Chipless RFID based on Micro-Doppler Effect

Ashkan Azarfar, Nicolas Barbot, Etienne Perret

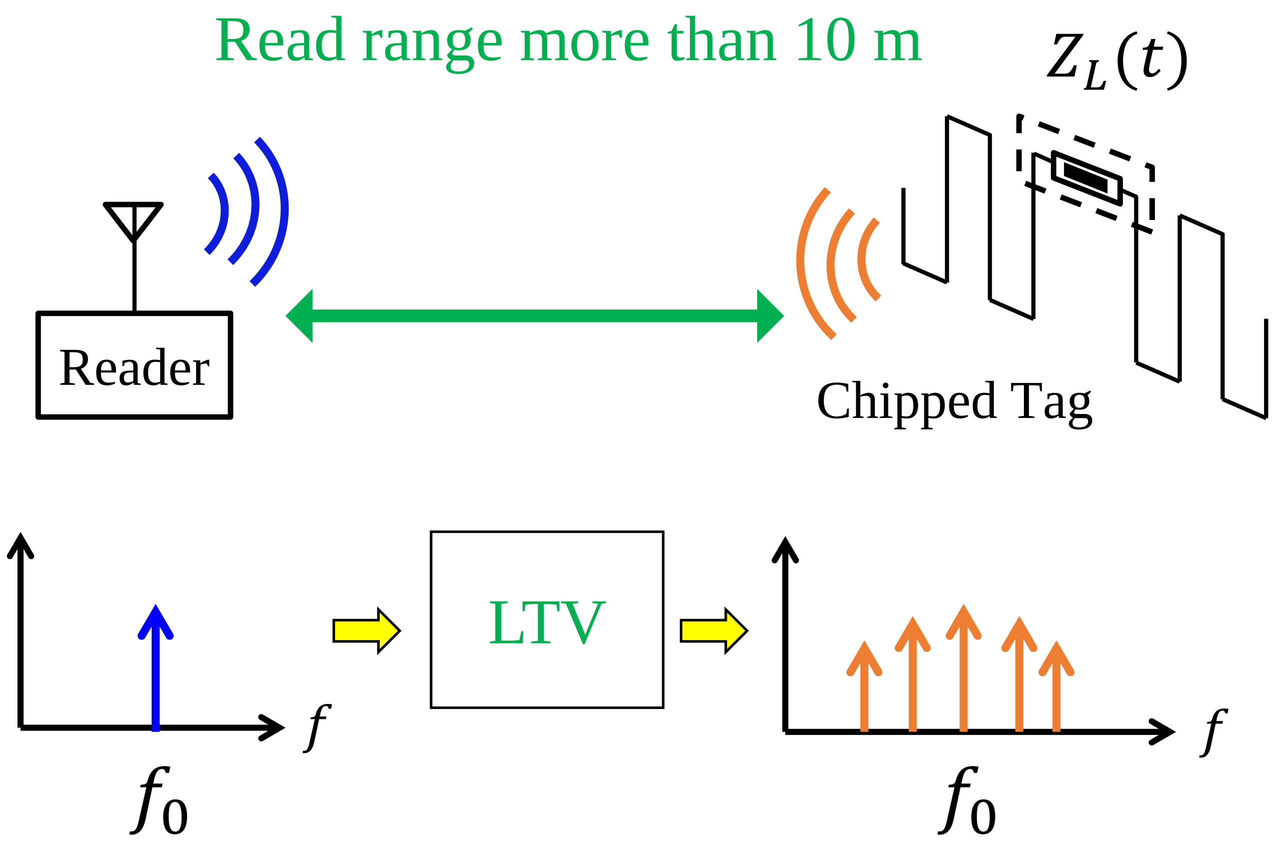
University of Grenoble Alpes, Grenoble INP, LCIS

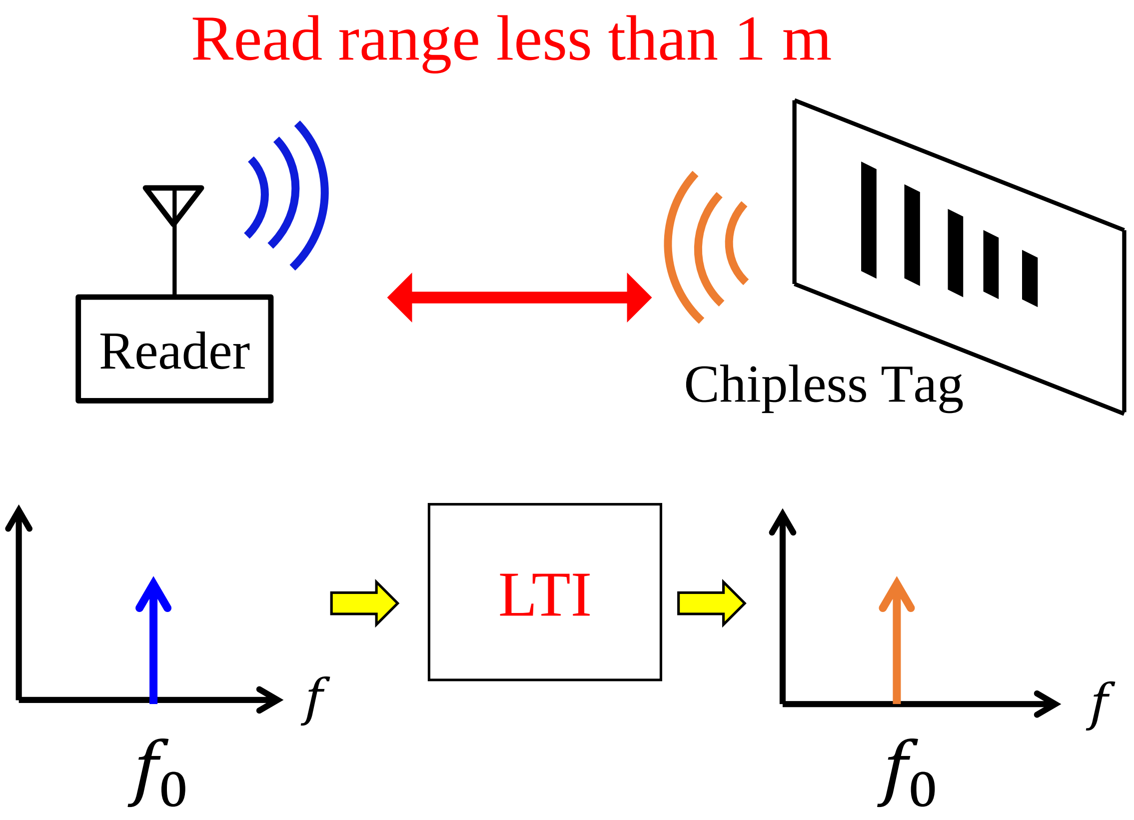
Outline

- Motivation
- Micro-Doppler Effect
- Model and analysis (rotational motion)
- Experimental results (rotational motion)
- Vibration sensing
- Conclusion

Motivation

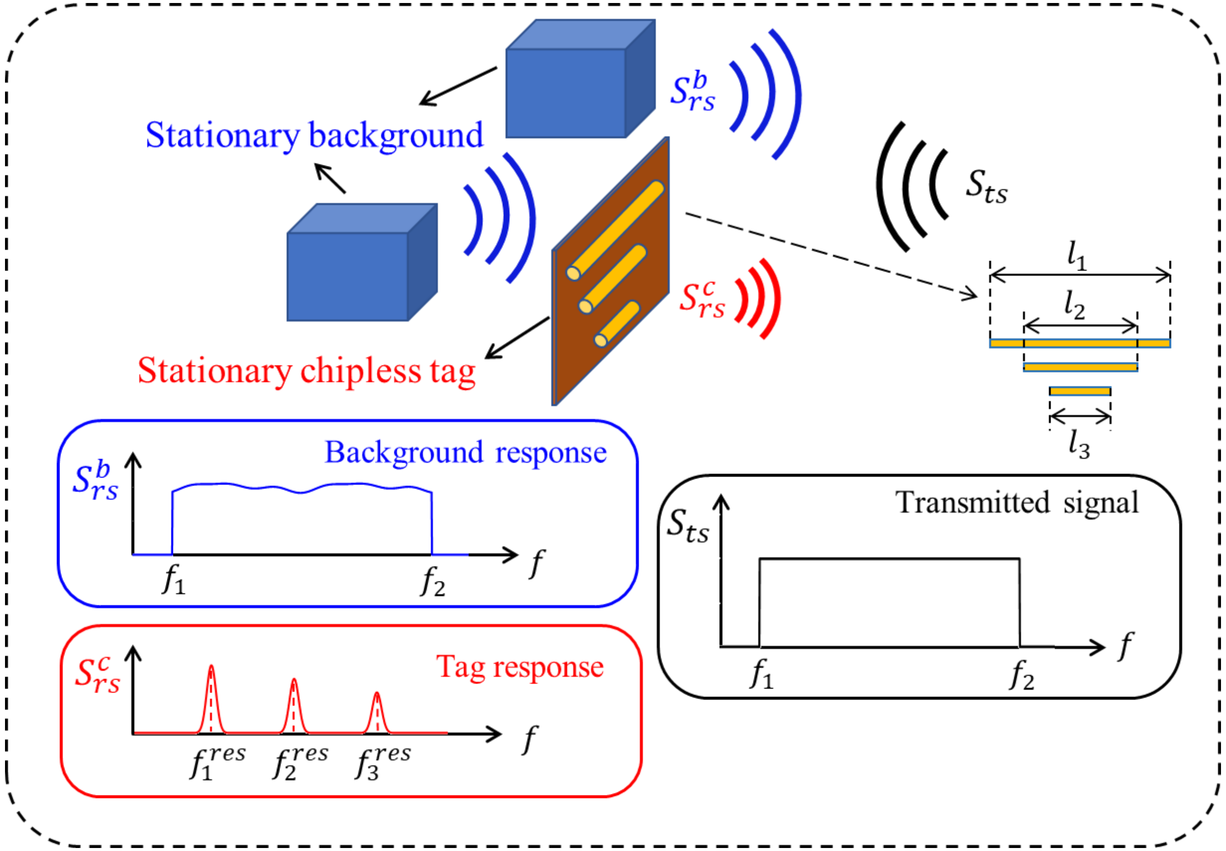
Read rang: UHF chipped RFID vs. Chipless RFID

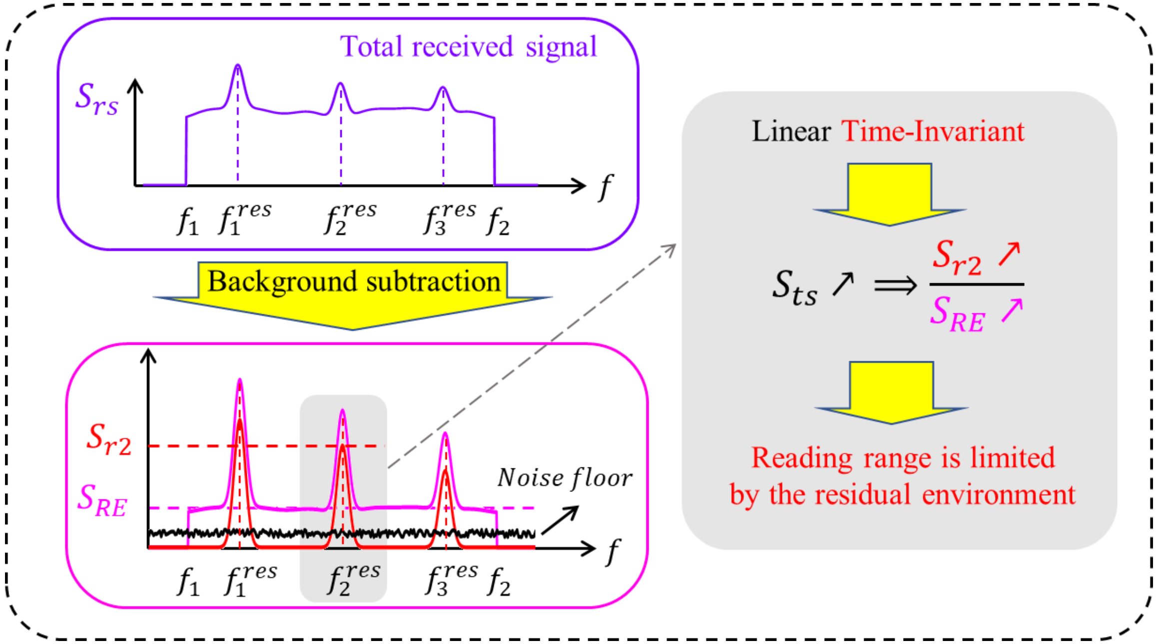




Motivation

Chipless limited read range : LTI property and residual environment



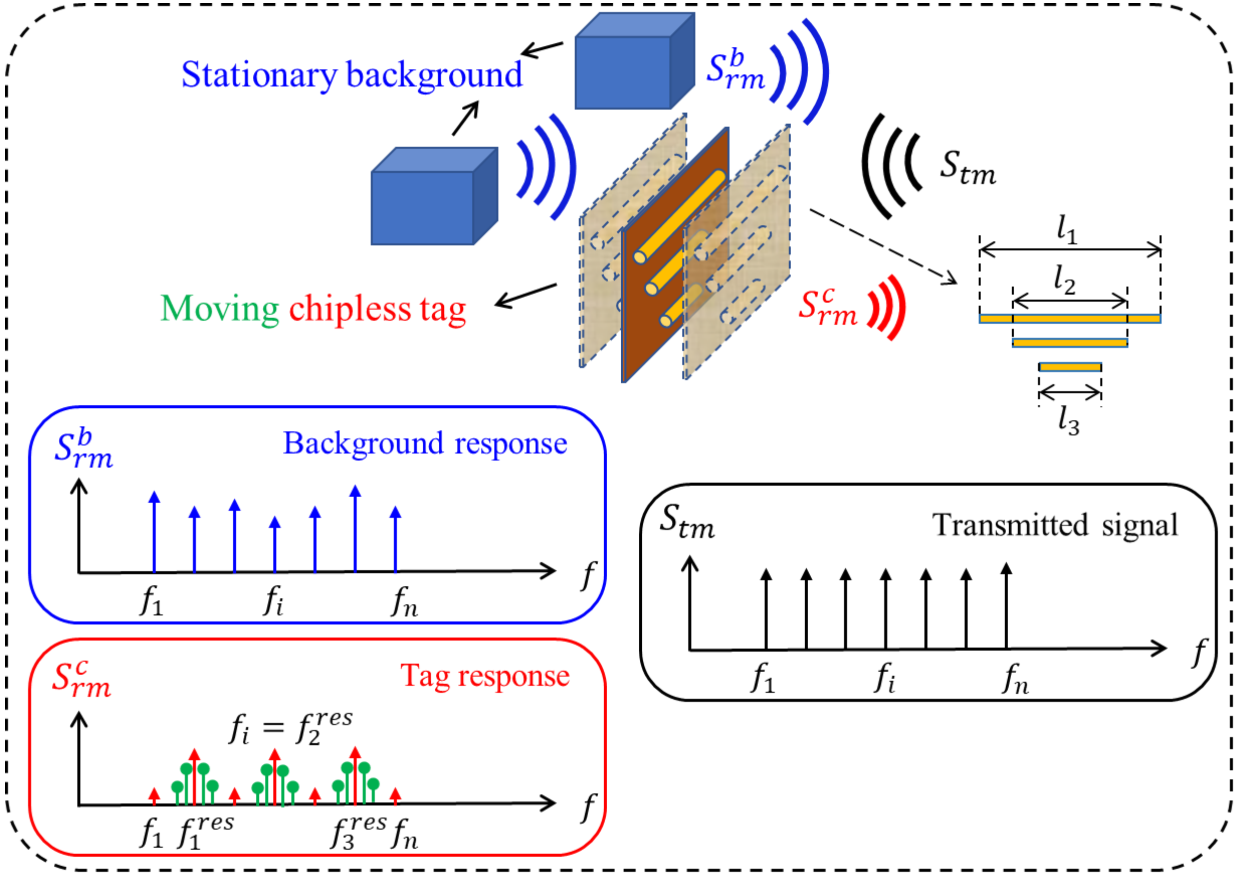


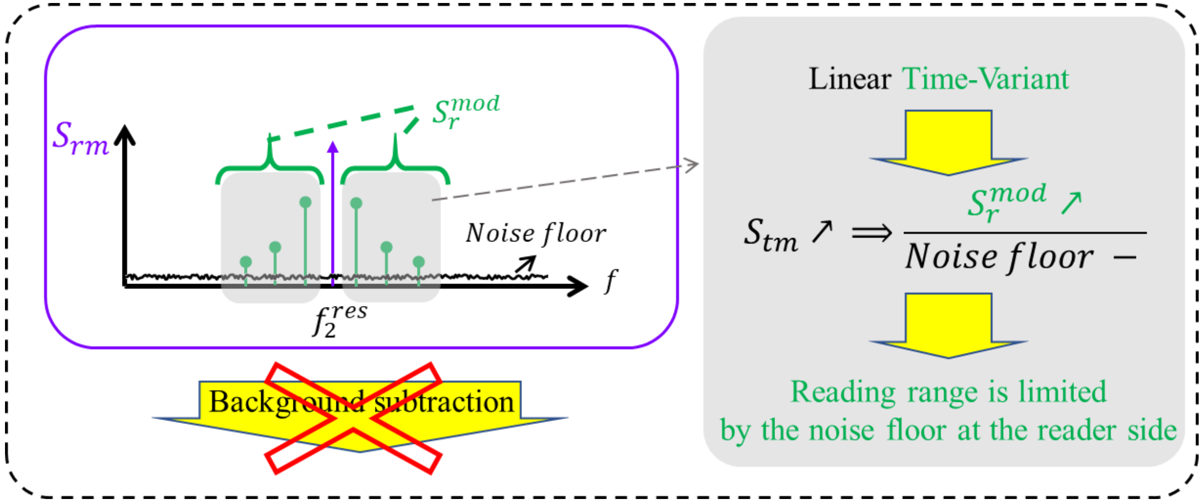
Radar equation for read range calculation :

$$d_{max} = \sqrt[4]{\frac{P_t G_T G_R \lambda^2 \sigma}{(4\pi)^3 \, P_{r\ min}}}$$

Motivation

Movement; a solution to break the LTI property





Radar equation for read range calculation : ✓

$$d_{max} = \sqrt[4]{\frac{P_t G_T G_R \lambda^2 \sigma_d}{(4\pi)^3 \, P_{r\ min}}}$$

Micro-Doppler Effect

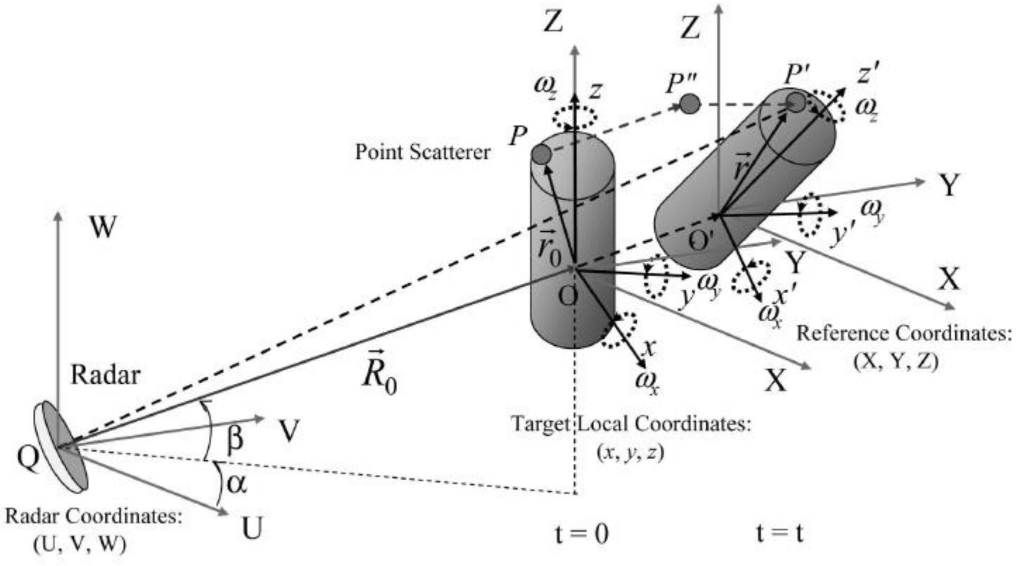
EM scattering from objects which have micromotions in addition to their bulk motion.

Micro-Doppler model

For regular periodic motions like vibration and rotation, analytical expressions can be derived.

Micro-Doppler detection

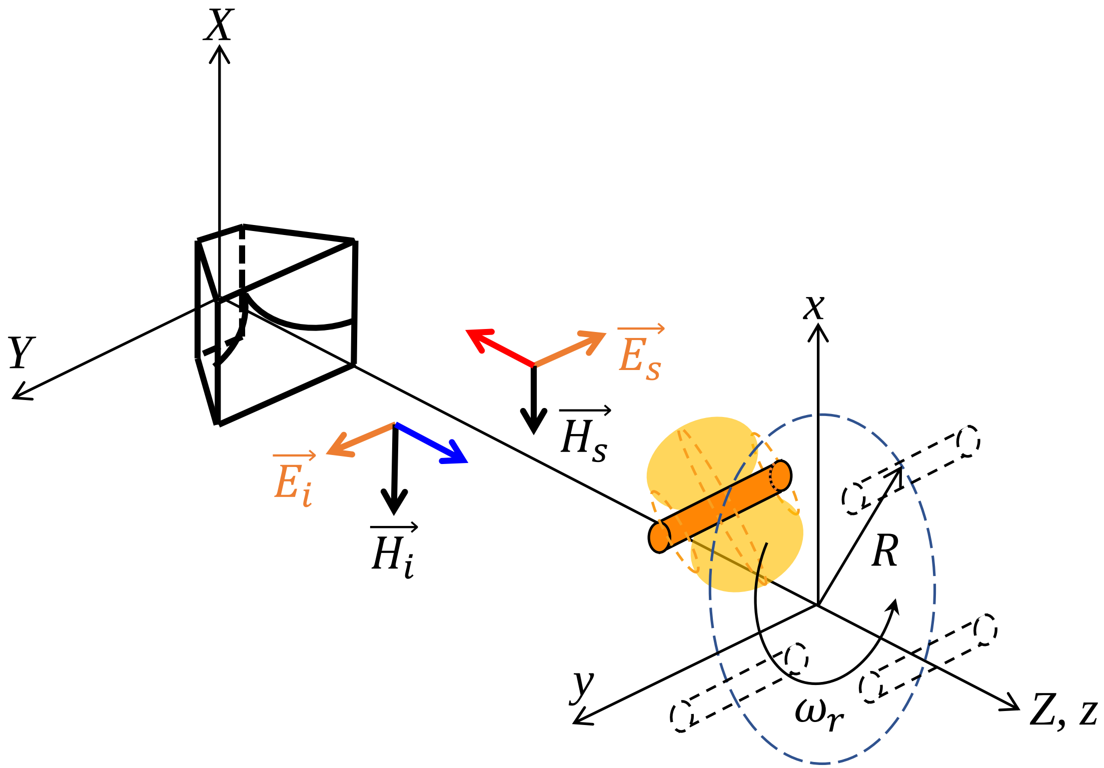
Coherent reception is essential to preserve even small phase variation.

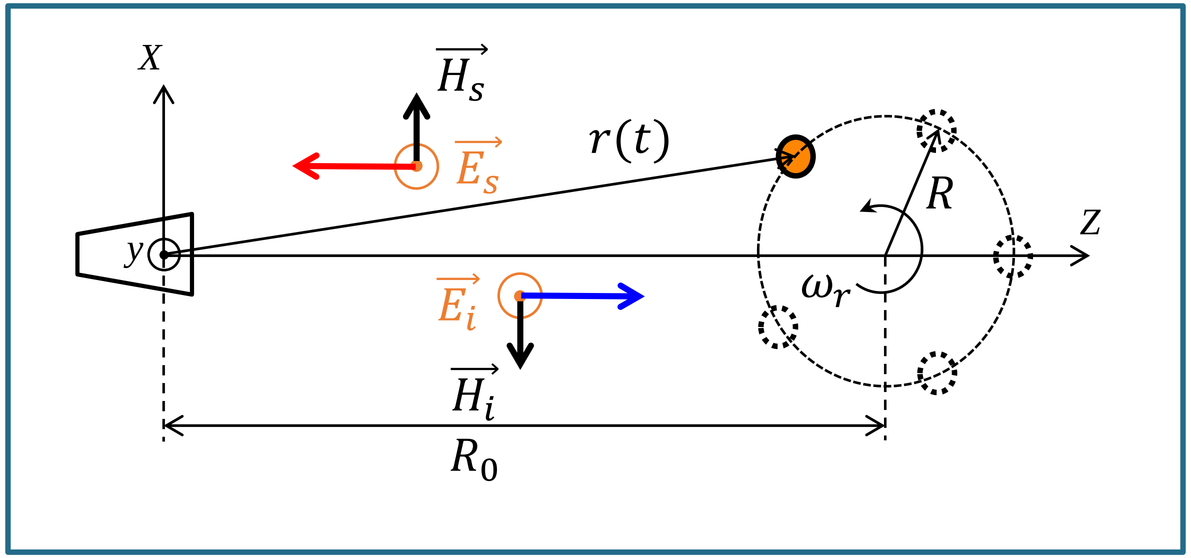


V. Chen et al , *Micro-Doppler Effect in Radar: Phenomenon, Model, and Simulation Study*, 2005

Model and analysis (rotational motion)

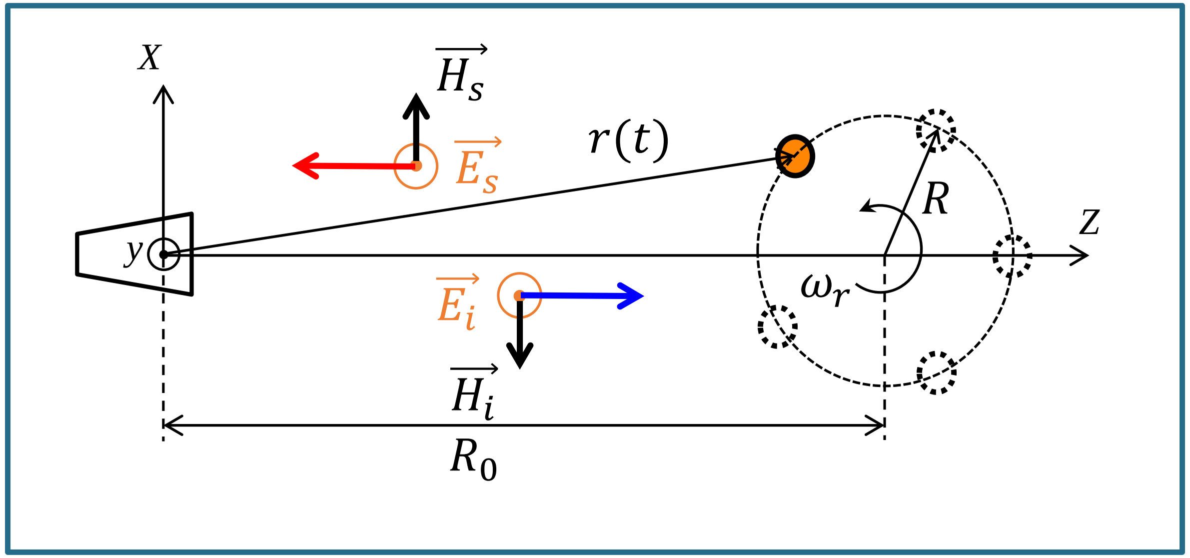
Backscattering from rotating dipole





Model and analysis (rotational motion)

Backscattering from rotating dipole



$$\vec{E_i}(\vec{r}) = E_0 e^{-jkz}\,\hat{y} \qquad k = \frac{2\pi f_0}{c_0}$$

$$R_0 \gg R$$

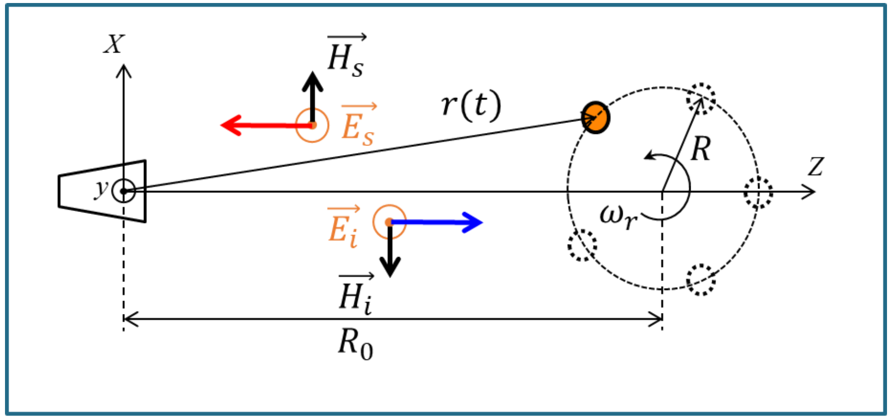
$$r(t) \approx R_0 + R\sin(\omega_r t)$$

$$|\rho(f_0)|^2 = \sigma(f_0)$$

$$\vec{E_s}(\vec{r},t) = E_0\rho(f_0)\frac{e^{jkz}}{\sqrt{4\pi}\;z}\,e^{-j2k(R_0+R\sin(\omega_r t))}\hat{y}$$

Model and analysis (rotational motion)

Backscattering from rotating dipole



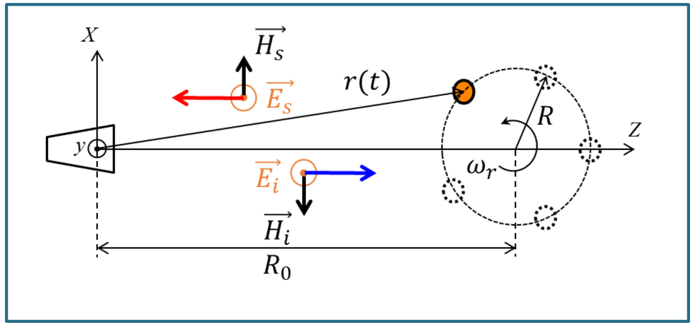
$$\vec{E_i}(\vec{r}) = E_0 e^{-jkz}\,\hat{y}$$

$$\vec{E_s}(\vec{r},t) = E_0\rho(f_0)\frac{e^{jkz}}{\sqrt{4\pi}\ z}\,e^{-j2k(R_0+R\sin(\omega_r t))}\hat{y}$$

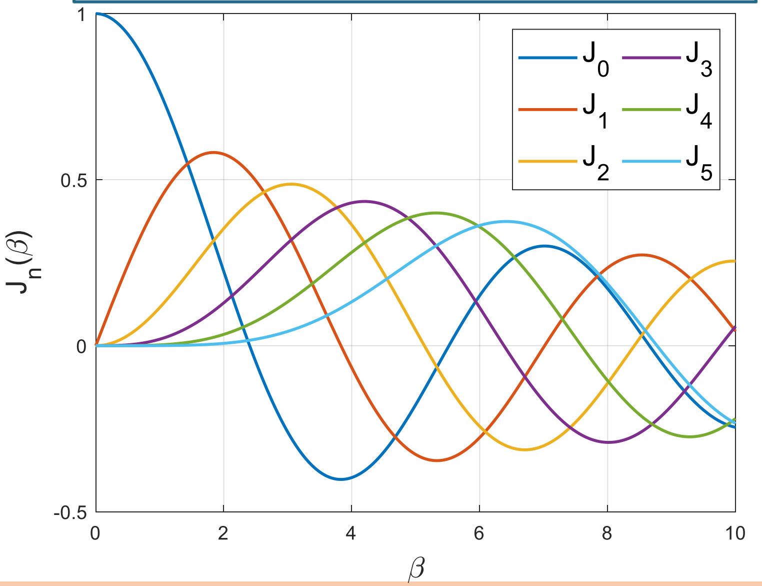
$$\vec{\boldsymbol{E}_s}(\vec{r},f) = E_0\rho(f_0)\frac{e^{jkz}}{\sqrt{4\pi}\ z}\,e^{-j2kR_0}\sum_{n=-\infty}^{+\infty} J_n(\beta)\,\delta(f-nf_r)\,\hat{y} \qquad \beta = \frac{4\pi R}{\lambda}$$

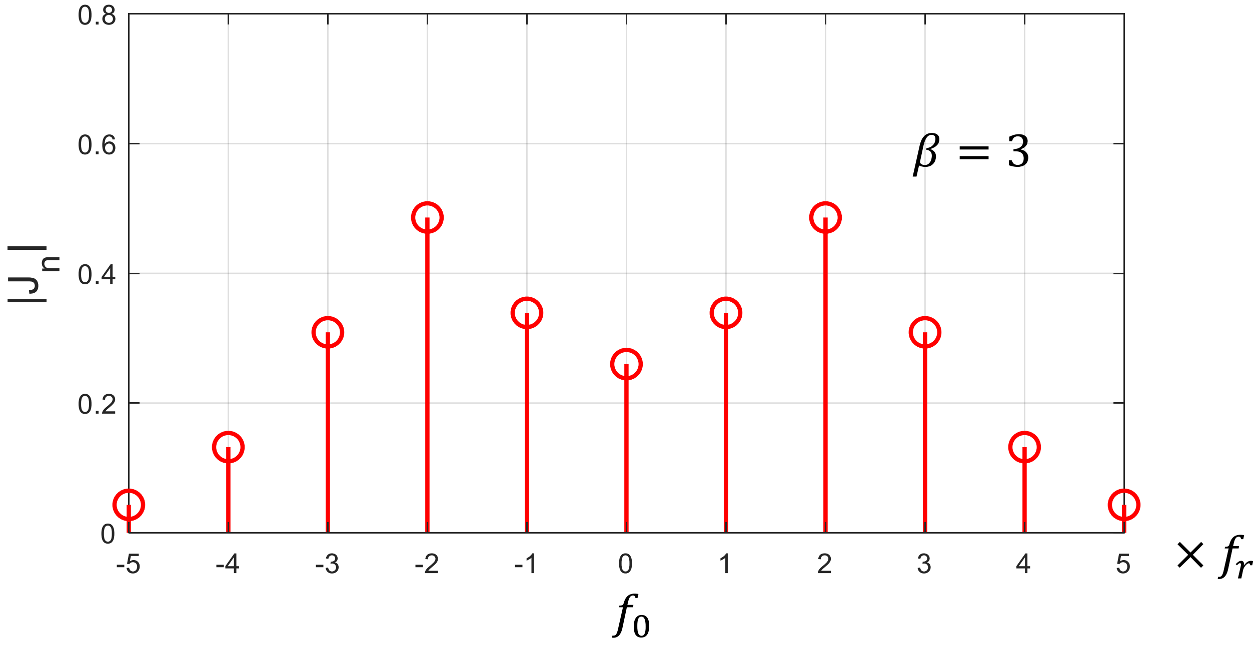
Model and analysis (rotational motion)

Backscattering from rotating dipole



$$\overrightarrow{\boldsymbol{E}}_s(\vec{r}, f) = E_0 \rho(f_0) \frac{e^{jkz}}{\sqrt{4\pi}\ z} e^{-j2kR_0} \sum_{n=-\infty}^{+\infty} J_n(\beta)\, \delta(f - n f_r)\ \hat{y}$$



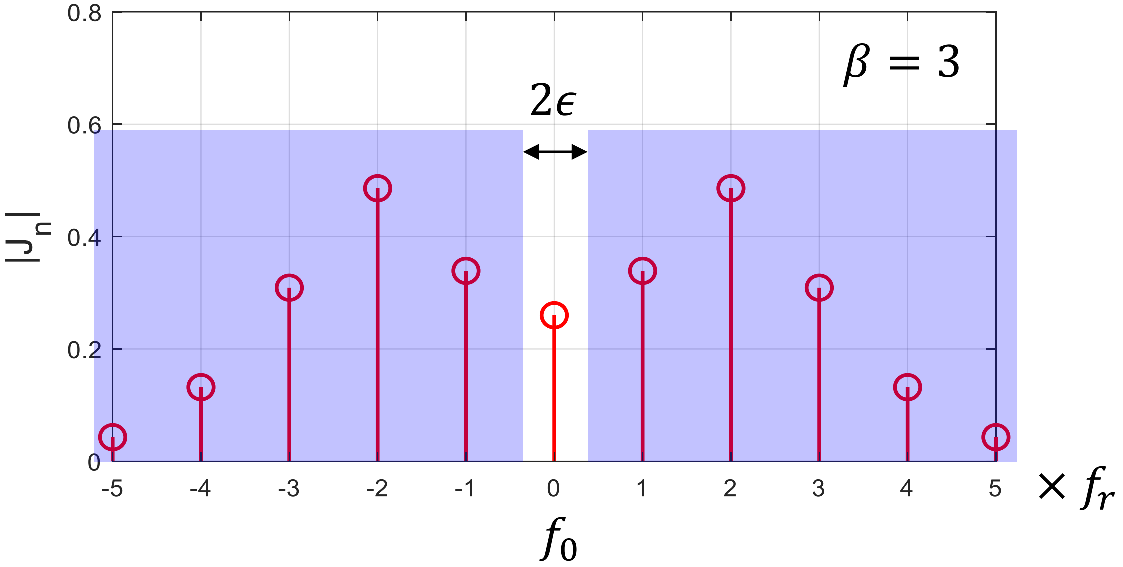


Model and analysis (rotational motion)

Differential RCS

$$\overrightarrow{E_i}(\vec{r}) = E_0 e^{-jkz}\,\hat{y}$$

$$\overrightarrow{\boldsymbol{E}_s}(\vec{r}, f) = E_0 \rho(f_0) \frac{e^{jkz}}{\sqrt{4\pi}\ z} e^{-j2kR_0} \sum_{n=-\infty}^{+\infty} J_n(\beta)\,\delta(f - n f_r)\,\hat{y}$$



Classical RCS (non-modulated scatterer) $$\sigma(f_0) = \lim_{r\to\infty} 4\pi r^2 \frac{|E_s|^2}{|E_i|^2}$$

Differential RCS (modulated scatterer) $$\sigma_d(f_0) = \lim_{r\to\infty} 4\pi r^2 \frac{\int_{-\infty}^{-\epsilon} |E_s|^2\ df + \int_{+\epsilon}^{+\infty} |E_s|^2\ df}{|E_i|^2}$$

Model and analysis (rotational motion)

Identification based on differential RCS

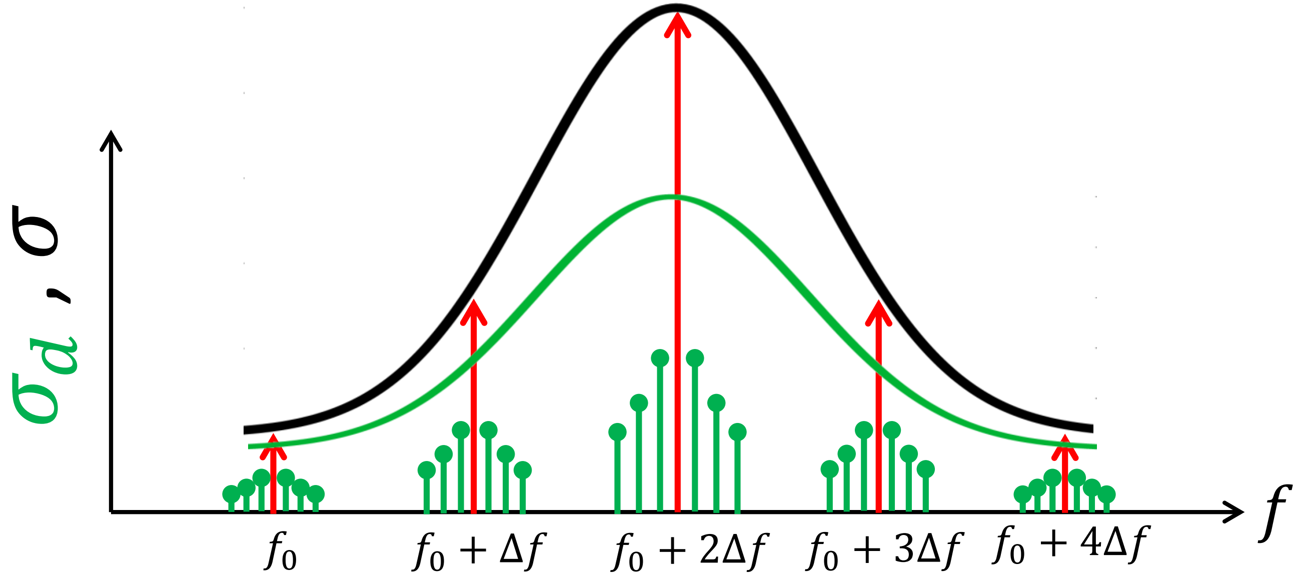
$$\overrightarrow{E_i}(\vec{r}) = E_0 e^{-jkz}\,\hat{y}$$

$$\overrightarrow{\boldsymbol{E_s}}(\vec{r},f) = E_0\rho(f_0)\frac{e^{jkz}}{\sqrt{4\pi}\;z}\,e^{-j2kR_0}\sum_{n=-\infty}^{+\infty} J_n(\beta)\,\delta(f-nf_r)\,\hat{y}$$

$$\sigma_d(f_0) = \lim_{r\to\infty} 4\pi r^2 \frac{\int_{-\infty}^{-\epsilon}|E_s|^2\,df + \int_{+\epsilon}^{+\infty}|E_s|^2\,df}{|E_i|^2}$$

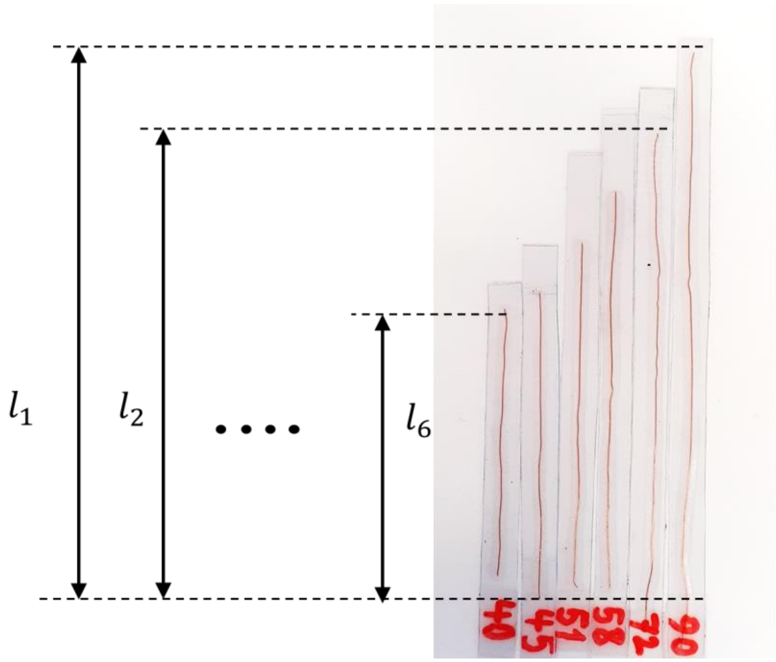
$$\sigma_d(f_0) = \sigma(f_0)(1-[J_0(\beta)]^2)$$

$$J_0(\beta) = 0 \;\rightarrow\; \beta_{opt}$$

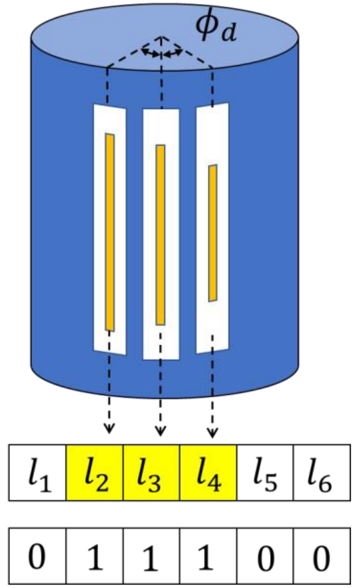


Experimental results (rotational motion)

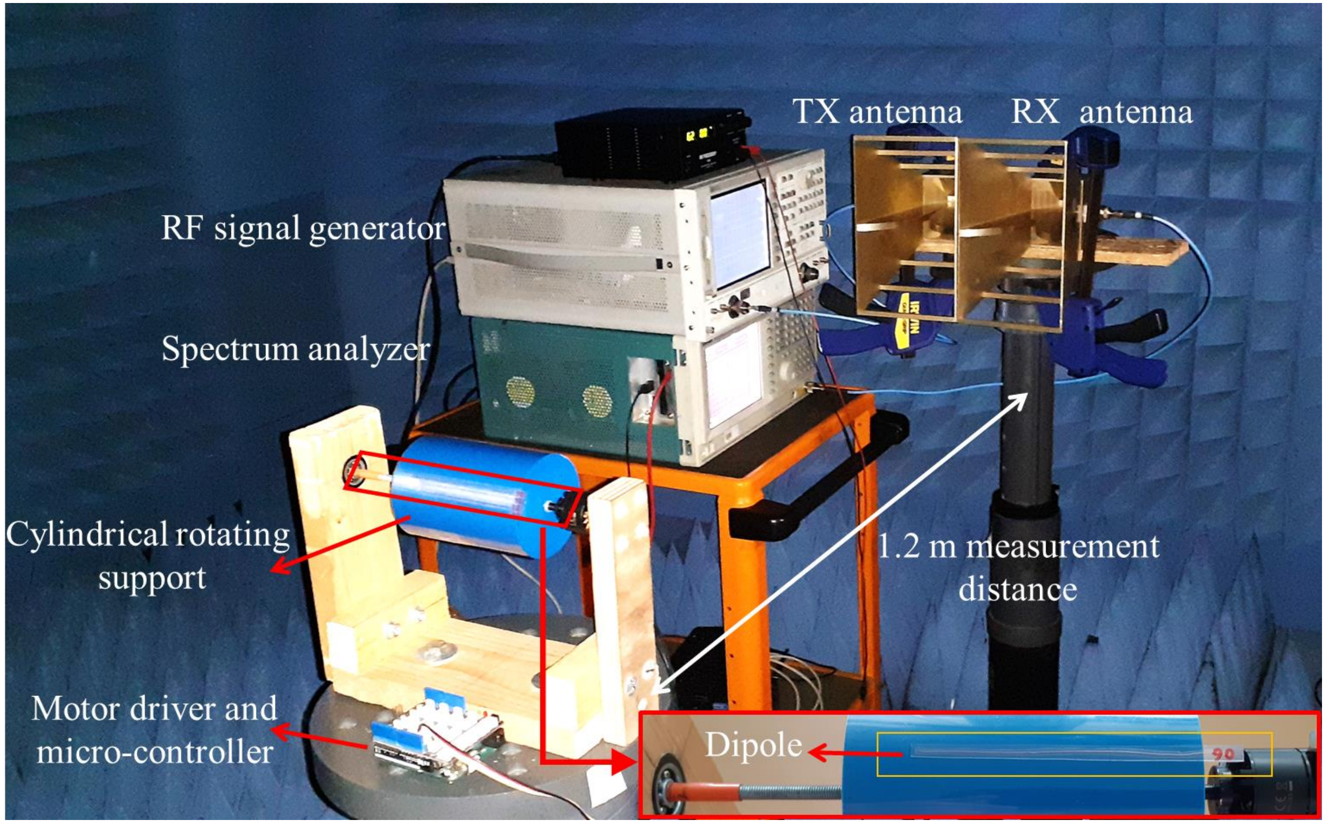
Measurement in anechoic chamber (Identification)



Six dipoles made of 100 μm copper wire

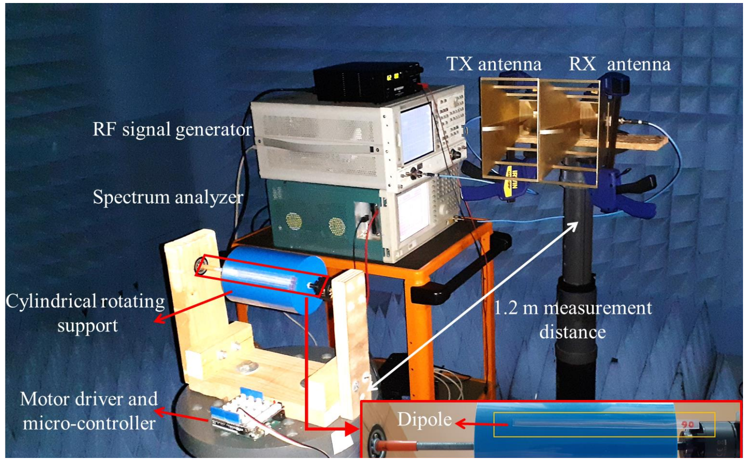


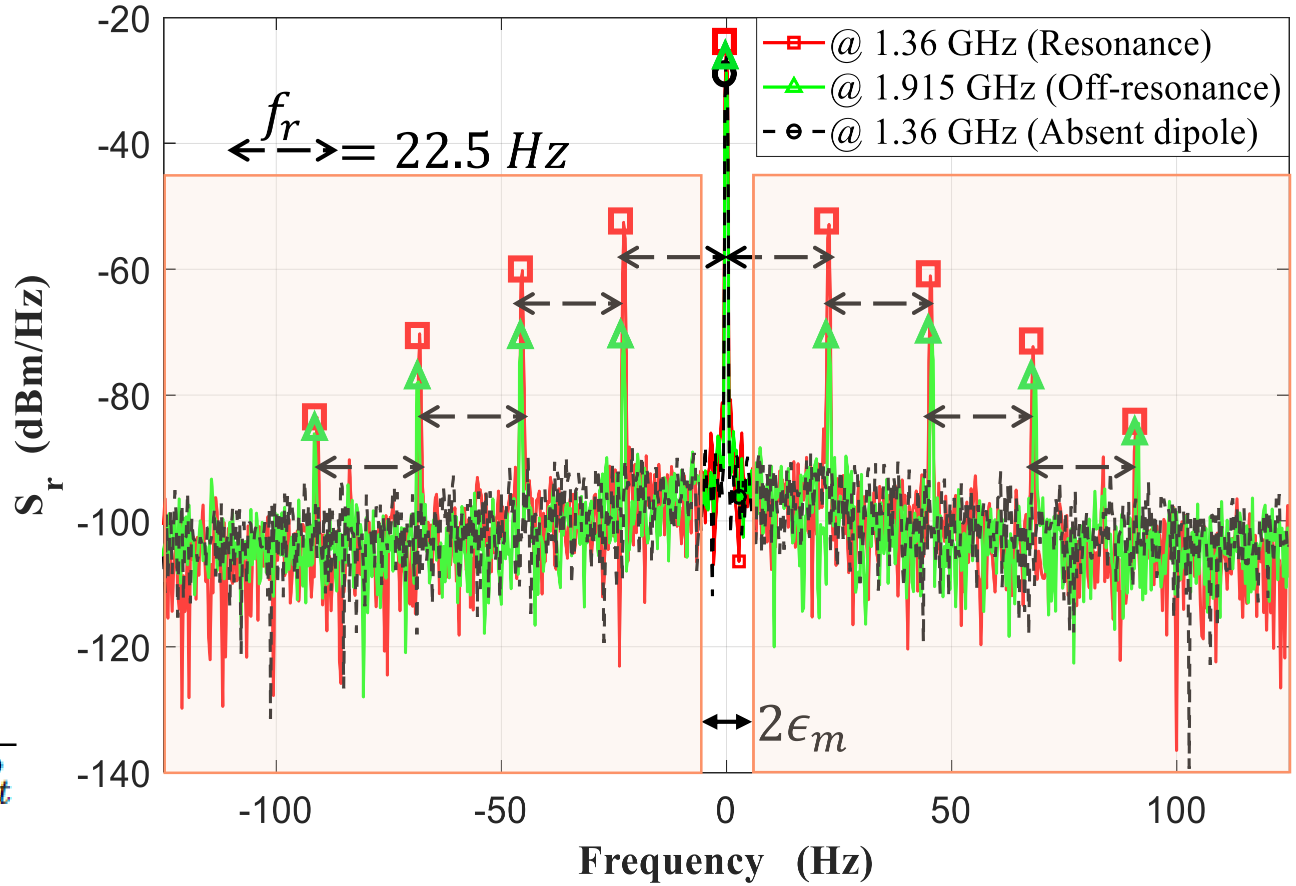
Cylindrical rotating support with $R = 35$mm



Experimental results (rotational motion)

Measurement in anechoic chamber (Identification)



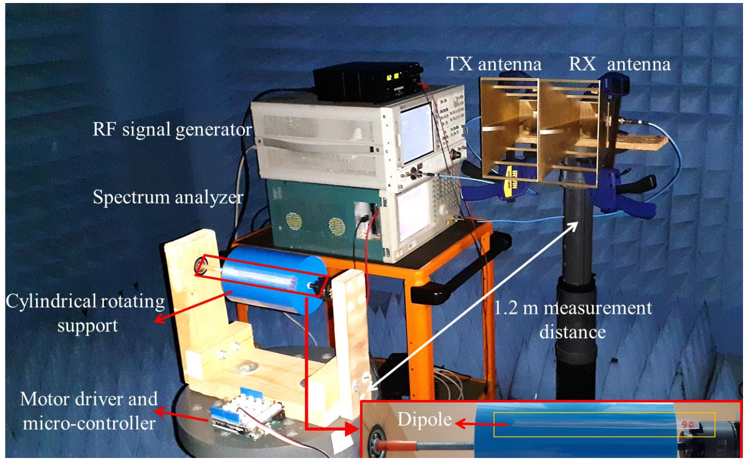


$$P_{bs\,d} = \int_{-\infty}^{-\epsilon_m} S_r(f)\,df + \int_{+\epsilon_m}^{+\infty} S_r(f)\,df$$

$$\sigma_d(f_0) = \frac{(4\pi)^3 d^4 P_{bs\,d}}{\lambda^2 G_r G_t (1-|\Gamma_r|^2)(1-|\Gamma_t|^2) P_t}$$

Experimental results (rotational motion)

Measurement in anechoic chamber (Identification)



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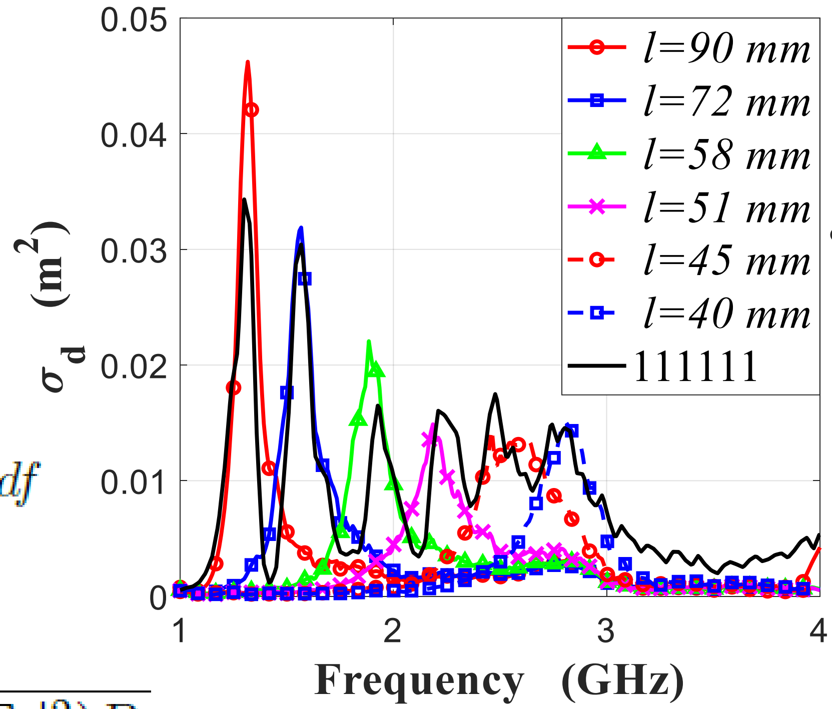
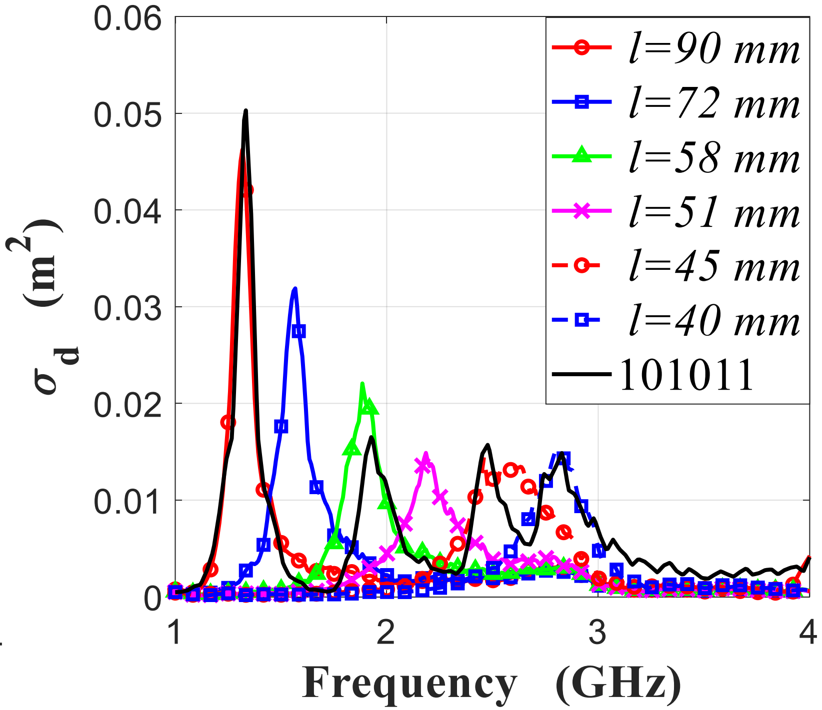
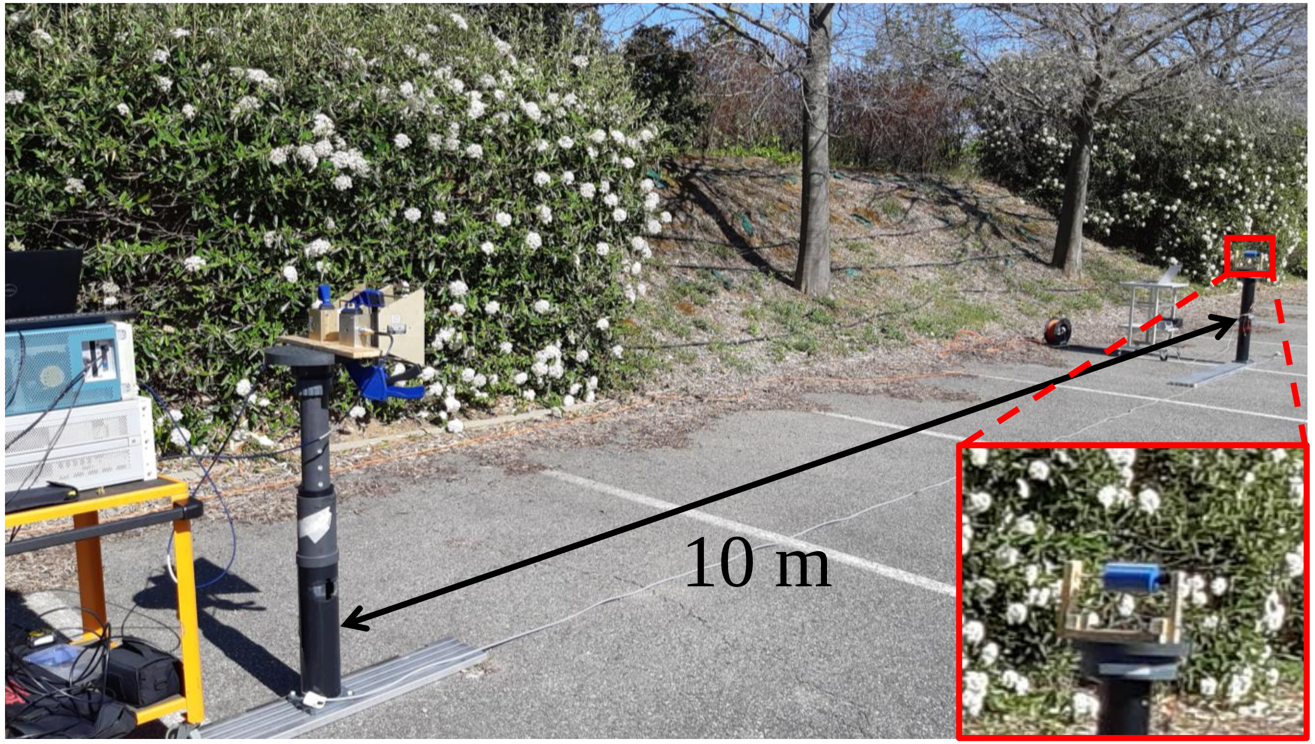
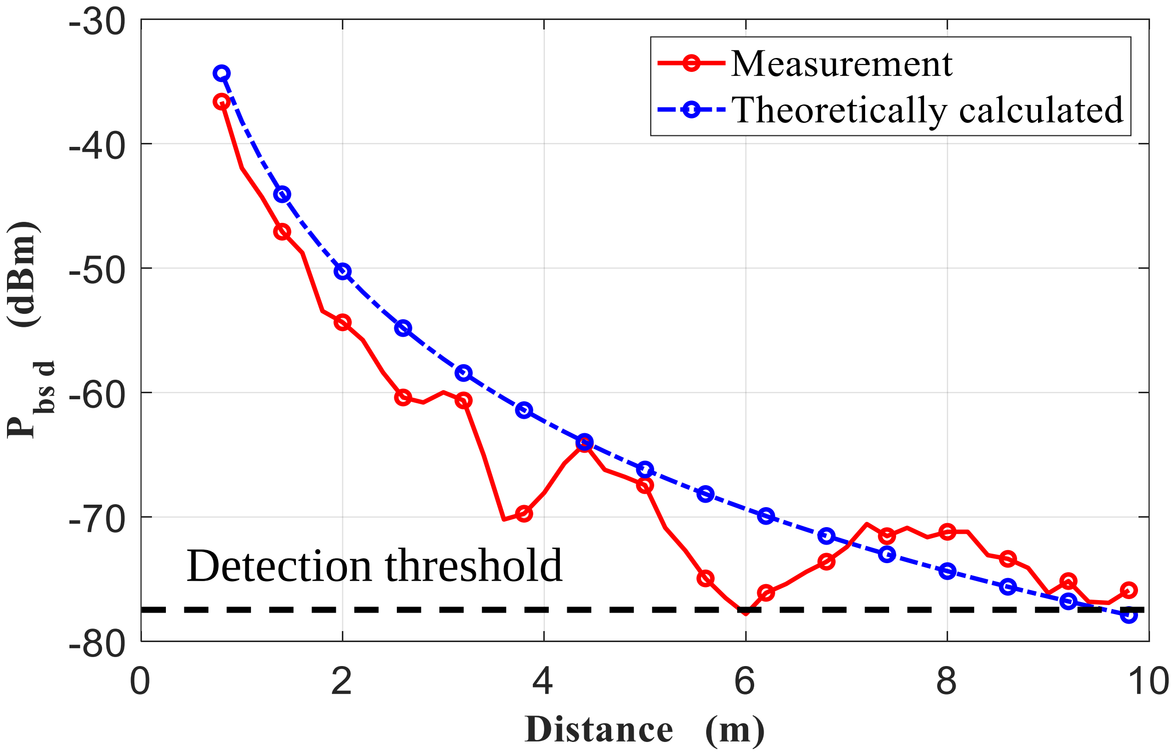




Experimental results (rotational motion)

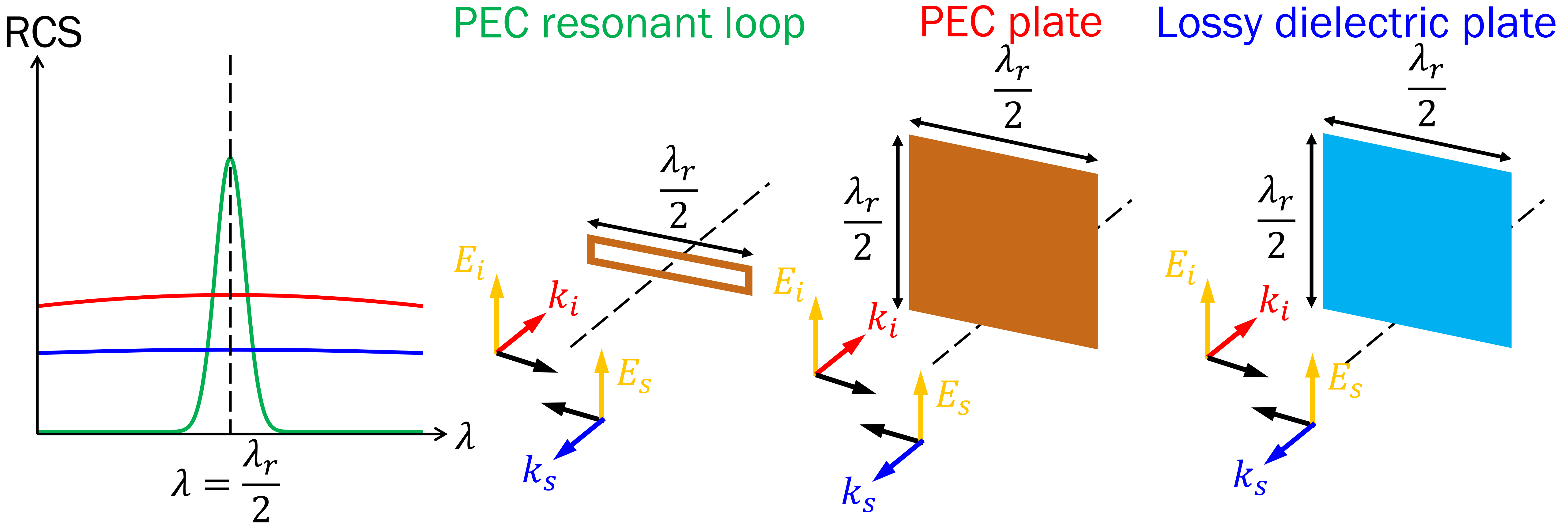
Measurement in real environment (Read range)





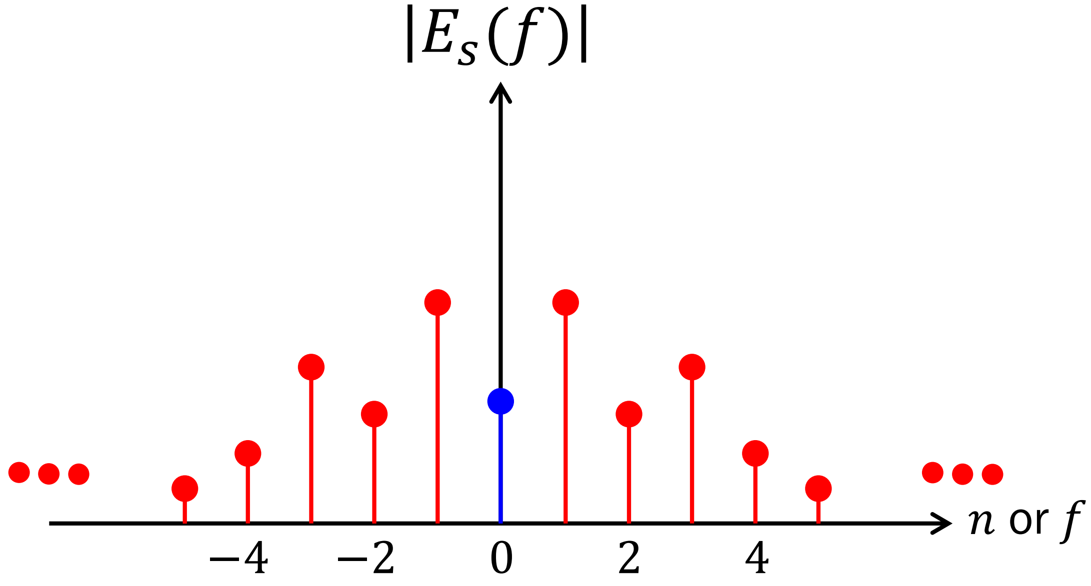
Vibration sensing

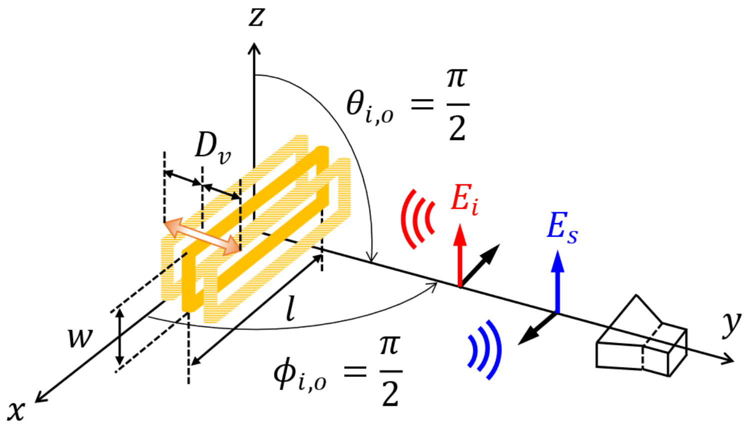
Read range enhancement based on resonant RCS

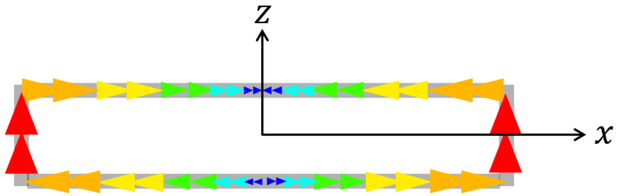


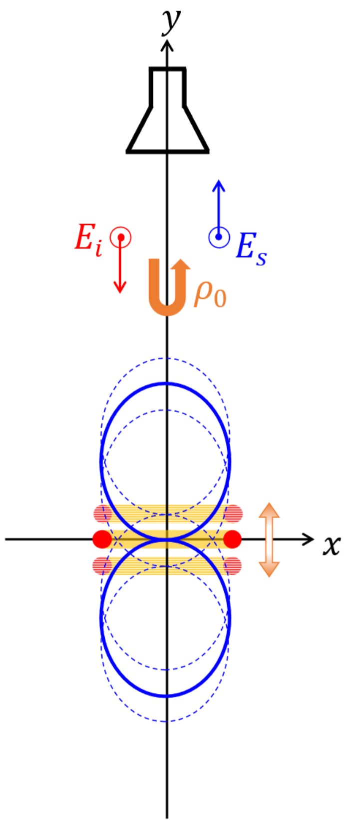
Vibration sensing

Calibration free vibration sensing and target identification







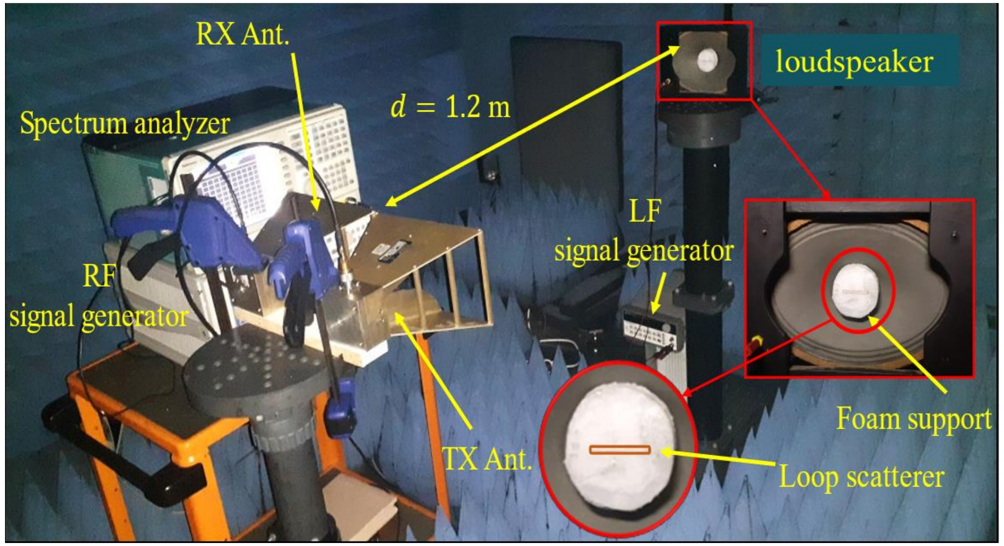


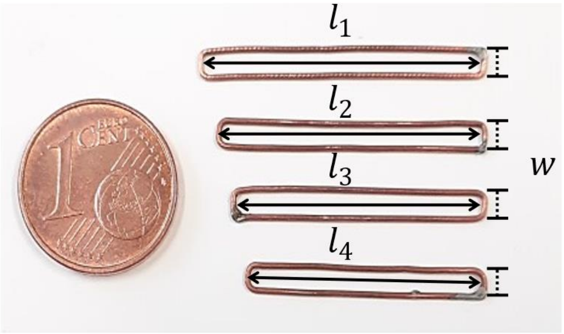
$$\min\left(\sum_{n=1}^{N-1}\left|\frac{|J_n(\beta)|}{|J_{n+1}(\beta)|}-\frac{|C_n|}{|C_{n+1}|}\right|^2\right) \rightarrow \hat{\beta}_s$$

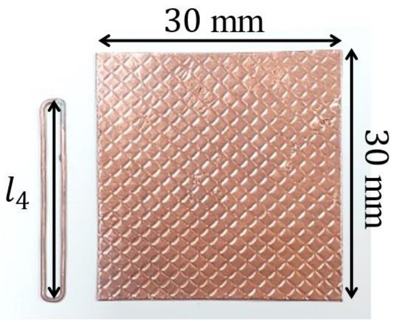
Estimated β

Vibration sensing

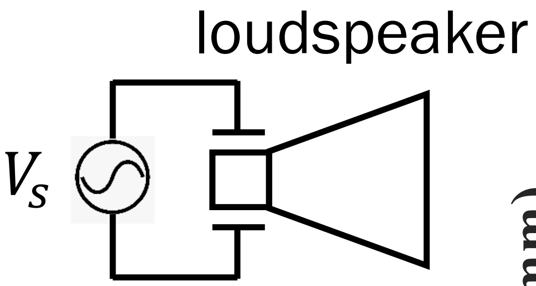
Experimental verification



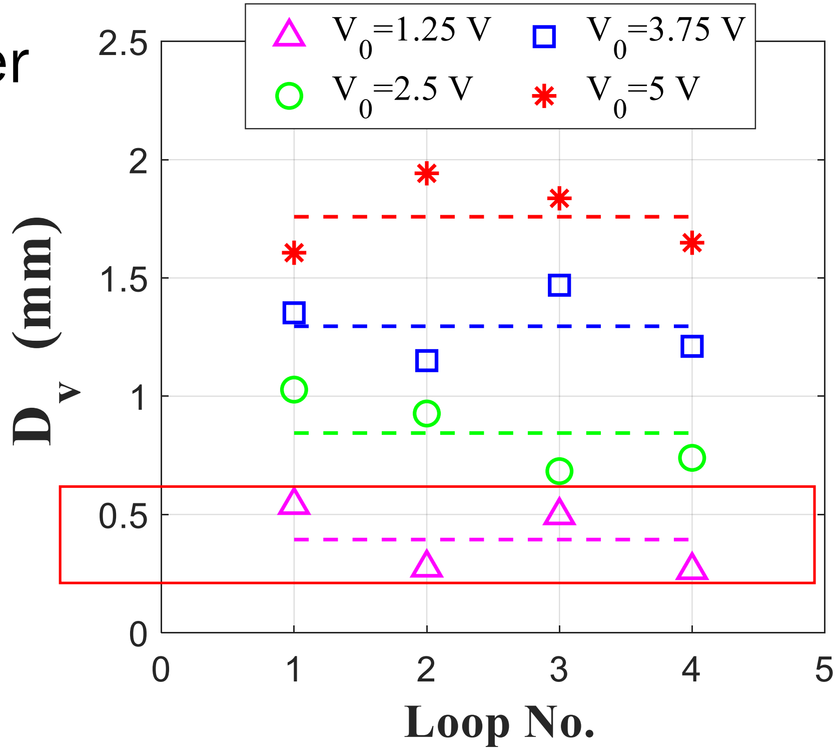




- Sensitivity ≈ 400 μm

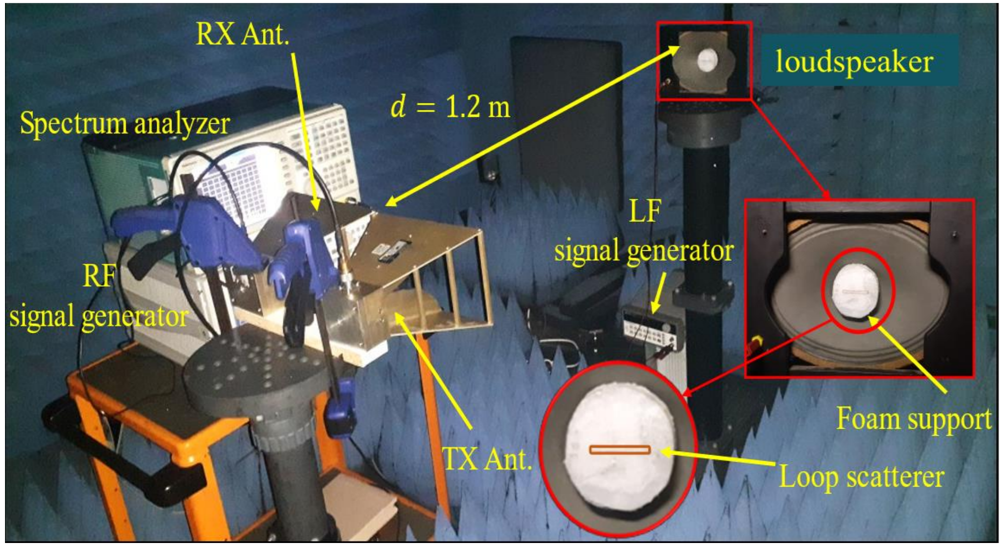


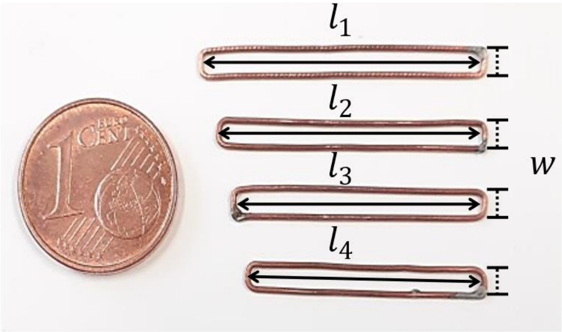
$$V_s = V_0 \sin 2\pi f_v t$$

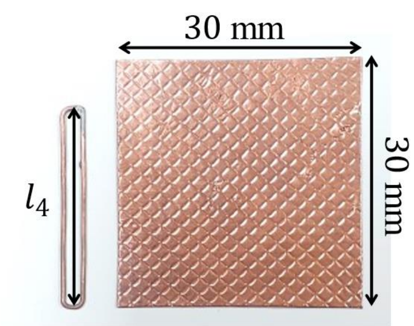


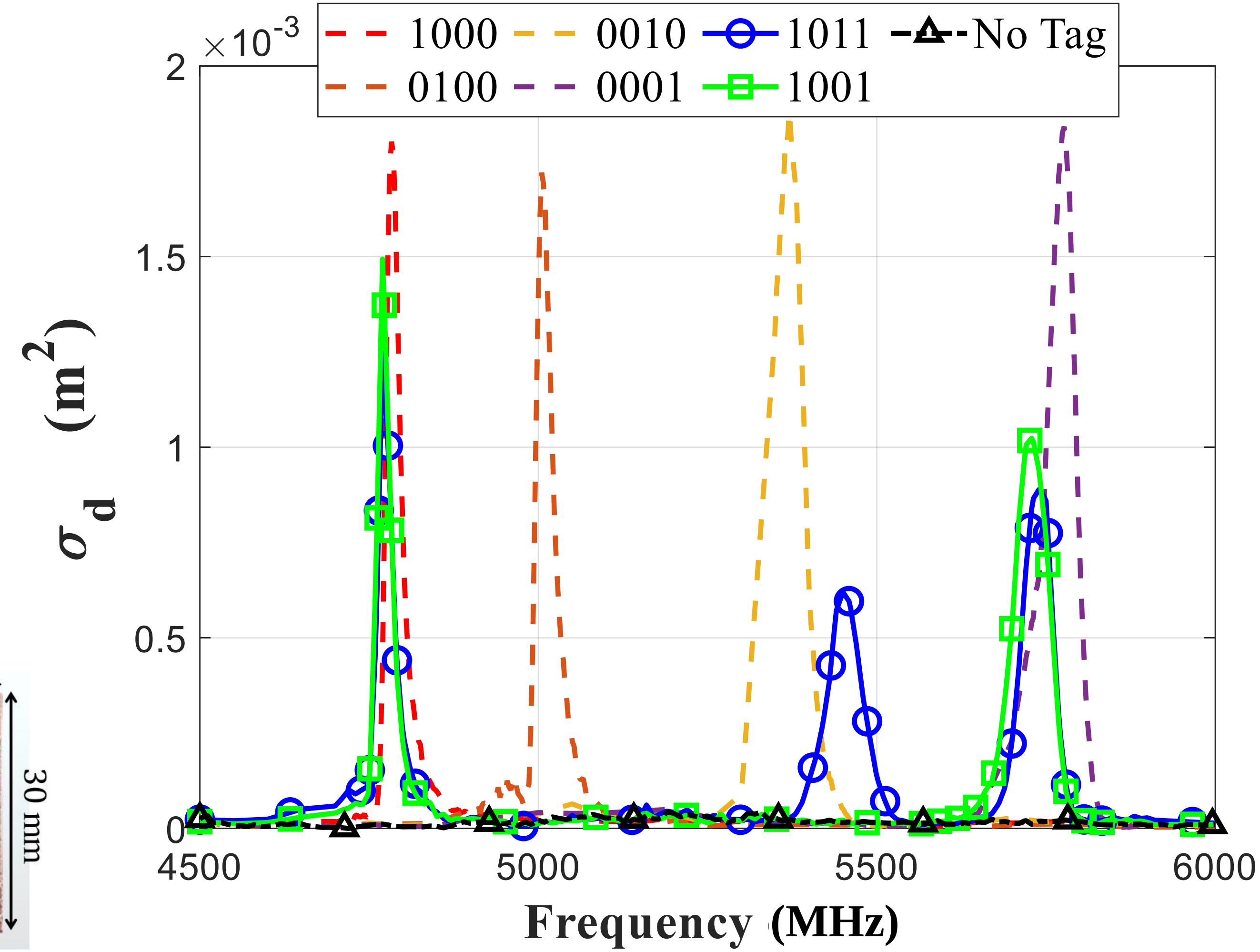
Vibration sensing

Experimental verification





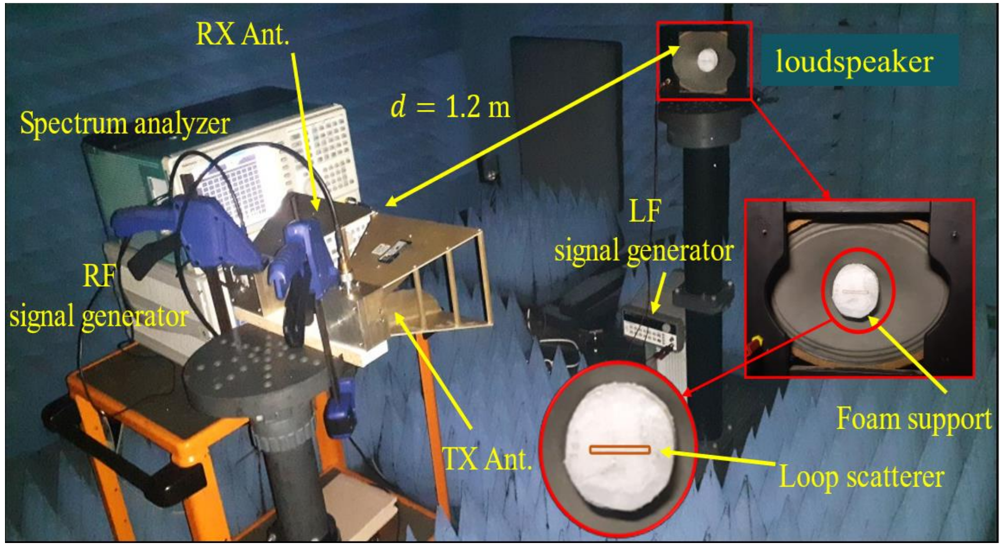


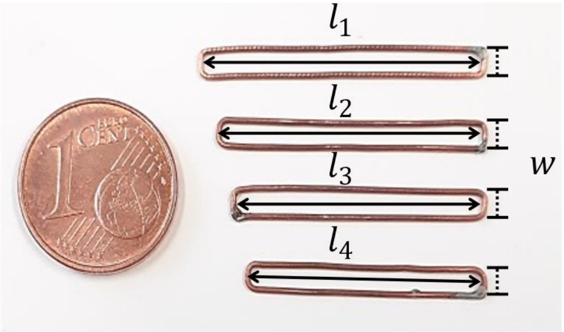


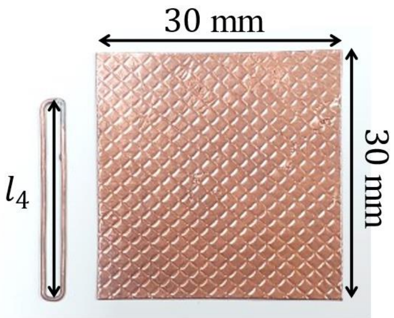
Vibration sensing

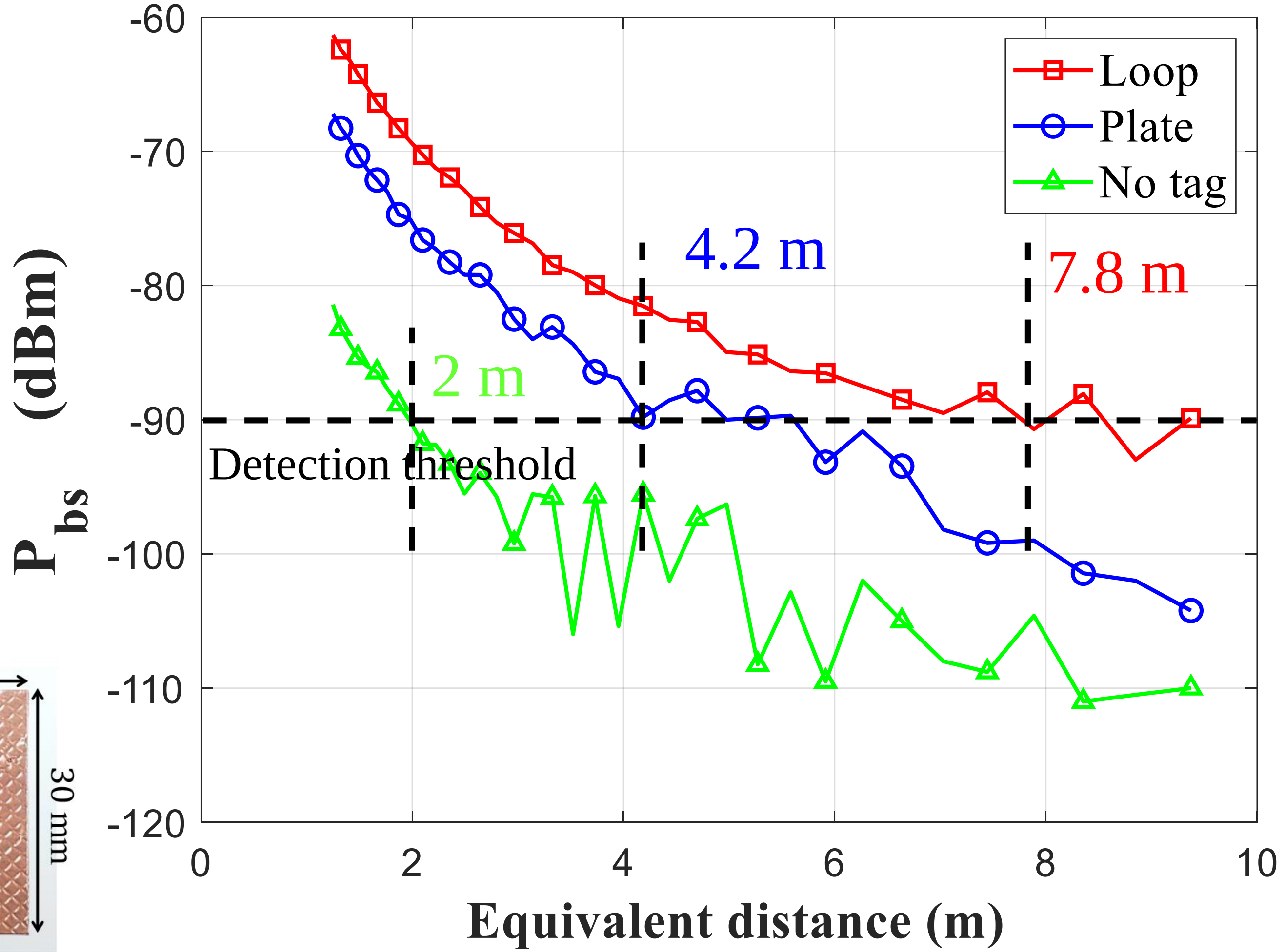
Experimental verification

- Read range ≈ 8 m









Conclusion

- First LTV chipless tag based on micro-Doppler effect
- Applicable for any moving target object
- Analytical model to express the backscattered signal and differential RCS
- Identification based on differential RCS
- Read range up to 10 m

Thank you for your attention