Impedance and FCC-e^-e^+

of perfect flat surfaces with uniform resistance

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Credit to Benoit Salvant and Sergio Calatroni.

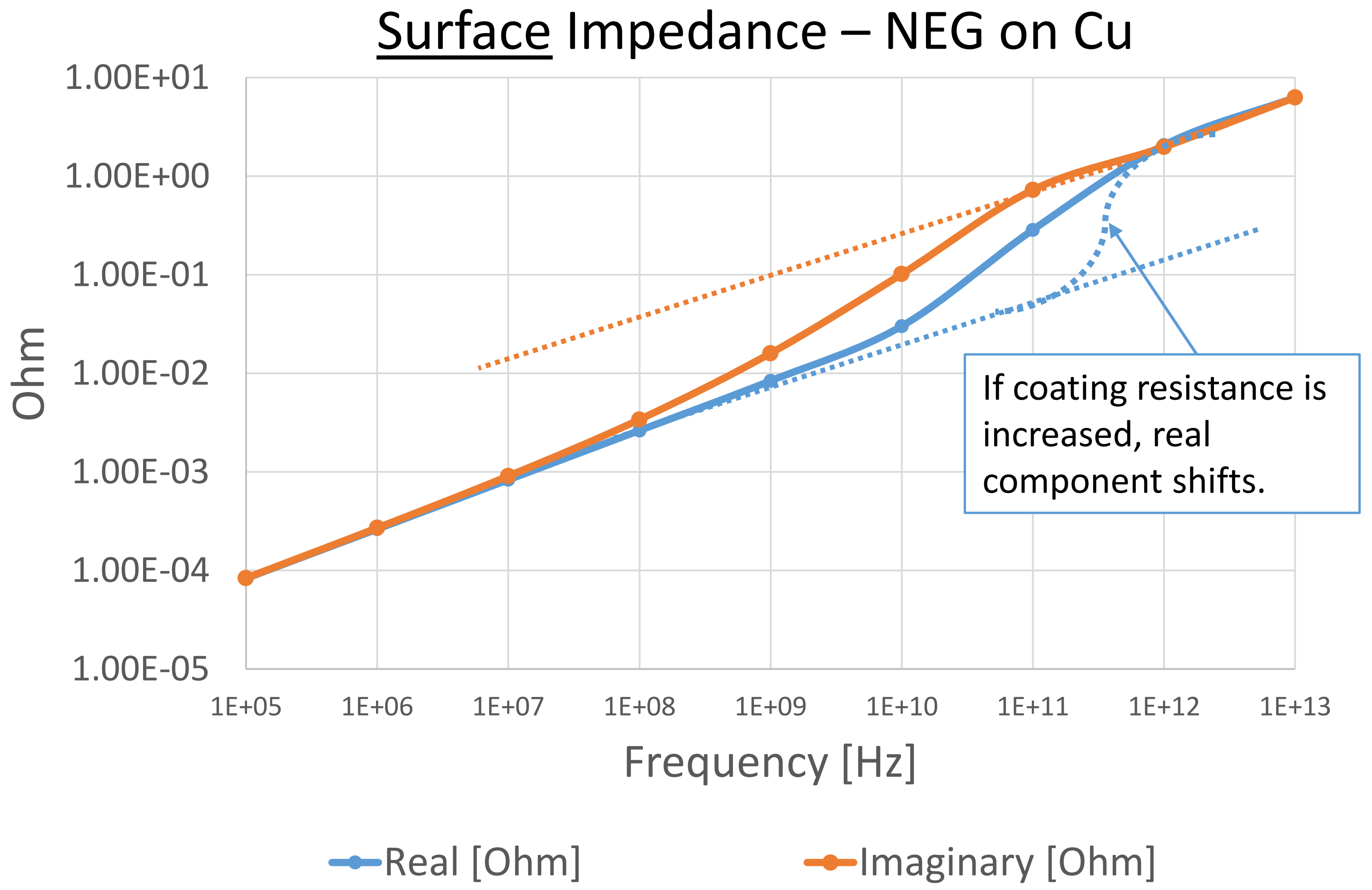
Content

- Impedance: bunch length, material resistance, and coating thickness.
- One identified problem with FCC-ee and coatings.
- Our task
- Model inputs
- Outputs
- Summary

We do not intend to consider vacuum, e-cloud or desorption effects, but the coatings assessed play a significant role in reducing these problems, and their influence on impedance is critical!

Impact of frequency

The bunch length does not change the impedance itself, but changes the frequency range of interest. Bunch length in FCC-ee is very small (2.1 mm) and this leads to higher active frequencies.



Dependencies:

- Frequency
- Thickness (coating)
- Material Resistance

Surface impedance is linked to longitudinal and transverse impedance.

Impedance, FCC-ee & Coatings

Longitudinal Impedance

- **Real component leads to <u>Power Loss</u>**
- **Real and Imaginary leads to <u>longitudinal instabilities</u>**

Eleonora Belli presented findings in FCC week 2017 and concluded

- For longitudinal impedance,
  - 1000 nm NEG leads to <u>longitudinal instabilities</u>.
  - 200 nm Amorphous Carbon and TiN <u>do not</u>.

Transverse Impedance

- **Leads to transverse instabilities.**

→

Amorphous Carbon and TiN (200 nm) and NEG (1000 nm) do not have a limitation for transverse impedance and instabilities

- but NEG (1 um) is identified as 'dangerous'.

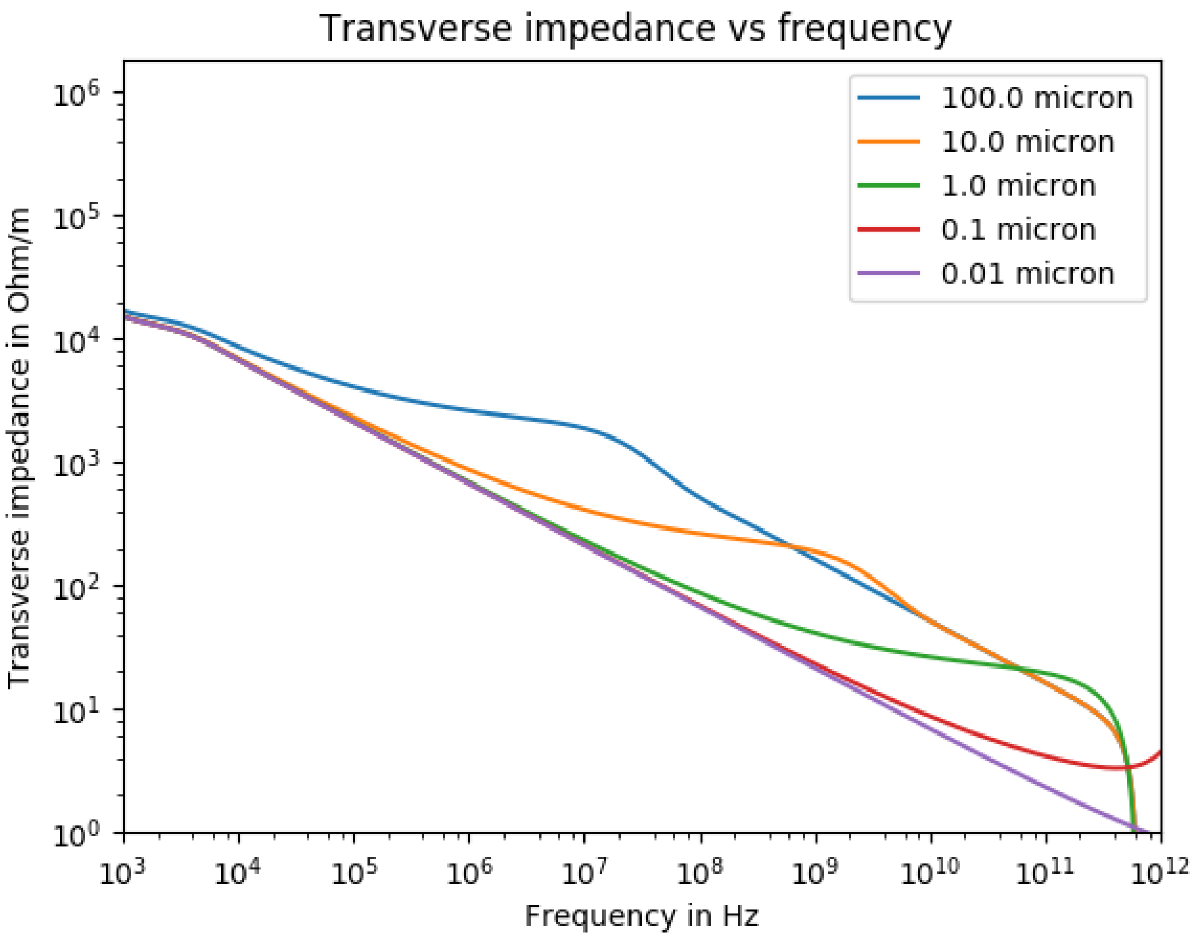
Taken from http://deathbattlefanon.wikia.com/wiki/Shelob

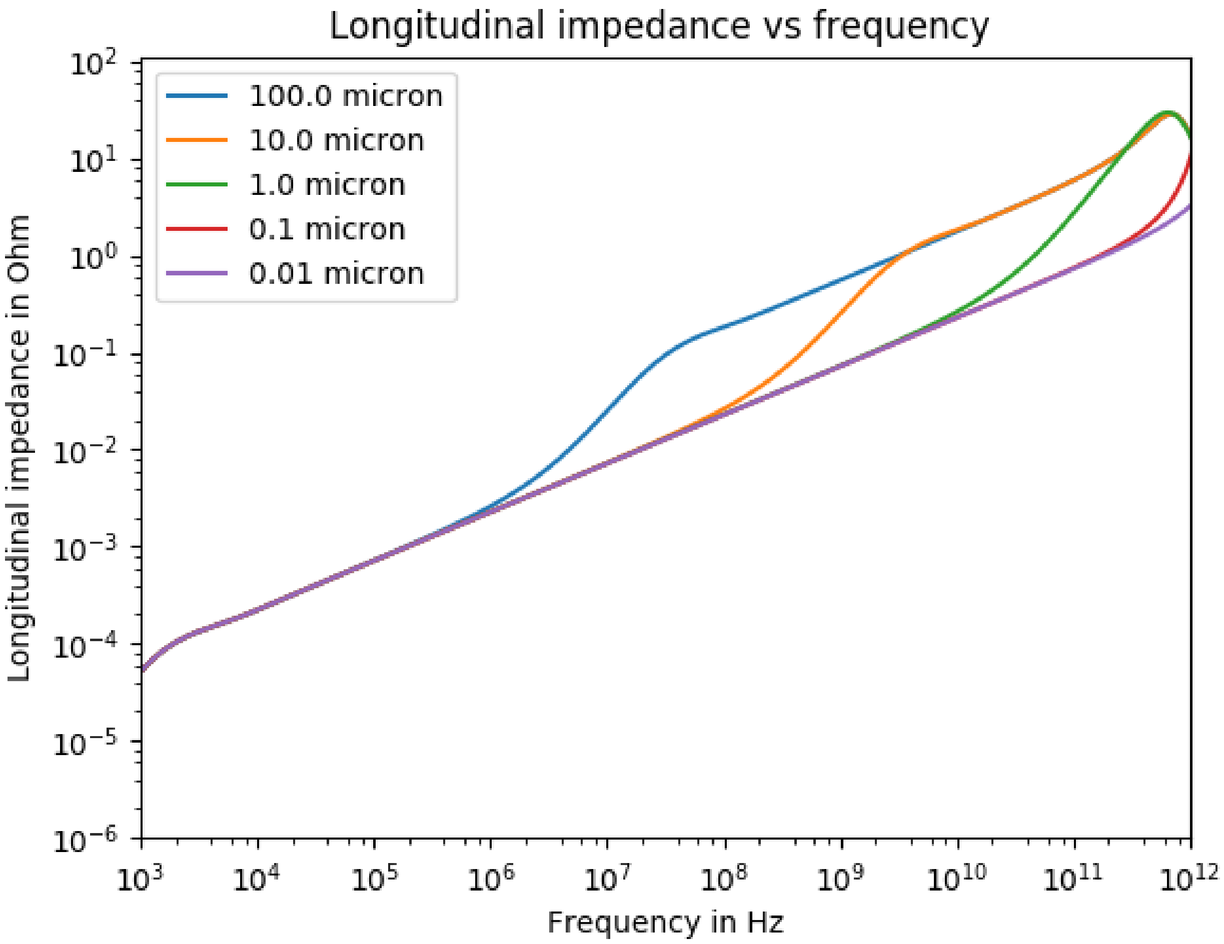
Impedance is like Shelob from Lord of the Rings.

She’s imaginary, and very real. If you try to pass a beam through her lair quietly and carefully your beam will get through.

If your beam moves with high frequency it will be slowed by her webs and she will paralyse and <u>eat your beam!</u>

Impact of NEG thickness on Cu (for example)





<u>Transverse impedance ∝ Longitudinal Impedance/Frequency</u>

Thicker coatings increase impedance.

Task

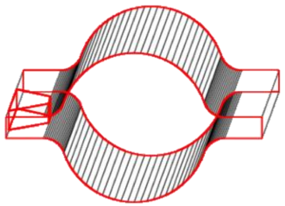
Understand impedance limitations due to coatings in the FCC-ee design, by calculating longitudinal and transverse impedance with a Python code (Impedance Wake 2D by Nicolas Mounet)

- What thickness of NEG will give the same impedance as 200 nm TiN and aC ?
- What materials should be used to reduce power loss?

Input parameters

Beam energy [GeV]	45.6
Circumference C [km]	97.75
Harmonic number	130424
RF voltage V_{RF} [MV]	255
Momentum compaction α_c [10^{-5}]	1.479
Horizontal tune Q_x	269.14
Vertical tune Q_y	267.22
Beam current I [A]	1.340
Bunches/ring	68240
Bunch population N [10^{11}]	**1.0 (real is 0.4)**
Energy spread (SR) $\sigma_{dp,SR}$ [%]	0.038
Bunch length (SR) $\sigma_{z,SR}$	**1 sigma - 2.1 mm** **7 x10^{-3} nanoseconds**
Pipe thickness [mm]	2
Pipe radius [mm]	**37**

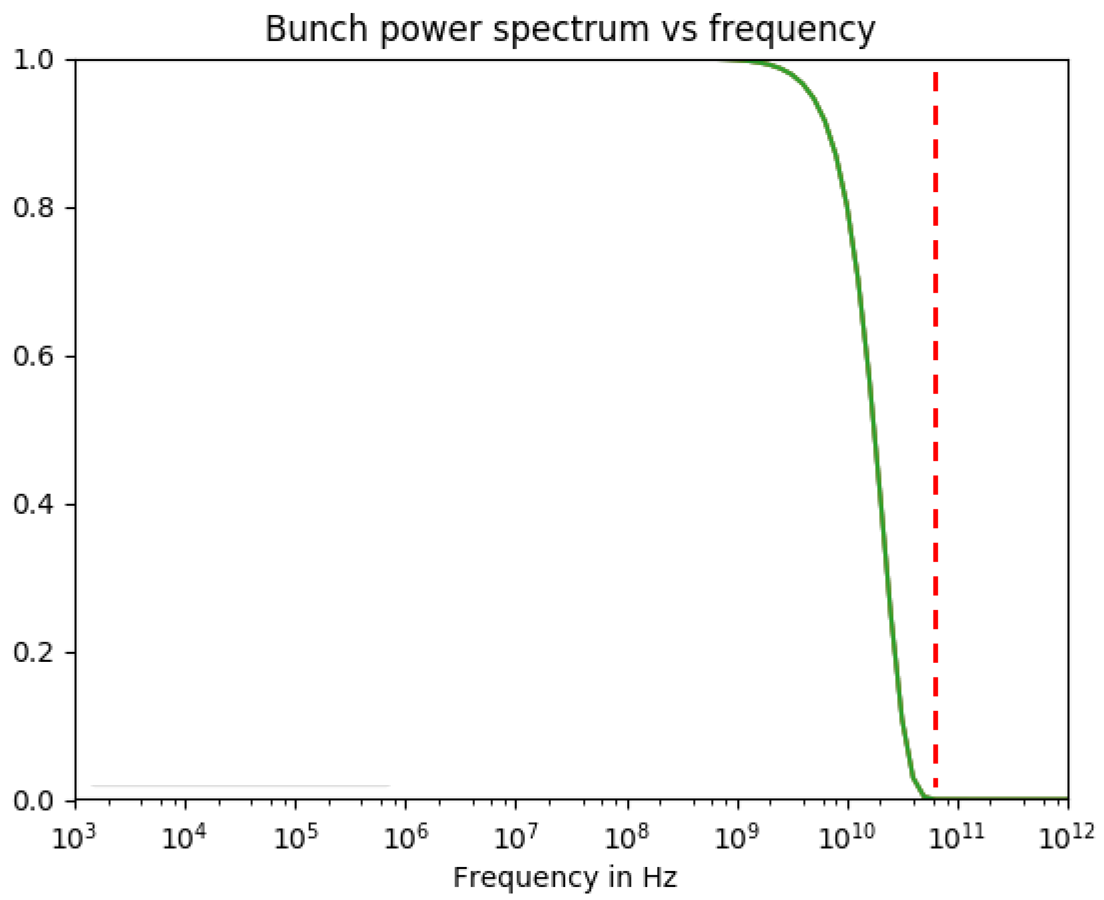
The code considers only a circular pipe cross-section.

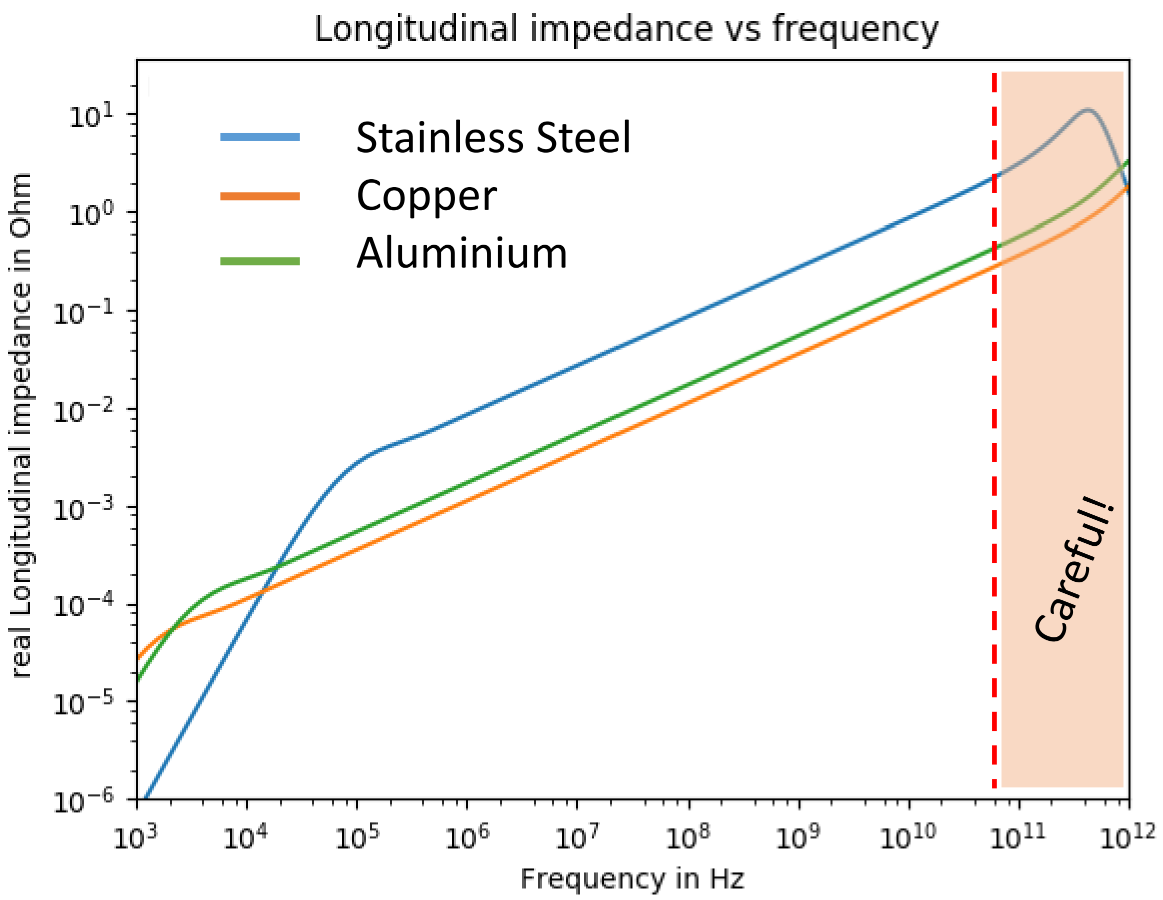


Substrates	**Resistivity [Ω.m]**
Copper	1.7 x10^{-8}
Stainless steel	1 x10^{-6}
Aluminum	4 x10^{-8}

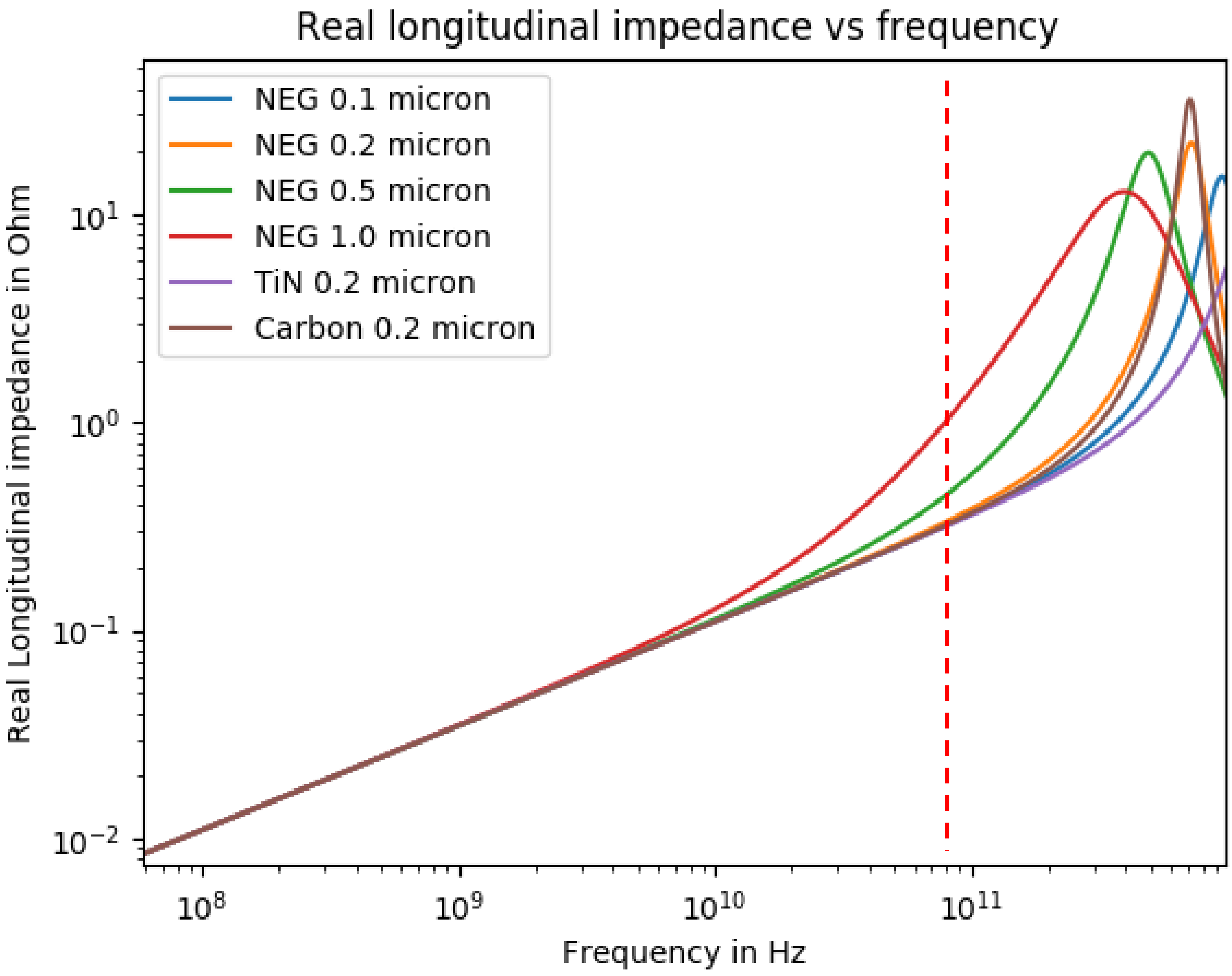
Coatings	**Resistivity [Ω.m]**	**Thickness [nm]**	**Secondary Electron Yield**
Amorphous carbon	1 x10^{-4}	400	1.0
Titanium	5.6 x10^{-7}		-
Titanium + amorphous carbon		300+50	1.0
NEG	1 x10^{-6}	various	1.8 (not active) 1.1-1.2 (active)
TiN	5 x10^{-7}	200	0.8 – 0.9

Active frequencies & Beam pipe impedance





Go for copper!

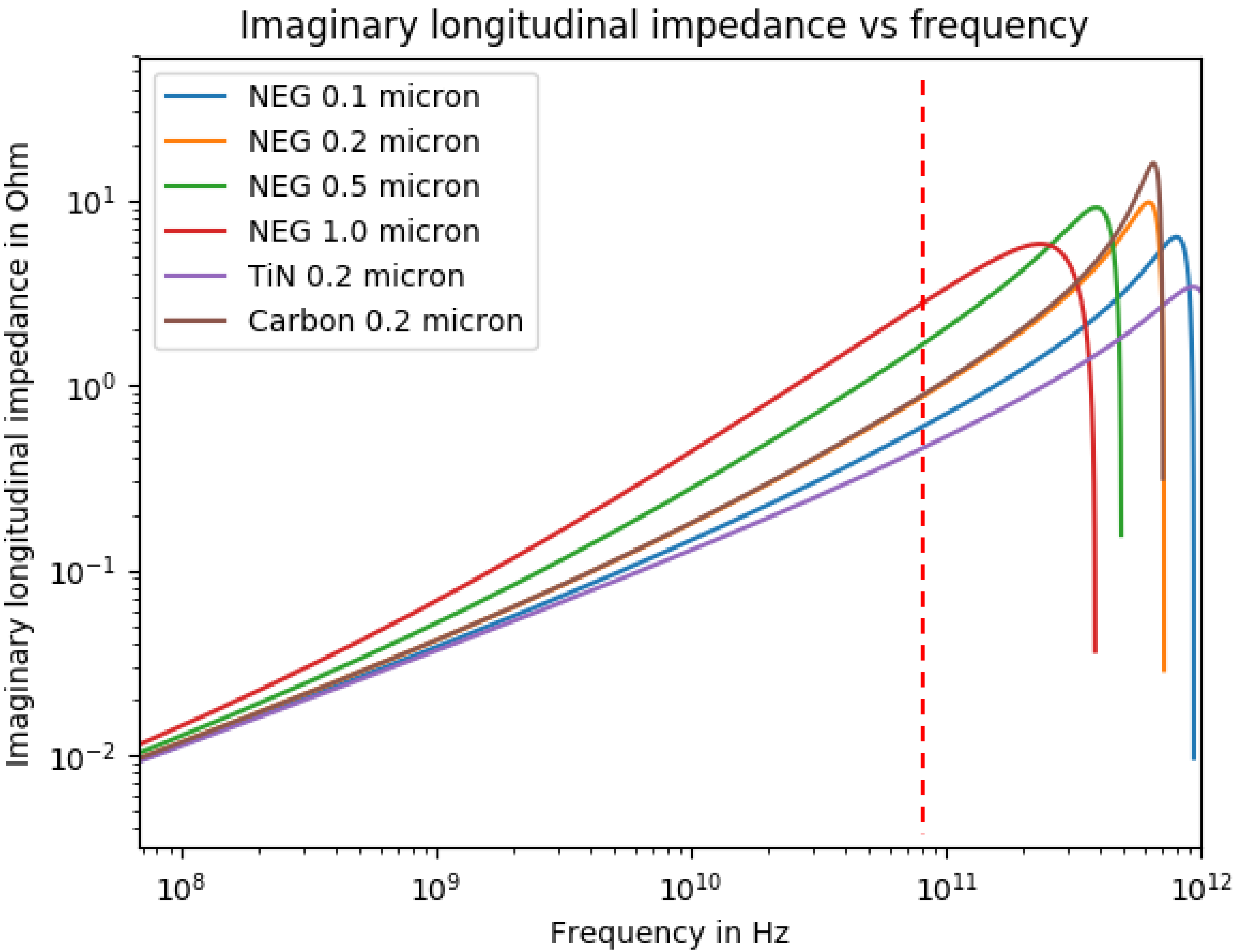


Cu with Coating?

Similar performance for aC, TiN, NEG ≤ 200 nm.

500 nm NEG less than 1000 nm NEG and may be acceptable.

Power Loss is calculated from this data.



Longitudinal instabilities can develop over time due to this component.

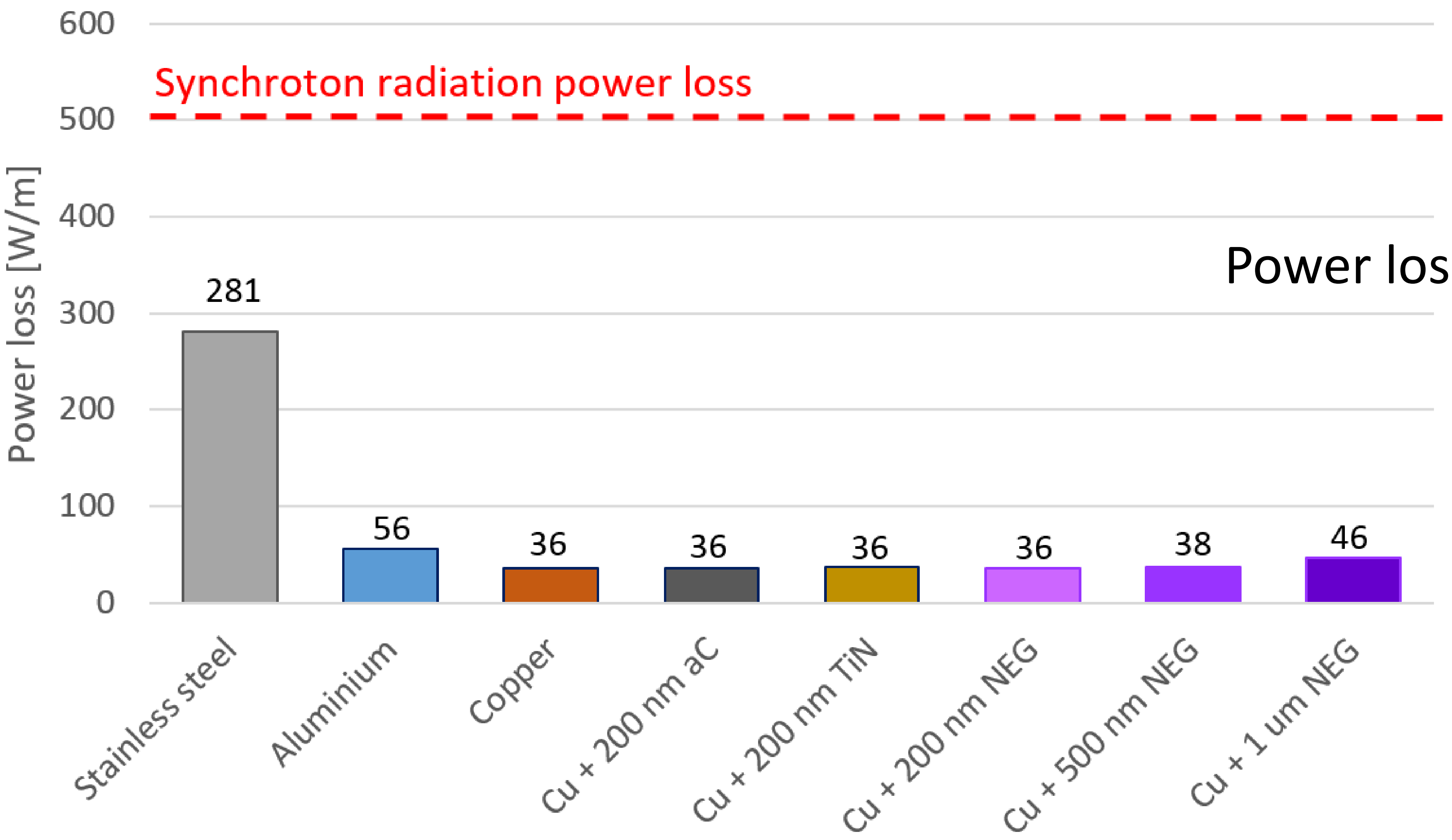
Similar performance for aC, NEG at 200 nm thickness.

100 nm of NEG has better performance.

200 nm of TiV has the best performance. Due to lower resistance!

SuperKEKB (similar to FCC-ee) uses TiN…

Power Losses [W/m]



Power losses are significant!

Summary

For a 2.1 mm bunch length:

- Cu substrates are best to reduce power loss.
- Power losses from impedance are non-negligible!
- TiN on Cu is shown to have the lowest impedance.
- aC and NEG (200 nm) have similar impedance.

Choose desirable secondary electron yield (TiN & aC), vacuum, outgassing or desorption characteristics to decide. NEG may only be used to reduce outgassing in this case.

* Perfect flat surfaces with uniform resistance.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