# Dielectric Properties of Jordanian oil shales

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# TALK OUTLINE

- **Background**
  - What are dielectric properties?
    - Why we need to know dielectric properties?
    - How to measure dielectric properties?
  - What are Microwaves?
  - Microwave Heating Principles
- **Experimental work**
  - Measurement method and sampling
  - The Rig
- **Results**
  - TOC vs. ε’ and ε”
  - Effect of Temperature
  - Effect of Frequency
  - Penetration Depth
- **Concluding Remarks**

# What are dielectric properties?

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

**Permittivity**

$\varepsilon'$

- **Real part (dielectric constant)**
    - **Ability of the material to store EM energy within its structure**

$\varepsilon''$

- **Imaginary part (loss factor)**
    - **Ability of the material to dissipate the stored energy into heat**
    - $< 10^{-2}$ : low loss type, difficult to heat with microwaves
    - $> 5$: depth of penetration can be small, non-uniform heating results, heating very rapid
    - typically increases with temperature, sometimes sharply!

# What are dielectric properties?

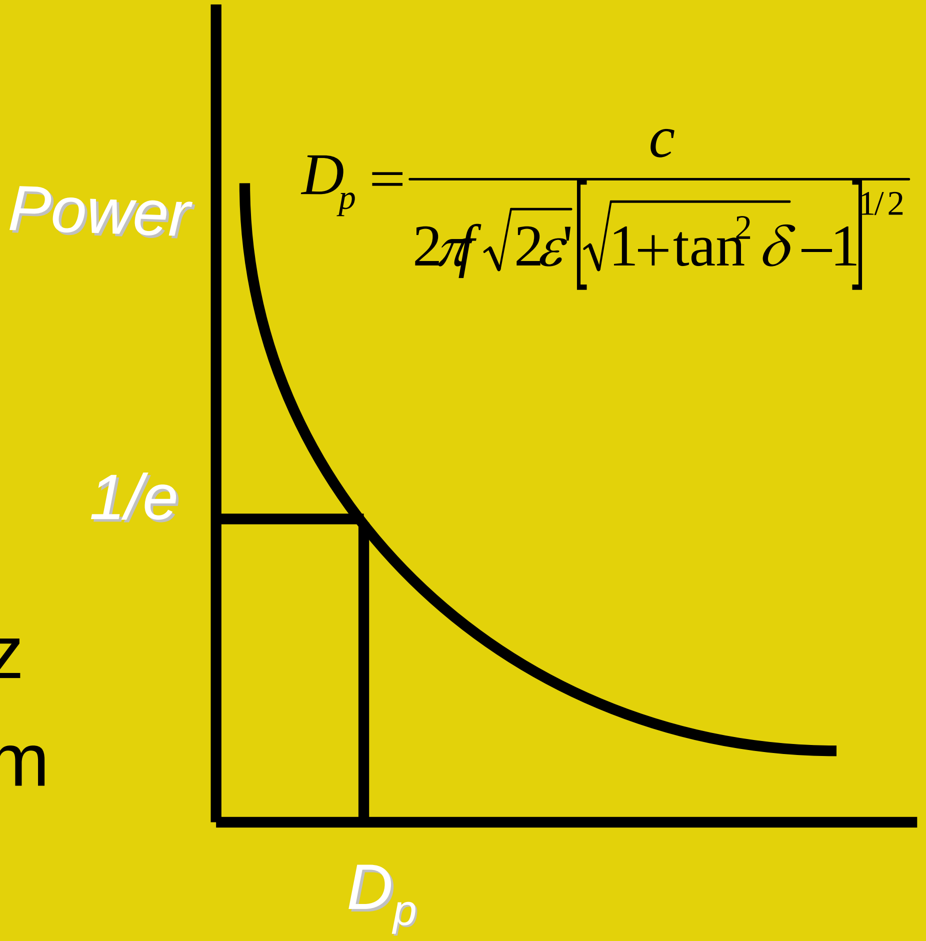
**Loss Tangent:**

- **How well a material dissipates stored energy**

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

Penetration depth ($D_P$) determined by dielectric properties & frequency

- Typically cm at 2450 MHz
- Object >> Dp, non-uniform heating



$$D_p = \frac{c}{2\pi f\sqrt{2\varepsilon'}\left[\sqrt{1+\tan^2\delta}-1\right]^{1/2}}$$

# Why we need dielectric properties?

## Microwave Heating Equation

$$Pd = 2\pi f \varepsilon_o \varepsilon'' E_o^2$$

Where

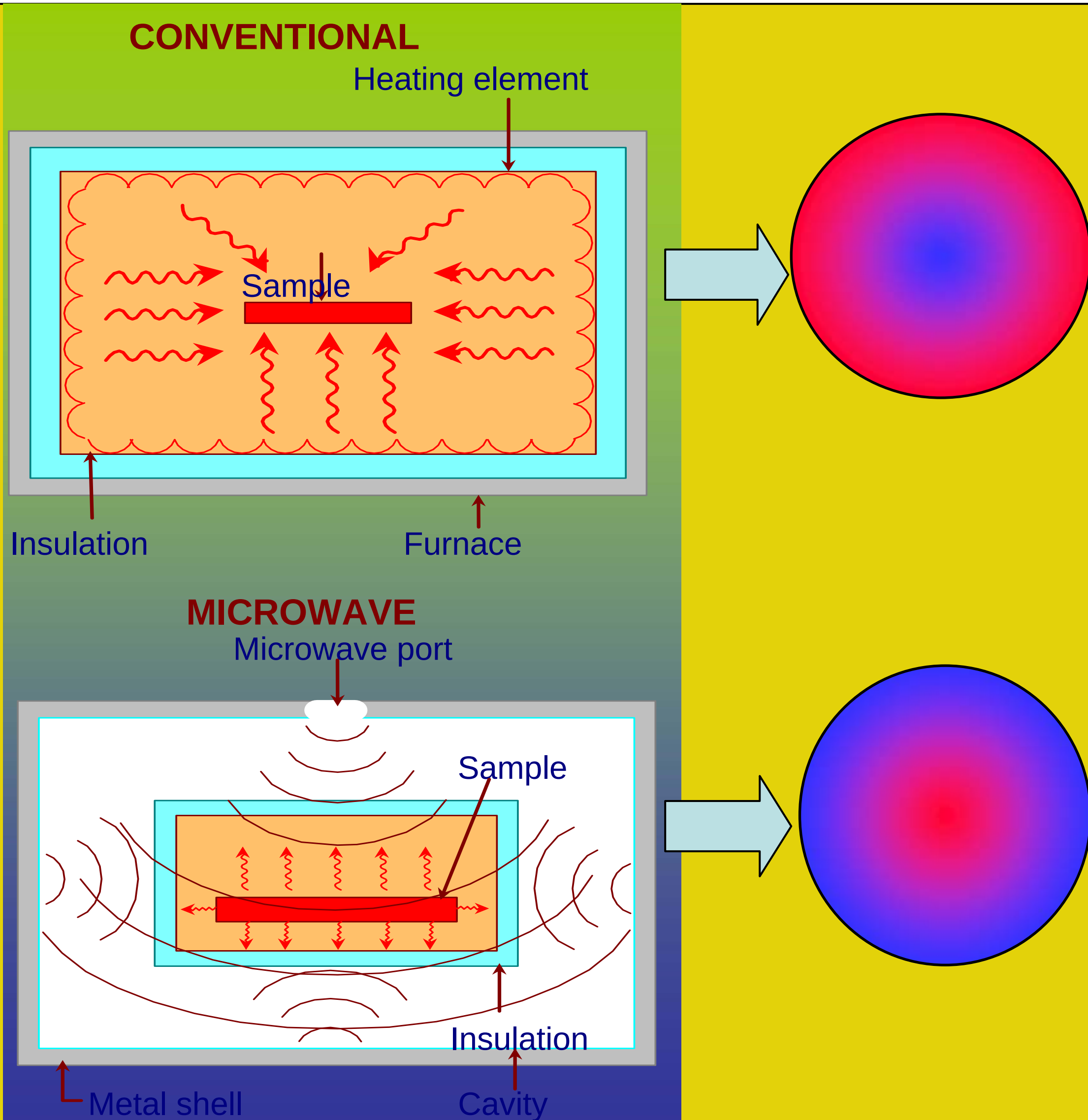
- Pd is power density (W/m$^3$)
- f is frequency of applied radiation (Hz)
- $\varepsilon_0$ is permittivity of free space (8.854 x 10$^{-12}$F/m)
- $\varepsilon''$ is effective dielectric loss factor of the material
- $E_o$ is magnitude of electric field within material (V/m)

# Why we need dielectric properties?

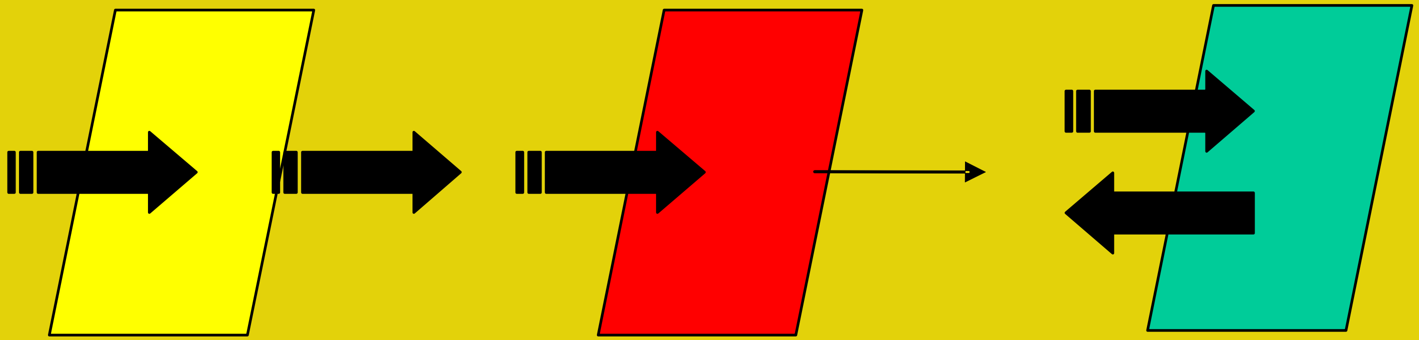
- Dielectric properties of materials vary greatly, variation occurs as a result of :-
    - composition
    - density
    - temperature
    - frequency
- Knowledge is essential for system design
- Published data should only be used as a guide

# Microwave Heating Basics

- **Conventional heating**
  - **entire furnace is hot**
  - **sample hotter on surface (initially)**
- **Microwave heating**
  - **only sample is heated**
  - **heating is volumetric**
  - **sample ends up hotter in centre**



# Microwave Interaction with Materials



- Transparent material

Teflon
Quartz glass
Silica

- Absorbing material

oxides
Ionic species
Polar solvents

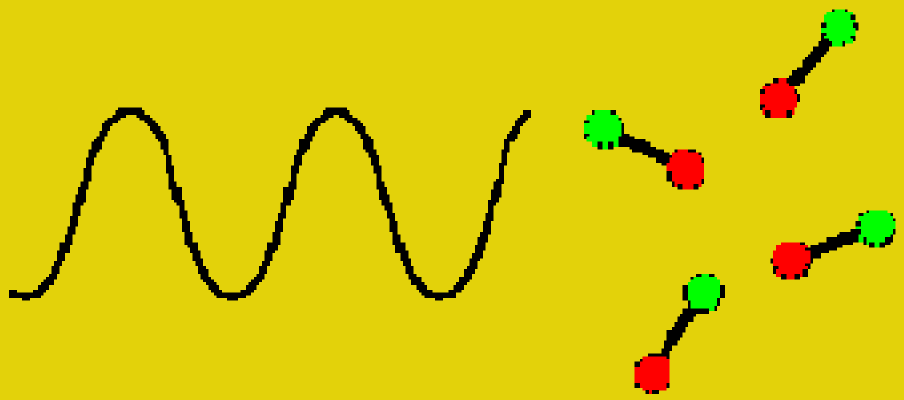
- Reflecting material

Metals

# Microwave Heating Mechanism

## Orientation polarization

When microwave energy is passing through the matter, molecules of the matter having dipole moments will rotate and try to align themselves with the electric field



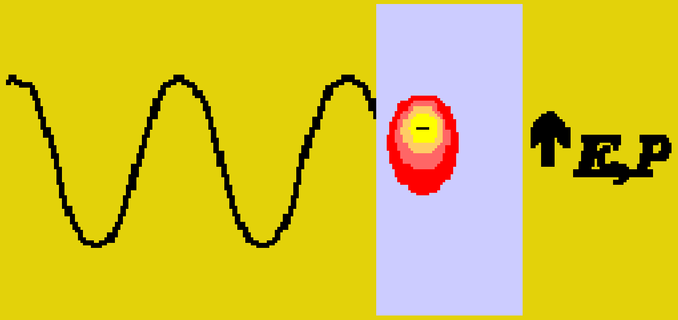
Polar ends of molecules tend to align themselves and oscillate in step with the oscillating electric field of microwaves. Collisions and friction between the moving molecules result in heating. Generally, the more polar is a molecule, the more effectively it will couple with microwaves

- http://homepages.ed.ac.uk/ah05/microwave.html

# Microwave Heating Mechanism

## Conduction mechanism

If the material irradiated is an electrical conductor, the charge carriers are moved through the material under the influence of the electric field. The induced currents will cause heating in the sample due to electrical resistance



If the material is too conducting microwaves will not penetrate through causing arcing on the surface.

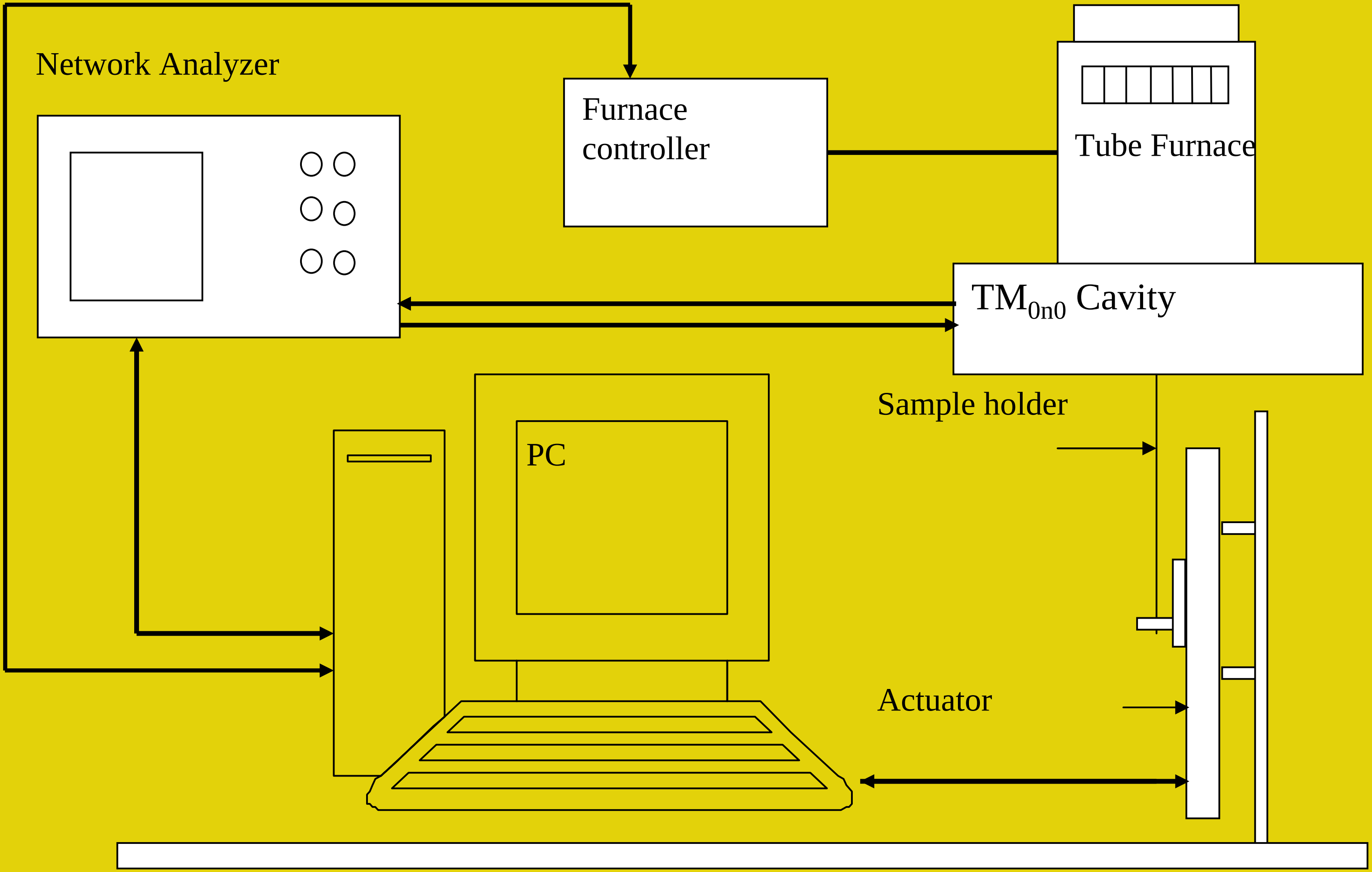
- http://homepages.ed.ac.uk/ah05/microwave.html

# Measurement of dielectric properties

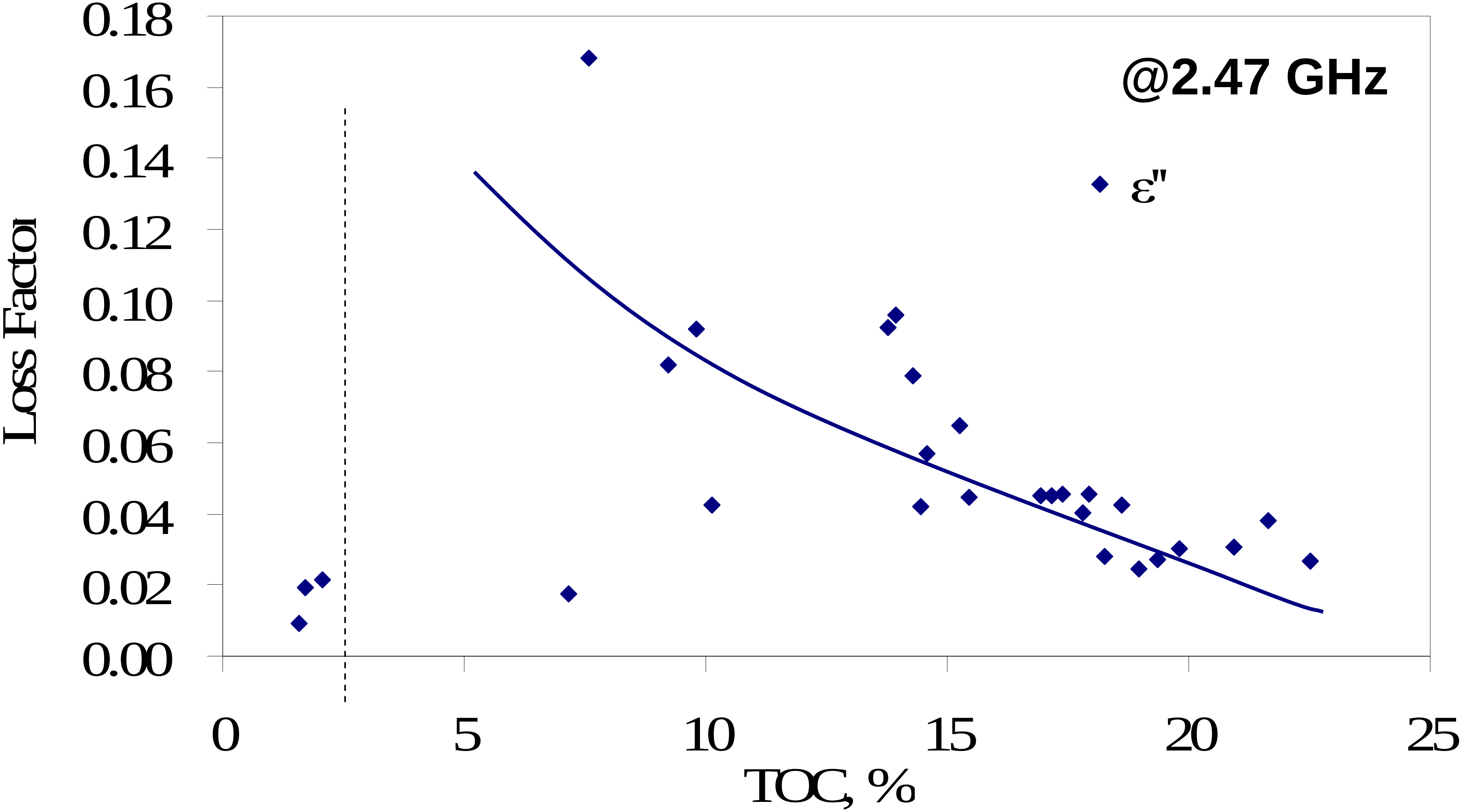
- Cavity perturbation method
  - Possibility to measure at high T
  - Based on simple perturbation theory
  - Very small powdered sample
  - Limited number of frequencies
  - Suitable for low loss materials
- Coaxial probe method
  - Broad band technique
  - Can be used with block sample
  - Suitable for high loss materials
  - Polished surface is required

# Hot Cavity Perturbation Method

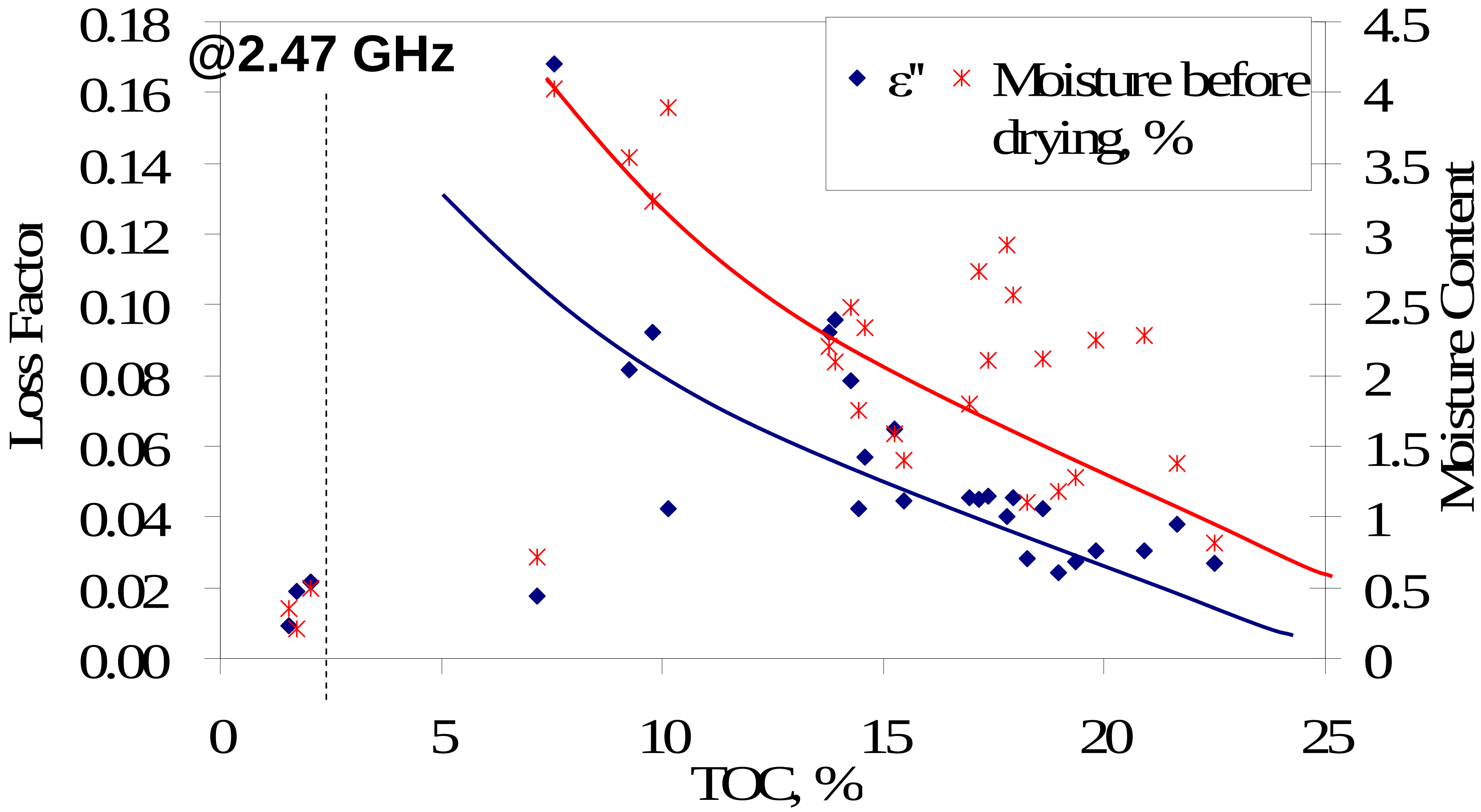
- **Experimental Set-up**



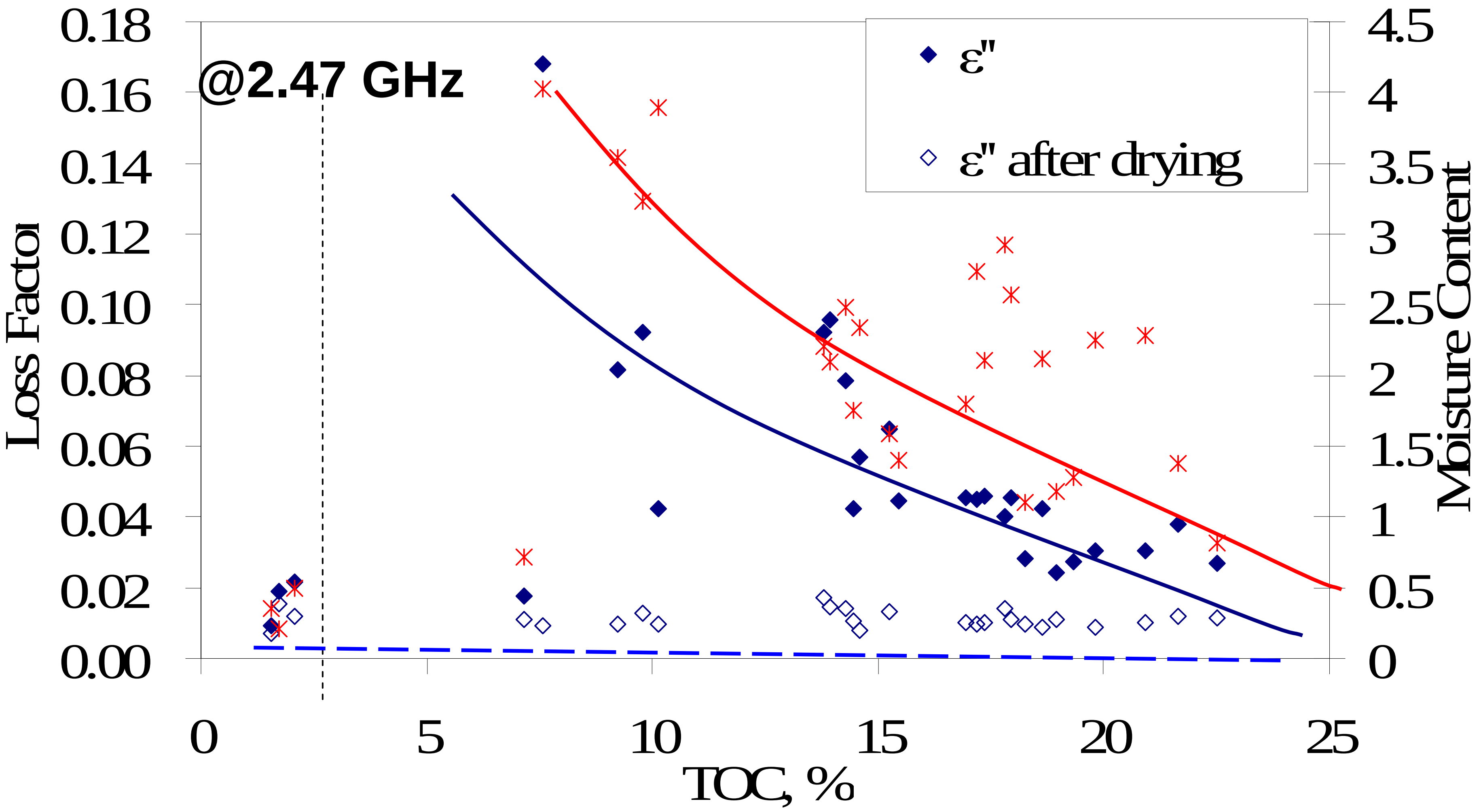
# Results 1
# TOC vs. ε”



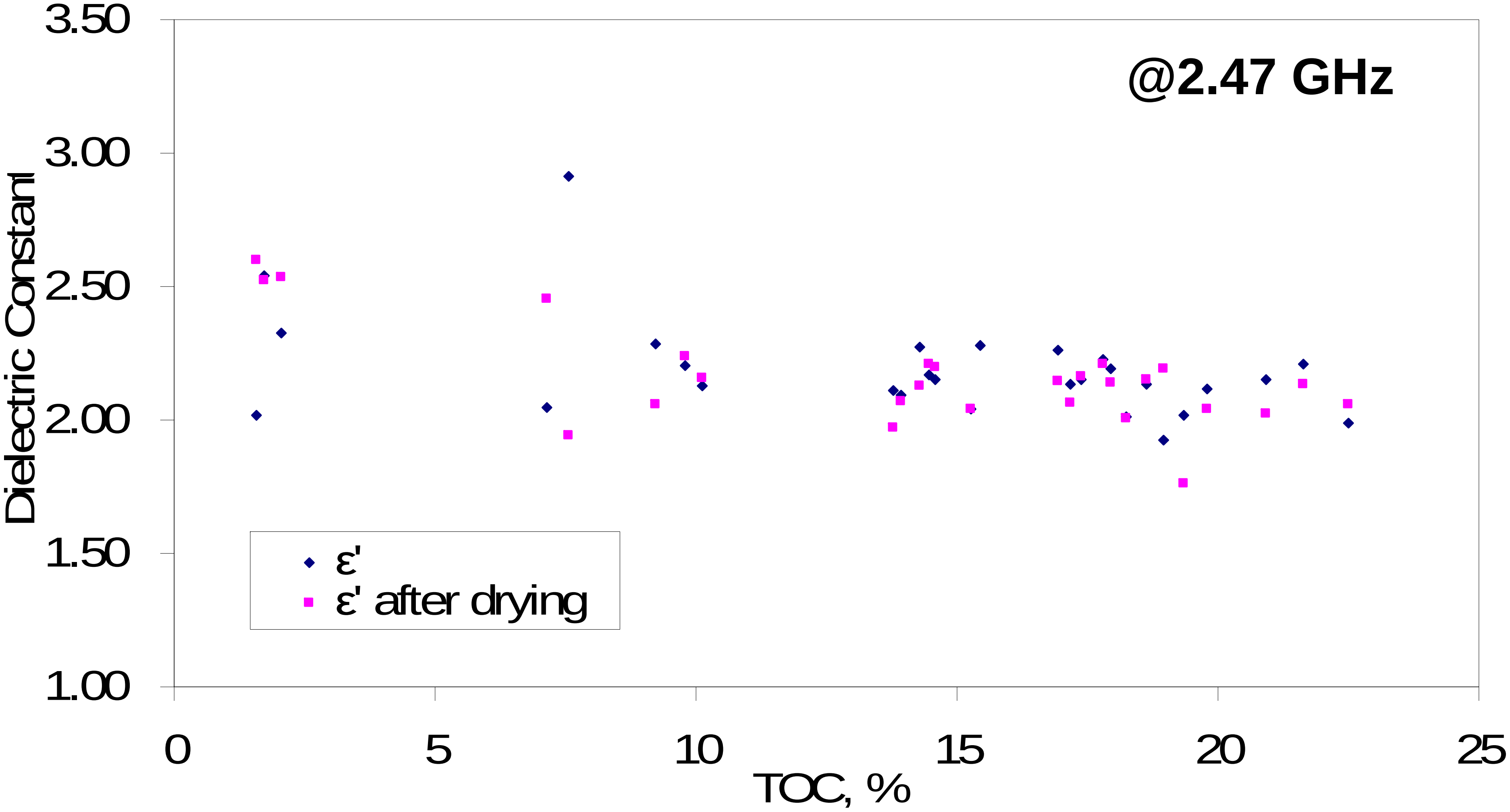
# Results 2
# TOC vs. ε” & % Moisture



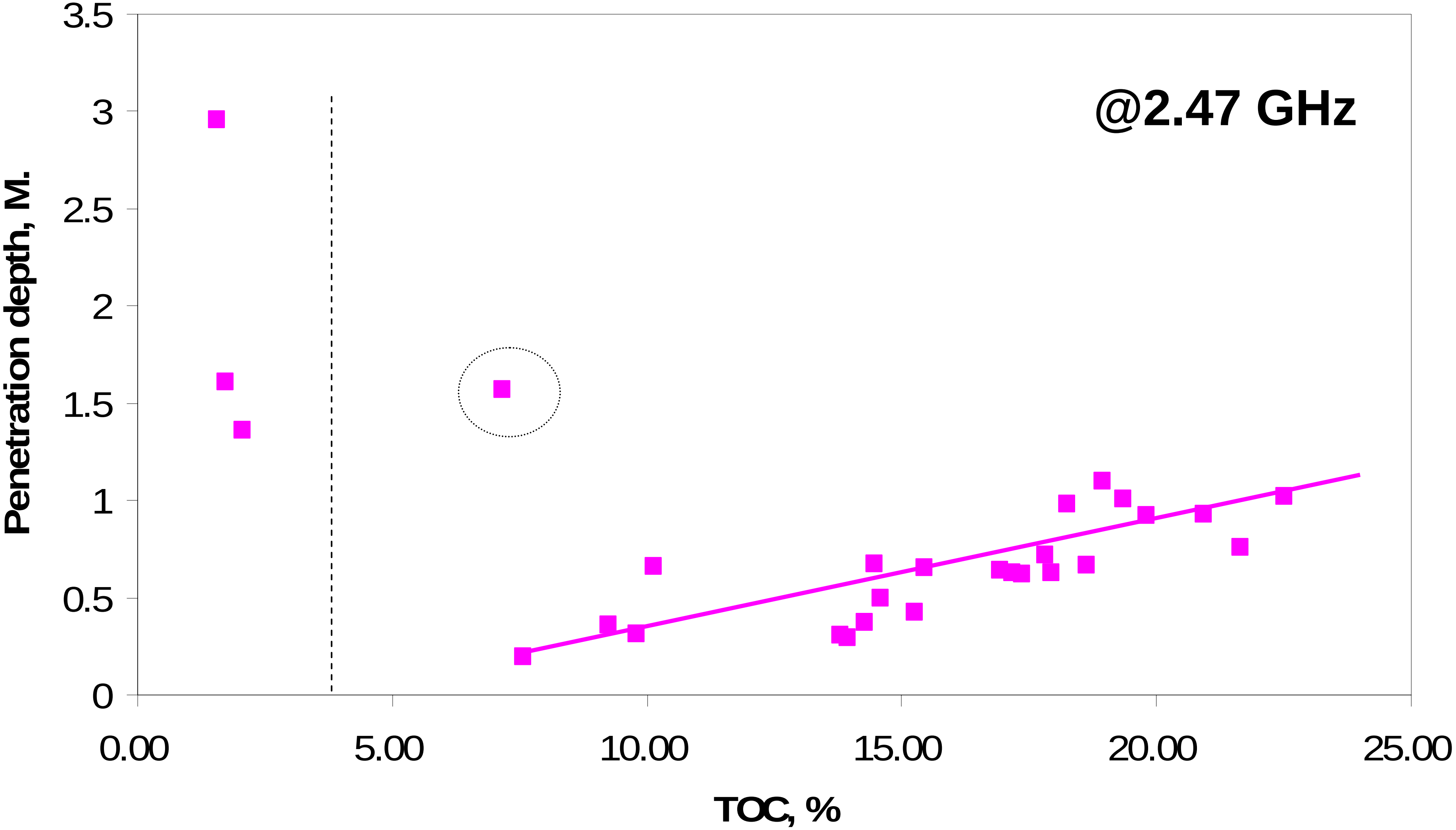
# Results 3
# TOC vs. ε" –Effect of Drying



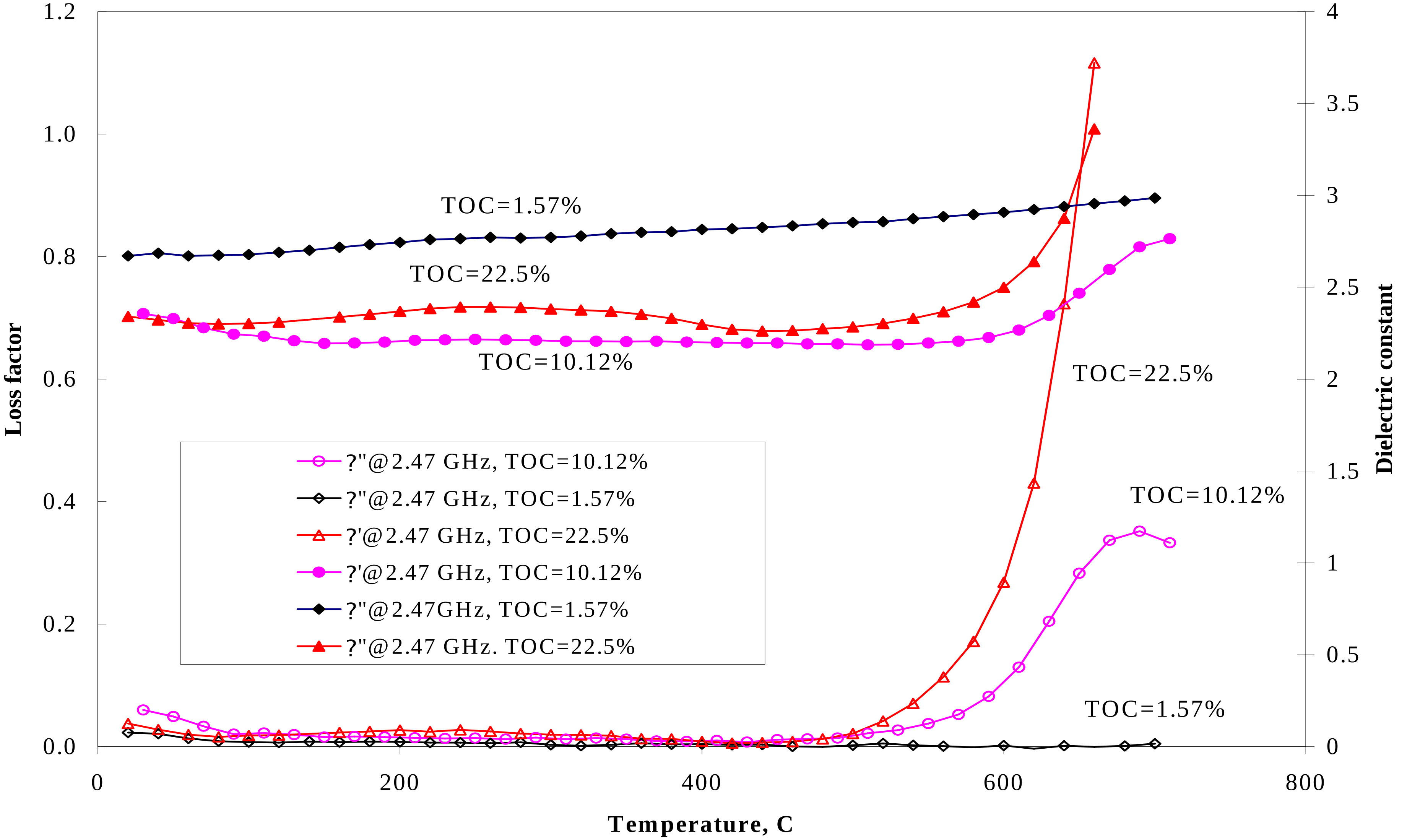
# Results 4
# TOC vs. ε’



# Results 5
# TOC vs. Dp

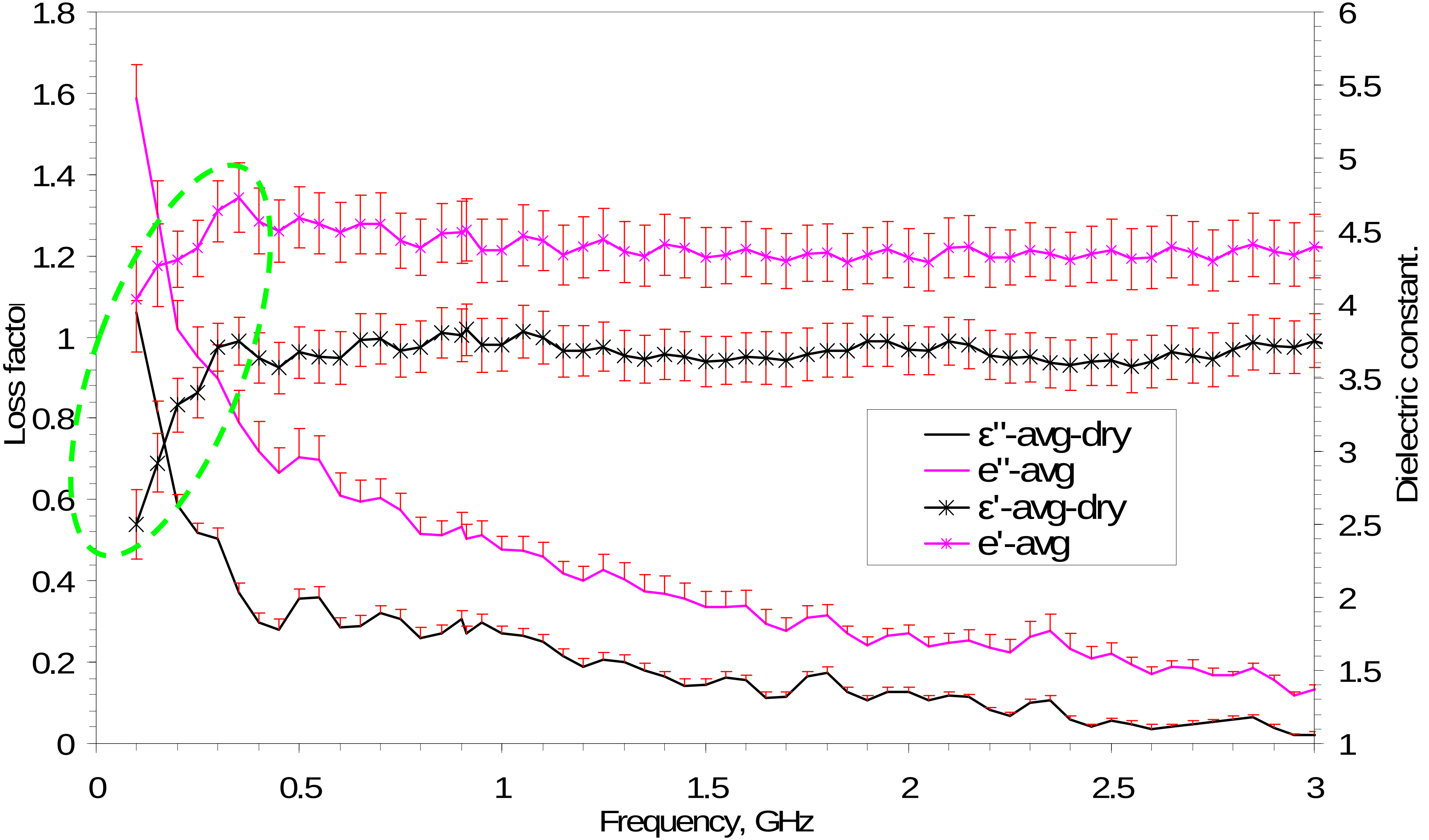


# Results 6
# Effect of Temperature

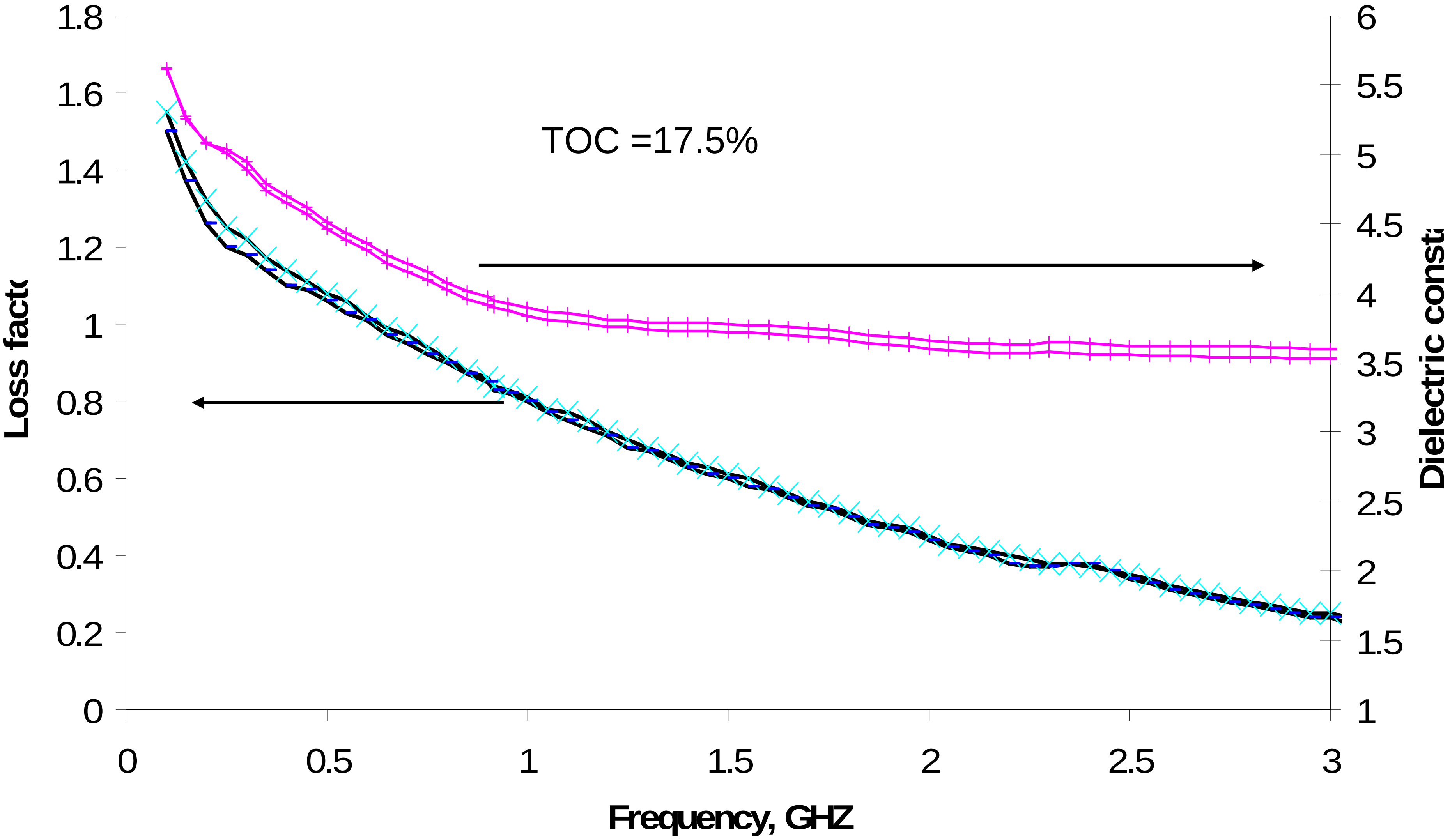


# Coaxial probe method

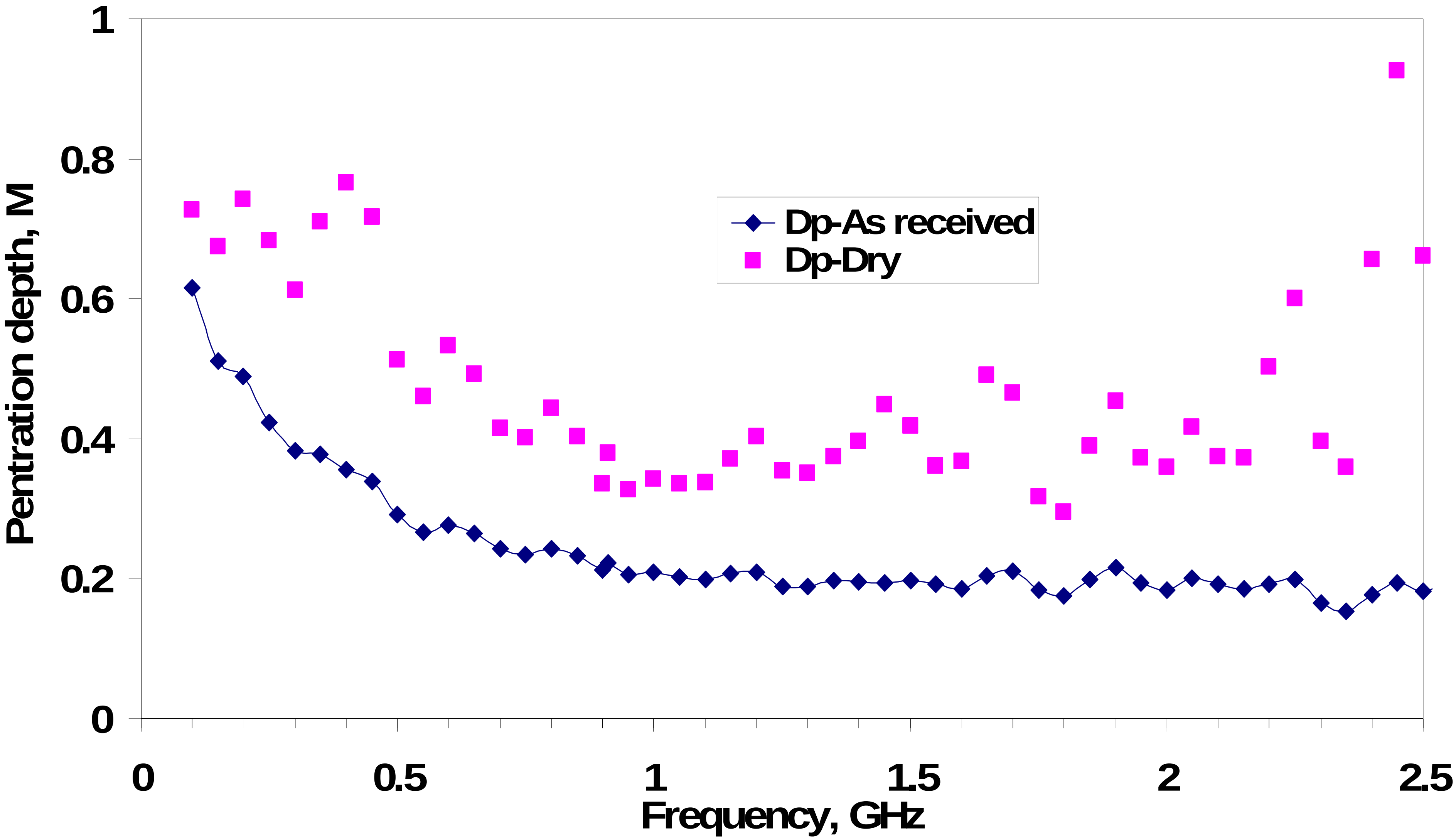
# Effect of Frequency As Received & dried



# Effect of Frequency
# As Received 1



# Penetration depth



# Conclusions

- **Knowledge of dielectric properties is essential to evaluate the whether EM energy is suitable to heat materials or not**
- **Short description of microwave heating principles was given**
- **Water content is the major contributor to both imaginary and real parts of oil shale permittivity**
- **Imaginary part (loss factor) of oil shale drops significantly after drying**
- **Above 500 ˚C, oil shale experiences a sharp increase in loss factor leading to thermal runaway. This effect increases with increased TOC**
  - **The reason for that is the carbonization of oil organic matter**

# Conclusions

- **Loss factor decreases with frequency from about 1.6 @ 100MHz to about 0.2 at 3 GHz**
- **To make use of microwave energy for pyrolysis of oil shale, water content, particle size, frequency, and incident power are the major controlling factors of the pyrolysis process**

# Thank you

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