Custom Interconnects

0.020" Fuzz Button Interconnect / Test Socket

0.80 mm pitch

Measurement and Model Results

8/25/2014

Prepared by

Gert Hohenwarter

Table of Contents

Objective

The objective of these measurements is to determine the RF performance of a Custom Interconnects 0.020" Fuzz Button contact in a 0.80 mm pitch socket. For G-S-G configurations, a signal pin surrounded by grounded pins is selected for the signal transmission. For the G-S-S-G configuration, two adjacent pins are used for signal and all other pins are grounded. Measurements in both frequency and time domain form the basis for the evaluation. Parameters to be determined are pin capacitance and inductance of the signal pin, the mutual parameters, the propagation delay and the attenuation to a maximum frequency of 40 GHz.

Methodology

Capacitance and inductance for the equivalent circuits were determined through a combination of measurements in time and frequency domain. Frequency domain measurements were acquired with a network analyzer (Agilent 8722). The instrument was calibrated up to the end of the 0.022” diameter coax probes that are part of the test fixturing. The device under test (DUT) was then mounted to the fixture and the response measured from one side of the contact array. When the DUT pins terminate in an open circuit, a capacitance measurement results. When a short circuit compression plate is used, inductance can be determined.

Time domain measurements are obtained via Fourier transform from VNA tests. These measurements reveal the type of discontinuities at the interfaces plus contacts and establish bounds for risetime and clock speeds.

Test procedures

To establish capacitance of the signal pin with respect to the rest of the array, a return loss calibration is performed. Phase angle information for S11 is selected and displayed. When the array is connected, a change of phase angle with frequency can be observed. It is recorded and will be used for determining the pin capacitance.

The self-inductance of a pin is found in the same way, except the contact array is compressed by a metal plate instead of an insulator. Thus a short circuit at the far end of the pin array results. Again, the analyzer is calibrated and S11 is recorded. The inductance of the connection can be derived from this measurement.

Setup

Testing was performed with a test setup that consists of a brass plate that contains the coaxial probes. The DUT is aligned and mounted to that plate. The opposite termination is also a metal plate with coaxial probes, albeit in the physical shape of an actual device to be tested or a flat plate with embedded coaxial probes.

Figs. 1 and 2 show a typical arrangement base plate and DUT probe:

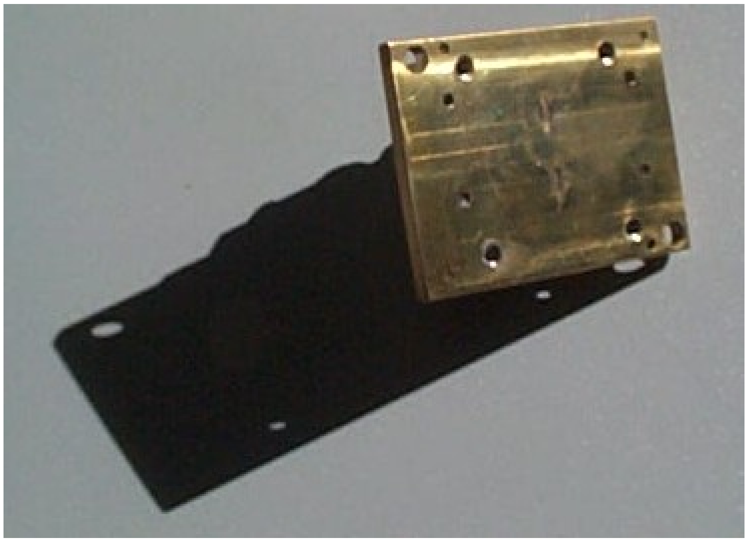


Figure 1 base plate example

Figure 2 DUTplate example

The contact housing and base plate as well as the DUT plate are then mounted in a test fixture as shown below in Fig. 3:

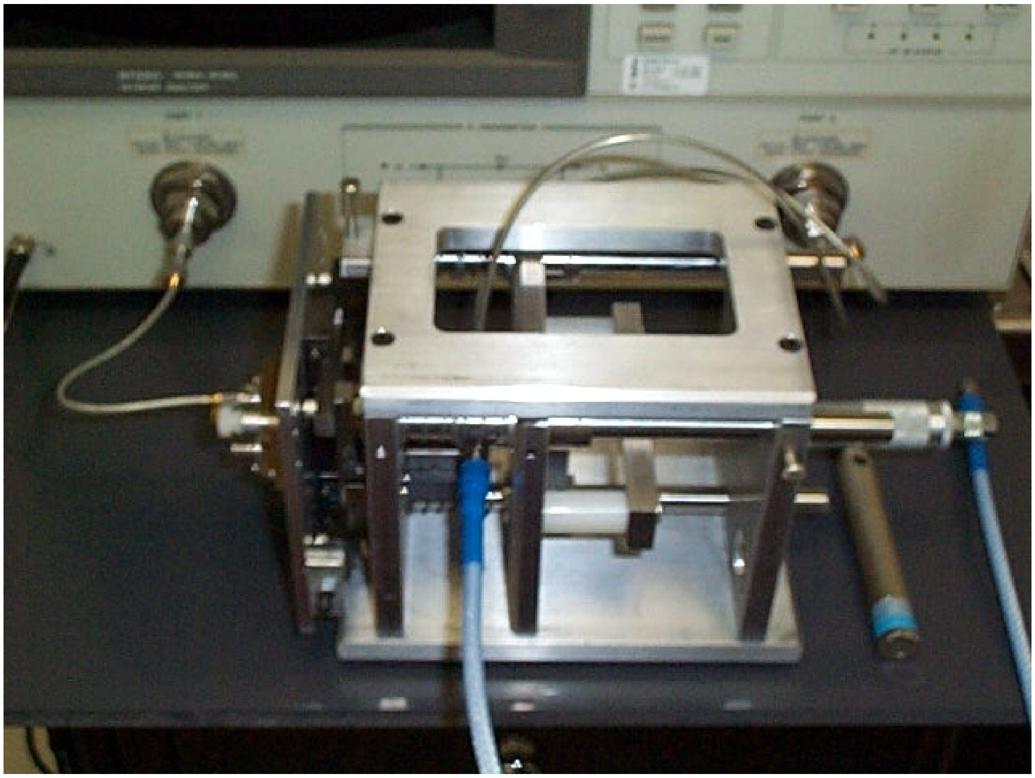
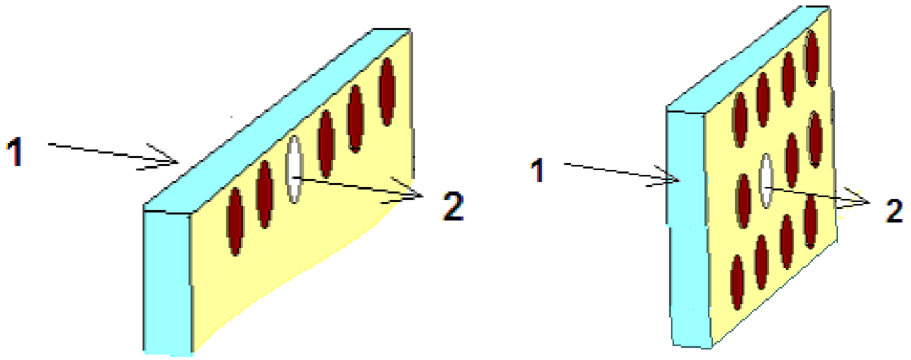


Figure 3 Test fixture example

This fixture provides for independent X,Y and Z control of the components relative to each other. X, Y and angular alignment is established once at the beginning of a test series and then kept constant. Z (depth) alignment is measured via micrometer and is established according to specifications for the particular DUT.

Connections to the VNA are made with high quality coaxial cables with K connectors.

For G-S-G and G-S-S-G measurements, the ports are named as follows:



Single row DUTs

Multi-row DUTS

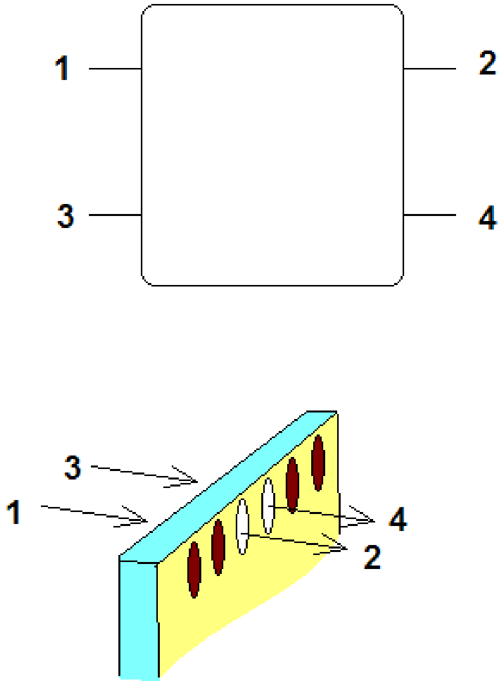
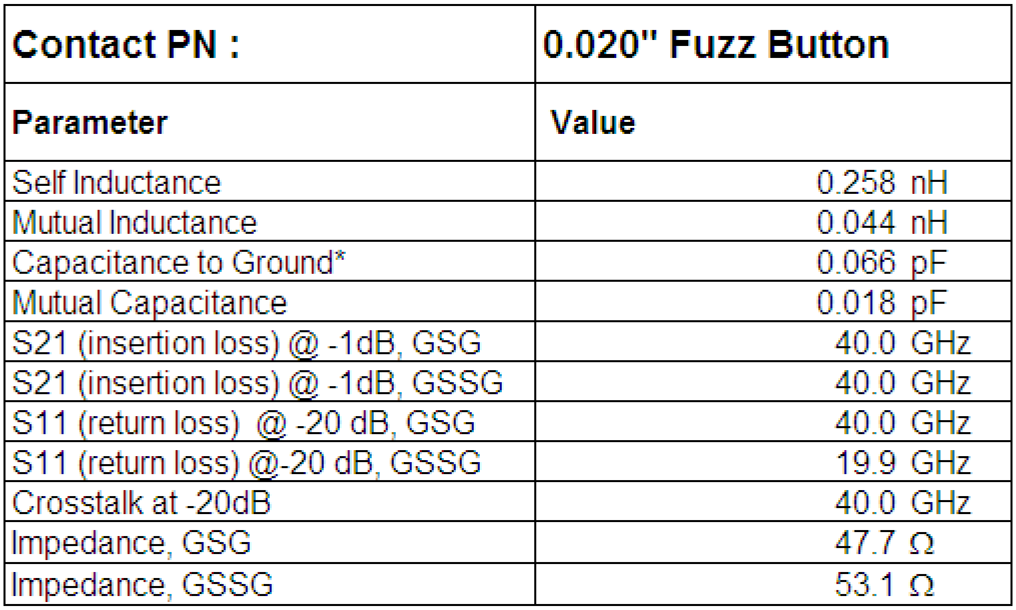


Figure 4 Ports for the G-S-G and G-S-S-G measurements

Signals are routed though two adjacent connections (light areas), unused connections are grounded (dark areas).

Custom Interconnects

Summary



Contact PN :	**0.020" Fuzz Button**
Parameter	**Value**
Self Inductance	0.258 nH
Mutual Inductance	0.044 nH
Capacitance to Ground*	0.066 pF
Mutual Capacitance	0.018 pF
S21 (insertion loss) @ -1dB, GSG	40.0 GHz
S21 (insertion loss) @ -1dB, GSSG	40.0 GHz
S11 (return loss) @ -20 dB, GSG	40.0 GHz
S11 (return loss) @-20 dB, GSSG	19.9 GHz
Crosstalk at -20dB	40.0 GHz
Impedance, GSG	47.7 Ω
Impedance, GSSG	53.1 Ω

Measurements G-S-G

Time domain

The time domain measurements will be presented first. TDR reflection measurements are shown below:

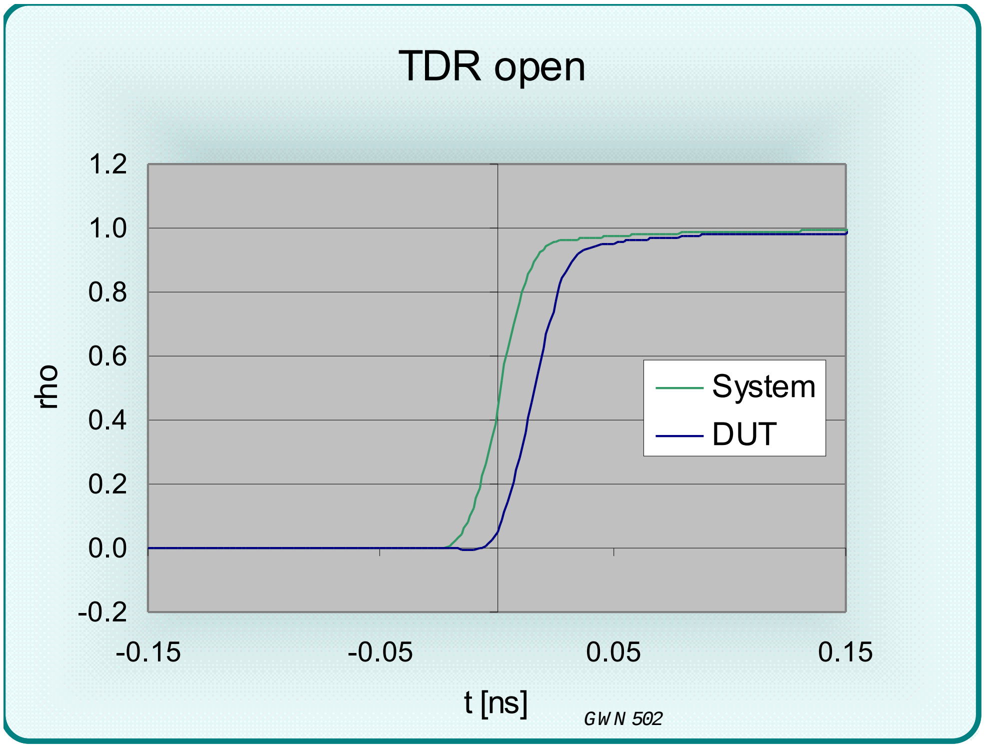


Figure 5 TDR signal from an OPEN circuited contact

The reflected signal from the contact array (right trace) shows only a small deviation in shape from the original waveform (left trace). The risetime is about 27.5 ps and is identical to that of the system with the open probe (27.5 ps). Electrical open circuit pin length is about 7.5 ps (one way).

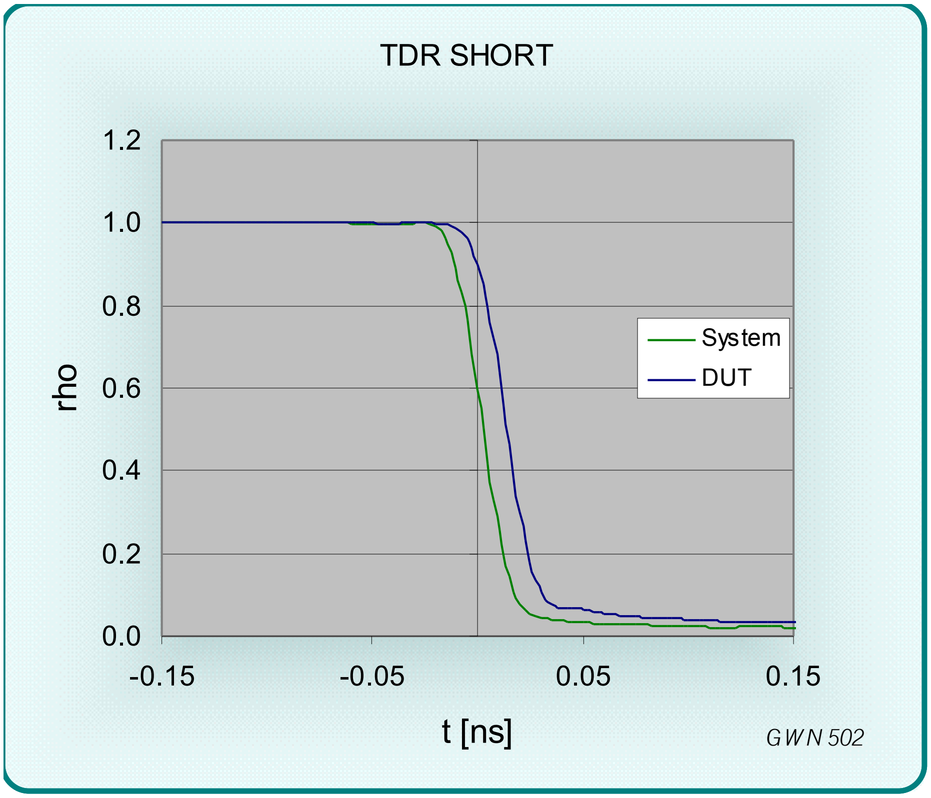


Figure 6 TDR signal from a SHORT circuited contact

For the short circuited contact array the fall time is about 30.0 ps. There is an insignificant increase over the system risetime of 27.5 ps caused by the contact impedance levels.

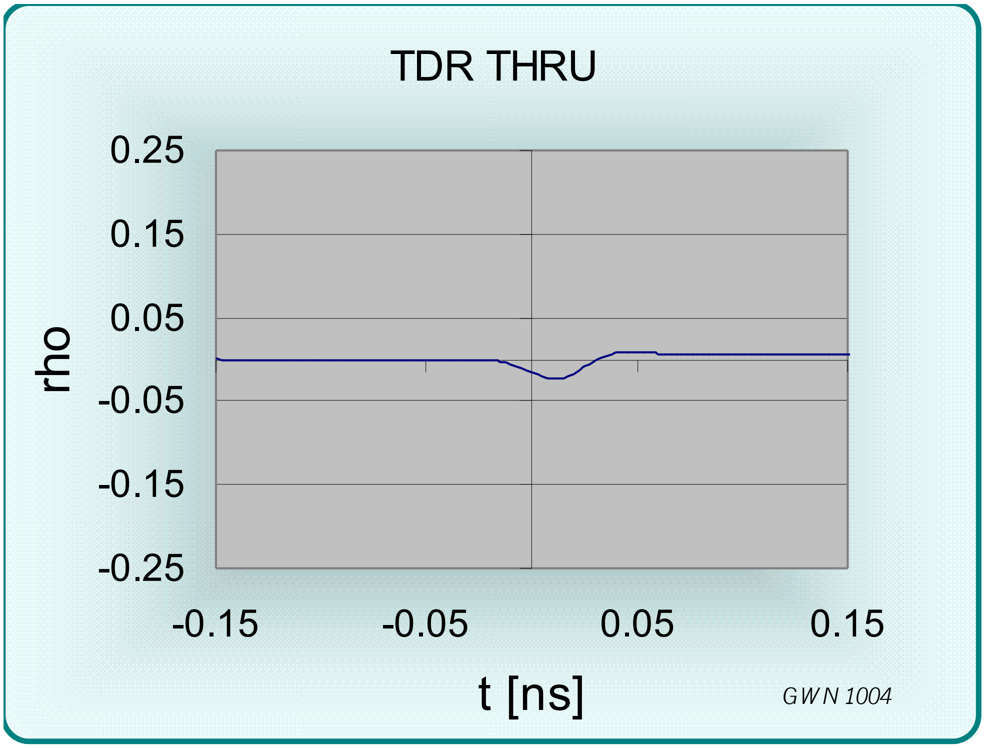


Figure 7 TDR measurement into a 50 Ohm probe

The thru TDR response shows primarily no perturbation to the signal. The peak corresponds to an impedance of 50.8 Ohms and is almost the same as 50 Ohms. The dip below the 0 line goes to 47.7 Ohms.

The TDT performance for a step propagating through the contact arrangement was also recorded:

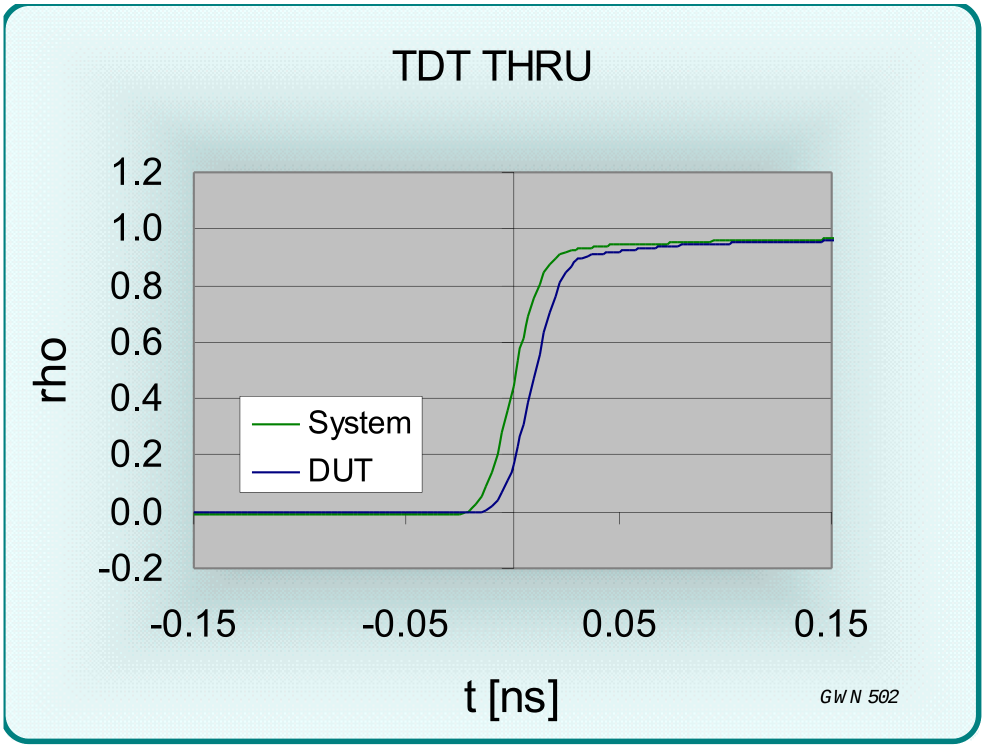


Figure 8 TDT measurement

The TDT measurements for transmission show almost the same risetime from the pin array (10-90% RT = 30.0 ps, the system risetime is 27.5 ps). The added delay at the 50% point is 10.0 ps. If the 20%-80% values are extracted, the risetime is only 20.0 ps vs. 20.0 ps system risetime.

Frequency domain

Network analyzer reflection measurements for a single sided drive of the signal pin with all other pins open circuited at the opposite end were performed to determine the pin capacitance. The analyzer was calibrated to the end of the probe and the phase of S11 was measured. From the curve the capacitance of the signal contact to ground can be determined (see Fig. 10).

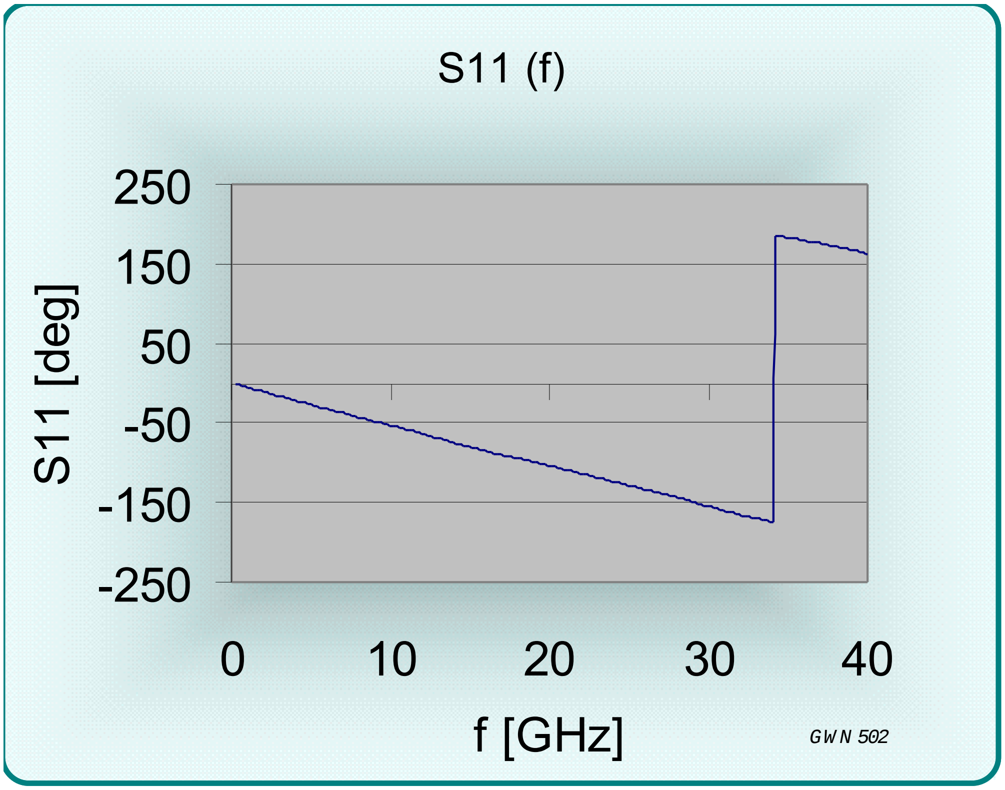


Figure 9 S11 phase (f) for the open circuited signal pin

There are no aberrations in the response. The 360 degree jump is due to the network analyzer data presentation which does not allow for values greater than +/- 180 degrees.

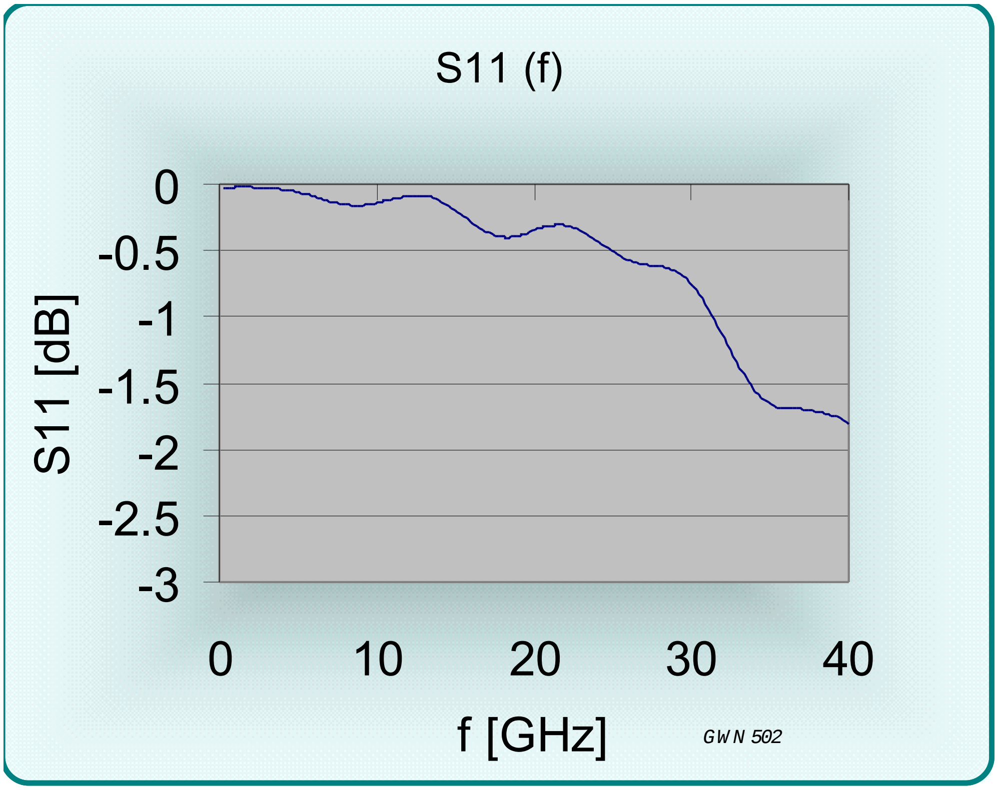


Figure 10 S11 magnitude (f) for the open circuited signal pin

While ideally the magnitude of S11 should be unity (0 dB), minimal loss and radiation in the contact array are likely contributors to S11 (return loss) for the open circuited pins at elevated frequencies.

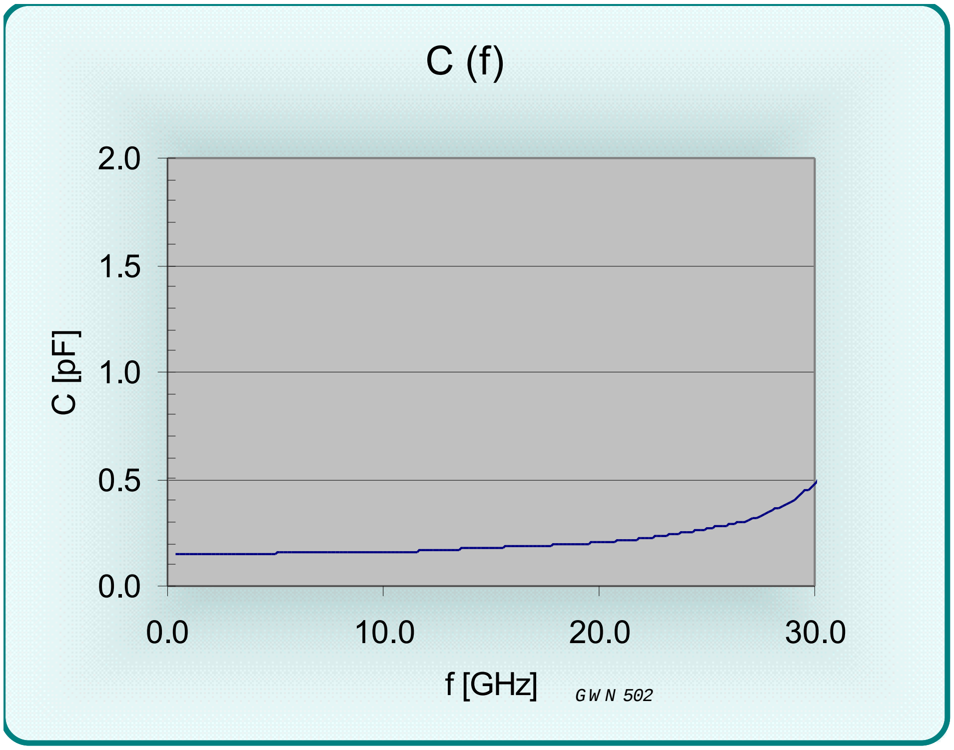


Figure 11 C(f) for the open circuited signal pin

Capacitance is 0.15 pF at low frequencies. The rise in capacitance toward 21 GHz is due to the fact that the pins form a transmission line with a length that has become a noticeable fraction of the signal wavelength. The lumped element representation of the transmission environment as a capacitor begins to become invalid at these frequencies and so does the mathematical calculation of capacitance from the measured parameters. This merely means the model is not valid anymore. As is evident from time domain and insertion loss measurements this does not imply that the DUT does not perform at these frequencies.

The Smith chart measurement for the open circuit shows no resonances. A small amount of loss is present. The Smith chart covers frequencies to 40 GHz.

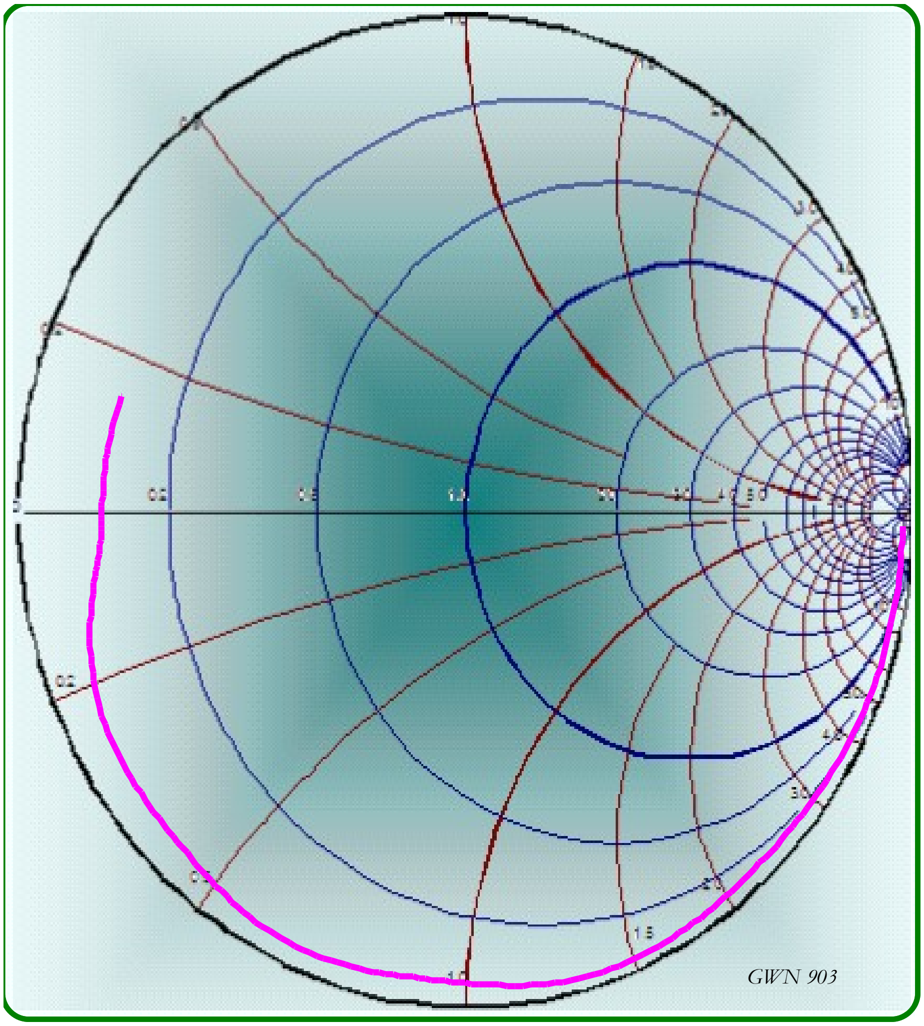


Figure 12 Reflections from the open circuited contacts

To extract pin inductance, the same types of measurements were performed with a shorted pin array. Shown below is the change in reflections from the shorted contact array. Calibration was established with a short placed at the end of the coax probe.

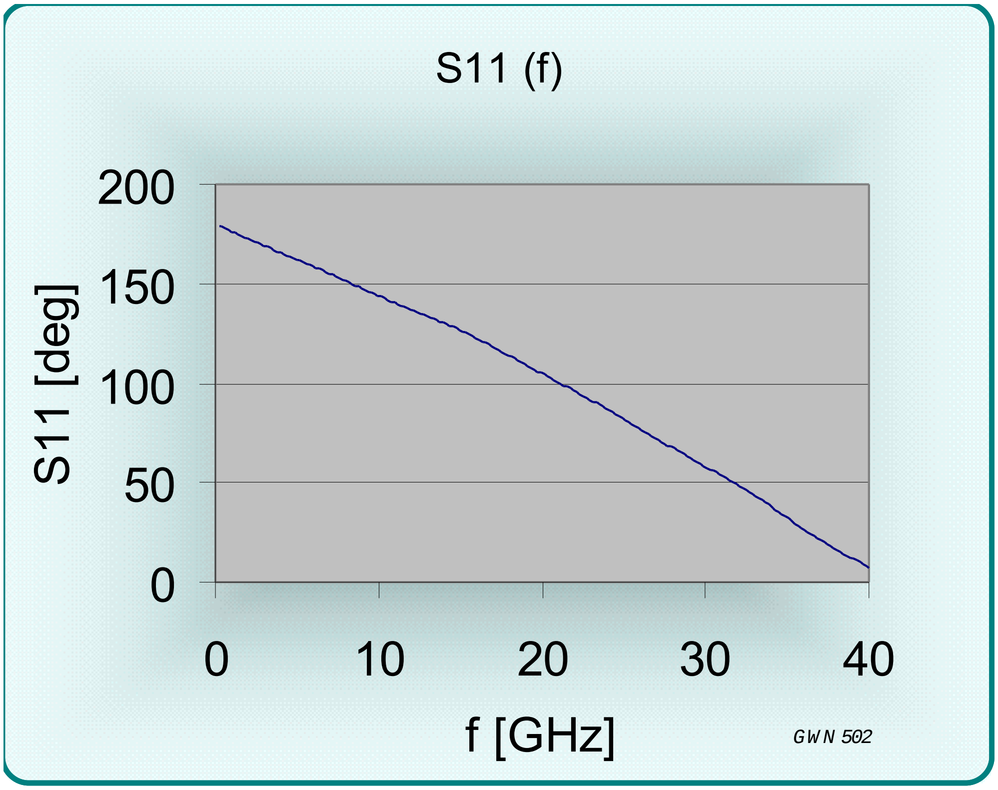


Figure 13 S11 phase (f) for the short circuited case

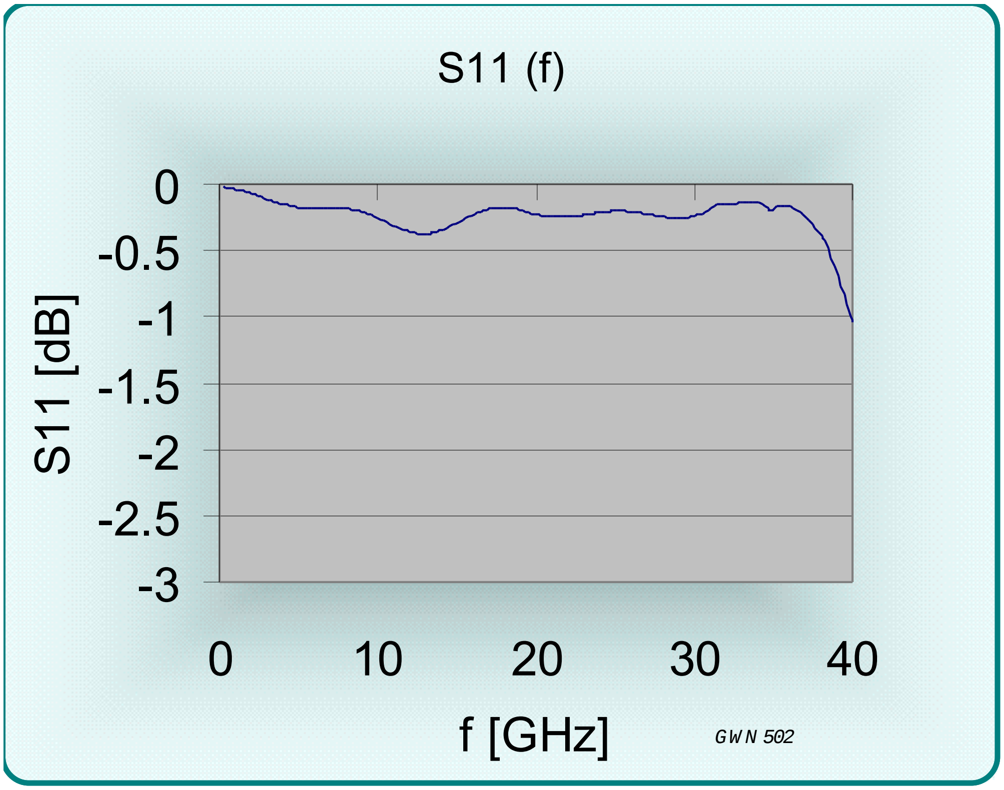


Figure 14 S11 magnitude (f) for the short circuited case

A small S11 return loss exists, likely the result of minimal loss and radiation.

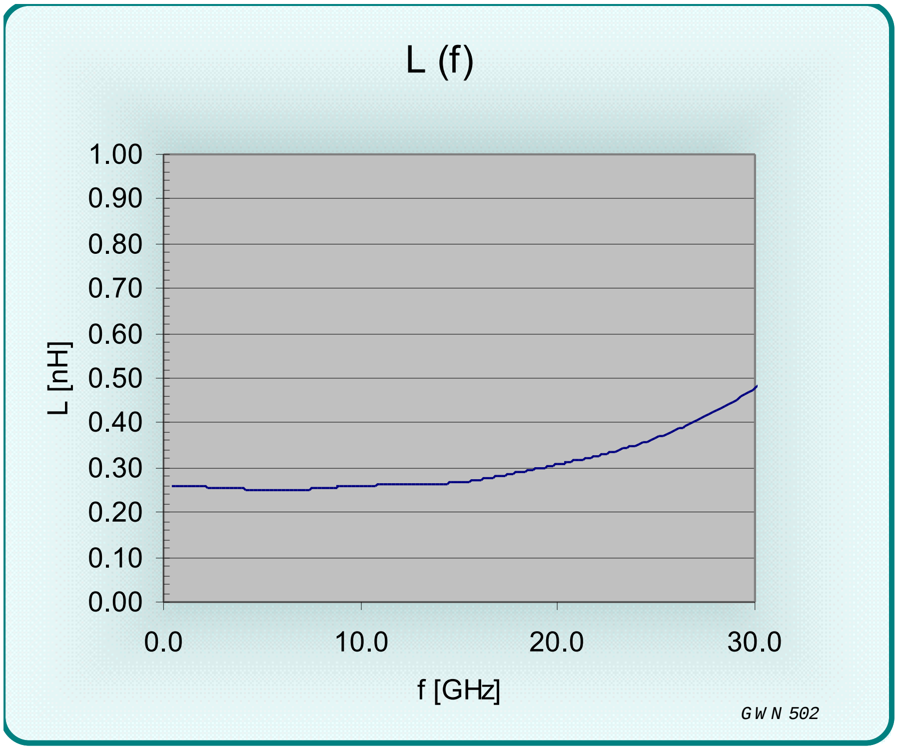


Figure 15 L(f) for the contact

The phase change corresponds to an inductance of 0.26 nH at low frequencies. Toward 26 GHz inductance increases. At these frequencies, the transmission line nature of the arrangement must be taken into account.

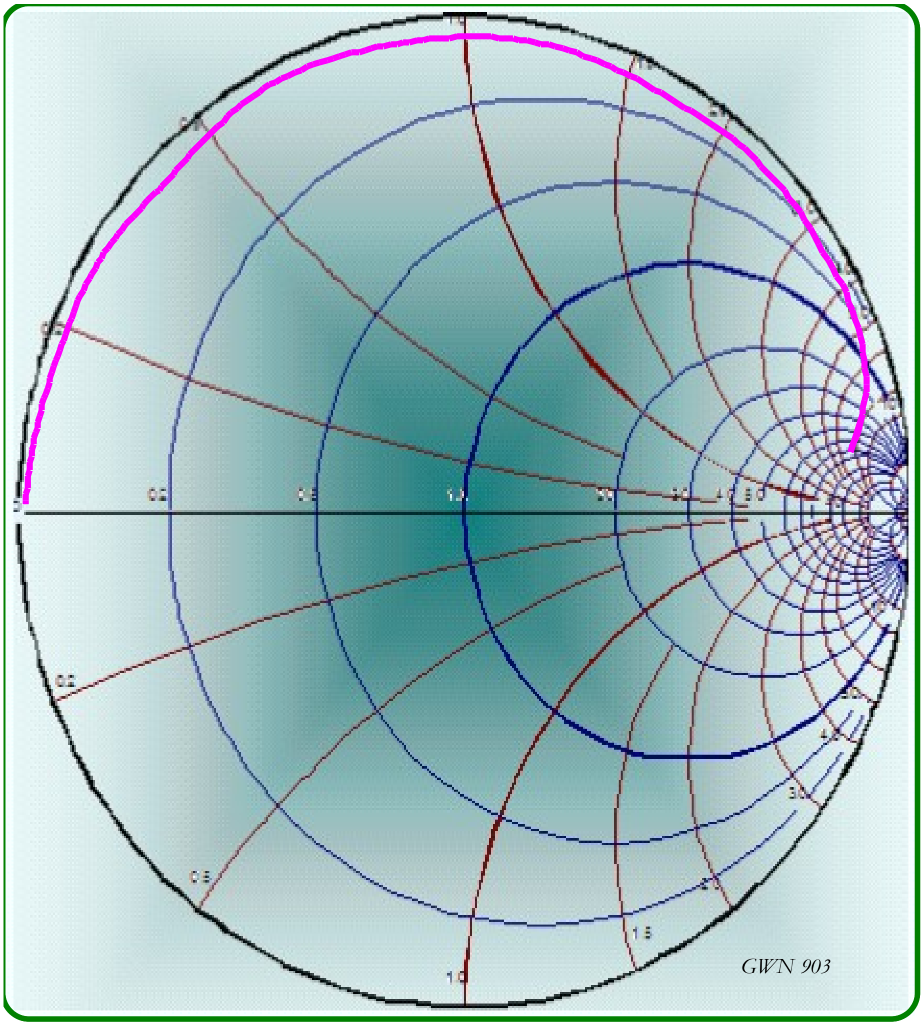


Figure 16 Short circuit response in the Smith chart

Only a small amount of loss is noticeable in the Smith chart for the short circuit condition. The Smith chart covers frequencies to 40 GHz.

An insertion loss measurement is shown below for the frequency range of 50 MHz to 40 GHz:

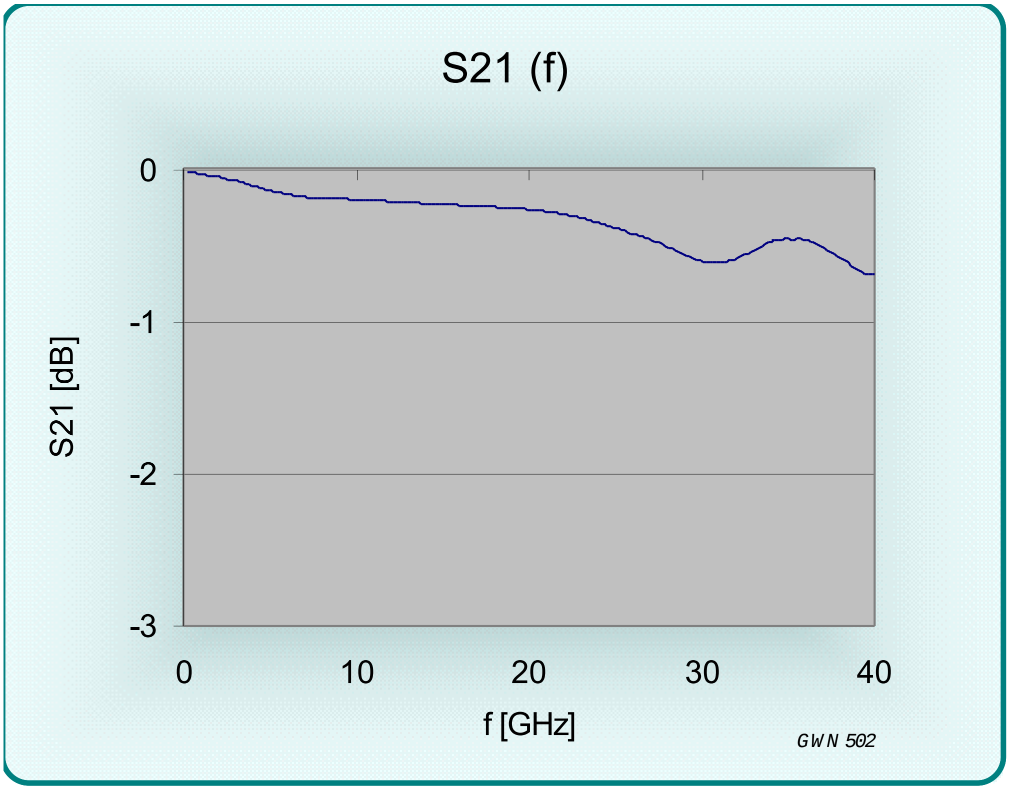


Figure 17 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 40.0 GHz. The 3 dB point is not reached before 40.0 GHz.

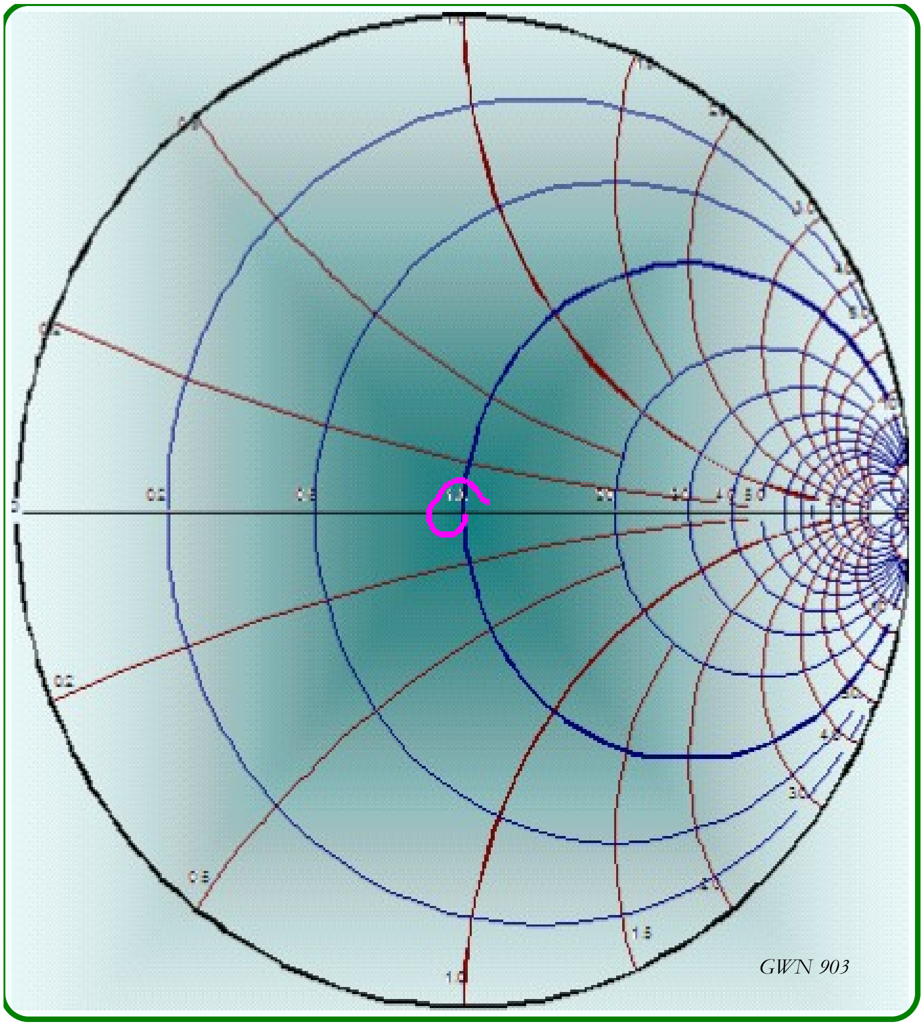


Figure 18 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows reactive components toward higher frequencies. The Smith chart covers frequencies to 40 GHz.

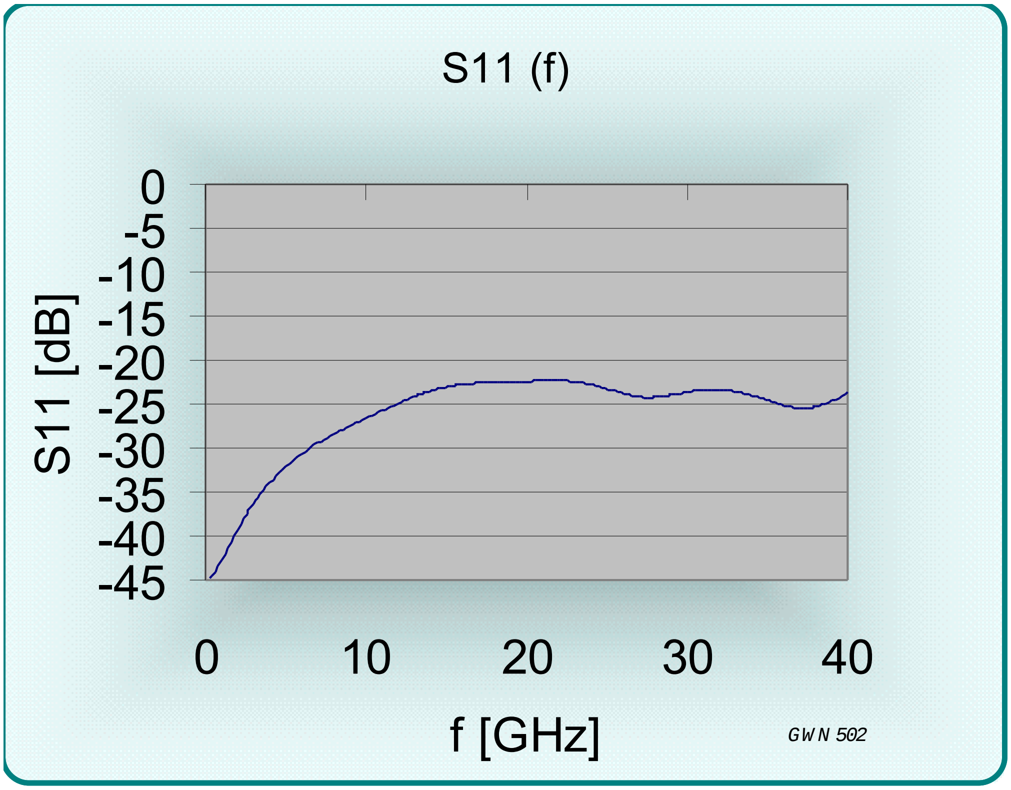


Figure 19 S11 magnitude (f) for the thru measurement into a 50 Ohm probe

The value of the return loss reaches -20 dB at a frequency of 40.0 GHz and -10 dB not before 40.0 GHz.

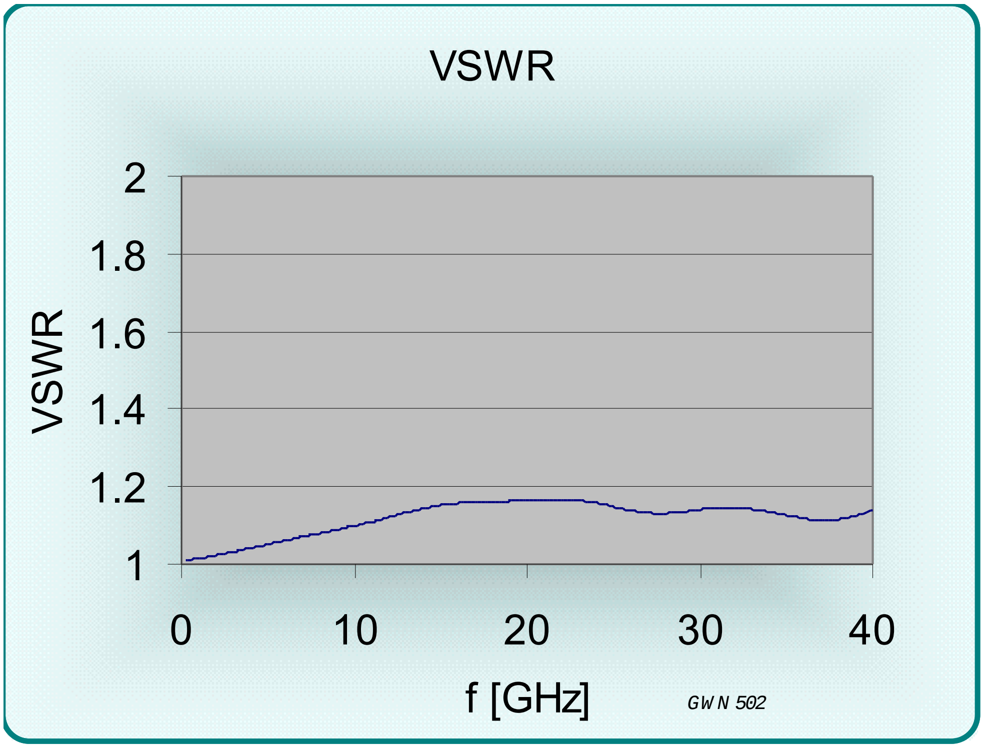


Figure 20 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 40.0 GHz.

Crosstalk was measured in the G-S-S-G configuration by feeding the signal pin and monitoring the response on an adjacent pin. Measurement results can be found in the section on the G-S-S-G configuration.

The mutual capacitance and inductance values will be extracted from G-S-S-G models and are also listed in that section.

Measurements G-S-S-G

Time domain

G-S-S-G time domain measurements will be presented first. A TDR reflection measurement is shown in Fig. 21 for the thru case at port 1 to port 2:

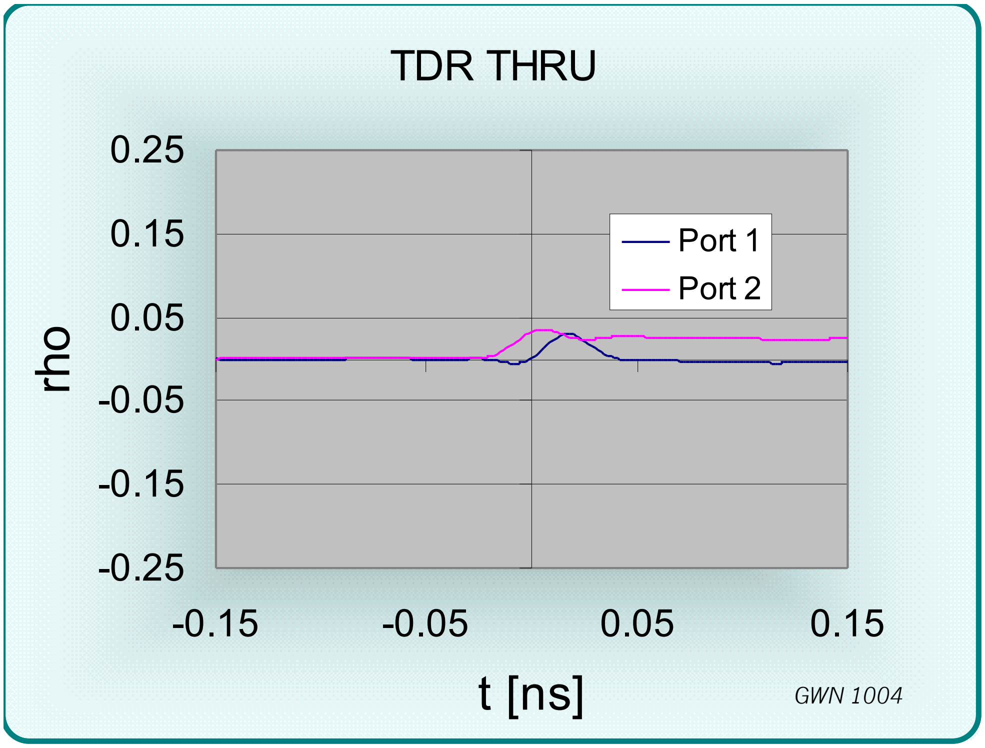


Figure 21 TDR through DUT into a terminated probe

The thru TDR measurement from port 1 to port 2 shows an inductive response. The low peak corresponds to a transmission line impedance of 53.1 Ohms. This is somewhat larger than the system impedance and higher than in the G-S-G case due to the fact that the connection adjacent to the signal pin is not grounded.

The TDT performance for a step propagating through the G-S-S-G pin arrangement was also recorded:

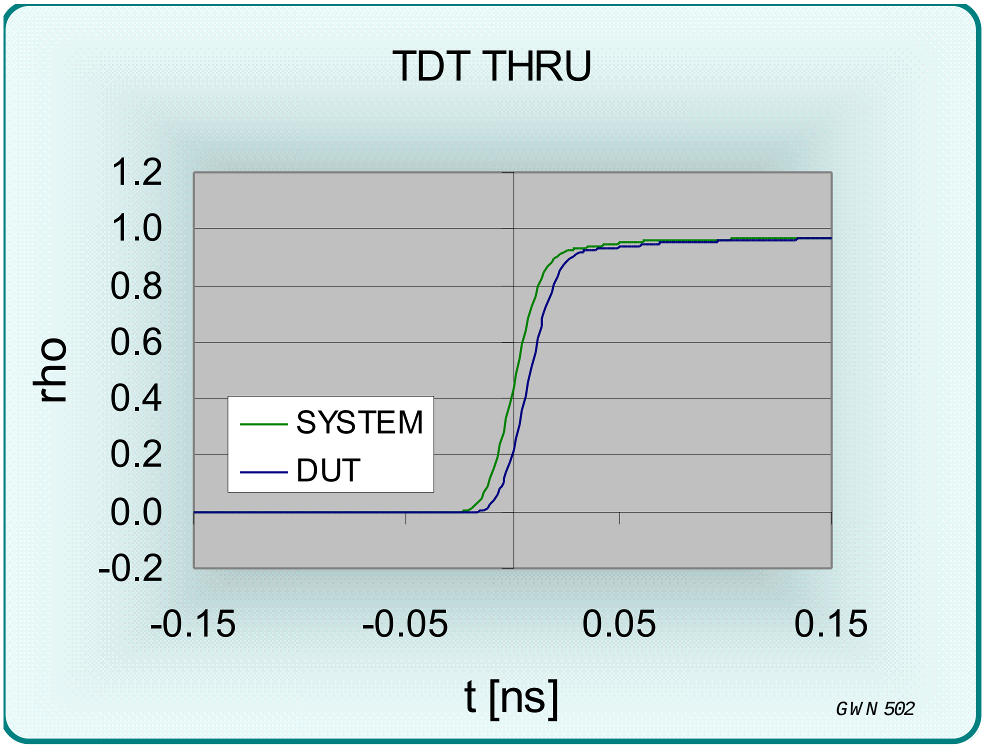


Figure 22 TDT measurement

The TDT measurements for transmission shows an identical risetime from the pin array (10-90% RT = 28.5 ps) as the system risetime (28.5 ps). The added delay at the 50% point is 7.5 ps. The 20%-80% values are 18.0 ps and 18.0 ps, respectively.

Frequency domain

Network analyzer reflection measurements for the G-S-S-G case were taken with all except the pins under consideration terminated into 50 Ohms (ports 1-4). As a result, the scattering parameters shown below were recorded for reflection and transmission through the contact array.

First, an insertion loss measurement is shown for port 1 to port 2.

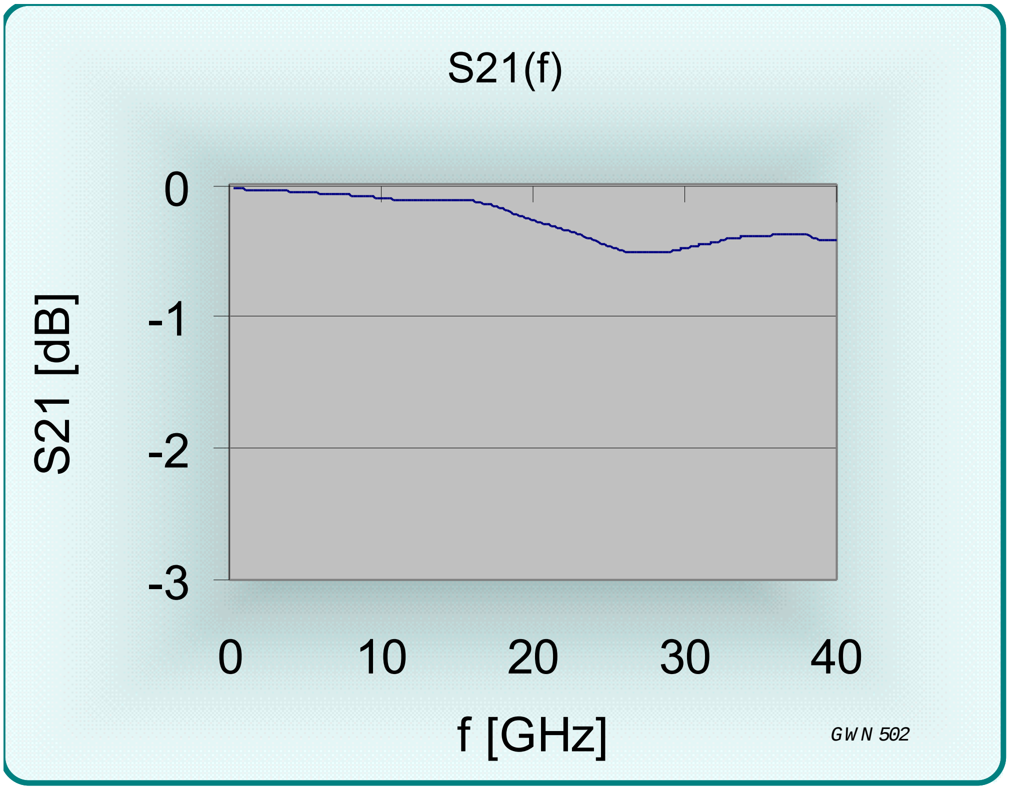


Figure 23 Insertion loss S21 (f) and S12 (f)

Insertion loss is less than 1 dB to about 40.0 GHz. The 3 dB point is not reached before 40.0 GHz.

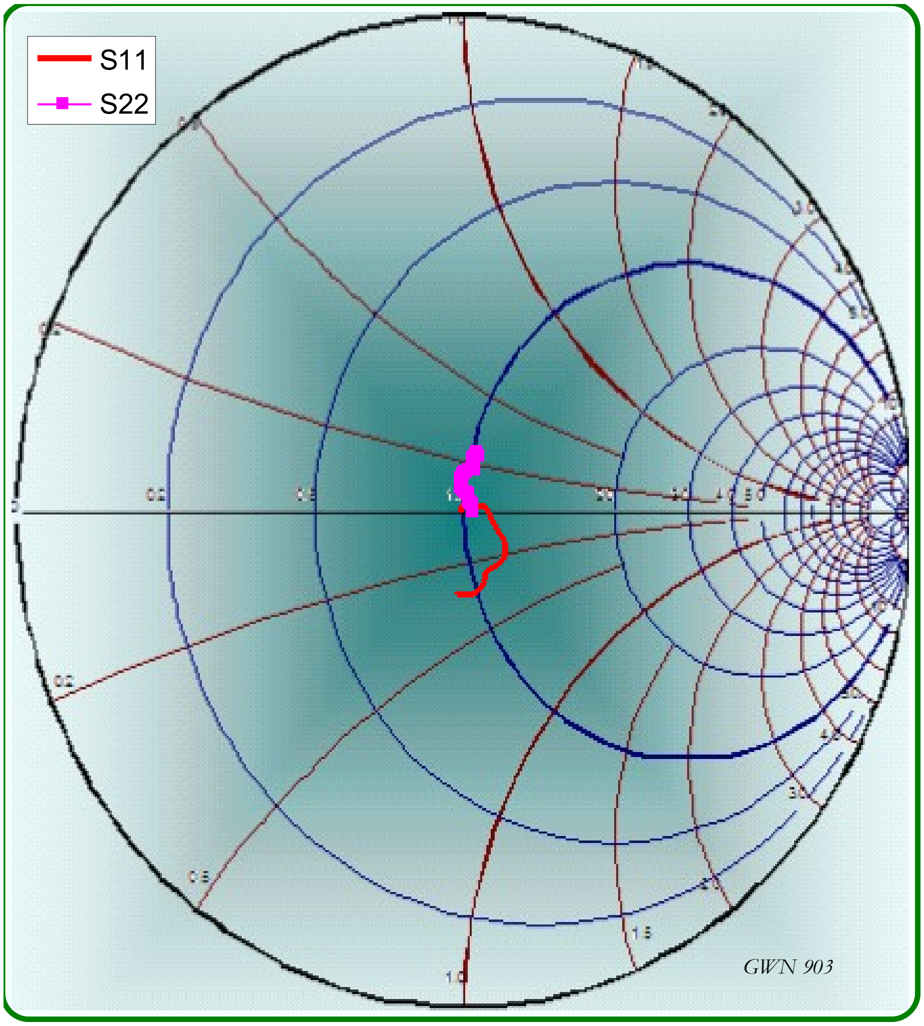


Figure 24 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows a good match with some reactive components at high frequencies. The Smith chart covers frequencies to 40 GHz.

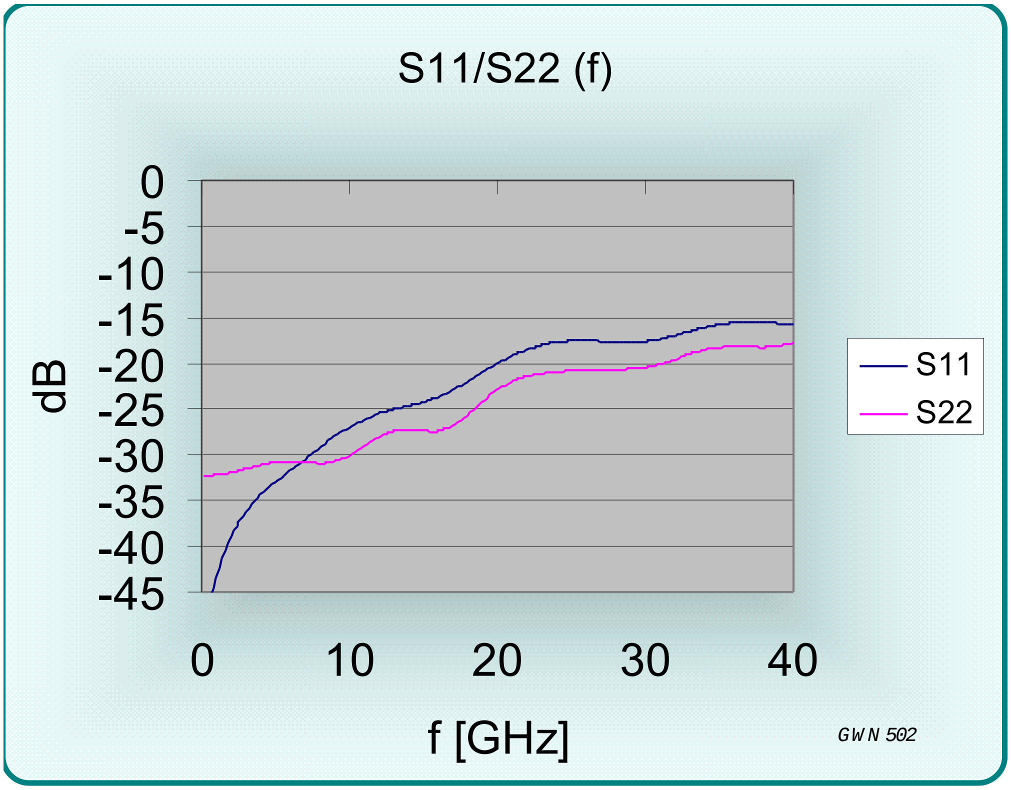


Figure 25 S11 magnitude (f) for the thru measurements into a 50 Ohm probe

The value of the return loss for the thru measurement reaches -20 dB at 19.9 GHz (S11) and 31 GHz (S22).

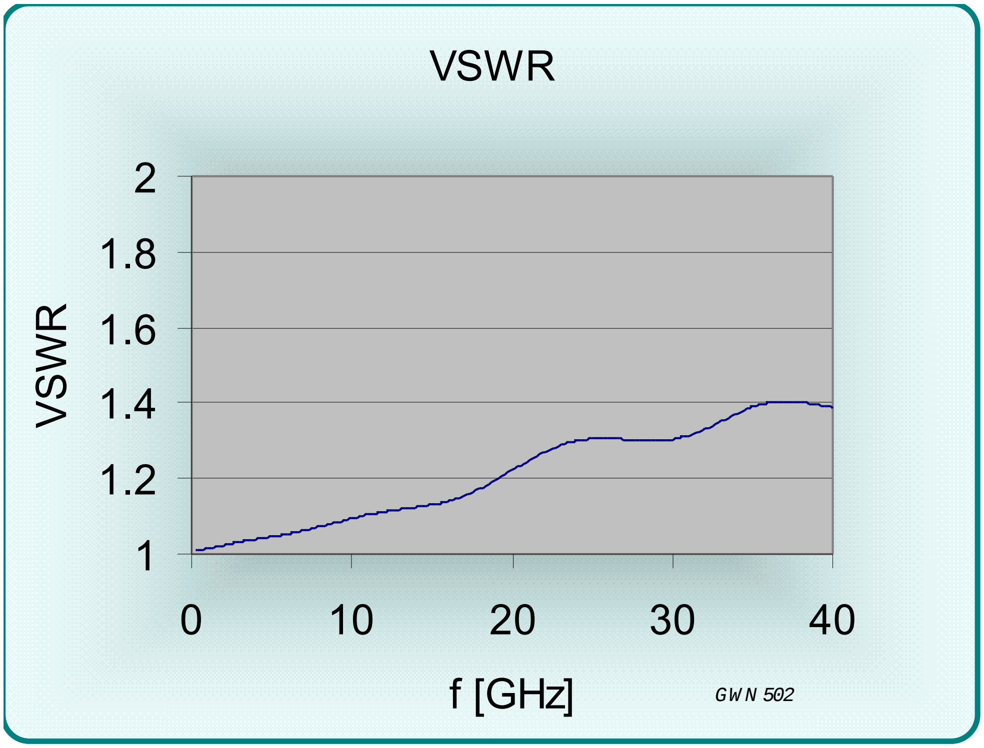


Figure 26 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 40.0 GHz.

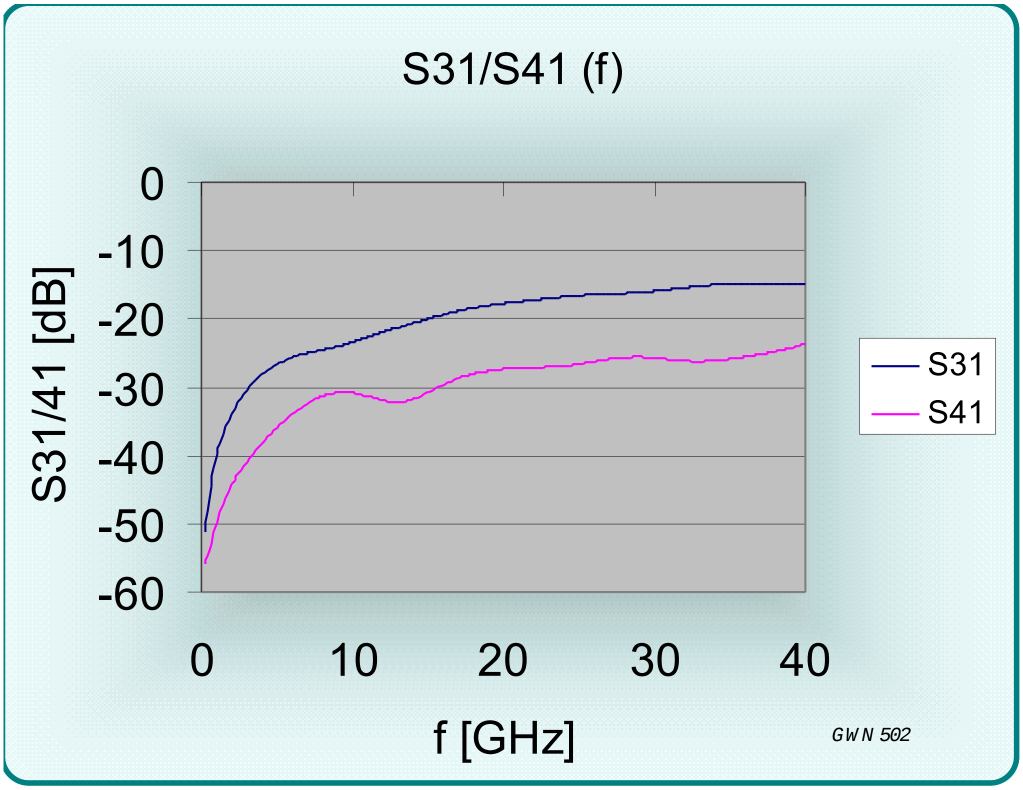


Figure 27 Crosstalk as a function of frequency

The graph shows forward crosstalk from port 1 to port 4 (S41) and backward crosstalk from port 1 to the adjacent terminal (port 3, S31). The -20 dB point is reached at 40.0 GHz (S41). Not before 40.0 GHz (S41) does the level of signal reach -10 dB.

For the purpose of model development the open circuit and short circuit backward crosstalk S31 is also recorded. It is shown below for the different sites. Model development results in a mutual capacitance of 0.018 pF and a mutual inductance of 0.04 nH.

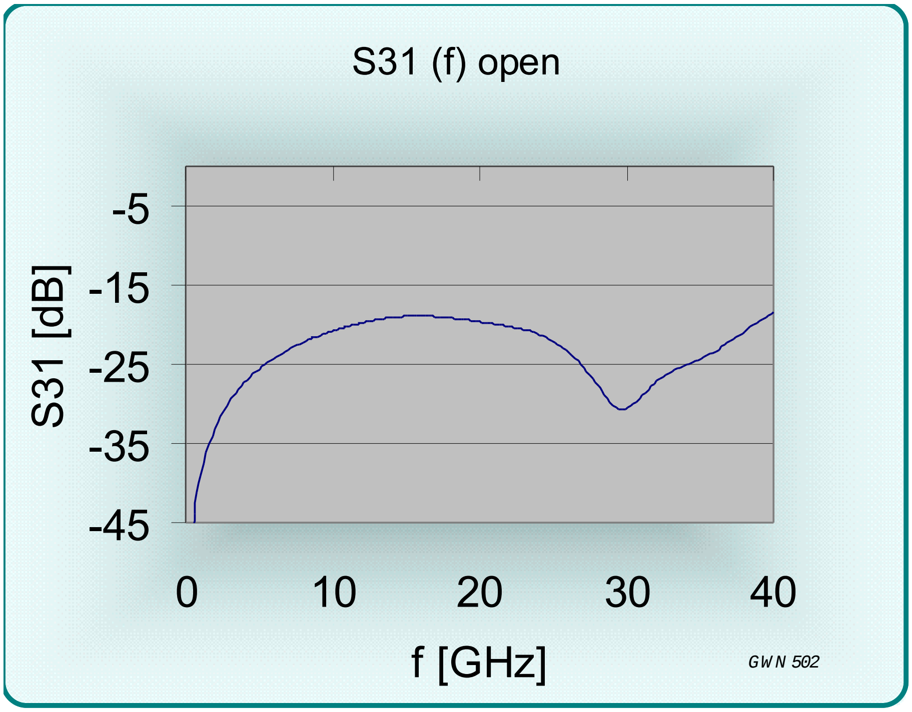


Figure 28 Open circuit crosstalk from port 1 to port 3

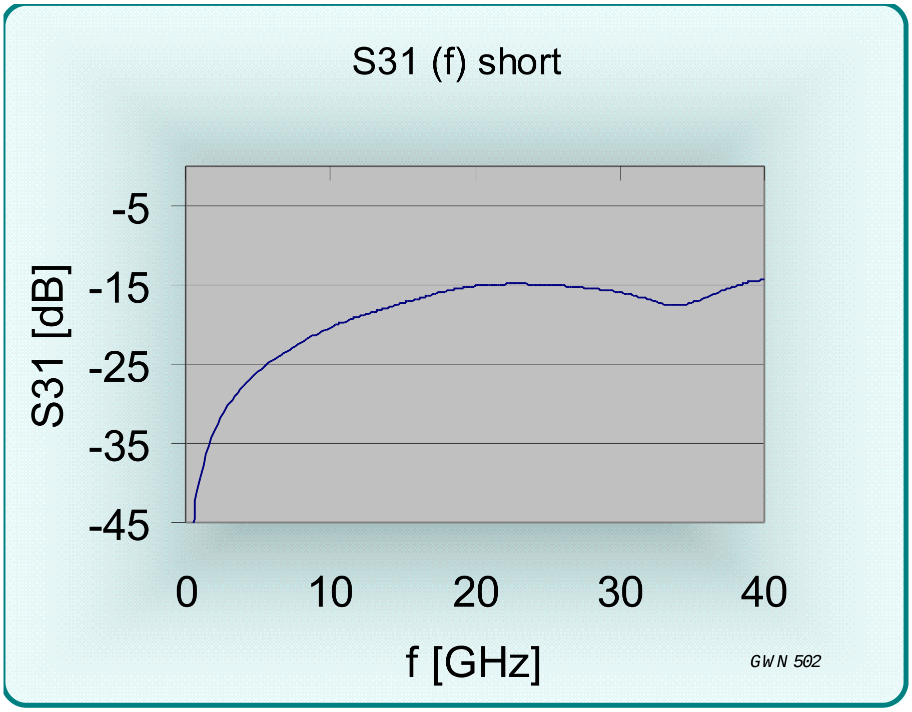


Figure 29 Short circuit crosstalk from port 1 to port 3

SPICE Models

A lumped element SPICE model for the contact in G-S-G configuration is shown below:

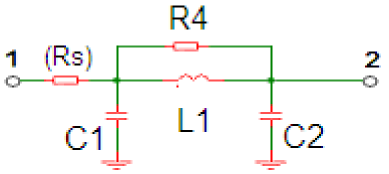


Figure 30 Lumped element SPICE model

The resistance value (R4) approximates the loss term encountered. The series resistance Rs is very small and does not significantly impact S-parameters. It can be determined by DC measurements but is not included in this model.

The values for the elements are

C1, C2		L1		R4	
0.076	pF	0.26	nH	1000	Ohms

Toward the cutoff frequency of the Pi section the lumped element model becomes invalid. This happens above 38 GHz for the above model. Hence, the second model developed is a transmission line model:

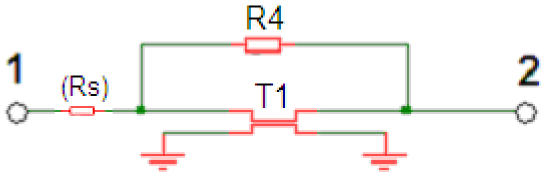


Figure 31 Transmission line model for the contact

Again, R4 describes loss and the series resistance Rs is very small and not included.

The array configuration with signal pins surrounded by ground pins provides a transmission line environment with the following parameters:

Zo		L		R4	
41.3	Ω	6.25	ps	10000	Ω

It should be noted that this calculated impedance differs from that measured because parameters for the calculation come from a lumped element model.

Time domain

The TDR simulation results indicate a capacitive response just as observed in the measurement (see TDR THRU).

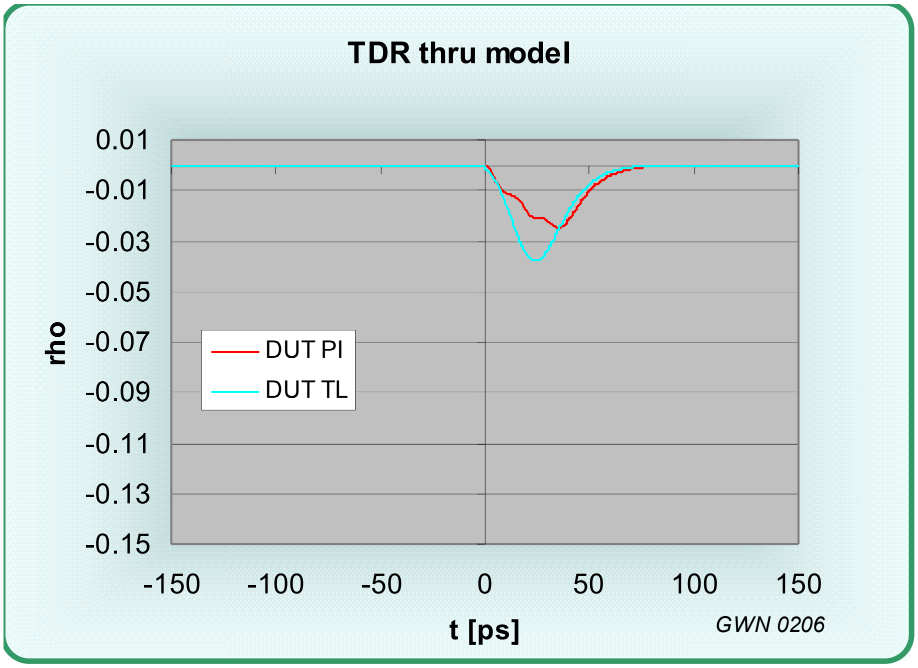


Figure 32 TDR model results

The transmission line models are better suited to the time domain simulation than the lumped element models since the latter cause a dual downward response from the two capacitors in the Pi section.

The risetime contributions of a signal transmitted through the pin are shown below:

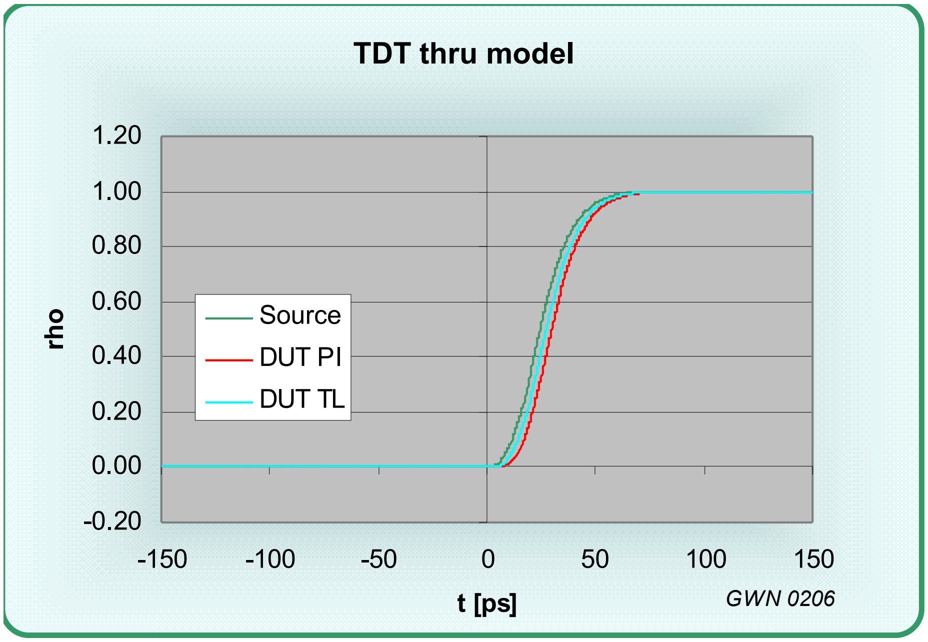


Figure 33 TDT model

Risetimes and signal waveform for the transmission line case are comparable to those measured.

Frequency domain

The model’s phase responses are also divided into lumped element and transmission line equivalent circuits.

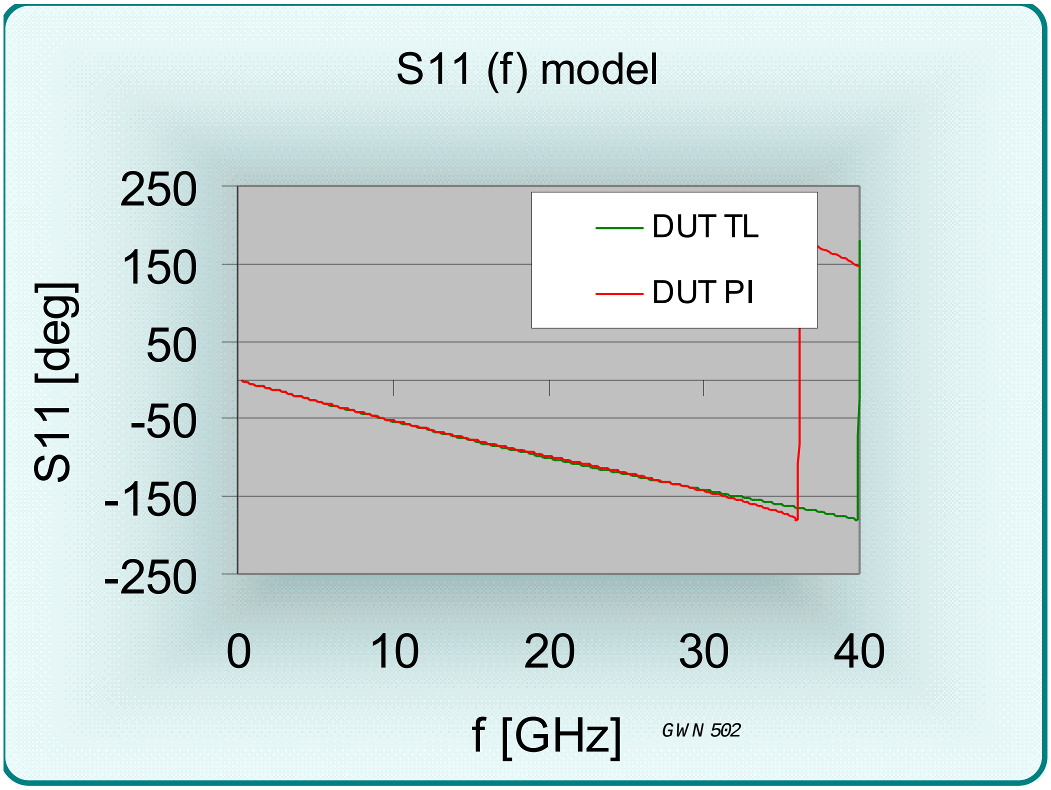


Figure 34 S11 phase (f) for open circuited case

The evolution of phase with frequency is comparable to that measured.

The response of the lumped element model illustrates that it is limited to a maximum frequency of about 38 GHz.

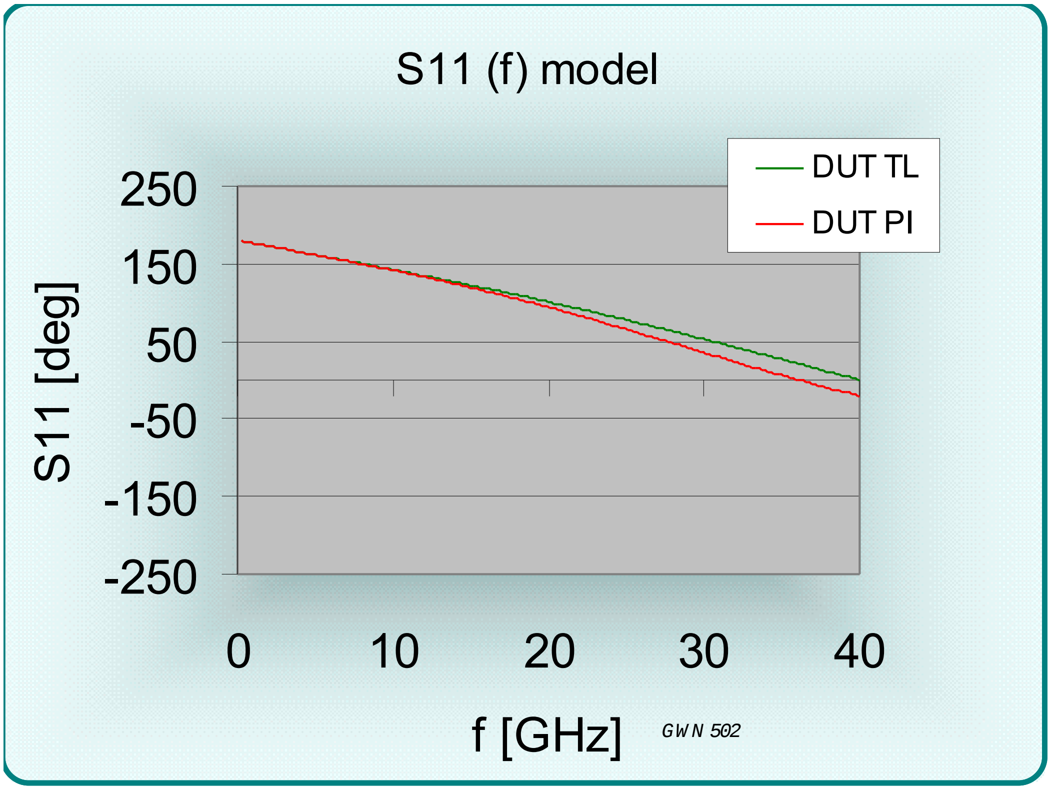


Figure 35 S11 phase response (short circuit)

The short circuit phase evolution with frequency is also comparable to that actually measured.

The insertion loss results below also clearly demonstrate the limits of the lumped element model. As the frequency approaches the cutoff frequency for the Pi section, the insertion loss increases significantly. The transmission line model does not suffer from this shortcoming. However, it does not predict the sharp drop in S21 at elevated frequencies. This is most likely due to a resonance and thus exceeds the purpose of and limitations of this model.

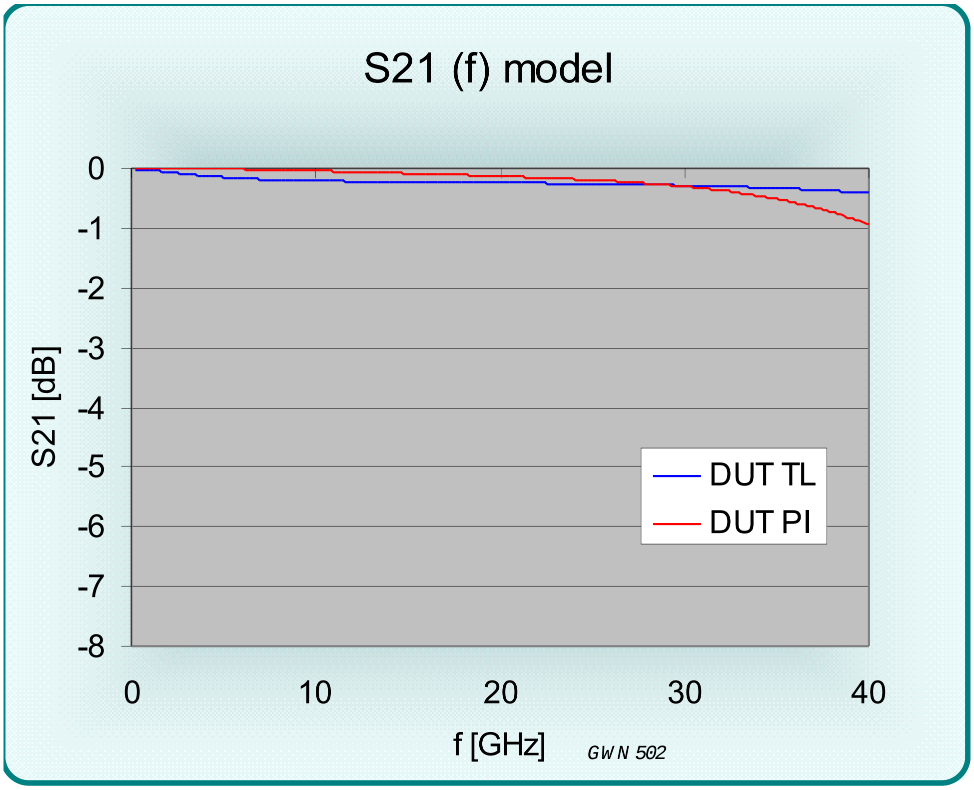


Figure 36 Insertion loss as a function of frequency

The lumped element frequency domain model used for evaluating the mutual elements also consists of the three sections of the single pin plus a mutual inductance and two coupling capacitors. The model was used in configurations corresponding to the actual measurements.

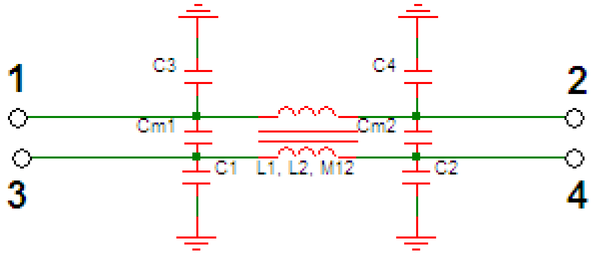


Figure 37 Equivalent circuit for G-S-S-G (mutual coupling)

The values for this model are:

C1,2,3,4	Cm1, Cm2			L1, L2	M12	
0.125		0.067	pF	0.50	0.241	nH

Since the lumped model does not remain valid at high frequencies, a transmission line model with coupled transmission lines and added loss terms was also established:

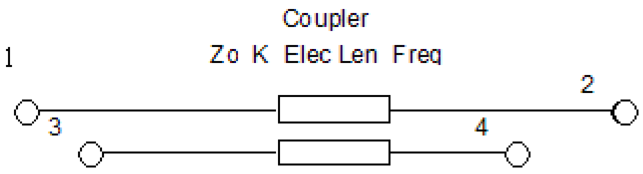


Figure 38 Transmission line equivalent circuit for crosstalk

The model shows two coupled transmission lines with the respective in- and outputs. Its elements are:

Zo		td		K	180 deg	@
47.7	Ω	10	ps	0.17	66.7	GHz

Simulations are performed like the measurements where S31 measures the backward crosstalk, while ports 2 and 4 are terminated in 50 Ohms. Likewise, the forward crosstalk S41 is determined with ports 2 and 3 terminated into 50 Ohms.

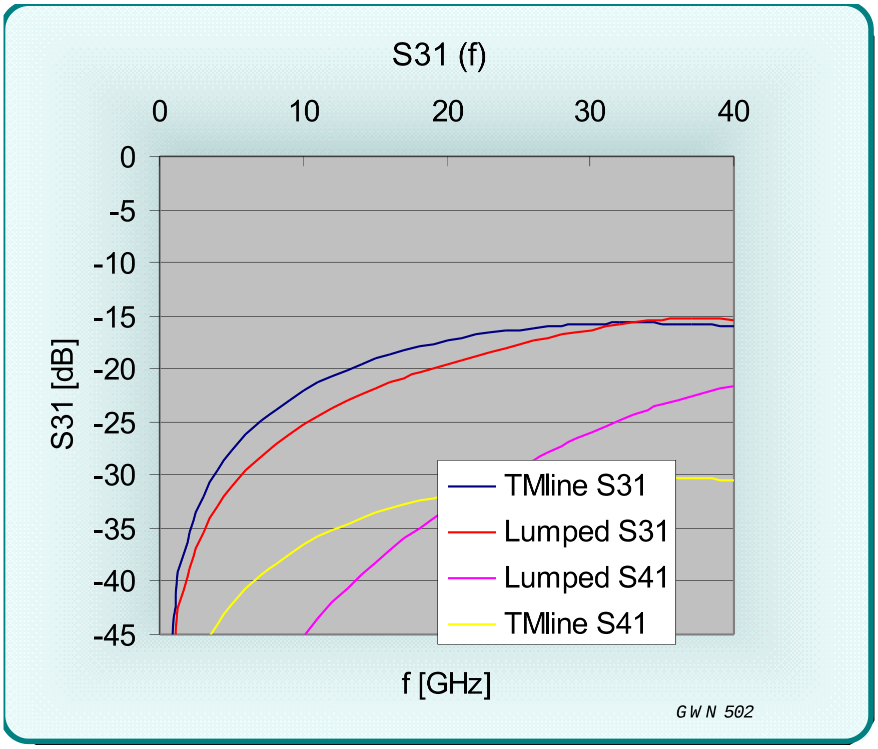


Figure 39 Crosstalk S31 and S41 [dB] as a function of frequency

When comparing the simulation results with the measurements it is apparent that the transmission line model produces more favorable results at higher frequencies.