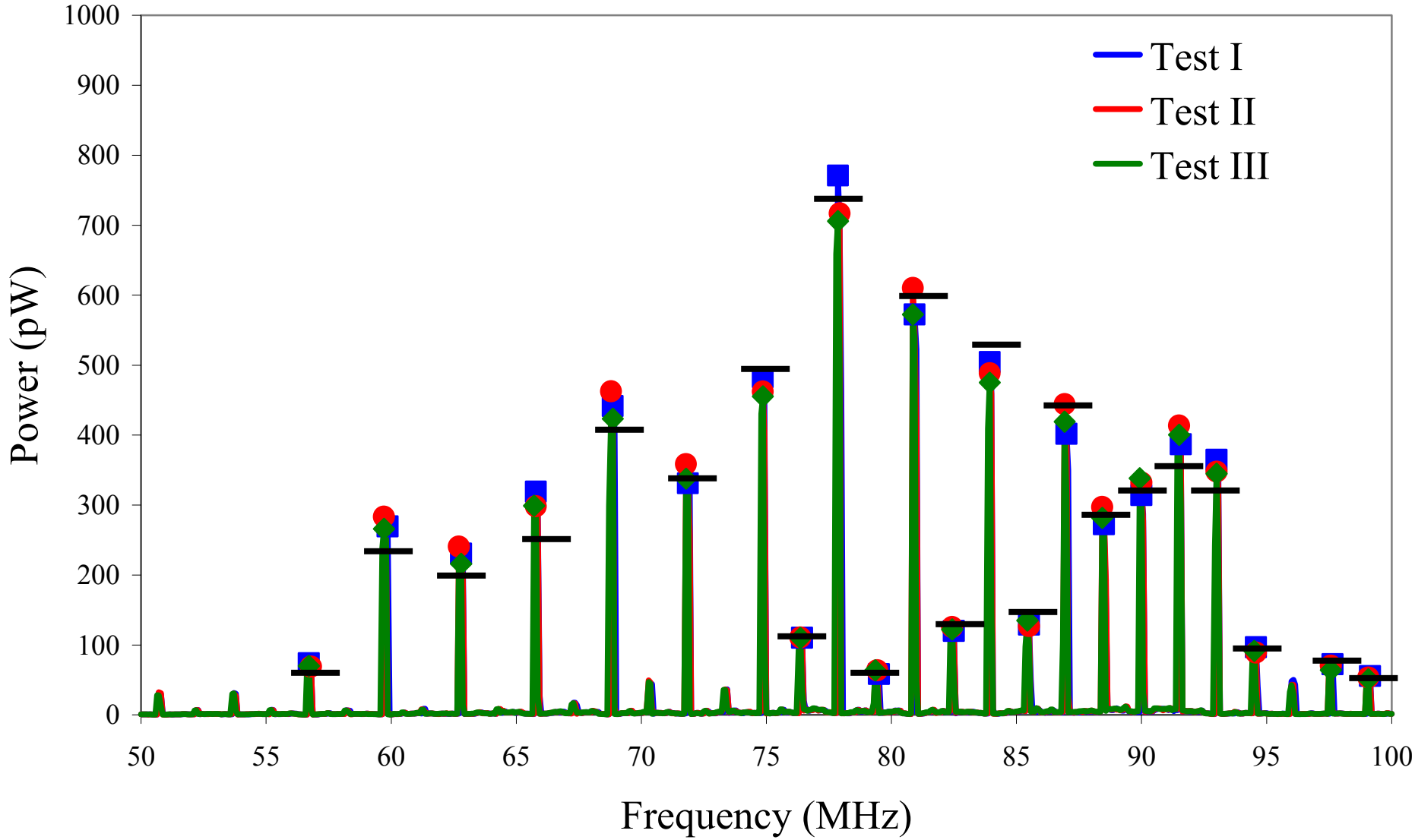
Total radiated power (including unknown phases)

$$P_t = \frac{20\,k^2}{e_o^2}\left[P_{a1} + P_{a2} + P_{a3} + P_{b1} + P_{b2} + P_{b3}\right]$$

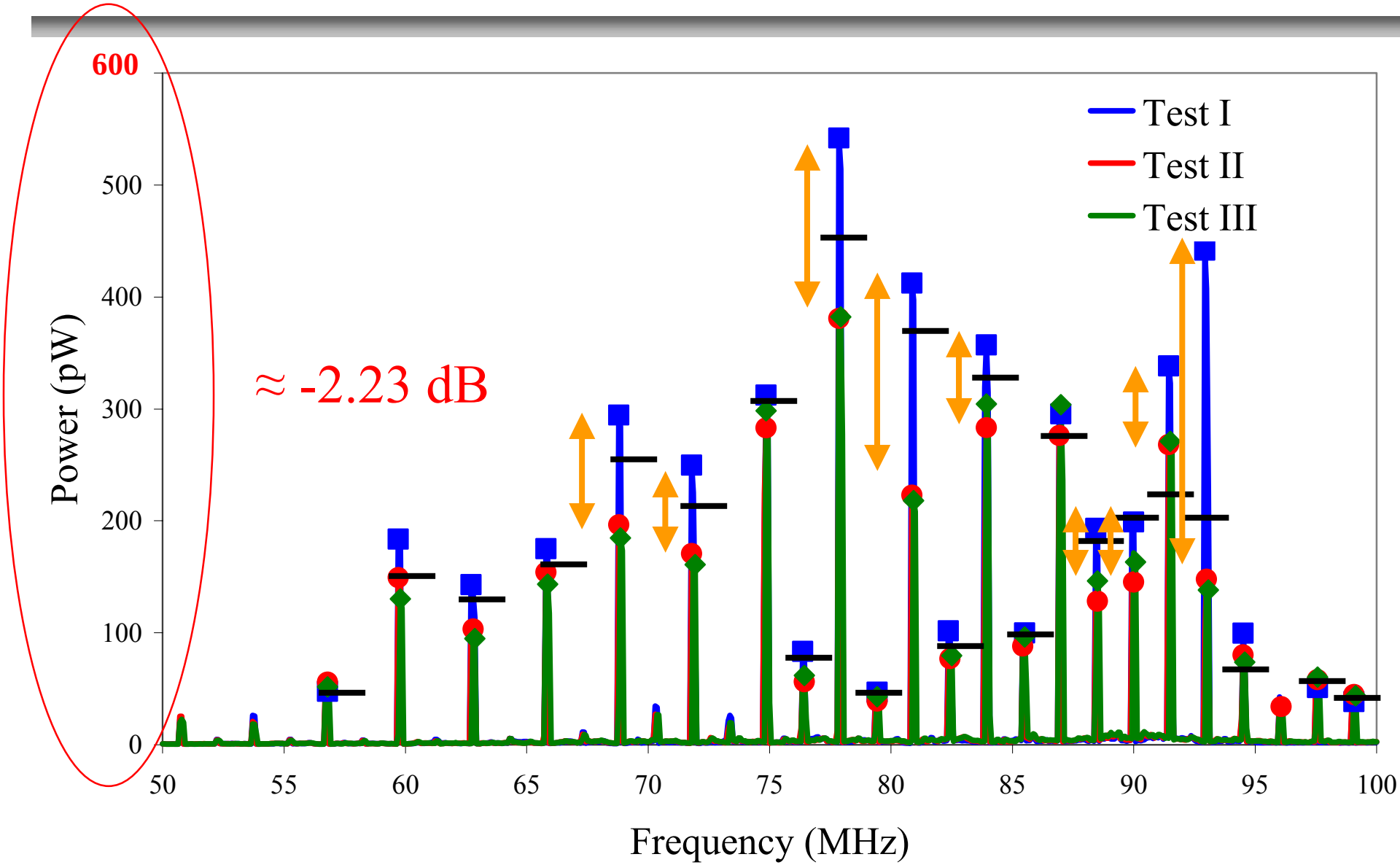
TEM cell (2 ports – 3 orientations)



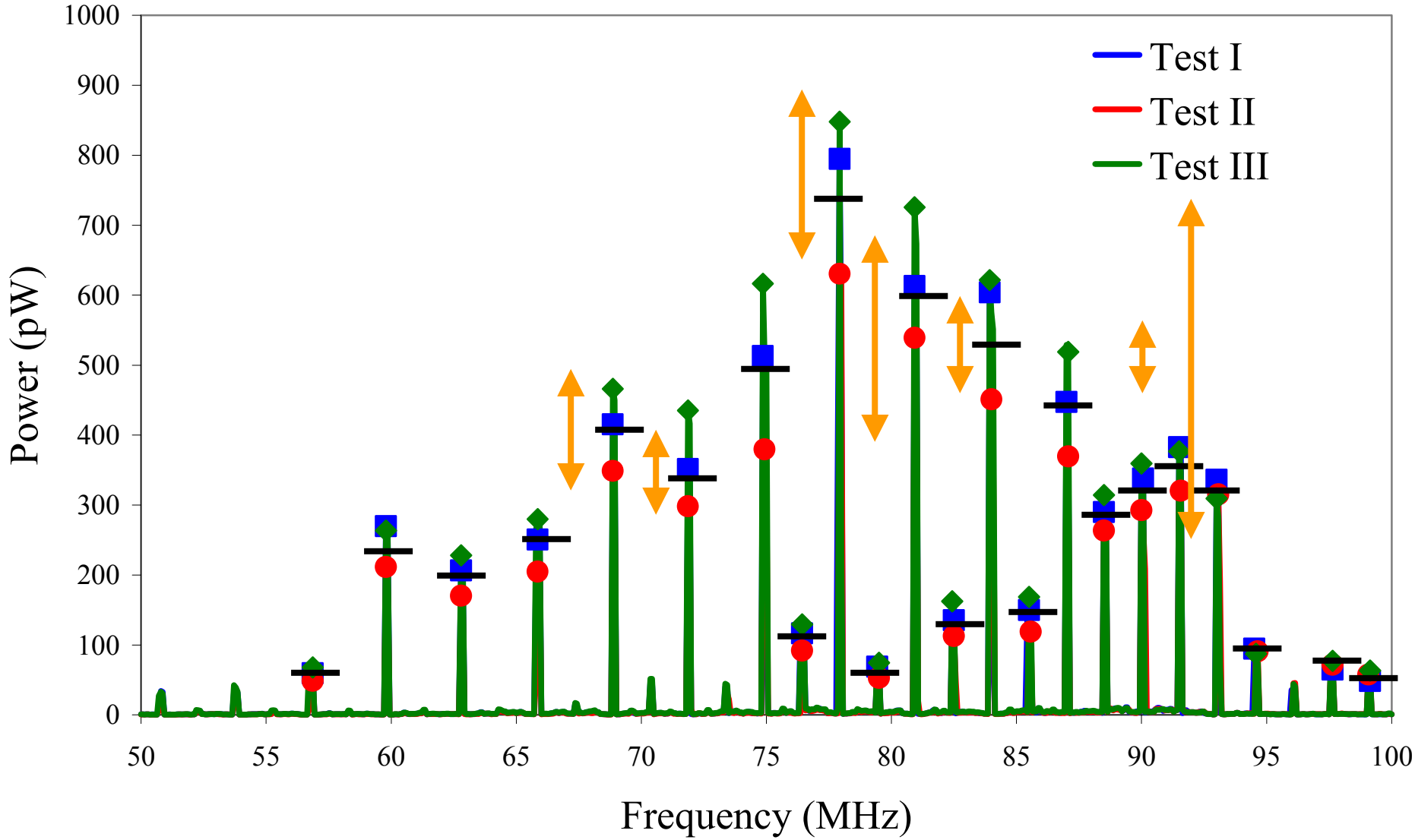
GTEM cell (1 port – 6 orientations)



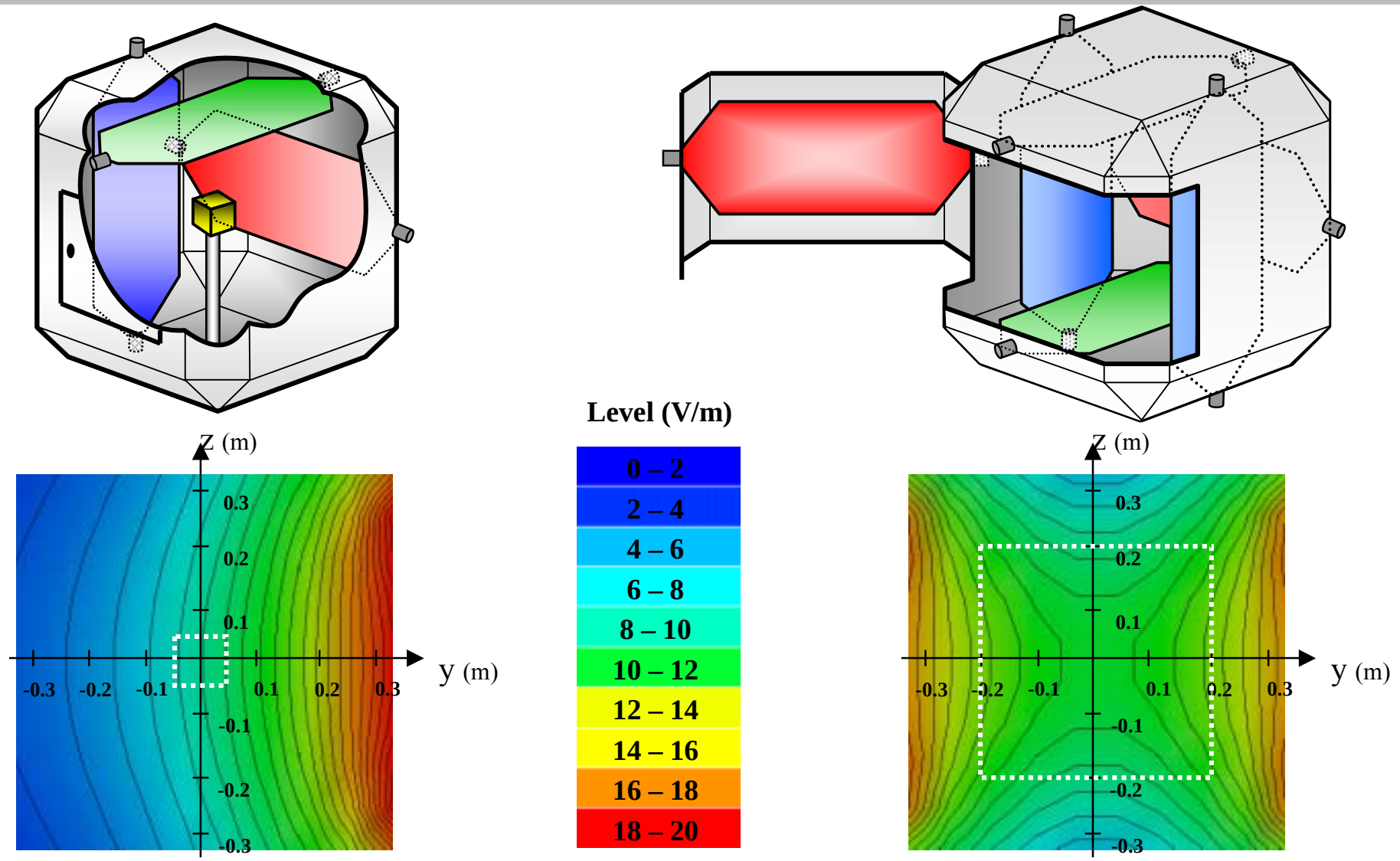
Prototype (6 ports – 1 orientation)



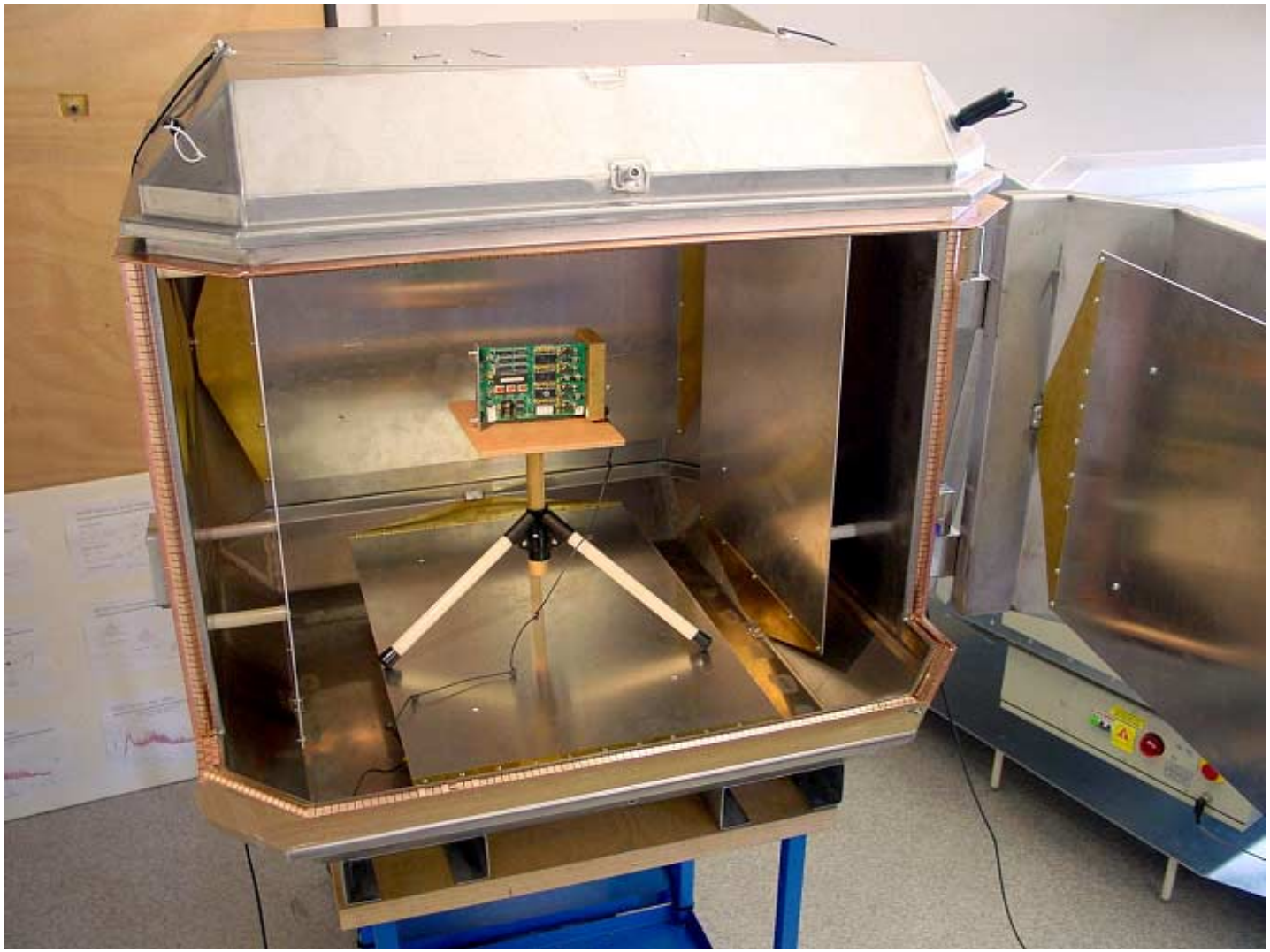
TEM cell (1 port – 3 orientations)



Field gradient and test volume



New balanced 6-plate 3D-TEM cell



Radiation in a waveguide

Electric and magnetic moments of the source

$$\begin{cases} \vec{M}_e = m_{ex} e^{j\psi_{ex}} \vec{x} + m_{ey} e^{j\psi_{ey}} \vec{y} + m_{ez} e^{j\psi_{ez}} \vec{z} \\ \vec{M}_m = m_{mx} e^{j\psi_{mx}} \vec{x} + m_{my} e^{j\psi_{my}} \vec{y} + m_{mz} e^{j\psi_{mz}} \vec{z} \end{cases}$$

Electrically small source

Electric and magnetic fields generated for an input power of 1 Watt

$$\begin{cases} \vec{E} = e_x e^{j\varphi_{ex}} \vec{x} + e_y e^{j\varphi_{ey}} \vec{y} + e_z e^{j\varphi_{ez}} \vec{z} \\ \vec{H} = h_x e^{j\varphi_{hx}} \vec{x} + h_y e^{j\varphi_{hy}} \vec{y} + h_z e^{j\varphi_{hz}} \vec{z} \end{cases}$$

Field uniformity in source volume

Normalized voltage on one port

$$V = -\frac{1}{2}\left(\vec{M}_e.\vec{E} + j\,k\,Z_o\,\vec{M}_m.\vec{H}\right)$$

General expression of measured power

$$
P = \frac{1}{4}\left[\begin{array}{l}
m_{ex}^2 e_x^2 + m_{ey}^2 e_y^2 + m_{ez}^2 e_z^2 \\
+ k^2 Z_o^2 \left(m_{mx}^2 h_x^2 + m_{my}^2 h_y^2 + m_{mz}^2 h_z^2 \right) \\
+ 2\, m_{ex} m_{ey} e_x e_y \cos\left(\Delta\psi_{exey} + \Delta\varphi_{exey}\right) \\
+ 2\, m_{ey} m_{ez} e_y e_z \cos\left(\Delta\psi_{eyez} + \Delta\varphi_{eyez}\right) \\
+ 2\, m_{ez} m_{ex} e_z e_x \cos\left(\Delta\psi_{ezex} + \Delta\varphi_{ezex}\right) \\
+ 2\, k^2 Z_o^2 m_{mx} m_{my} h_x h_y \cos\left(\Delta\psi_{mxmy} + \Delta\varphi_{hxhy}\right) \\
+ 2\, k^2 Z_o^2 m_{my} m_{mz} h_y h_z \cos\left(\Delta\psi_{mymz} + \Delta\varphi_{hyhz}\right) \\
+ 2\, k^2 Z_o^2 m_{mz} m_{mx} h_z h_x \cos\left(\Delta\psi_{mzmx} + \Delta\varphi_{hzhx}\right)
\end{array}\right]
$$

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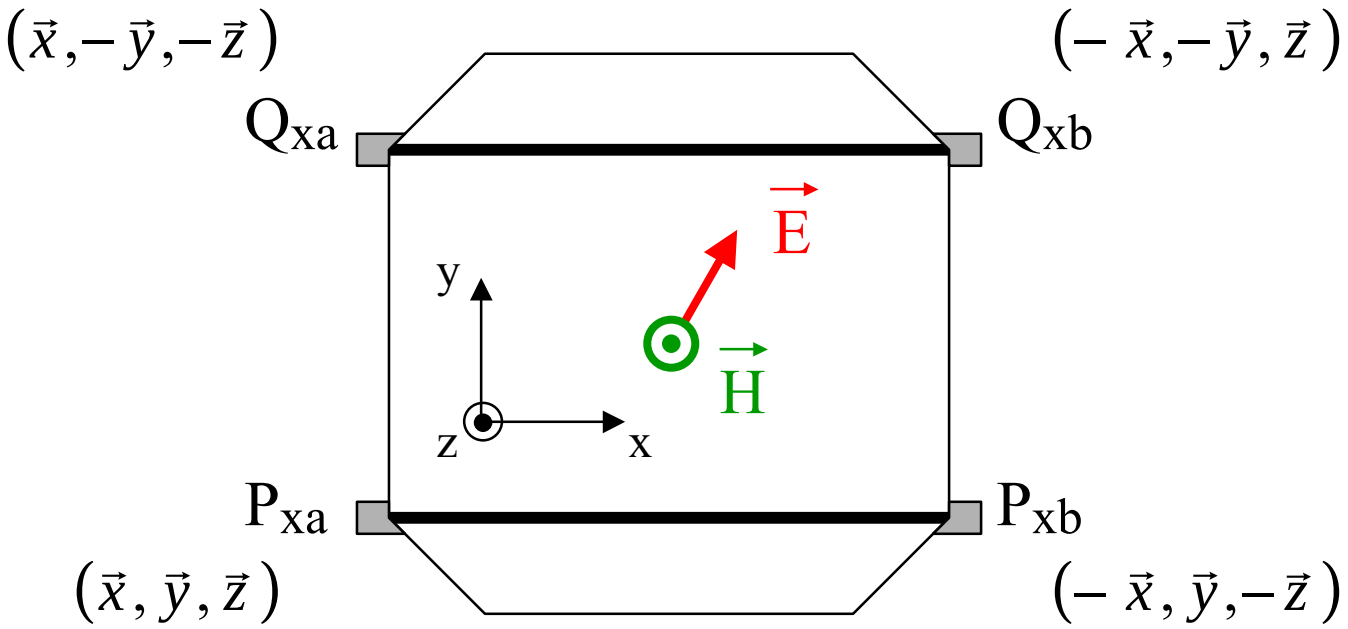
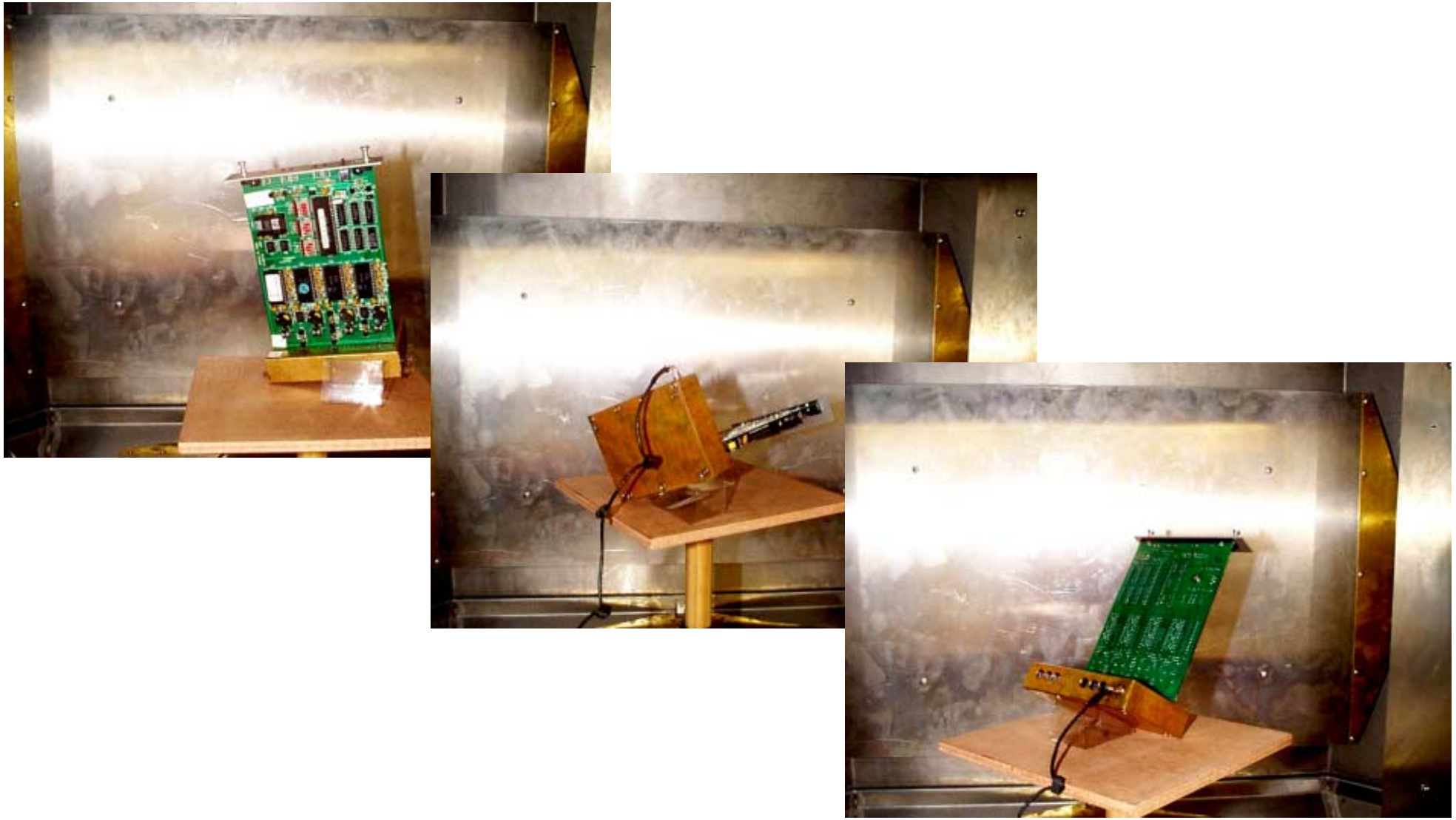
(cont'…)

$$
\begin{aligned}
&+ 2kZ_o\ m_{ex} m_{mx} e_x h_x \sin(\Delta\psi_{exmx} + \Delta\varphi_{exhx}) \\
&+ 2kZ_o\ m_{ey} m_{my} e_y h_y \sin(\Delta\psi_{eymy} + \Delta\varphi_{eyhy}) \\
&+ 2kZ_o\ m_{ez} m_{mz} e_z h_z \sin(\Delta\psi_{ezmz} + \Delta\varphi_{ezhz}) \\
&+ 2kZ_o\ m_{ex} m_{my} e_x h_y \sin(\Delta\psi_{exmy} + \Delta\varphi_{exhy}) \\
&+ 2kZ_o\ m_{ey} m_{mz} e_y h_z \sin(\Delta\psi_{eymz} + \Delta\varphi_{eyhz}) \\
&+ 2kZ_o\ m_{ez} m_{mx} e_z h_x \sin(\Delta\psi_{ezmx} + \Delta\varphi_{ezhx}) \\
&+ 2kZ_o\ m_{ex} m_{mz} e_x h_z \sin(\Delta\psi_{exmz} + \Delta\varphi_{exhz}) \\
&+ 2kZ_o\ m_{ey} m_{mx} e_y h_x \sin(\Delta\psi_{eymx} + \Delta\varphi_{eyhx}) \\
&+ 2kZ_o\ m_{ez} m_{my} e_z h_y \sin(\Delta\psi_{ezmy} + \Delta\varphi_{ezhy})
\end{aligned}
$$

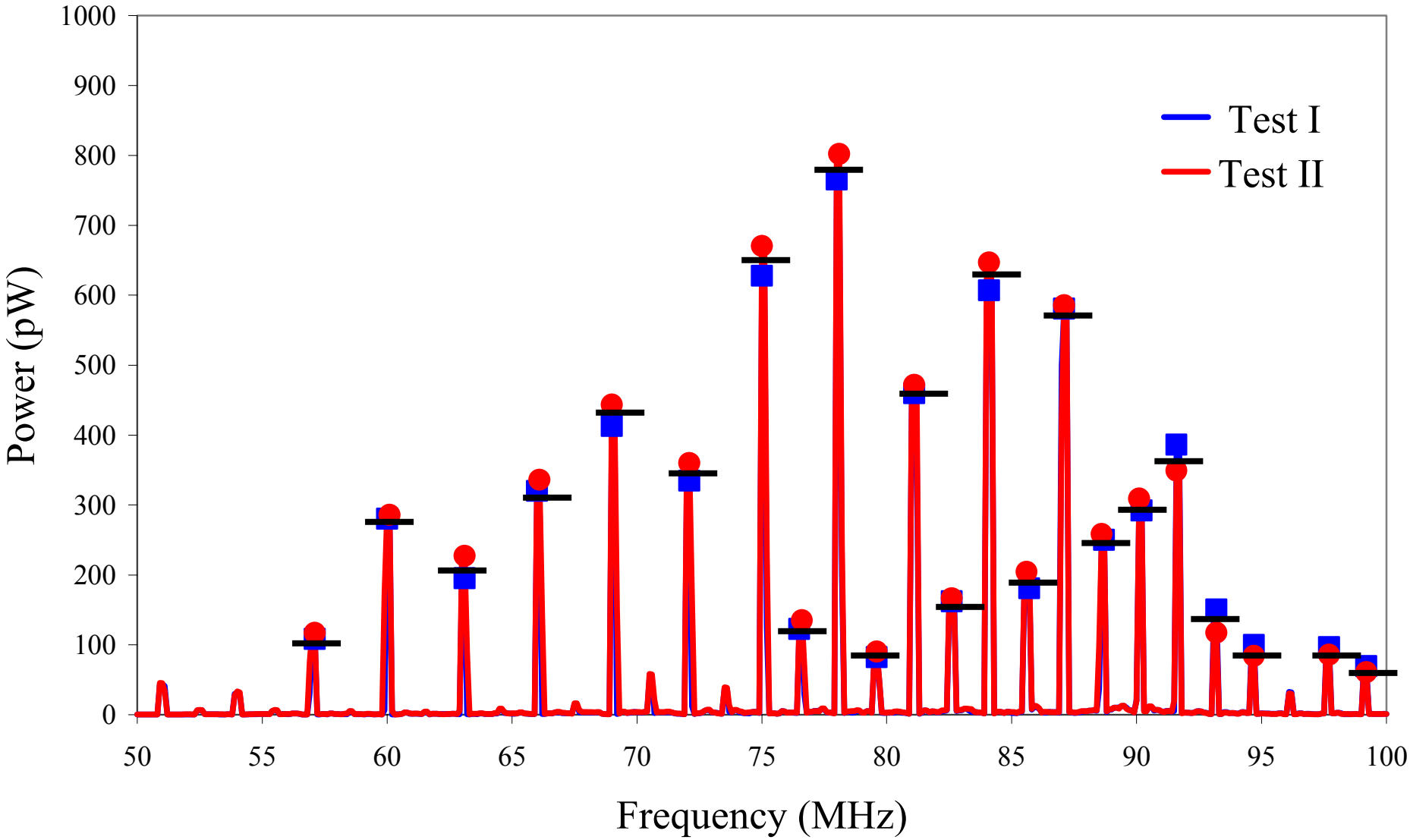
Symmetry properties in the center



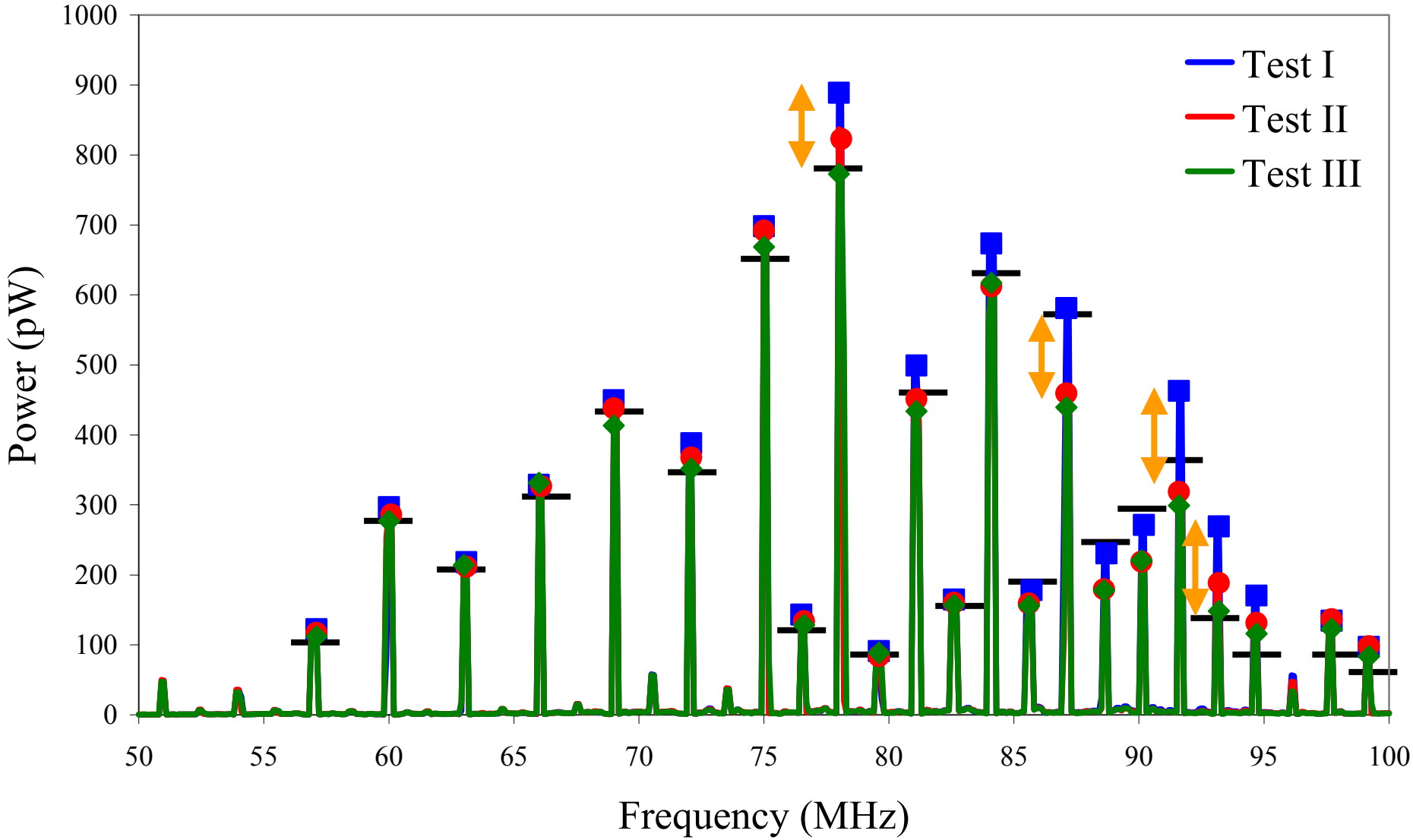
Arbitrary chosen orientations



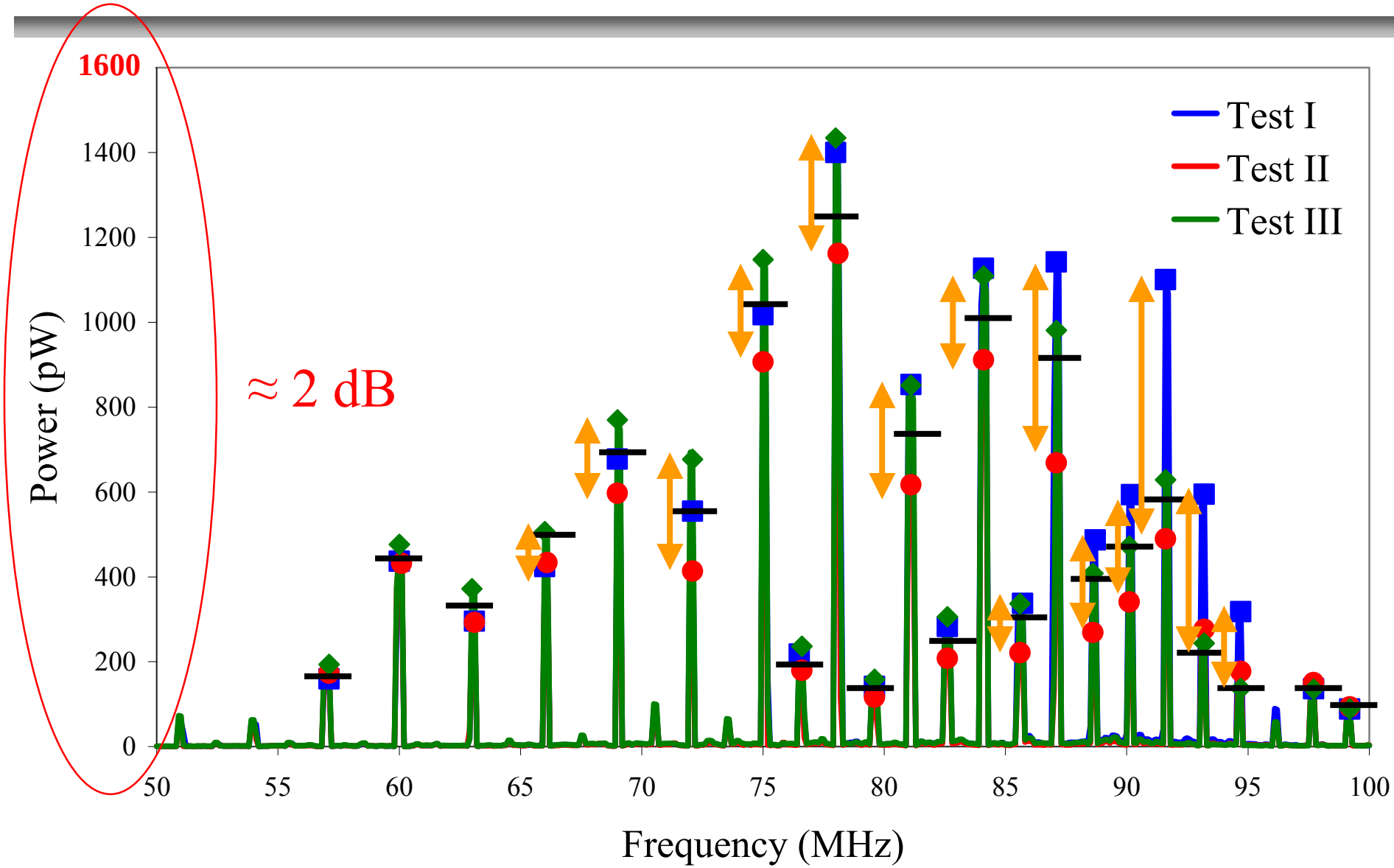
TEM cell reference



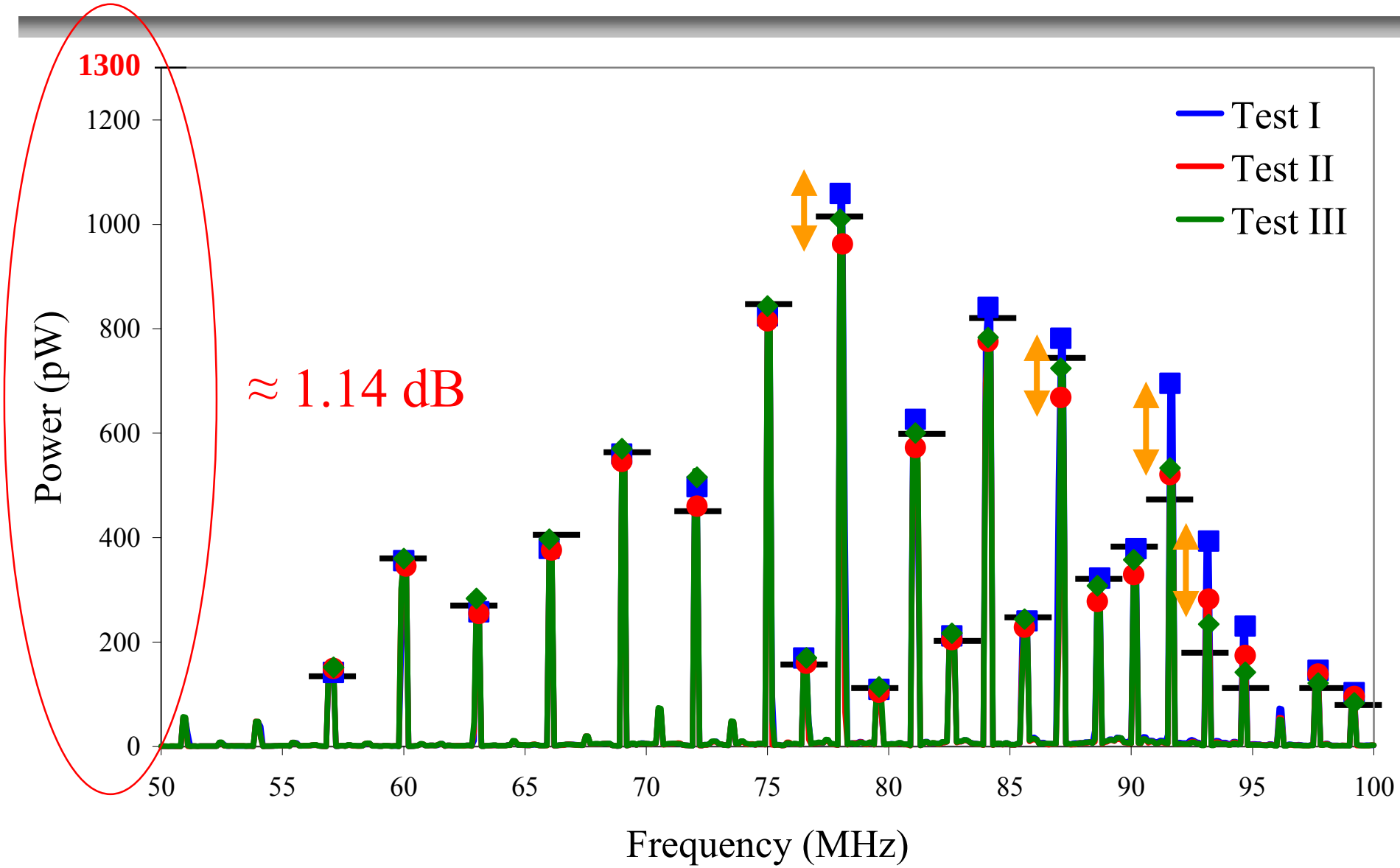
Balanced mode results



Summing the power of only 6 ports



Summing the power of all 12 ports



Conclusions and perspectives

- Results obtained with the first prototype were sufficiently encouraging to construct a cubic 6-plate 3D-TEM cell
- Excellent results in balanced mode but needs a hybrid coupler
- Equivalent results by summing all the 12 ports
- Poor results using only 6 ports
- Further work :
  - Optimization of the tapered sections
  - Radiation diagram combining several ports
  - Above the first resonant frequency ?