The Effects of Radiation Losses on the Measurement of Loss Tangent Using Microstrip Ring Resonators.

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Motivation

- The loss tangent of a moisture absorbing material is linked to the moisture content.
- This can be utilized to find the moisture content through loss tangent measurements.
- This work resulted from a measurement technique developed to measure the moisture content of *transformer press boards*.

- Our focus was on the dielectrics in sheet form used in transformers used in power distribution networks.

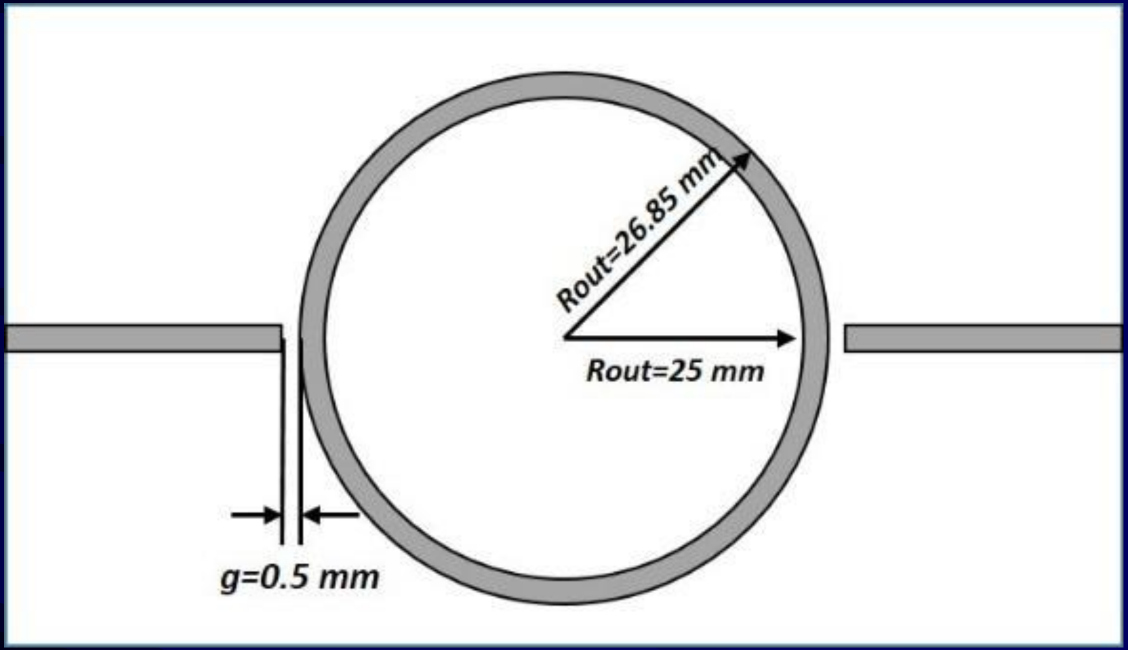
- If the moisture content (in the dielectric insulation) is measured, the transformer failure can be predicted and the reliability can be improved.

Our application

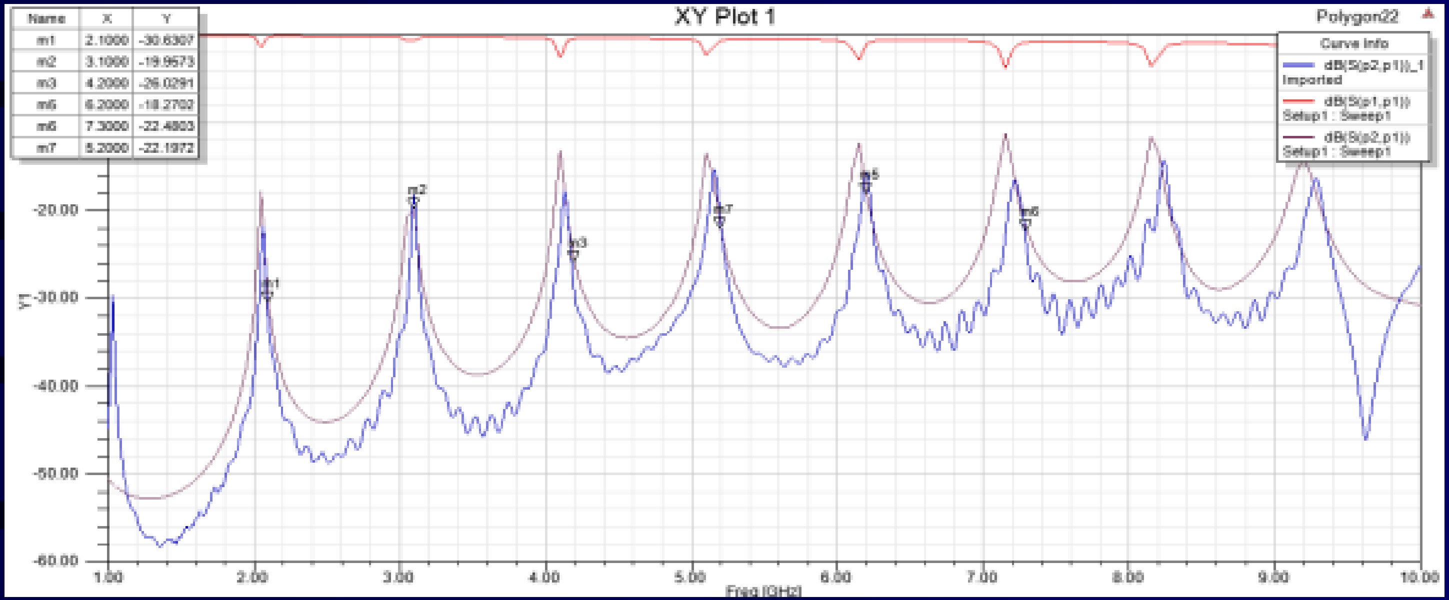
Microstrip line based techniques

- We consider microstrip line based techniques at microwave frequencies.
- At microwave frequencies, the losses due to the presence of moisture are significant.

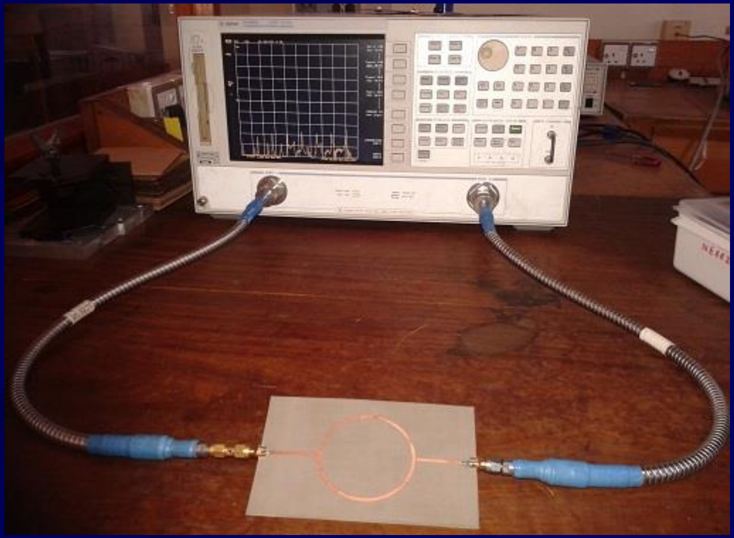
Ring resonator technique



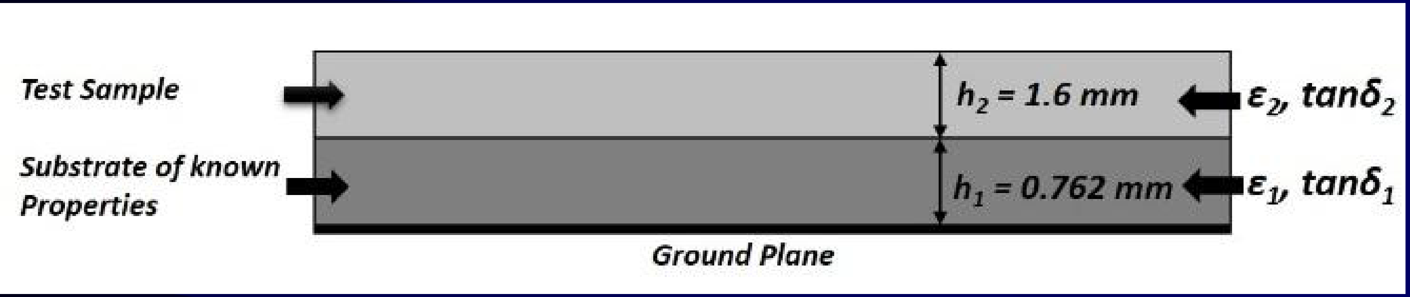
$$f_n = \frac{nc}{2\pi R_{mean\sqrt{\varepsilon_{reff}}}} \Rightarrow \epsilon_{eff}$$



- Experimental set up and measured data.



Multi-layer dielectric stack



- Complications arise due to the multi-layer nature of the problem.

Basis of calculations

$$\frac{1}{Q_u} = \frac{1}{Q_c} + \frac{1}{Q_r} + \frac{1}{Q_d}$$

$$Q_u = \frac{f_0}{(1 - |S_{21}|)B_{3dB}}$$

$\boldsymbol{Q_c}$: **Hammerstad equations.**

$\boldsymbol{Q_r}$: **Neglect?**

$$\tan\delta_{eff} = \frac{1}{Q_u}$$

$$\tan\delta_{eff} = \frac{1}{\epsilon_{reff}} \sum_{i=1}^{2} p_i \tan\delta_i$$

p_i: **Schneider's filling factor**

Is radiation significant? The contribution of this paper.

- Radiation losses are usually ignored in measurements.

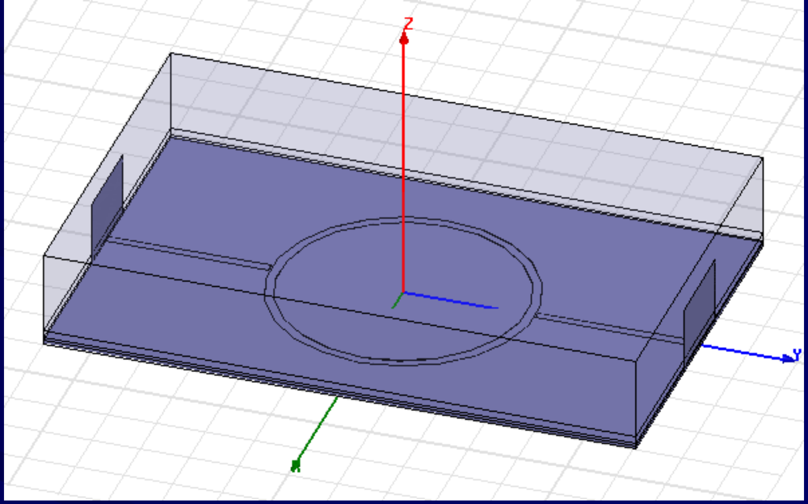
- In some techniques, the radiation losses with and without the test sample are assumed to be equal and balanced out.

Radiation loss

- Although difficult, analytical formulas can be obtained for the radiation from the ring structure. However, these techniques ignore the effects of the feeder lines and gaps.
- Measurement needs an anechoic chamber and are not suitable for low-cost dielectric measurements.

Simulation using HFSS

- In this paper, we use finite element based EM simulation to accurately obtain the radiation losses.



- The solution gives $\tilde{E}$ and $\widetilde{H}$ at every

Finding Qs

- Constituant Q factors (Q_d, Q_r, and Q_c) and Q_u can be found since $\tilde{E}$ and $\widetilde{H}$ are known.

$$Q = \frac{w_m + w_e}{P_l} . \omega$$

w_e, w_m: Average electrical/magnetic stored energy.

P_l: Energy dissipation per second.

Stored energy densities in terms of field components:

$$w_m = \frac{1}{2} Re \int (\tilde{B} . \tilde{H}^*) \, dV$$

$$w_e = \frac{1}{2} Re \int (\tilde{D} . \tilde{E}^*) \, dV$$

Energy densities in terms of field components:

$$P_{rad} = \frac{1}{2} Re \int (\tilde{E} \times \widetilde{H}^{*}) dS$$

$$P_c = \frac{1}{2} Re \int (\tilde{J} . \tilde{E}^{*}) dV$$

$$P_d = \frac{\omega}{2} \mathrm{Re} \int (\widetilde{D} . \tilde{E}^{*}) \, \mathrm{dV}$$

Evaluation of integrals: HFSS field calculator

- $begin 'Named_Expression'
- Name('DieledtricLoss')
- Expression('+(Integrate(Volume(substrate), Volume_Loss_Density), Integrate(Volume(TestSample), Volume_Loss_Density))')
- NameOfExpression('Volume_Loss_Density')
- EnterVolume('substrate')
- Operation('VolumeValue')
- Operation('Integrate')
- NameOfExpression('Volume_Loss_Density')
- EnterVolume('TestSample')
- Operation('VolumeValue')
- Operation('Integrate')
- Operation('+')
- $end 'Named_Expression'

Results

Resonant frequency	4.037 GHz
3 dB Bandwidth	20 MHz
S21 at resonance	-23.96 dB
Conduction loss	8.5 mW
Dielectric loss	178.48 mW
Radiation loss	31.76 mW
Stored magnetic energy	5.19×10^{-7} mW
Stored electrical energy	4.87×10^{-7} mW

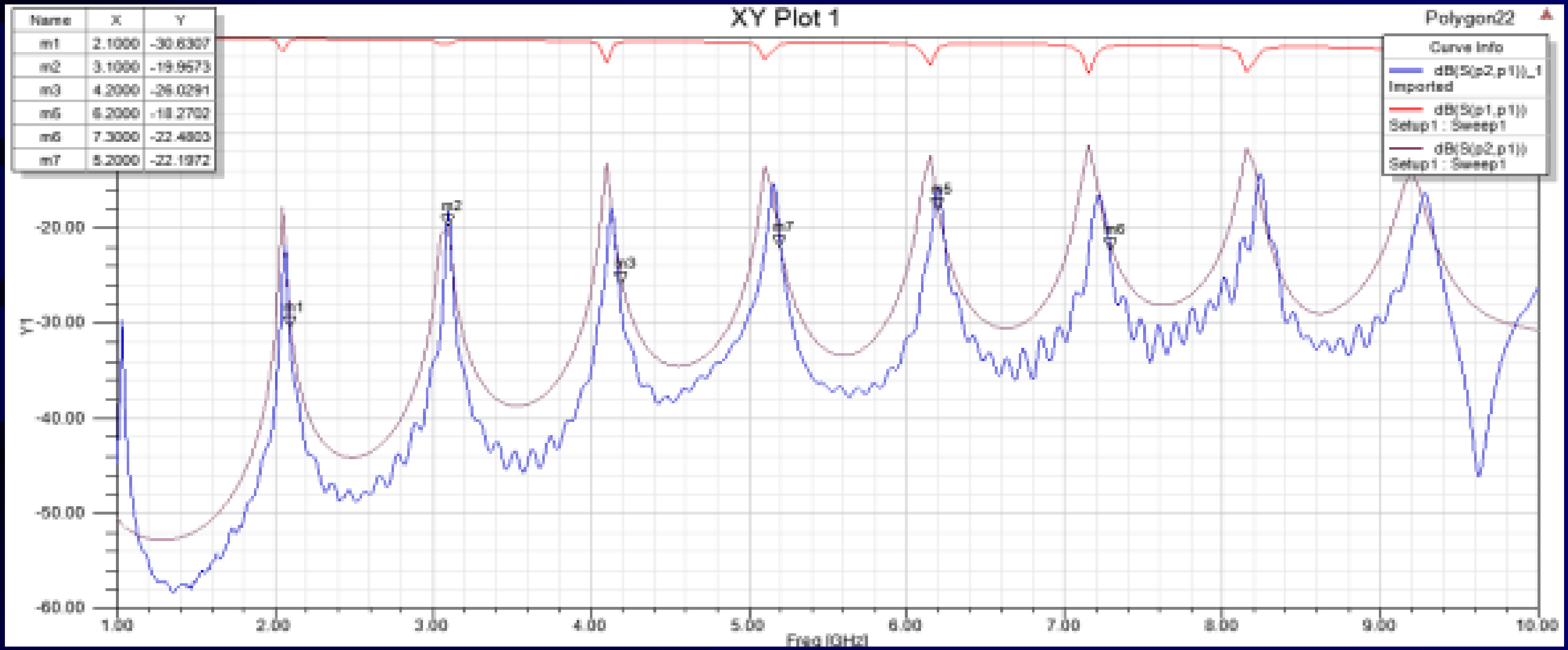
- Note: HFSS normalizes input power to 1W.

Results

Q_u **from and eigen-solution with HFSS**	**115.2**
Q_u from stored energy and loss (equation 12 in the paper)	116.2
Effective permittivity (equation 5 in the paper)	3.33
Relative permittivity of the test sample	5.18
Loss tangent with radiation accounted	0.03
Loss tangent with radiation ignored	0.04

- How do we know the above results are correct?

1. Measured vs. simulated results



2. Cross check the value of Q_u

- Since we know w_e , w_m , P_c , P_r , *and* P_d unloaded Q (Q_u) can be calculated.
- Alternatively, Q_u can be obtained from an eigen solution.

- Method 1: $Q_u = 116.2$
- Method 2: $Q_u = 115.2$
- Error = 1.2 %

Conclusion

- Results showed that the radiation, dielectric, and conductor losses amount to 3.9%, 81.6%, 14.5% in the simulated problem.
- Results further showed that ignoring the radiation loss resulted in a 33.3% error.

On going work

- The above conclusions lead to focus our attention to strip-line based measurements which are free from radiation effects.

- The work presented is a part of a more detailed work which has been accepted for publication in August 2016, it IEEE transactions of Dielectrics and Insulators.

Thank you.