RF shielding properties of Cu / $Ni_{79}Fe_{16}Mo_5$ films

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Overview

- Background
- Thin film shielding
- Experimental
- Conclusions

Background (1/6)

Electromagnetic interference (EMI) shielding

- Electronically produced, radiated waves in microwave and radio frequencies.

- To reduce emission and/or ensure immunity of electronic systems.

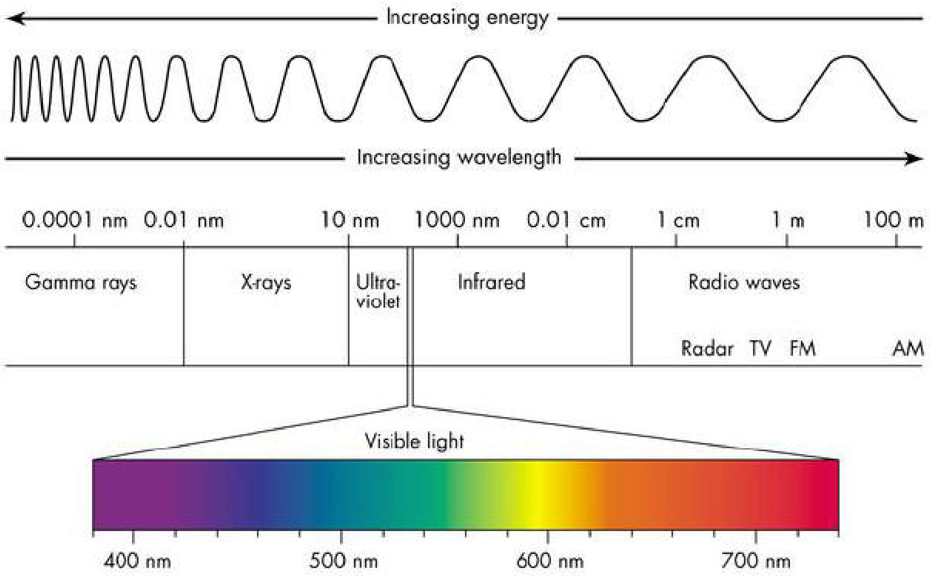


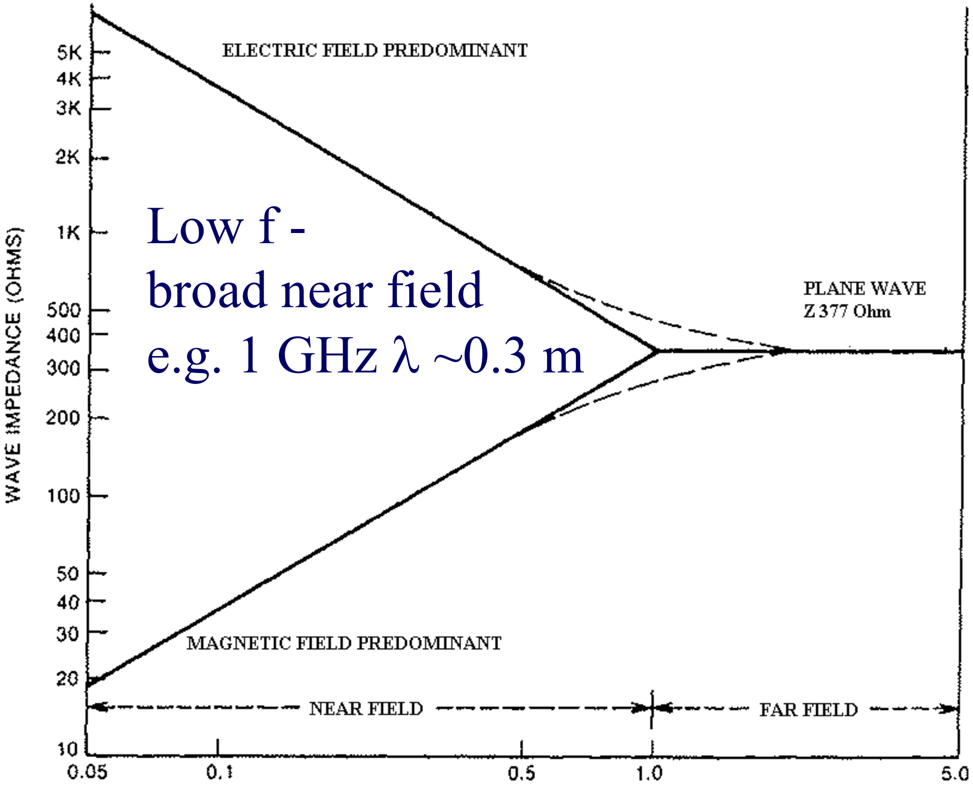
Fig. EM spectrum

- Light weight RF shield is typically a conductive thin film on plastic housing.

Background (2/6)

Radiated electromagnetic interference

- Static E and H fields
  - charges and magnetized material
- Low frequency fields
  - Use of electrical power
  - shield geometry, grounding
- RF fields
  - Electronic systems
  - current return path not needed



Low f -
broad near field
e.g. 1 GHz λ ~0.3 m

Fig. Z_{wave} (E/H) vs. d

Background (3/6)

Modification of E and H fields by a homogenous shield

Reflectors, typically high frequency E and H fields

- Mobile charge carriers (σ) generates opposing fields
  - Moves according to external E field
  - Carry induced H field induced eddy currents

Absorbers, typically a low frequency and magnetostatic fields

- Polarization (ε) reduce field inside the material
  - Electric dipoles by a high ε
  - Magnetic dipoles
- Concentration of a magnetic flux (μ)

Background (4/6)

Electromagnetic interference shielding

- ❖ µT H fields can cause disturbance e.g. in video display units.
- As the frequency rise, In highly conductive shield H-field induce eddy currents
  → Currents create opposing H field
  → A magnetic field repulsed to run parallel to the shield.
- In the highly permeable shield field is drawn into a metal

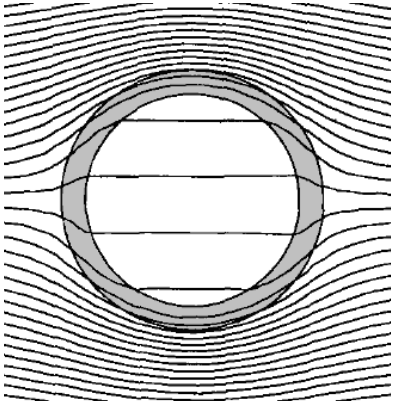


Fig. Low B

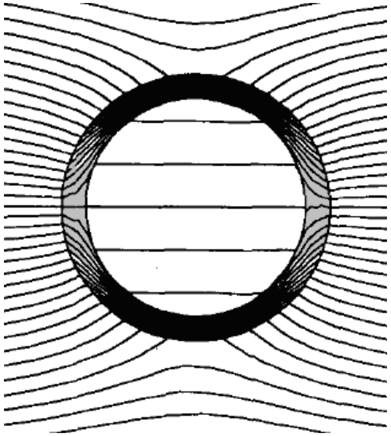


Fig. High B

Background (5/6)

Why multilayers ?

- ❖ A low σ
- ❖ A low saturation field
- ❖ Nonlinear behauviour of high μ materials.
- ❖ μ is higher for thinner sputtered layers, degreased amount of a material
- • Graded saturation and permeability

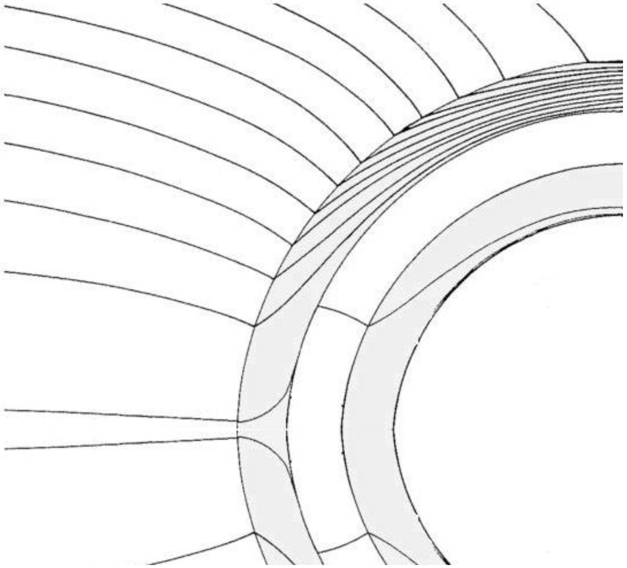


Fig. Flux lines in a spherical, high μ shell with dielectric spacer

Background (6/6)

$Ni_{79}Fe_{16}Mo_5$

- A fine grained Permalloy structure
- Bulk μ_r 100 000 (0)
- Magnetically soft
- Low magnetostriction

  (μ vs. strain)

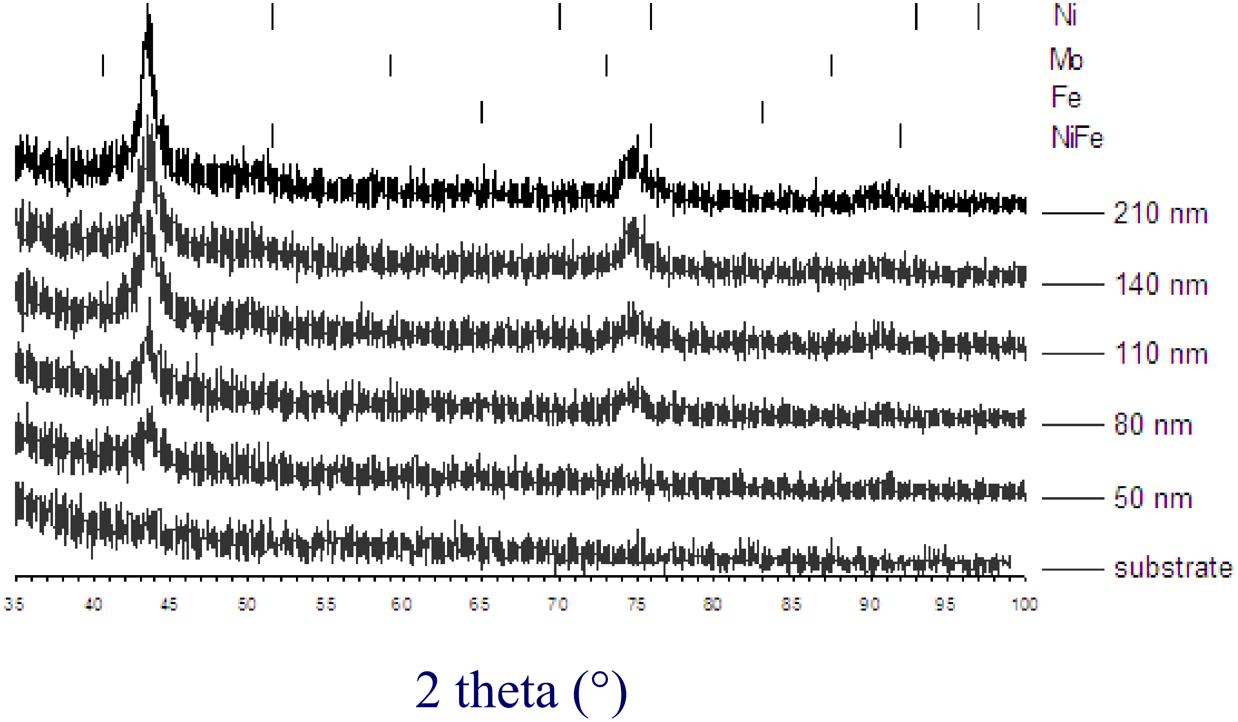


Fig. X-ray diffraction patterns. Cu Kα, grazing incidence 2°, assymmetric Bragg

Thin film shielding (1/5)

Plane wave shielding with metals

- Primary reflection
  - Cancellation of the electric and/or the magnetic field in the air-shield interface.
- Absorption
  - Attenuation of oscillating currents within the thickness of a shield, electric heating.
- Attenuated secundary reflection(s)
  - Other interfaces, most RF current in δ

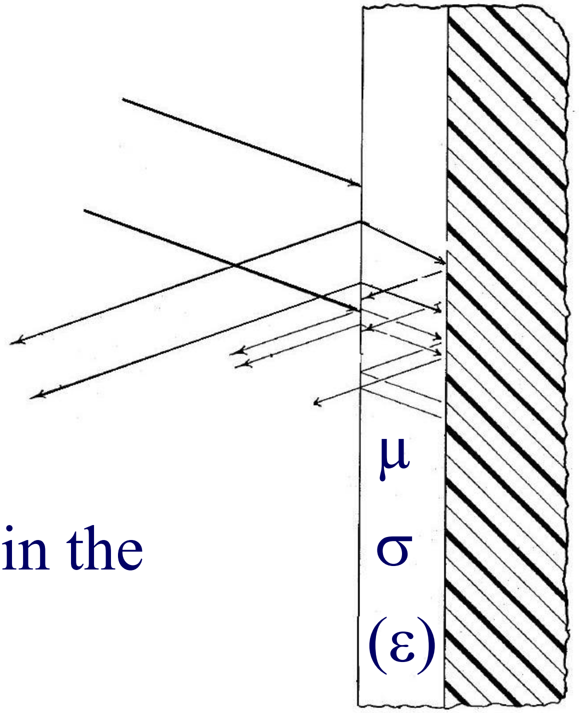


Fig. Plane wave indicent to a thin, homogenous metallic shield

Thin film shielding (2/5)

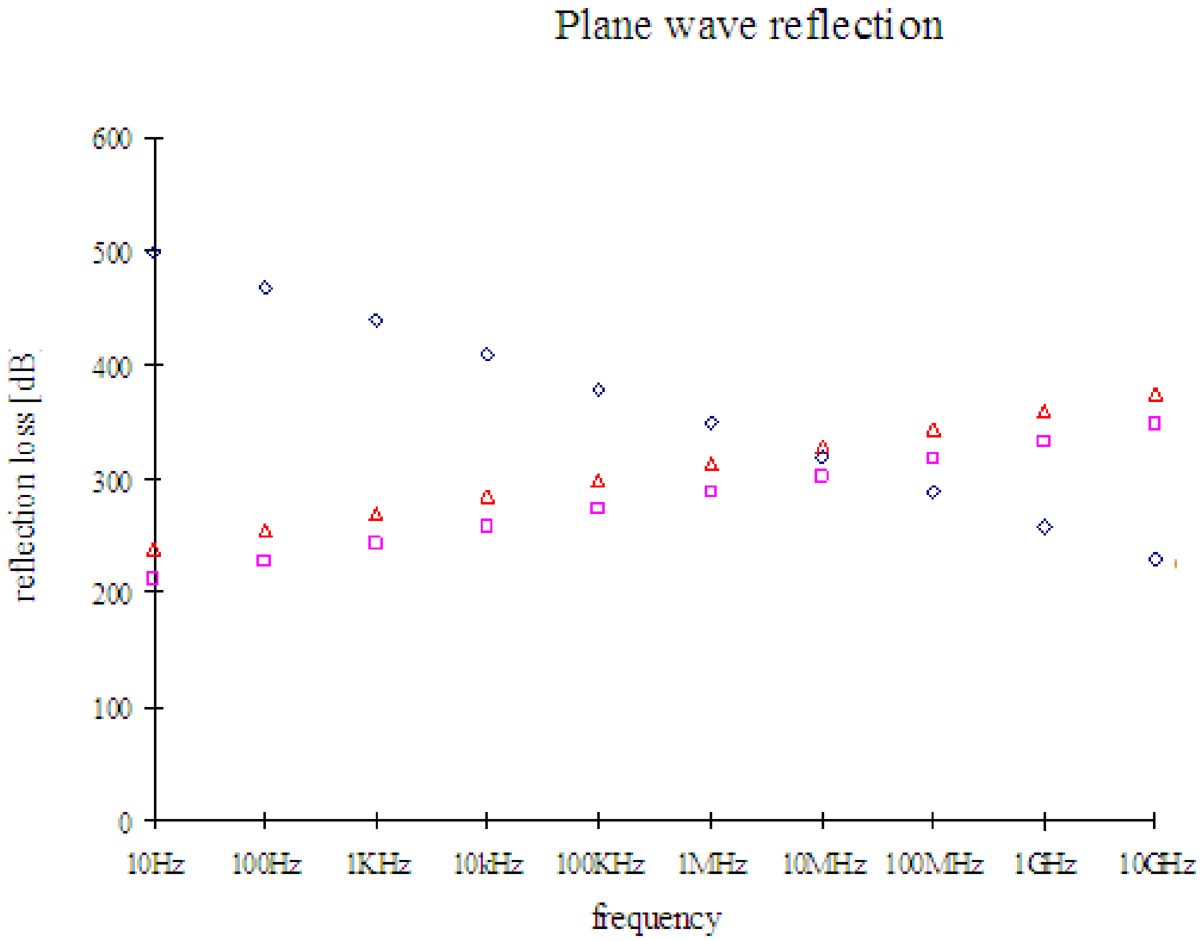
Plane wave reflection from a metallic homogeniuos shield *

$$R_{dB} = 20\log_{10}\left|\frac{(\xi+1)^2}{4\xi}\right|, dB \qquad \xi = \frac{Z_{wave}}{Z_{metal}} \qquad Z_{metal} = \sqrt{\frac{j\omega\mu}{\sigma}}$$

- A high Z ratio → high R
- For the E → Z_{wave} is high, if σ high →R high
- For the H → Z_{wave} is low, if μ low →R low

* Transmission theory of shielding / S.A. Shelkunoff

Thin film shielding (3/5)



NiMoFe μ_r=60000

NiMoFe μ_r=8000

Bulk Cu

Thin film shielding (4/5)

Plane wave absorption in a metallic homogeneous shield

❖ Skin depht $\delta = \sqrt{\frac{2}{\omega\mu\sigma}}, m$

- Current amplitude falls to 1/e ~9 dB attenuation
- μ, σ, f
- $\sigma \rightarrow \infty$, $A \rightarrow 0$
- 5δ ~ 99% Absorption

❖ Number of skin dephts

$$A \approx 8.686\left(\frac{t}{\delta}\right), dB$$

- Bulk copper: 100 MHz $\delta = 20$ µm

10 GHz $\delta = 0{,}7$ µm

($\sigma = 5.96\times10^{7}$ S/m, $\mu = 1.26\times10\text{-}6$ N/A^{2})

NiMoFe: 100 MHz $\delta = 14$ µm

10 GHz $\delta = 0{,}04$ µm

($\sigma = 2.13\times10^{6}$ S/m, $\mu = 7.50\times10\text{-}2$ N/A^{2})

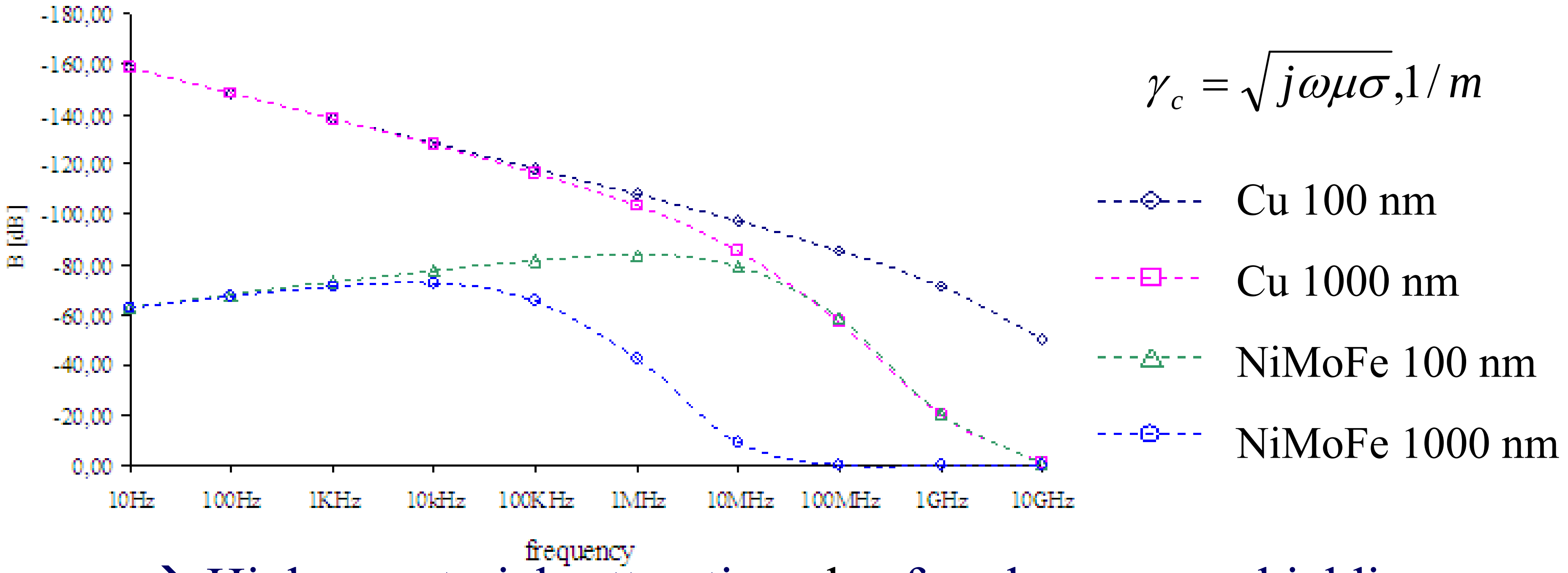
Thin film shielding (5/5)

Multiple reflections in thin metallic homogeneous shield

- When A < 15 dB

$$B_{dB} = 20\log_{10}\left[1 - \frac{\left(Z_{ratio} - 1\right)^2}{\left(Z_{ratio} + 1\right)^2} e^{-2t\gamma_c}\right], dB$$

$$\gamma_c = \sqrt{j\omega\mu\sigma}, 1/m$$



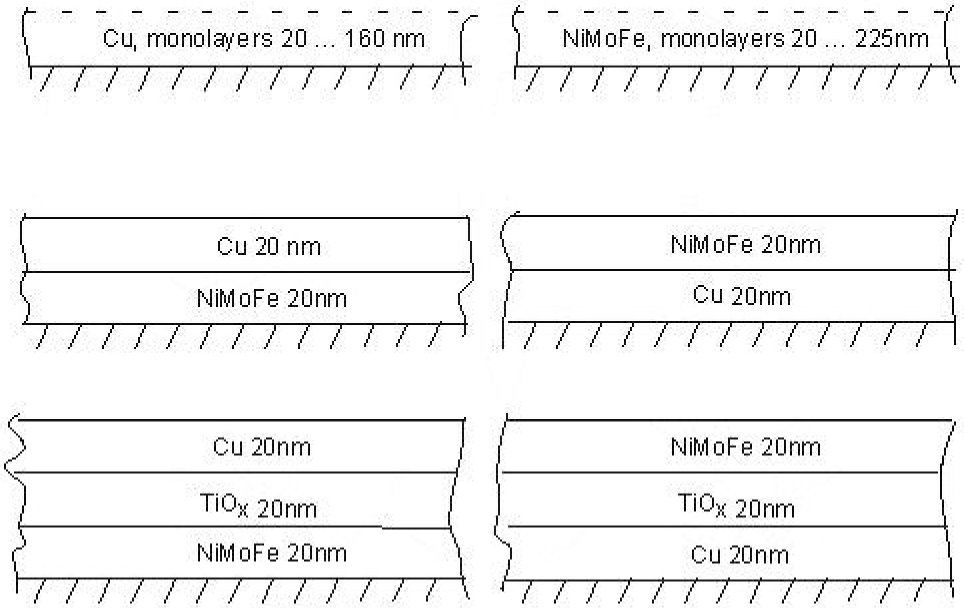
→ High μ materials attracting also for plane wave shielding.

Experimental (1/11)

Experimental

- RF plane wave attenuation
- RF plane wave return loss
- RF H-field attenuation

- DC magnetron sputtering



Cu, monolayers 20 … 160 nm

NiMoFe, monolayers 20 … 225nm

Cu 20 nm
NiMoFe 20nm

NiMoFe 20nm
Cu 20nm

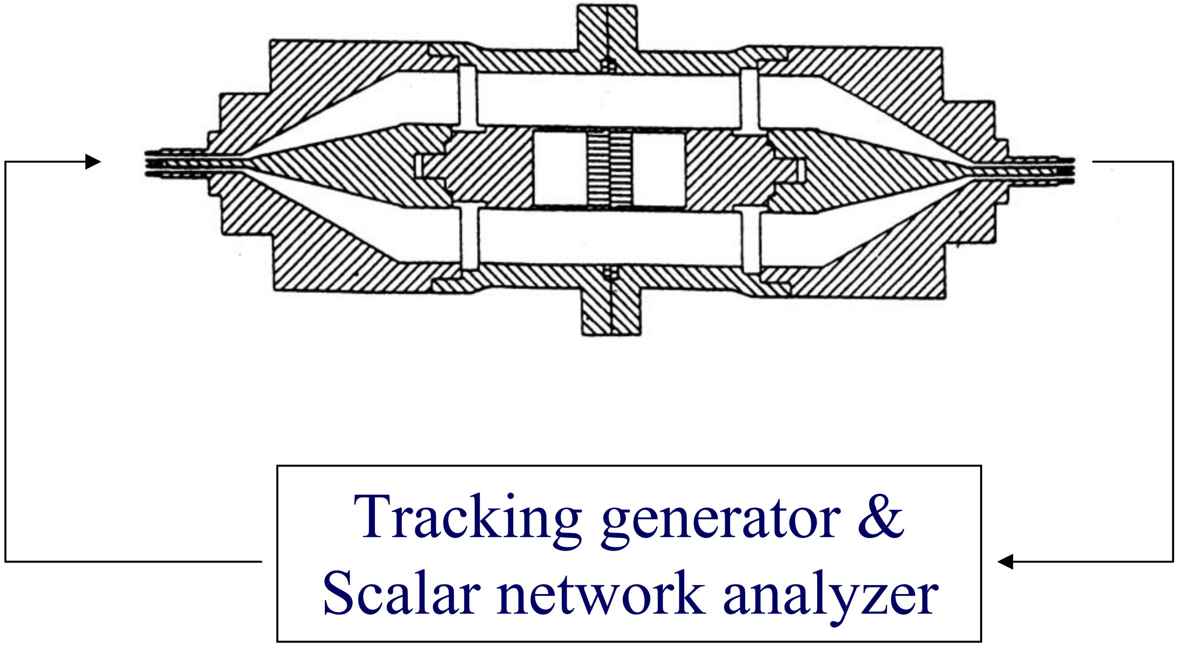
Cu 20nm
TiO_x 20nm
NiMoFe 20nm

NiMoFe 20nm
TiO_x 20nm
Cu 20nm

$t \ll \delta$

Experimental (2/11)

RF plane wave attenuation (insertion loss) measurement setup



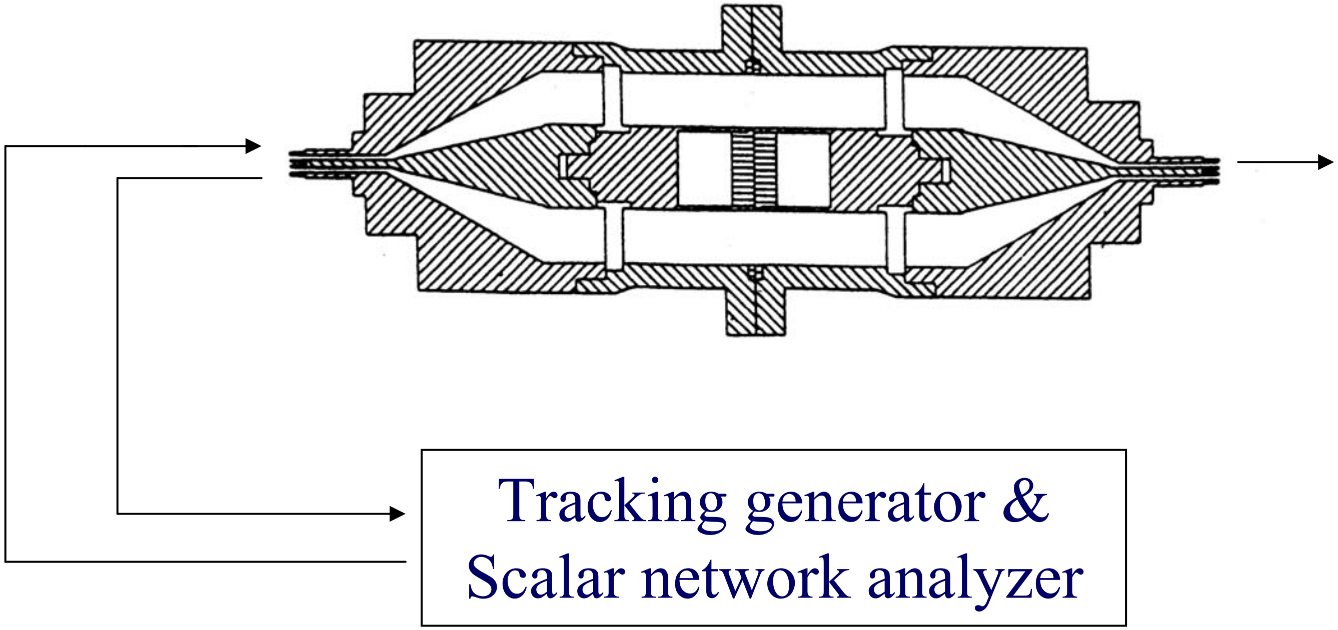
Tracking generator &
Scalar network analyzer

- r.m.s. amplitude of a sine wave in frequency domain
- ASTM D 4935-89.

$$SE = 10\log\left(\frac{P_t}{P_i}\right) = 20\log\left(\frac{V_t}{V_i}\right)(dB)$$

Experimental (3/11)

RF plane wave return loss measurement setup



Tracking generator &
Scalar network analyzer

$$SE = 10\log\left(\frac{P_r}{P_i}(dB)\right)$$

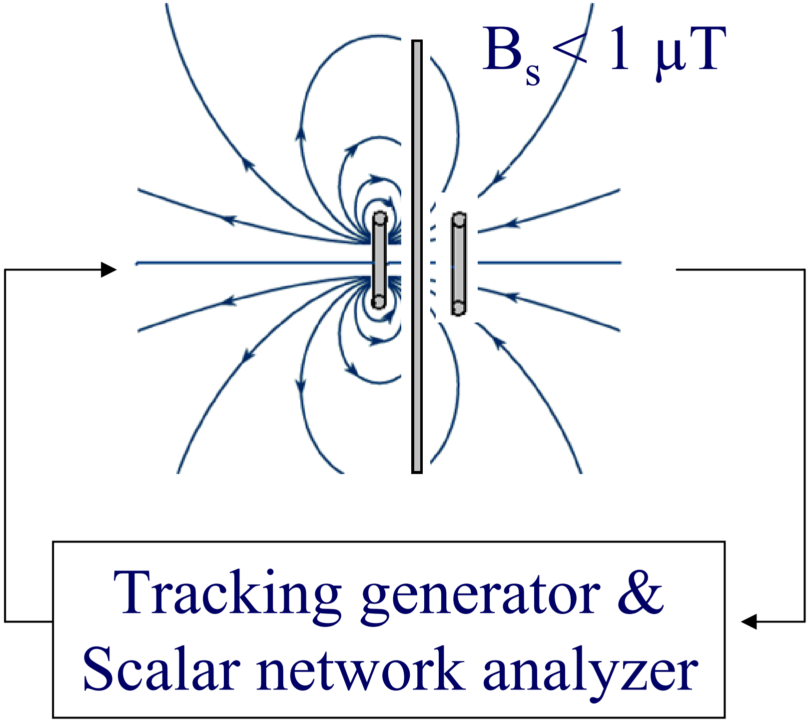
- P_i = Reflection from gold

Experimental (4/11)

RF H-field attenuation measurement setup

- Radial H-field measurement
- Shielded magnetic loop probes
- Sine wave, loop approximates magnetic dipole when λ < 2πr.

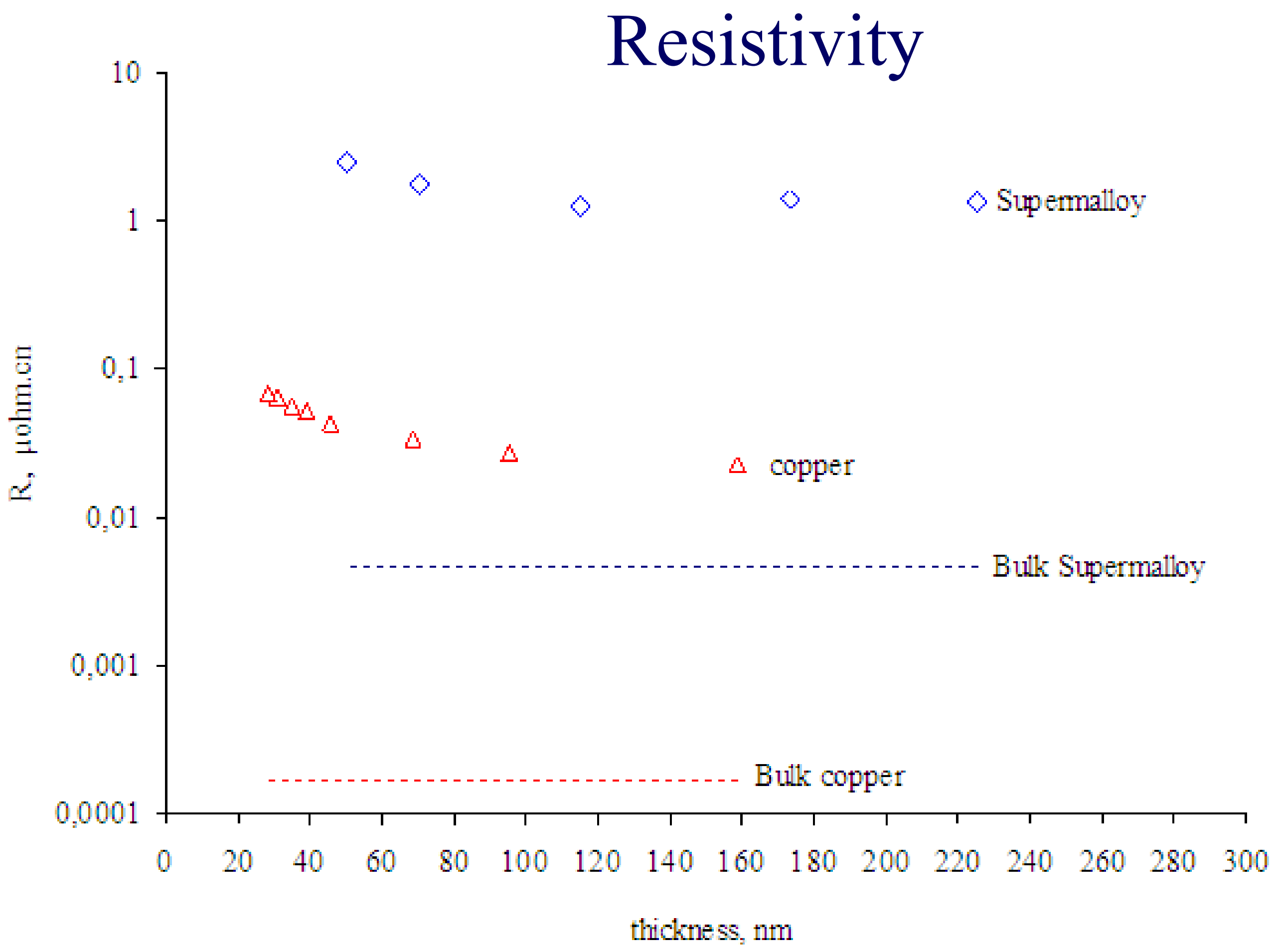
$$SE = 10\log\left(\frac{P_r}{P_i}(dB)\right)$$



Tracking generator &
Scalar network analyzer

Fig. Schematic setup

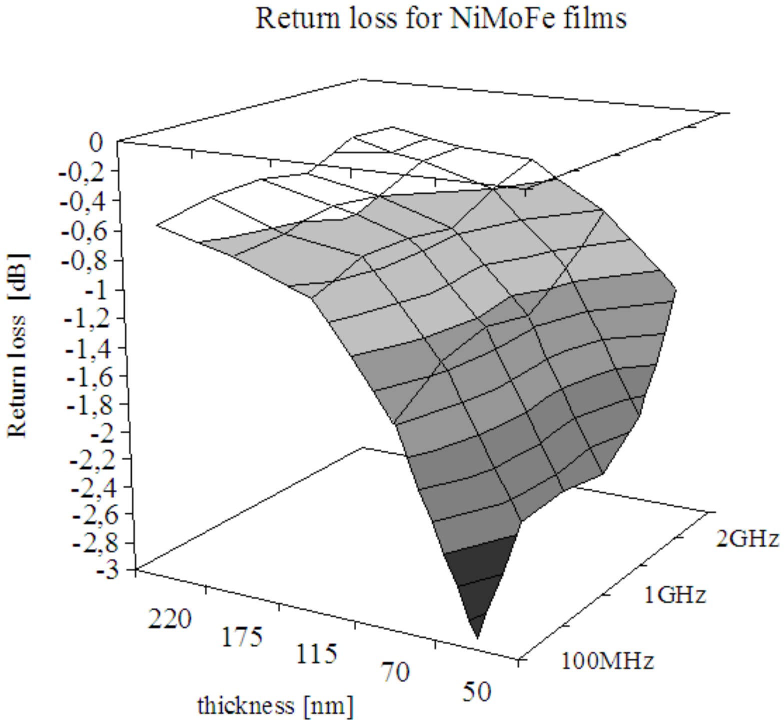
Experimental (5/11)

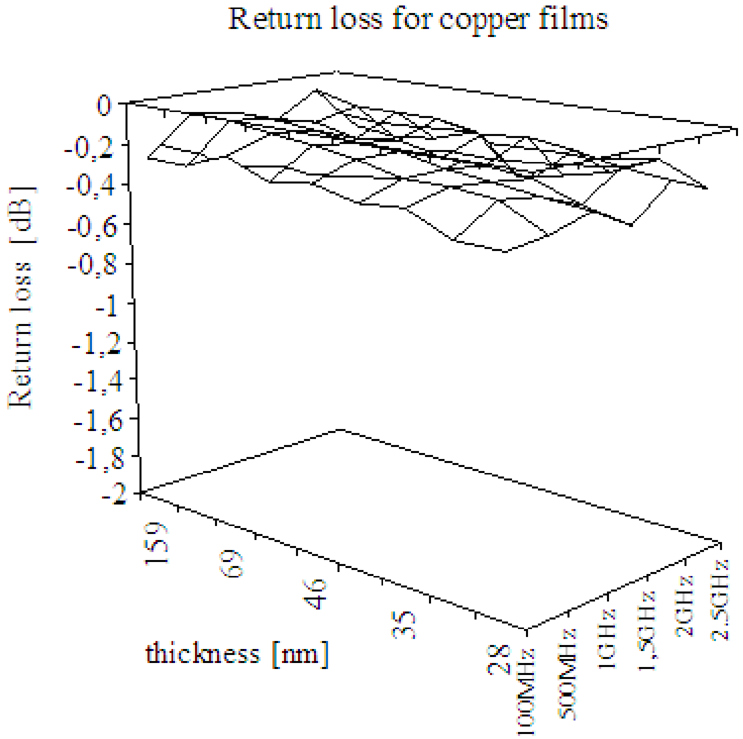


❖ R, µ and magnetization field → Z, δ

Experimental (6/11)

RF Plane wave return loss (reflection)

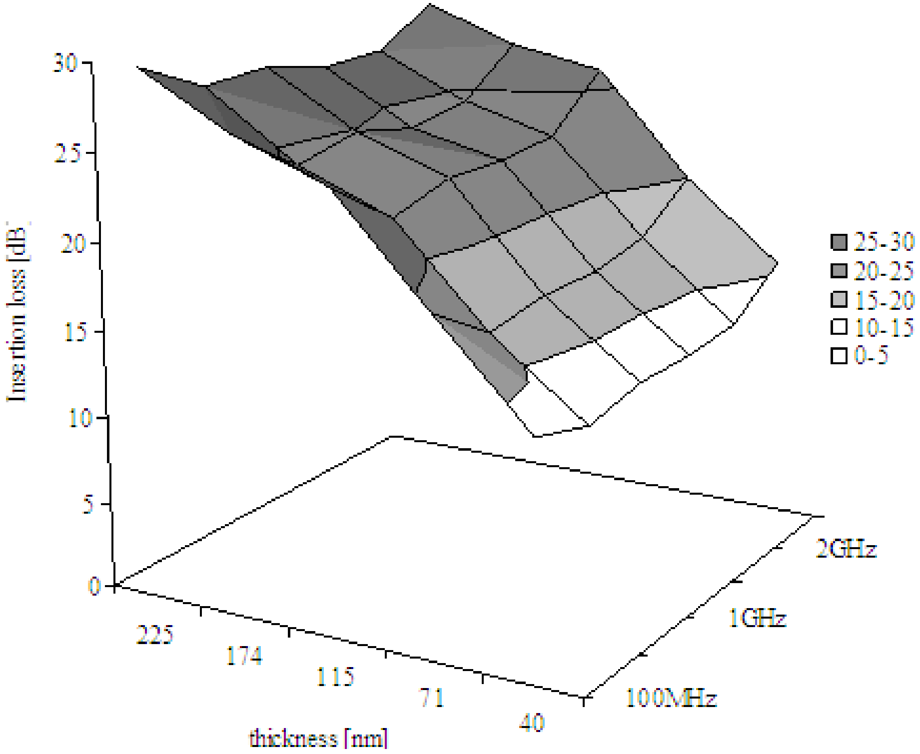




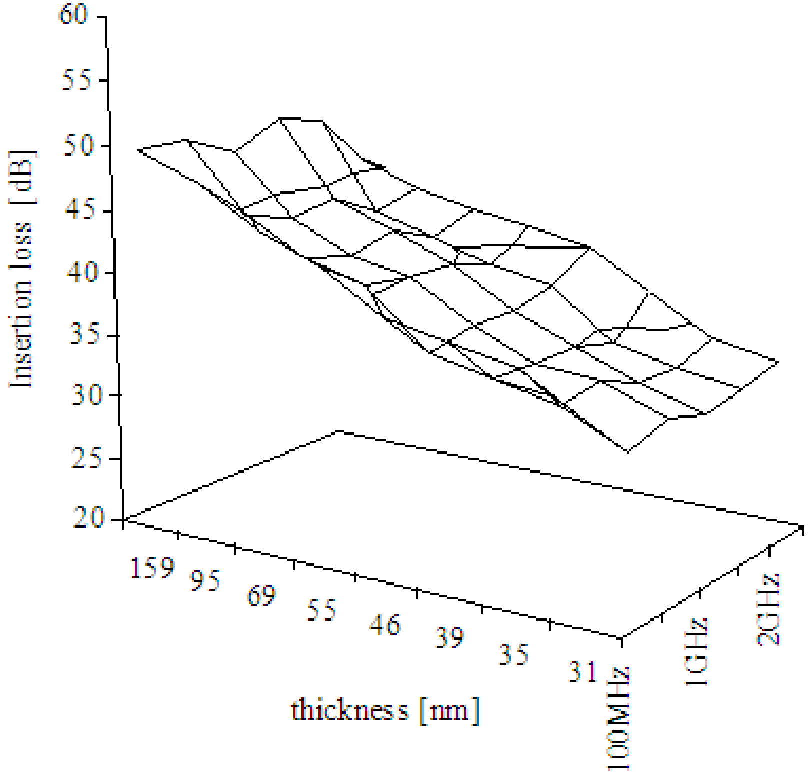
- Reflection independent on t.
- 3 dB ~50% in power. If μ/σ ratio (Zbarrier) ↓, Return loss ↑ (R ↓)

Experimental (7/11)

RF Plane wave attenuation



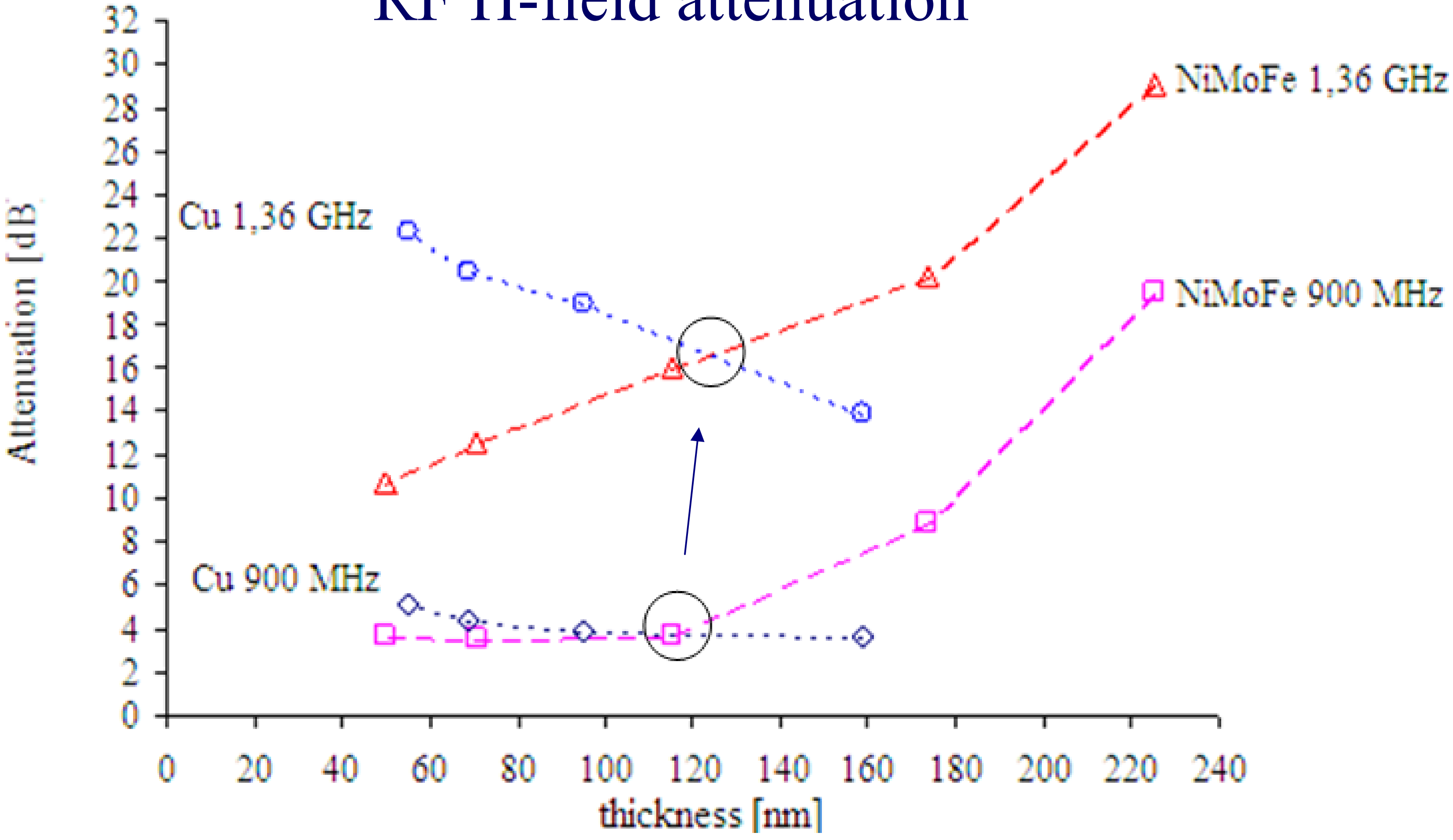
Attenuation - NiMoFe



Attenuation - copper films

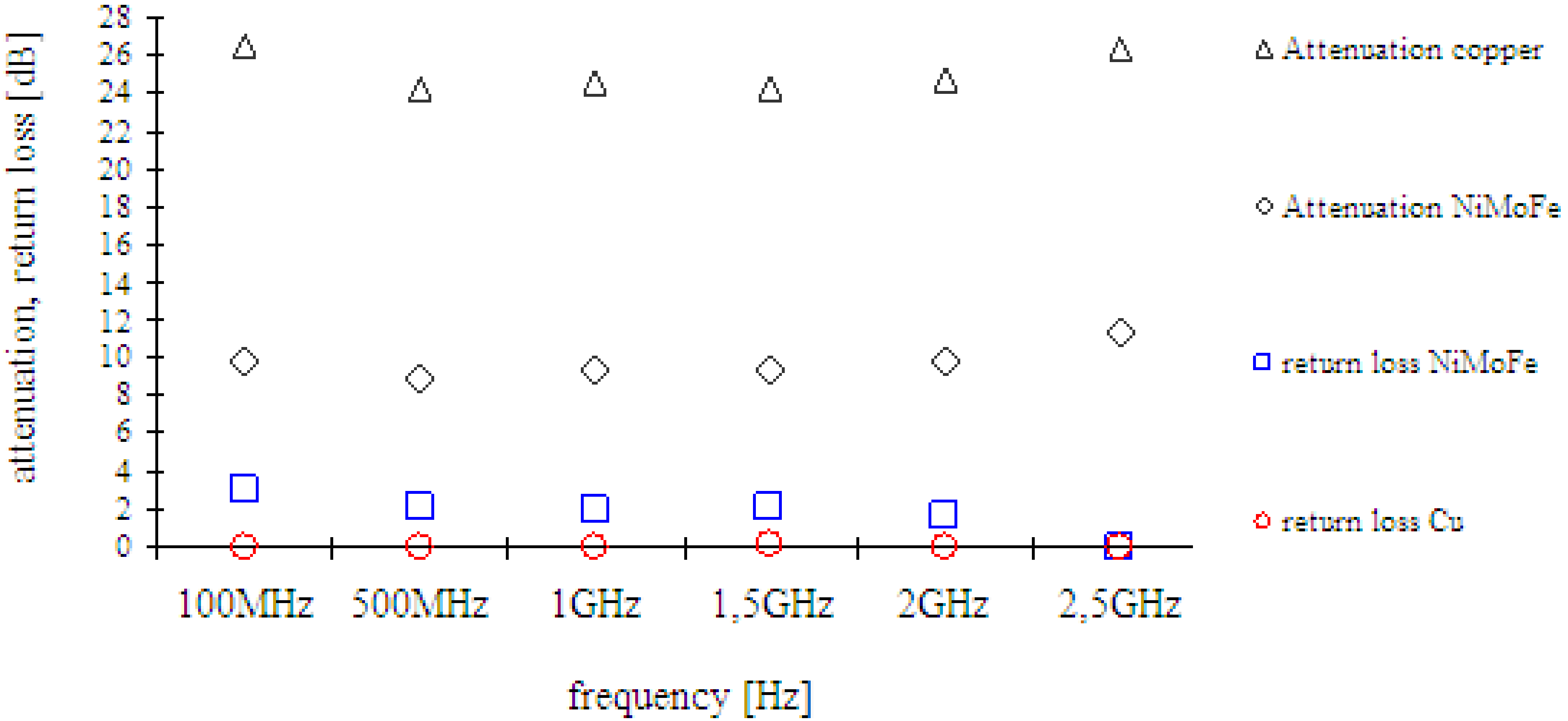
Experimental (8/11)

RF H-field attenuation



Experimental (9/11)

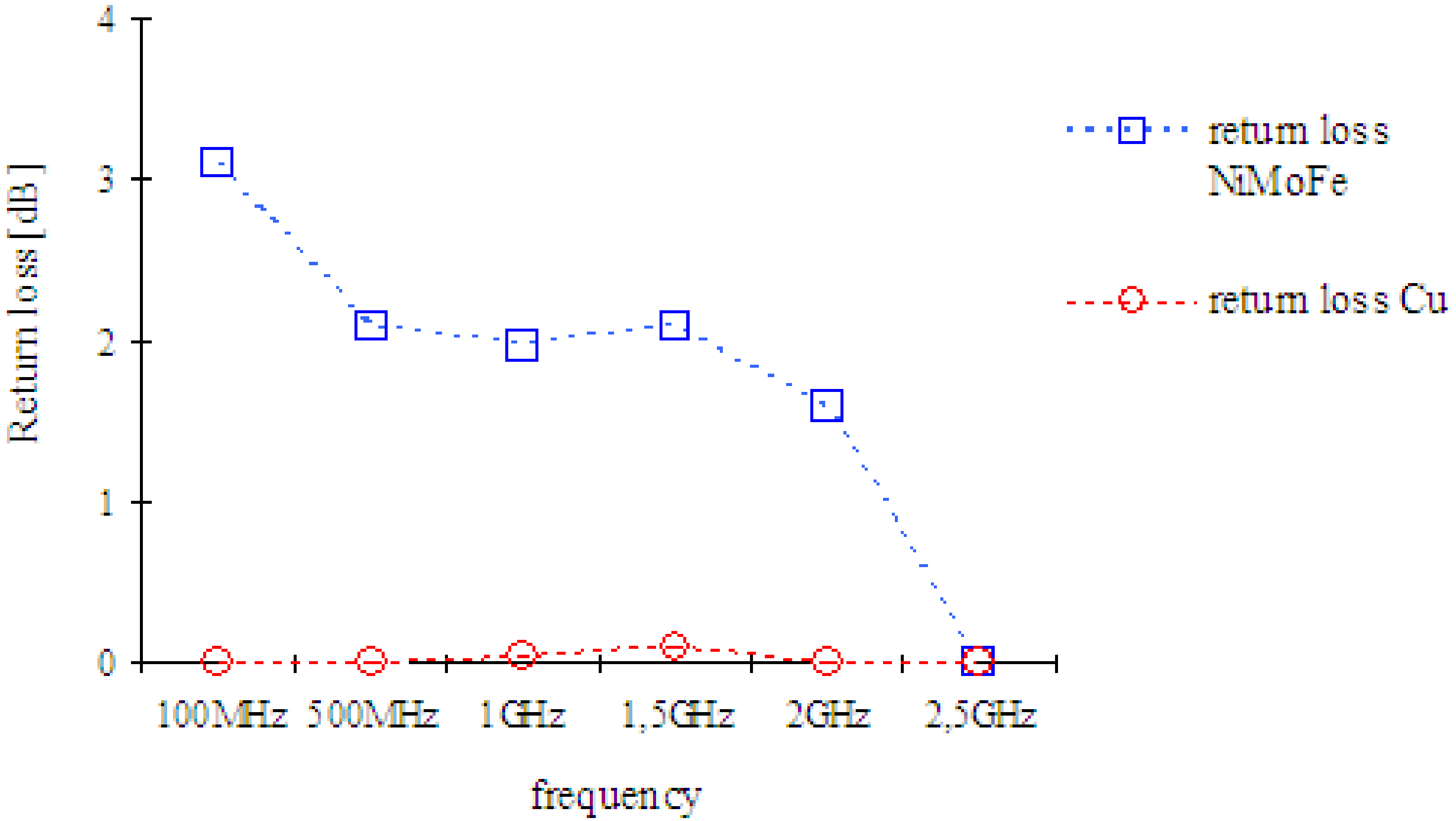
RF Plane wave attenuation and return loss - 20 nm thick layers



- ❖ SE_{Cu}-SE_{NiMoFe}~15dB, 3dB from reflection: $\delta_{Cu} < \delta_{NiMoFe} \rightarrow \mu_{r\ NiMoFe}$~25

Experimental (10/11)

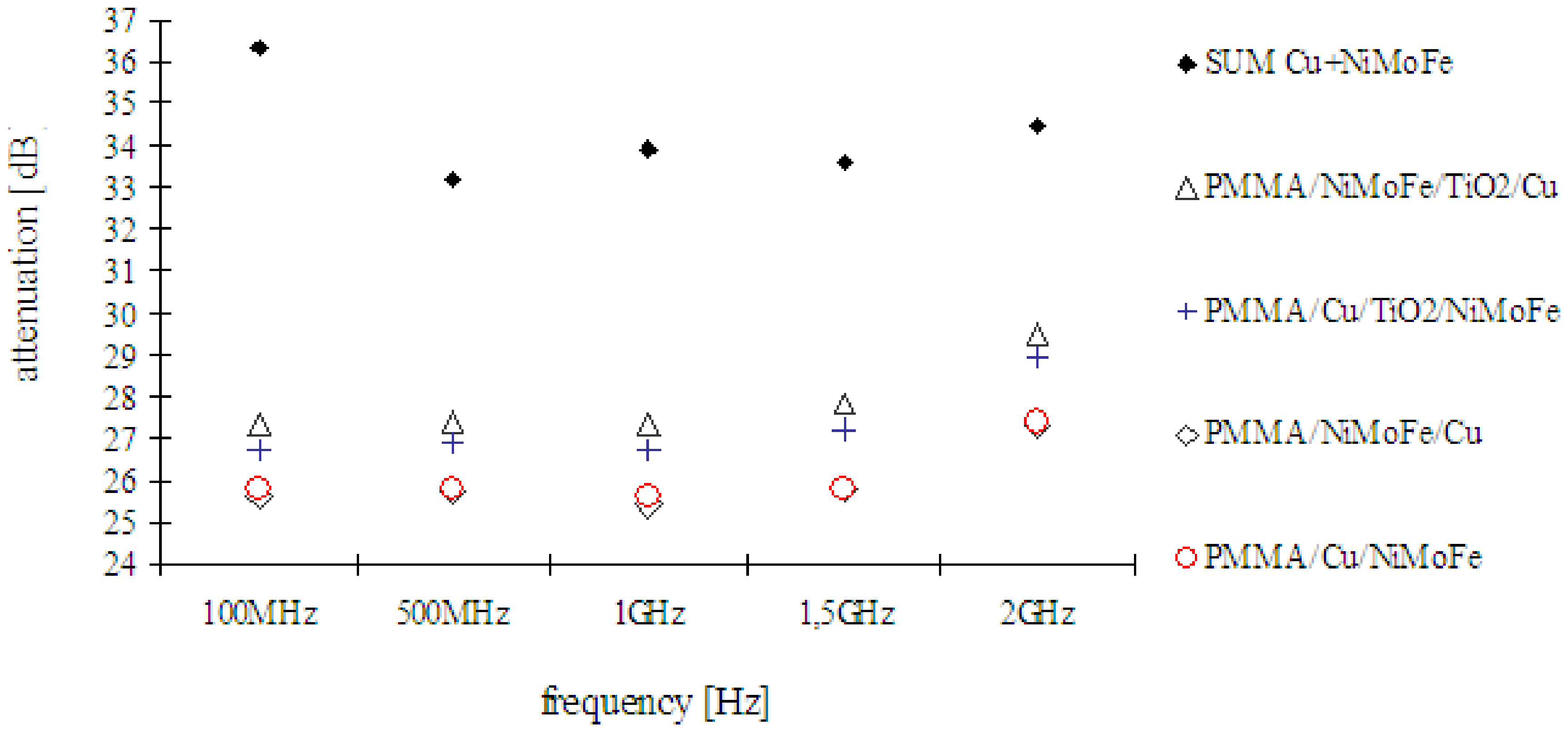
RF Plane wave return loss - 20 nm thick layers



- If μ/σ ratio ($Z_{barrier}$) ↓, Return loss ↑ (R ↓)

Experimental (11/11)

Multilayers - effect of internal interfaces



- ❖A few dB gain when metallic layers separated by a dielectric

Conclusion

- Copper provides higher RF far field shielding than $Ni_{79}Mo_5Fe_{16}$.
- $Ni_{79}Mo_5Fe_{16}$ layers thicker than ~120 nm provides higher RF magnetic field shielding compared to a copper when small loop source is close to a shield.
- A few dB higher plane wave attenuation was obtained when dielectric spaces layer was used between 20 nm thick metallic layers.

Thank you !

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