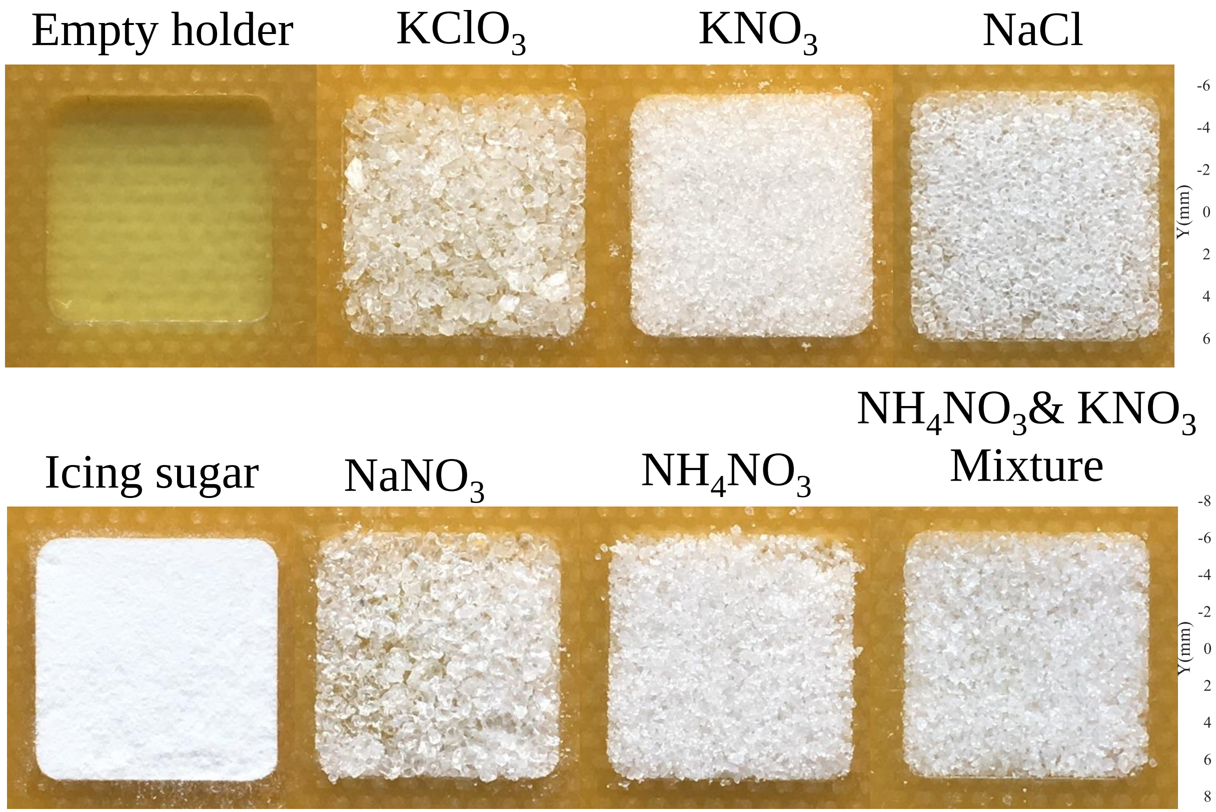
Progress on DRDC projects

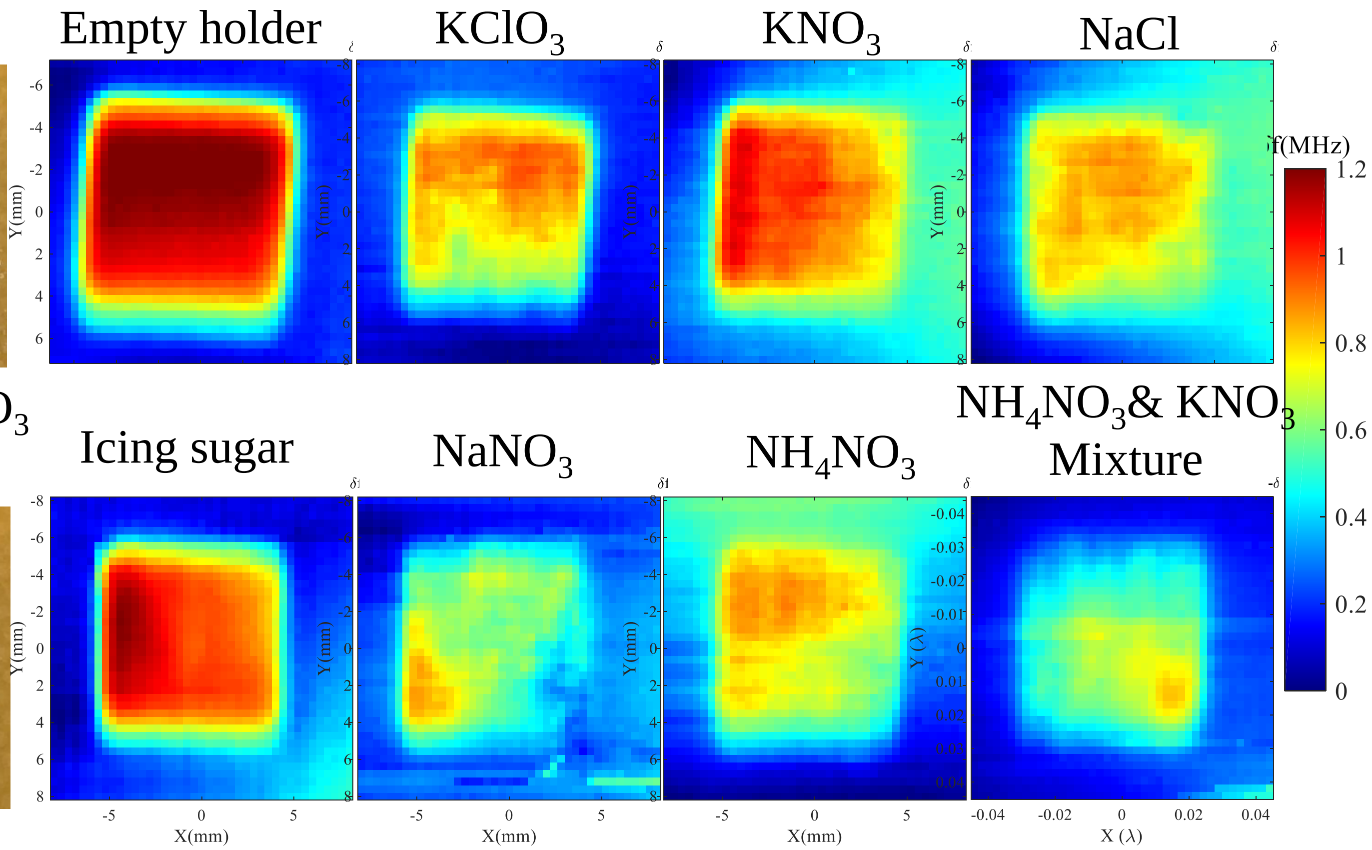
Yutong Zhao

Jan 7th 2019

Optical image

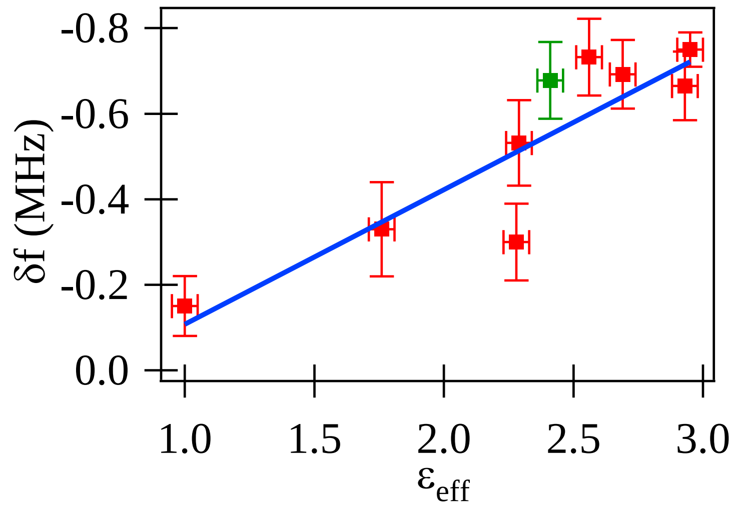
Microwave image





$$\frac{\delta f}{f_0} \approx \frac{\iiint_V \Delta\epsilon |E|^2 dv}{\iiint \epsilon |E|^2 dv} = \frac{\Delta\epsilon \cdot V}{\epsilon \cdot V}$$

$$\frac{\Delta\epsilon_{eff} \cdot V}{\epsilon \cdot V} = \frac{\epsilon_{sample} V_{sample} + \epsilon_{air} V_{air}}{\epsilon_{air}(V_{sample} + V_{air})}$$

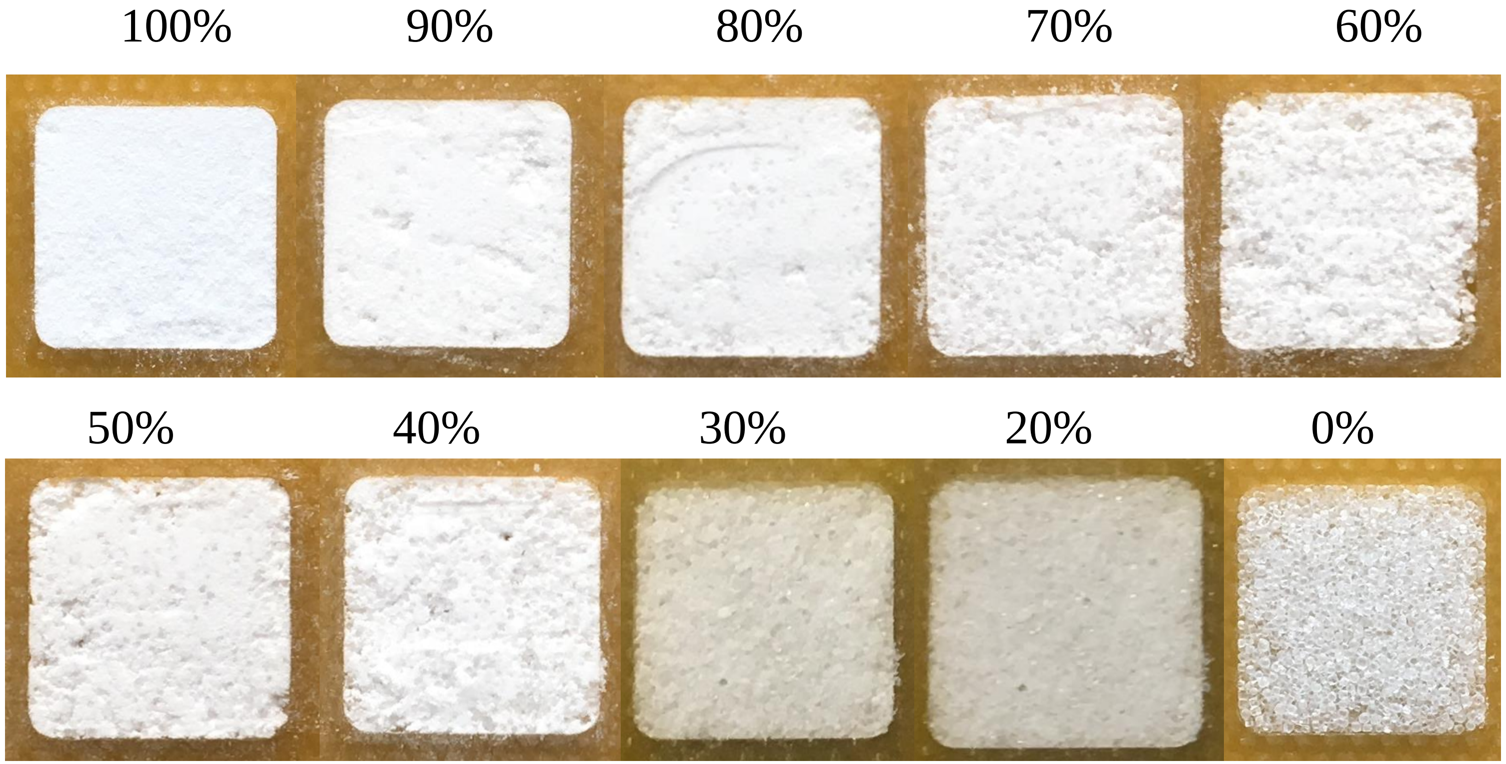


Materials	Sample mass(mg)	Density	Volume fraction	Permittivity(ϵ)	ϵ_{eff}	$-\delta\bar{f}$(MHz)
Air	0	~ 0	100%	~1	1	1.001
$KClO_3$	79	2.32 g/cm^3	38.01%	4.36	2.28	0.852
KNO_3	84	2.109 g/cm^3	44.27%	3.91	2.28	0.618
NaCl	102	2.17 g/cm^3	52.03%	4.71	2.95	0.485
$NaNO_3$	95	2.257 g/cm^3	36.59%	4.60	2.69	0.418
NH_4NO_3	56	1.72 g/cm^3	47.06%	5.37	2.56	0.458
Icing sugar	49	0.65 g/cm^3	84.27%	1.90	1.76	0.820
NH_4NO_3 & KNO_3 Mixture	68	1.94 g/cm^3	38.89%	4.63	2.41	0.472

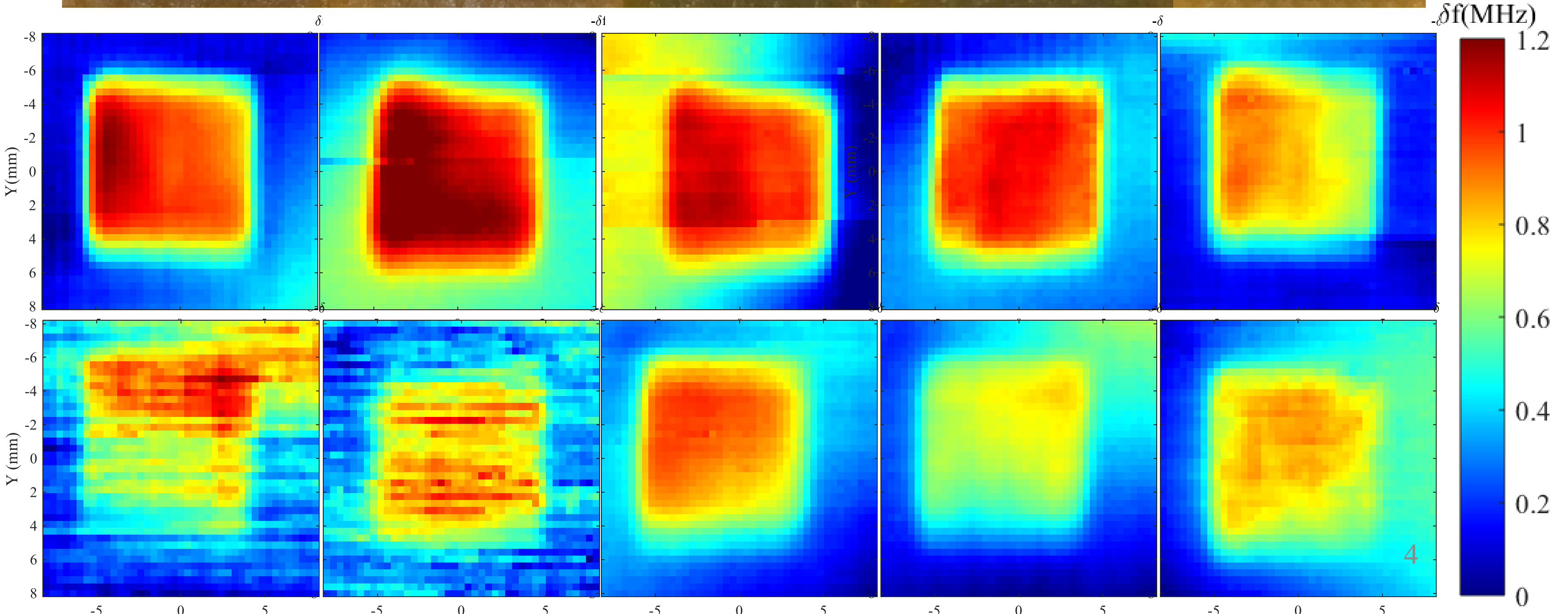
Mixture of icing sugar and NaCl

In volume fraction

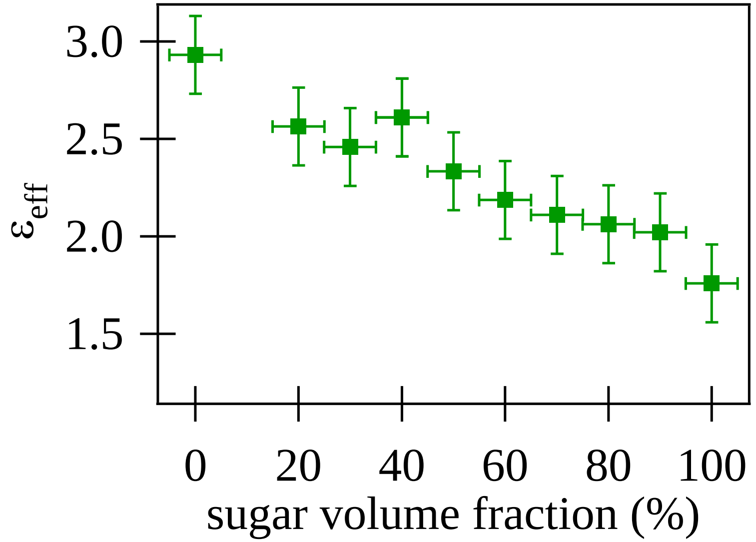
Optical image

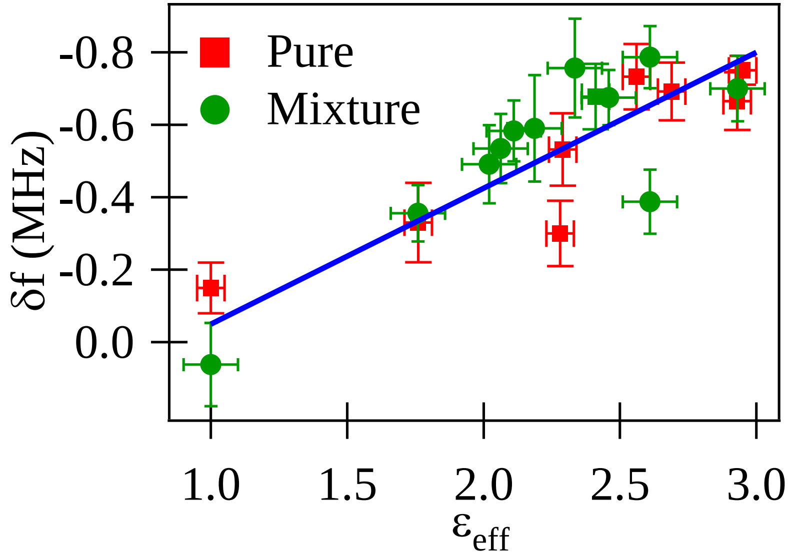


Microwave image

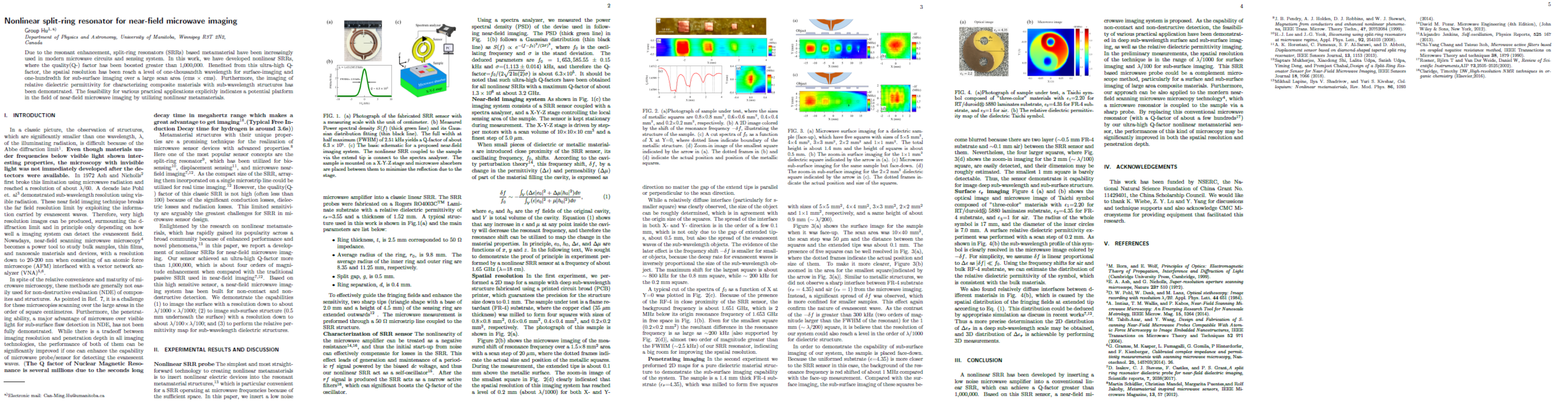


Sugar Volume fraction(%)	Sample mass(mg)	ϵ_{eff}	$-\delta\bar{f}$(MHz)
0	101	2.93	0.450
20	83	2.57	0.475
30	78	2.46	0.763
40	87	2.61	0.393
50	73	2.33	0.560
60	66	2.19	0.567
70	63	2.11	0.616
80	62	2.06	0.659
90	62	2.02	0.794
100	49	1.76	0.364

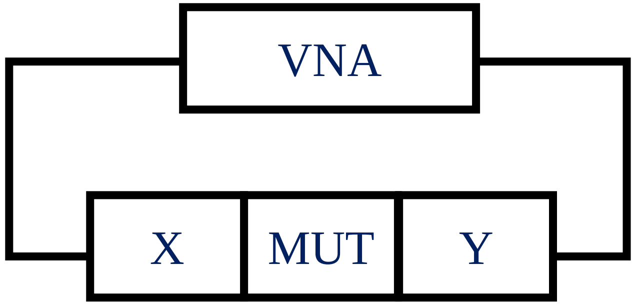




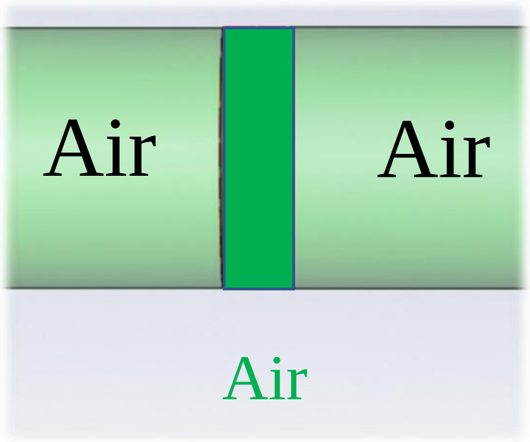
First draft of the paper of dielectric imaging


Nonlinear split-ring resonator for near-field microwave imaging

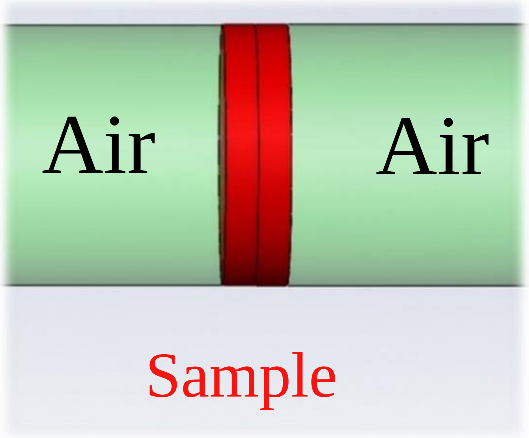
Broadband method



X band waveguide



$$M_1 = x \cdot T_{ref_1} \cdot T_1 \cdot T_{ref1}^{-1} \cdot y$$



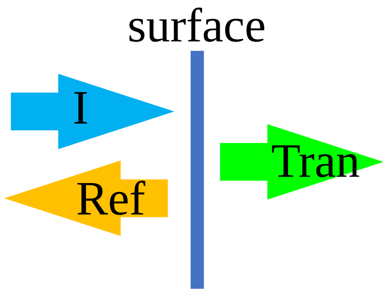
$$M_2 = x \cdot T_{ref_2} \cdot T_2 \cdot T_{ref2}^{-1} \cdot y$$

$$M_i = \begin{pmatrix} S_{12}^i - \dfrac{S_{11}^i S_{22}^i}{S_{21}^i} & \dfrac{S_{11}^i}{S_{21}^i} \\ -\dfrac{S_{22}^i}{S_{21}^i} & \dfrac{1}{S_{21}^i} \end{pmatrix}$$

$$T_i = \begin{pmatrix} e^{-\gamma_i d} & 0 \\ 0 & e^{\gamma_i d} \end{pmatrix}$$

Propagation constant
$\gamma_i = \gamma_i(\epsilon_i^*)$

$$T_{refi} = \begin{pmatrix} \dfrac{1}{1-\Gamma_i} & \dfrac{\Gamma_i}{1-\Gamma_i} \\ \dfrac{\Gamma_i}{1-\Gamma_i} & \dfrac{1}{1-\Gamma_i} \end{pmatrix}$$



Reflection coefficient

$\Gamma_i = \Gamma_i(\epsilon_i^*)$

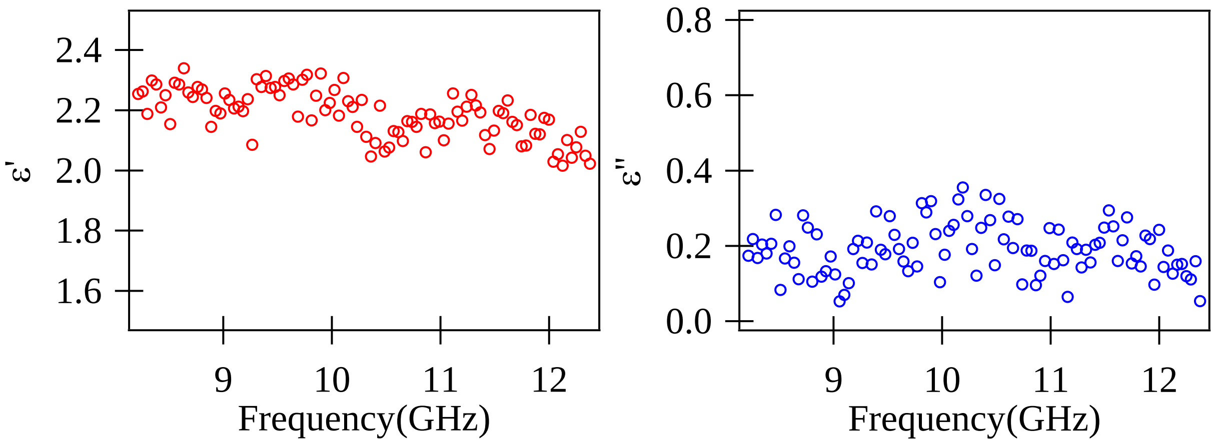
$$Tr(M_1 M_2^{-1}) = Tr(T_{ref1} T_1 T_{ref1}^{-1} \cdot T_{ref2} T_2^{-1} T_{ref2}^{-1})$$

Solving the following equation

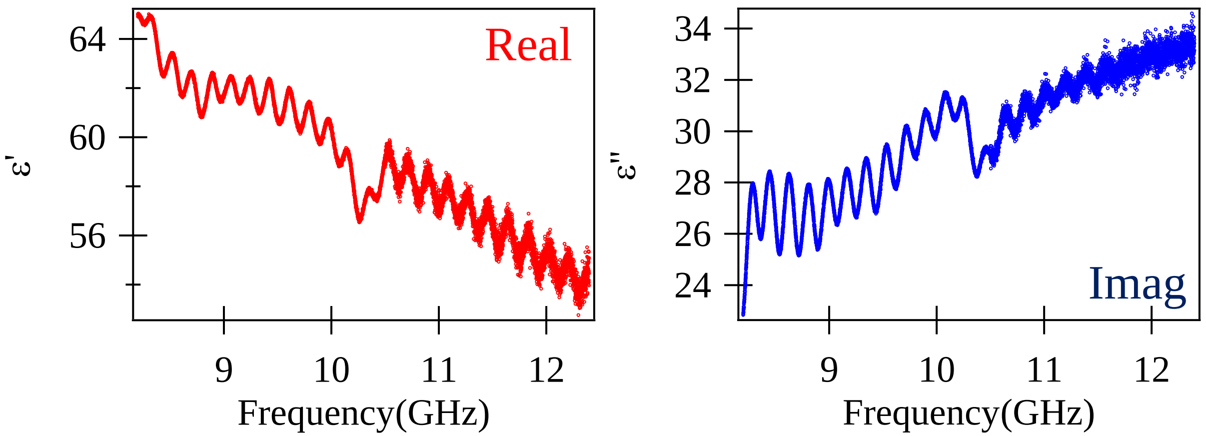
$$f(\epsilon) = Tr(LHS) - Tr(RHS) = 0$$

Results using broadband method

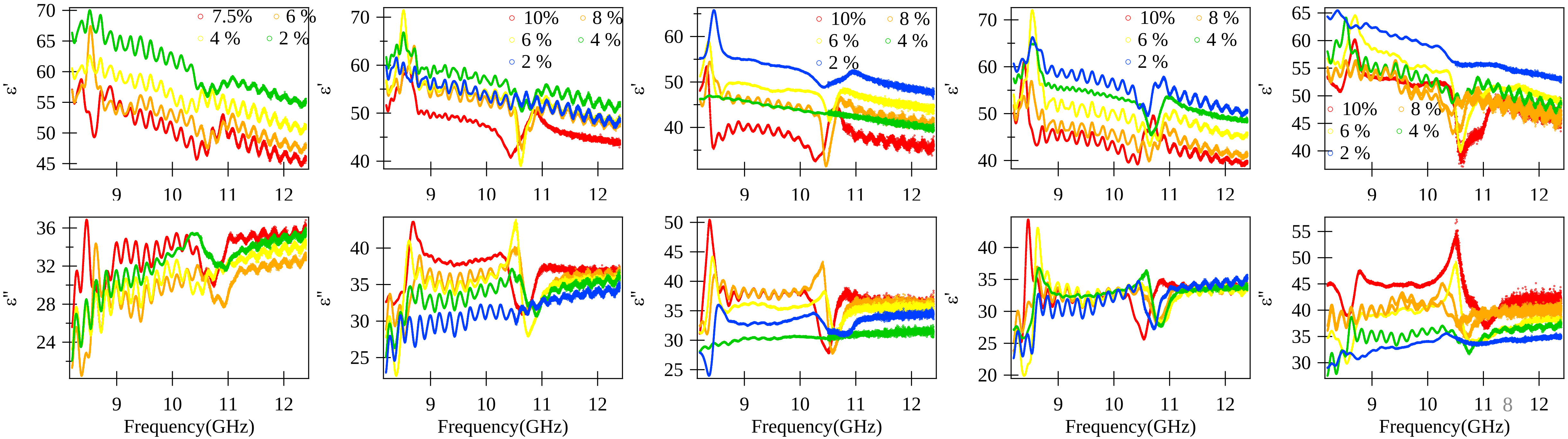
RO5880 material:



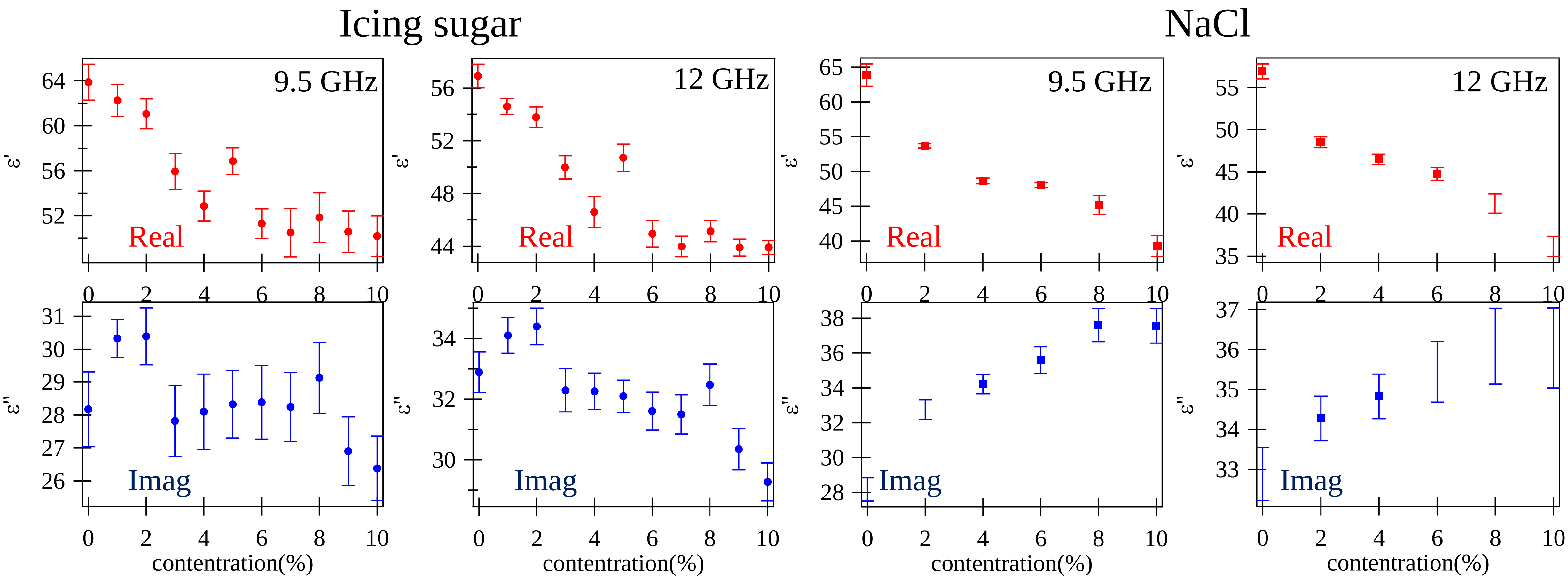
DI water



$KClO_3$ KNO_3 NaCl $NaNO_3$ NH_4NO_3



Summary of the results



$$\varepsilon(r) \simeq \frac{\varepsilon_{\mathrm{DPB}}}{3h^2(l_h/r) + 1},$$

Dielectric Constant of Ionic Solutions: A Field-Theory Approach

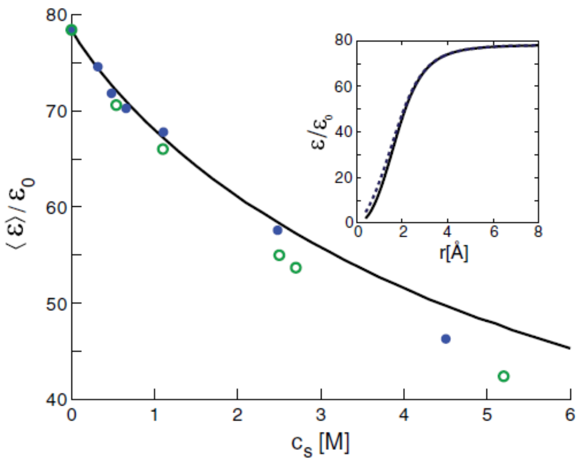


FIG. 1 (color online). The dielectric constant $\langle\varepsilon\rangle$ averaged inside a specific volume around a single ion (solid line) as function of ionic concentration, c_s. The comparison is done with experimental values for RbCl (empty circles) and CsCl (full circles) [19]. In the inset, the exact (solid line) and approximated [dashed line, Eq. (11)] solutions of the DPB equation (9) are shown as a function of the distance r from a point charge (ion). Choosing as a fit parameter the dipole moment of water to be $p_0 = 4.8$ D (instead of the physical value $p_0 = 1.8$ D) [23] allows us to obtain $\varepsilon_{\mathrm{DPB}} = 80\varepsilon_0$ and $l_h \simeq 1.5$ Å.

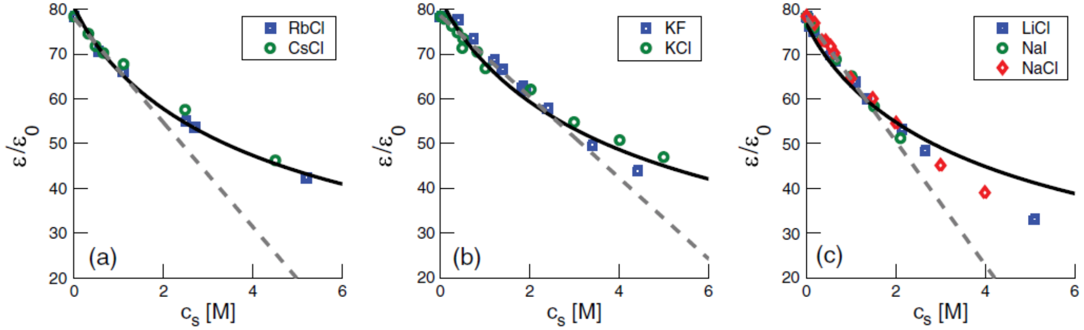
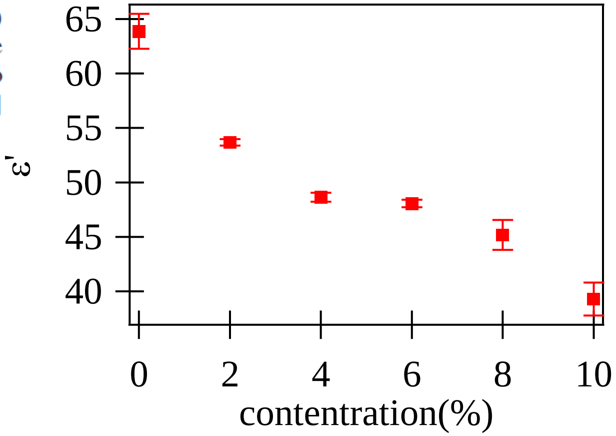
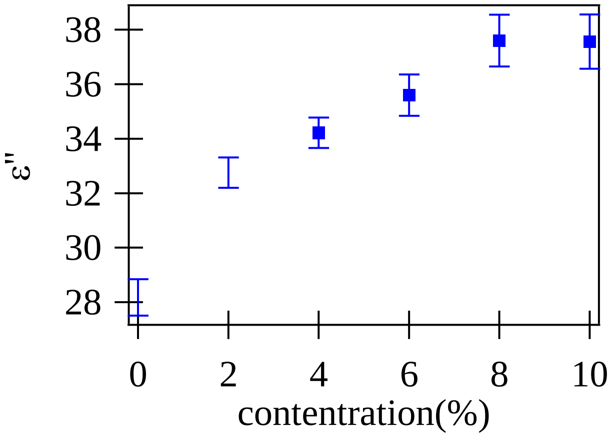


FIG. 2 (color online). Comparison of the predicted dielectric constant ε from Eq. (16), with experimental data from Ref. [19], as function of ionic concentration c_s for various salts. The theoretical prediction (solid line) was calculated using a as a fitting parameter. In (a) the fit is for RbCl and CsCl salts with $a = 2.66$ Å; in (b) the fit is for KF and KCl with $a = 2.64$ Å; while in (c) the fit is for LiCl, NaI, and NaCl with $a = 2.71$ Å. The dashed lines are the linear fit to the data in the low $c_s \leq 1$ M range. The slope of the linear fit is $\gamma/\varepsilon_0 = 11.7$ M^{-1} in (a), 9.0 M^{-1} in (b), and 13.8 M^{-1} in (c). The value of γ for each salt varies by about 10–20% and the linear fit should be taken as representative of the low c_s behavior.

The dielectric constant (our measurement)





For this year’s DRDC contract,

data collection: 95%

data analysis: 60%

report writing: 10%

Next step:

1. Determine the car gasoline and diesel using broadband method.
2. Summarize the rest of the data and fit with model.
3. Compare with the previous data.
4. Writing a report of these works.