# Paricon Technologies, Inc.

## Conductive Elastomer

Measurement and Modeling

Rev. 1.0

Prepared by

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## *Objective*

The objective of these measurements is to determine the rf performance of three different Paricon Technologies Conductive Elastomer Connectors. The contact pads are arranged in a G-S-G configuration as well as a coax-to-coax connection. Measurements in both frequency and time domain form the basis for the evaluation. Parameters to be determined are contact capacitance of the signal contact with respect to ground, the signal contact inductance, the propagation delay, and the attenuation for frequencies up to 40 GHz.

An equivalent circuit and a SPICE model are to be established and its performance compared against measured values. The equivalent circuit should contain elements representing the time domain response.

## *Methodology*

Capacitance and inductance for the equivalent circuits were determined via measurements in the frequency domain. Measurements to 40 GHz were performed with a HP 8722C vector network analyzer. The instrument was calibrated with a HP85052D 3.5 mm calibration kit. Once the device under test (DUT) was connected, time gating was employed to eliminate measurement contributions from the probe, its K-connector and associated interfaces.

When the elastomer is terminated into an open circuit, a capacitance measurement results. When a short circuit plate is used on the other side of the contacts, self inductance and mutual inductance can be determined.

Time domain measurements are performed via the time domain transform of the network analyzer. These measurements reveal the type of discontinuities at the interfaces and the contacts. With the information about capacitive and inductive responses it becomes possible to establish a basic equivalent circuit for the SPICE model.  These measurements also establish bounds for digital system risetime and clock speeds.

## Test procedures

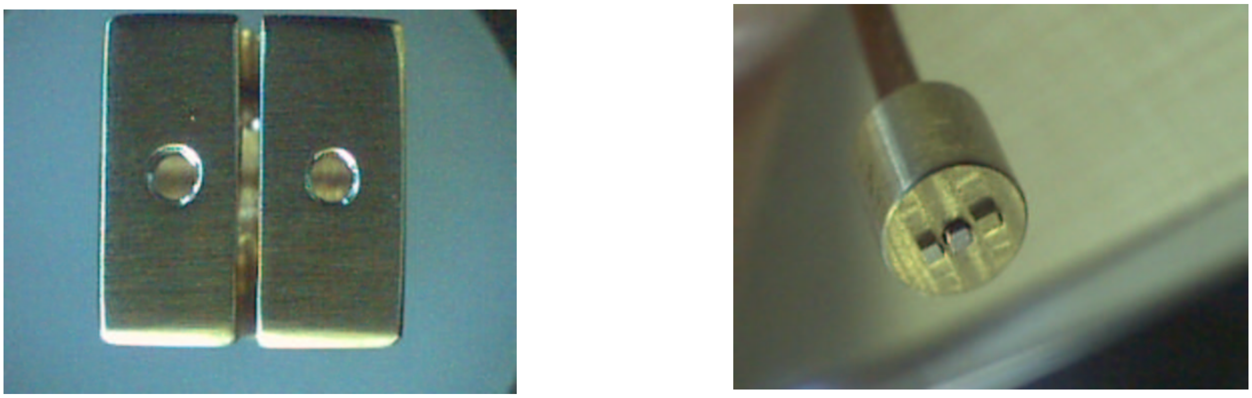
To establish capacitance of the signal contact with respect to ground, a full one port return loss calibration is performed.  Phase angle information for S11 is selected and displayed.  When the elastomer is connected and compressed, an approximately linear increase of phase angle with frequency can be observed.  It is recorded and used for determining the contact capacitance.

The self inductance of the connection is found in a similar way, except the elastomer is shorted by a metal foil at the opposite end, away from the probe.  Again, the analyzer is calibrated and S11 is recorded.  The inductance of the connection can be derived from this measurement.

Material A is identified as A1-010712-00306, material B is A1-010517-0105 and material C is A1-010608-0101.

## Setup

Testing was performed with a test fixture consisting of blocks that hold the coaxial cable feeds in the appropriate position.  Square pads of 0.028” x 0.028” size with a 0.050” pitch provide G-S-G (ground-signal-ground) connections. Blocks and fixture are made of brass.  Alignment is achieved through a fixture block that forces the coaxial pads to line up on-axis.  Holes in the blocks receive the SR-083 semi-rigid coaxial cable probes (OD = 0.083").  Fig. 1 and 2 show this arrangement and its components.



Probe tip
Pads: 0.028” x 0.028”
Pitch: 0.050”

2 port test arrangement

Fig. 1  Micro-coax probe and mounting block

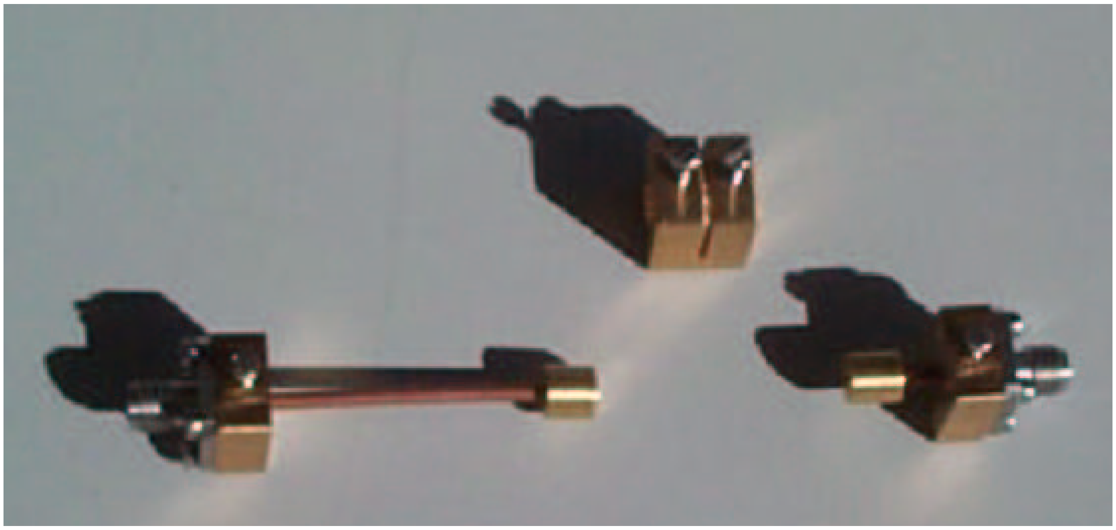


Fig. 2 Conductive elastomer test setup: Fixture block with probes engaged

## *Measurements*

### Time domain

The first set of measurements obtained in the time domain shows two traces representing reflected signals from the probe with the elastomers connected and unconnected (Figs. 3 and 4).

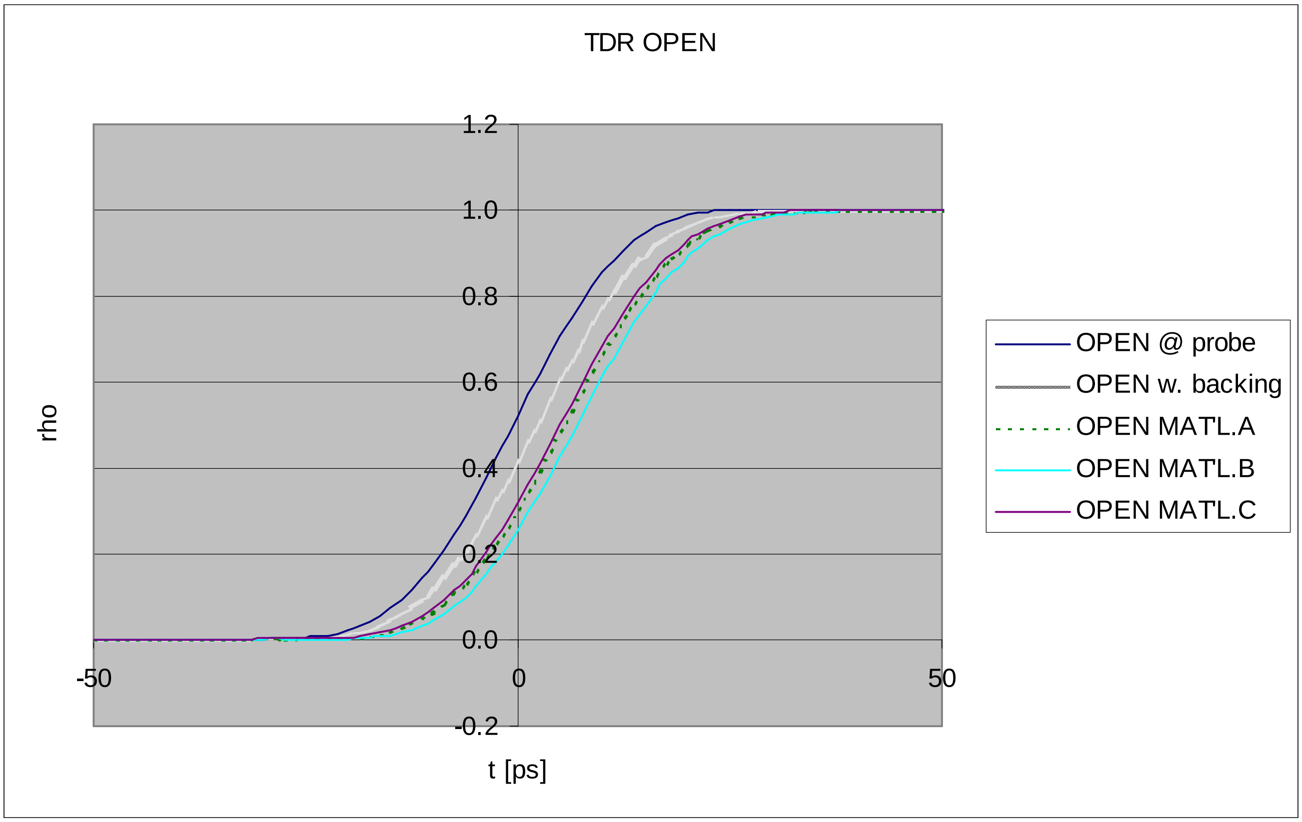


Fig. 3 TDR signal from an OPEN at probe, backing, and OPEN inclusive elastomers and backing

All reflected signals have a similar 10%-90% risetime of approximately 32 ps. There is no significant contribution from the elastomers. This suggests a transmission line behavior of the G-S-G arrangement with a characteristic impedance near 50 Ohms.

Electrical length is about 4.7 ps round trip or 2.3 ps one way for material B and 3 ps round trip or 1.5 ps one way for materials A and C.

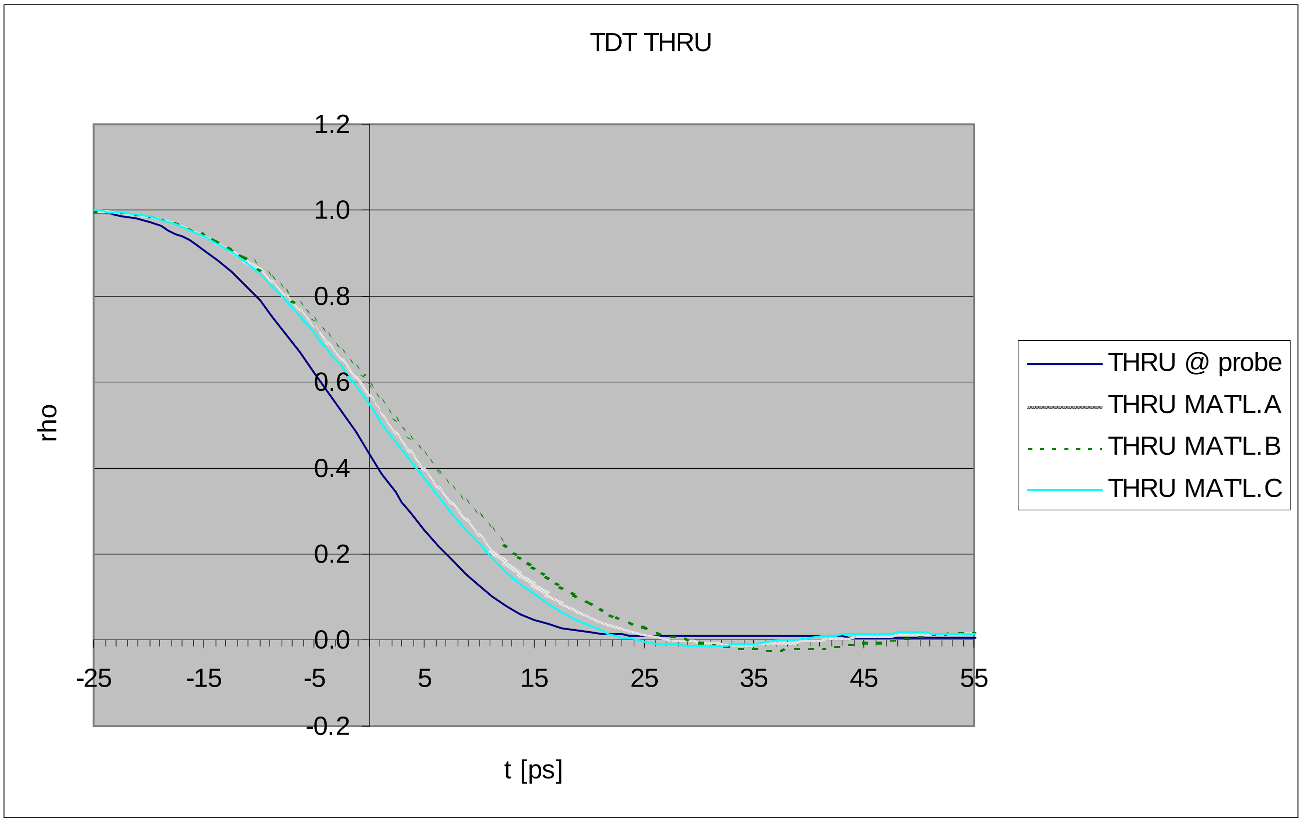


Fig. 4 TDR response of the shorted elastomers

The inductance of the contact pads contributes to the response of the shorted elastomer. Thus, fall times are slightly higher for the complete arrangement than for the system alone. Nevertheless, in this case, too, the contribution of the elastomer to the fall time is practically negligible.

The thru response in Fig. 5 shows a slightly inductive response. It is obtained by driving the contacts through one probe and connecting a second probe with a 50 Ohm termination on the opposite contact side.

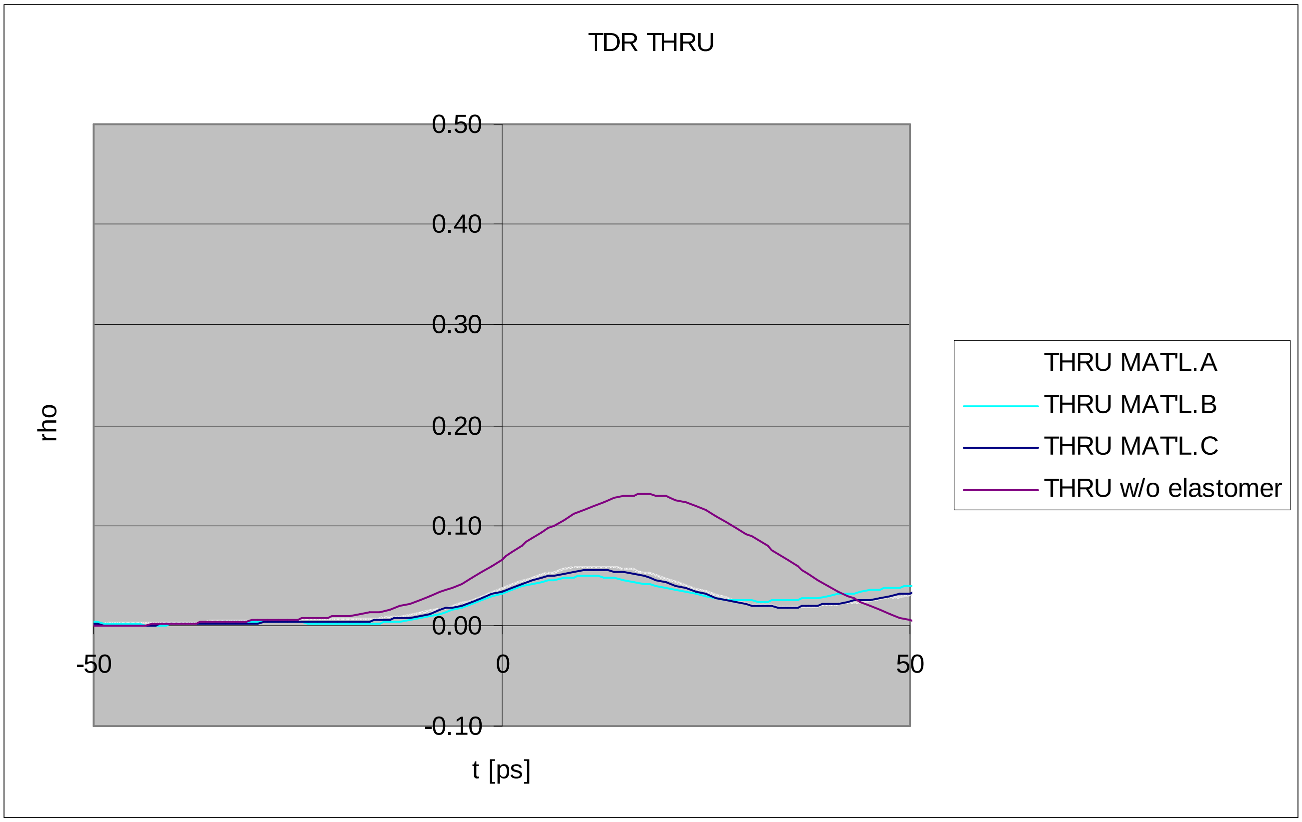


Fig. 5 TDR measurement through elastomers into a second probe

The characteristic impedance corresponding to the peak for Materials A,B and C is about 55 Ohms. The direct THRU without elastomer between the contacts shows a considerably higher peak. This is hardly surprising since the elastomer will fill the gap between the coax probes when pressure is applied, thus increasing the dielectric constant in that area. Since the individual contact areas are relatively far apart, a characteristic impedance higher than 50 Ohms results. The presence of the elastomer leads to a lower characteristic impedance and thus a lower peak response.

It was found during these measurements that the 0.028”x 0.028”x 0.050” pad arrangement presents a significant inductance component to the propagating signal. This inductance masks the true performance of the elastomer material. Therefore, THRU measurements in time and frequency domain were performed with the elastomer being inserted between two 0.047” microcoax probes without the 0.028” square pads.

The TDT performance for a step propagating through the contact arrangement was recorded for such an arrangements and shows a 10%-90% signal risetime of 25 ps (Fig. 6).

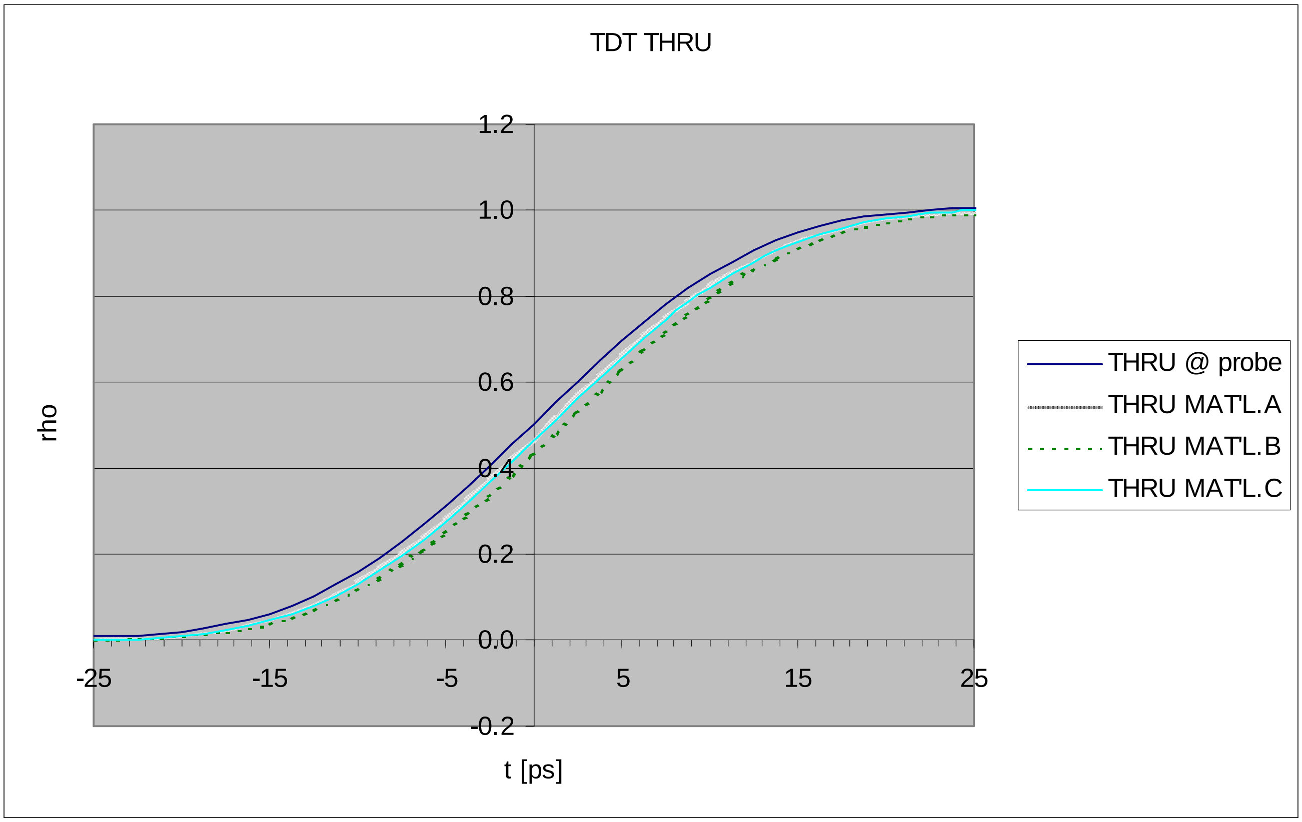


Fig. 6 TDT measurement through elastomers into a 50 Ohm coax probe

As is evident in Fig. 6 excellent signal fidelity is obtained with very little change to the signal rise from the presence of the elastomer in all cases. In this particular measurement, material B adds a delay of about 1.9 ps, materials A and C contribute 0.75 ps. There is less delay here than in the case of the square pads. This is in part because of the shorter signal paths (and lower inductance) of this arrangement. Also, the compression of the elastomer in this case may be larger than with square pads.

## Frequency domain

Signal contact to ground capacitance was measured by recording the phase change as a function of frequency for the open circuited elastomer connection (Fig.7).

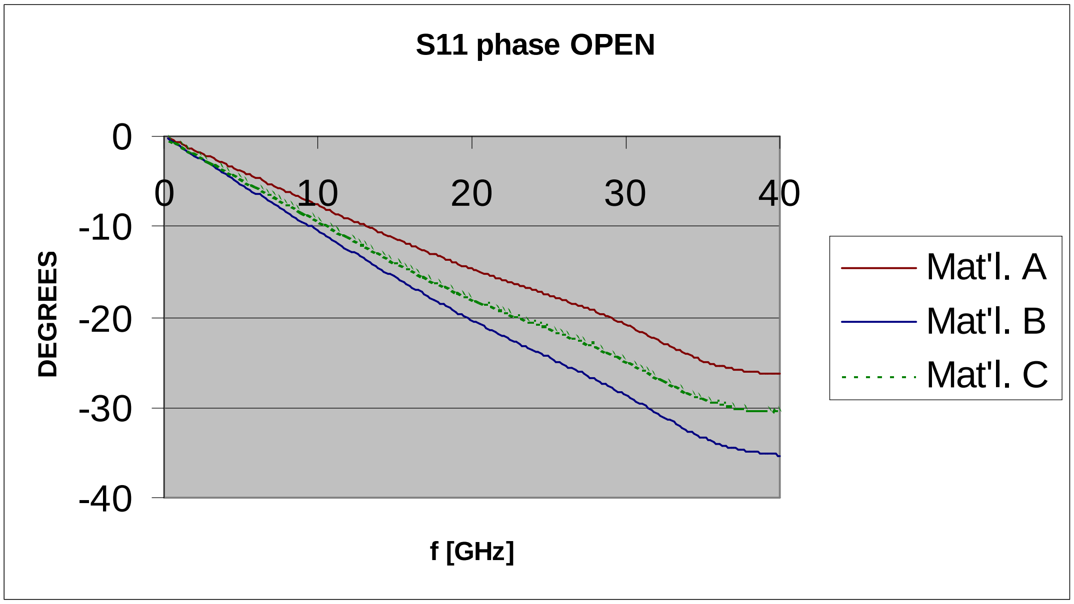


Fig. 7  S11 (f) for the open circuited elastomer

The corresponding record of S11 in the Smith chart shows capacitive characteristics with a deviation from the lossless case at elevated frequencies (Fig. 8):

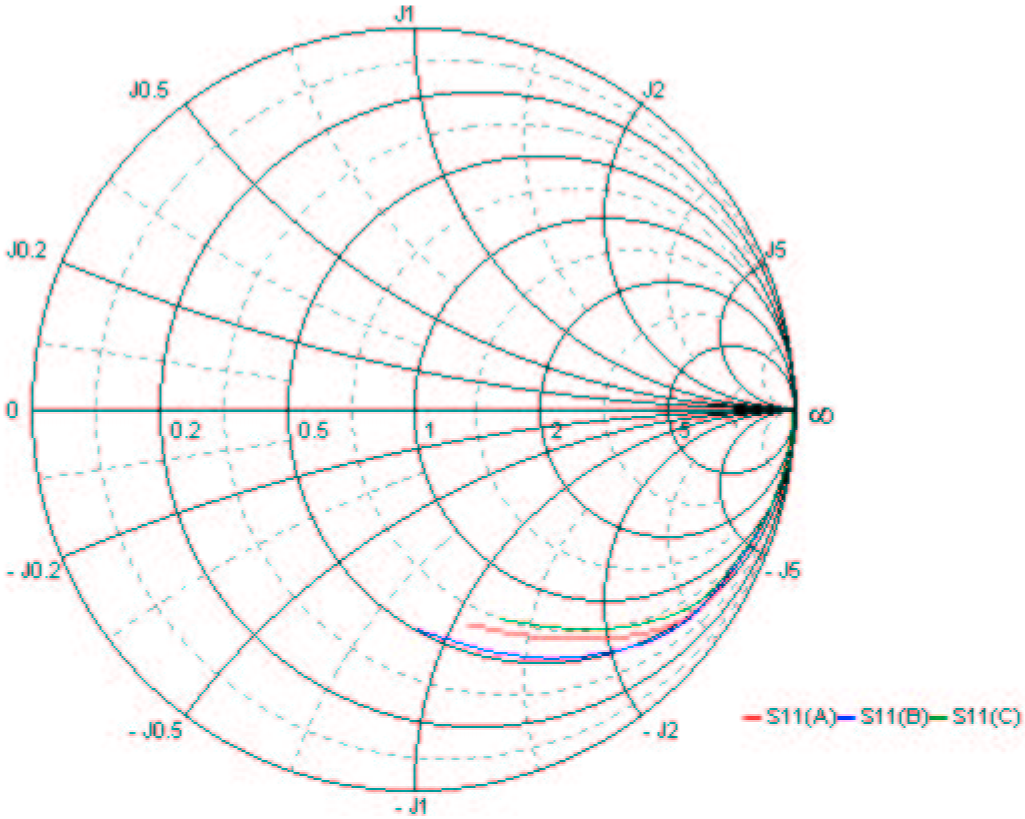


Fig. 8 S11 (f) to 40 GHz for the open circuited connector

Network analyzer reflection measurements were performed with one signal probe against the elastomer and the elastomer open circuited at the opposite end. A dielectric backing plate was pressed against it. This allowed determination of the contact to ground capacitance. The analyzer was calibrated with an open 3-pin probe (G-S-G). The phase of S11 was then recorded. From the slope of that curve the capacitance was determined to be 0.023 pF for material A, 0.032 pF for material B and 0.028 pF for material C. With values this small it must be kept in mind that actual values vary depending on pressure applied. Measurement error may also be an issue.

To extract the contact inductance, the same type of measurements was performed with a shorted elastomer. Fig. 9 shows the change in reflections for the three different cases. Calibration was established with a short placed at the end of the coax probe.

The plane of this short circuit is the end of the coaxial section of the probe. Hence, the inductance of the probe must be subtracted from subsequent measurement results.

Fig. 9 S11 (f) for the short circuited case, 0.028”pads x 0.050” pitch

This measurement yields an inductance of 0.094 nH for material A, 0.11 nH for material B and 0.12 nH for material C.

The Smith chart display for S11 in the short-circuited case is shown in Fig. 10:

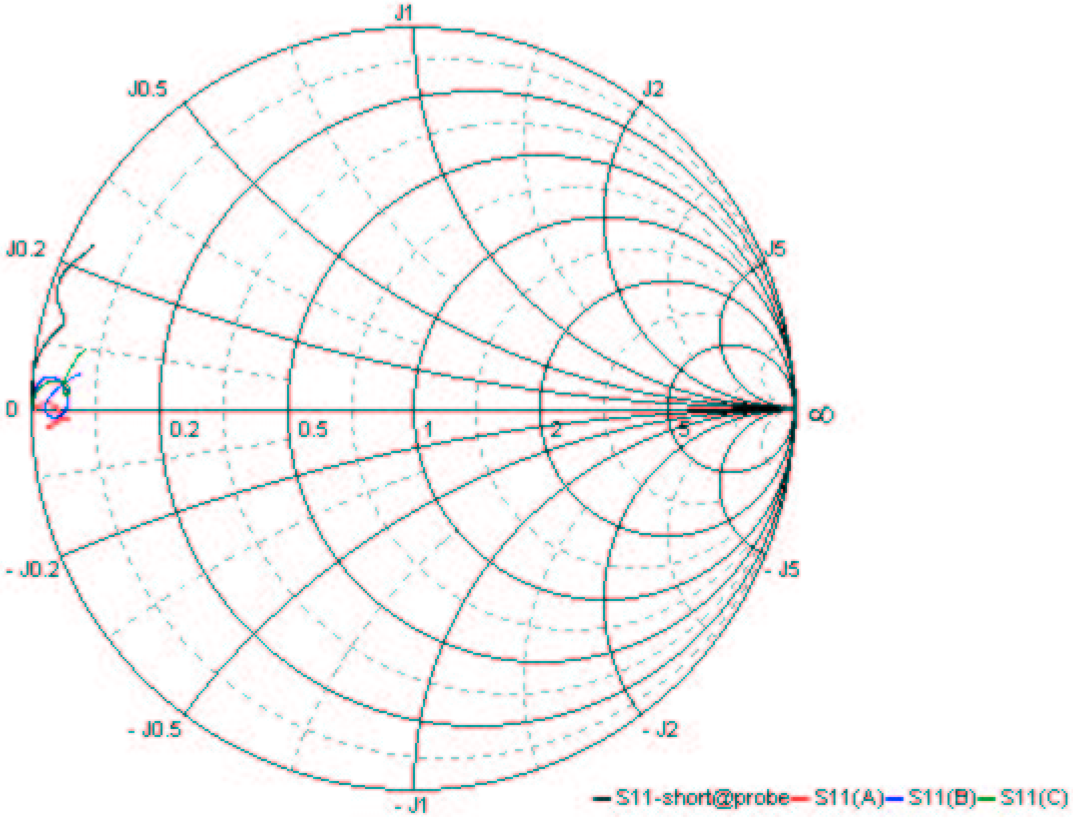


Fig. 10 S11 (f) to 40 GHz for short circuited case

The curve labeled ‘S11-short @ probe’ exhibits the highest inductance. Responses from inserting the elastomer exhibit a small resonance loop at very high frequencies. Its cause is likely the insertion of the elastomer dielectric into the small space between the raised portion of the probe pads. This effectively reduces the characteristic impedance of the probe-elastomer-probe connection and thus leads to a lower inductance value as well. The result is consistent with the time domain response for the THRU case (see Fig. 5) where the highest reflection peak is observed for the direct connection between probes with the elastomer absent.

An insertion loss measurement is shown in Fig. 11 for the frequency range of 50 MHz to 40.05 GHz with a scale of 2 dB per division.

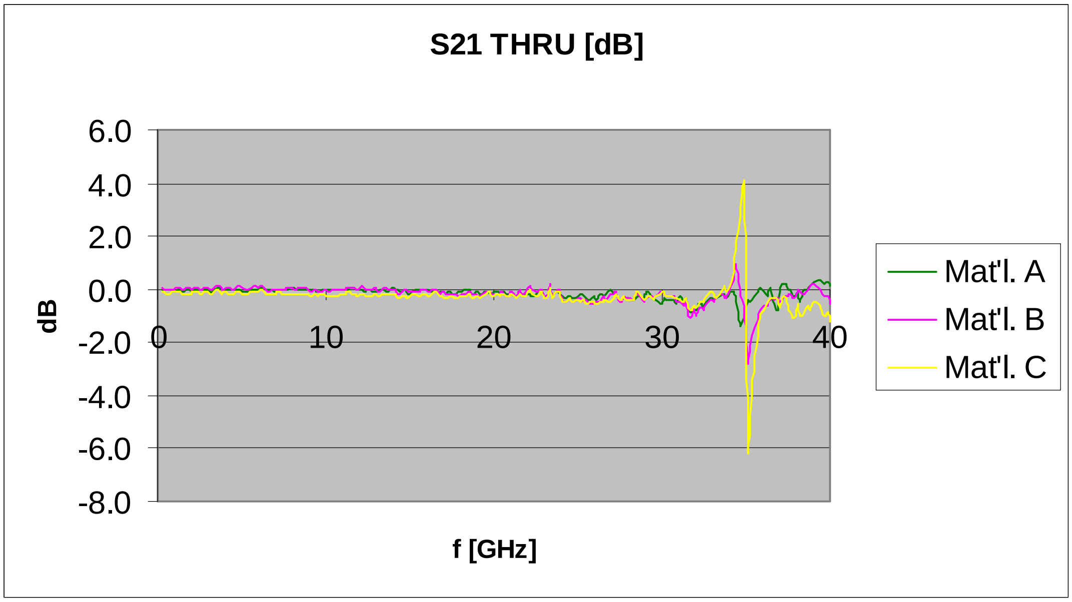


Fig. 11 Insertion loss S21 (f) [2 dB/div.]

Insertion loss is less than 0.5 dB to 25 GHz and less than 1 dB to 36 GHz in all cases. Above that frequency a system resonance obscures the actual response of the material.

## *Modeling results*

### Time domain

The first model for the conductive elastomer is a SPICE model for time domain simulations (Fig. 12). The differences between the three materials are from most applications standpoints small, hence only one general case is considered here.

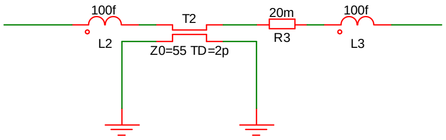


Fig. 12 SPICE transmission line model for the conductive elastomer

The G-S-G configuration with a signal contact surrounded by ground contacts provides a transmission line environment. The characteristic impedance of either of the center contact to ground is 55 Ohms. The transmission line pulse delay in the equivalent circuit is 2 ps. A parasitic inductance at either end of the transmission line is included to account for the probe contact sections and is not part of the model for the elastomer itself. The inductance values are comparable or greater than the elastomer inductance. The TDR simulation result shown in Fig. 13 shows a small inductive rise just like the measurement .

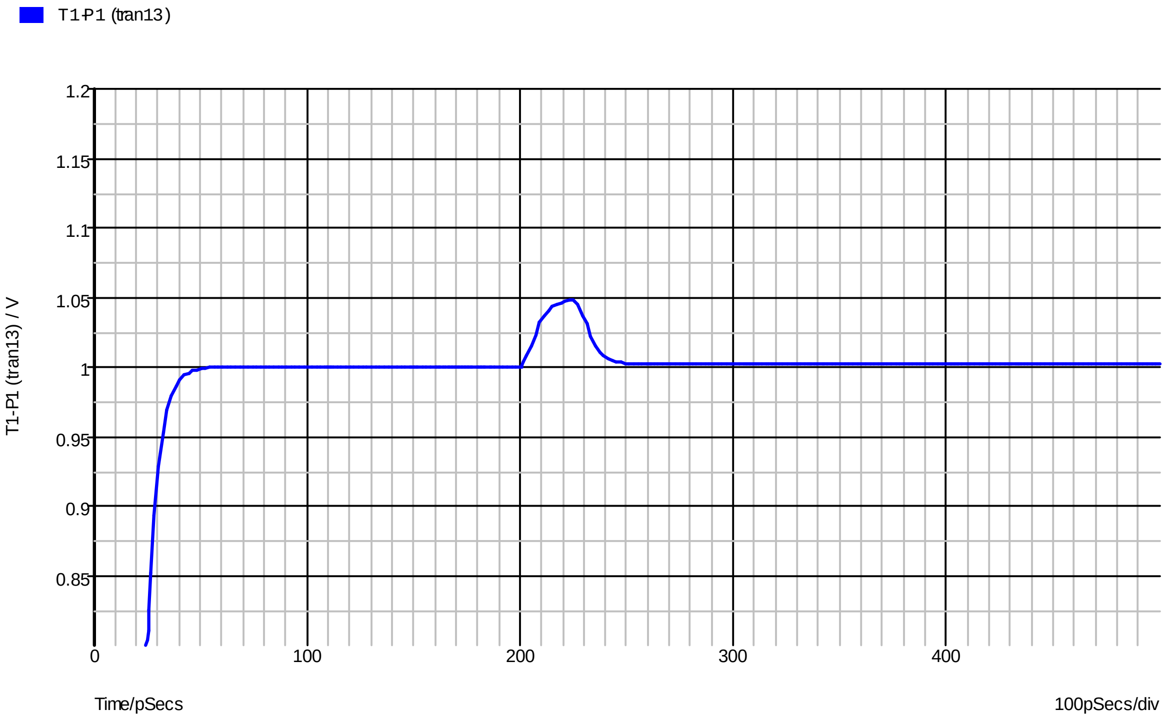


Fig. 13 Conductive elastomer TDR model

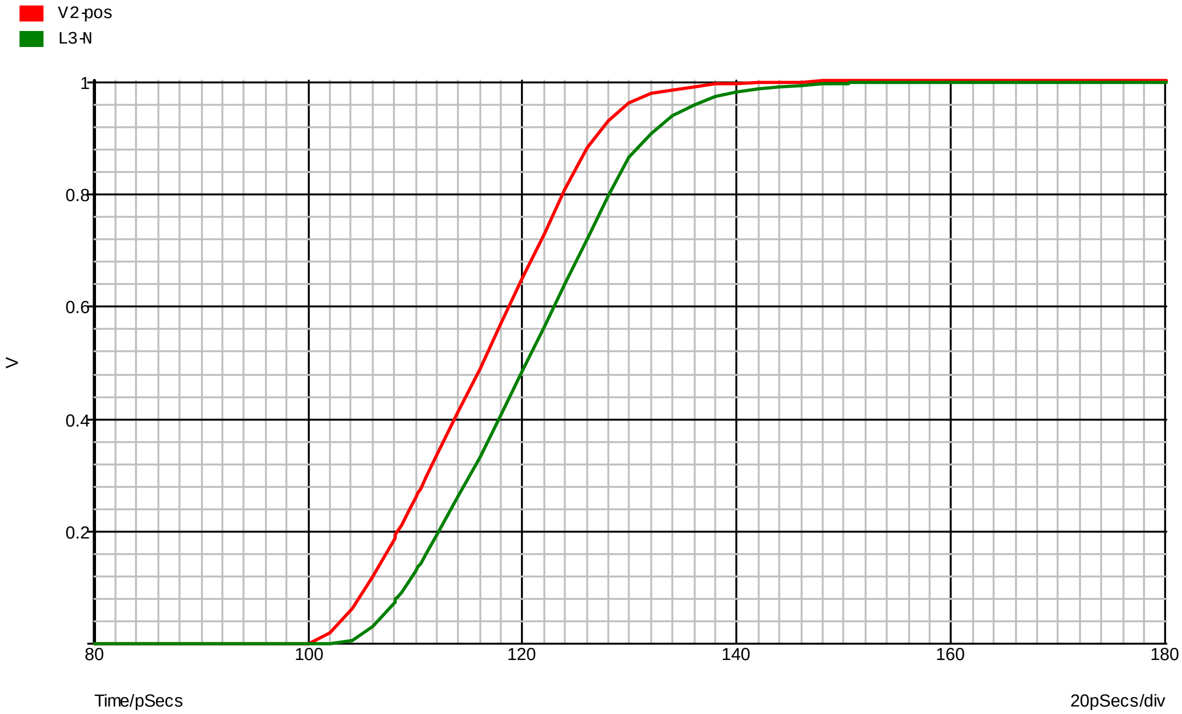


Fig. 14 Conductive elastomer TDT model

The risetime contribution of a signal transmitted through the contact to the overall system risetime is negligible (see Fig. 14) and consistent with measurement results. And like in the measurement, the signal delay is larger than the 2 ps of the transmission line itself, caused by the parasitic inductances of the contact pads.

A plot of phase as a function of frequency for the above arrangement in an open circuit configuration is shown in Fig. 15:

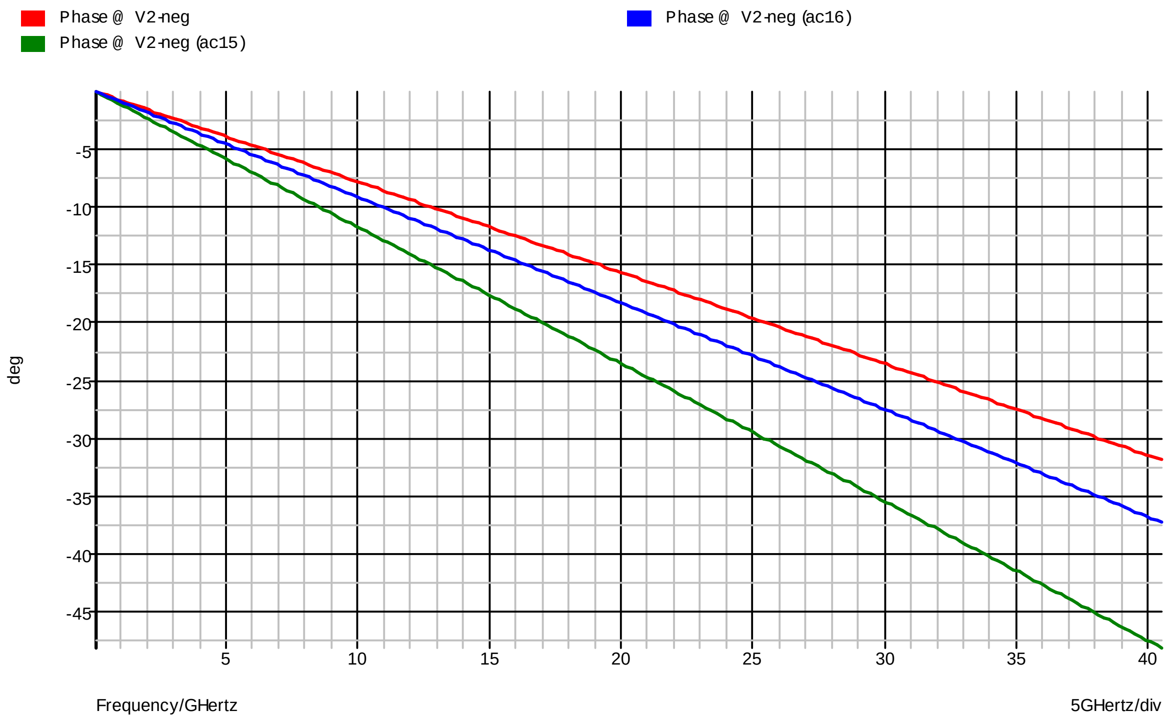


Fig. 15 S11 (f) phase for open circuit conditions

The respective line lengths assumed in this case are 1.2 ps, 1.4 ps and 1.8 ps. There is a small discrepancy between the model and the actual case, since the model does not take fringe capacitance into account.

The short-circuited situation, too, yields results that compare well with the measurement (Fig. 16):

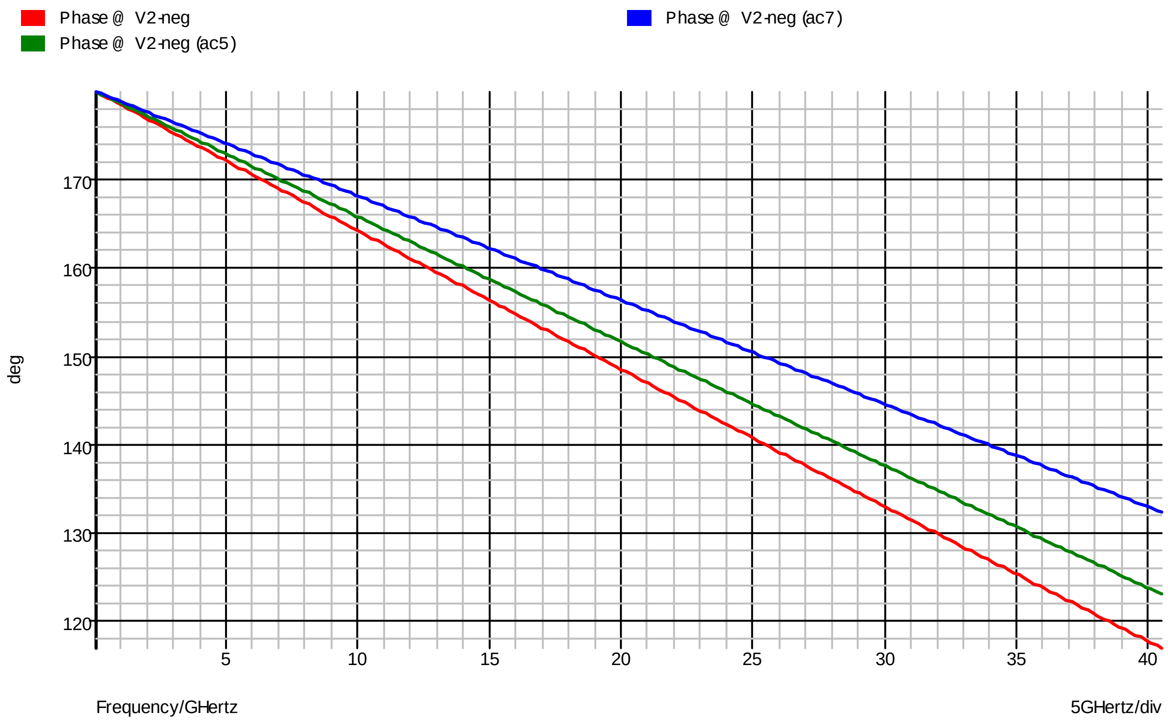


Fig. 16 S11 (f) phase for short circuit conditions

The line lengths here are 1.5 ps, 1.8 ps and 2 ps. These numbers differ from the open circuit case and it may be assumed that feed inductance manifests itself in additional delay. Also, at inductances this small, measurement error may be present.

As a result of the lossless model of the transmission line, the modeled insertion loss is lower than that observed in the measurement (Fig. 17):

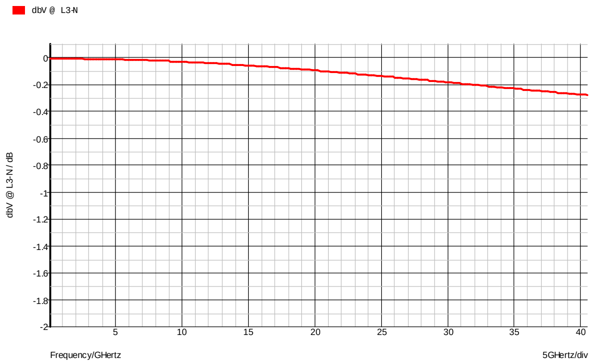


Fig. 17 Insertion loss as a function of frequency

## Frequency domain

The lumped element model for the elastomer itself consists of a Pi -section consisting of a 120 pH inductor and two 0.016 pF shunt capacitors (Fig. 18).

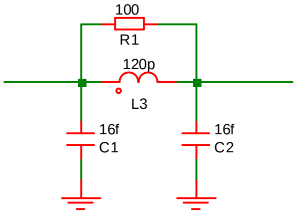


Fig. 18 Lumped element equivalent circuit

The lumped element representation can be used at frequencies where the length of the transmission line is about 1/10 of the wavelength (about 33 GHz). The model's phase and amplitude responses (Fig. 19,20,21) are nearly identical to the ones measured.

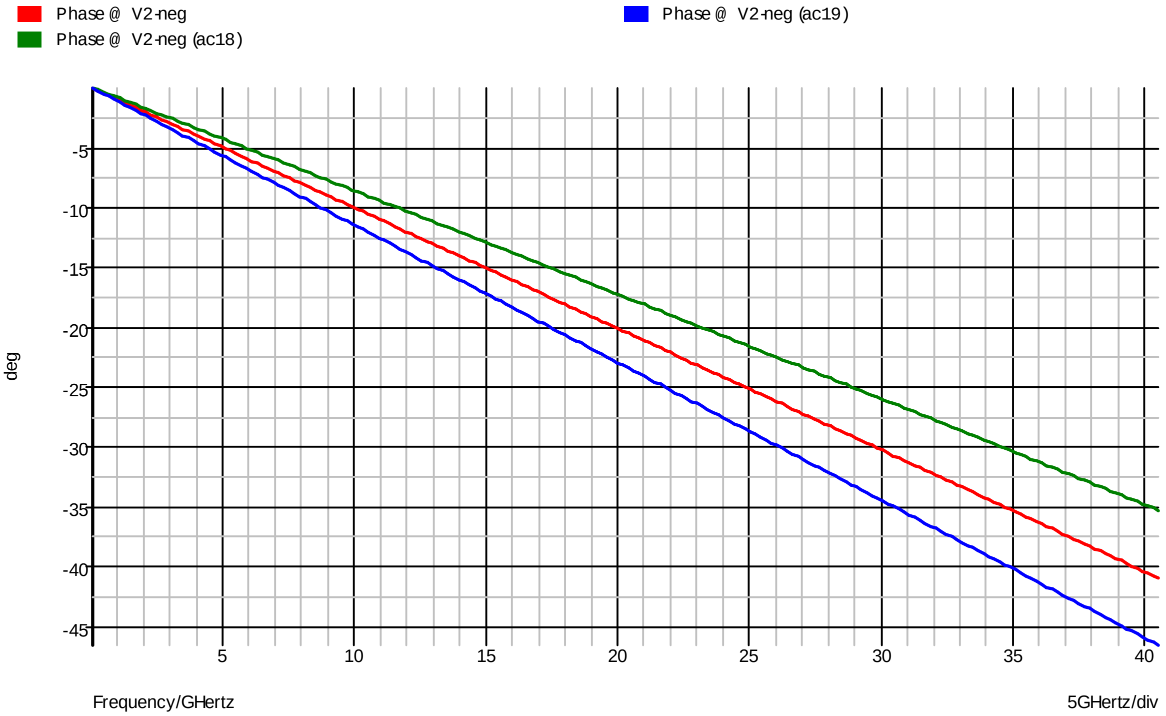


Fig. 19 Conductive elastomer S11 phase (f) for open circuited contacts

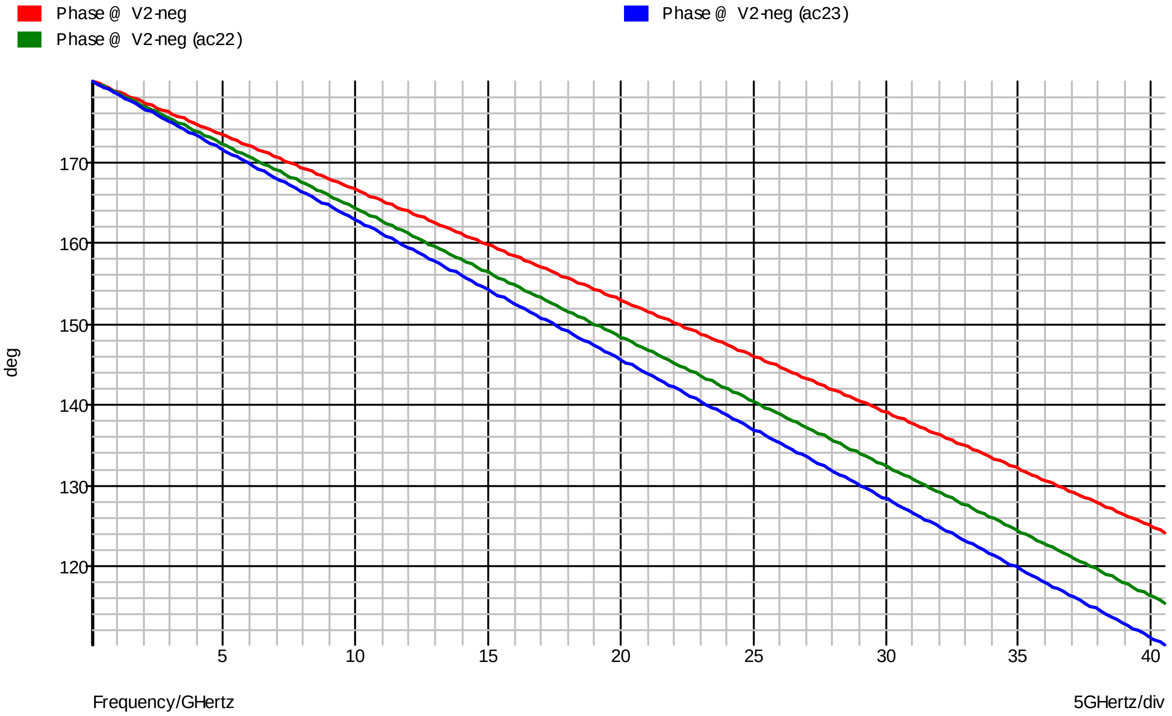


Fig. 20 Lumped element model S11 phase response (short circuit)

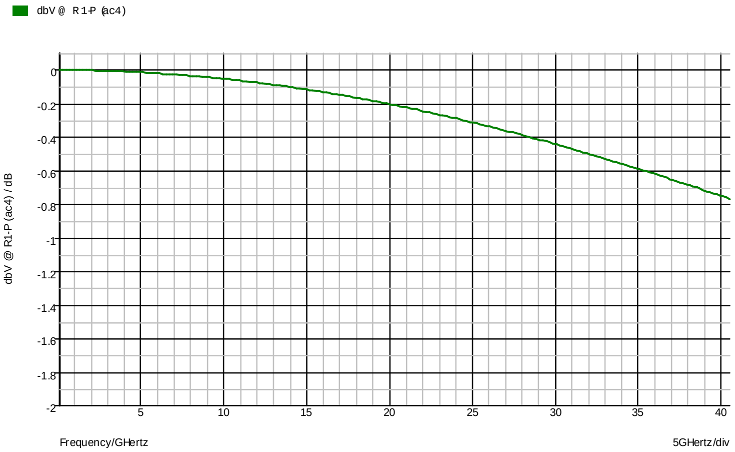


Fig. 21 Insertion loss of the lumped element model as a function of frequency

While the insertion loss response model is free of resonances, its results compare qualitatively reasonably well to the measurement.

## *Conclusions*

The Paricon Technologies conductive elastomer was characterized in a configuration with a signal contact surrounded by 2 ground contacts. These contacts form a transmission line with a characteristic impedance of 55 Ohms. Interfaces to the HP 8722C network analyzer were established through SR-083 semi-rigid coaxial cable probes with K-connectors.

The major component of the SPICE model for the array is a 55 Ohm transmission line of 2 ps electrical length. Small additional inductances are added at either end in the equivalent circuit to account for the square pads and their height. Risetime contributions of all elastomers to the overall system risetime are very small and negligible compared to the system risetime of about 30 ps.

The insertion loss S21 for a through arrangement was below 0.5 dB up to a frequency of 25 GHz and less than 1 dB below 36 GHz for all materials. The lumped element equivalent circuit applicable in the frequency domain shows a total contact inductance of 0.094 nH (A), 0.11 nH (B) and 0.12 nH (C). The center contact to ground capacitance was determined to be 0.023 pF (A), 0.032 pF (B) and 0.028 pF (C) for the G-S-G configuration. The center contact to single ground capacitance is half this value.

# Paricon Technologies, Inc.

## Conductive Elastomer

Data sheet

10/4/01

## *Connector test configuration:*

G-S-G and micro-coax configurations, excitation through micro-coax probes with contact pads 0.028” x 0.028” in size and 0.050” pitch

## *Performance:*

**Time domain:**

Signal delay = 2 ps typ.
Risetime, thru into 50 $\Omega$ = 30 ps (test system risetime)

**Frequency domain:**

Insertion loss < 0.5 dB to 25 GHz
< 1 dB to 36 GHz

**Equivalent circuit parameters:**

Inductance = 0.094 nH (A)
0.11 nH (B)
0.12 nH (C)
S to GND capacitance = 0.023 pF (A)
0.032 pF (B)
0.028 pF (C)
Transmission line = $Z_0 = 55\ \Omega$ , $T_l = 2$ ps (typ)