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PCB DK and DF Extraction based on the Wheeler Incremental Inductance Method

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Abstract: DK and DF of the substrate have an important effect on the impedance matching of RF circuits, and they may change under the influence of high temperature during the PCB fabrication. Therefore, the DK DF extraction method for a fabrication finished PCB not a raw dielectric substrate is very important. Based on a pair of striplines, the proposed algorithm can extract the DF and DF values of a fabrication finished PCB substrate. It is named as an **on-stripline** extraction method. The proposed method is based on the derived differential mode and common mode attenuation constants of the stripline. The ration of them can eliminate the conductor roughness effect. The Diordjevic Dielectric model is used to represent a dispersive substrate in a broad frequency band. The advantages of the proposed method are: on-stripline, broadband, dispersive and eliminating the effect of the conductor roughness.

Introduction

- Accurate DK DF knowledge can avoid signal integrity and power integrity problems.

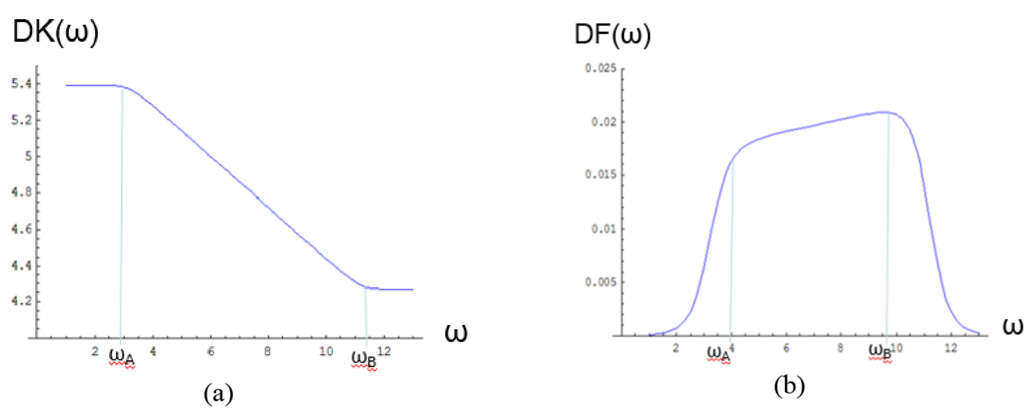


Fig. 1. (a) DK and (b) DF change with frequency changing.

- Many substrates are dispersive.

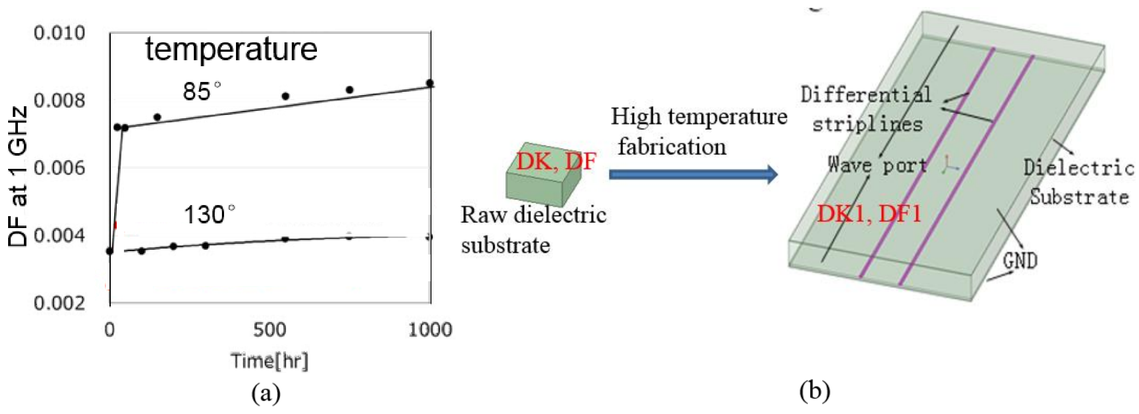


Fig. 2. (a) DF change with temperature changing, (b) DK, DF of raw substrate may be different from those of PCB substrate during high temperature fabrication.

- DK and DF of PCB substrate are different from those of raw dielectric substrate after PCB high temperature fabrication.

Proposed Method

Flow chart

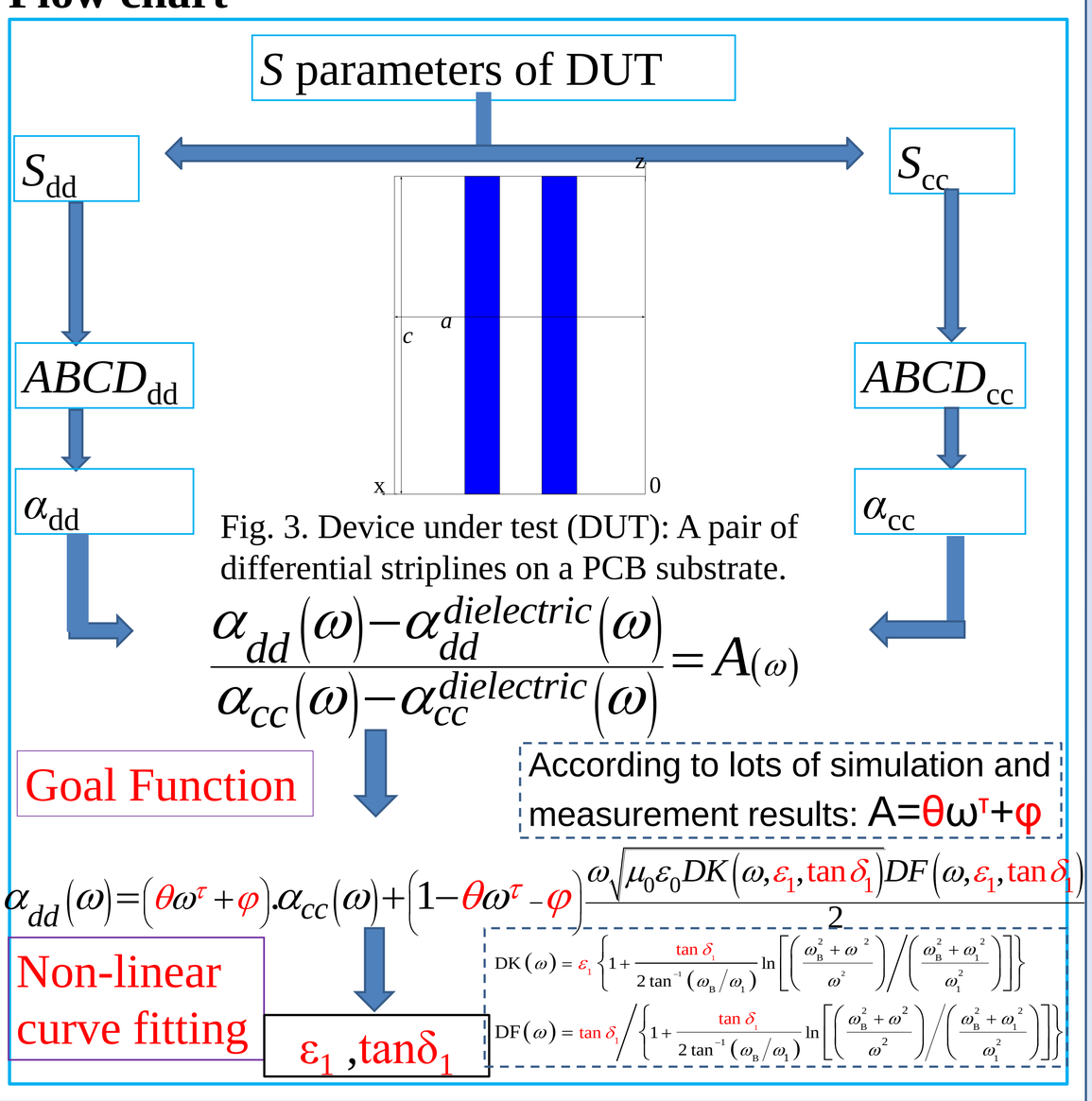


Fig. 3. Device under test (DUT): A pair of differential striplines on a PCB substrate.

$$\frac{\alpha_{dd}(\omega)-\alpha_{dd}^{dielectric}(\omega)}{\alpha_{cc}(\omega)-\alpha_{cc}^{dielectric}(\omega)}=A_{(\omega)}$$

Goal Function

According to lots of simulation and measurement results: $A=\theta\omega^{\tau}+\varphi$

$$\alpha_{dd}(\omega)=(\theta\omega^{\tau}+\varphi)\cdot\alpha_{cc}(\omega)+\left(1-\theta\omega^{\tau}-\varphi\right)\frac{\omega\sqrt{\mu_0\varepsilon_0 DK(\omega,\varepsilon_1,\tan\delta_1)}DF(\omega,\varepsilon_1,\tan\delta_1)}{2}$$

Non-linear curve fitting → ε_1, $\tan\delta_1$

$$DK(\omega)=\varepsilon_1\left\{1+\frac{\tan\delta_1}{2\tan^{-1}(\omega_B/\omega_1)}\ln\left[\left(\frac{\omega_B^2+\omega^2}{\omega^2}\right)\Big/\left(\frac{\omega_B^2+\omega_1^2}{\omega_1^2}\right)\right]\right\}$$

$$DF(\omega)=\tan\delta_1\Big/\left\{1+\frac{\tan\delta_1}{2\tan^{-1}(\omega_B/\omega_1)}\ln\left[\left(\frac{\omega_B^2+\omega^2}{\omega^2}\right)\Big/\left(\frac{\omega_B^2+\omega_1^2}{\omega_1^2}\right)\right]\right\}$$

Proposed method details

$$\alpha_{dd,cc}=\alpha_{dd,cc}^{dielectric}+\alpha_{dd,cc}^{conductor} \quad (1)$$

- For attenuation constant from lossy dielectric substrates:

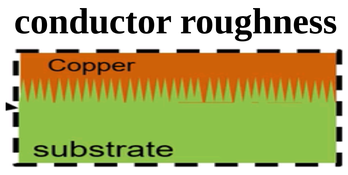
$$\alpha_{dd,cc}^{dielectric}=\mathrm{real}\left(\gamma_{dd,cc}^{dielectric}\right)=real\left(j\omega\sqrt{\mu_0\varepsilon}\right)=\sqrt{-\omega^2\mu_0\varepsilon_0 DK(\omega)(1-jDF(\omega))} \quad (2)$$

- For attenuation constant from conductor striplines:

Wheeler Incremental Inductance method:

Lossy conductor contributes an $\triangle L$:

Huray factor (HF): conductor roughness



$$P_l=\int_c\left|\bar{H}_t\right|^2 dl\Big/2\sigma\delta_s=\left|I\right|^2\omega\Delta L/2,\quad P_{total}=\left|\bar{I}\right|^2 Z_0/2 \quad (3)$$

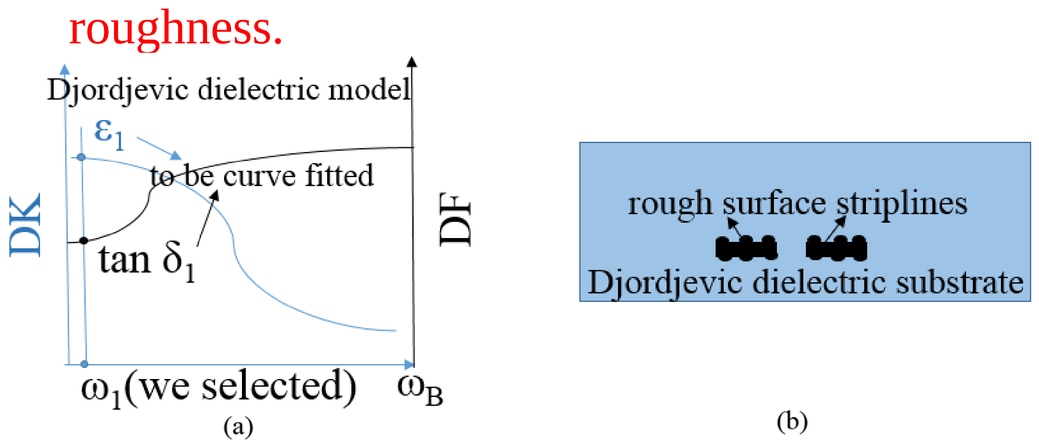
$$\alpha_{dd,cc}^{conductor}=P_l/2P_{total}=\omega\Delta L_{dd,cc}/2Z_{0dd,cc} \quad (4)$$

$$\alpha_{dd}(\omega)=HF.\alpha_{dd,cc}^{conductor}+\alpha_{dd,cc}^{dielectric}=HF\cdot\omega\Delta L_{dd}/2Z_{0dd}+\omega\sqrt{\mu_0\varepsilon_0 DK(\omega)}DF(\omega)/2$$

$$\alpha_{cc}(\omega)=HF.\alpha_{dd,cc}^{conductor}+\alpha_{dd,cc}^{dielectric}=HF\cdot\omega\Delta L_{cc}/2Z_{0cc}+\omega\sqrt{\mu_0\varepsilon_0 DK(\omega)}DF(\omega)/2 \quad (5)$$

Novelty point

- $A(\omega)$ can eliminate the influence of the conductor roughness.

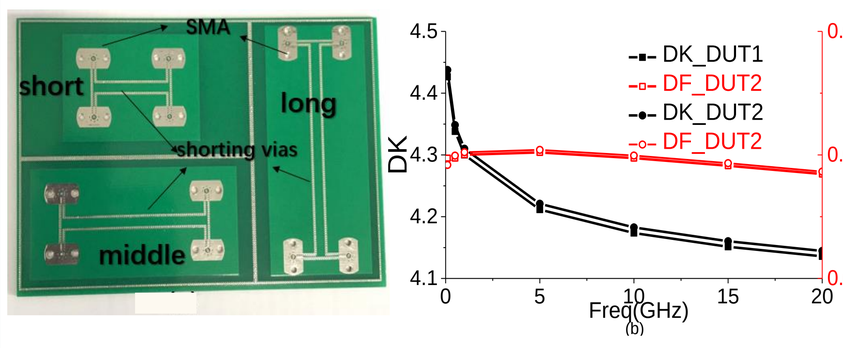


- Djordjevic Dielectric model use ε_1, $\tan\delta_1$ to represent DK, DF function of a dispersive substrate in a broad frequency band with only one measurement.
- In goal function, α_{dd} and α_{cc} are obtained, θ, τ, φ, ε_1, $\tan\delta_1$ are unknown to be curve fitted.
- The on-striplines method can extract DK and DF of a fabrication finished PCB not a raw dielectric substrate.

Simulation Results

Results show the proposed method can accurately extract DK and DF on rough conductor in a broad frequency band.

Measurement Results



DK, DF from two pairs of striplines are the same, because they are on one PCB substrate.