Cornell University
Laboratory for Elementary-Particle Physics

Application of NEG Coatings on a Metal Surface and Measurements of its RF Properties

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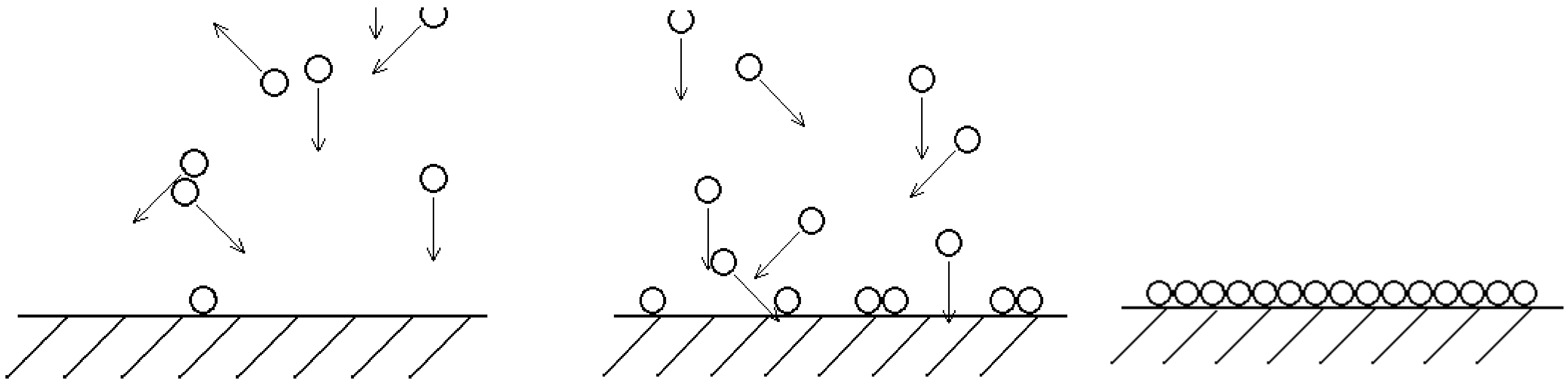
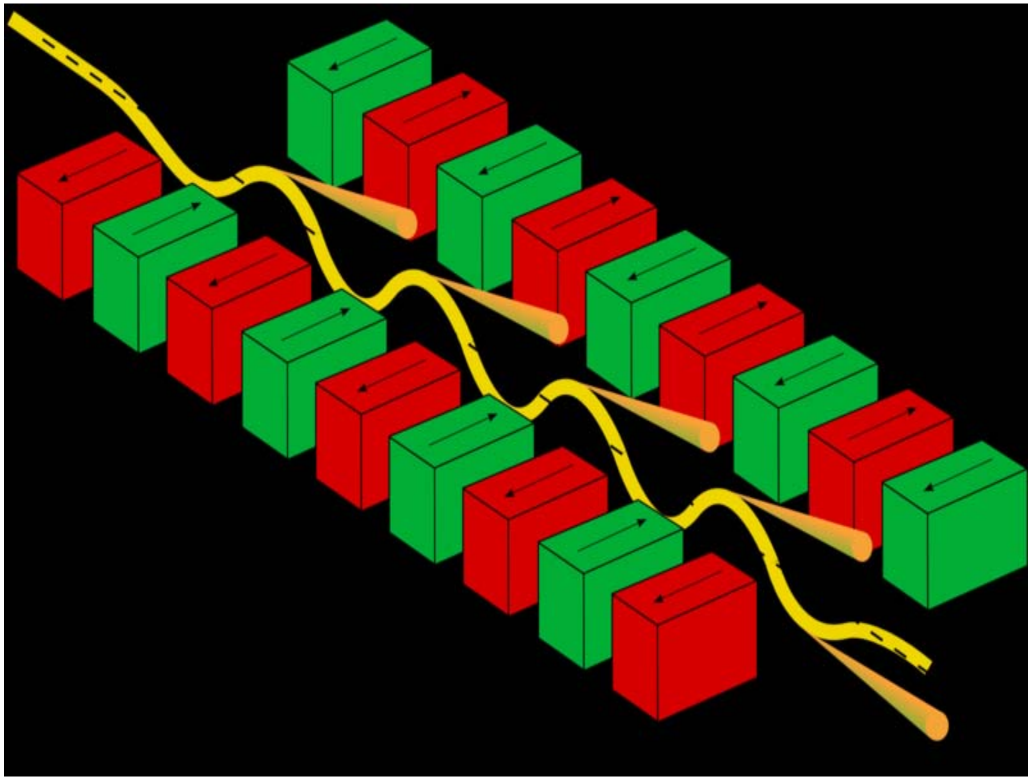
Review of NEG Coatings

- Provide local distributed pumping in gas conductance limited areas often found in accelerators
- Surfaces containing activated NEG coatings have a reduced Secondary Electron Yield
- Coating provides resistive barrier against thermal outgassing and an activated NEG coating reduces desorption due to bombardment



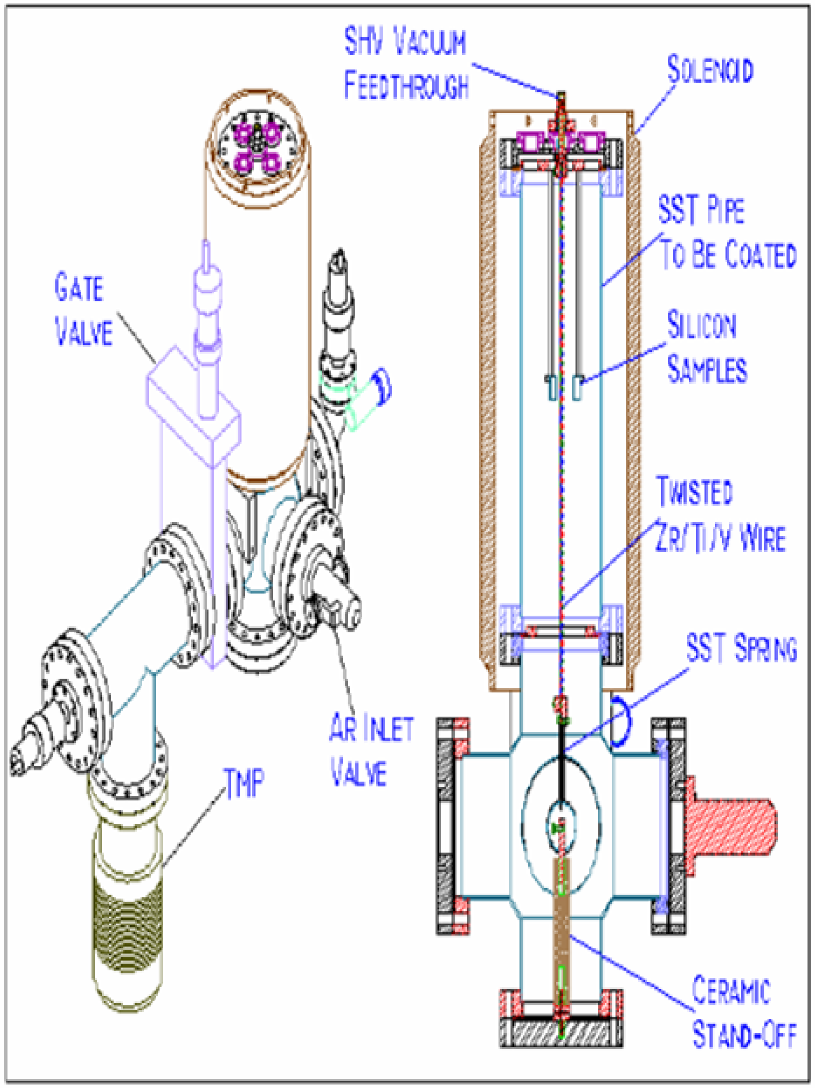
Beam Response

- Beam response to NEG coating is largely unknown
  - Will the coating effect the beam's performance?
  - Undulators of ERL are very narrow
  - Gas conductance limited
  - Surfaces close to beam therefore experience high fields
  - Must understand the NEG's impedance at high frequency bands
  - Develop method to do so
  - Test RF properties with a Vector Network Analyzer



Coating

- DC Magnetron Sputtering used to coat two plates
- Coating thickness of 1 μm and 2 μm
- Equiatomic Cathode of Ti Zr & V
- Introduce Argon to UHV
- Pressure during sputtering ~5 mtorr
- Magnetic Field introduced to promote electron impact ionization
- Negative Potential applied to cathode attracts energetic Argon ions
- Cathode ejects atoms which create NEG coating



Coating Rate

- A coating rate exists:

$$R_{atom} = \frac{N_{atom}}{A} = \frac{N_{ion} \cdot Y_{sputter}}{A} = \frac{I_{ion} \cdot Y_{sputter}}{2\pi a L \cdot q_e}$$

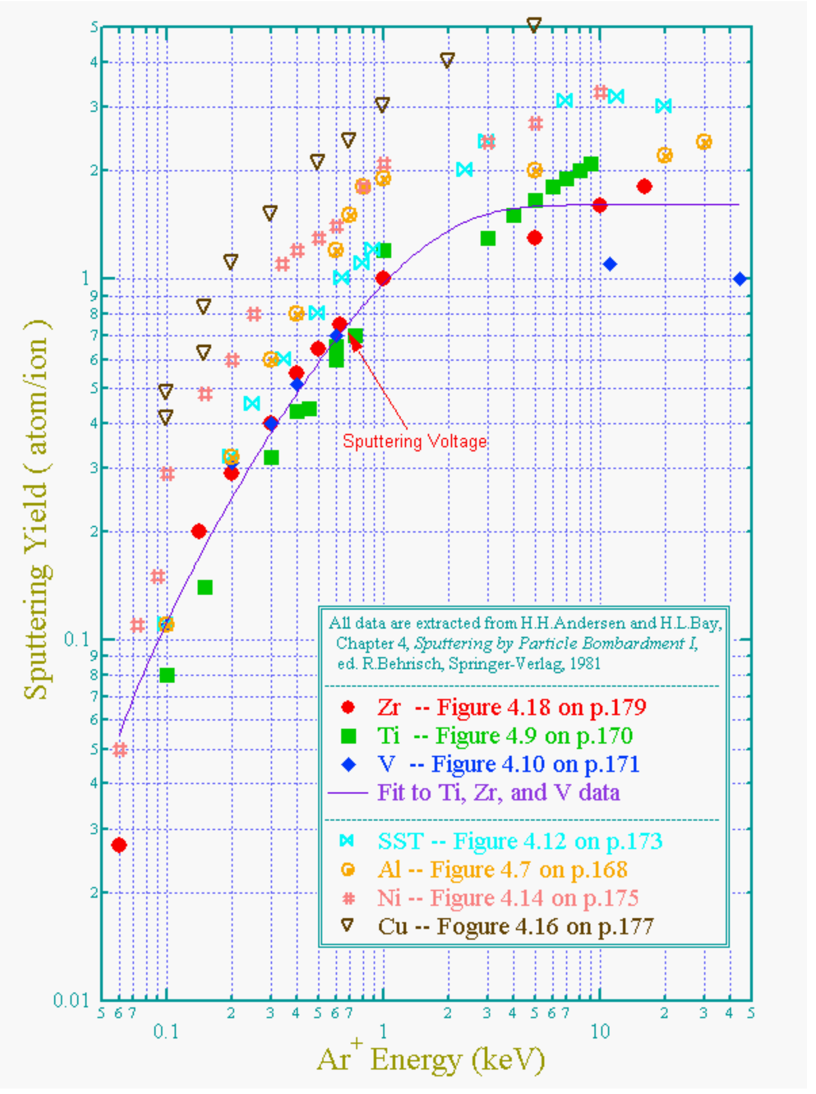
$$R_{growth} = \frac{R_{atom}}{n_{NEG}}$$

Where $L=36.35$ *cm*, $q_e=1.602*10^{-19}$ *C*, $Y_{sputter}=0.75$ *at 682 eV*, and $n_{NEG}=5.83*10^{22}$ *atoms/cm3*

$$R_{growth} = 3.517 \cdot \frac{I_{ion}}{a} nm/\sec$$

Plates were mounted a distance a=3.744 cm and ion discharge current maintained at $I_{ion}=25$ *mA, we have:*

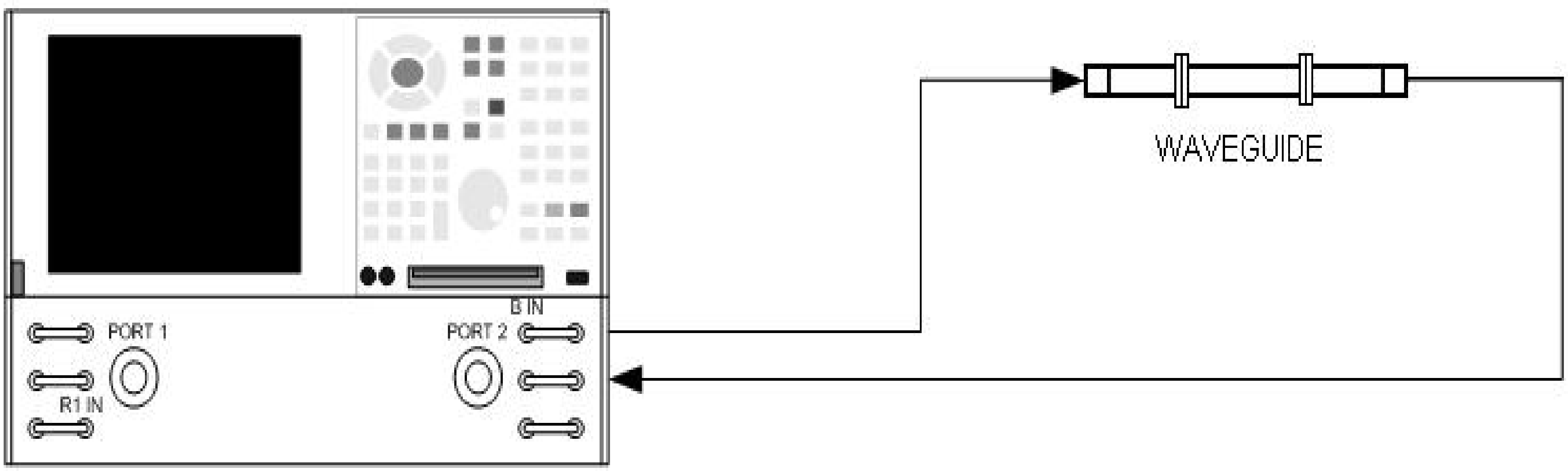
$$R_{growth} = 0.023485 nm/\sec$$



$$Ysputter = 1.61 - 1.65e^{-.957E}$$

Taking Measurements

- Vector Network Analyzer measures amplitude and phase properties of RF waves
- Transmission and reflection waves are used to calculate power losses
- A range of RF waves are sent through waveguides between ports

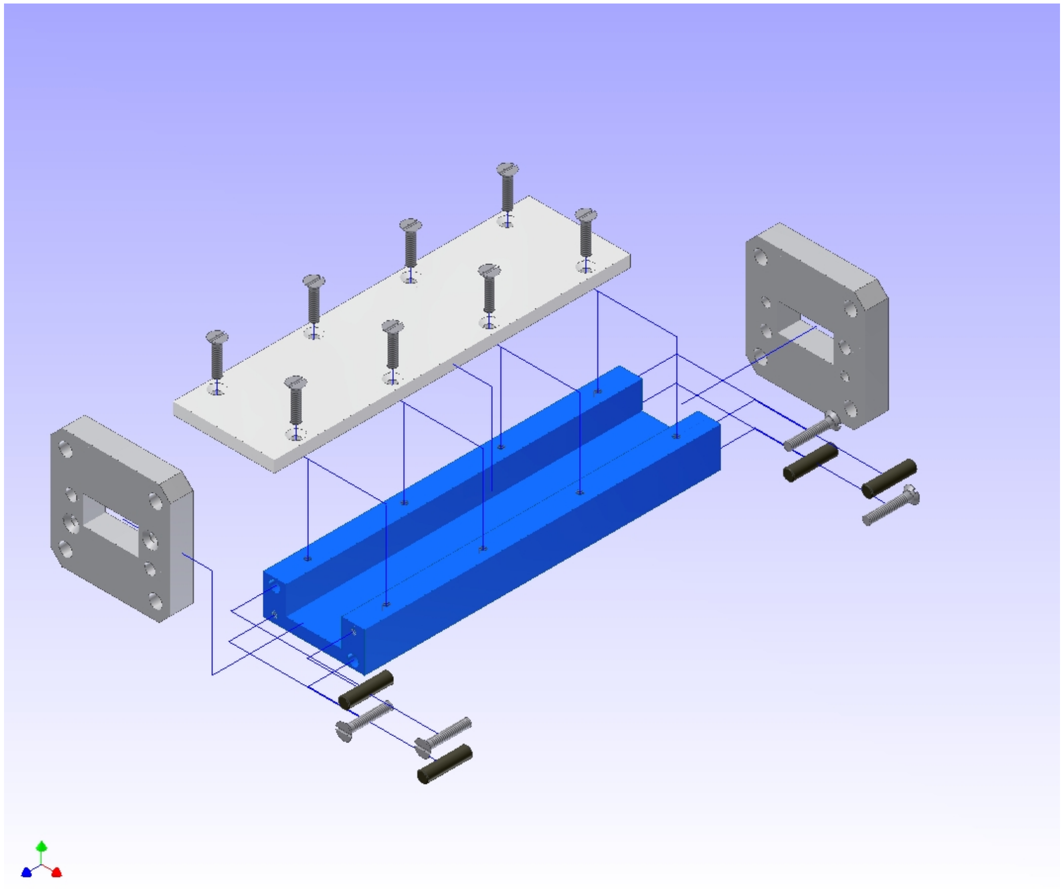


Range of Measurements

- To test the desired frequency range we must first determine if the method works
- Desired range is from 12.4 GHz to 40 GHz
- Method must work for all sizes of waveguide
- Design waveguide to be used in study

Waveguide Design

- A U-channel base is attached to the two flanges via ream and bore holes
- A removable plate is attached to the U-channel to complete the waveguide
- The plate allows you to use various coating thicknesses
- Can now pass RF waves through a waveguide coated with the NEG
- Dimensions: 620 x 310 mils



Loses in Waveguide

- Power loses in the broad and narrow walls of the waveguide can be calculated as follows:

$$P_b = \int_0^{\Lambda/2}\int_0^{a} \frac{H_x^2 + H_z^2}{\sigma\cdot\delta}\cdot dxdz \qquad P_n = \int_0^{\Lambda/2}\int_0^{b} \frac{H_z^{'2}}{\sigma\cdot\delta}\cdot dydz$$

Where

$$H_x = H_0 \frac{2a}{\Lambda}\sin\left(\frac{\pi\cdot x}{a}\right)\cos\left(\frac{2\pi\cdot z}{\Lambda}\right) \qquad H_z = H_0\cos\left(\frac{\pi\cdot x}{a}\right)\sin\left(\frac{2\pi\cdot z}{\Lambda}\right) \qquad H_z^{'} = H_0\sin\left(\frac{2\pi\cdot z}{\Lambda}\right)$$

- A ratio of losses in the broad wall, the coated wall, to total losses can now be determined
- The ratio r is found to be 0.324 for 12.4 GHz and 0.361 for 18 GHz

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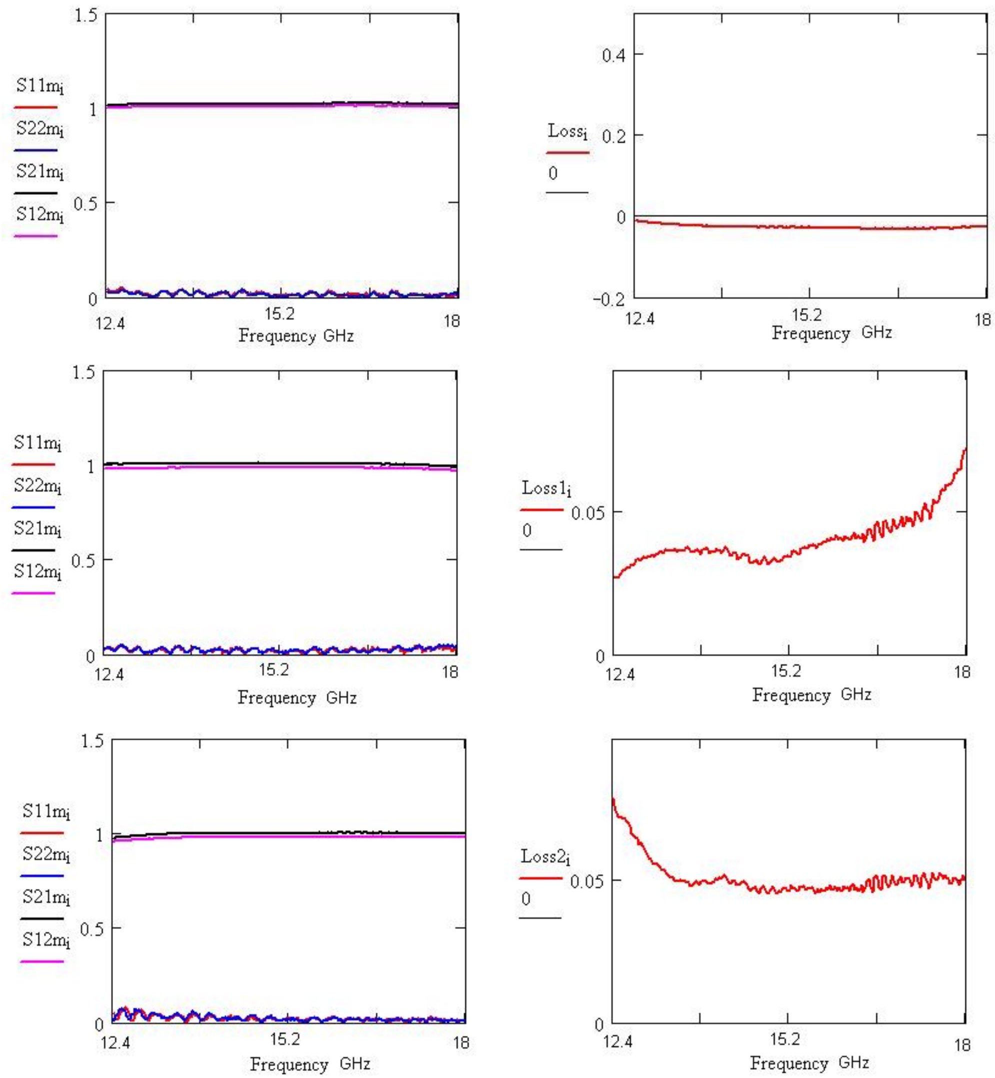
RF Measurements

- Measurements of transmitted and reflected waves with uncoated, 1 μm, and 2 μm coated plates, respectively
- Substantial amount of error associated with measurements, and was taking into account. However the reliability of the results may suffer
- The two measurements with NEG coatings show ~5% power losses



Increasing Power Losses

- Current Density varies between the coating and the metal
- For metal:

$$j = j_0 e^{-\Delta/\delta_c} e^{-(z-\Delta)/\delta_m} \cdot \frac{\sigma_m}{\sigma_c}$$

- For coating:

$$j = j_0 e^{-z/\delta_c}$$

- Integration over all space gives total current I, which can be used to solve for:

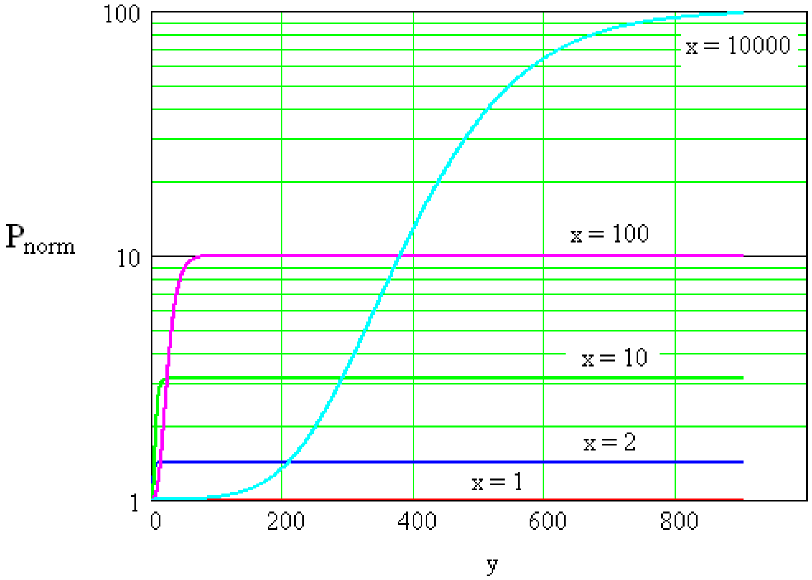
$$j_0 = \frac{I}{\delta_c \left[1 + \left(\frac{\delta_c}{\delta_m} - 1 \right) e^{-\Delta/\delta_c} \right]}$$

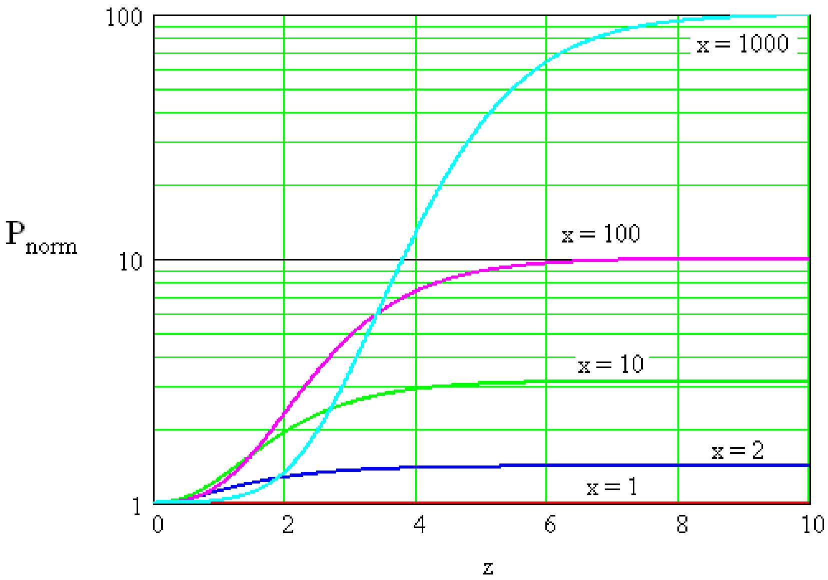
- Integration of the current density squared gives power

Power Losses

- Ratio of power loses with a coated surface versus an uncoated surface can now be found:

$$\frac{P_{c+m}}{P_m} = \frac{\sigma_m \delta_m}{\sigma_c \delta_c} \cdot \frac{\left[1 + \left(\frac{\delta_c}{\delta_m} - 1\right) e^{-2\Delta/\delta_c}\right]}{\left[1 + \left(\frac{\delta_c}{\delta_m} - 1\right) e^{-\Delta/\delta_c}\right]^2}$$

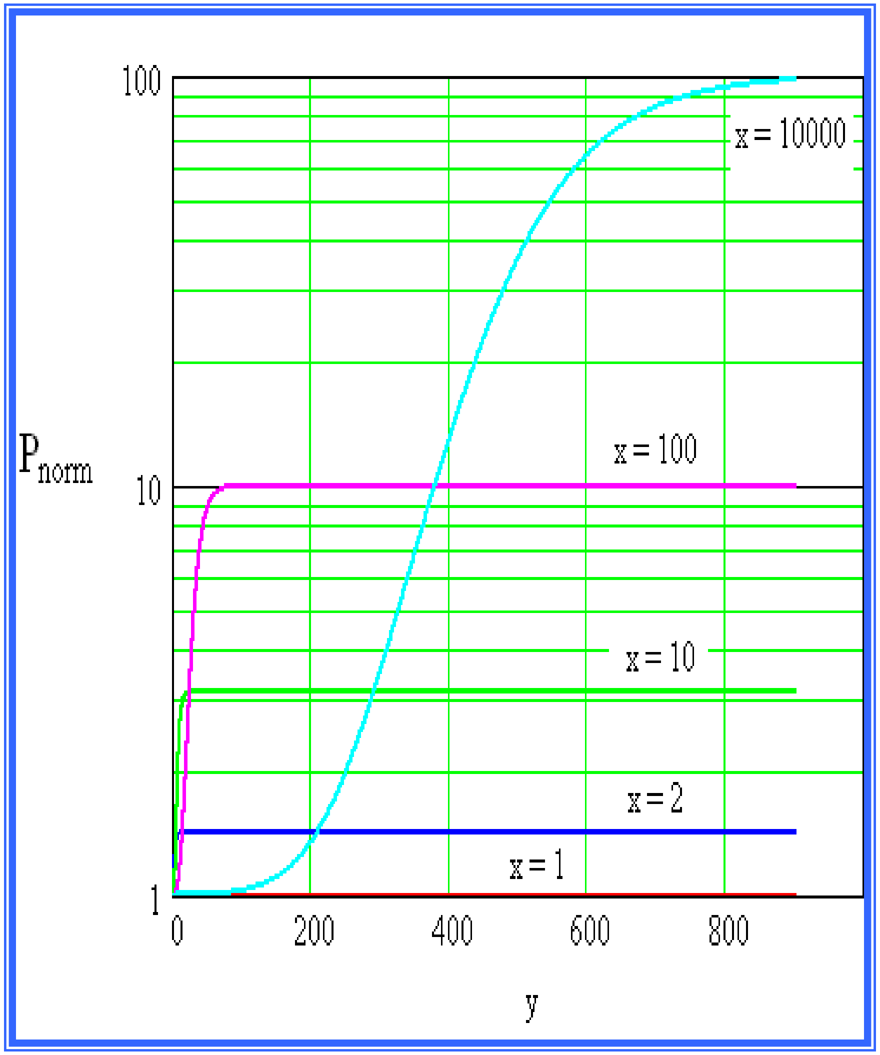




$$x = \frac{\sigma_m}{\sigma_c} \qquad y = \frac{\Delta}{\delta_m} \qquad z = \frac{\Delta}{\delta_c}$$

Implications

- In order for there to be a 50% power loss in the RF signal, the amplitude of S21 would have to be ~0.7
- A coating would need to be 10,000 times less conductive than Aluminum in order for the Attenuation to be great enough for these power losses
- The NEG coating appears to be on the order of 100 times less conductive than Aluminum
- The peak of light blue lines corresponds to roughly y=800 and this implies a coating of over 500 μm



Conclusions

- Impedance of NEG coatings are difficult to study
- Method has been developed to study the RF properties of NEG coatings
- Additional development and testing of remaining frequency ranges needed
- Required thickness to see substantial power losses is unreasonably big
- Power losses due to NEG coatings alone seem to be insignificant
- There is no negative effect on the impedance of the beam
- The vacuum benefits of the NEG coating can therefore be used for those purposes
- Ferrite materials are a good candidate for absorbing large amounts of power

Acknowledgements

- I would like to thanks Yulin Li and Valery Shemelin for all of their assistance
- Rich Galik for the opportunity and wonderful organizational skills
- LEPP