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Simplify & Validate: A Single Structure Approach for Separate PCB Dielectric & Conductor Roughness Loss Characterization

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Abstract

To find out the reasons for possible PCB manufacturing failure due to losses, a new easy-to-use production floor technique with separation of dielectric, conductor and roughness effects is needed. This paper presents a novel method that identifies material properties using just one structure and one TDR/TDT measurement. The post-processing of the measurement extracts the frequency-dependent models for dielectric, conductor, and copper surface roughness. The proposed technique called XMOT (eXtract and MOnitor PCB material properties using a T-resonator only). It can be used to collect the statistics of the material variations during manufacturing and monitor changes in dielectric and conductor roughness properties.

Author(s) Biography

Yasin Damgaci is a Senior Signal Integrity Engineer at Hewlett-Packard Enterprise and holds a PhD degree in Electrical Engineering from Utah State University. He has been working on methodologies for high-speed interface modelling, system level signal/power integrity design, bring up, validation and debug.

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Christopher Cheng received the B.S. and M.S. degrees in Electrical Engineering from Cornell University, Ithaca, NY. in 1987 and 1989 respectively. From 1989 to 1996. Mr Cheng worked for the Sun Microsystems Corporation, CA, USA, as a Signal Integrity engineer. From 1996 to 1999, he worked for Intel Corporation, CA, USA, as a Principal Engineer. In July 1999, he joined 3PAR Data Corporation as a Principal Engineer, Fremont, CA. Currently, he is with Storage Division in Hewlett-Packard Enterprise Company as a Distinguished Technologist.

Yuriy Shlepnev is President and Founder of Simberian Inc., where he develops Simbeor electromagnetic signal integrity software. He received M.S. degree in radio engineering from Novosibirsk State Technical University in 1983, and the Ph.D. degree in computational electromagnetics from Siberian State University of Telecommunications and Informatics in 1990. He was principal developer of electromagnetic simulator for Eagleware Corporation and leading developer of electromagnetic software for simulation of signal and power distribution networks at Mentor Graphics. The results of his research are published in multiple papers and conference proceedings.

1. Introduction

As today, there is no standard/methodology to monitor the material properties in production, other than control of the total loss per length. The test coupons are usually designed for just loss extraction and control. Most of the time, processes are tuned by manufacturers for impedance, and insertion loss using trial batches before actual sample production. Currently, no standard/methodology monitors the material properties in production other than total loss per length. To find out the reasons for possible board/manufacturing failure due to losses, a new technique is needed which allows the separation of dielectric, conductor and roughness effects. The main objective of this work is to develop space efficient method that is accurate up to medium high frequency with high testing throughput while being cost effective using almost all existing testing infrastructures in a high volume PCB manufacturing environment.

Manufacturers usually use standardized techniques such as SET2DIL [1], Gamma extraction part of SPP technique [1], [2], and Delta-L or eigenvalue technique [3] to control the losses only. On the other hand, development teams start using accurate techniques such as GMS-parameters [4], SPP Light with S-parameters [5] and techniques based on different types of de-embedding for the material characterization [6], [7]. T-resonator technique originally developed for microwave application was also recently adapted for the digital interconnects [8].

We are trying to close the gap between manufacturers and development labs, and build unified cost-efficient and accurate technique for the material characterization. To be able to do that, we need simple enough measurement technique and structure on the manufacturing floor. Recently, authors have proposed Gamma-T Technique [9]. Gamma-T Technique uses time domain method with the existing factory testing infrastructure (TDR/TDT equipment with hand-held probes). Gamma-T is allowing high throughput using the handheld probe and TDR scope without time consuming SMA mounting or VNA calibration. The most important advantage of the Gamma-T comparing to existing methodologies is allowing seamless separation of dielectric and conductor roughness effects. However, Gamma-T technique uses 3 structures (short and long transmission line segments and T-resonator) and 3 TDT measurements to be able to identify materials characteristics (dielectric permittivity, loss tangent and surface roughness of the copper). This paper proposes a novel method that identifies material properties using just one structure and one TDR/TDT measurement. The post-processing of the measurements extracts the frequency-dependent models for dielectric, conductor, and copper surface roughness. The proposed technique called XMOT (eXtract and MOnitor PCB material properties using a T-resonator only). It can be used to collect the statistics of the material variations during manufacturing and monitor changes in dielectric and conductor roughness properties.

2. Broadband material models

First of all we have to define broadband material models that can be used for the analysis of PCB/packaging interconnects. One broadband model for dielectrics and one model for conductor roughness are selected and described here as the most suitable for PCB characterization. **Models like that have to be the outcome of the model identification process, not just frequency points that are typically provided by the dielectric or PCB manufacturers.** There is usually no information available from manufacturers that is suitable for electrical modeling of the conductor surface roughness.

Wideband Debye (aka Djordjevic-Sarkar or Swensson-Dermer) [10] is the dielectric model that is often used for broadband analysis of PCB and packaging interconnects – it is simple, causal and easy to identify. Expression for complex permittivity of the wideband Debye model can be written as follows [10]:

$$\varepsilon(f) = \varepsilon(\infty) + \frac{\varepsilon_d}{(m2 - m1) \cdot \ln(10)} \cdot \ln\left[\frac{10^{m2} + j \cdot f}{10^{m1} + j \cdot f}\right] \quad (2.1)$$

Where, f is frequency (the original formula of [10] is adjusted to use linear frequency instead of the radial for convenience). Values of dielectric constant at infinity $\varepsilon(\infty)$ and parameter ε_d can be defined with dielectric constant and loss tangent at just one frequency point (as it is done throughout this paper). Values of *m1* and *m2* define position of the first and last pole in the continuous spectrum defined by the model. Those are typically set to very low and very high values outside of the frequency band of interest (*m1=4, m2=12*), but they may be also treated as variables in the identification process in cases if dielectric exhibit high dispersion and large growth of the losses for instance.

To simulate the effect of conductor roughness, we will use the unified roughness correction coefficient that can be expressed as follows [11]:

$$K_{ri} = 1 + (RF - 1) \cdot F(SR, \delta_s) \quad (2.2)$$

It is applied to the complex transmission line impedance per unit length. In general, it describes multiplicative increase of conductor absorption with frequency as a transition from 1 at lower frequencies (or zero frequency) to maximal value defined by the roughness factor parameter *RF*. *RF* can be greater than or equal to 1. Function *F* describes transition from zero at low frequencies to the unit at high frequencies. δ_s is skin depth, and defined as follows:

$$\delta_s = (\pi \cdot f \cdot \mu \cdot \sigma)^{-1/2} \quad (2.3)$$

Parameter *SR* is a metric parameter that defines size of a surface model basic element – bump size or ball radius. In general, *SR* just defines onset frequency of the skin-effect on a rough surface – when *SR* parameter becomes comparable with skin depth, the losses due to conductor roughness start growing. It may correlate with Ra or Sa parameters measured for a rough surface, but such measurements are available only from the copper foil manufacturers and the copper surface is further treated by PCB manufacturer usually without any numbers to characterise it.

Huray-Bracken roughness correction coefficient is used in this paper as the causal version of the Huray snowball correction coefficient with the following transition function [11]:

$$F_{hur}\left(r,\delta_s\right) = \left(1+\left(1-j\right)\frac{\delta_s}{2r}\right)^{-1} \quad (2.4)$$

The first parameter *SR* in [2.1] is the ball radius from the original Huray model in this case. With the transition function (3.4), the roughness factor in formula (2.2) is related to the original Huray snowball model as follows (see definition of the parameters in [11]):

$$RF = 1+\frac{3}{2}\frac{N\cdot 4\pi\cdot r^2}{A_{hex}} \quad (2.5)$$

The roughness factor can be also computed from or converted to the Hall-Huray surface ratio (*sr*) used in some software with the following formulas:

$$RF = 1+\frac{3}{2}\cdot sr; \;\; sr = \frac{2}{3}\cdot\left(RF-1\right) \qquad (2.6)$$

3. Material Identification with XMOT technique

In the previously proposed Gamma-T technique [9]; T-resonator is used first, to identify the loss tangent (LT) at lower frequency, where the conductor roughness effect can be neglected. Then, the complex propagation constant (Gamma) is extracted from TDT measurements for two transmission line segments. The Gamma is used for the material model identification (Dk and roughness model parameters) by simple matching of the measured and simulated attenuation and phase delay. To separate the dielectric and conductor losses, the LT value identified with the T-resonator is used to define the dielectric losses in Wideband Debye model (2.1). All additional losses are attributed to the conductor surface roughness model that is identified by matching the real part of Gamma. A disadvantage of the Gamma-T technique is the use of 3 structures and 3 separate measurements. The three structures of Gamma-T are short transmission line segment, long transmission line segment and T-Resonator. The new XMOT technique (eXtract and MOnitor PCB material properties using only an asymmetrical T-resonator) is a simplified version of Gamma-T technique and a space efficient method that is accurate up to medium-high frequency. We propose to do just one TDR/TDT measurement on a single un-symmetric T-resonator. It can be used to extract the loss tangent at the first resonance exactly as it is done in the Gamma-T technique. Also, the same structure can be used to extract and match transmission line attenuation and phase delay up to 10-15 GHz. The extracted analytical dielectric (2.1) and conductor roughness (2.2)-(2.4) models will allow prediction of the losses and delay up to higher frequencies (20 GHz in this case).

T-resonator is a well-known approach to extract the dielectric properties of the PCB material at the resonance frequencies [8], [9]. The proposed T-resonator has asymmetrical arms (Figure 3.1). It can be used to identify the loss tangent at the resonance frequency following exactly the algorithm as described in our previous paper [9]. In addition to that, asymmetrical lengths of the through transmission line segments are designed to mimic the behavior of short and long transmission line segments. The methodology starts with step or pulse signal, which is launched from one end of T-resonator. When the initiated signal hits the T-junction, some portion of the signal is transmitted to the open-ended stub, some is reflected and some goes through. The signal

reflected back from the stub end is considered as the primary launching signal and the stub-end is the virtual launching point. When the primary launching signal hits the T-junction again, the signal is propagated in two directions forward (Signal B in Fig. 3.1) and backward (Signal A in Fig. 3.1) and acquired by the TDT/TDR. These signals can be used to extract the complex propagation constant over a wide frequency bandwidth. The pulse reflected from the open end and measured at the port 1 and port 2 has similar discontinuities on the way, but different length of the transmission line segments. For the case shown in Fig. 3.1, the length difference is 2X. Parameter X should be selected to have the first resonance of stub resonator below 1 GHz in general. The stub resonates at the frequency with the quarter of wavelength in strip line approximately equal to the stub length (open end and T-junction shift the resonance slightly). The X is equal to 2 inch in this paper to have the first resonance at about 730 MHz
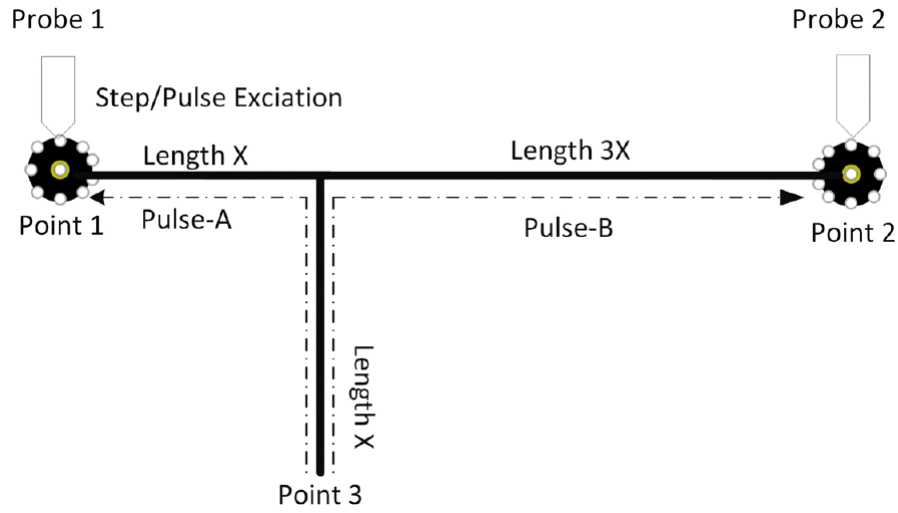
Fig. 3.1. Asymmetrical T-Resonator

The loss tangent extraction algorithm is almost the same as described earlier for the Gamma-T technique. Here is a brief description of the updated version of the algorithm. First, the TDT signal is transformed into frequency domain and reference signal measurement is used to compute magnitude of the transmission parameter or |S[2,1]|. Next, the first resonance is found and used to compute the loaded quality factor of the resonator with the following formula:

$$Q_T = \frac{f_{res}}{\Delta f_{+3dB}} \quad (3.1)$$

Where f_{res} is the resonance frequency and Δf_{+3dB} is the bandwidth of the resonance at +3 dB from the insertion loss level at the resonance frequency. The loss tangent can be computed as follows:

$$\tan \delta = \frac{1}{Q_T} - \frac{1}{Q_C} \quad (3.2)$$

Where Q_C is the quality factor of the same resonator computed with the conductor losses only (without the dielectric losses). It can be computed either approximately with the following expression:

$$Q_C = \frac{\beta}{2 \cdot \alpha_C} \quad (3.3)$$

Where α_C and β are real and imaginary parts of the complex propagation constant in strip line with the conductor losses only. Formula (3.3) works well for T-resonators with short through line segments. Though, it leads to under-estimation of the conductor losses in case of the un-symmetric T-resonator. To improve the model quality we used complete T-resonator model with the conductive losses only to compute the quality factor Q_C with the formula (3.1). In addition to loss tangent, the resonant frequency can be used to identify preliminary dielectric constant as follows:

$$\varepsilon_r = \left(\frac{\lambda_{res}}{4 \cdot Lres} \right)^2 \quad (3.4)$$

Where *Lres* is the stub length. Note that the value of the Dk computed with (3.4) is preliminary – it does not include the effect of the open-end and T-junction and will be further refined with the extracted phase delay. At this point extracted loss tangent (3.2) and dielectric constant (3.4) can be used to define the Wideband Debye dielectric model (2.1).

The next step is the extraction of Gamma. To do that we will use the pulses reflected the open end as illustrated in Fig. 3.2. Those are the second pulses on TDR/TDT measurements.
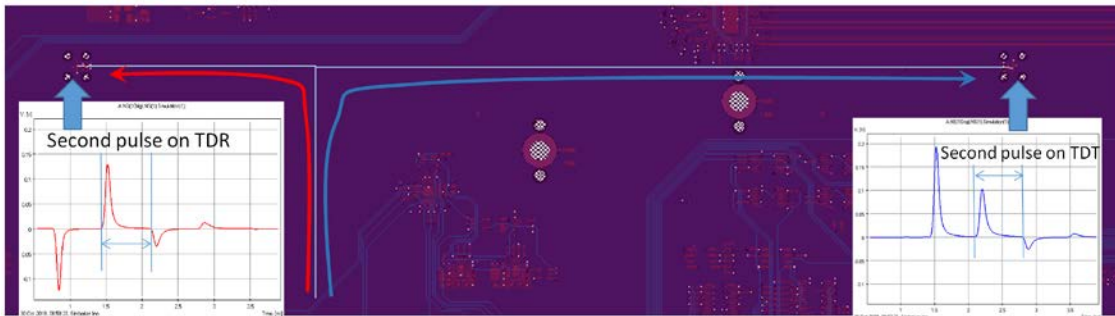
Fig. 3.2. Gamma extraction from TDR and TDT measurements for un-symmetric T-resonator.

The second pulses are windowed as also illustrated in Fig 3.2, converted into frequency domain with the fast Fourier transform $V(f) = fft(V(t))$ and used to compute the complex propagation constant is computed as follows:

$$\Gamma(f) = \alpha(f) + j \cdot \beta(f) = \frac{1}{\Delta L} \ln \left(\left| \frac{V_{TDT}(f)}{V_{TDR}(f)} \right| \right) + j \cdot \frac{1}{\Delta L} \arg \left(\frac{V_{TDT}(f)}{V_{TDR}(f)} \right) \quad (3.5)$$

Here $\Gamma(f)$ is the complex propagation constant (Gamma), $\alpha(f)$ is attenuation in Np/m, $\beta(f)$ is phase constant in rad/m, ΔL is the difference in the length between long and

short sections of the through line segment in m, $V_{TDT}(f)$ is the Fourier transform of the second pulse response windowed from TDT, $V_{TDR}(f)$ is the Fourier transform of the second pulse response windowed from TDR. Technically, the second pulse on the TDR corresponds to the pulse response measured for the short transmission line segment and the second pulse on TDT corresponds to the pulse response measured for the long transmission line segment in the Gamma-T or SPP methods. Though XMOT requires just one measurement to extract both pulses.

After Gamma is extracted, the final step is the same as in the Gamma-T algorithm [9]. It uses transmission line model with the material models to be identified with matching the attenuation and phase delay. First, dielectric constant in the Wideband Debye model (2.1) is adjusted to match the measured phase delay. Next, conductor roughness model parameters *SR* and *RF* in the unified roughness correction coefficient are adjusted to match the attenuation. The causal Huray-Bracken roughness model defined with formulas (2.2)-(2.4) changes the internal conductor inductance. Thus, an additional adjustment of the Dk may be needed after the conductor roughness identification step. Moreover, if the conductor is very rough, the roughness can also affect the loss tangent identification. In this case the LT identification and the following after this steps must be repeated to improve the model accuracy.

Finally, the XMOT procedure can be summarized as follows:
1. Acquire step or pulse response for two port asymmetrical T-resonator (TDR and TDT).
2. Filter the noise with Gaussian filter and, if necessary, convert the step responses into the pulse responses with smoothing derivatives.
3. Calculate the first resonance frequency from TDT and identify loss tangent LT and preliminary value of dielectric constant Dk at the resonance frequency.
4. Window the pulses reflected from the open end from the TDT and TDR responses.
5. Convert windowed pulses reflected from the open-ended stub into frequency domain and calculate the complex propagation constant or Gamma (Attenuation and Phase).
6. Use the field solver to tune Dk and conductor roughness model parameters (SR and RF) to match measured attenuation iteratively and phase delay.
7. Optionally adjust the loss tangent by taking into account the identified roughness model in computation of the conductive resonator losses (step 3) and repeat step 6.

4. Numerical experiment

As a proof the concept and to illustrate the method, we will start with a numerical experiment and use layout of the manufactured board for the analysis. The domain decomposition technique implemented in Simbeor software is used here to simulate the un-symmetric T-resonator as shown in Fig. 4.1. The structure is automatically decomposed into 3 discontinuities (two identical probe launches and T-junction) and strip line segments – about 2 inch stub, and 2 and 6 inch segments of the through line. Full wave electromagnetic Simbeor 3DML solver is used to simulate the discontinuities and quasi-static field solver Simbeor SFS is used to build models for the transmission line segments. S-parameter models of the discontinuities and transmission line segments are united into 2-port circuit also shown in Fig. 4.1. Structure to measure the reference signal is also shown in Fig. 4.1 – it contains just 2 probe launches connected with short line segment. Just one model of the launch is built with the electromagnetic analysis and re-used for all other simulations, to reduce the simulation time.
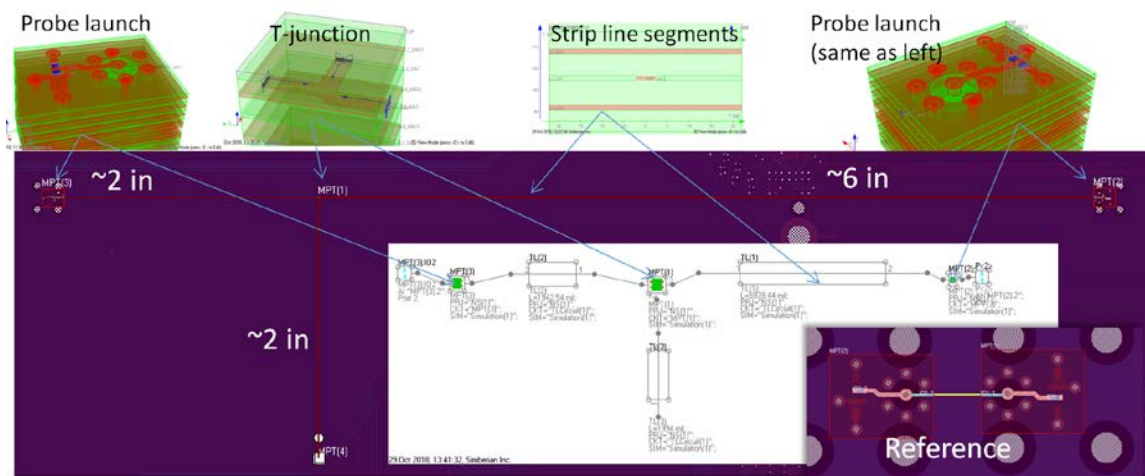
Fig. 4.1. Decompositional analysis of the un-symmetrical T-resonator structure and reference signal structure (bottom right). T-resonator is broken into 3 discontinuities connected with transmission line segments.

The following adjustments and models from the PCB manufacturer are used in the post-layout analysis:
o Strip line conductor thickness 1.15 mils (original stack up layer thickness 1.2 mils);
o Dielectric layer thickness above strip 4.90 mils (original stack up layer thickness 5 mils);
o Dielectric layer thickness below strip 5.44 mils (original stack up layer thickness 5.6 mils);
o Trace width 4.6 mils (designed as 5 mils;
o No data on shape of trace – assumed rectangular;
o Dielectric parameters: Dielectric constant 4, loss tangent 0.015 – no frequency;

o No data on copper resistivity (assumed RR=1) and conductor roughness model (assumed SR=0.1 um, RF=7);

Obviously, we cannot expect high accuracy of the analysis with the preliminary models of the materials, especially of the conductor and conductor roughness. But, the goal here is the proof of concept – we need to show that with TDR/TDT measurements we will be able to identify the specified models of the dielectric and conductor. First, 2-port S-parameters of the T-resonator are computed and rational model is used to compute the time-domain response – TDR and TDT as shown in Fig. 4.2 Gaussian step with 40 ps 10-90% rise time is used as the stimulus.
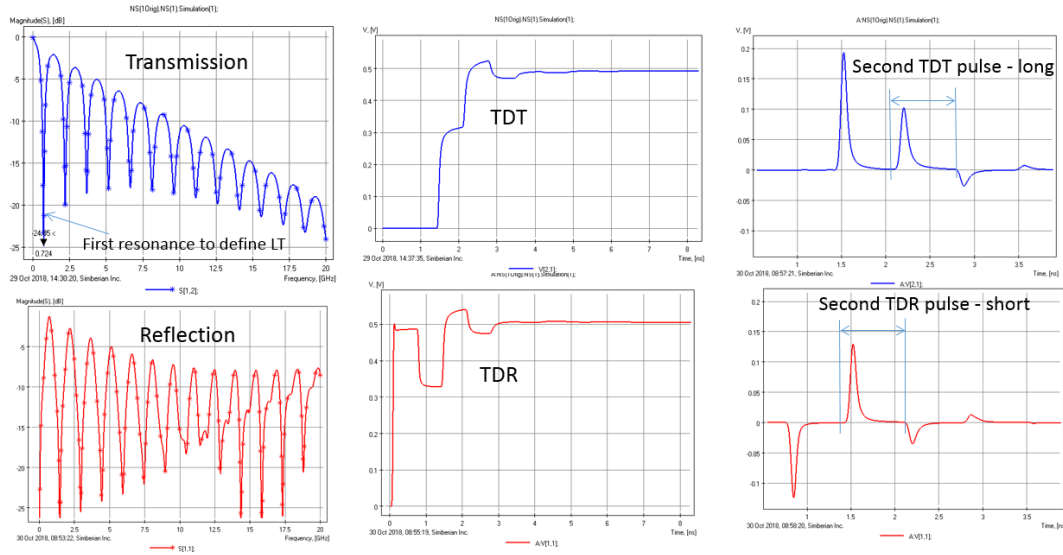
Fig. 4.2. Decompositional analysis of the un-symmetrical T-resonator structure. S-parameters are used to compute TDR/TDT and pulse response of the T-resonator. The second pulses are windowed and used to extract complex propagation constant (Gamma).

Additional Gaussian filter with -40 dB at 40 GHz is used to remove the high-frequency harmonics above the S-parameters bandwidth similar to Gamma-T technique as described in [9]. Smoothing derivatives of 7-th order are used to compute the transmitted and reflected pulse responses. The second pulse of the transmitted signal (top right plot in Fig. 4.2) corresponds to the path B in Fig. 3.1. This signal is used first to identify the loss tangent at the first resonance as in the Gamma-T technique. It can be done directly from the S-parameters, but to test the procedure we used the transmitted pulse response to compute S21 using computed reference signal – exactly as we plan to do it in the real experiment. The computed loss tangent is LT=0.0148 at 723.35 MHz – this is instead of LT=0.015 @ 1 GHz as in the original model. This accuracy is acceptable.

After the loss tangent identification we proceed with the complex propagation constant or Gamma extraction and dielectric constant and conductor roughness model identification. After the windowing as shown in Fig. 4.2 the second pulse on the transmitted response corresponds to the long line segment used in the Gamma-T or SPP techniques. The second pulse on the reflected signal corresponds to the path (A) in Fig. 3.1. After the windowing as shown in Fig. 4.2, the pulse will correspond to the short transmission line

segment used in the Gamma-T or SPP techniques. Two pulses are then converted into frequency domain and Gamma is extracted following the Gamma-T procedure described in [9] and illustrated in Fig. 4.3.
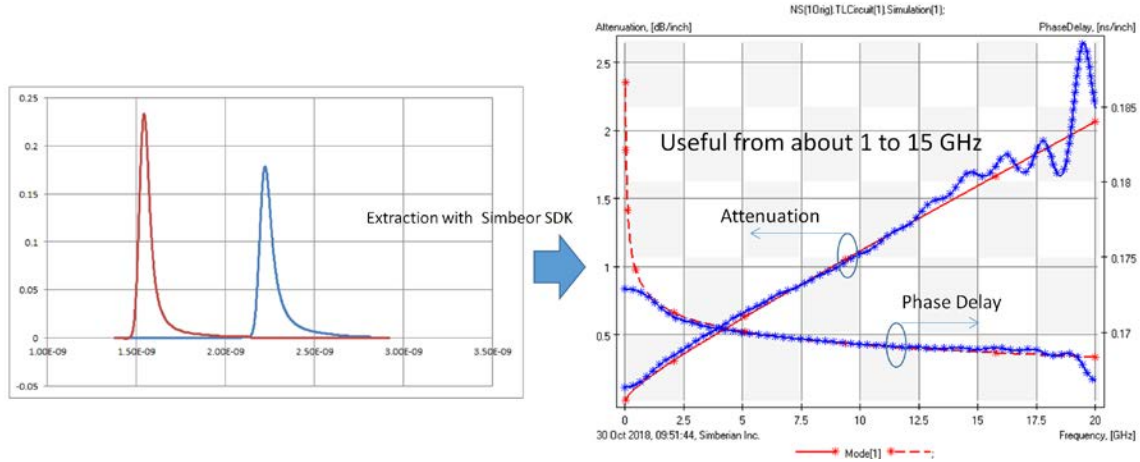

Fig. 4.3. Two pulses (windowed as shown in Fig. 4.2) are used to compute Gamma plotted as attenuation in dB/inch and phase delay in ps/inch on the right plot with blue stars. Red curves are attenuation and phase delay from the model after the material model identification.

Attenuation and phase delay plots of the extracted propagation constant are shown in Fig. 4.3 with blue stars. We can observe two defects of the computed Gamma. First, due to the restriction on the window duration, both phase delay and attenuation have defect at lower frequencies. On the other hand, due to the superposition of the first and second pulses and additional reflections from the T-junction and launches there are defects in the extracted Gamma at higher frequencies. The phase delay can be used for the Dk identification from about 2 GHz to 17 GHz. The identified Dk is 3.99 at 1 GHz, instead of the original 4. This is good accuracy. To identify the model parameters SR (ball radius in the Huray-Bracken model (2.4)) and RF for conductor roughness model, we use extracted attenuation from 2 to 15 GHz. The roughness model has 2 parameters. Because of this, multiple outcomes with slightly different results are possible. One of the outcomes with SR=0.11 um, RF=7.8 is used in the model plotted in Fig. 4.3. This model slightly over-estimates the conductor losses, but the result is very close to the original model. Finally, the original and identified models parameters are listed in the table below.

Model parameter	Original	Identified	Difference
Dk @ 1 GHz	4.0	3.99	0.25%
LT @ 1 GHz	0.015	0.01484	1%
SR, um	0.1	0.11	10%
RF	7	7.8	11%

5. Measurement Results

To test the proposed XMOT technique, test structures are embedded on one of the real design rather than test coupons. To be able to validate the XMOT technique's accuracy, Gamma-T technique test structures (2 different length transmission lines and short resonator) are used in the design also. Gamma-T resonator and XMOT resonator resonance frequency is designed to be same for comparison purposes.

One of the test boards with launches designed for the Introbotix hand-held probes is shown in Fig. 8.1. The board stack up is similar to what is expected in the production environment. Launch and vias are optimized with Simbeor electromagnetic signal integrity software [16].

Fig. 5.1 shows test set-up for TDR/TDT measurements. Step responses are used for material identification. 1 ps step time used with 4000 horizontal acquisitions points.
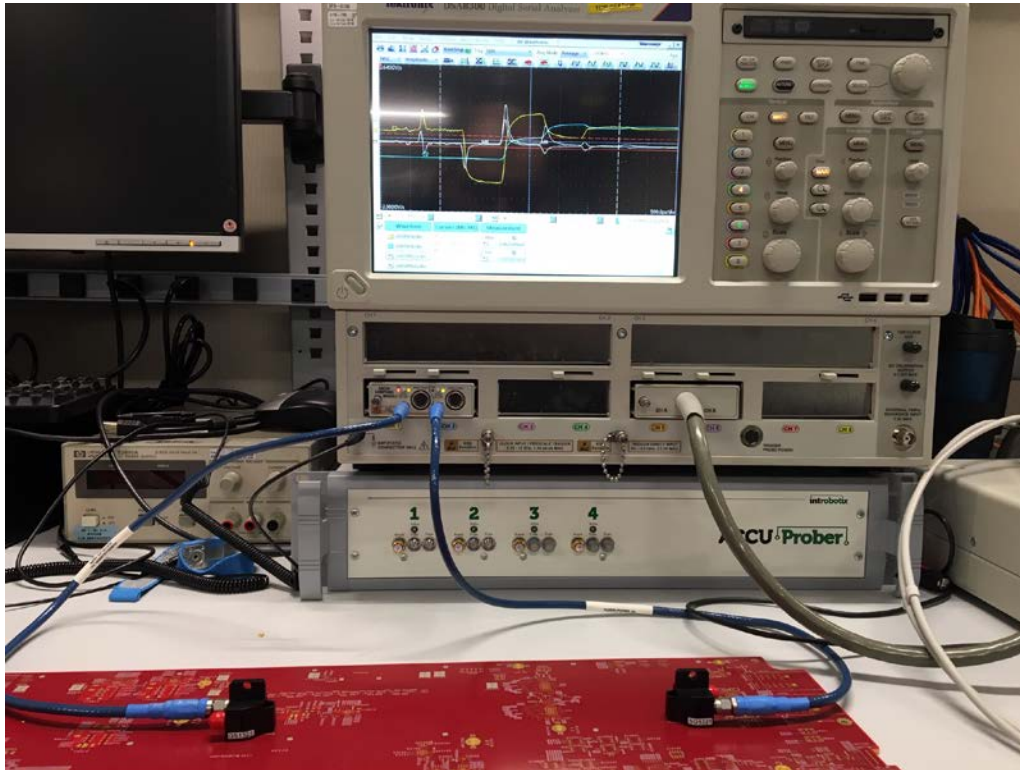
Fig. 5.1. Test board with Introbotix hand-held probes. Launch is optimized for the probe footprint for single-ended transmission line. Tektronix DSA 8300 with 80E04 sampling modules used for measurements

TDR/TDT measurements with probes
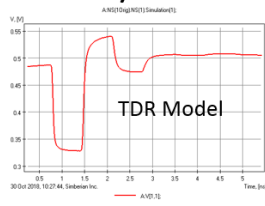
Problem – multiple reflections – ripples
Meas.: Oct. 15, 2018 – 1 ps time step,
hand-held probes
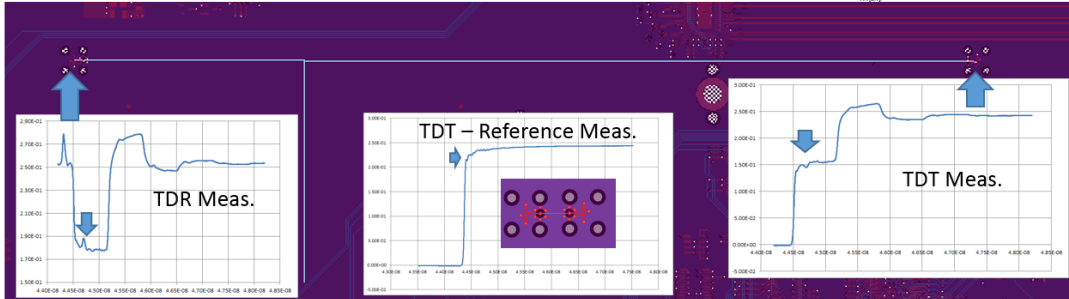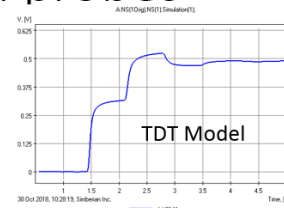
- T-Resonator Analyzer LT=0.021 @ 715.86 MHz

Extraction with Simbeor SDK
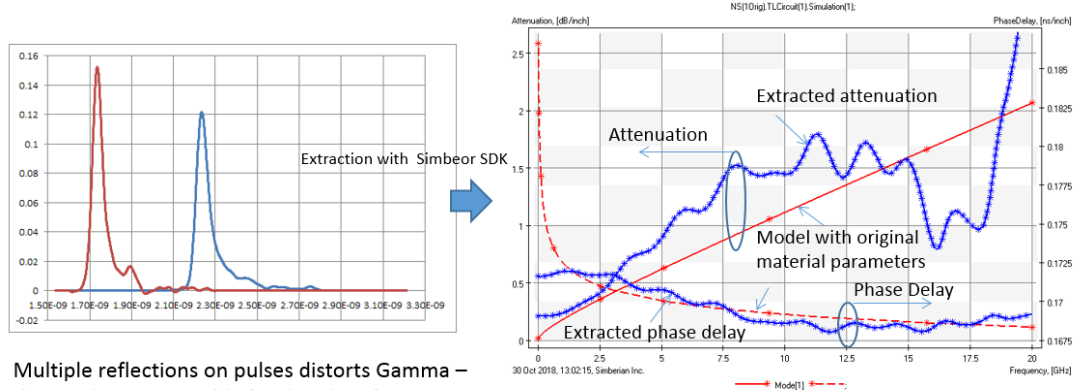
Multiple reflections on pulses distorts Gamma –
the result is not suitable for the identification
The problem can be reproduced in numerical
experiment with additional reflections from probes

Fig. 5.2. Dk, DF extraction results using TDR/TDT measurement with hand held probes

As seen from results, attenuation results are quite deviated from expected values. Also, we noticed that LT is much higher than expected values. After many experiments with TDR using different values for acquisition points, longer time, rise time change etc. LT results remain same. Also, additional reflection from probes, makes gamma extraction quite unreliable. At this point, we decided to compare results using VNA and RF probes.

Fig 5.3 shows VNA, cable and RF probes set-up. VNA is calibrated using calibration substrate SOLT structures within 10 MHZ- 20 GHz range.
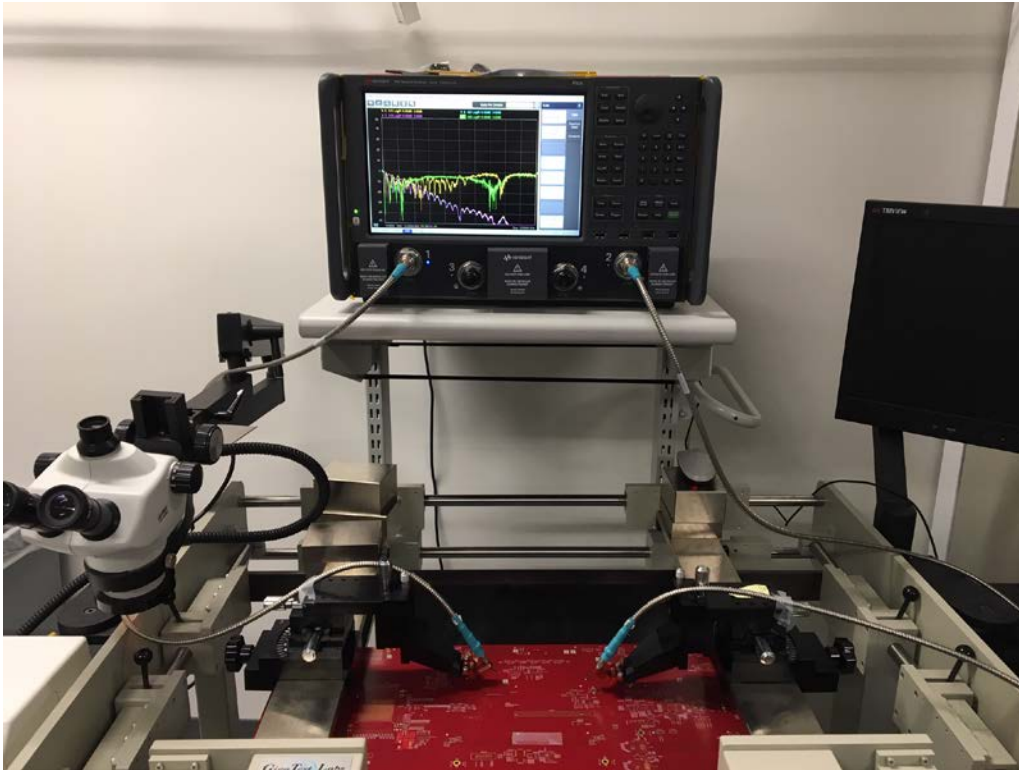
Fig. 5.3. Test board with GigatestLabs RF probes. GigatestLabs calibration substrate used for VNA calibration
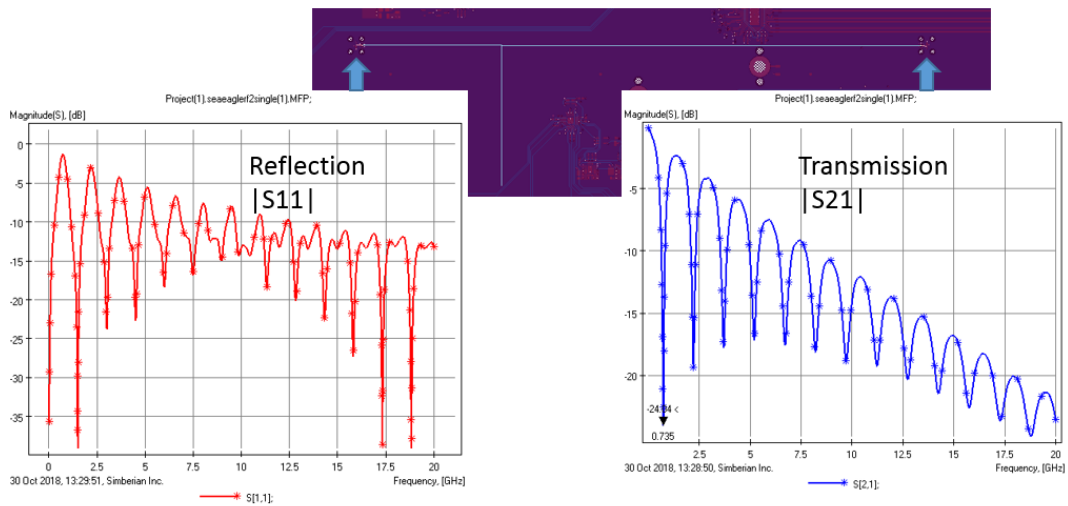
Fig. 5.4. S-parameter measurements
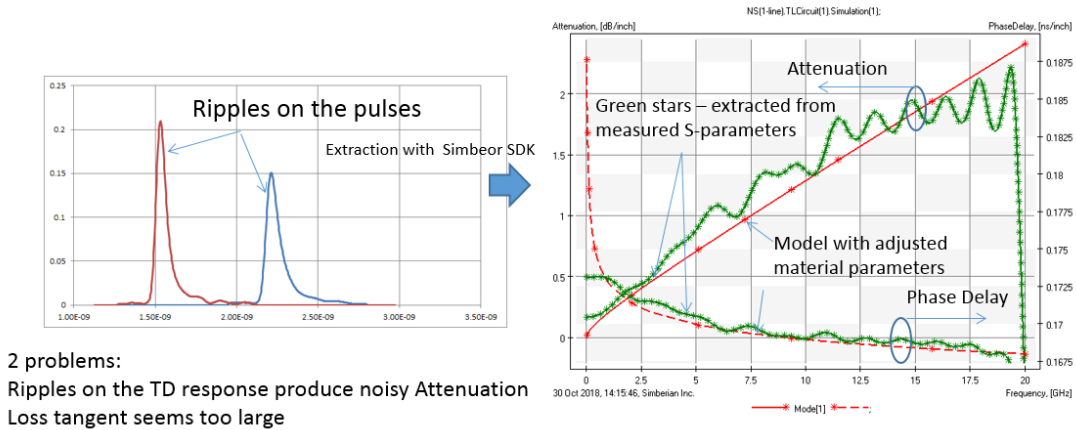
- T-Resonator Analyzer: LT=0.0189 @ 733.06 MHz

Fig. 5.5. Dk, DF extraction results using VNA measurement with RF probes

As seen from Fig 5.5, attenuation results are still deviated from expected values. Also, LT is still much higher than expected values. We start looking possible post processing schemes to improve results and tried to find the gap between measurements and simulations.

One of the first improvements that can be made de-embedding probe effects. Simbeor is used for deembedding probe/launch discontinuity and results are shown in time domain in Fig 5.6.
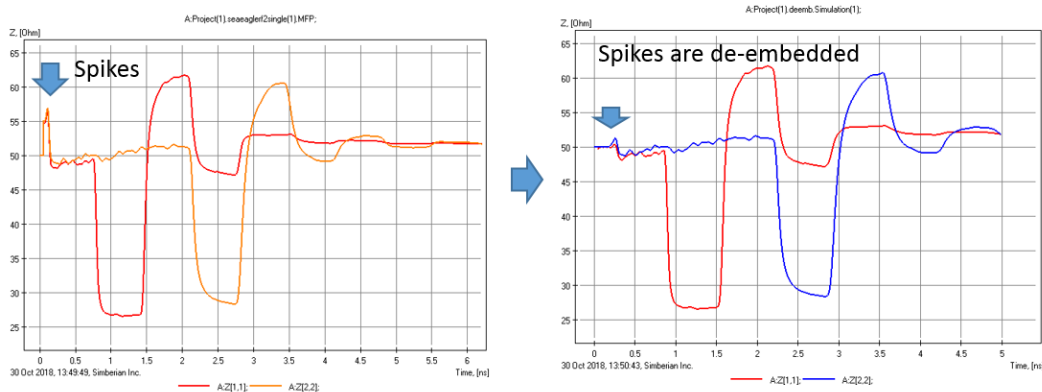
Fig. 5.6. Deembedding results in time domain

Figure 5.7 shows extracted Dk, DF after deembedding. Although Gamma extraction gets better LT results remain higher than expected.

- T-Resonator Analyzer: LT=0.0189 @ 733.06 MHz
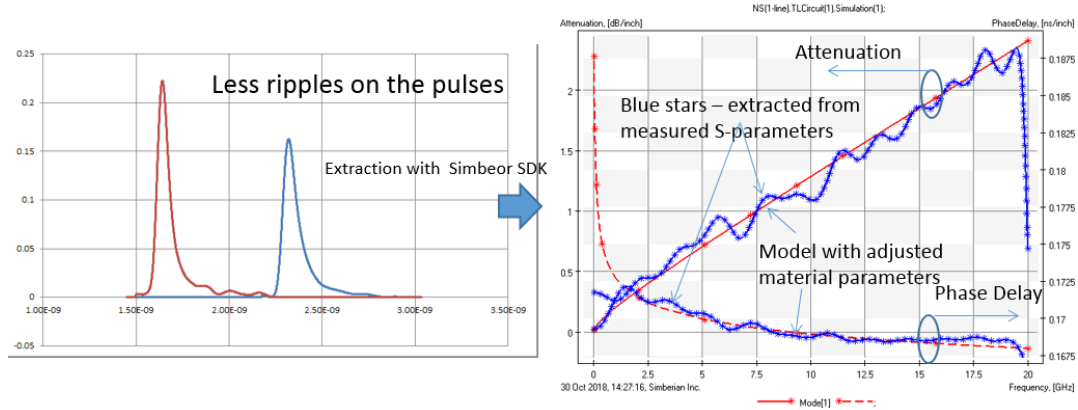
Fig. 5.7. Dk, DF extraction results using VNA measurement with RF probes and deembedding

We start looking further investigation the reason for high LT around 733 MHz range. We rely on PCB manufacturer's cross section data which might be not be the exact case in our sample. Another reason would be high copper resistivity or roughness effect at 733 MHz.

Since, the samples don't have 4-point probe measurement fixtures, we used VNA at 10-50 MHz range insertion loss to extract bulk resistivity. As a result, we found out that copper resistivity is higher than expected. After, including higher bulk resistivity into an acoount, LT values are calculated around ~ 0.014 @ 733 MHz.

Extraction results can be seen in Fig 5.8 and Fig 5.9.

6-inch T-line segment attenuation at lower frequencies is used to identify relative resistivity (RR)

With RR=1.35, extracted loss tangent:
LT=0.0147 @ 733 MHz with SR=0.1 um, RF=7
LT=0.0138 @ 733 MHz with SR=0.2 um, RF=7

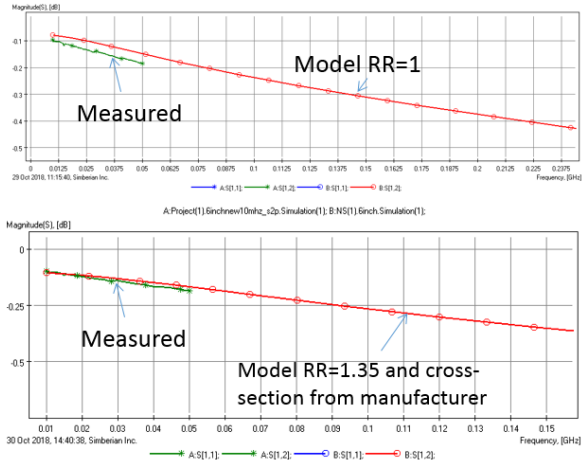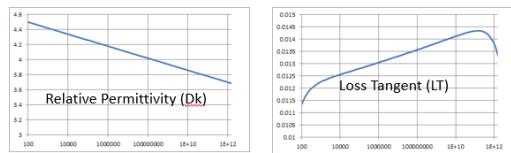Roughness slightly changes the result – the process of the identification may require iterative refinement

Fig. 5.8. Resistivity calculation procedure

• Dielectric: Wideband Debye Dk=3.95 LT=0.0138 @ 733 MHz

Loss tangent is identified with T-resonator Q-factor
Dielectric constant is identified by matching Phase Delay
Roughness model is identified by matching attenuation

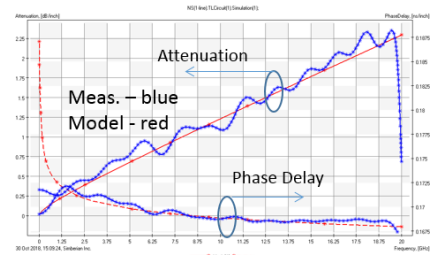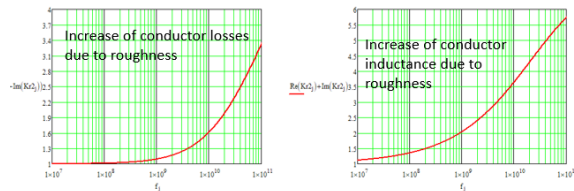• Conductor: Relative Resistivity 1.35, Huray-Bracken roughness model with SR=0.2 um, RF=7

Fig. 5.9. Dk, DF extraction results using VNA measurement with RF probes + deembedding + resistivity correction

6. Validation with Gamma-T

Gamma was extracted from TDT measurements for two transmission lines and used to identify Wideband Debye dielectric model Dk at 733 MHz by matching computed and measured effective dielectric constant as illustrated in Fig. 6.1. Finally, conductor roughness model parameters are identified by matching the measured and computed transmission line attenuation as also illustrated in Fig. 6.2. The low and high frequency defects are simply smoothed out by the frequency continuous dielectric and conductor roughness models used in the field solver. Simbeor SFS quasi-static field solver was used for the dielectric and conductor roughness model identification. The models are re-usable in other quasi-static and electromagnetic solvers. To validate the results of the cost-effective technique, the same structures were investigated with the S-parameters measured with RF probes and VNA. As, it can be seen from Fig 6.2, Gamma-T is less sensitive to the reflections from launch and probes. Identification is easily achieved up to 20 GHz. Although, XMOT data can be used for identification, it is much harder to design launches, and almost transparent launch design is needed.
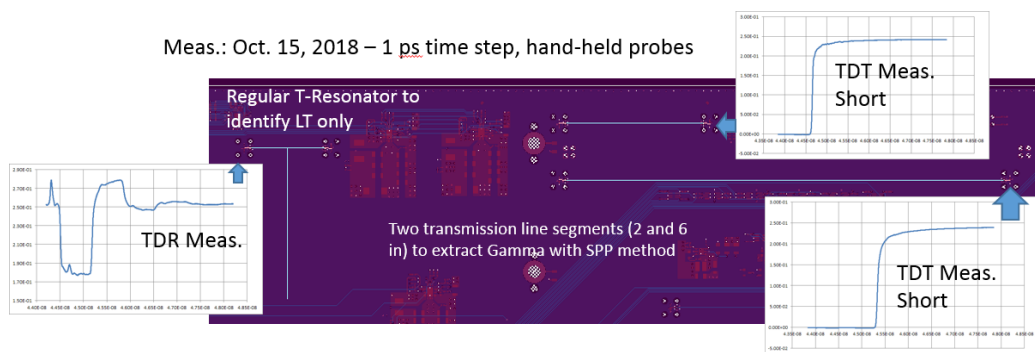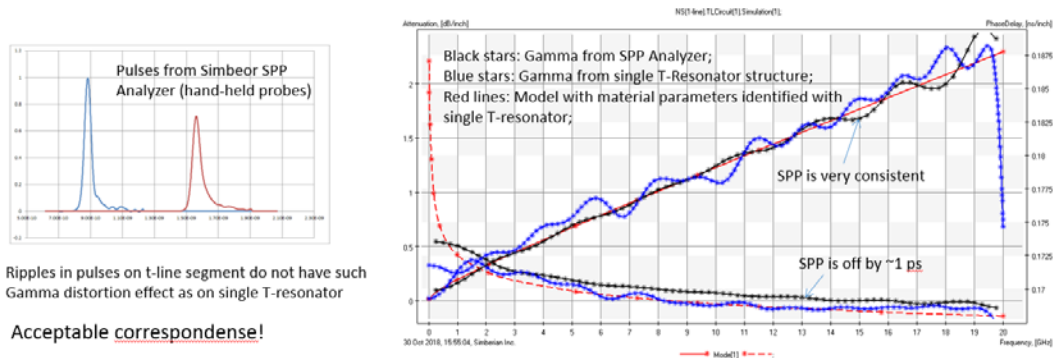

Fig. 6.1. TDT Measurement Results for Gamma-T

Fig. 6.2 Dk, DF extraction results using Gamma-T Technique

7. Conclusion

New XMOT technique for the material model validation and/or identification has been proposed. It is fast and simplified version of Gamma-T technique that authors recently proposed. It is shown that single asymmetrical T-resonator structure can represent three structures that is need for Gamma-T. Asymmetrical T-resonator design is more sensitive to reflections, and transparent launch design needed. The identification still can be achieved over a wide frequency band using Wideband-Debye material models. This technique would be useful for space limited applications and the monitoring the real board manufacturing statistics.

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