We3G—1

Resonance-Related Fluctuations on Experimental Characteristic Impedance Curves for PCB and On-Chip Transmission Lines

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Problem Statement:

- Fluctuations in transmission line measurements versus frequency curves have been observed, and generally, they have been modeled by a lumped admittance in each port.
- These fluctuations are associated with resonances originated by standing waves bouncing back and forth between the transitions at the transmission line terminations —probing platforms, pads.
- It is difficulty, if not impossible, to completely remove the parasitic effect of these transitions by de-embedding the measurements.

Problem Statement:

- Besides these resonances the additional transition from probing pads to the transmission line used to connect to the VNA introduces more reflections.
- This makes obtaining smooth and physically expected frequency-dependent curves a tough task, to say the least.
- Hence, these effects must be quantified and taken into account to correctly model the measured transmission line.

Contribution:

- We point out —for the first time to the best of our knowledge— that these fluctuations also occur in the transition itself.
- These are associated with resonances originated by standing waves bouncing back and forth in the transitions at the transmission line terminations.
- We herein propose a distributed model to consider the extra reflections satisfactorily.

Theoretical background:

- Accurate knowledge of the complex Z_c is necessary for TL characterization and some calibration routines.
- A measurement of a "pure" TL provides, once S parameter data is transformed to an ABCD matrix:

$$\mathbf{T}_h = \begin{bmatrix} \cosh(\gamma l) & Z_c \sinh(\gamma l) \\ \sinh(\gamma l)/Z_c & \cosh(\gamma l) \end{bmatrix}$$

- From which the characteristic impedance can be determined.

$$Z_c = \sqrt{\mathbf{T}_h\ [1,2]/\mathbf{T}_h\ [2,1]}$$

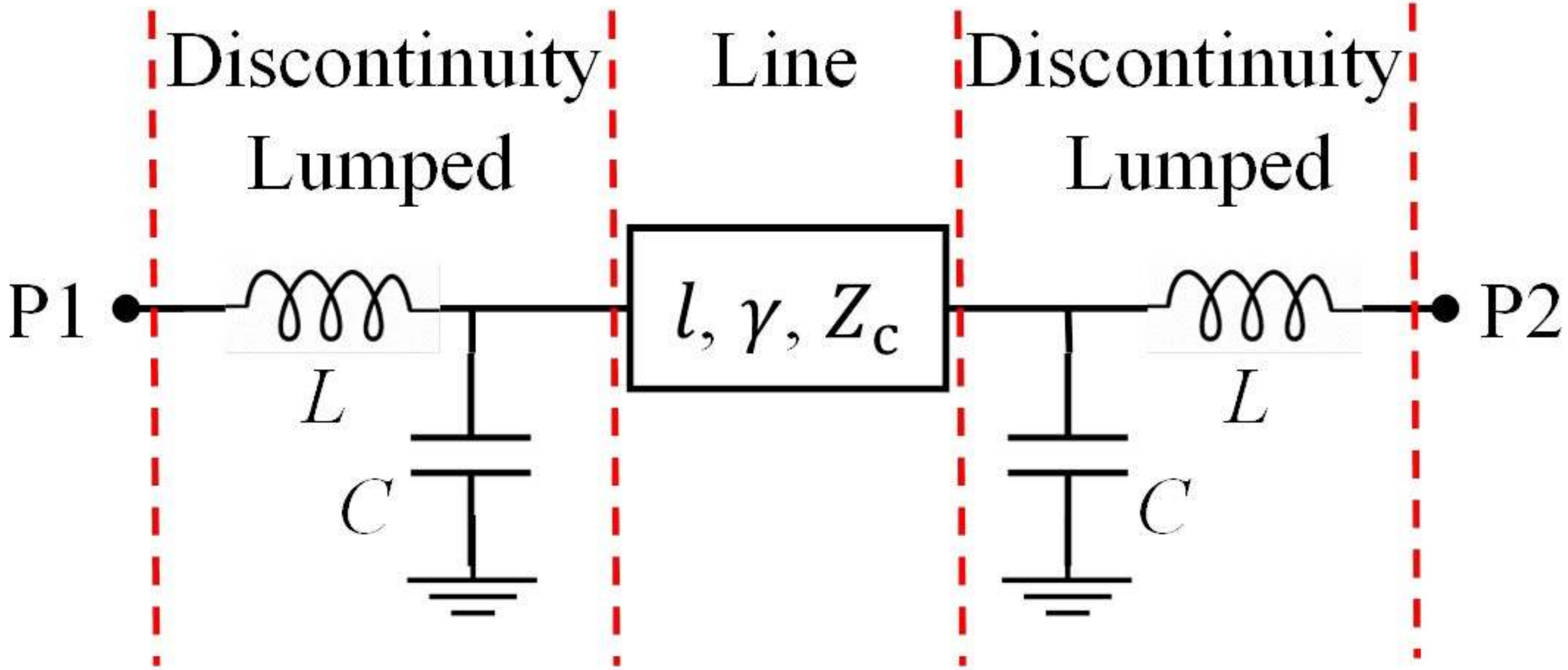
Theoretical background:

- But we cannot measure a “pure” transmission line, since the measurement necessarily involves probing pads or platforms. Thus the measurement becomes:

$$\mathbf{T}_{LhL} \approx \begin{bmatrix} 1 & j\omega L \\ j\omega C & 1 \end{bmatrix} \mathbf{T}_h \begin{bmatrix} 1 & j\omega L \\ j\omega C & 1 \end{bmatrix}$$

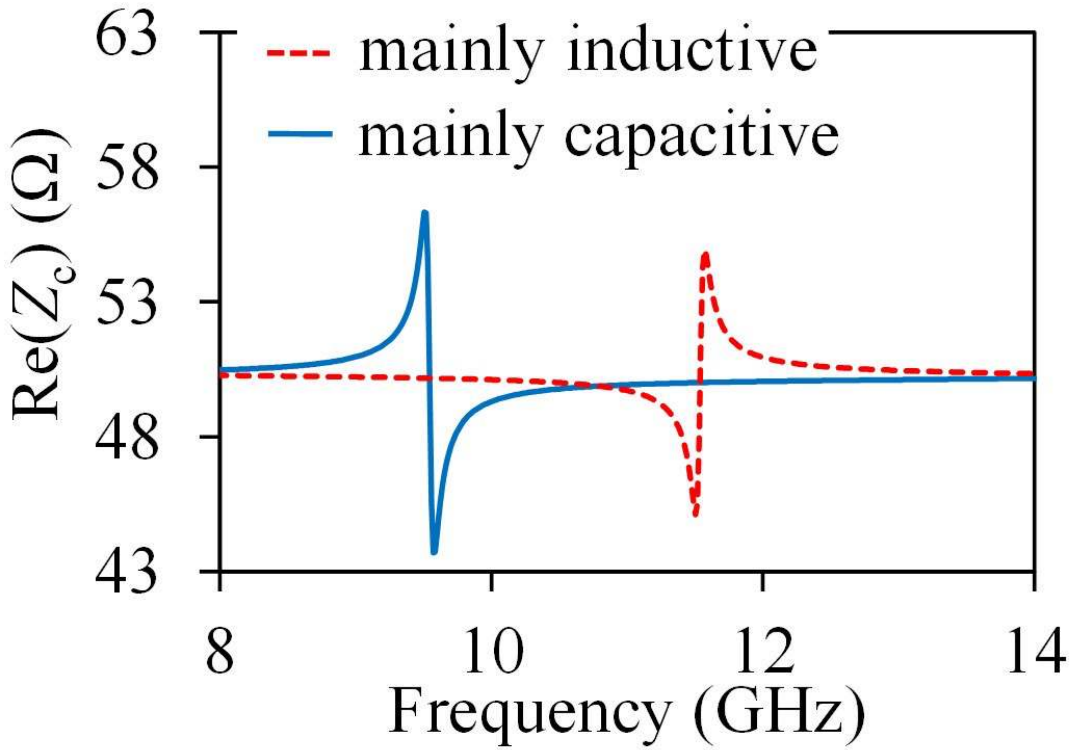
- Where the probing platforms are modeled by lumped admittances.

Traditional model:



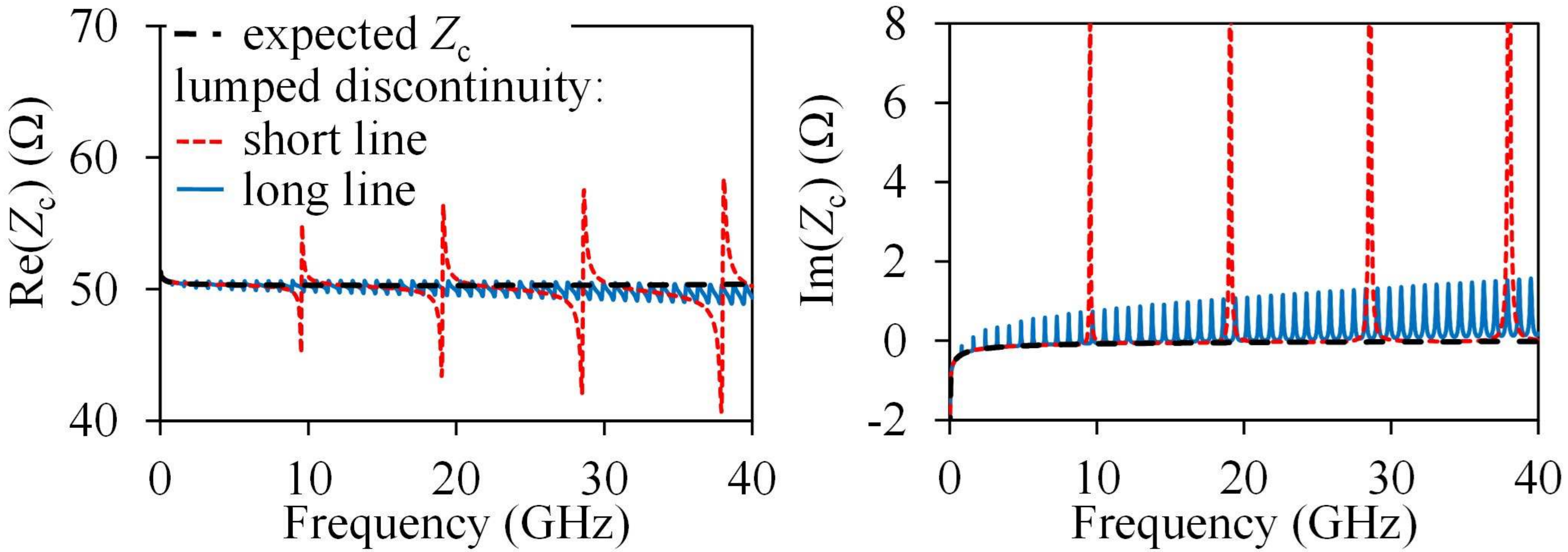
Theoretical background:

- Hence, $Z_c = \sqrt{\mathbf{T}_h\ [1,2]/\mathbf{T}_h\ [2,1]}$ does not yield the value of Z_c but curves that include glitches around a constant value for Z_c.



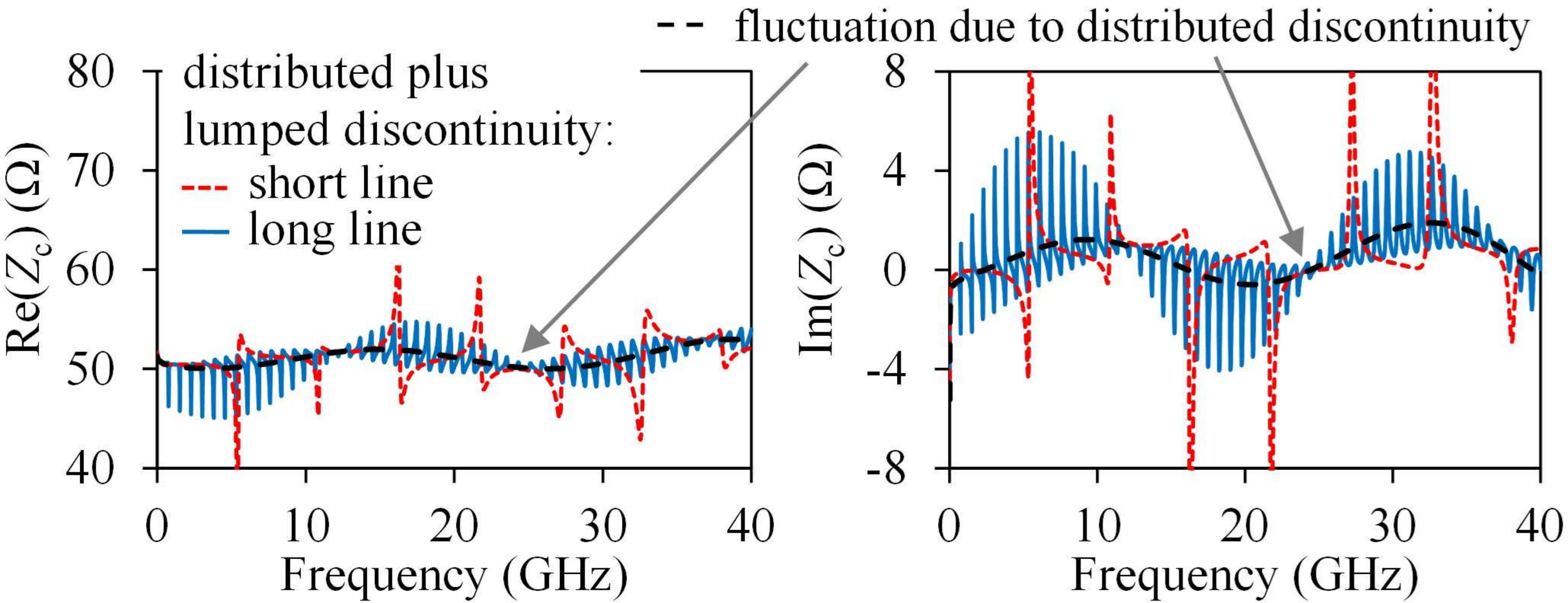
Theoretical background:

- The periodicity of the glitches depends on line length:



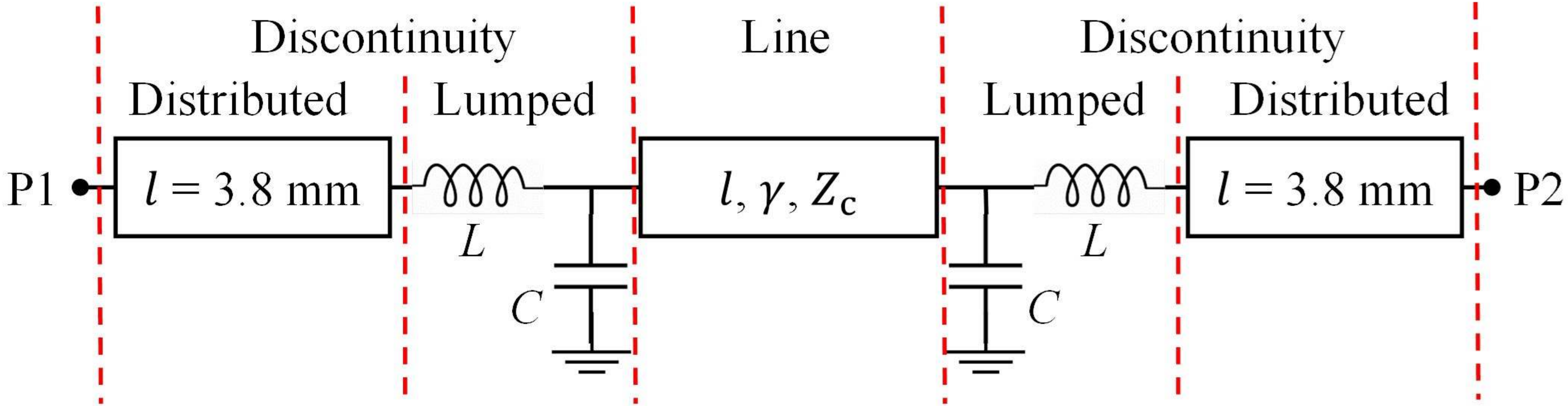
Experimental observations:

- We observed an additional fluctuation upon measuring TLs:



Experimental observations:

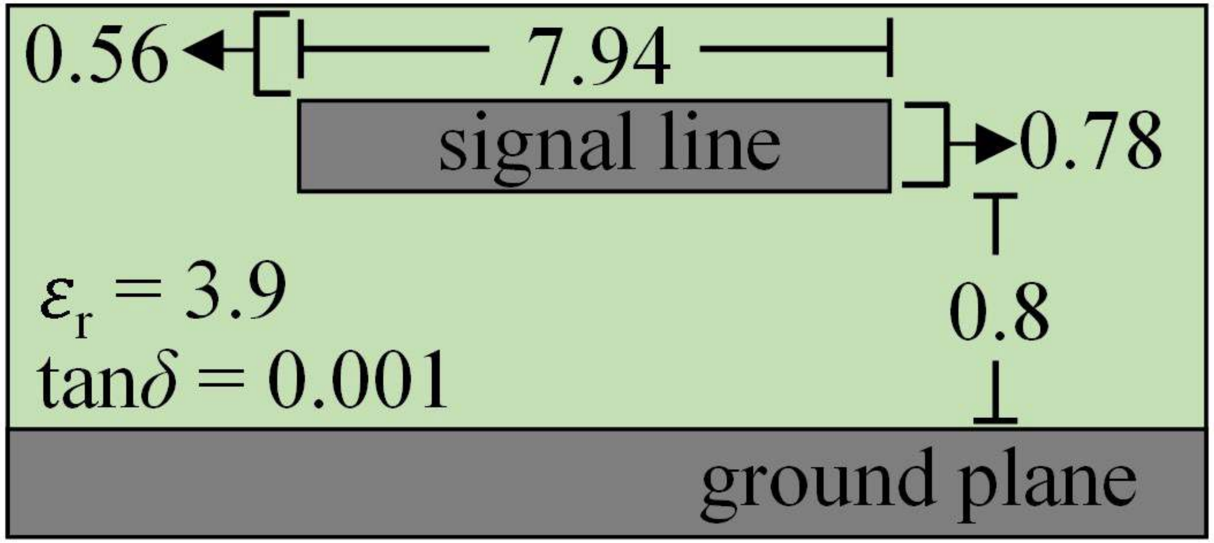
- These can be modeled with a distributed model to account for the connector:

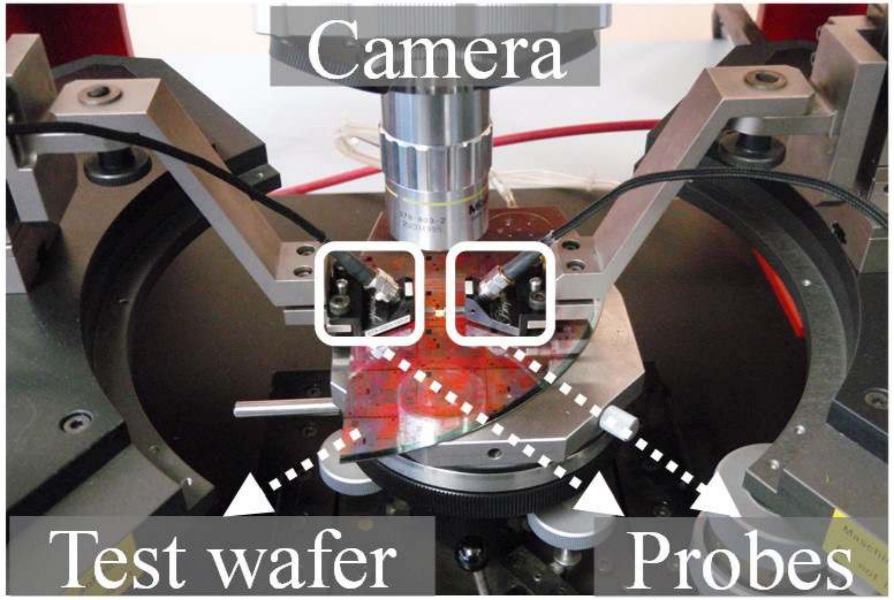


Experimental considerations:

- To prove the hypothesis, three different types of structures were built, measured and analyzed.
    - Lines on chip on a CMOS process, measured with probes.
    - Lines on PCB terminated with probe adapters.
    - Lines on PCB terminated with coaxial connectors.

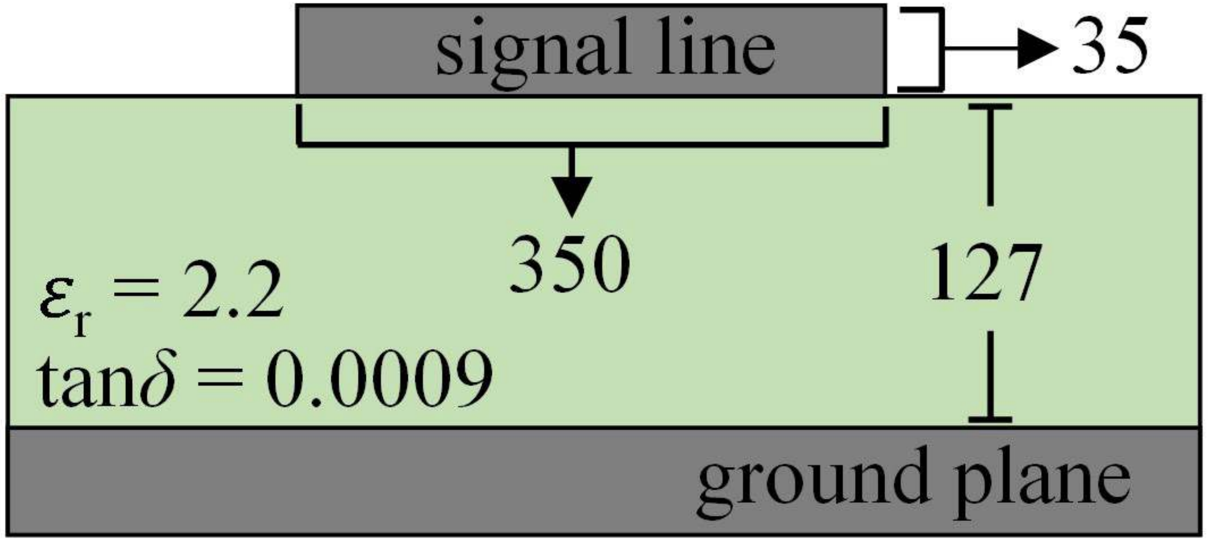
On-chip lines terminated with probe-pads

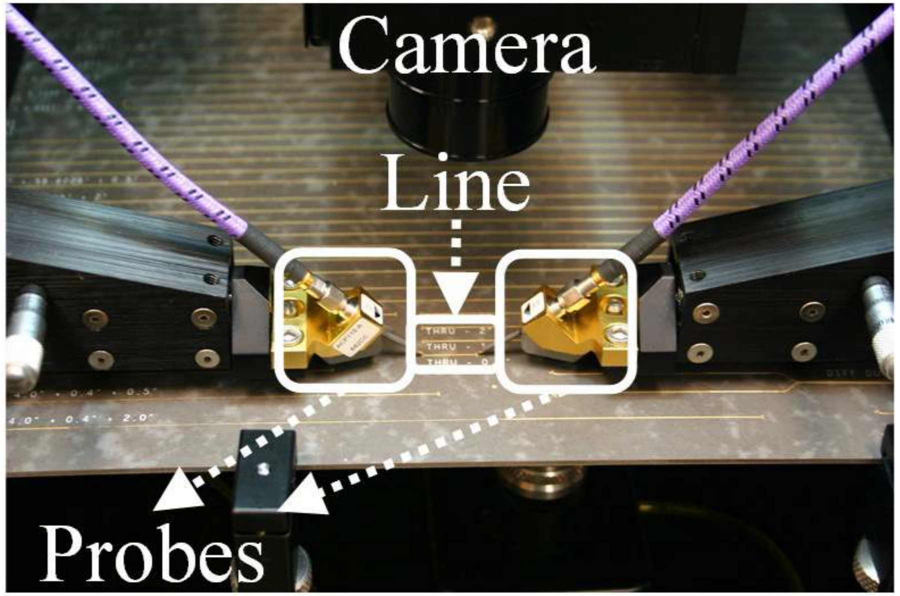




Lengths l=1,380μm; 2,450μm; 4,600μm.

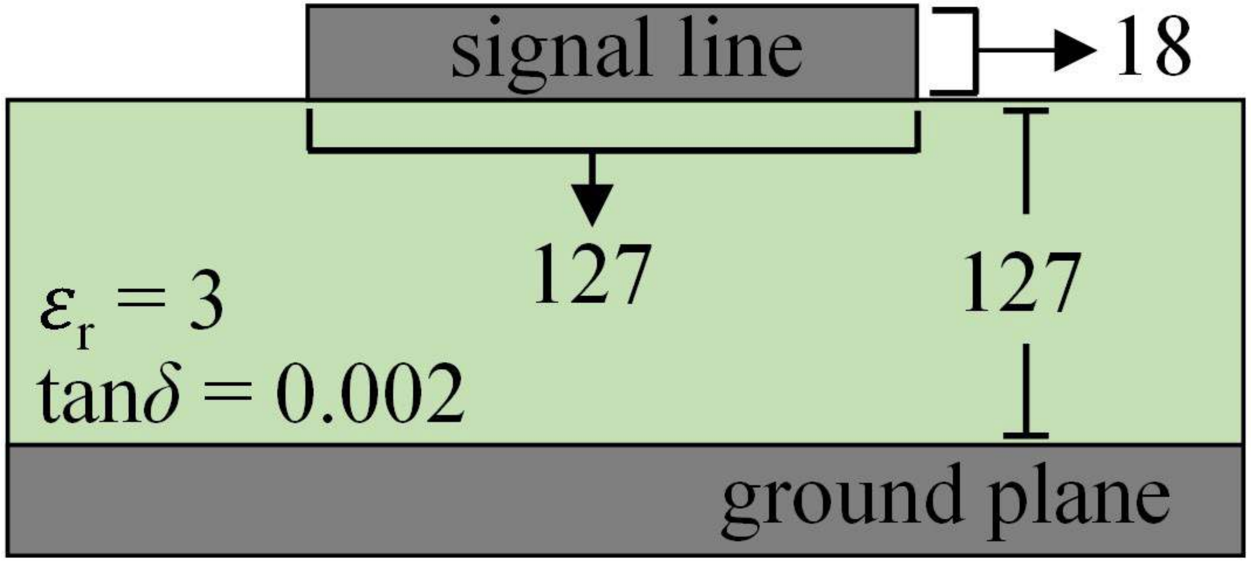
PCB lines terminated with probe-pads

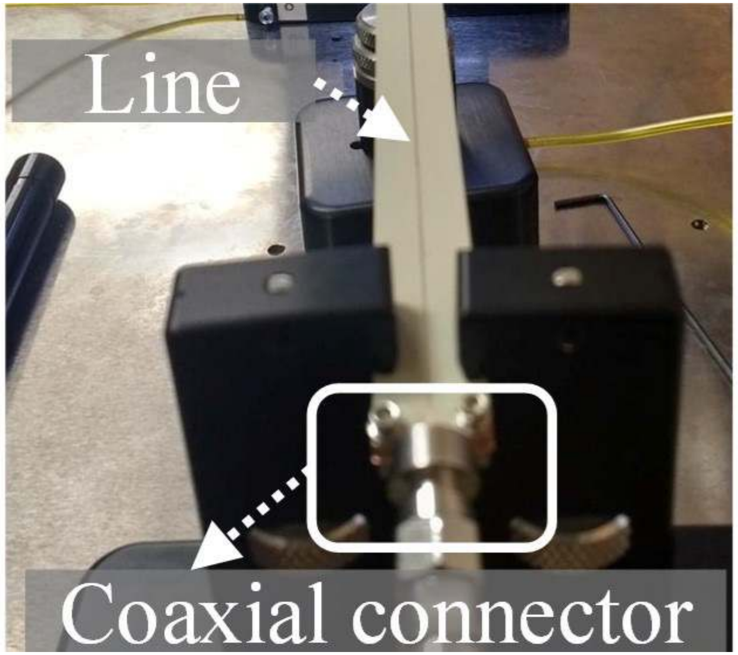




Lengths l=12.7mm; 101.6mm. $Z_c \approx 51\Omega$.

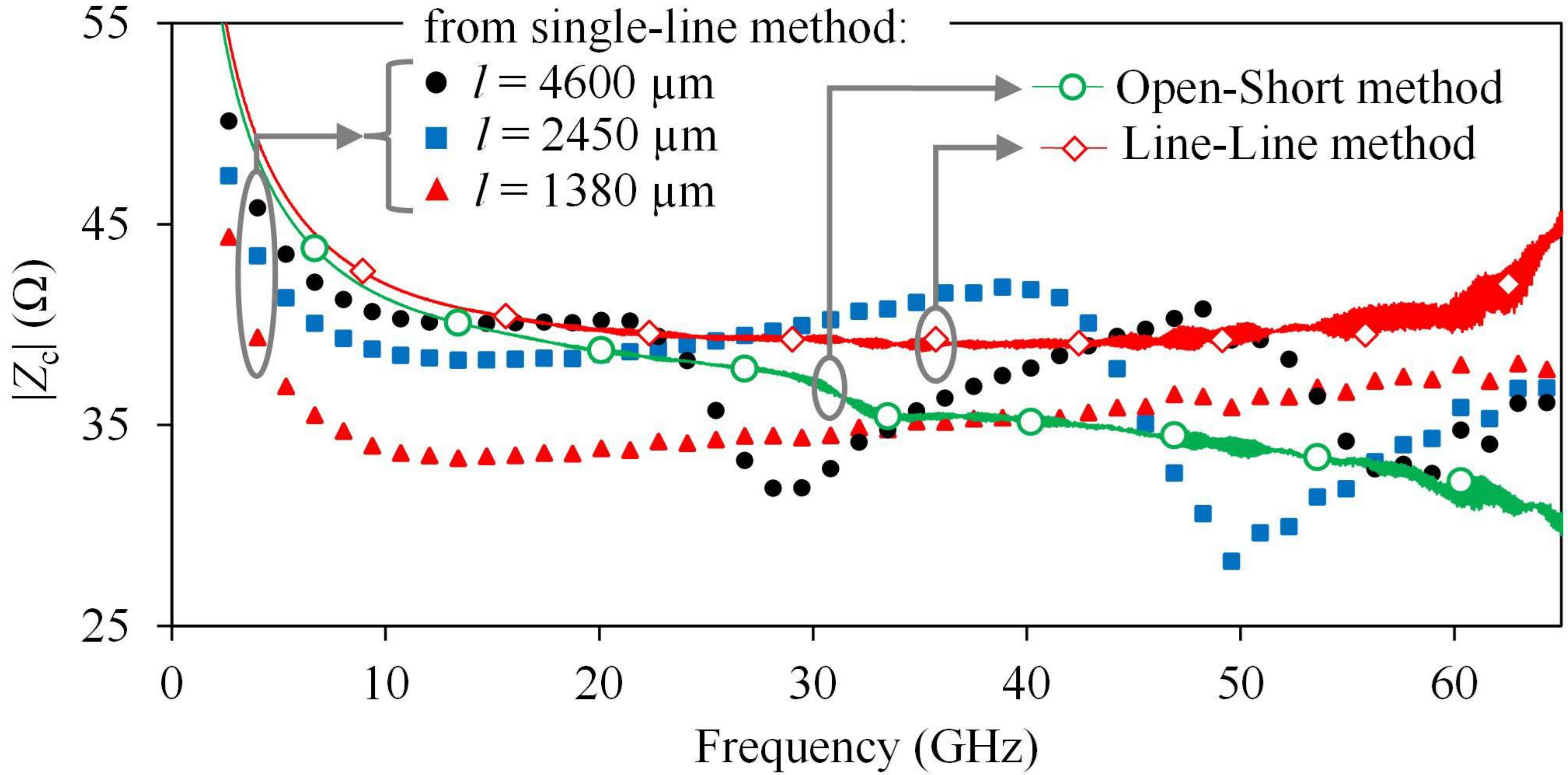
PCB lines terminated with coaxial connectors





Lengths l=25.4mm; 317.5mm. $Z_c \approx 72\Omega$.
40 GHz General Precision Connector, 2.92mm interface.

Results —On chip lines



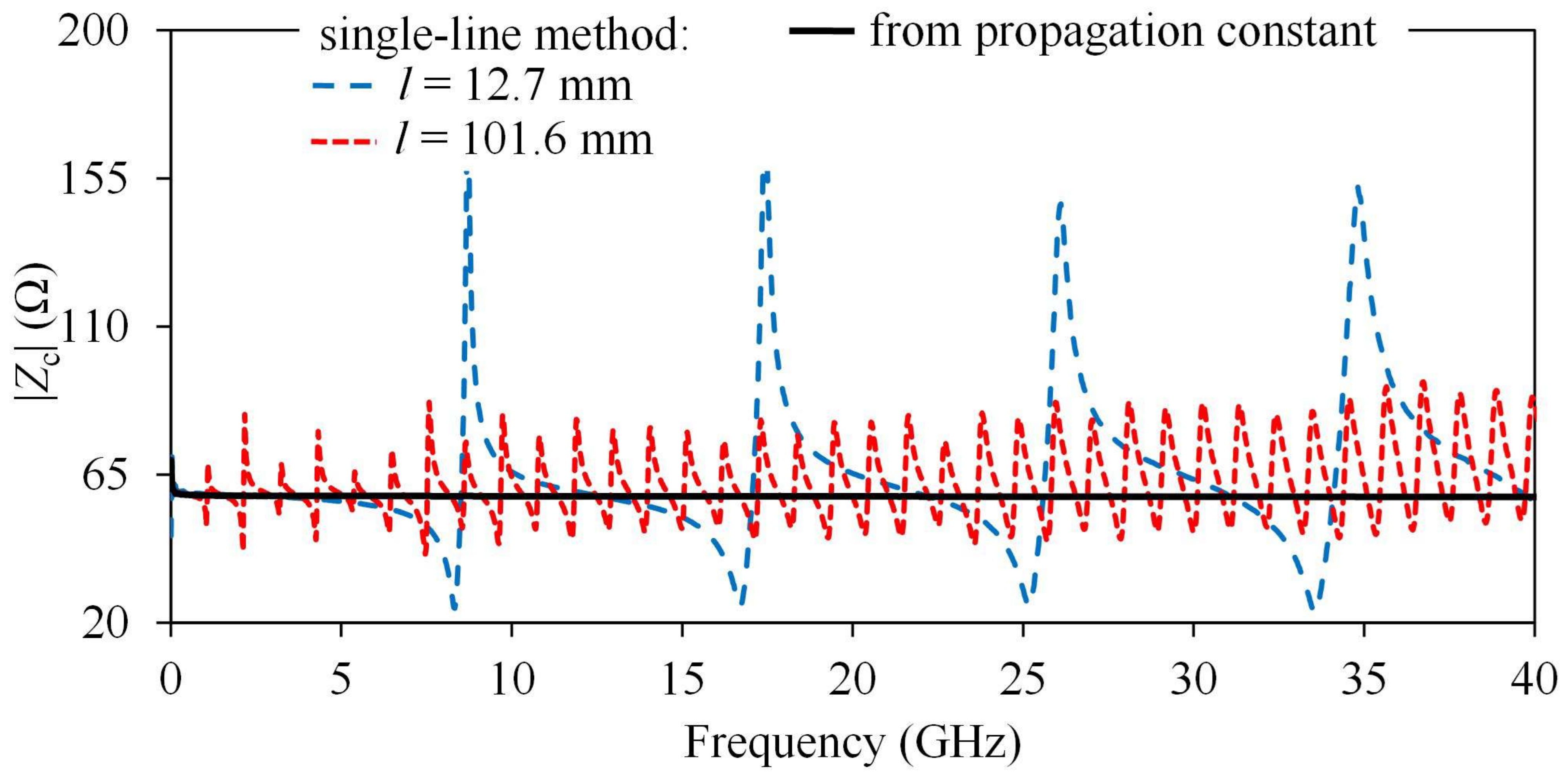
Analysis:

- The figure presents Z_c using $Z_c = \sqrt{\mathbf{T}_h[1,2]/\mathbf{T}_h[2,1]}$ for different line lengths.
- In addition to the fluctuations due to the transistions, Z_c exhibits large discrepancies depending on line length, which is unexpected.
- Using the open-short method, the fluctuations due to discontinuities are smoothed, but an unexpected Z_c roll-off is observed as frequency increases.

Analysis:

- The variation is attributed to the consideration that the open and short transitions between the pads and the line is abrupt.
- Using the line-line method, a quasi flat Z_c is achieved from 10 GHz to 50 GHz, whose value can be expected to be close to the expected one.
- The extraction method considers that the transition can be represented by means of a lumped shunt admittance.
- This assumption is valid provided the pad array is relatively small, true for on-chip interconects, not for PCB.

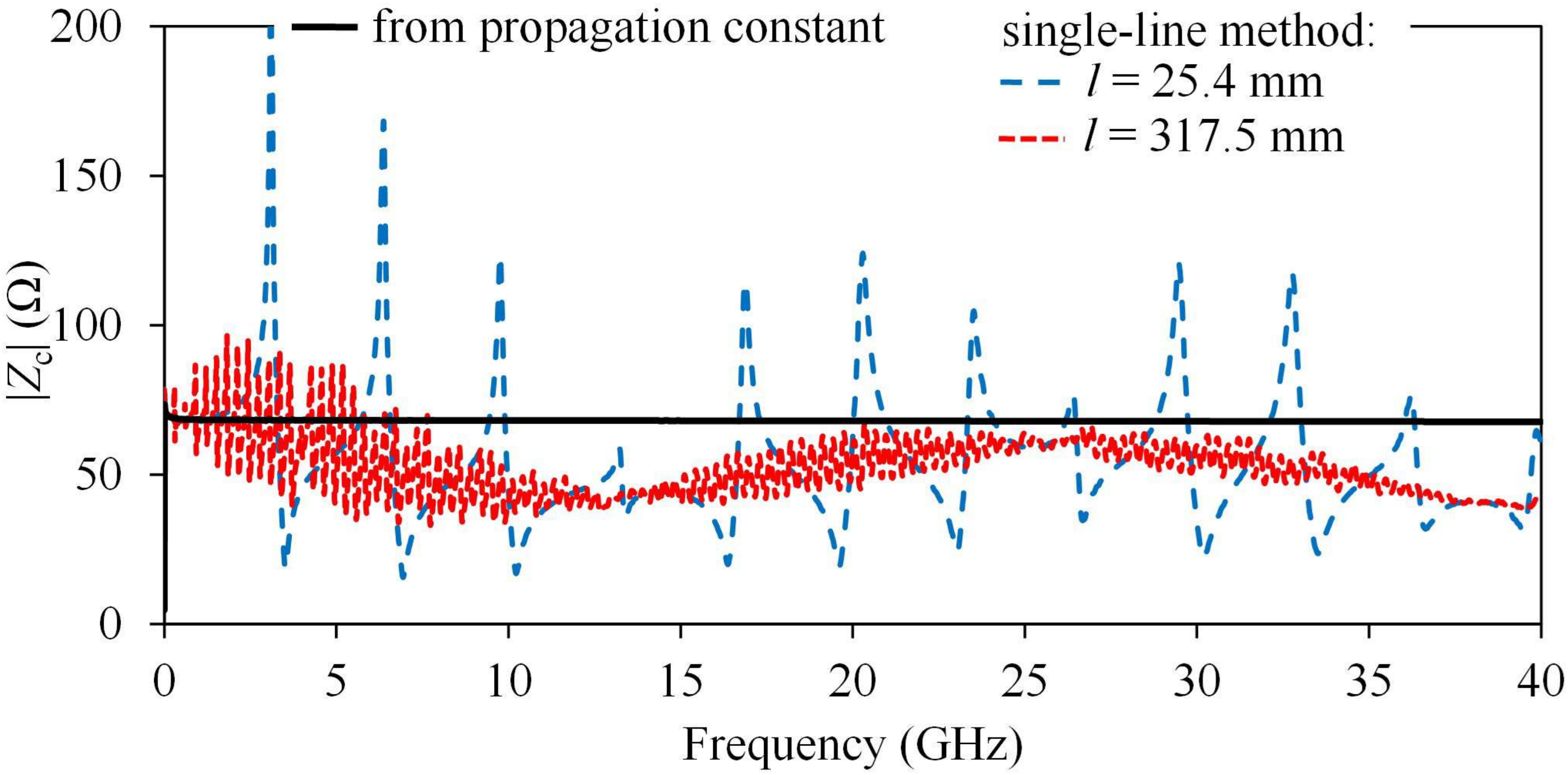
Results —PCB with probe pads



Analysis:

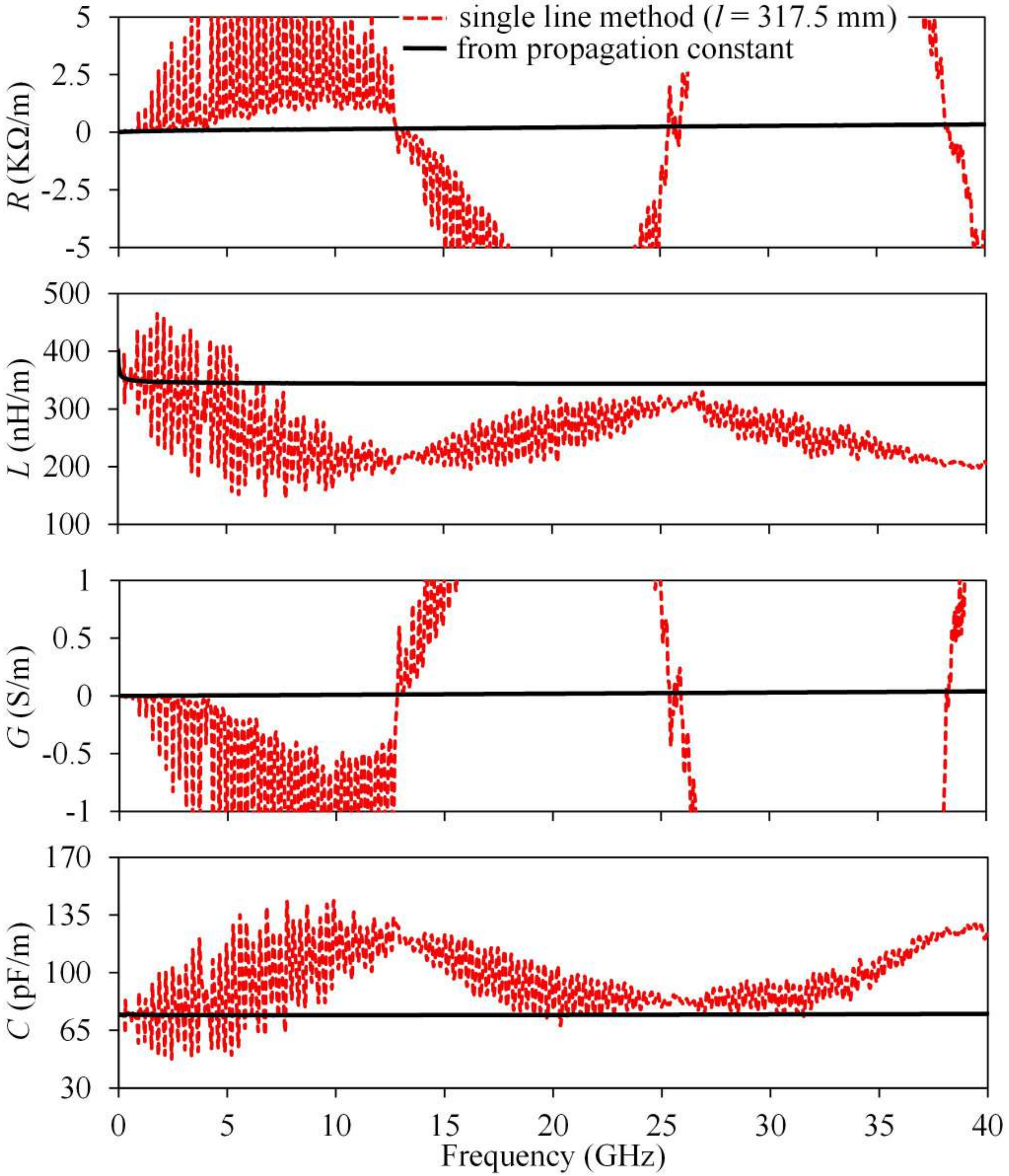
- On these lines, the resistance PUL is much smaller, but the associated length might be considerable, and a significant number of fluctuations may be observed within a few tenths of GHz.
- The reflections have a greater magnitude for the short line, but occur at a higher rate in the long one.
- Z_c obtained from γ is smooth, and can be a good approximation.
- Knowledge of frequency-dependent complex permittivity as well as loss tangent are necessary to apply the method.

Results —PCB with coaxial connectors

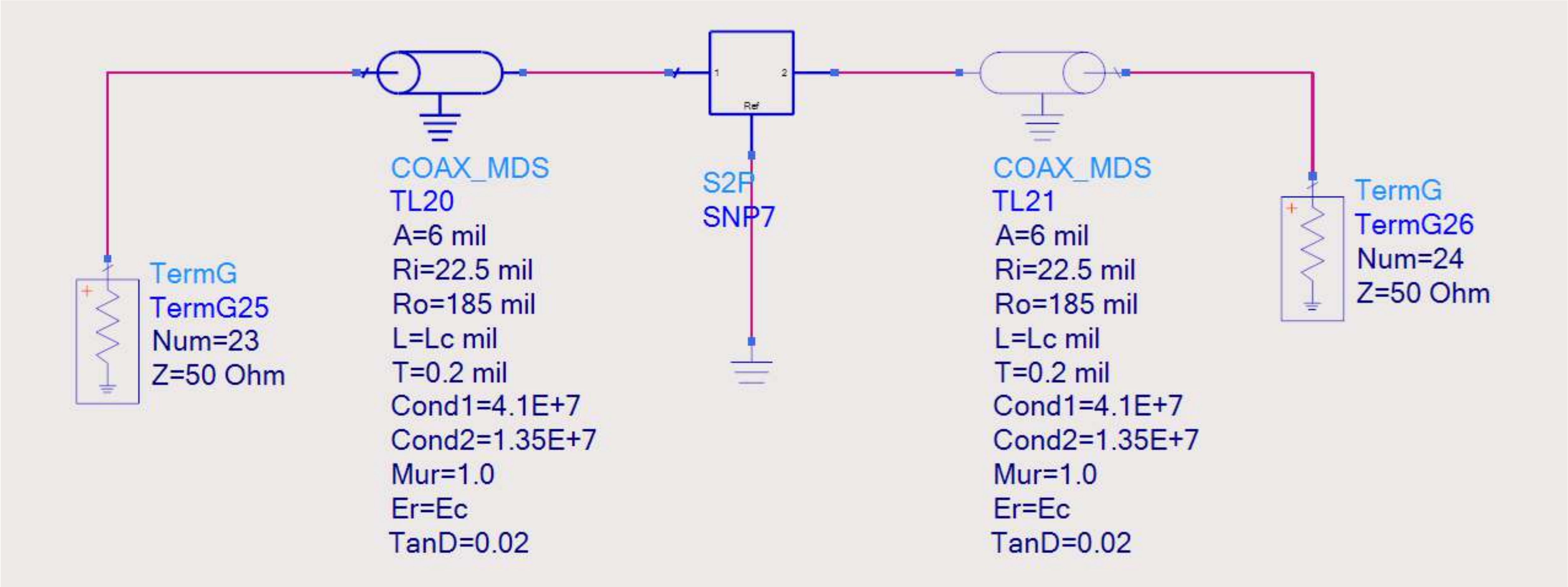


Analysis:

- These lines (connector terminated) exhibit an additional effect that considerably hinders the accurate determination of Z_c.
- Since the electrical length of the connector is large, fluctuations also appear at lower periodicities.
- To account for them, a distributed model for the connector is necessary.
- An important consequence is the difficulty in determining transmission line parameters accurately, as shown in the following graph.

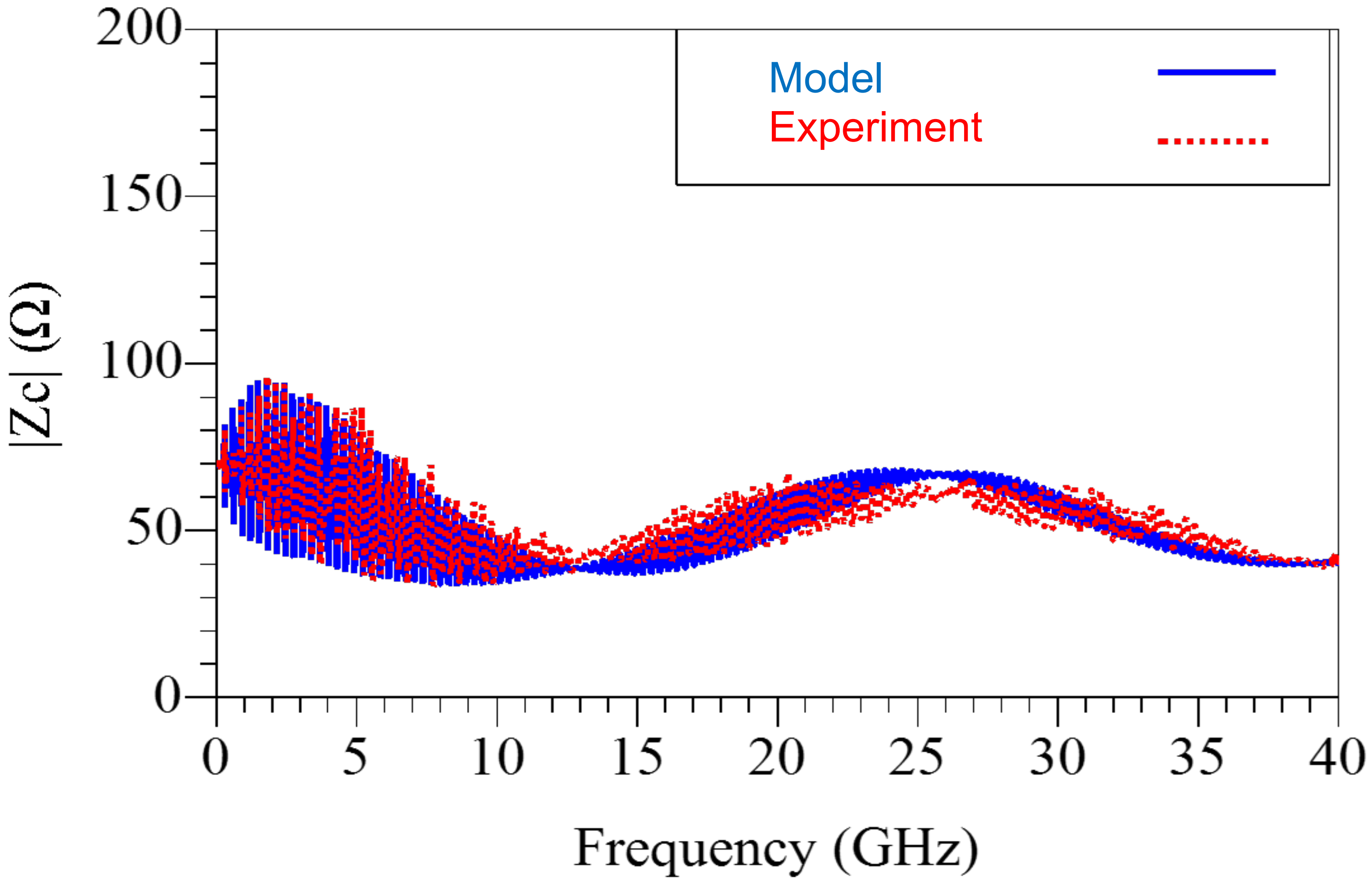

single line method (l = 317.5 mm)
from propagation constant
R (KΩ/m)
5
2.5
0
-2.5
-5
L (nH/m)
500
400
300
200
100
G (S/m)
1
0.5
0
-0.5
-1
C (pF/m)
170
135
100
65
30
0
5
10
15
20
25
30
35
40
Frequency (GHz)

Model:


COAX_MDS
TL20
A=6 mil
Ri=22.5 mil
Ro=185 mil
L=Lc mil
T=0.2 mil
Cond1=4.1E+7
Cond2=1.35E+7
Mur=1.0
Er=Ec
TanD=0.02
S2P
SNP7
Ref
COAX_MDS
TL21
A=6 mil
Ri=22.5 mil
Ro=185 mil
L=Lc mil
T=0.2 mil
Cond1=4.1E+7
Cond2=1.35E+7
Mur=1.0
Er=Ec
TanD=0.02
TermG
TermG25
Num=23
Z=50 Ohm
TermG
TermG26
Num=24
Z=50 Ohm

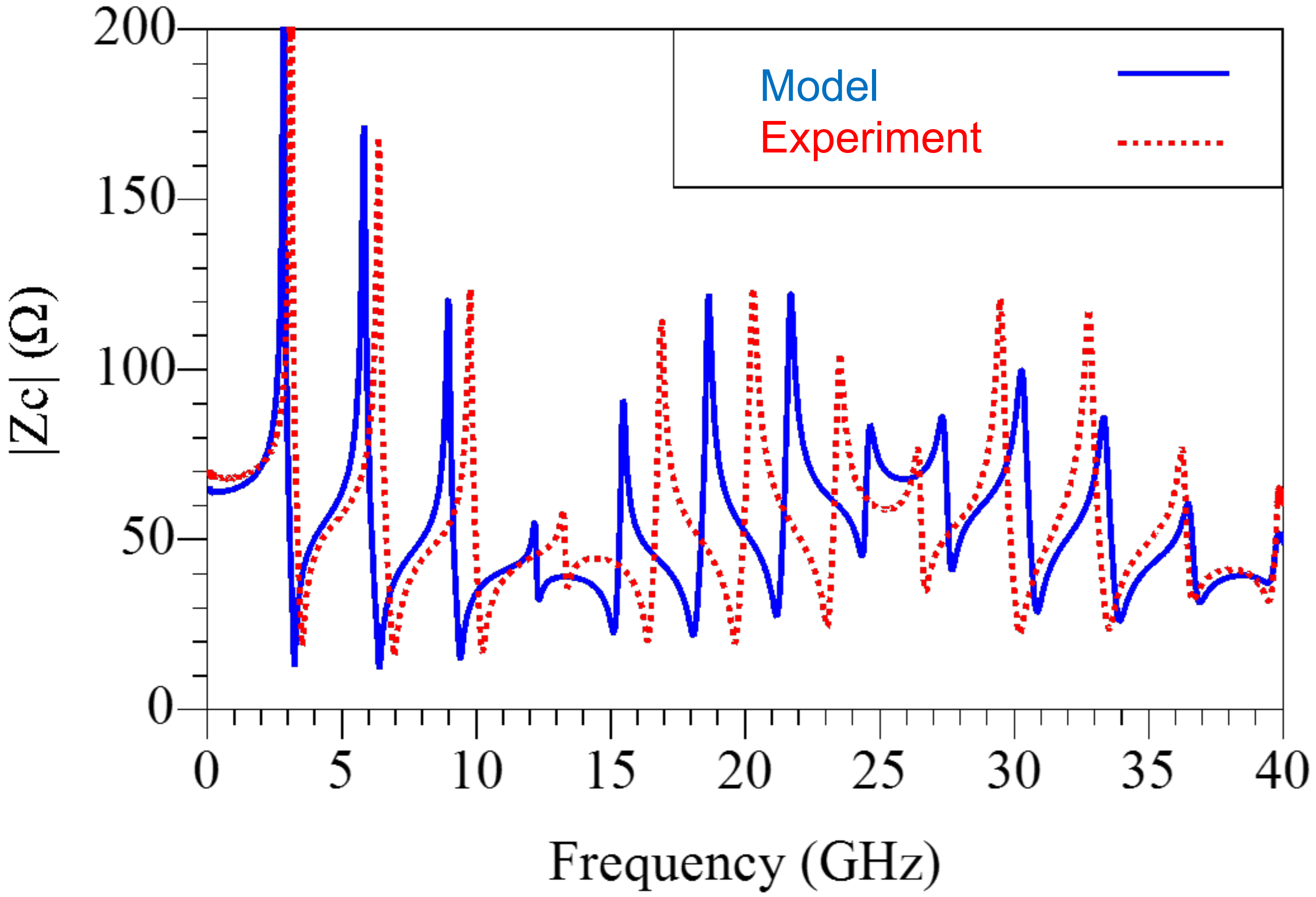
Measurement vs Model:

PCB line terminated with a coaxial connector, *l*=317.5 mm



Measurement vs Model:

PCB line terminated with a coaxial connector, *l*=24.5 mm



Discussion:

- For microstrip lines manufactured on PCB the Z_c curve does not considerably vary with frequency since the losses are relatively small.
- On chip lines present very thin films, which translated into resistances per unit length in the order of KΩ/m.
- This high resistance causes the characteristic impedance to have a strong variation over a wide range of frequencies.

Conclusion:

- Short lines —for instance on chip— are less impacted by the effect described herein than long lines —those on PCB, for example.
- In fact, algorithms such as the line-line one provide good results by modeling the transition as a a shunt admittance up to some tens of GHz.
- For long lines, however, the fluctuation effect is considerable.

Conclusion:

- The effect is accentuated when using transitions that exhibit a noticeable distributed nature within the measurement range.
- We have proposed a distributed transmission line model to represent this effect.
- To the best of our knowledge, this is the first time this effect has been reported.

Thank you very much for your kind attention!

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