Investigation of Measurement Techniques for the Determination of the Dielectric Constant of Substrate Boards for Microwave Circuits

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Outline

- Motivation
- Assumptions
- Method I : Capacitance Measurement.
- Method II : Full Sheet Resonance method.
- Method III : An Evaluation through a simple Microstrip Transmission Line Resonator.
- Total Results and Comparison.
- Conclusion

Motivation

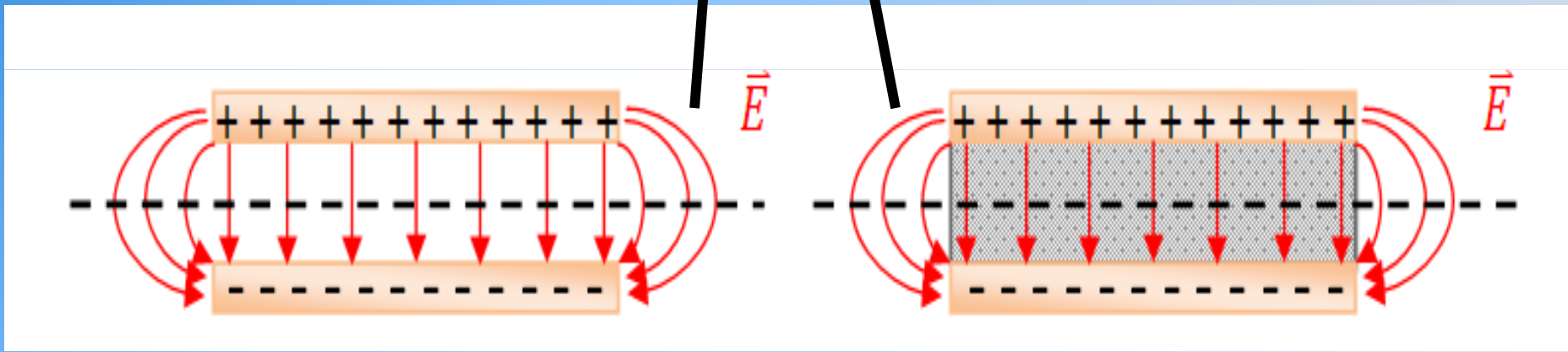
- To investigate the measurement method for determination of relative dielectric constant of a substrate board:

- Example of substrate RO4003:
  - manufacturers' result : 3.38 ± 0.05
  - recommended for use in circuit design: 3.55

-Three methods to be concerned here.

Assumptions

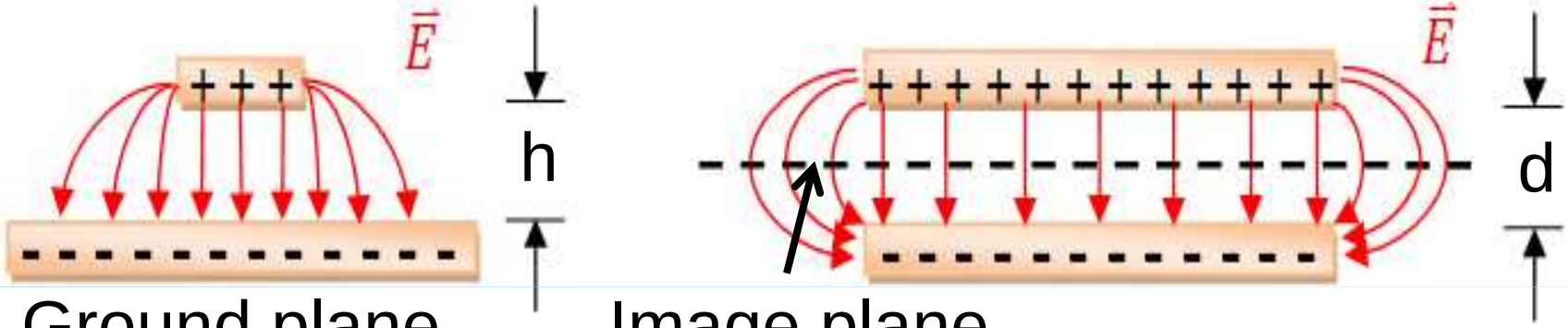
Stray electric field at the edge of the board.



(a) Air-filled laminate panel.

(b) Dielectric substrate filled laminate panel.

Assumptions



(a) (b)

(a) Air-filled microstrip line with thickness of h.

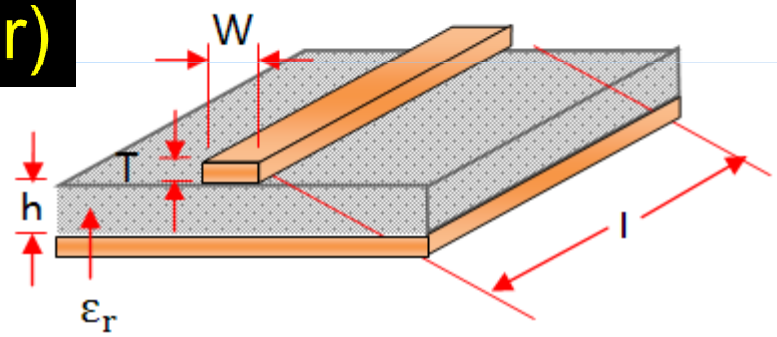
(b) Air-filled laminate panel with thickness of d. (d=2h)

Assumptions

End-effect length ΔI (method I)

Treated as open-ended transmission line resonator (method III)

ε_r = 1.0 (Air)



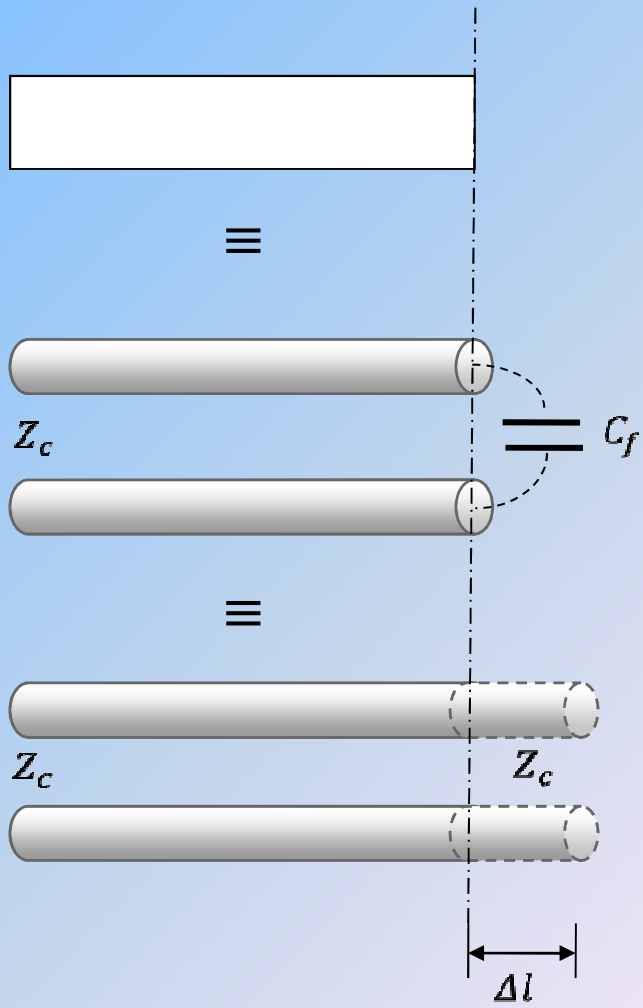
Fringing Capacitance (method I)

Microstrip transmission line.

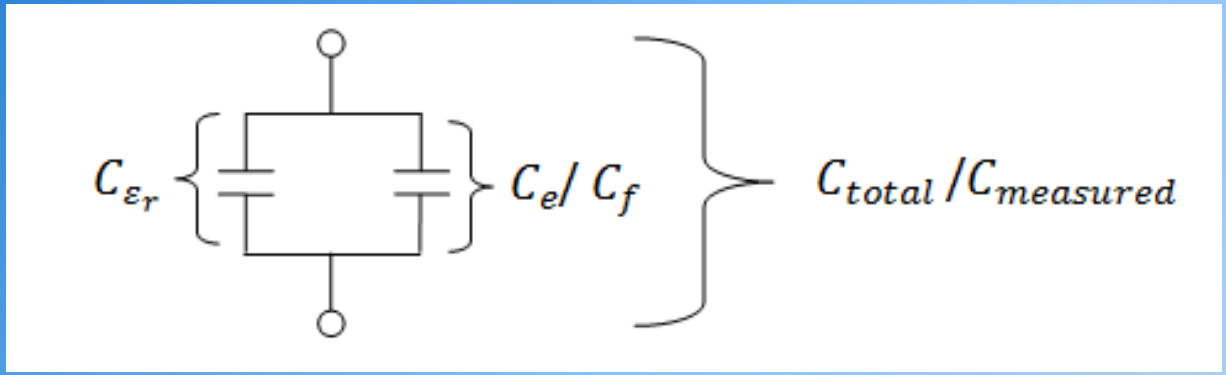
Characteristic Impedance, Zc

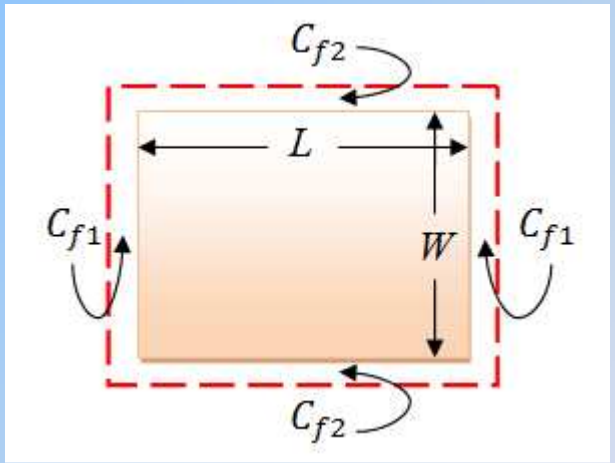
Method I : Capacitance Measurement.

- Several methods to determine the **stray electric field**.
- It can be represented as a **Fringing / Edge capacitor** or an **End-effect length Δl**.



Method I : Capacitance Measurement.

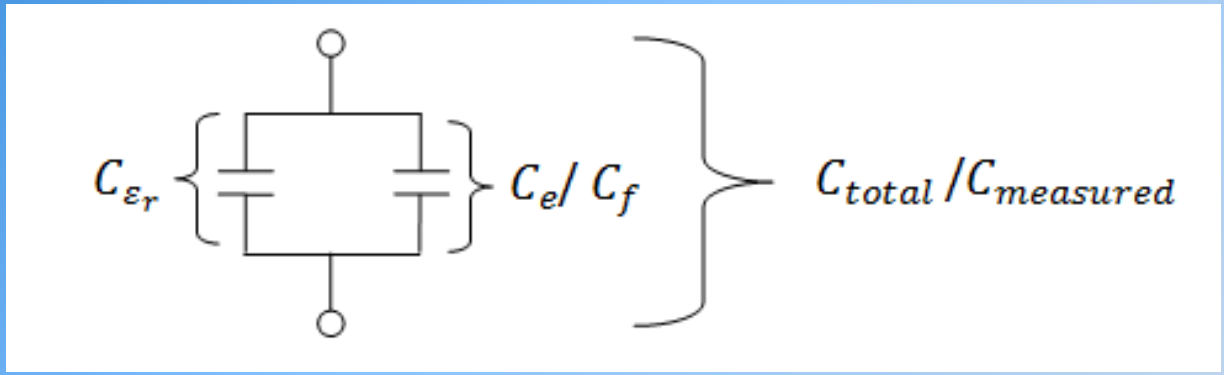




Formula for the determination of the parallel-plate substrate board`s capacitance C_{ε_r} :

$$C_{total/measured} = \underbrace{\frac{\varepsilon_r \varepsilon_o W \cdot L}{h}}_{C_{\varepsilon_r}} + 2C_{e1/f} + 2C_{e2/f}$$

Method I : Capacitance Measurement.



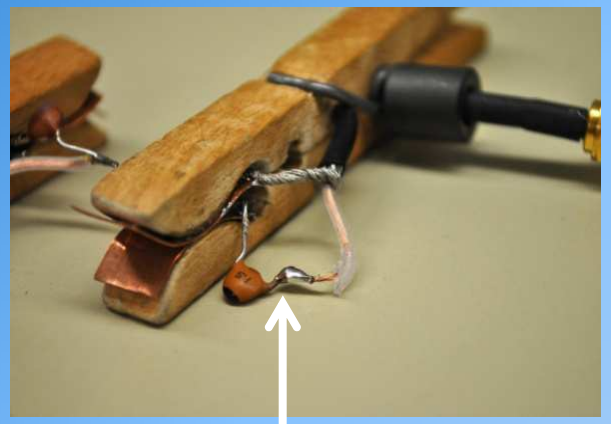
Determination of relative dielectric constant of the laminate panels (Inclusion of stray fields):

$$\varepsilon_r = \frac{C_{\varepsilon_r}.h}{\varepsilon_o.A}$$

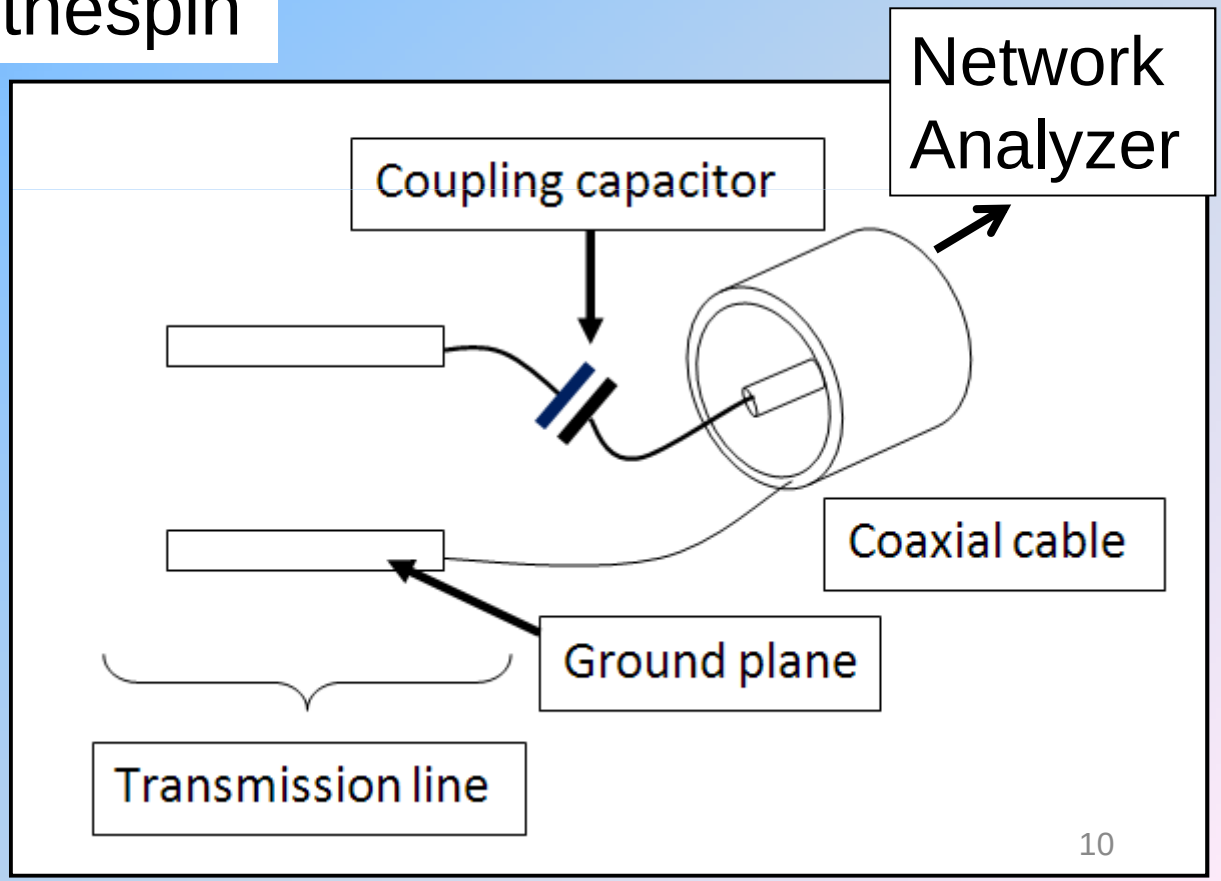
Method II : Full Sheet Resonance method.

- Connecting probes

Modified wooden clothespin

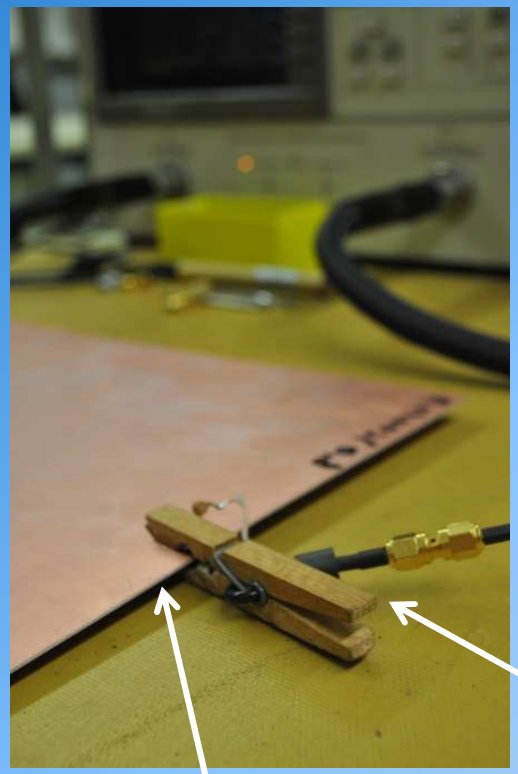


1.5pF capacitor



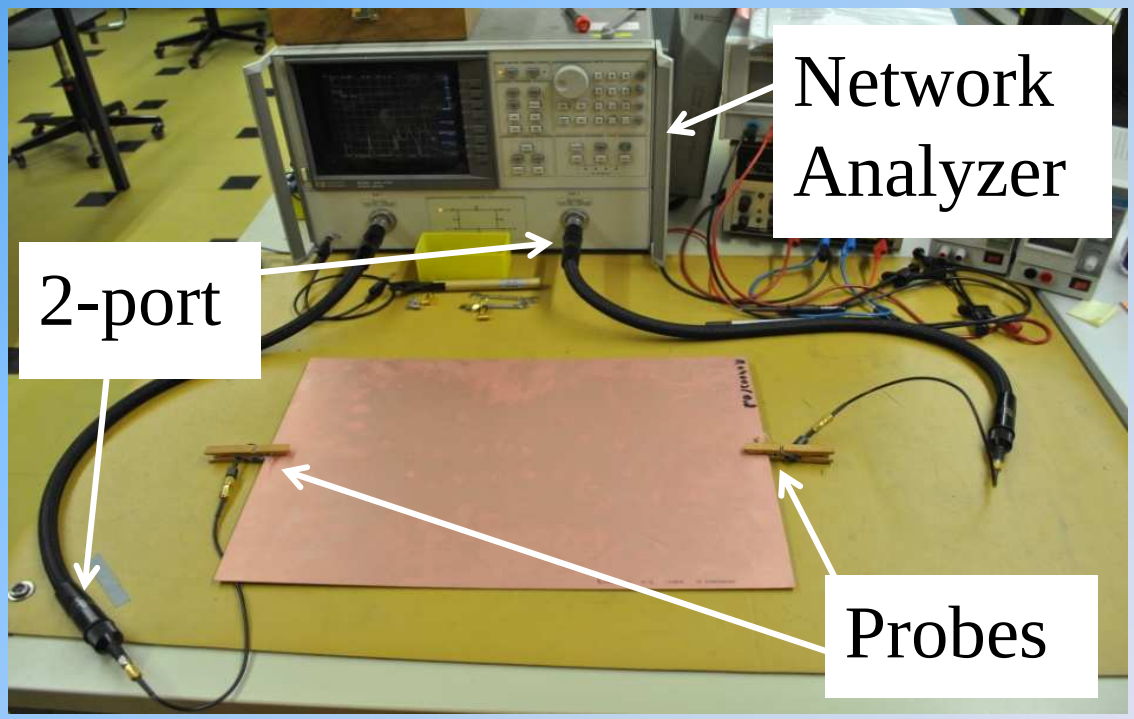
Method II : Full Sheet Resonance method.

- Setup



Substrate Board
(Test sample)

Probe



Connection of test sample of Substrate board to the network analyzer.

Method II : Full Sheet Resonance method.

- Determination of relative dielectric constant the substrate boards:

$$\varepsilon_r = \frac{{C_o}^2}{4{f_{mn}}^2} \cdot \left\{ \left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right\}$$

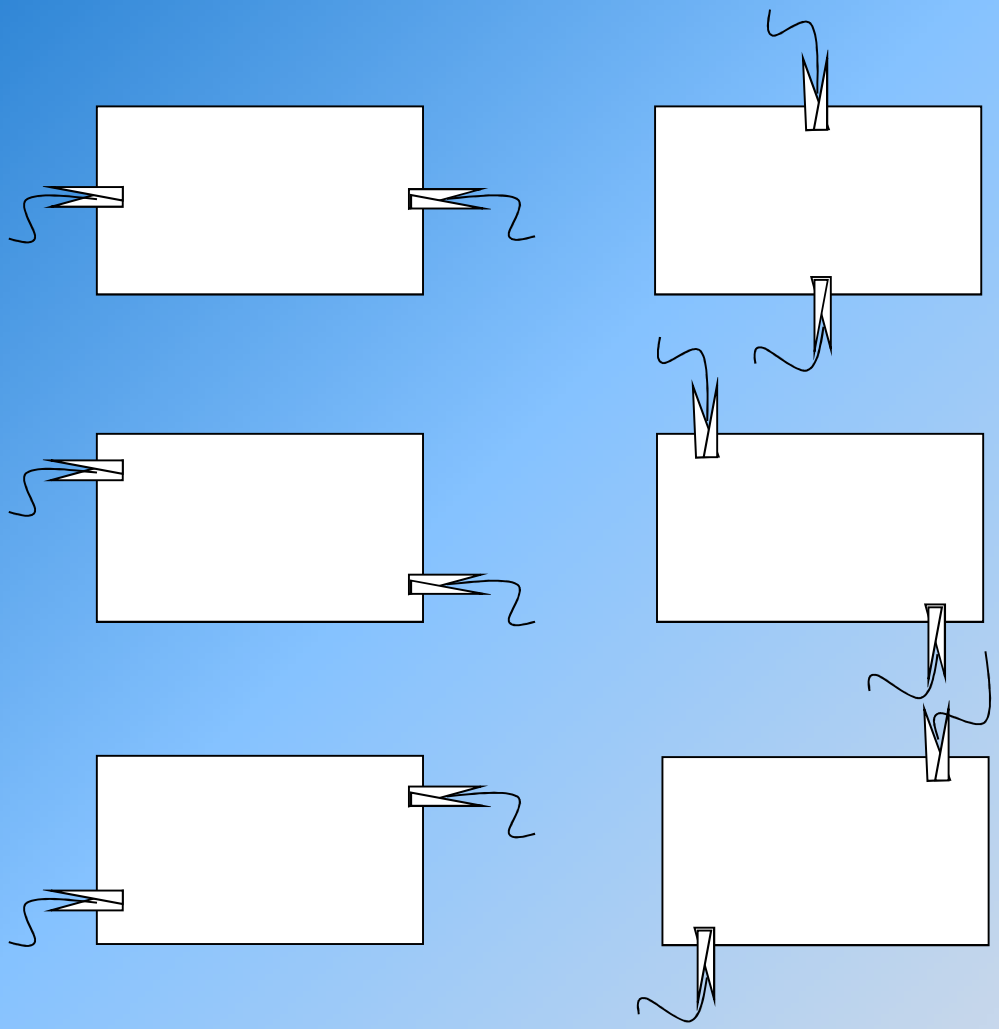
C_o : Speed of light. ($2.9979 \times 10^8 ms^{-1}$)

fmn : Resonance frequency.

(m,n) : Corresponding resonance mode.

W : Width of the conducting.

L : Length of the microstrip line.



- This method has to be carried out in few directions for the resonance frequencies measurement and the matching of resonance modes of *m* along the length and *n* along the width.

Method II : Full Sheet Resonance method.

- **Example results of RO4350 test sample**:
- Measured dimensions:

-Length : 457.83 mm

-Width : 305.33 mm

- Modified dimensions with inclusion of stray fields by end-effect length(Dimensions have been enlarged):

-Length : 460.162 mm

-Width : 307.788 mm

Method II : Full Sheet Resonance method.

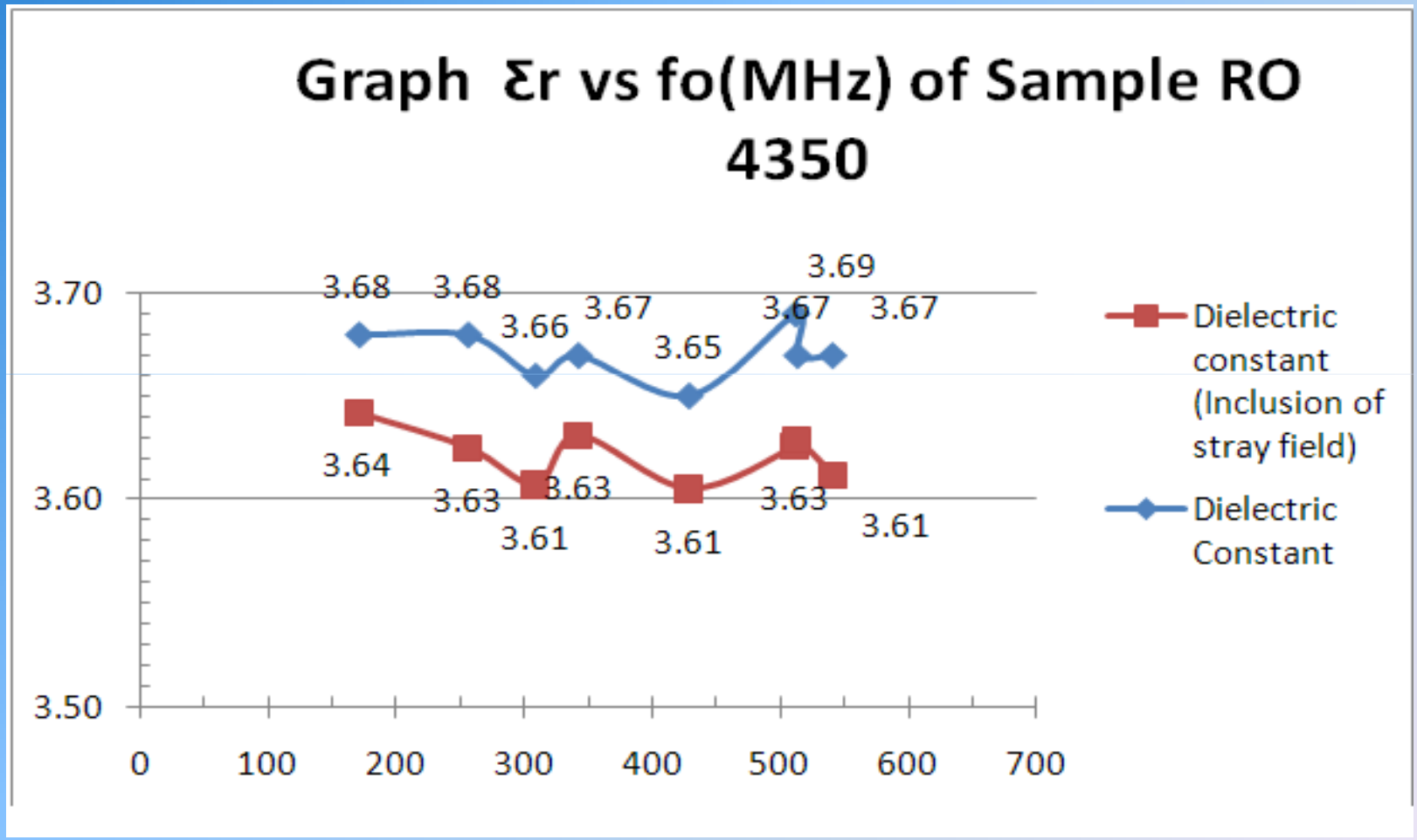
- **Example results of RO4350 test sample**:

Peaks	f_o(MHz)	modes	Dielectric Constant, ε_r	Dielectric Constant, ε_r (Inclusion of stray field)
1	170.7	(1,0)	3.68	3.64
2	255.8	(0,1)	3.68	3.63
3	308.5	(1,1)	3.66	3.61
4	341.9	(2,0)	3.67	3.63
5	428.4	(2,1)	3.65	3.61
6	511.5	(0,2)	3.69	3.63
7	513.0	(3,0)	3.67	3.63
8	540.4	(1,2)	3.67	3.61
		Average	**3.67**	**3.62**

- Manufacturer's results for RO4350:

  3.48±0.05

Method II : Full Sheet Resonance method.



Graph of ε_r versus f_o (MHz) of Sample RO4350

Method III : An Evaluation through a simple Microstrip Transmission Line Resonator.

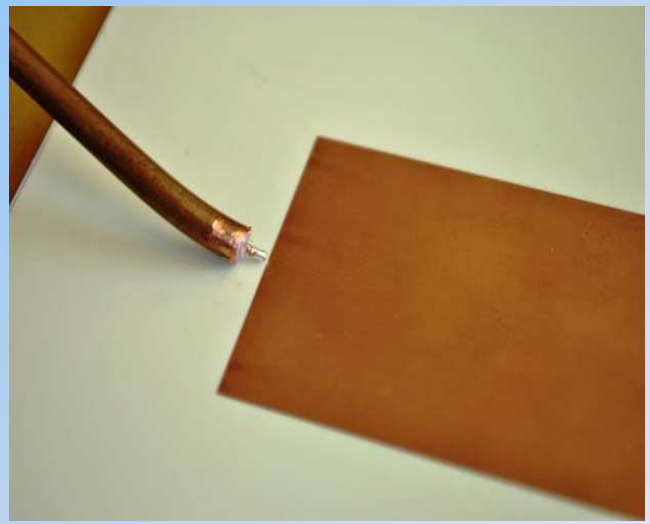
- A piece of substrate has been cut out and treated as a simple microstrip transmission line and open-ended transmission line resonator.

- The measured resonance frequency through S21measurement will be used to tune the corresponding dielectric constant of the substrate in a simulation (ADS).

Method III : An Evaluation through a simple Microstrip Transmission Line Resonator.

- A simple Microstrip Transmission Line Resonator has been designed with aid of a simulation(ADS).
- Fabrication of the resonator. (Sample RO4350)
- S21 measurement has been carry out on the resonator.
- Measured resonance frequency will be used to tune the dielectric constant.

Method III : An Evaluation through a simple Microstrip Transmission Line Resonator.

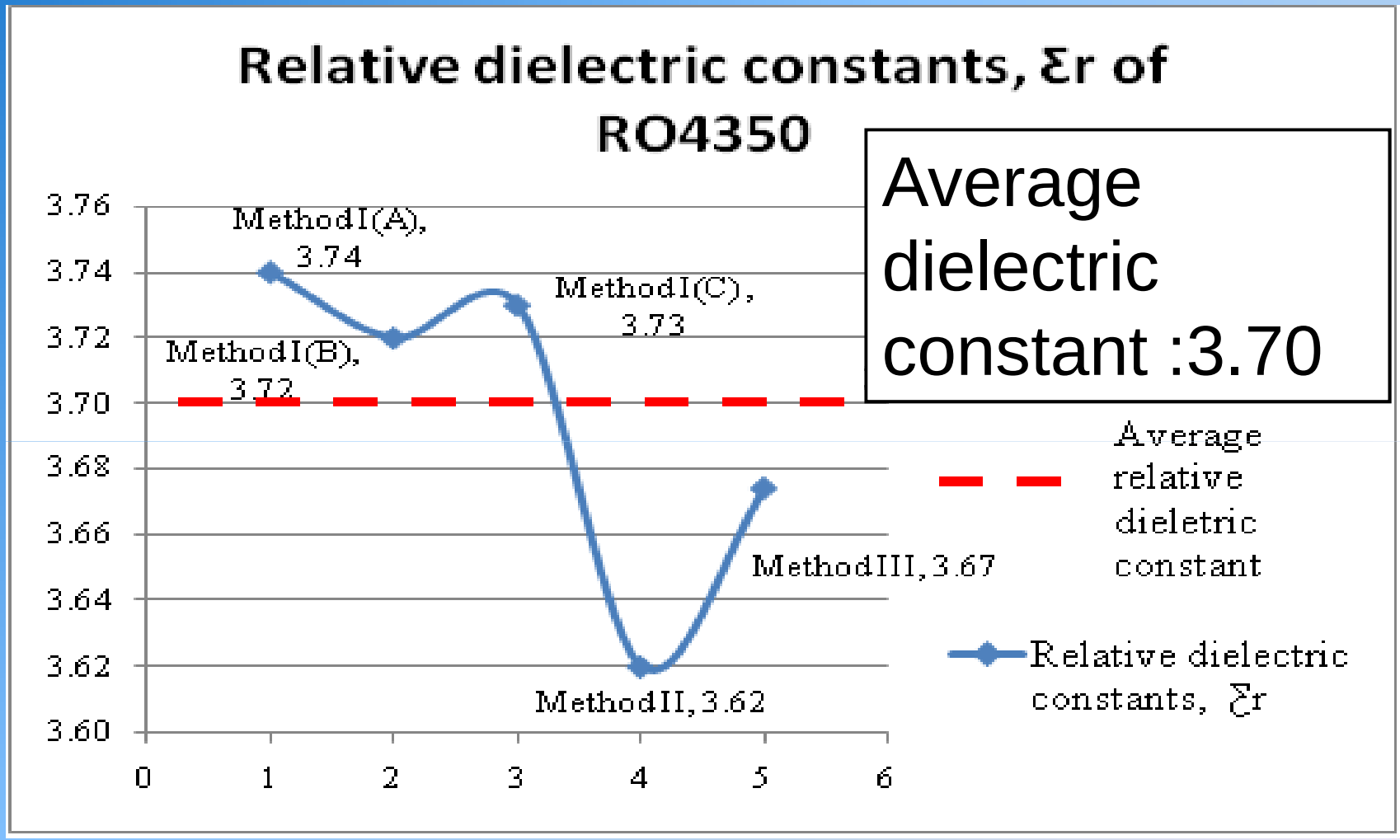


By bring near the probe to the strip line without touching it as creating a capacitive coupling to the measurement.

Method III : An Evaluation through a simple Microstrip Transmission Line Resonator.

- The 1st peak of resonance frequency has been measured and recorded down. It's **251.7MHz** of resonance frequency.
- It's **3.674** of the relative dielectric constant of the substrate (RO4350).
- Manufacturer's results for RO4350: **3.48±0.05**.

Total results of all three methods



Graph results of relative dielectric constant for sample RO4350

All results and comparison

- **Test sample RO4350:**
- Average dielectric constant of three methods : **3.70**
- Manufacturer’s dielectric costant: **3.48±0.05**
- Recommended for use in circuit design:
- **3.66** (from datasheet)

Conclusion

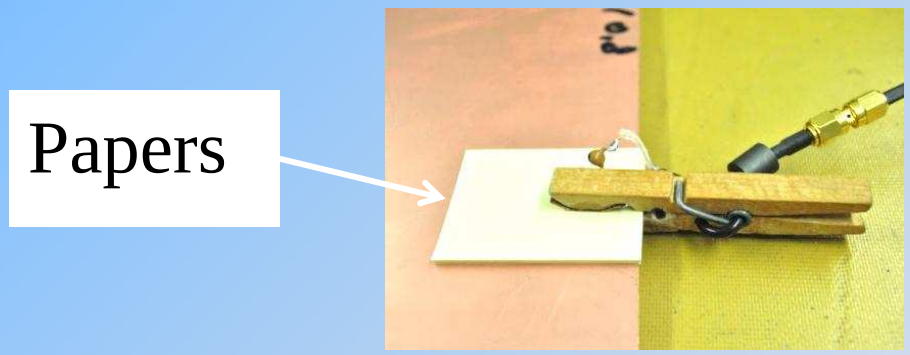
- Average relative dielectric constant of substrate boards show an improvement result with inclusion of stray electric field through these measurement techniques compared to manufacturer’s results.
- It’s suggested to include the effect in the determination methods of relative dielectric constant .

Thank You for Your attention!

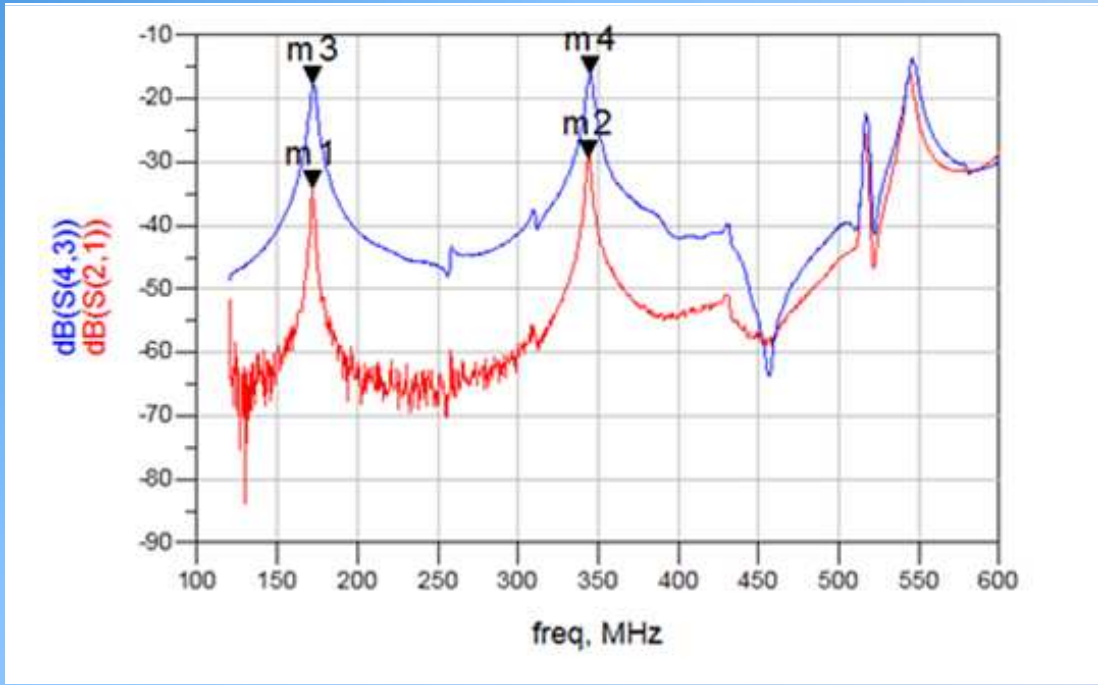
Extra Slides

Method II : Full Sheet Resonance method.

- Capacitive coupling :
- Capacitive coupling is needed to obtain more precise results of resonance frequencies measurement.
- The of resonance frequencies will be shifted at above magnitude of -20dB.



- Resonance frequencies of high capacitive coupling have been shifted for few kHz compared to low capacitive coupling.
- Hence, Some papers have been added to reduce the capacitive coupling, in order to get more precise result of resonance frequencies.



Example:
m1
Freq= 171.6MHz
dB(S(2,1))= -34.033

m3
Freq= 172.2MHz
dB(S(2,1))= -34.033

It is shifted few kHz of resonance frequency.

Capacitive coupling :

1st peak (MHz)	dB(S(2,1))	2st peak (MHz)	dB(S(2,1))	3rd peak (MHz)	dB(S(2,1))	C1(pF)
174,22	-84,06	348,39	-53,83	522,51	-42,09	0,01
174,22	-72,96	348,39	-40,47	522,51	-45,30	0,02
174,22	-59,38	348,39	-42,04	522,51	-40,22	0,05
174,21	-47,82	348,38	-36,29	522,50	-17,33	0,10
174,21	-24,01	348,38	-16,38	522,49	-8,49	0,20
174,20	-11,08	348,36	-1,16	522,46	-2,02	0,50
174,19	-8,71	348,33	-0,47	522,42	-0,15	1,00
174,15	-1,36	348,27	-0,01	522,34	-0,01	2,00
174,12	-0,28	348,22	-0,01	522,28	0,00	3,00

Limitation of capacitive coupling for the corresponding resonance frequencies.

Total results of all three methods

- **Test sample RO4350:**

RO4350	
Test methods	Relative dielectric constant, ε_r
Method I(A)	3,74
Method I(B)	3,72
Method I(C)	3,73
Method II	3,62
Method III	3,67
Average	3,70