MKI Kicker Wire Measurements

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Measurement Set-up

- Fully assembled MKI kicker with ceramic pipe
- 0.5 mm copper wire placed in center of MKI Kicker

Three measurement techniques were applied.

- Ordinary transmission and reflection measurements without matching resistors. Easy to carry out, relatively high measurement uncertainty; multiple reflections inside the kicker can occur.
- Time domain gating used on the transmission and reflection data to remove multiple reflections. May introduce errors close to the limits of the frequency band.
- Resonator measurements. More tedious, but very high sensitivity at distinct resonance frequencies. Imaginary part of impedance cannot be derived easily.

Resonator Measurement

- The TEM transmission line composed of the coated ceramic pipe and the wire can be used as a TEM resonator
- Capacitive coupling with low coupling coefficient k chosen, where k is given by $k = S_{21}/(1-S_{21})$ [1]
- Loaded quality factor Q_L measured for each peak as well as S_{21}
- Line attenuation α can be easily calculated from [2]

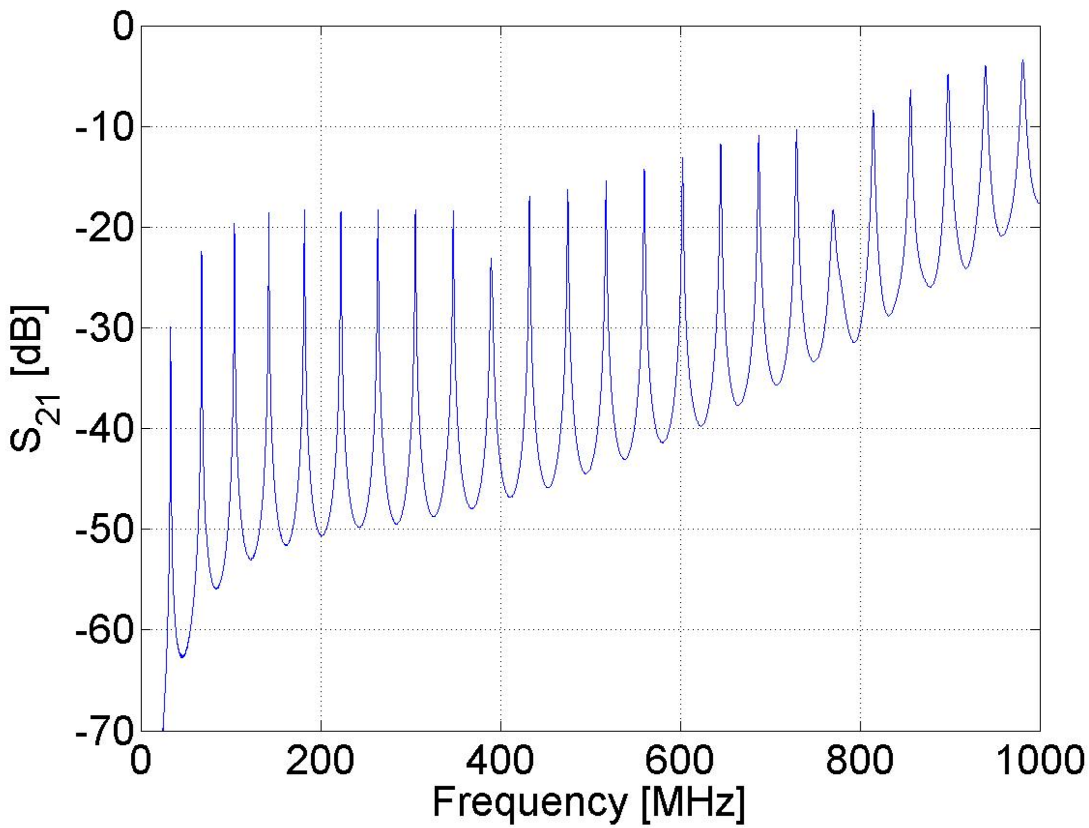
$$\alpha = \frac{\pi}{\lambda Q_0} \,[\mathrm{Np/m}]$$

- with $Q_0 = Q_L * (1+k)$ for $k << 1$ [1]
- For too strong coupling, the unloaded Q factor can be obtained by correcting the measured Q factor knowing S_{21}
- For too weak coupling the Q measurement gets impacted by noise
- An appropriate coupling coefficient between these two extremes was chosen

[1] Bray, J.R. and Roy, L., Measuring the unloaded, loaded, and external quality factors of one- and two-port resonators using scattering-parameter magnitudes at fractional power levels, IEE (2004)
[2] Meinke, H. and Gundlach, F. W., Taschenbuch der Hochfrequenztechnik, Berlin (1968)

Resonance Pattern

- Typical resonance pattern
- In this case the S_{21} at the resonance peaks and therefore the coupling coefficient was a bit too high => errors in the range of a few % in the unloaded Q, since the correction is not exactly valid



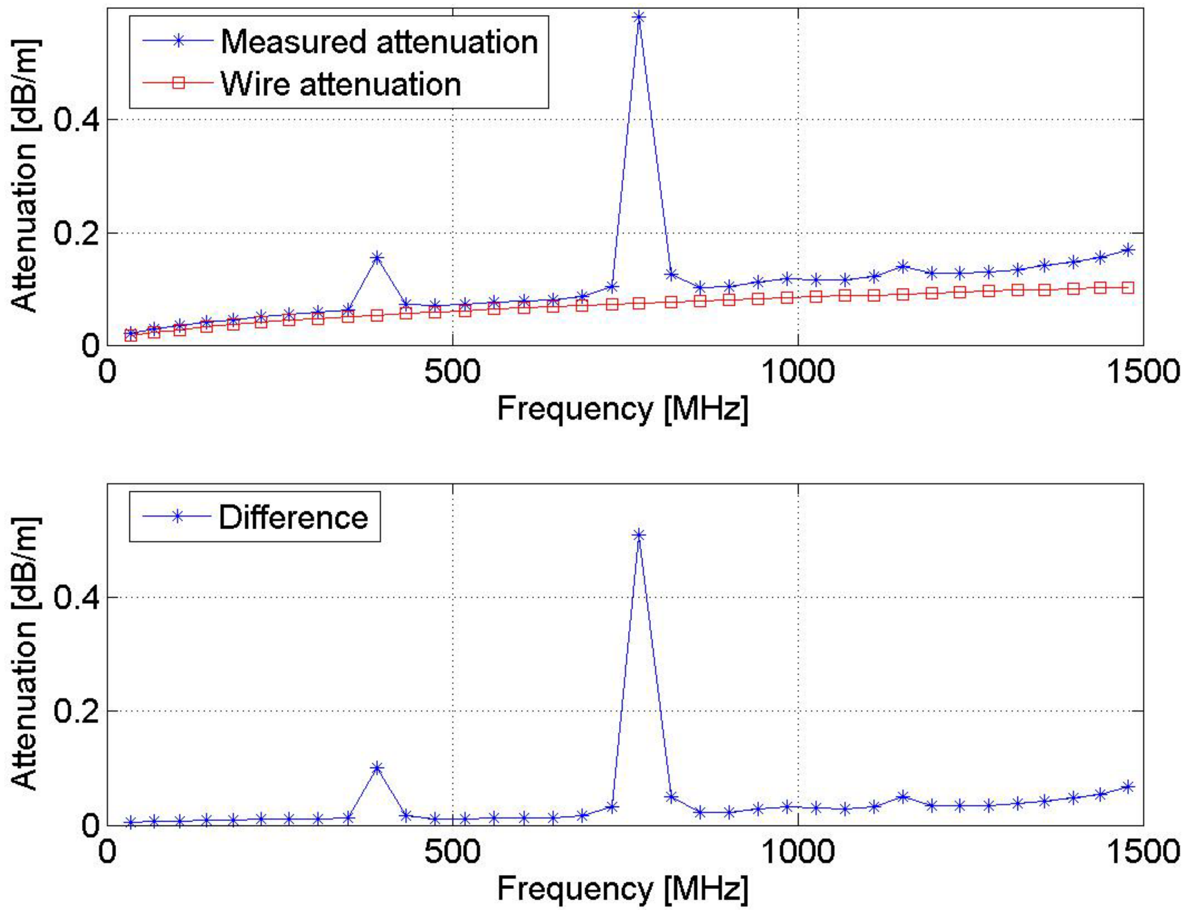
Resonator Results

- Attenuation evaluated at 36 resonance peaks below 1500 MHz
- Measured attenuation only slightly above the values calculated for the wire used
- Two distinct kicker resonances found at 390 and 770 MHz
- Wire attenuation calculated from

$$\alpha_w\ [\mathrm{Np/m}] = \sqrt{\pi\rho\varepsilon_0 f}\ \frac{1}{d\ln(D/d)}\ [1]$$

with the wire resistivity ρ, the wire diameter d and the beam pipe diameter D

- Finite skin depth effect as well as field penetration through slots was accounted for.

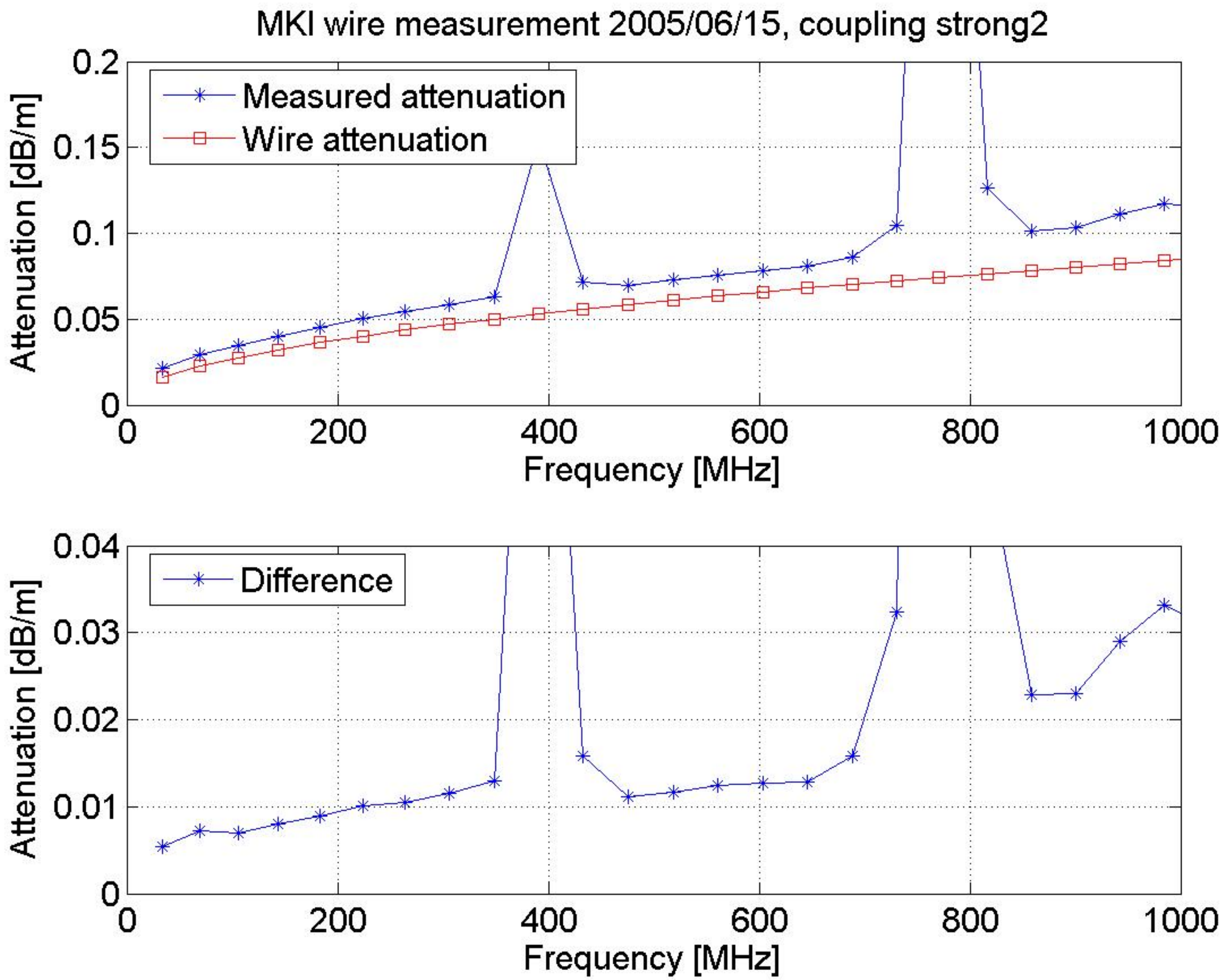


[1] Fontolliet, P.-G., Systemes de Telecommunications, Traite d'Electricite, Vol. 17, Lausanne (1999)

Resonator Results - Details

- Apart from the two kicker resonances, the additional attenuation is rather low, between 0.005 and 0.012 dB/m below 500 MHz

- The attenuation of the wire is much larger that this additional attenuation



Kicker Impedance per meter

- The DC resistance R_0 of a wire of length L, resistivity ρ and diameter d is given by

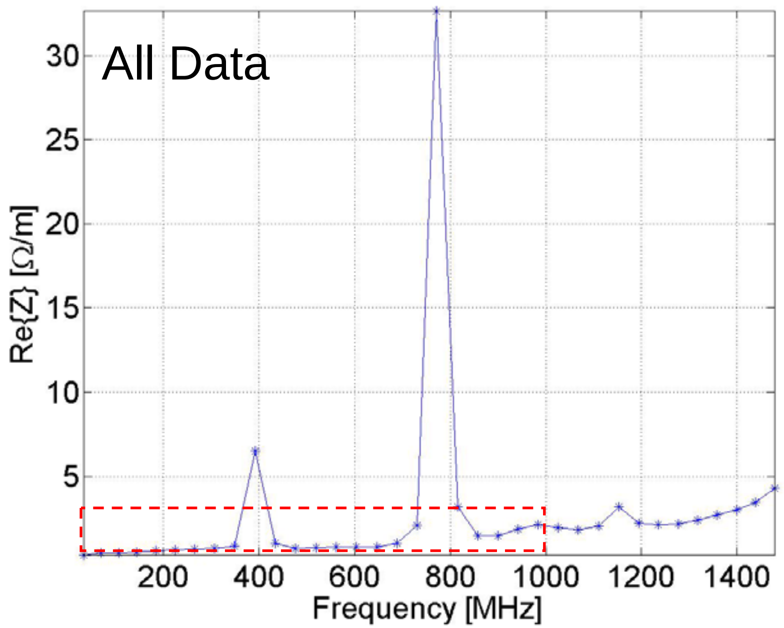
$$R_0\ [\Omega] = \frac{4L\rho}{\pi d^2}\ [1].$$

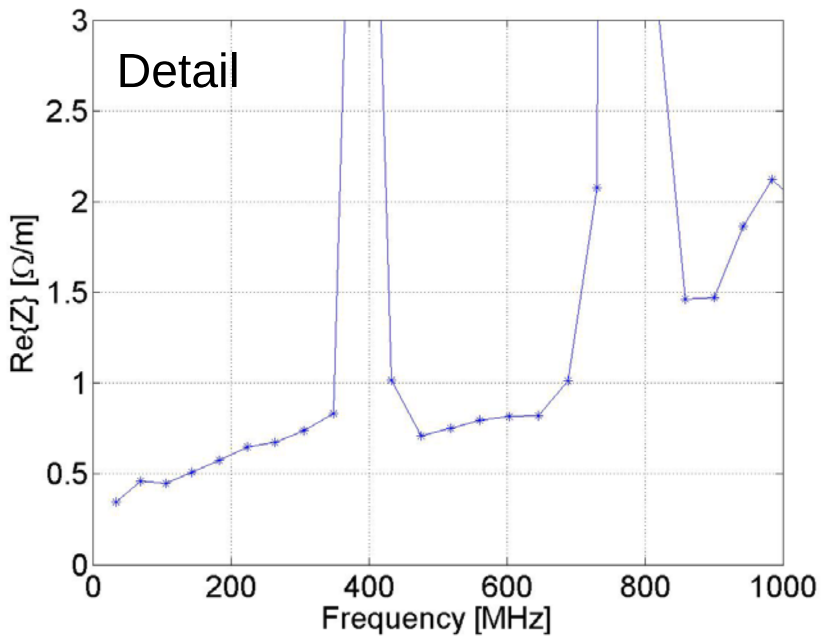
[1] Meinke, H. and Gundlach, F. W., Taschenbuch der Hochfrequenztechnik, Berlin (1968)

- For skin depths δ small compared to d the high frequency resistance

$$R\ [\Omega] = R_0 * d/(4\delta)\ [1].$$

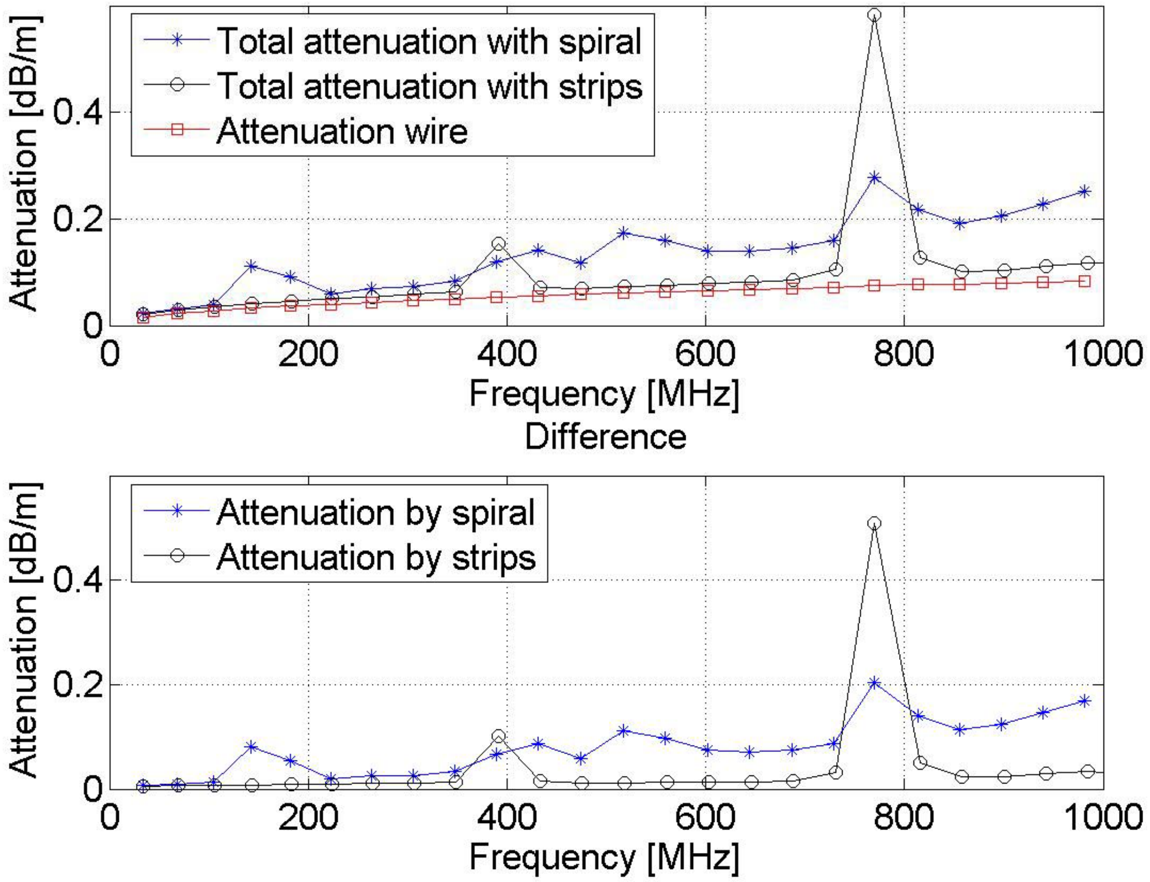
- This resistance is proportional to the line attenuation
- Comparing the measured kicker attenuation to the calculated wire attenuation the real part of the kicker impedance can be found





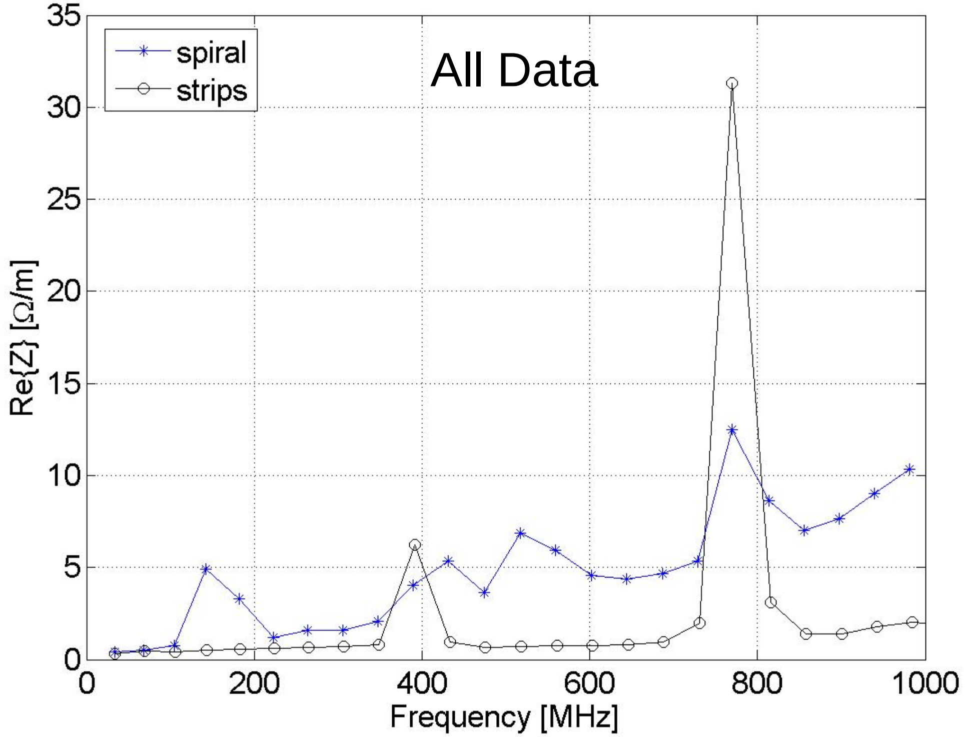
Attenuation with Spiral

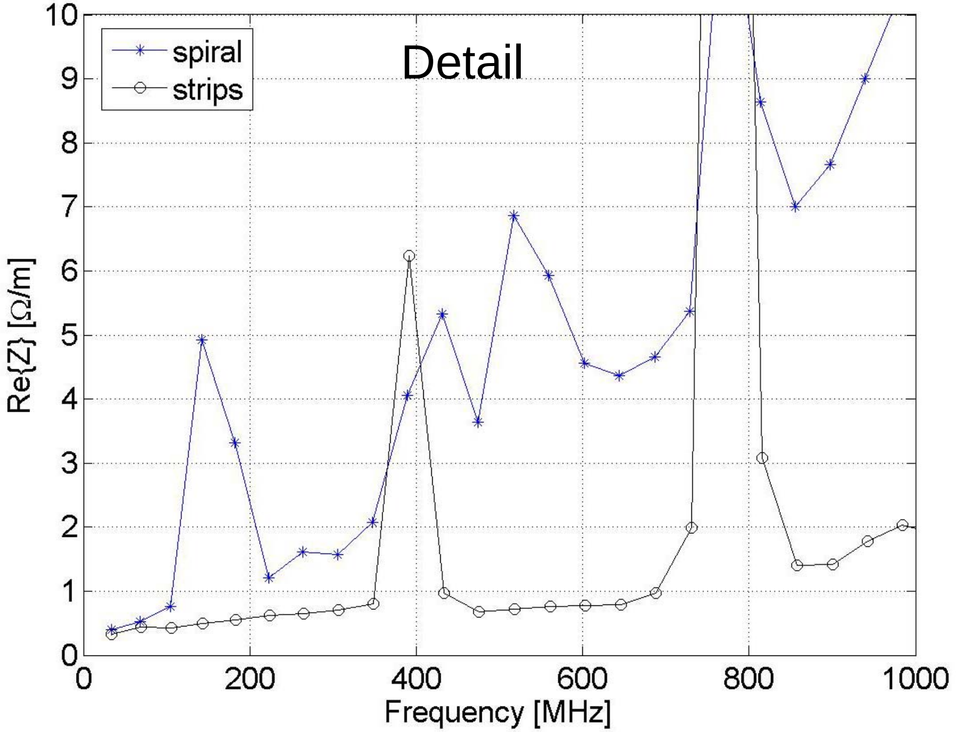
- Measurements with spiral compared to longitudinal strips
- Higher attenuation found for spiral



Impedance of Spiral

- Impedance of spiral compared to longitudinal strips

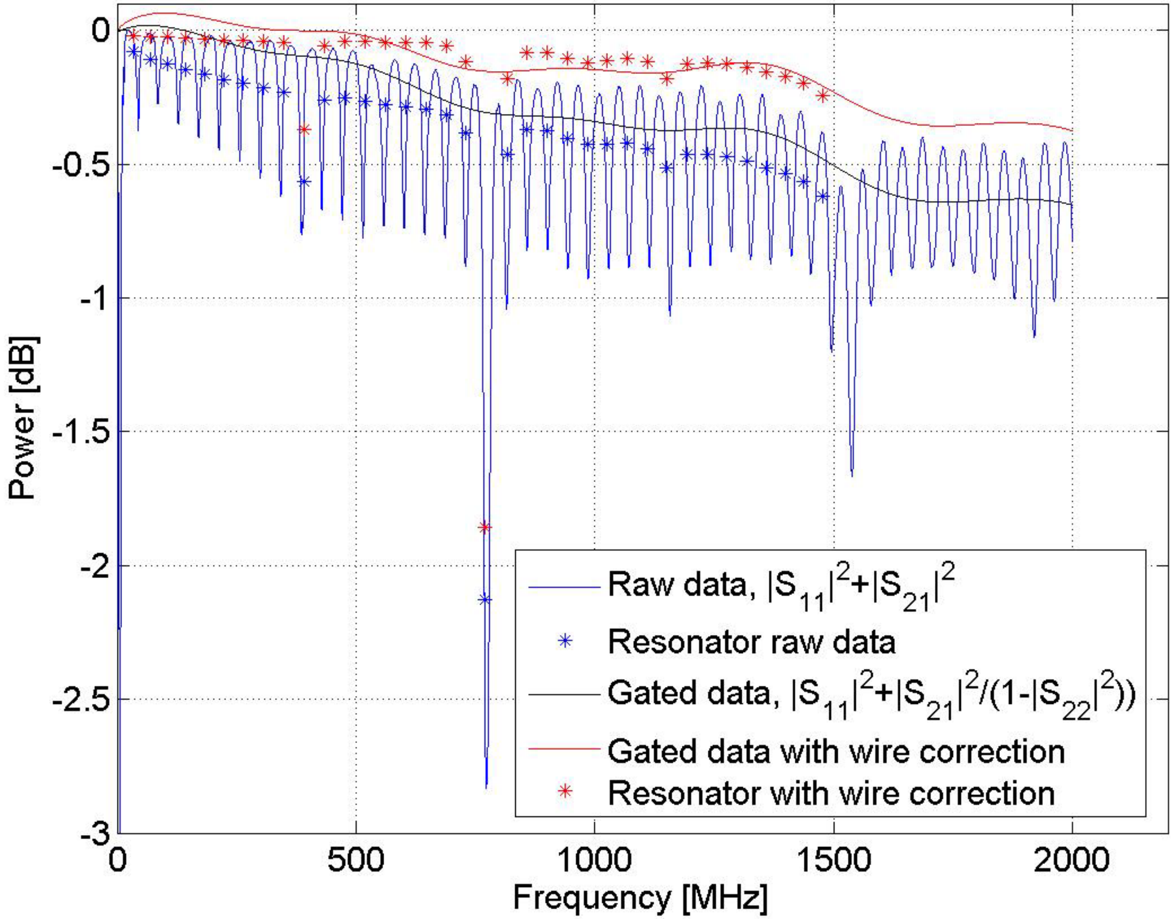




Comparison of Measurement Techniques

- Wave power should add up to 0 dB, otherwise the results are unphysical (active device!!!)
- Resonator measurement by far most reliable
- Good agreement between "Raw data" and "Resonator raw data" (blue)
- Ripples in "Raw data" due to multiple reflections inside kicker
- Gated data too high at low frequencies; residue of gating process
- Fair agreement between corrected gated data and resonator data (red)

Power balance; 0 dB would be obtained for a lossless device

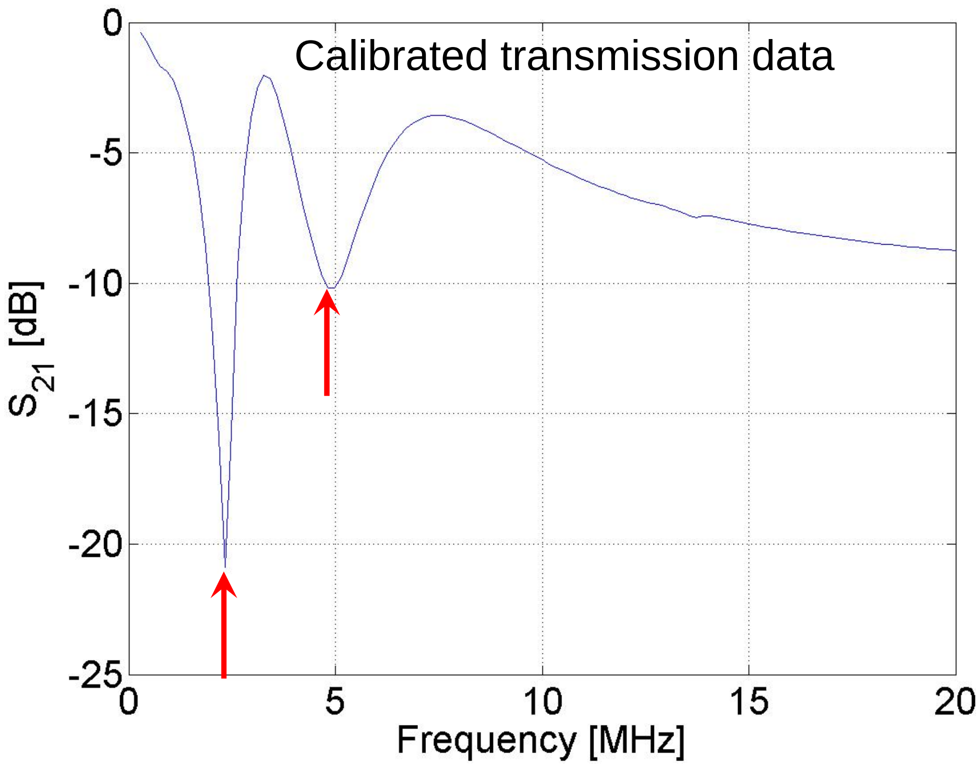


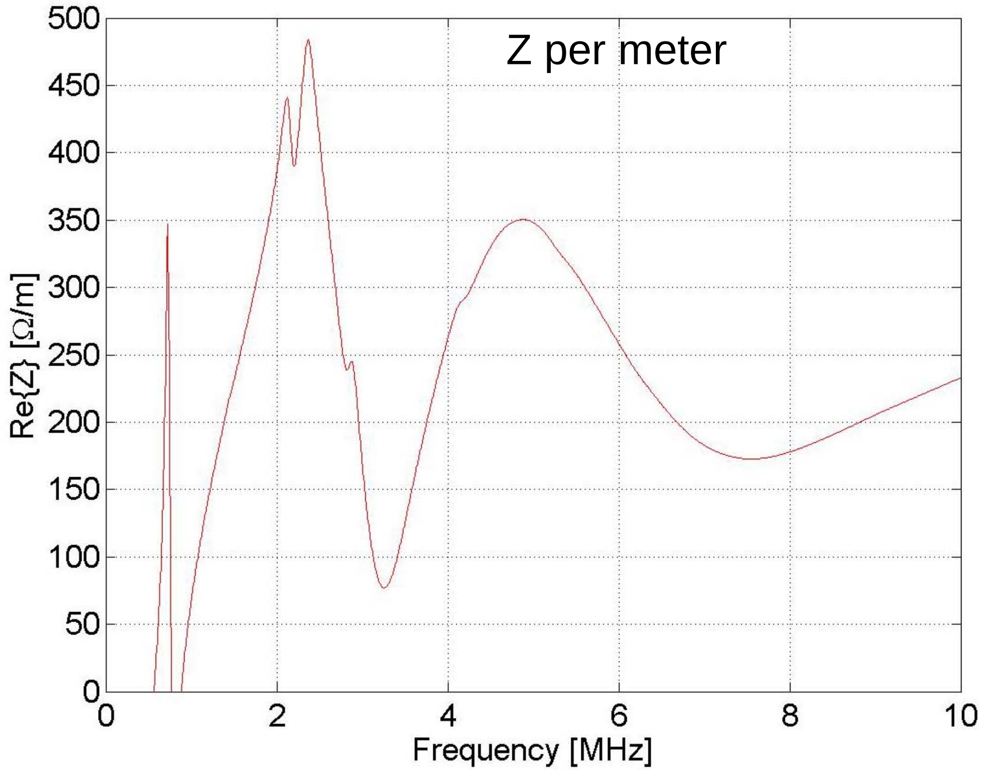
Resonances below 40 MHz

- Rather strong resonances at 2.3 and 4.8 MHz have been found
- The impedance was calculated using the log formula with the system impedance Z_0 = 50 Ω and the calibrated S_{21} representing the ratio $S_{21,DUT}/S_{21,REF}$.

$$Z\,[\Omega] = -2Z_0 \ln\left(\frac{S_{21,DUT}}{S_{21,REF}}\right) \quad [1]$$

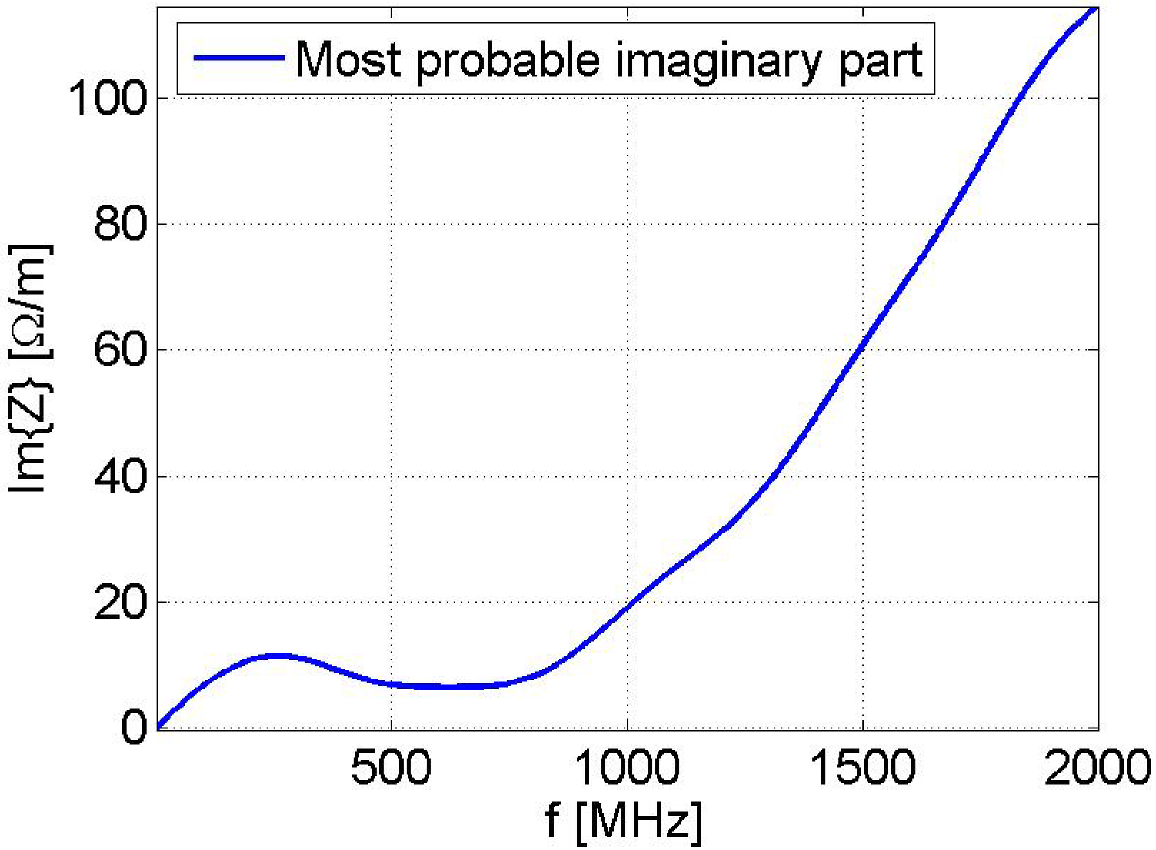
[1] Chao, A. W. and Tigner, M. (Editors), Handbook of Accelerator Physics and Engineering (1998)





Imaginary Part of Z per meter

- Gated transmission data can be used, since wire attenuation does not impact phase
- Phase correction performed according to measured line length
- Correction very sensitive on length of connectors, even dielectrics in the connectors play a role...
- No peaks at low frequency visible like on the previous slide, since here gated data was used

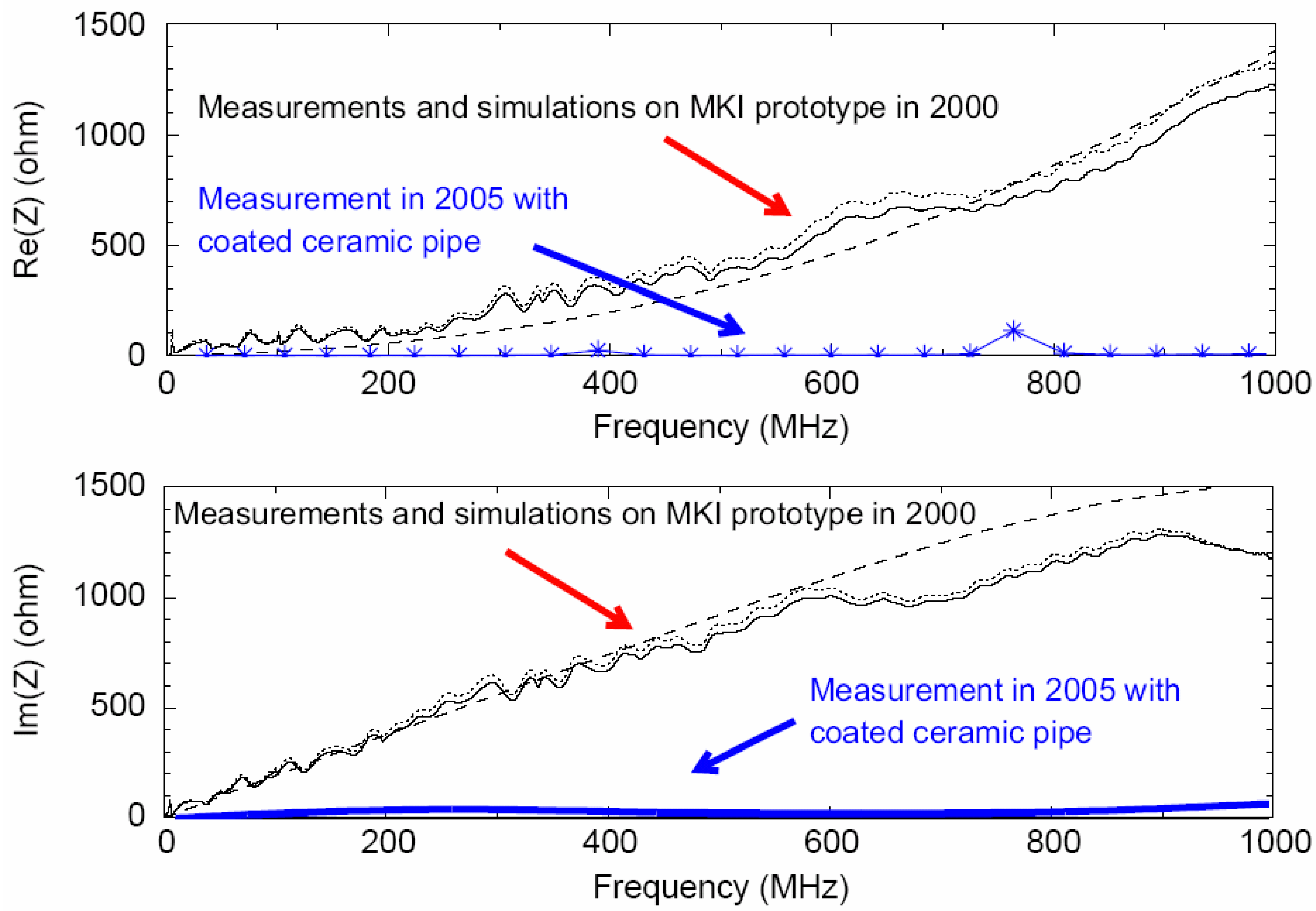


Comparison with Previous Data

- The impedance of the entire MKI prototype was measured in 2000 (F. Caspers et al., Impedance Measurements on the LHC Injection Kicker Prototype, LHC Project Note 219, 2000)

Improvement:

- Roughly factor 100 in real part of impedance and
- About factor 20 in imaginary part



Conclusion

- From these measurements we may conclude that we will not get a significant beam-induced heating problem in this type of kicker with the shielding strips properly installed (assuming 20 W/Ω)
- We do have strong resonances below 10 MHz where better damping could be evaluated, e.g. by using an MnZn ferrite torus instead of the recently used NiZn

Acknowledgements

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