微波天線型化學感測器
A Novel Design of Antenna for Chemical Sensors

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Outline

- Introduction
  - Meta-material design
- Motivation
- Patch Antenna Biosensor
  - Off-resonance design
- CPW Antenna Biosensor
  - On-resonance design
- Results
- Conclusion

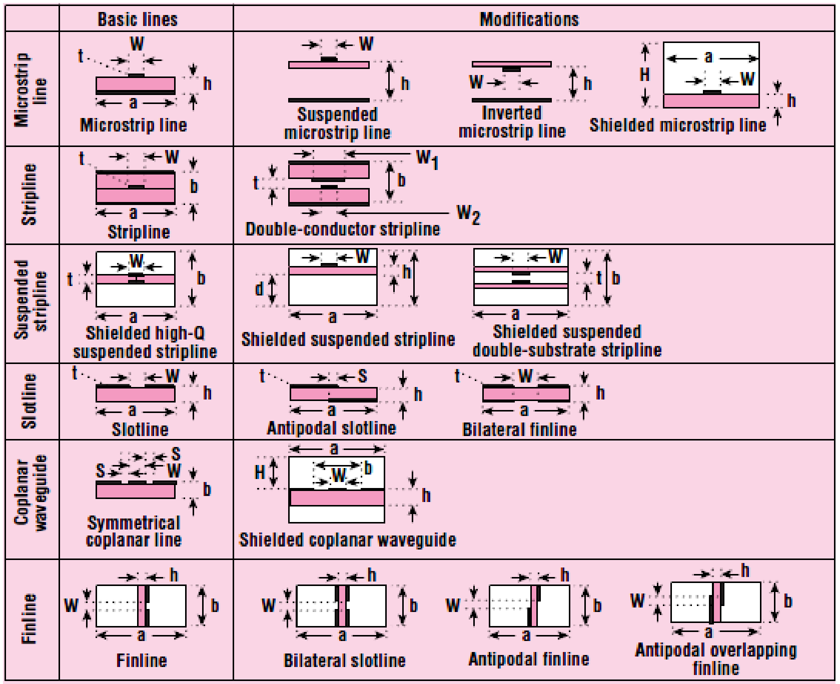
Introduction

- Existing approaches
  - Optical and magnetic sensing
    - ✓ High sensitivity, high selectivity
    - ✓ Required labeling and chemical modification, and the process is time consuming

- Microwave sensor
  - Permittivity (ε) and permeability (μ)
  - Biomedical application
    - ✓ Small
    - ✓ Quickly
    - ✓ Label free
    - ✓ Low cost
    - ✓ Electronic way to gain information

Introduction

- Commonly used types of printed transmission line [4]



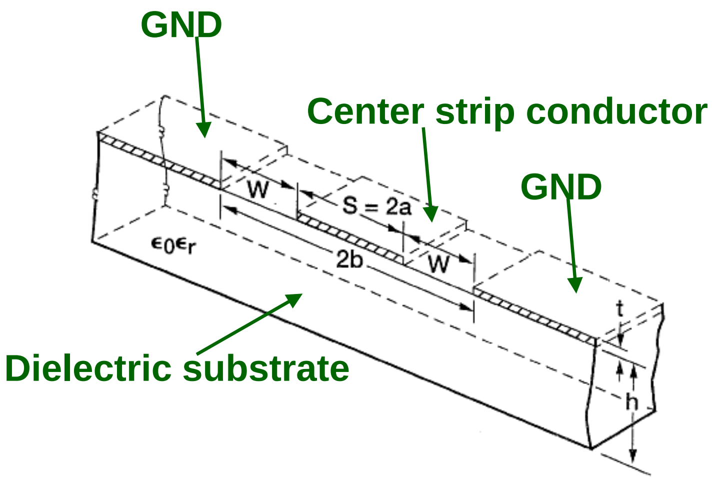
A comparison of various transmission-line types

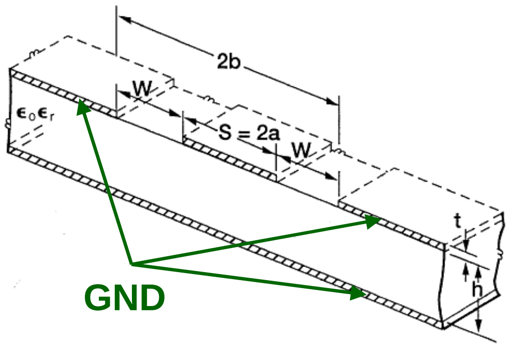
Transmission line	Q factor	Radiaton	Dispersion	Impedance range	Chip mounting
Microstrip (dielectric) (GaAs, Si)	250 100 to 150	Low High	Low	20 to 120	Difficult for shunt, easy for series
Stripline	400	Low	None	35 to 250	Poor
Suspended stripline	500	Low	None	40 to 150	Fair
Slotline	100	Medium	High	60 to 200	Easy for shunt, diffi-cult for series
Coplanar waveguide	150	Medium	Low	20 to 250	Easy for series and shunt
Finline	500	None	Low	10 to 400	Fair

Ref. : Leo G. Maloratsky, "Reviewing The Basics Of Microstrip Lines" MICROWAVES & RF, MARCH 2000

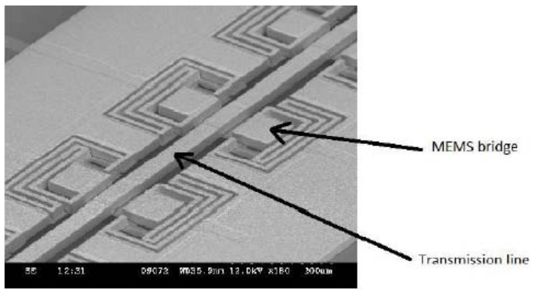
Introduction

- Coplanar Waveguide (CPW)
  - Types of Coplanar Waveguides [5]
    - Conventional CPW
    - Conductor backed CPW
    - Micromachined CPW





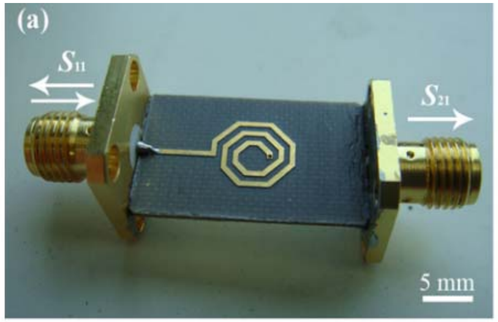
Conductor backed CPW

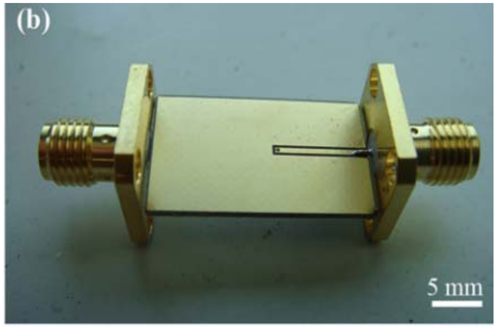


Micromachined CPW [1]

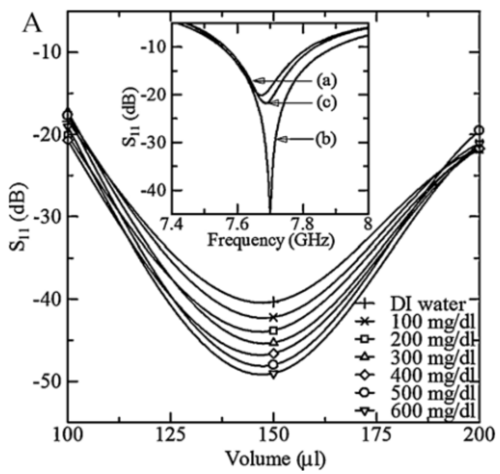
Advantages:
Simple and easy to fabricate.
Good circuit isolation, Less radiation loss (ground plane exist between trace)

Non-Contact Spiral Resonant Sensor

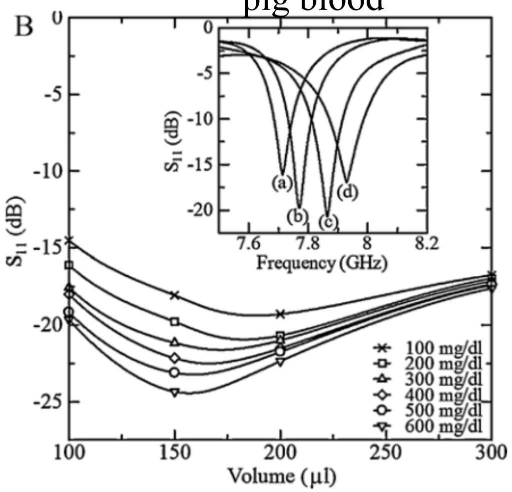




glucose



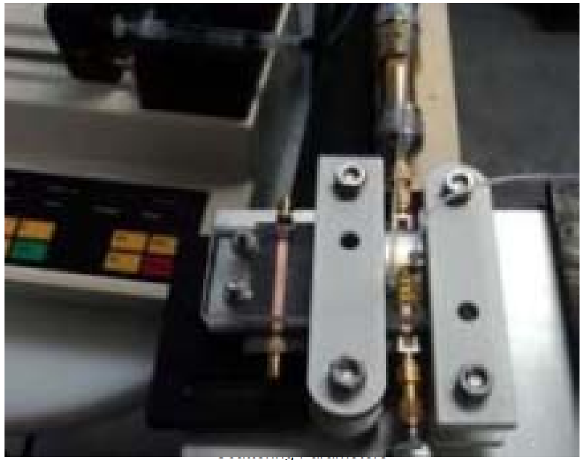
pig blood



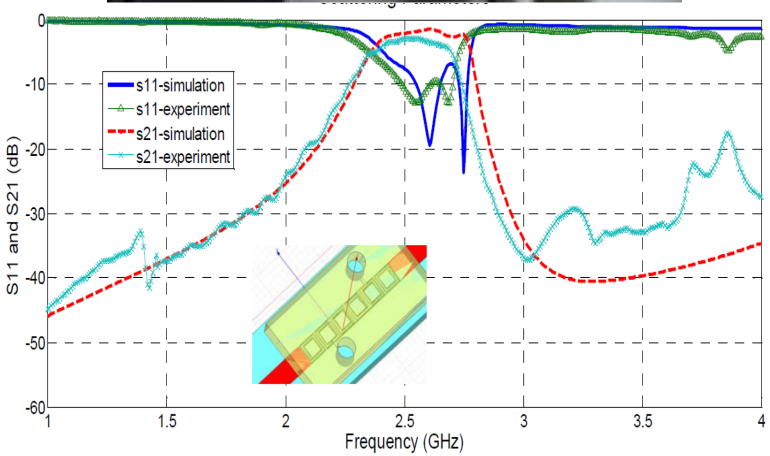
- The Petri dish diameter was chosen to be 8mm for full interaction of the spiral sensor with the samples.
- The change in $|S_{11}|$ is not directly related to the change in the glucose concentration.

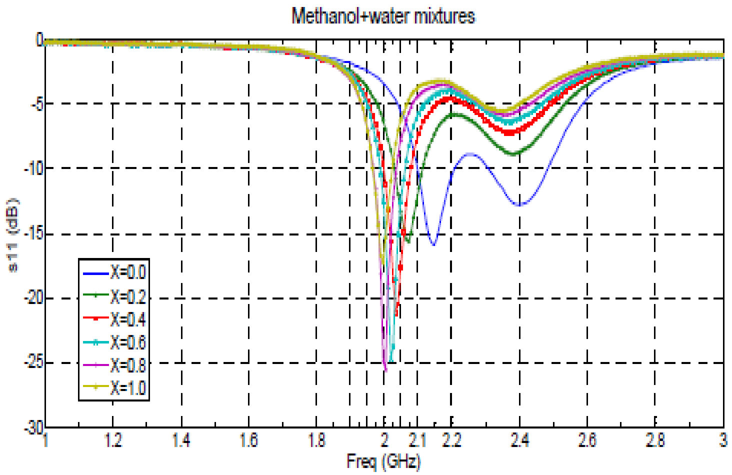
Ref:**Medical Engineering & Physics 34 (2012) 299–304**

Microwave Artificially Structured Microfluidic Sensor



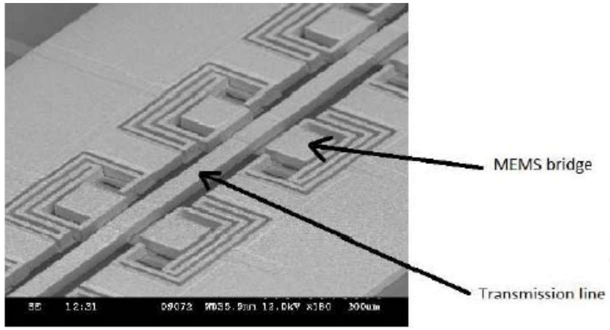
- Fabricated Metamaterial RF device with PDMS microfluidic channels
- Complex for sample handling
- Good for liquid samples only.

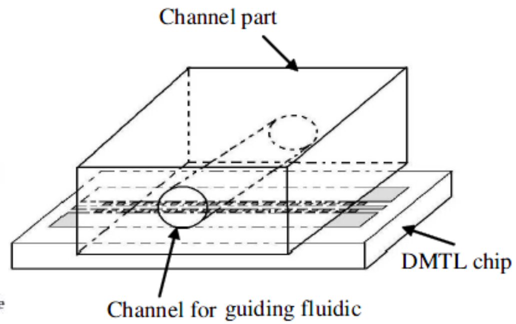


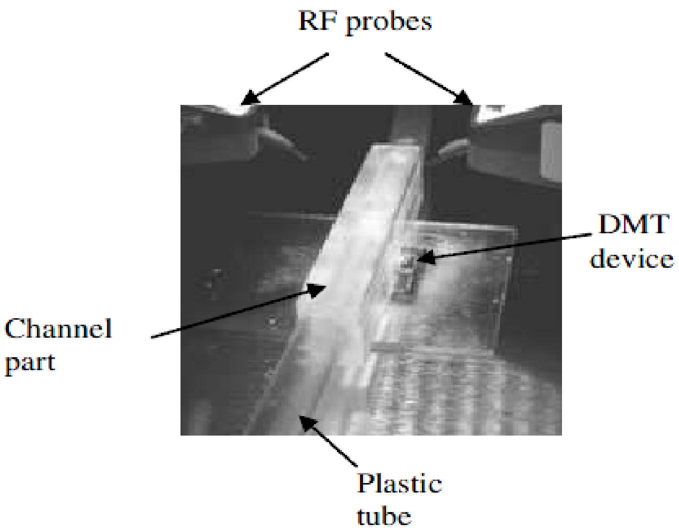


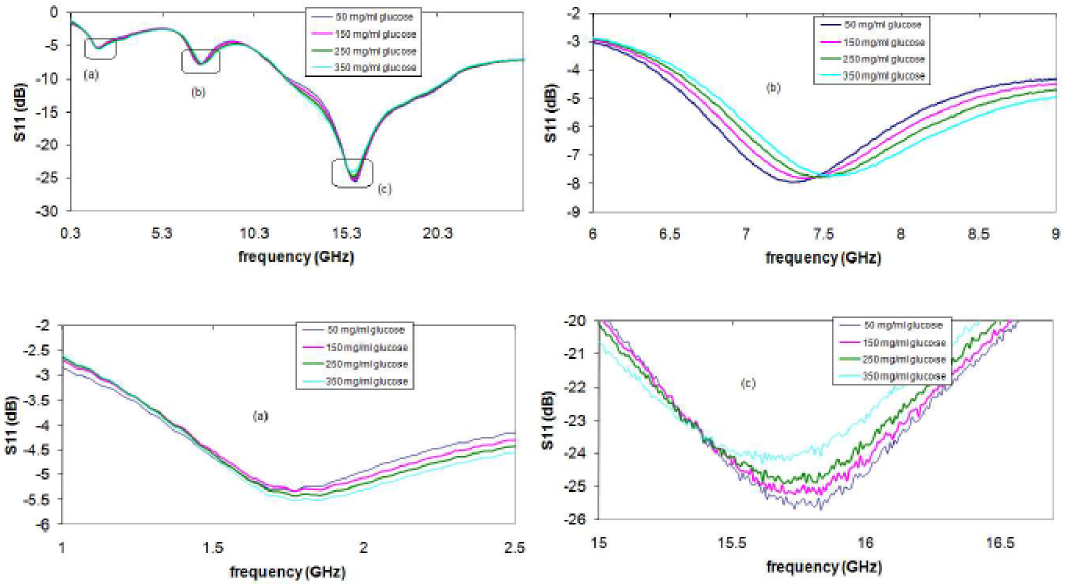
Ref: **Electronic Components and Technology Conference (ECTC), 1889-1893, 2011**

Coplanar microwave distributed MEMS transmission line



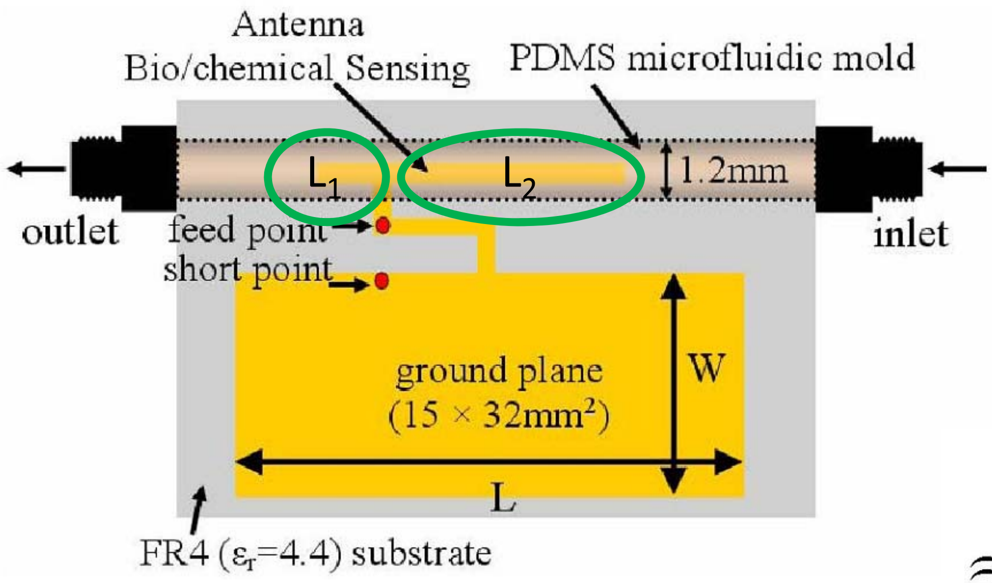






Ref.: L. J. Li, "SIMULTANEOUS DETECTION OF ORGANIC AND In-ORGANIC SUBSTANCES IN A MIXED AQUEOUS SOLUTION USING A MICROWAVE DIELECTRIC SENSOR", Progress In Electromagnetics Research C, Vol. 14, 2010

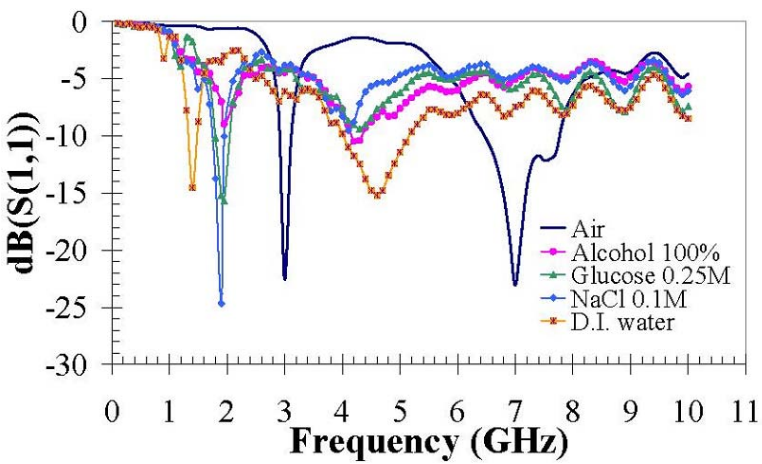
Planar Inverter F Antenna biosensor



- Large background noises
- Sample size
  - 25 mm × 1.2 mm

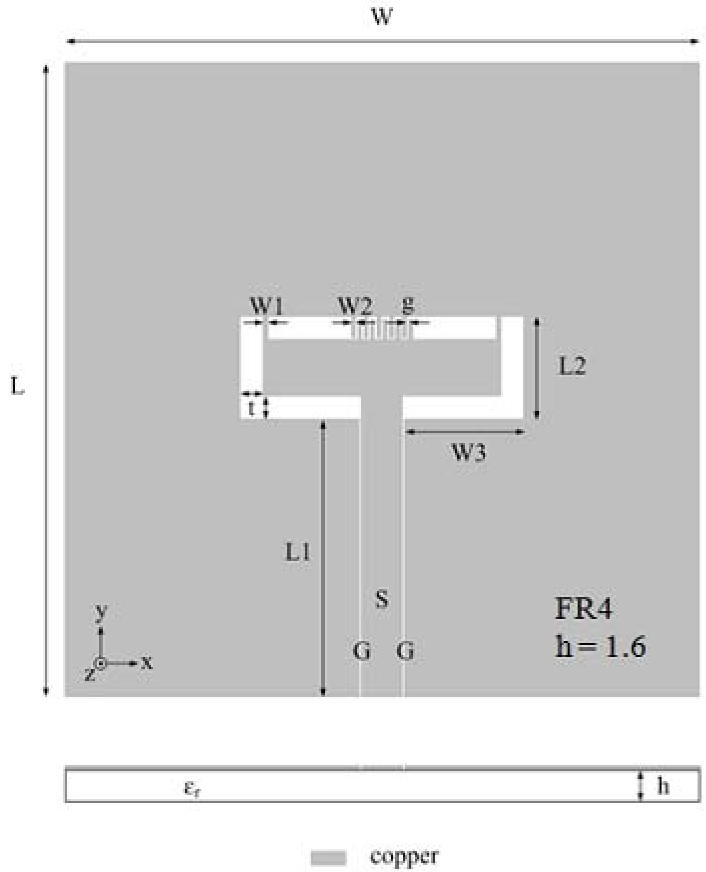
L_1 = 6 mm, L_2 = 19 mm

$$f_1 = \frac{c_0}{4 \times \sqrt{\epsilon_r} \times L_1} \qquad f_2 = \frac{c_0}{4 \times \sqrt{\epsilon_r} \times L_2}$$

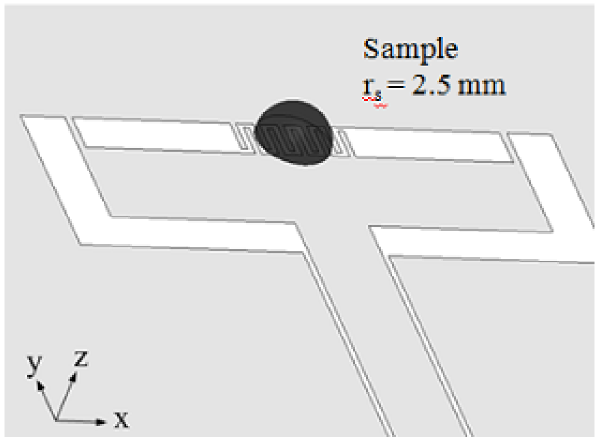


BME annual meeting 2005, Chun-Li, 12/17-18/2005

Slot Loop Antenna Biosensor



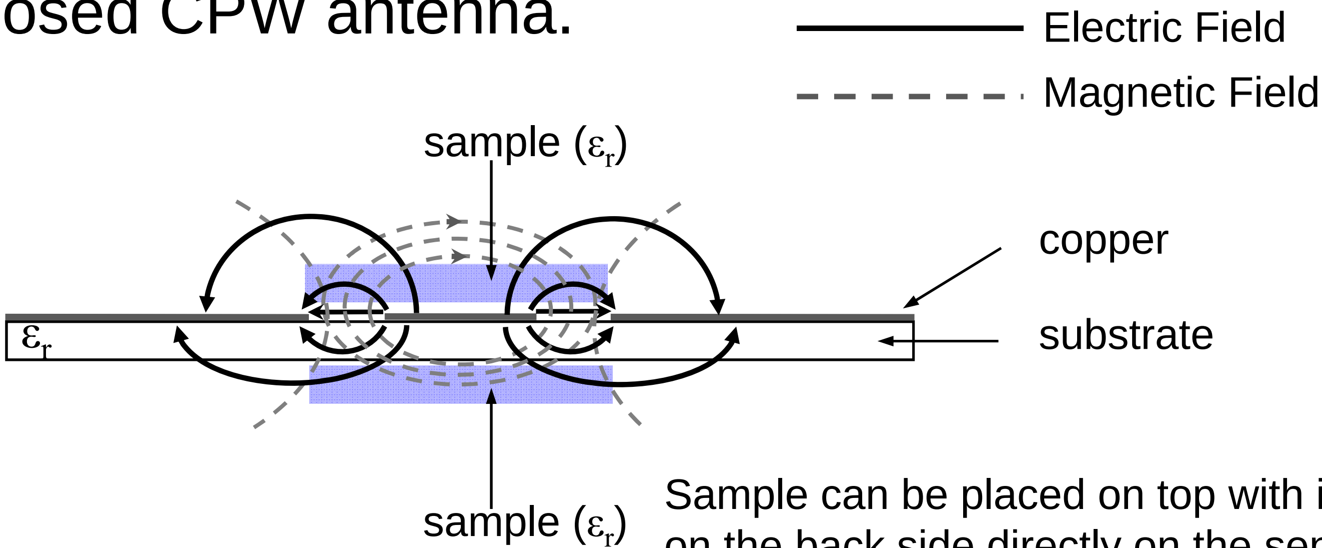
- Realization of meta material concept in this design
- Required large ground plane for antenna size @80mm × 80mm
- Sensitive to sample shape



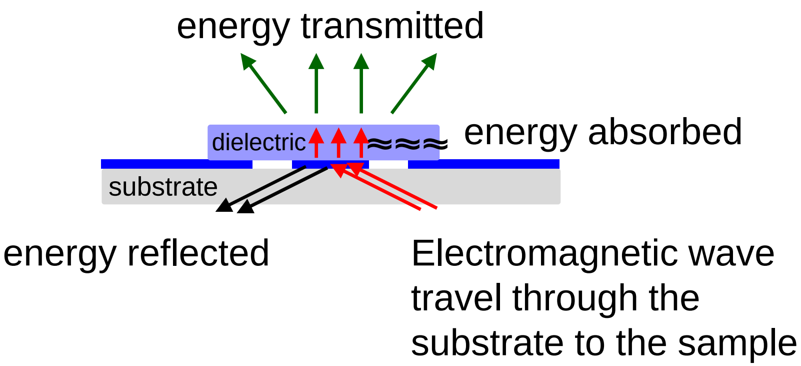
Ref: **Jeromy Hsu, Master thesis, NTU 2010.**

Method

- The electric field and magnetic field distribution of proposed CPW antenna.



Sample can be placed on top with insulation or on the back side directly on the sensing area.



The absorption of energy and the variation in the phase of the waves depend on the permittivity of the medium.

Method

Basic principles [3]

Propagation constant γ *is given by*

$$\gamma = \alpha + j\beta = j2\pi/\lambda\ (\varepsilon_r' - j\varepsilon_r'')^{1/2}$$

where α *is the attenuation constant,* β *is the phase constant,* λ *is the free space wavelength.*

The complex relative permittivity of the material ε_r *is mathematically expressed as:*

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$$

The ratio of the imaginary part to real part is loss tangent, tan δ*:*

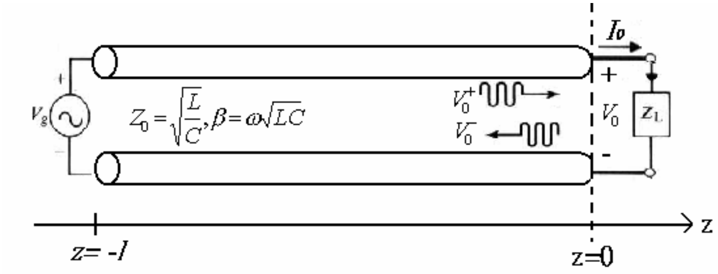
$$\tan\delta = \varepsilon_r'' / \varepsilon_r'$$

(often called the material dissipation factor)

where ε_r' = *dielectric constant,* ε_r'' = *dielectric loss factor*

Method

Reflection Coefficient Γ



$$\Gamma_L \equiv \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

reflection coefficient at the load

Where Z_0 is the impedance towards the source, Z_L is the impedance towards the load.

The return loss can be calculated by;

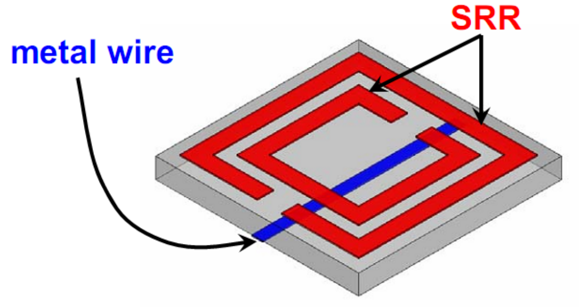
$$\text{return loss } (S_{11}) = -20 \log_{10} |\Gamma| \;\; (dB)$$

Motivation

- Design of a biosensing device
  - Small
  - Real-time
  - Non-invasive
  - Accurately
  - cost effective
  - Simple

Introduction – meta-material

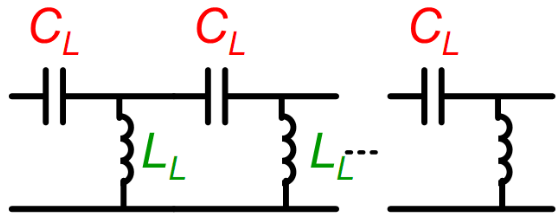
- Split-Ring Resonator (SRR) Approach



SRR-based LHM unit-cell

SRR: provides μ<0
metal wire: provides ε<0

- Transmission Line Approach



Perfect LH transmission line

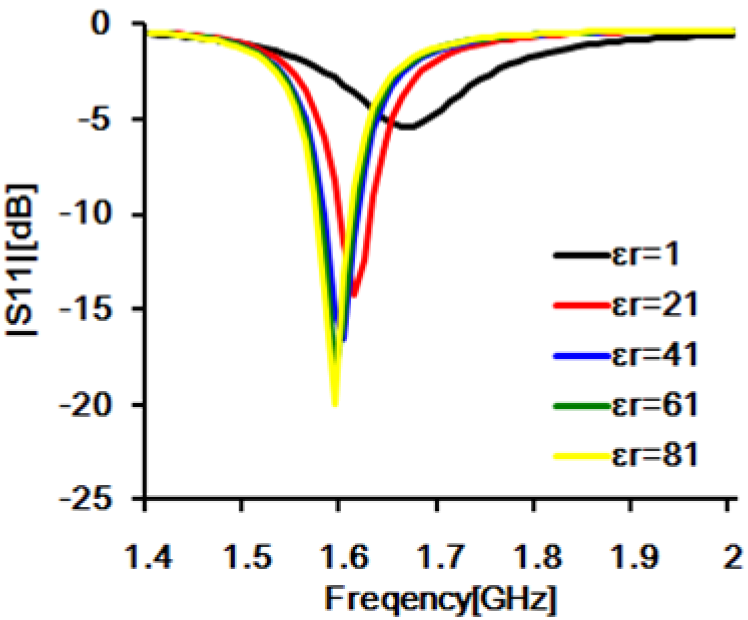
Series capacitance (C_L) and shunt inductance (L_L) combination supports a fundamental backward wave.

$$\beta = \frac{-1}{\omega\sqrt{C_L L_L}}$$

- Meta-material
  - Reduce the size of microwave structures and samples
  - Operating at lower resonant frequency

Ref:
Science, 292, 77-79, 2001.
Ieee Transactions on Antennas and Propagation, 52, 1159-1166, 2004.

Methods – resonant frequency



$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$\varepsilon_r \uparrow \Rightarrow C \uparrow \Rightarrow f_r \downarrow$$

$$S11 = \frac{V_-}{V_+} = \Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

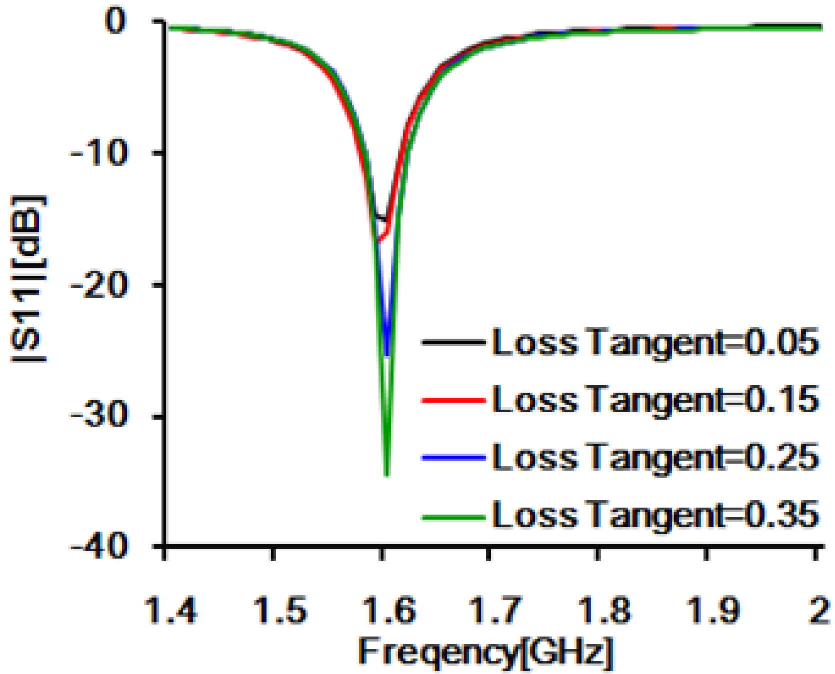
$(Z_0 = 50\Omega, TL's\ characteristic\ impedance)$

$$Z_{in} = \sqrt{\frac{L}{C}} \qquad (if\ \varepsilon_r = 1,\ Z_{in} = 377\Omega)$$

$$\varepsilon_r \uparrow \Rightarrow C \uparrow \Rightarrow Z_{in} \downarrow \Rightarrow \mathrm{S11} \downarrow$$

- In biosensing application :
  - Assume relative permeability μ_r=1

Methods - loss Tangent



$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \quad (if\ lossless\ ,\varepsilon_r'' = 0)$$

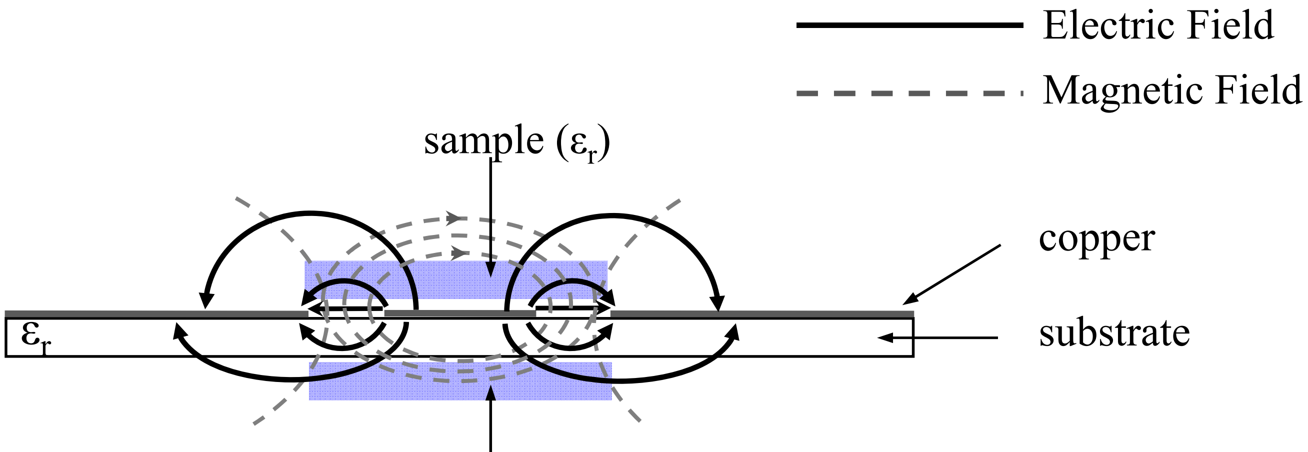
$$tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'}$$

$$tan\delta \uparrow \Rightarrow \varepsilon_r \times \Rightarrow f_r \times$$

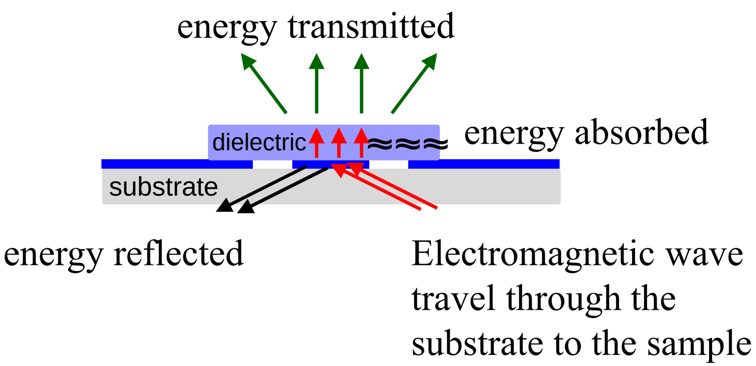
$$tan\delta \uparrow \Rightarrow S11 \downarrow$$

CPW Antenna Biosensor

- The electric field and magnetic field distribution of proposed CPW antenna.



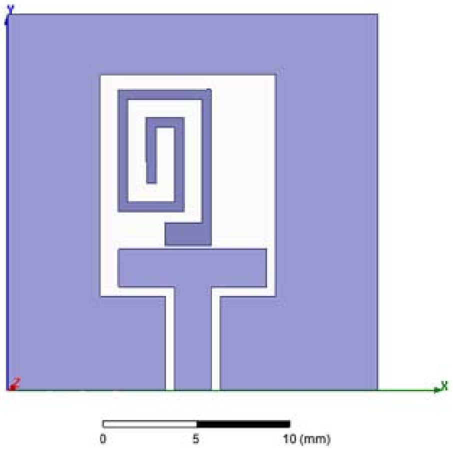
Sample can be placed on top with insulation or on the back side directly on the sensing area.



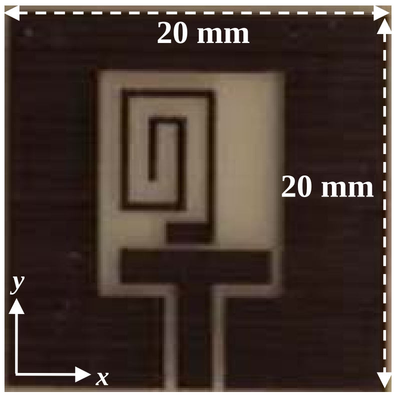
The absorption of energy and the variation in the phase of the waves depend on the permittivity of the medium.

CPW Antenna Biosensor

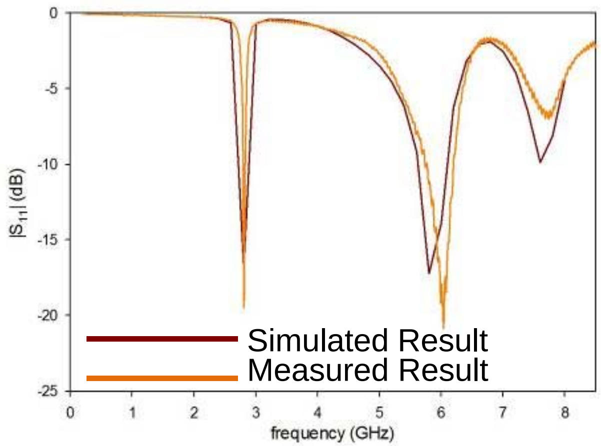
	Simulated		Measured	
Frequency / return loss	2.8 GHz	-16.8 dB	2.8 GHz	-18 dB
	5.8 GHz	-17 dB	6 GHz	-20 dB
Dimension	20(L)x20(w)x0.8(T) mm^3			
Substrate	0.8mm FR-4 single layer			



(a)



(b)

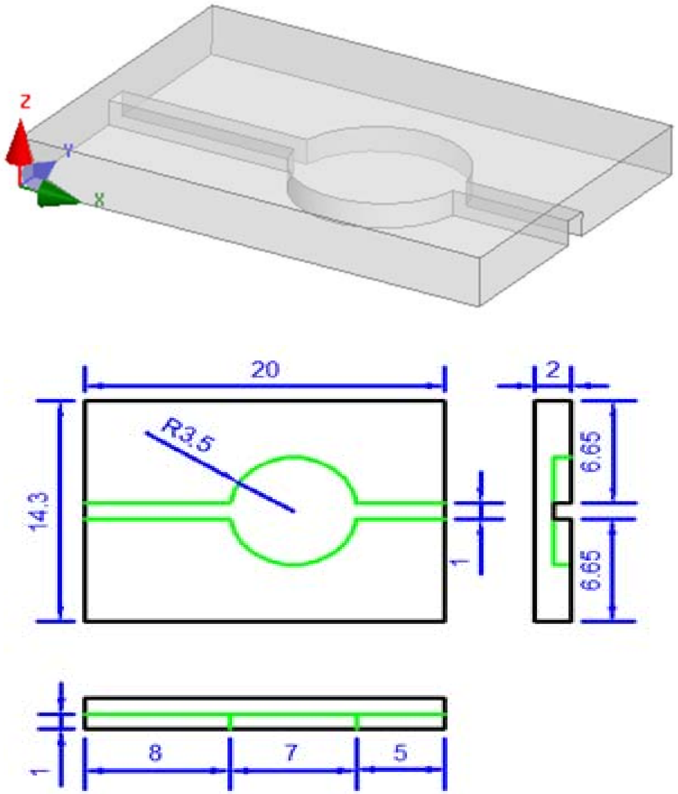


(c)

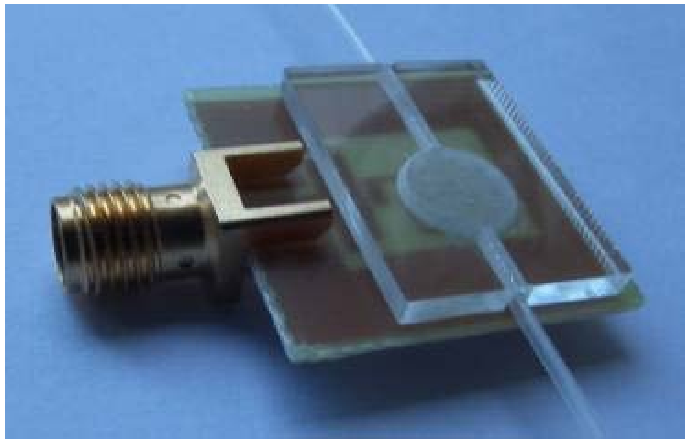
Geometry of the CPW antenna (a) simulated and (b) fabricated, (c) simulated and measured result of the proposed CPW antenna.

Measurements

- Fluidic Channel Design



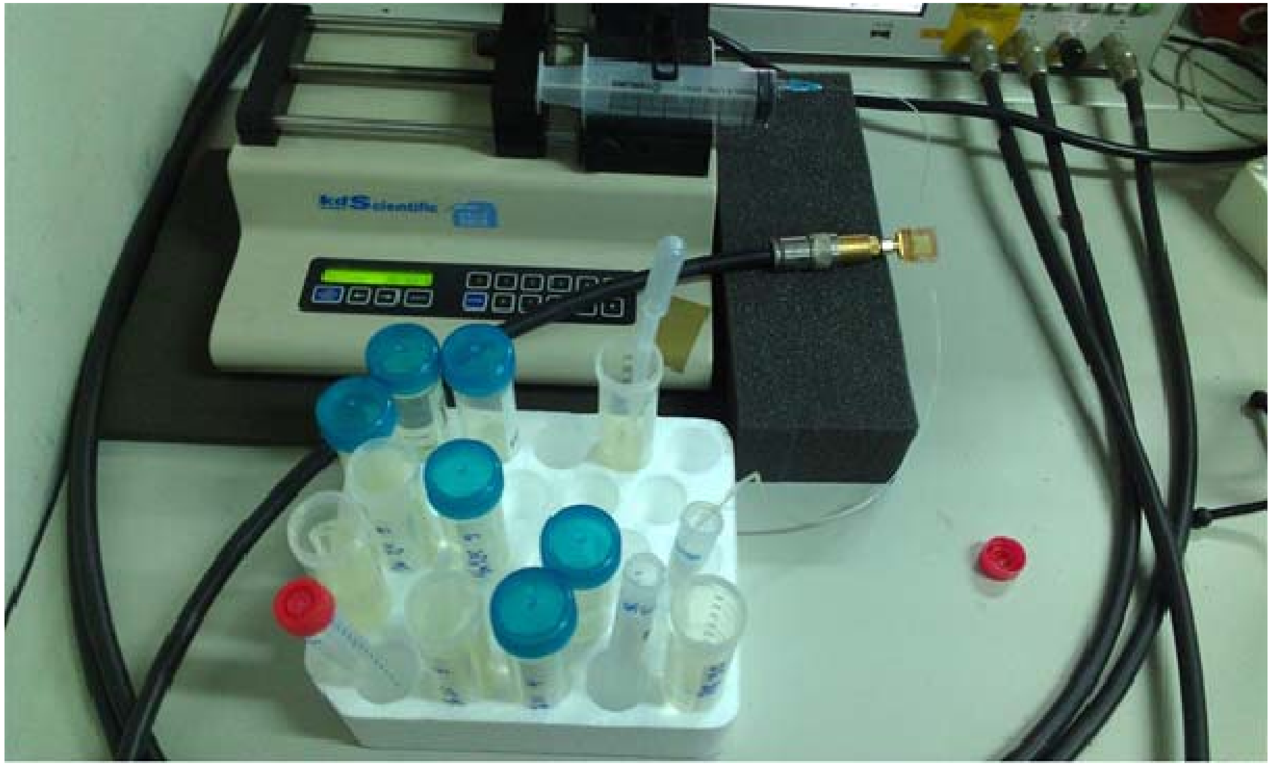
Model and dimension of fluidic channel.



Configuration of acrylic fluidic channel and CPW antenna biosensor.

Measurements

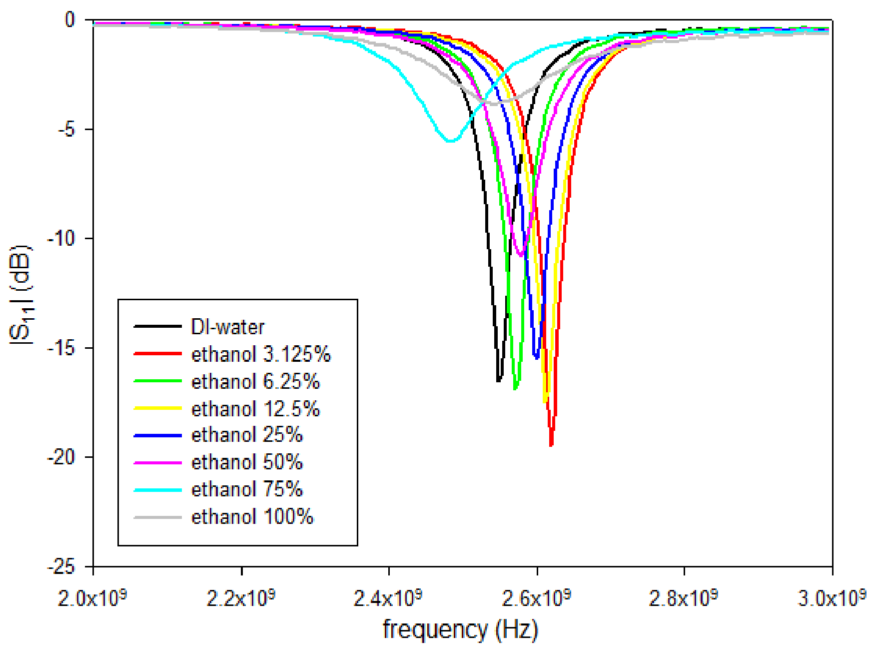
- Fluidic Channel Measurement Setup

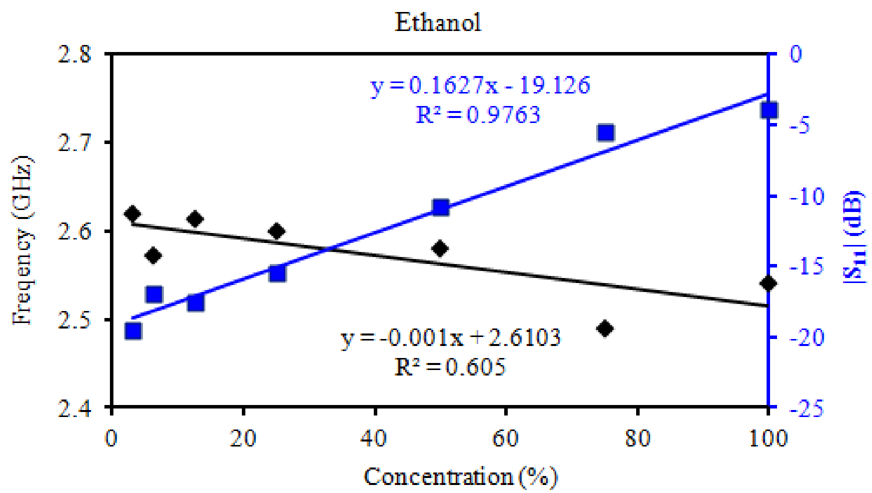


Measurement setup of the syringe pump system with CPW antenna biosensor and fluidic channel. 60ml syringe is used for the experiment and the pumping rate is set to **2 ml/min**.

Measurements

- Ethanol with different concentration

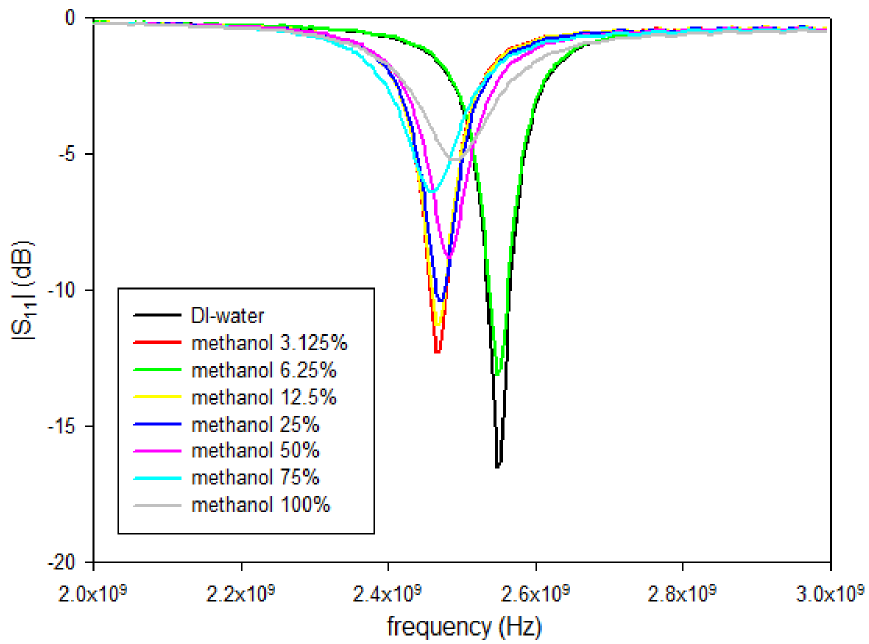


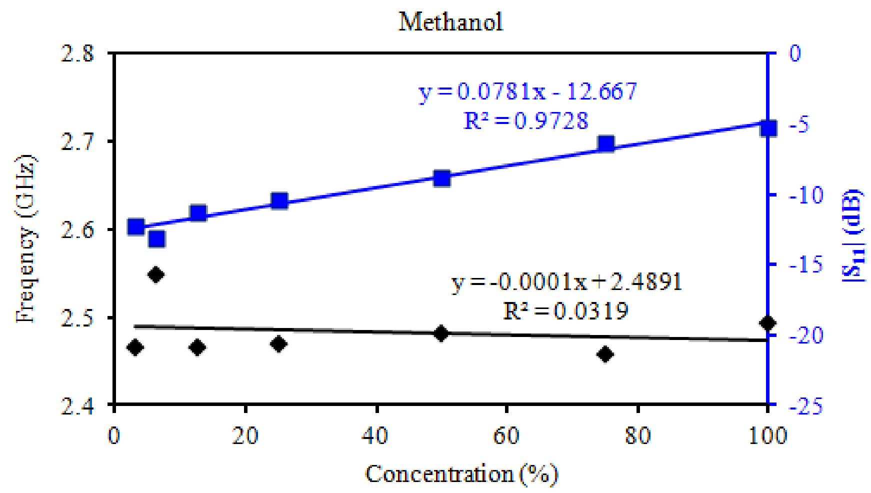


Measurement setup of the syringe pump system with CPW antenna biosensor and fluidic channel. 60ml syringe is used for the experiment and the pumping rate is set to 2 ml/min.

Measurements

- Methanol with different concentration

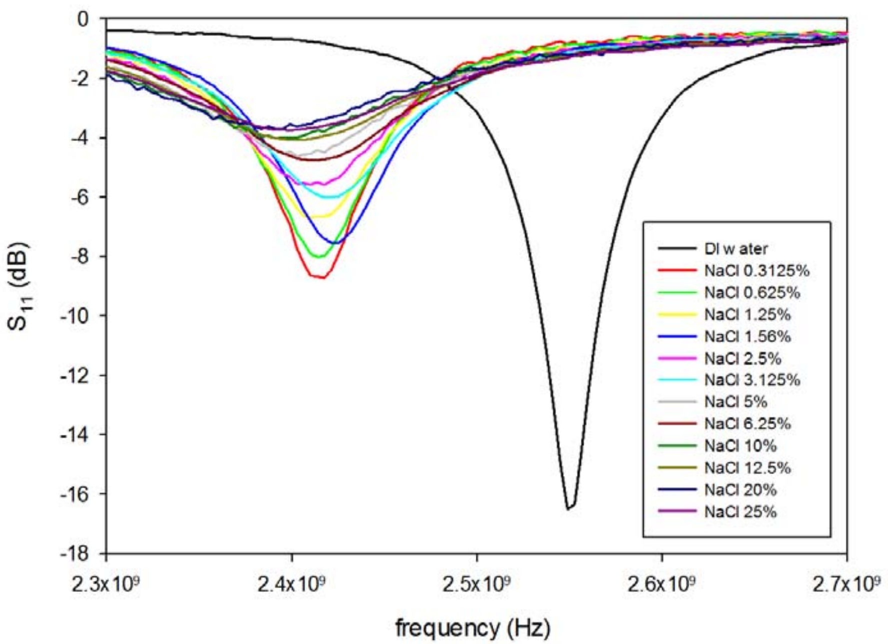


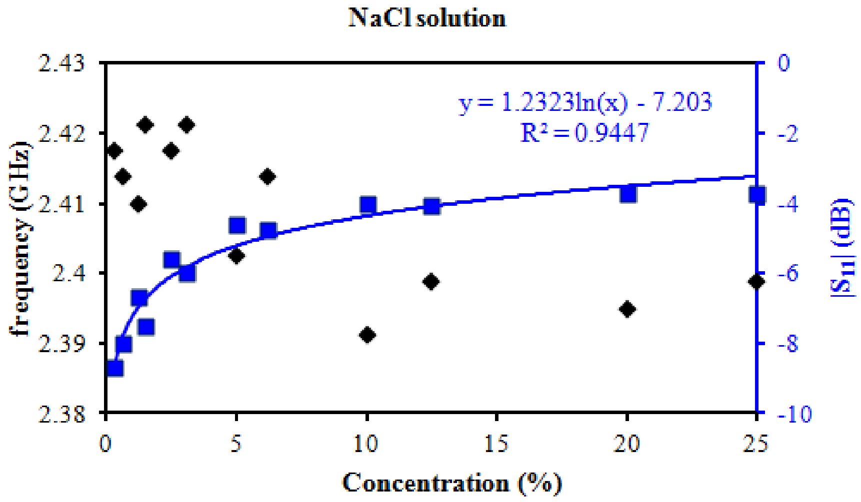


Measurement setup of the syringe pump system with CPW antenna biosensor and fluidic channel. 60ml syringe is used for the experiment and the pumping rate is set to 2 ml/min.

Measurements

- NaCl solution with different concentration

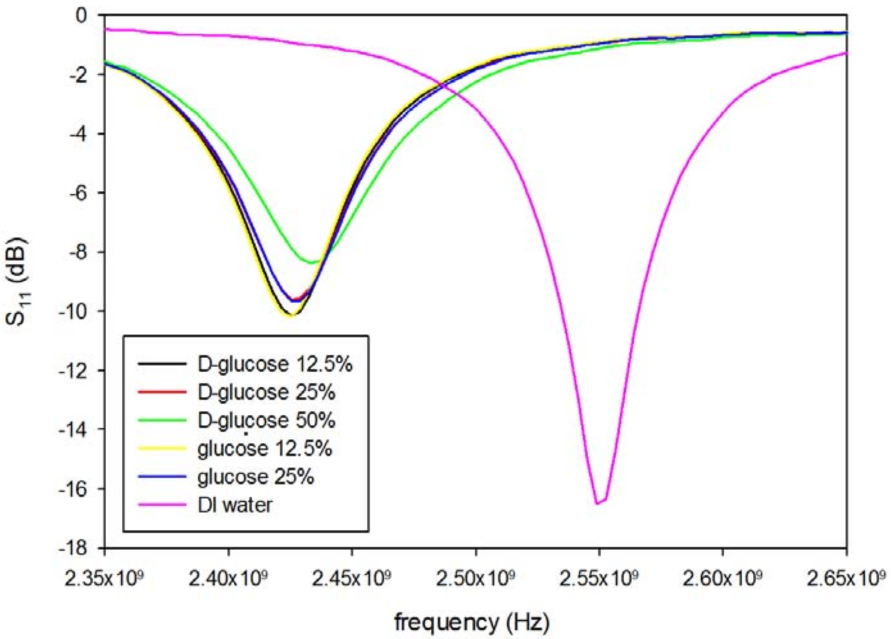




Measurement setup of the syringe pump system with CPW antenna biosensor and fluidic channel. 60ml syringe is used for the experiment and the pumping rate is set to 2 ml/min.

Measurements

- Glucose solution with different concentration

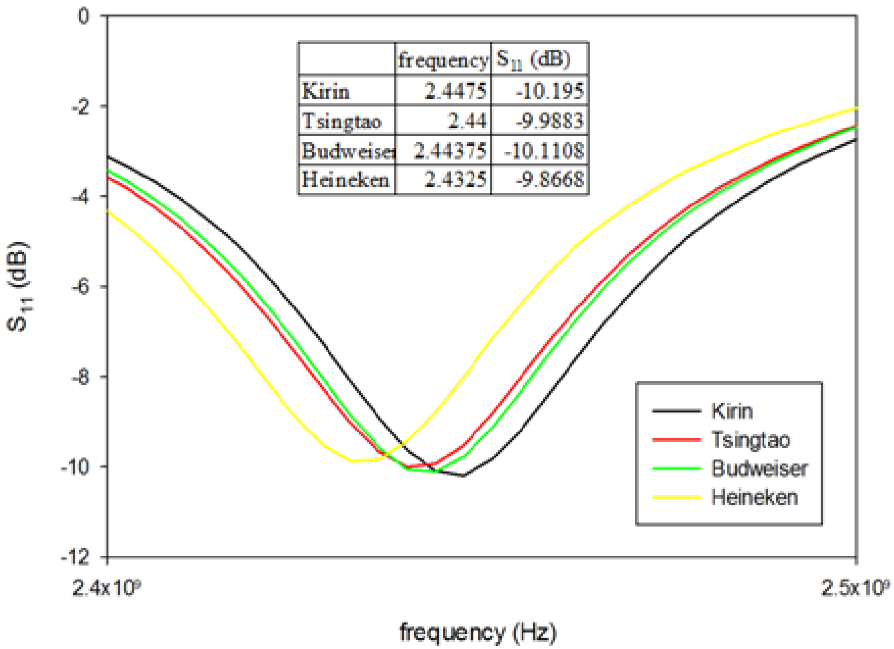


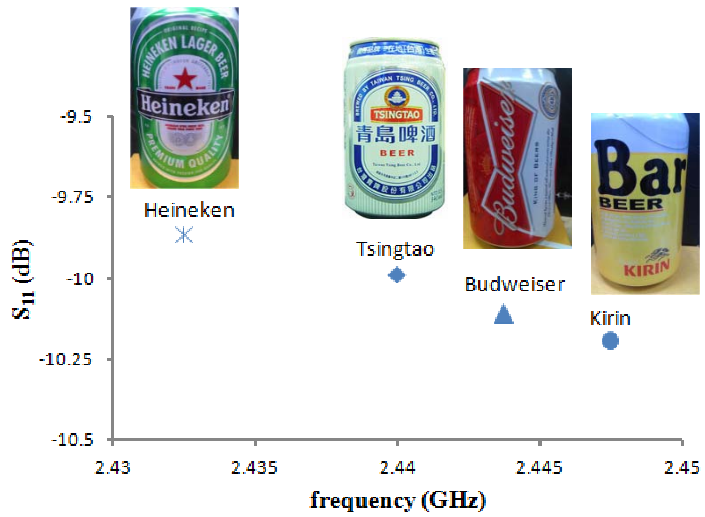
Glucose	Frequency (GHz)	Return loss $\|S_{11}\|$ (dB)
DI water	2.54875	-16.4923
D-glucose (12.5%)	2.425	-10.16
D-glucose (25%)	2.425	-9.58414
D-glucose (50%)	2.4325	-8.35572
glucose (12.5%)	2.425	-10.1915
glucose (25%)	2.42875	-9.66195

Measurement setup of the syringe pump system with CPW antenna biosensor and fluidic channel. 60ml syringe is used for the experiment and the pumping rate is set to 2 ml/min.

Measurements

- Different brand of Beer

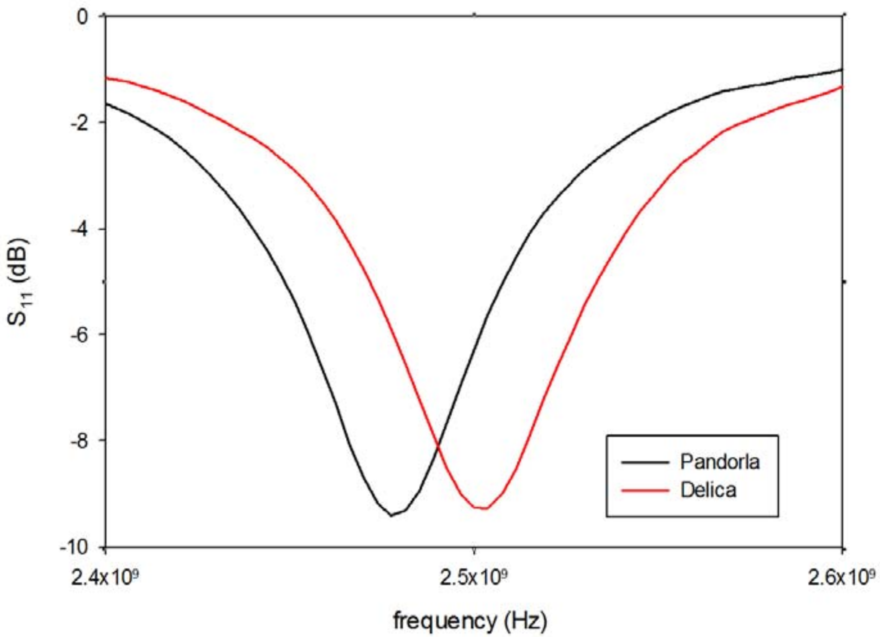


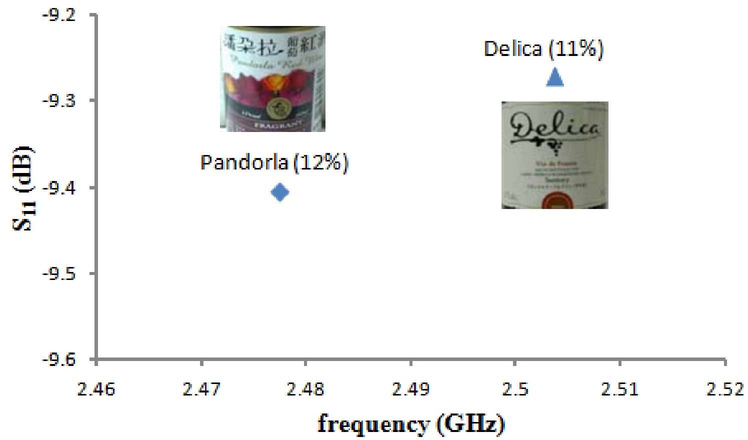


Measurement of different brand of beer through fluidic channel, different ingredient shown different result in return loss and resonant frequency.

Measurements

- Different brand of Red wine



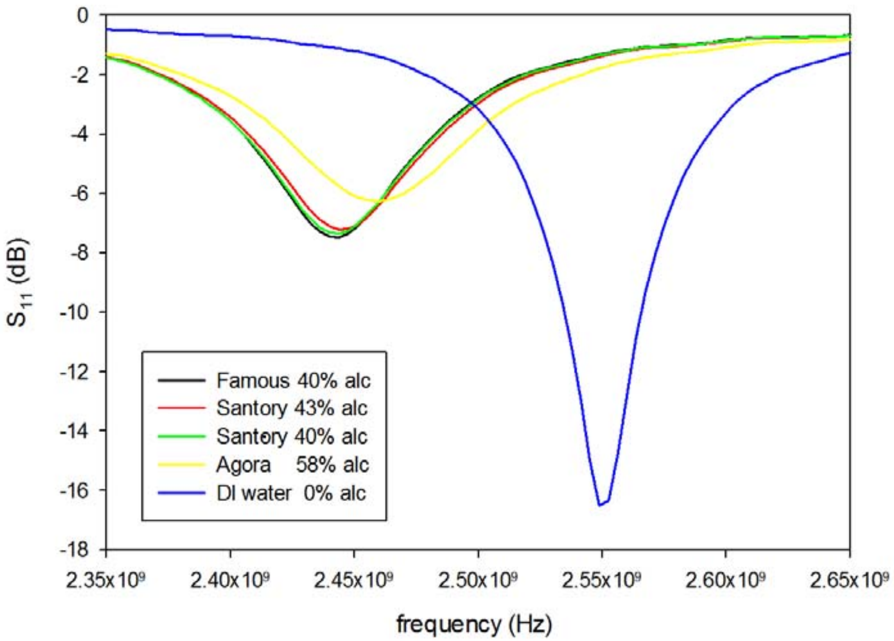


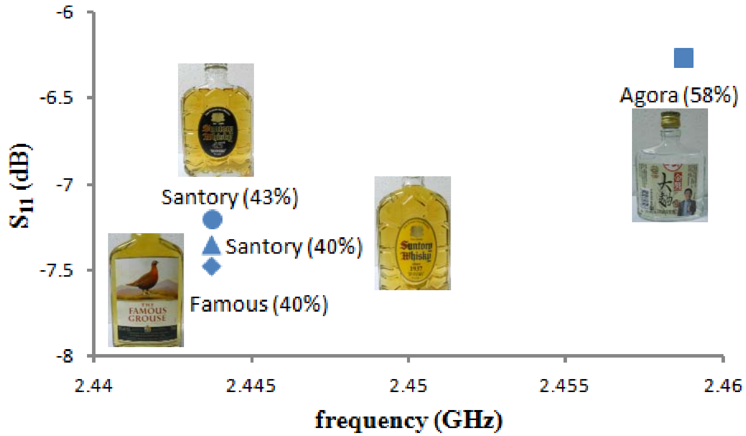
Red wine	Frequency (GHz)	Return loss $\|S_{11}\|$ (dB)
Pandorla (12%)	2.4775	-9.4064
Delica (11%)	2.50375	-9.27249

Measurements of different brand of red wine through fluidic channel, different concentration of alcohol content shown different resonant frequency and return loss.

Measurements

- Different brand of liquor





Liquor (Brand)	Freq. (GHz)	$\lvert S_{11} \rvert$ (dB)
DI water	2.54875	-16.4923
Famous (40%)	2.44375	-7.4807
Santory (43%)	2.44375	-7.2071
Santory (40%)	2.44375	-7.35203
Agora (58%)	2.45875	-6.26646

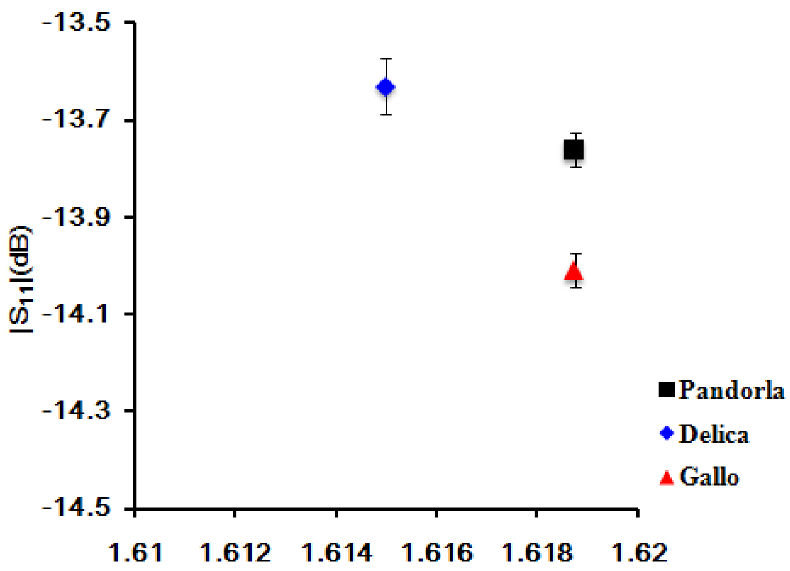
Measurement of different liquor with different alcohol content through fluidic channel and compared to DI water, different concentration exhibit different responds on frequency and return loss.

Red Wines

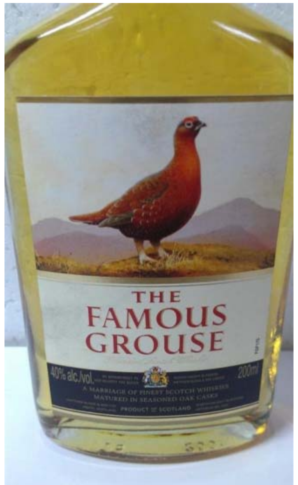

Delica
Vin de France
Suntory


Gallo
FAMILY
CABERNET
SAUVIGNON
CALIFORNIA


潘朵拉 葡萄紅酒
Pandorla Red Wine
12%vol
FRAGRANT

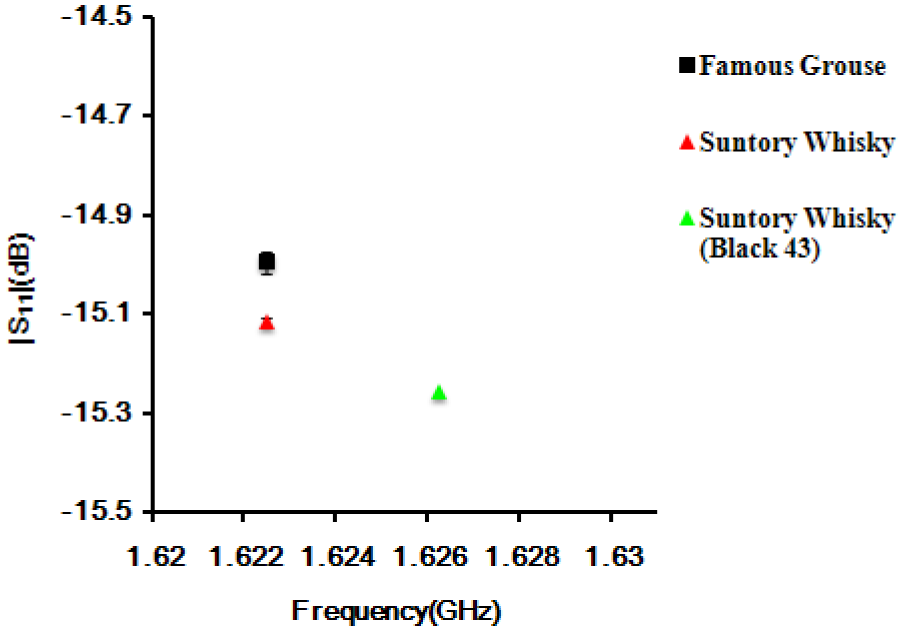

|S11|(dB)
-13.5
-13.7
-13.9
-14.1
-14.3
-14.5
1.61
1.612
1.614
1.616
1.618
1.62
Pandorla
Delica
Gallo

Liquors

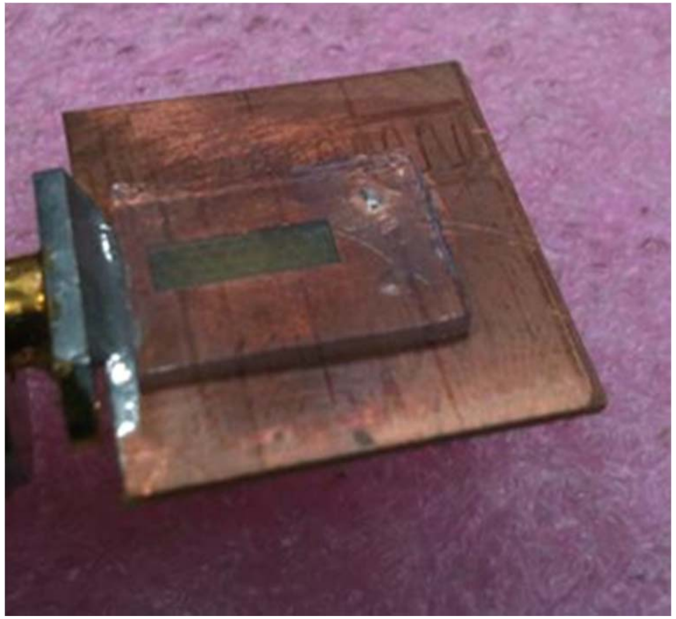

THE
FAMOUS
GROUSE

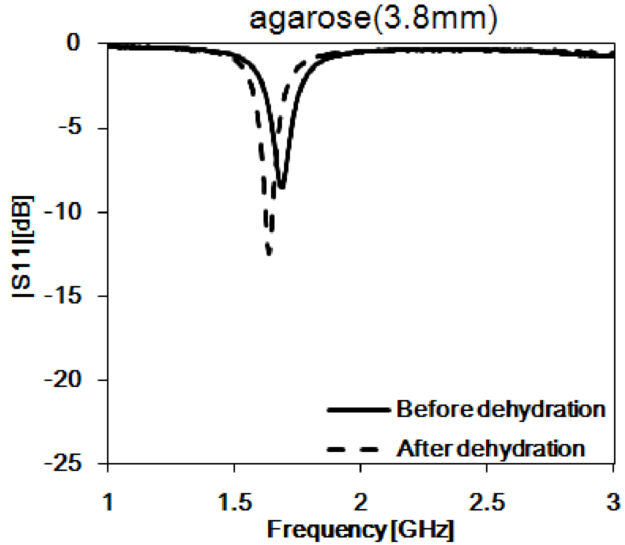

Suntory
Whisky
since
1937


Suntory
Whisky
43°

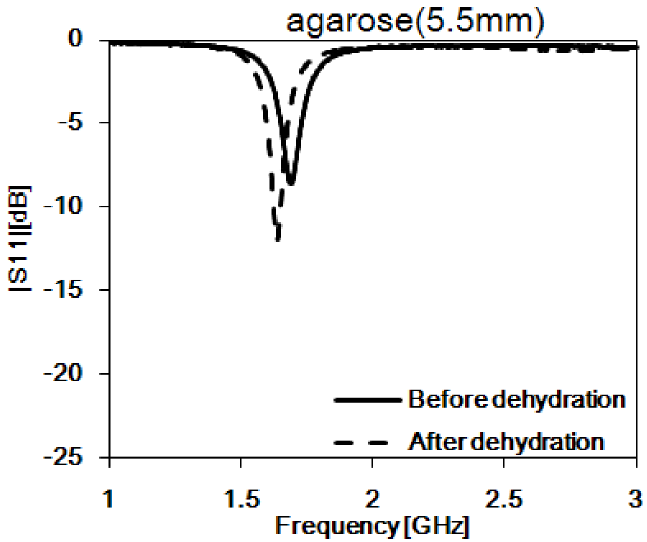

-14.5
-14.7
-14.9
-15.1
-15.3
-15.5
|S11|(dB)
1.62
1.622
1.624
1.626
1.628
1.63
Frequency(GHz)
Famous Grouse
Suntory Whisky
Suntory Whisky (Black 43)

Solid Samples Measurement

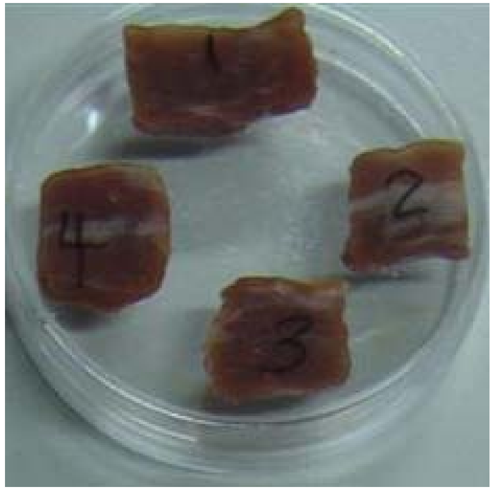


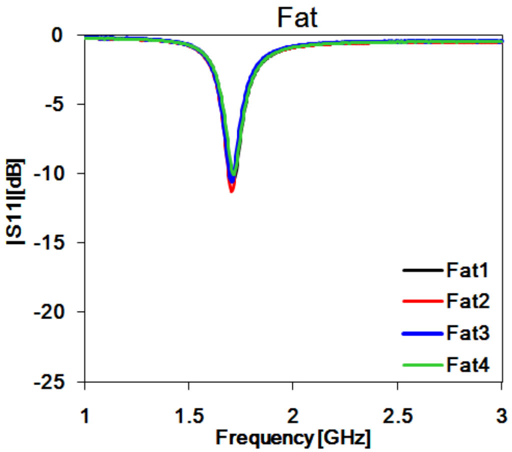


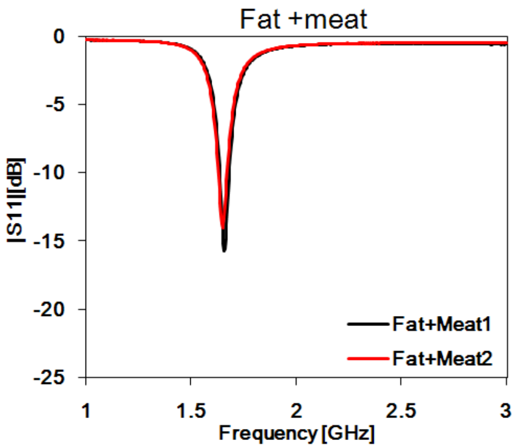
	Agarose(3.8mm)	Agarose(5.5mm)
Before Dehydration	**0.5706g**	**0.8617g**
Frequency	1.6875	1.6874
S11	-8.5419	-8.618
After Dehydration	**0.3536g**	**0.5841g**
Frequency	1.6375	1.6375
S11	-12.4334	-12.0268

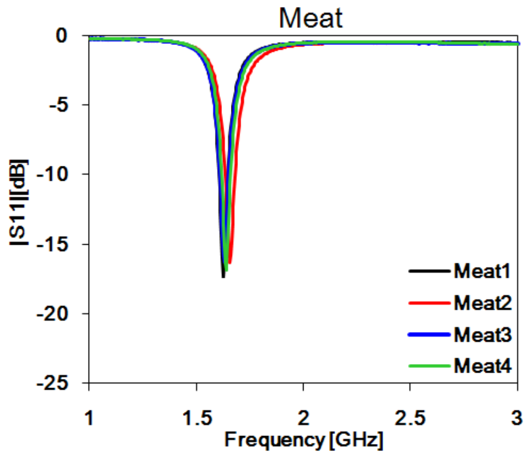


Pork

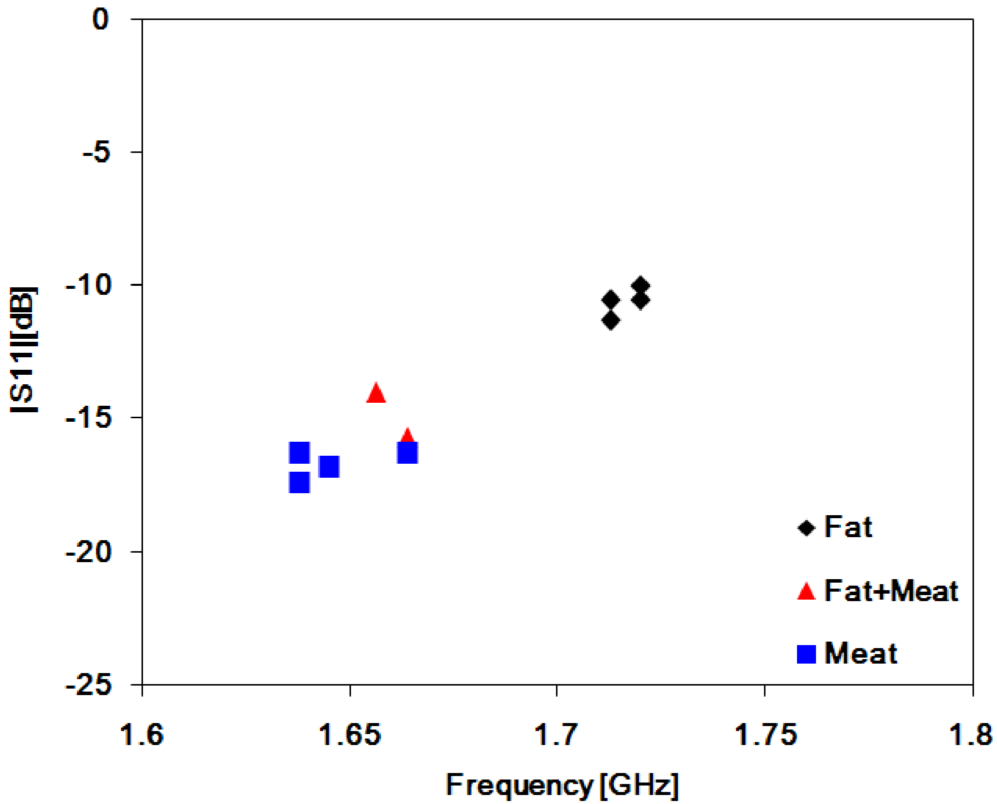



Fat
0
-5
-10
-15
-20
-25
|S11|[dB]
1
1.5
2
2.5
3
Frequency [GHz]
Fat1
Fat2
Fat3
Fat4


Fat +meat
0
-5
-10
-15
-20
-25
|S11|[dB]
1
1.5
2
2.5
3
Frequency [GHz]
Fat+Meat1
Fat+Meat2


Meat
0
-5
-10
-15
-20
-25
|S11|[dB]
1
1.5
2
2.5
3
Frequency [GHz]
Meat1
Meat2
Meat3
Meat4

Result



- Fat: $\varepsilon_r \approx 5.5$, $\tan\delta \approx 0.21$
- Muscle: $\varepsilon_r \approx 49$, $\tan\delta \approx 0.33$

Conclusion

- A biosensor antenna based on CRLH transmission line concept is proposed and successfully realized.
- It is demonstrated that this new bio-sensor is sensitive to the permittivity and conductivity of both liquid and solid samples for chemometric analysis using noncontact and label-free mode.
- The biosensor has the advantages of low profile, relative simplicity, accurately ease of fabrication, and low price.

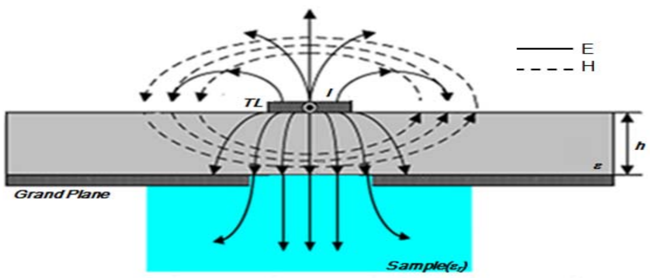
Conclusion

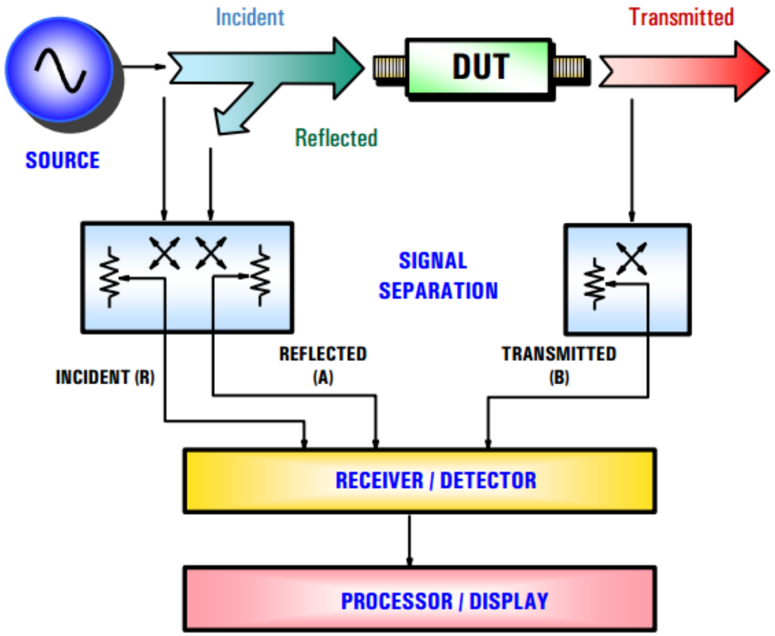
- The experimental results shown that the developed CPW antenna biosensor can be used for either **static** or **dynamic** measurements.

- The developed antenna biosensor with fluidic channel can be used in <u>real time monitoring</u> to assure the <u>quality</u> of liquid sample in food industries.

Future

- Thinner PCB
- Application
- Portable device
  - Sensors
  - Measurement equipments
    - DDS(Direct Digital Synthesis)+PLL (Phase Locked Loop)





Generalized Network Analyzer Block Diagram

The quality control group of Carlsberg Research Lab
http://www.crc.dk/flab/quality.htm

Thanks for you attention!!

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Thanks for you attention!!