

Paricon Technologies

BGA socket
0.50 mm pitch

Measurement and Model Results

prepared by

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Objective

The objective of these measurements is to determine the RF performance of a Paricon Technologies BGA socket. For G-S-G configurations, a signal pin surrounded by grounded pins is selected for the signal transmission. For G-S-S-G configurations, two adjacent pins are used 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 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 (HP8722C). 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 digital system risetime and clock speeds.

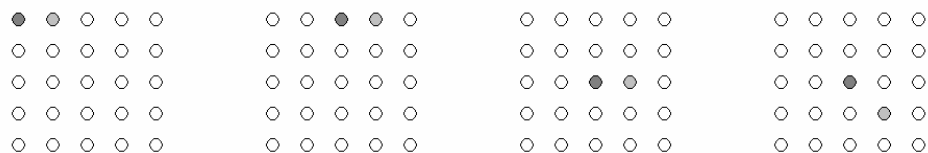
Test procedures

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 BGA socket 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. Measurements are performed for a corner pin of the contact array, a pin at the perimeter (edge) and one pin in the center (field):



The second pin indicates the configuration for G-S-S-G testing. The mutual parameters are also determined for the diagonal case.

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



Figure 1 BGA socket base plate example

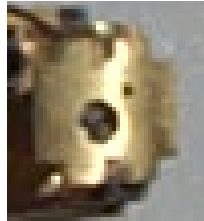


Figure 2 DUT plate

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

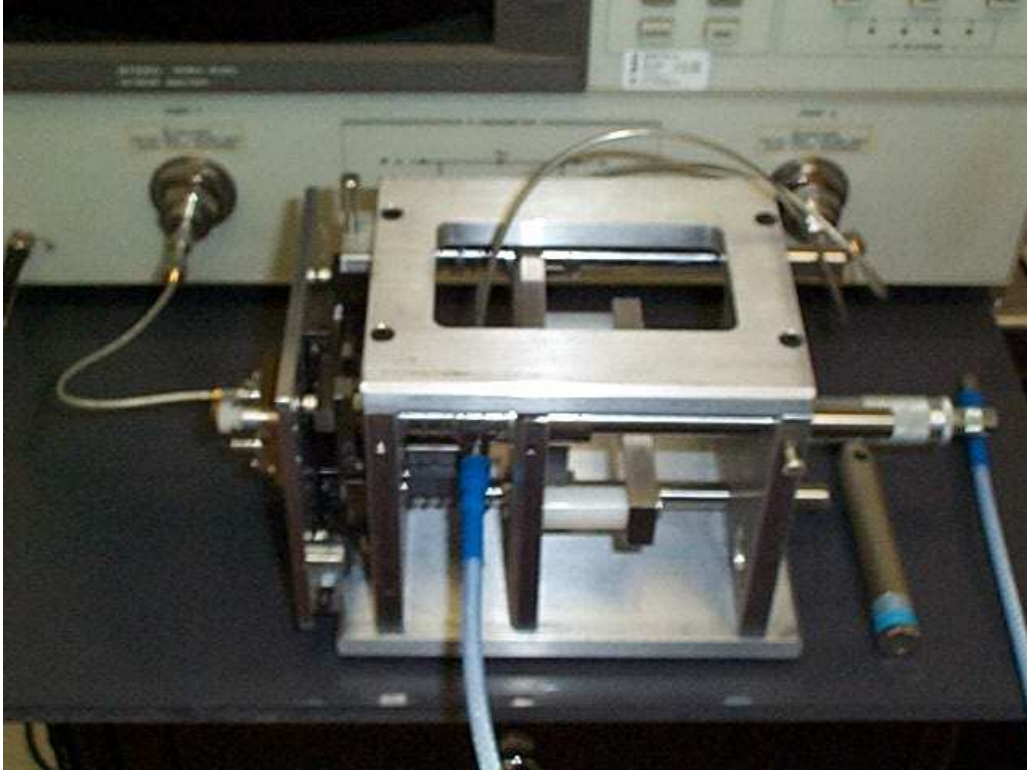


Figure 3 Test fixture

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:

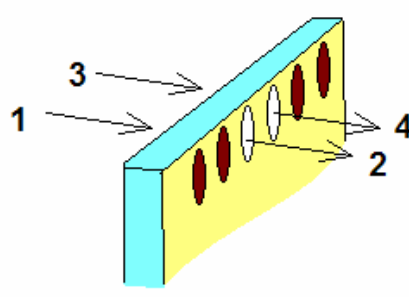
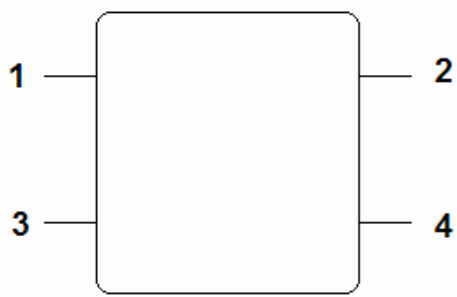
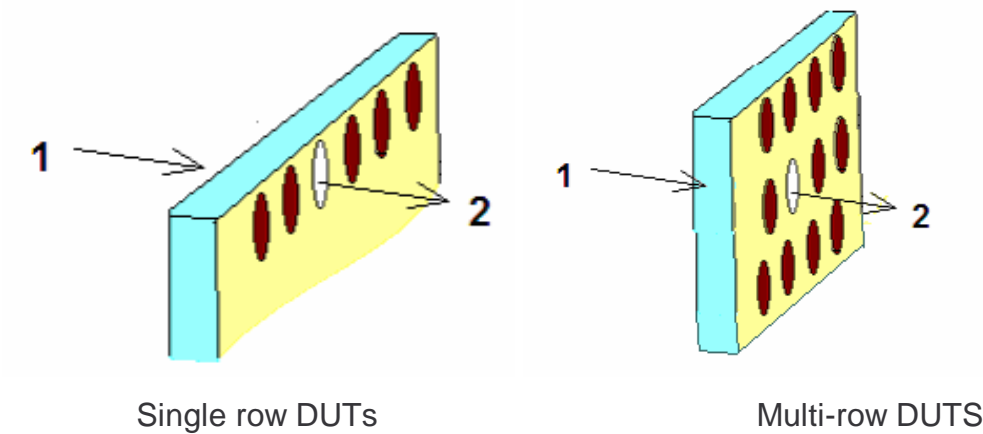


Figure 4 Ports for the G-S-G and G-S-S-G measurements

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

Measurements G-S-G

Time domain

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

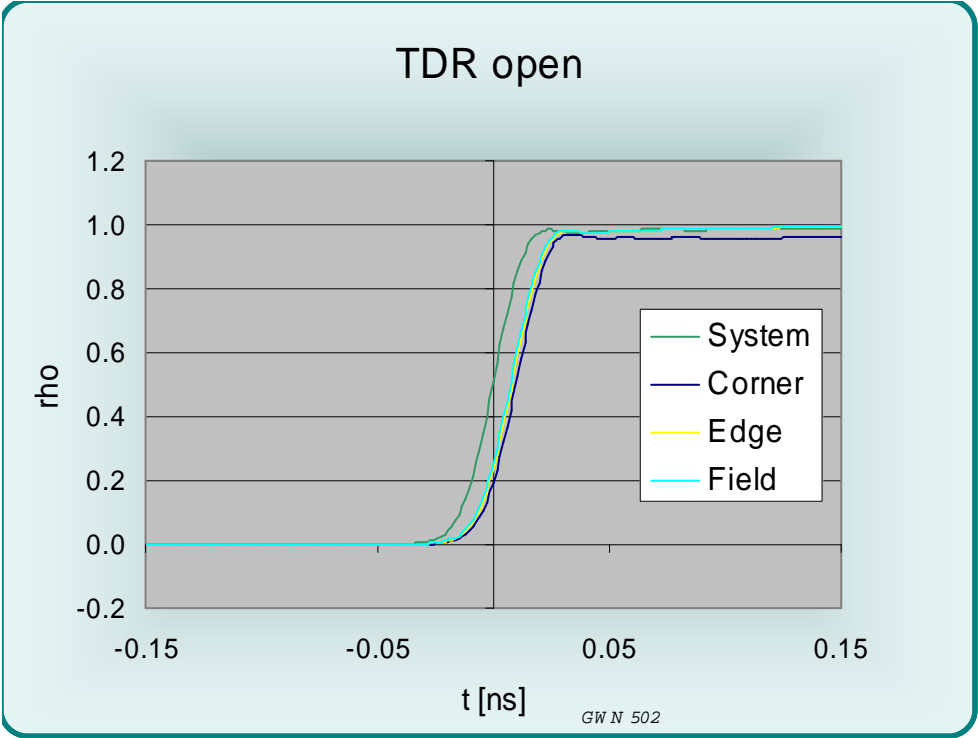


Figure 5 TDR signal from an OPEN circuited array

The reflected signals from the contact array (rightmost traces) show no deviation in shape from the original waveform (leftmost trace). The risetime is about 27.0, 27.0 and 27.0 ps for corner, edge and field, respectively and is identical to that of the system with the open probe (27.0 ps). Electrical pin length is about 5.3, 4.5 and 3.8 ps, respectively (one way).

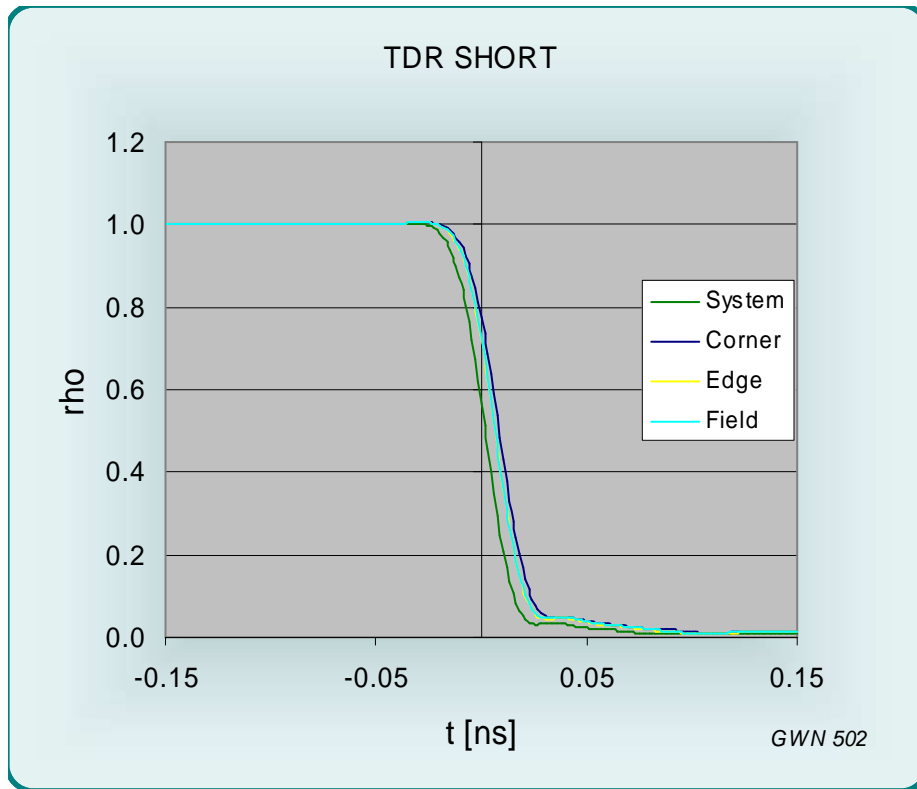


Figure 6 TDR signal from a SHORT circuited BGA contact array

For the short circuited 0 array the fall time is about 28.5, 28.5 and 28.5 ps for corner, edge and field, respectively. There is an insignificant increase over the system risetime of 27.0 ps caused by the contact impedance levels.

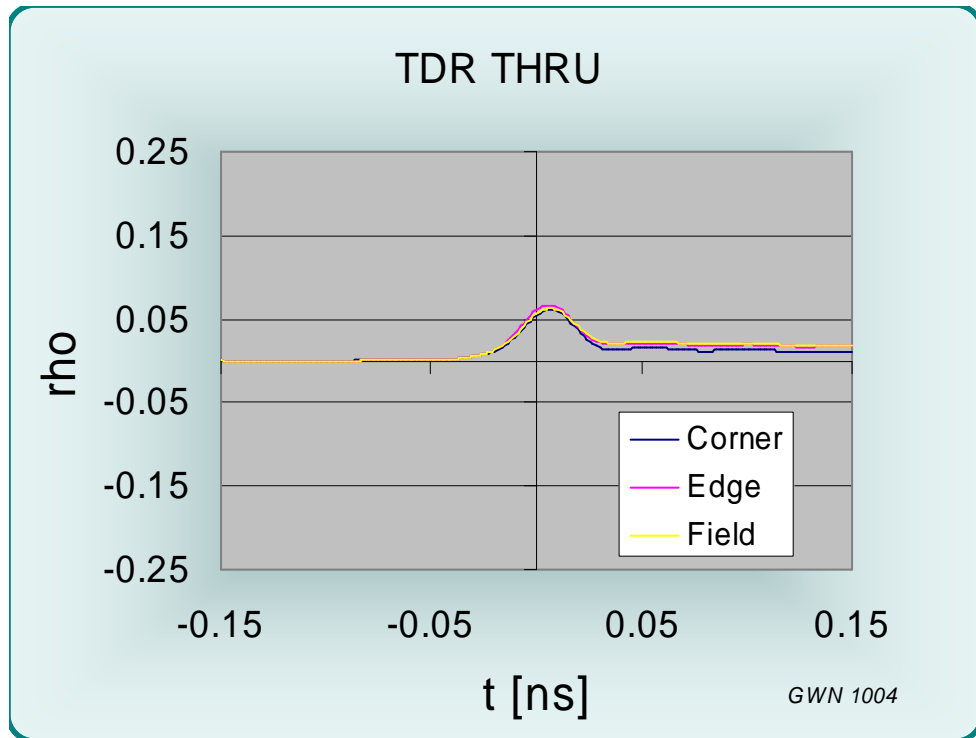


Figure 7 TDR measurement into a 50 Ohm probe

The thru TDR response shows primarily an inductive response. The peak corresponds to an impedance of 56.5, 57.2 and 56.7 Ohms for corner, edge and field. There is little difference between the three cases, possibly because spreading inductance dominates.

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

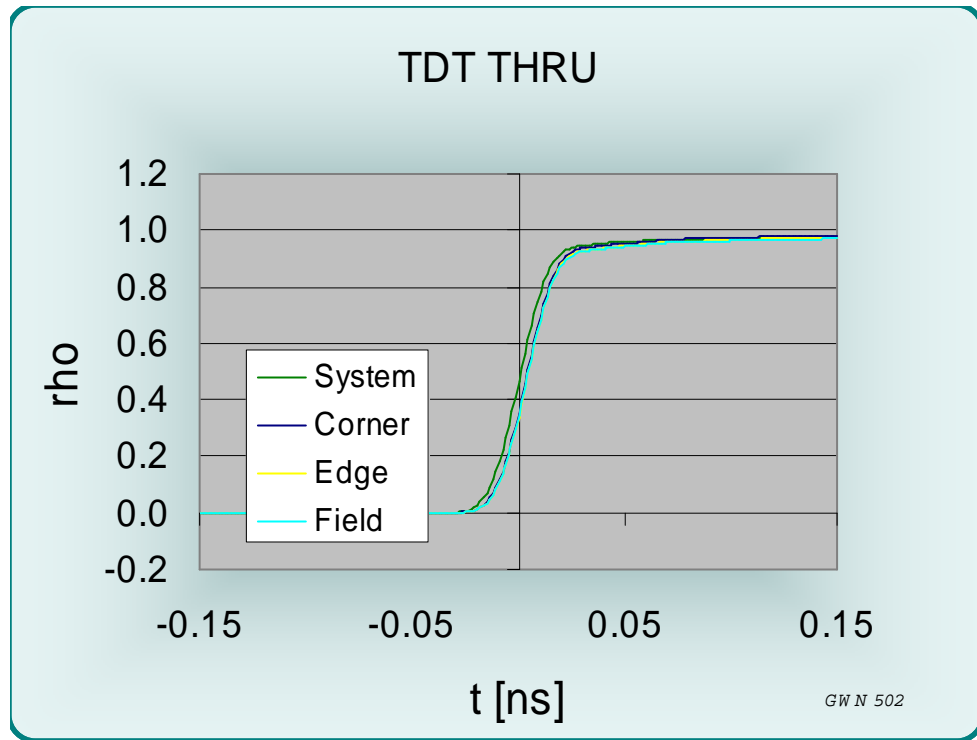


Figure 8 TDT measurement

The TDT measurements for transmission show almost the same risetime from the pin array (10-90% RT = 30.0, 30.0 and 30.0 ps for corner, edge and field, respectively, the system risetime is 28.5 ps). The added delay at the 50% point is 3.0, 3.0 and 3.0 ps, respectively. There is no significant signal distortion. If the 20%-80% values are extracted, the risetimes are only 19.5, 19.5 and 19.5 ps, respectively vs. 18.0 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).

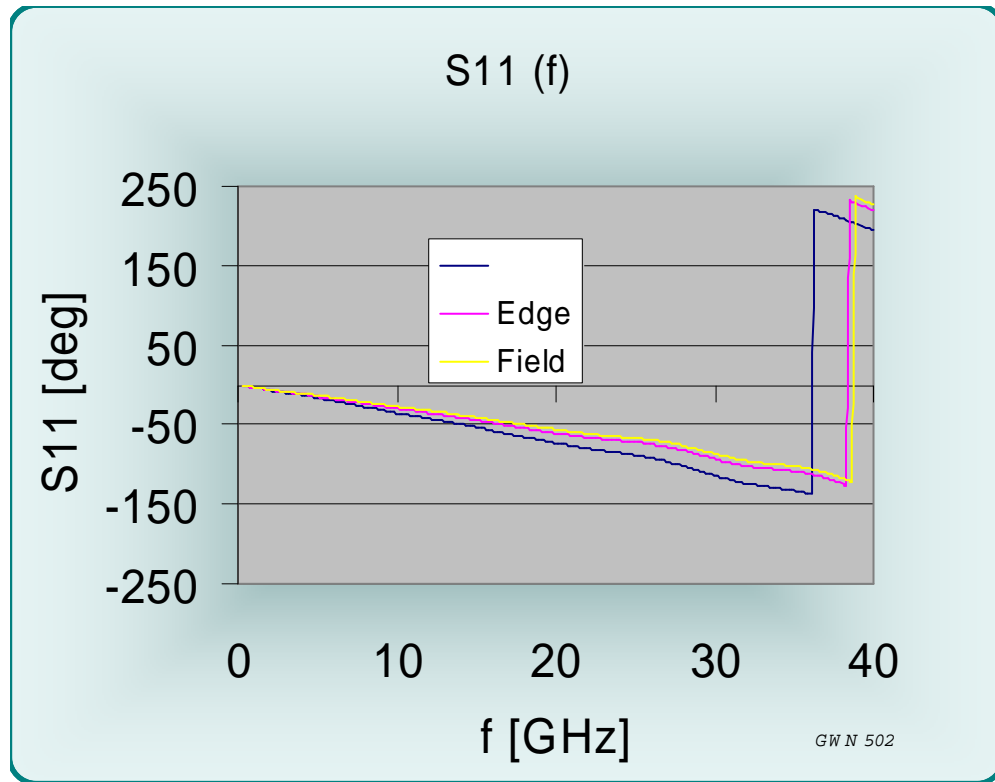


Figure 9 S11 phase (f) for the open circuited signal pin

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.

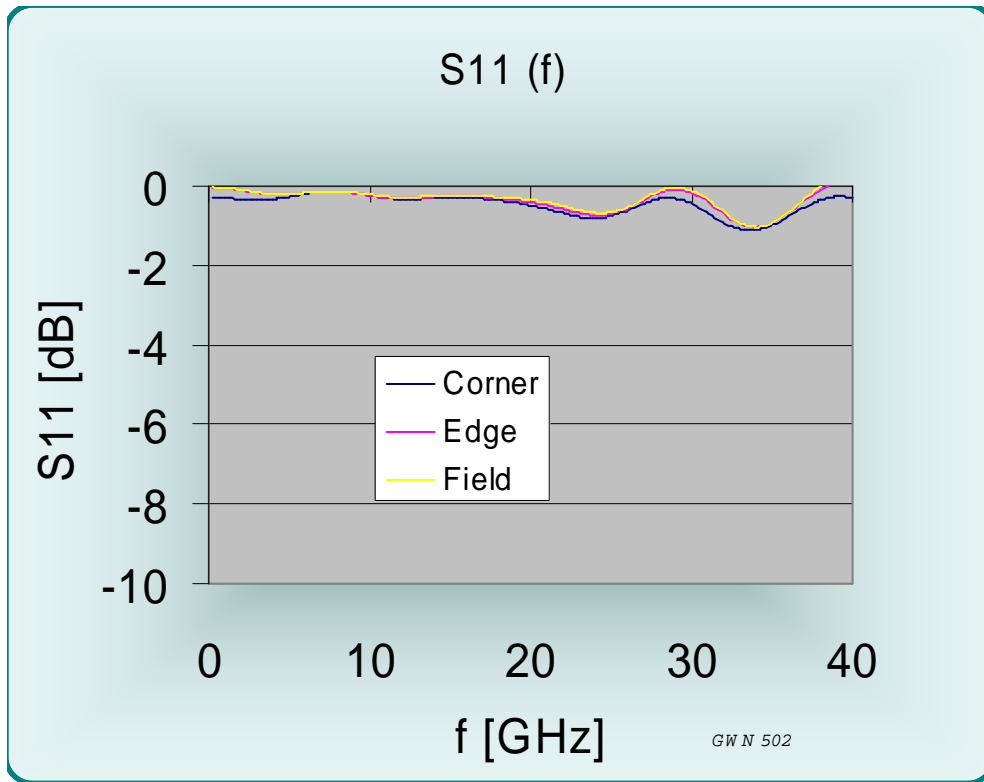


Figure 10 S11 magnitude (f) for the open circuited signal pin

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.

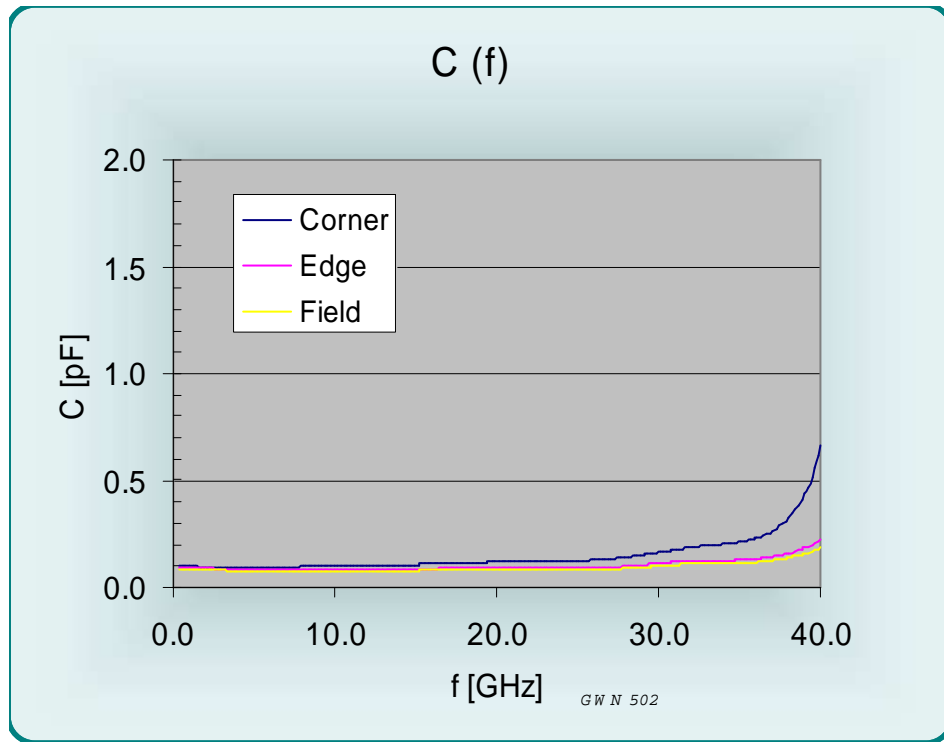


Figure 11 C(f) for the open circuited signal pin

Capacitance is 0.10, 0.09 and 0.09 pF for corner, edge and field, respectively, at low frequencies. Capacitance values do not follow expectation, possibly because of different numbers of vertical conductor columns being contacted. The rise in capacitance toward 39 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.

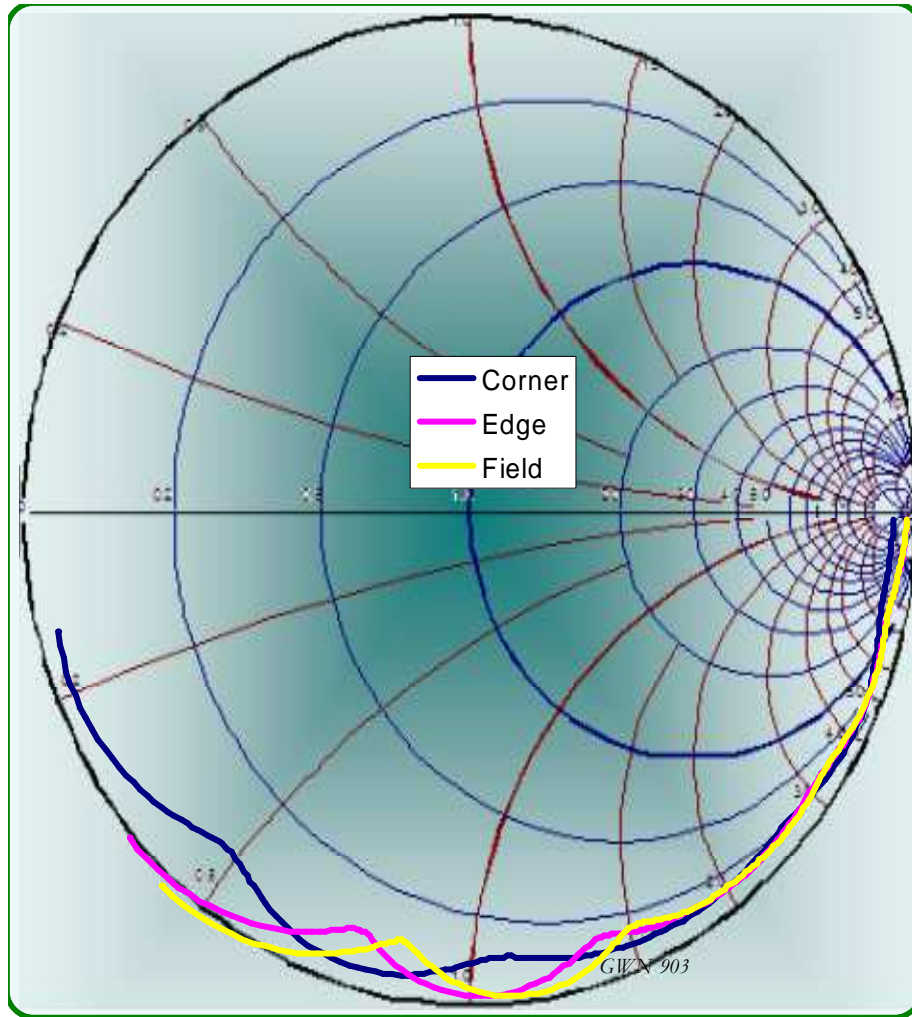


Figure 12 Reflections from the open circuited array

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 contact array. Calibration was established with a short placed at the end of the coax probe.

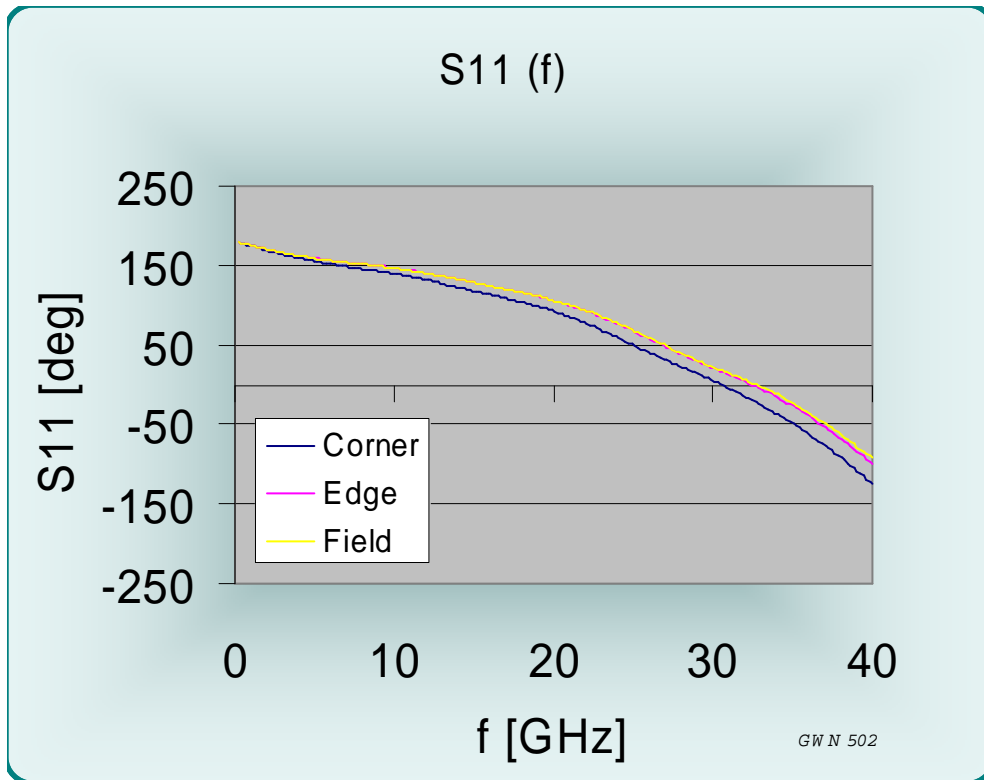


Figure 13 S11 phase (f) for the short circuited case

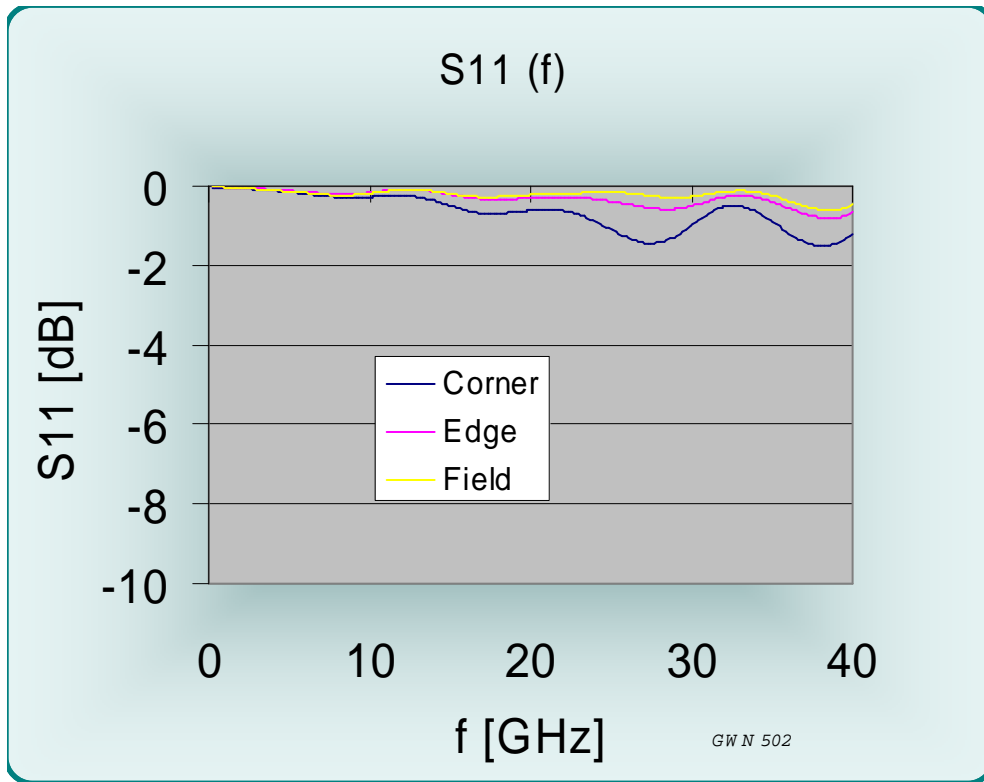


Figure 14 S11 magnitude (f) for the short circuited case

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

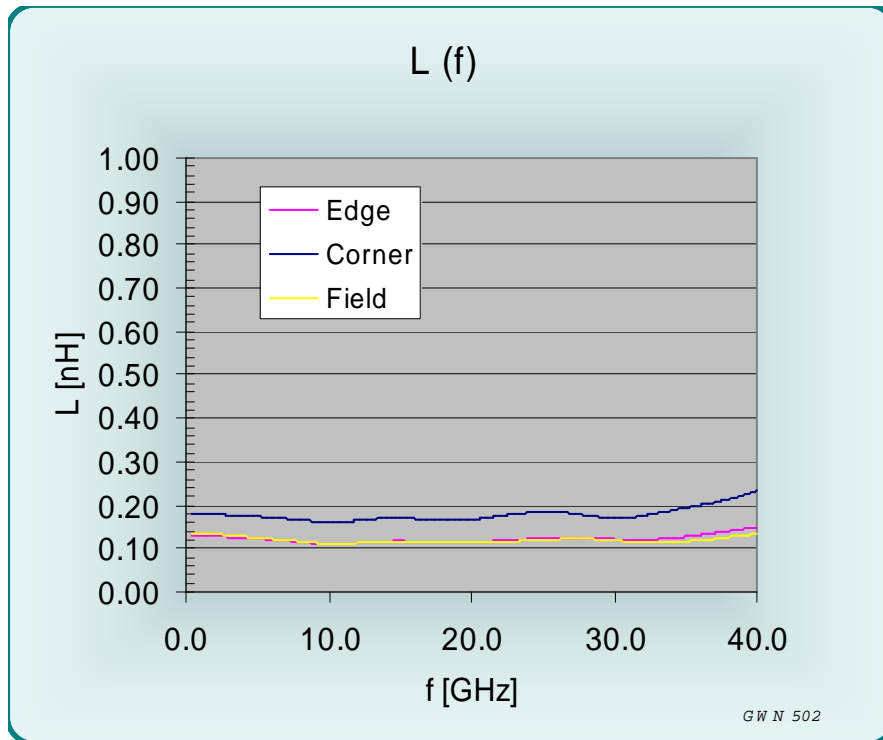


Figure 15 L(f) for the 0 array

The phase change corresponds to an inductance of 0.18, 0.13 and 0.13 nH for corner, edge and field, respectively, at low frequencies.

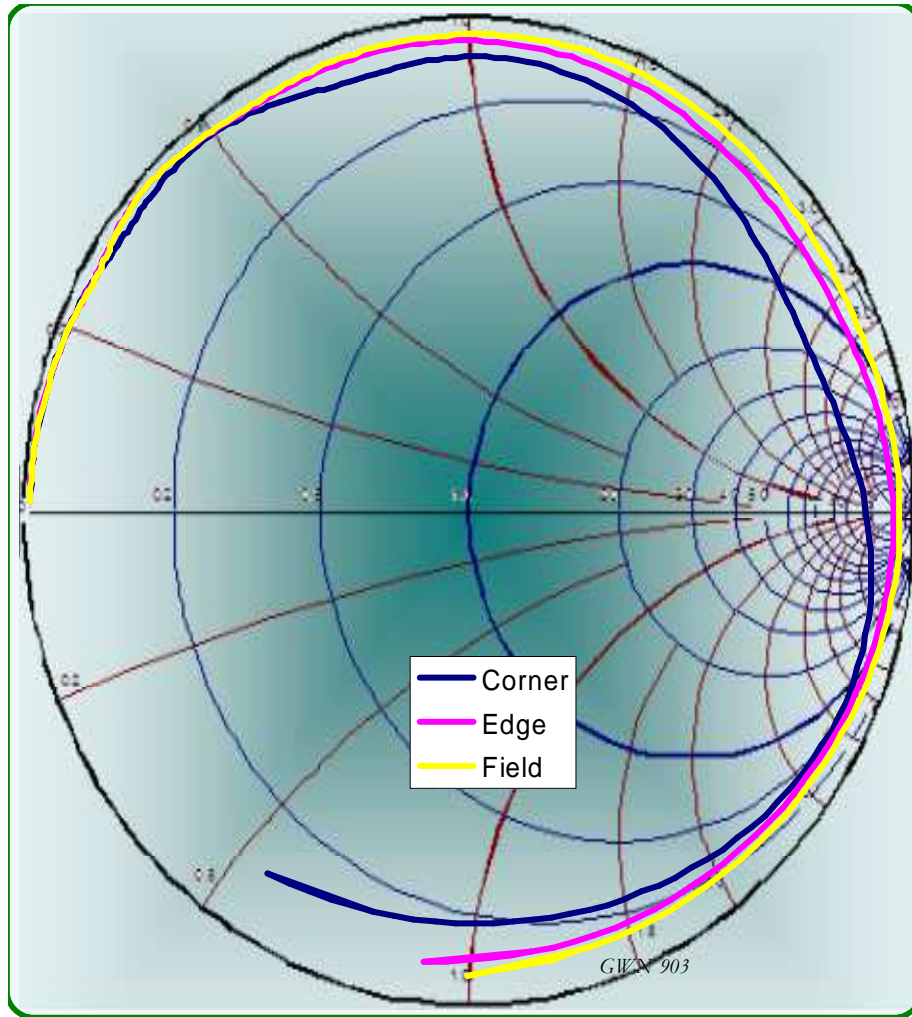


Figure 16 Short circuit response in the Smith chart

Only a small amount of loss is noticeable in the Smith chart for the short circuit condition.

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

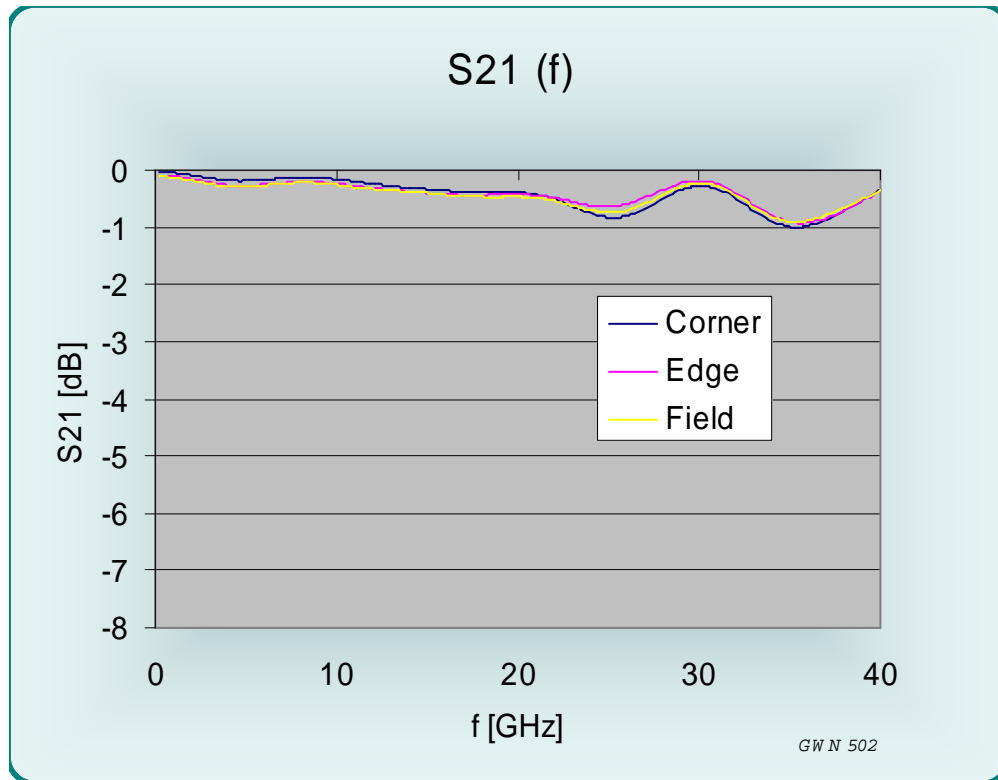


Figure 17 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 40.0 GHz.

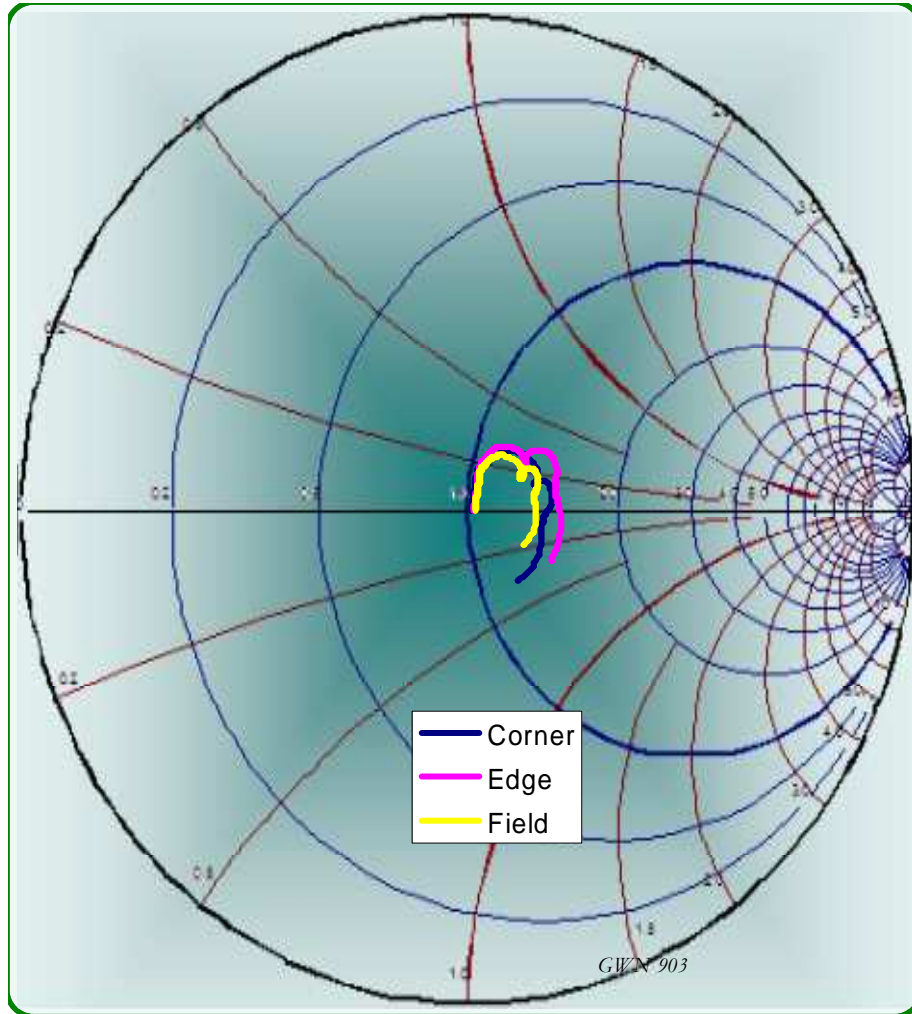


Figure 18 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements a good match at lower frequencies. Only above 30 GHz small reactive components become apparent.

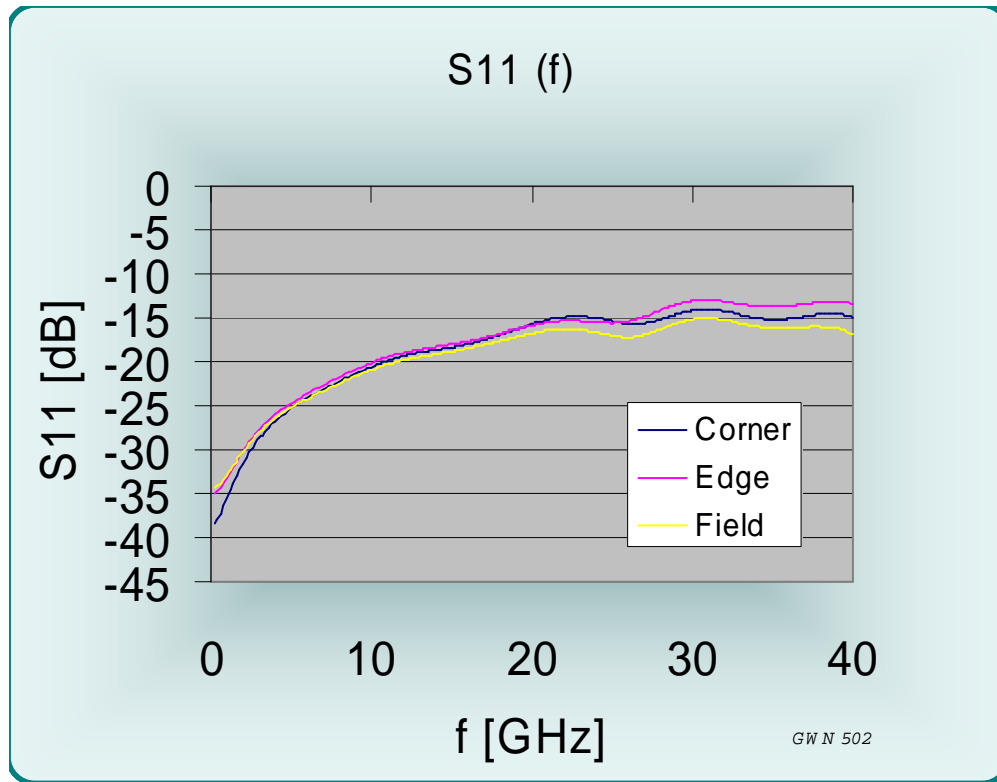


Figure 19 S11 magnitude (f) for the thru measurement into a 50 Ohm probe

Return loss reaches -20 dB at 11 GHz, 10 GHz and 12 GHz for corner, edge and field sites.

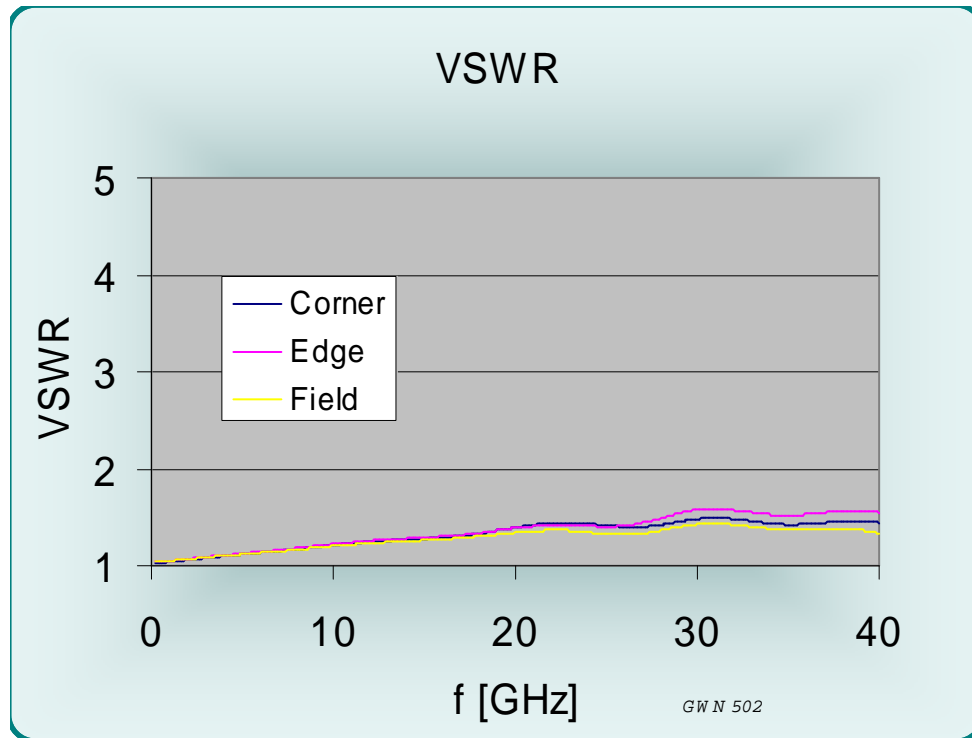


Figure 20 Standing wave ratio VSWR (f) [1 / div.]

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

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 transmission measurements were performed with a near symmetric 'field' configuration, mutual parameter determination was performed on all sites. Again, the 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:

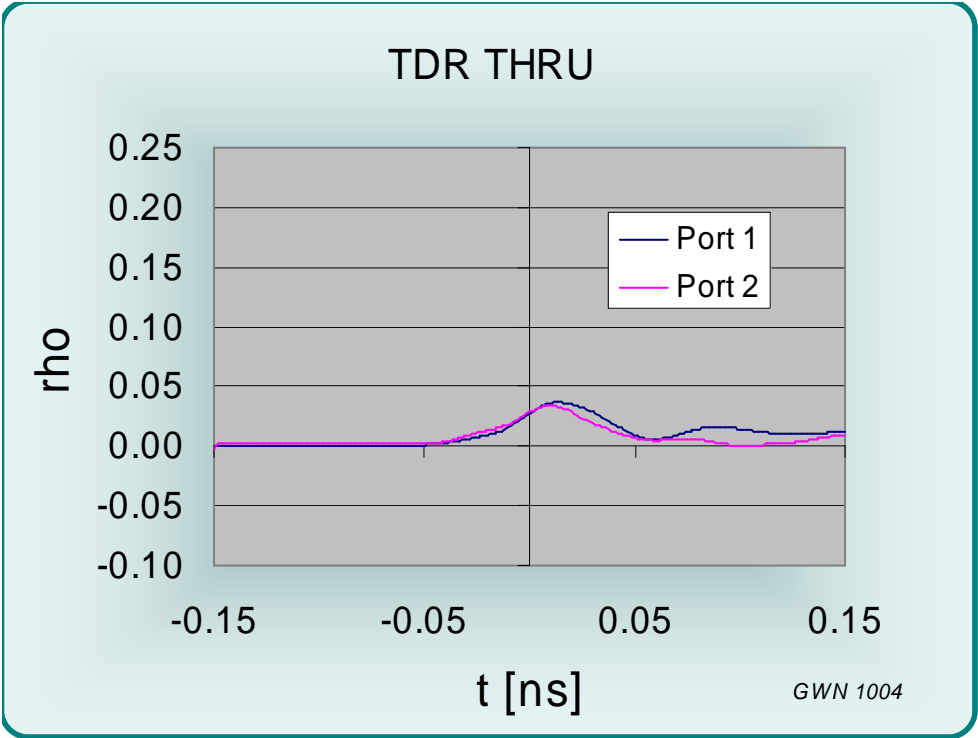


Figure 21 TDR through DUT into a terminated probe

The thru TDR measurement from port 1 to port 2 shows an inductive response. The peak corresponds to a transmission line impedance of 53.8 Ohms.

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

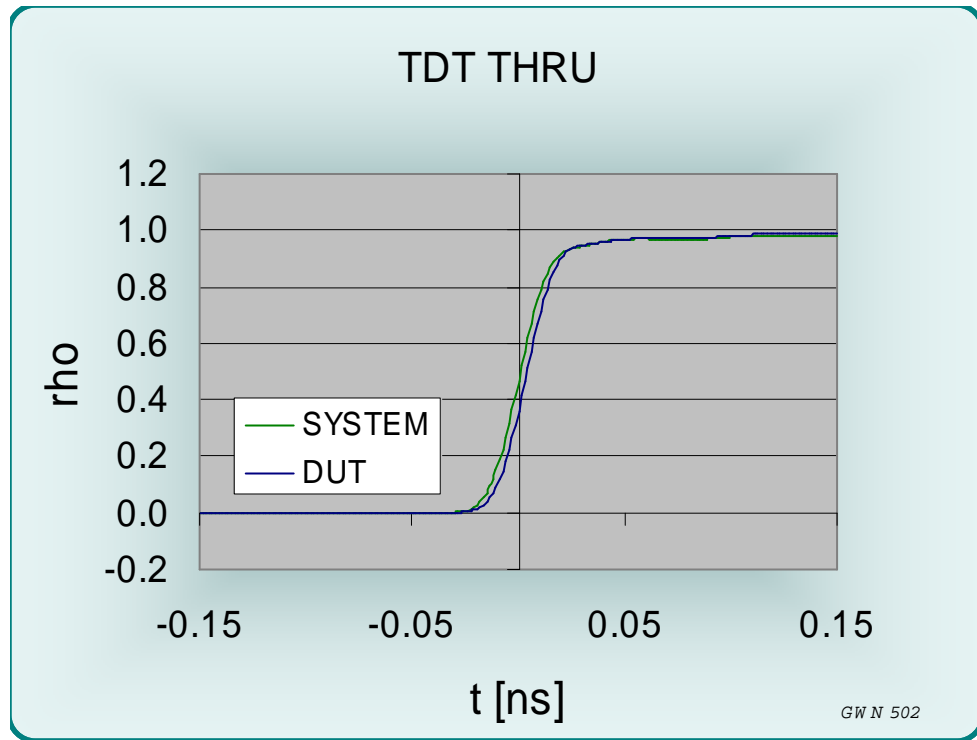


Figure 22 TDT measurement

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 3.0 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.

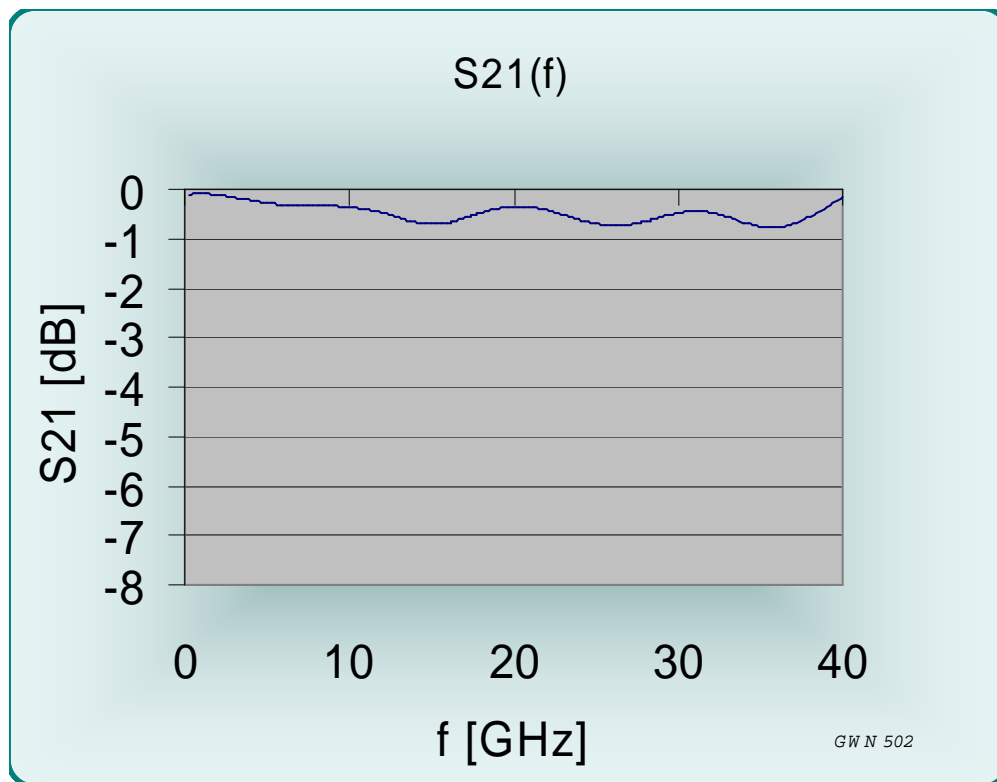


Figure 23 Insertion loss S21 (f) and S12 (f)

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

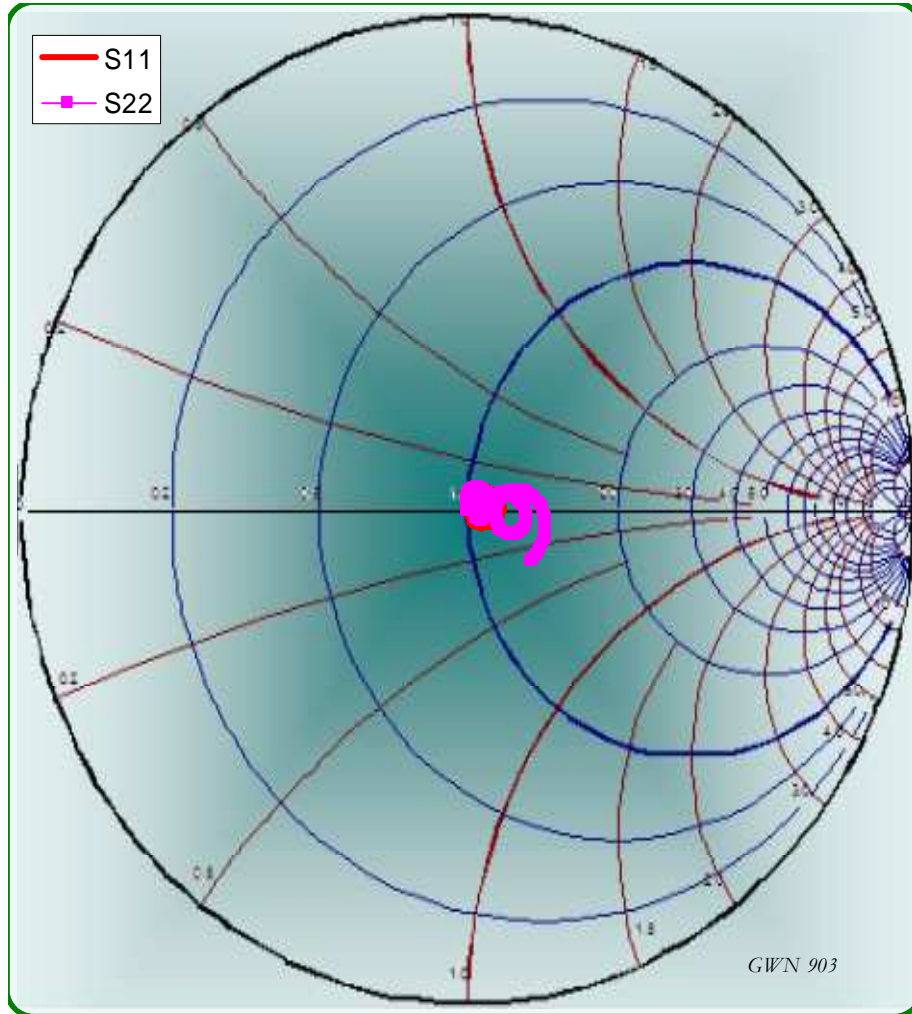


Figure 24 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows a good match with few reactive components at the highest frequencies.

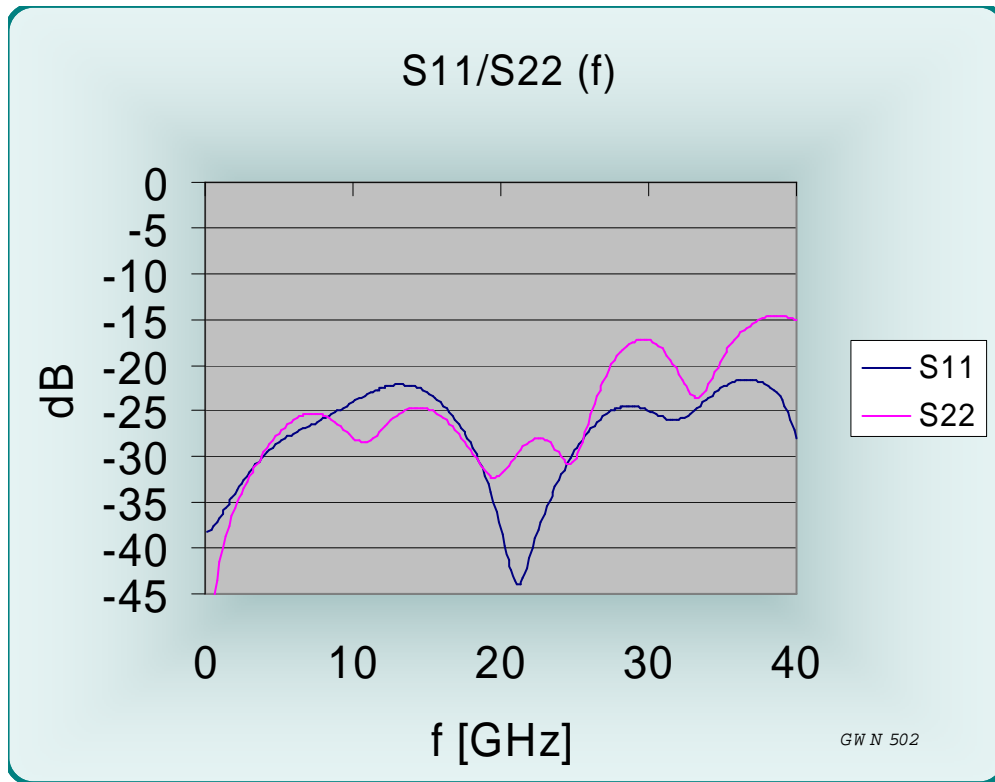


Figure 25 S11 magnitude (f) for the thru measurements into a 50 Ohm probe

The value of the return loss for the thru measurement reaches -20 dB at 40 GHz (S11) and 27 GHz (S22).

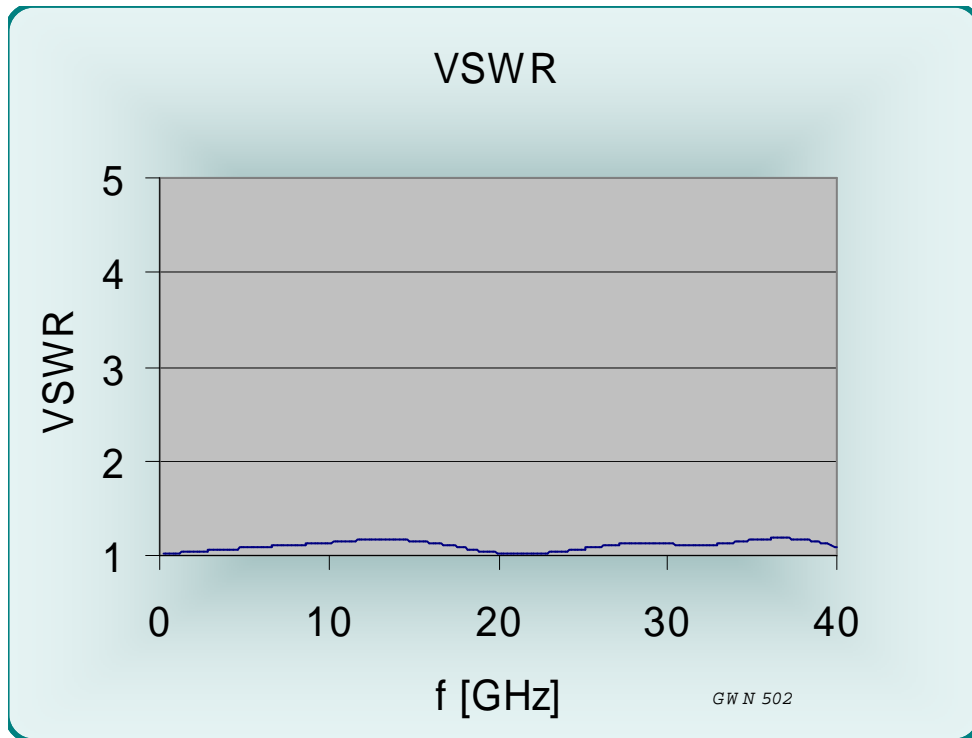


Figure 26 Standing wave ratio VSWR (f) [1 / div.]

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

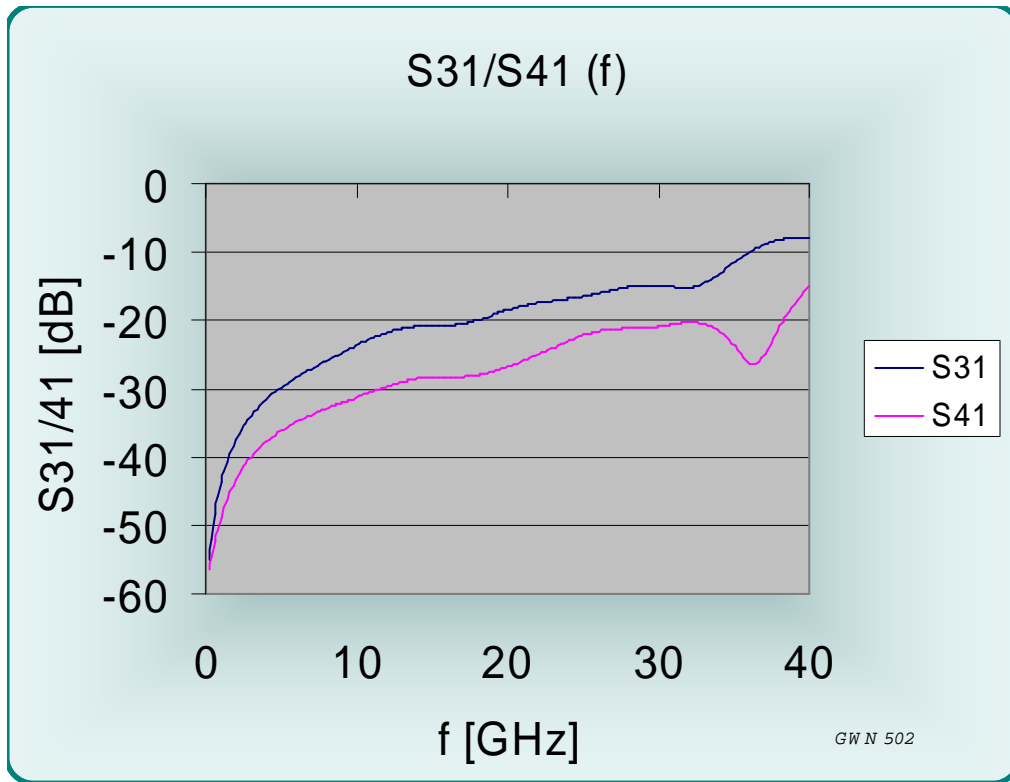


Figure 27 Crosstalk as a function of frequency

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 17.9 GHz (S31) and not before 38.3 GHz (S41). Not before 10.2 GHz (S31) and 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 yields a mutual capacitance of 0.010, 0.010, 0.009 and 0.003 pF and a mutual inductance of 0.06, 0.12, 0.08 and 0.044 nH for corner, edge field and diagonal sites, respectively.

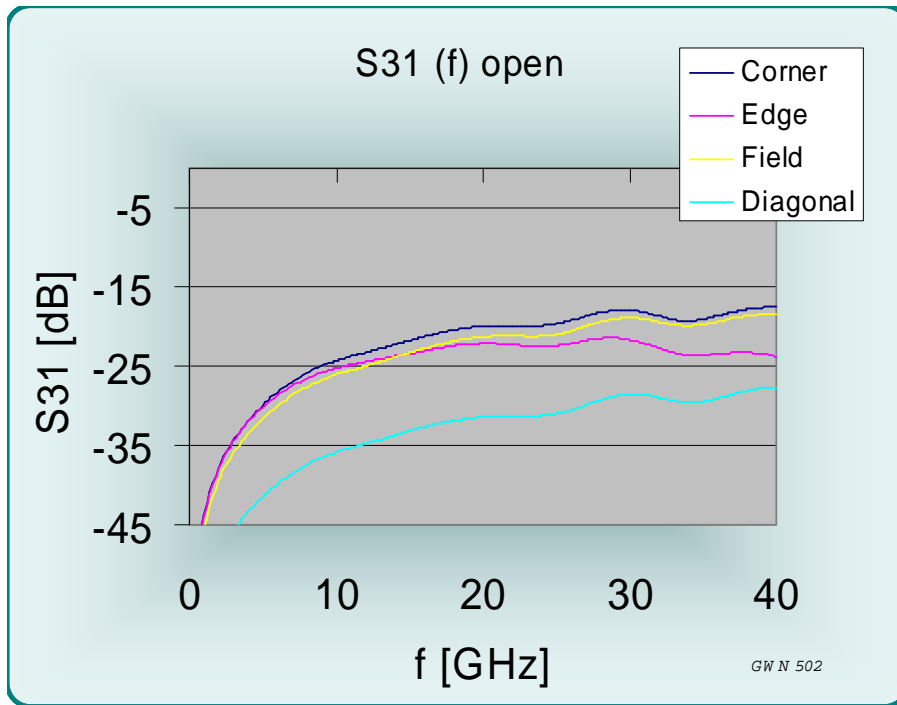


Figure 28 Open circuit crosstalk from port 1 to port 3

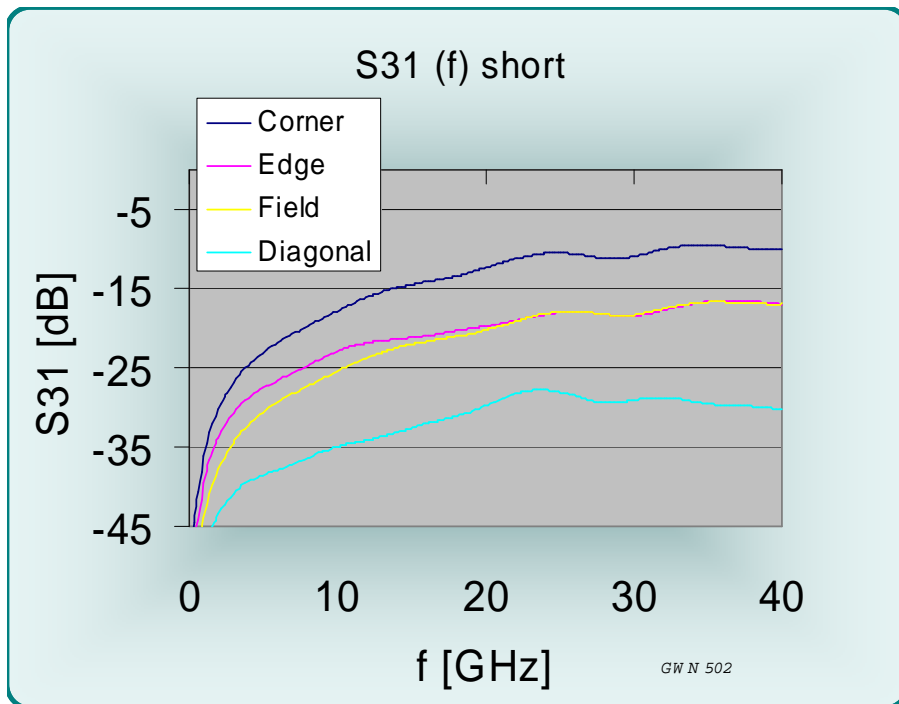


Figure 29 Short circuit crosstalk from port 1 to port 3

SPICE Models

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

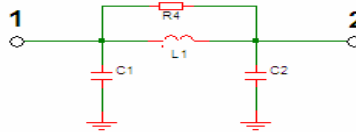


Figure 30 Lumped element SPICE model

The resistance value (R4) approximates the loss term encountered.

The values for the elements are

Site	$C_g = C1 + C2$		L1		R4	
Corner	0.098	pF	0.38	nH	300	Ohms
Edge	0.092	pF	0.33	nH	300	Ohms
Field	0.085	pF	0.34	nH	300	Ohms
Diagonal	0.085	pF	0.34	nH	300	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:

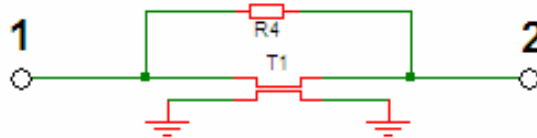


Figure 31 Transmission line model for the 0 array

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

	Zo		L		R4	
Corner	42.7	Ω	4.20	ps	400	Ω
Edge	37.4	Ω	3.44	ps	300	Ω
Field	39.6	Ω	3.38	ps	300	Ω

Values computed here are generally lower than those measured by TDR. A possible cause is a more complex equivalent circuit with short sections of low impedance transmission line that cannot be resolved by the limited risetime TDR measurement as well as spreading inductance contributions in the TDR measurements.

Time domain

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

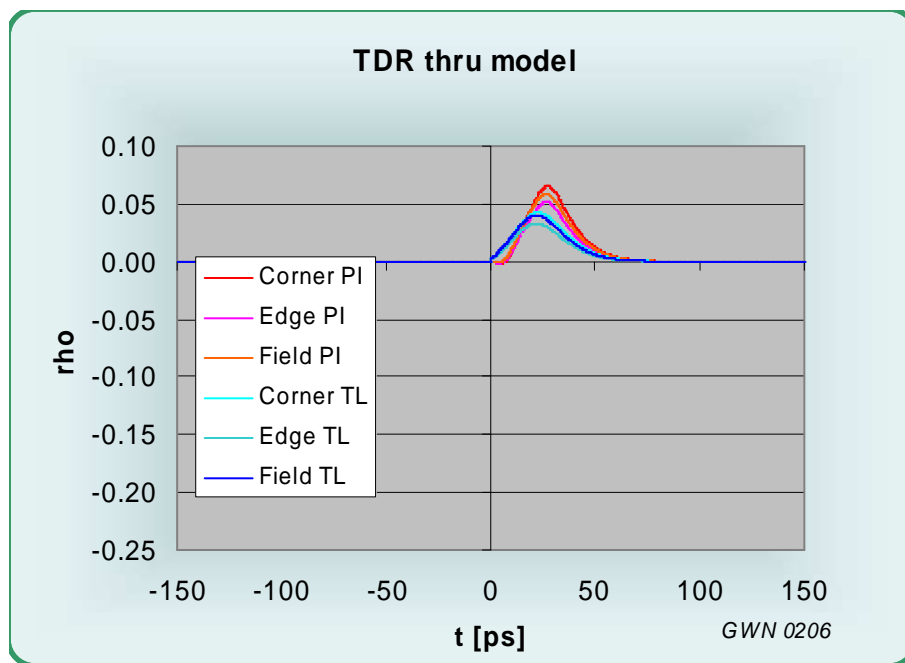


Figure 32 TDR model results

Since these models are computed from the model result, not the TDR result, the aforementioned lower impedance values are reflected in a divergent model from the TDR measurement.

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

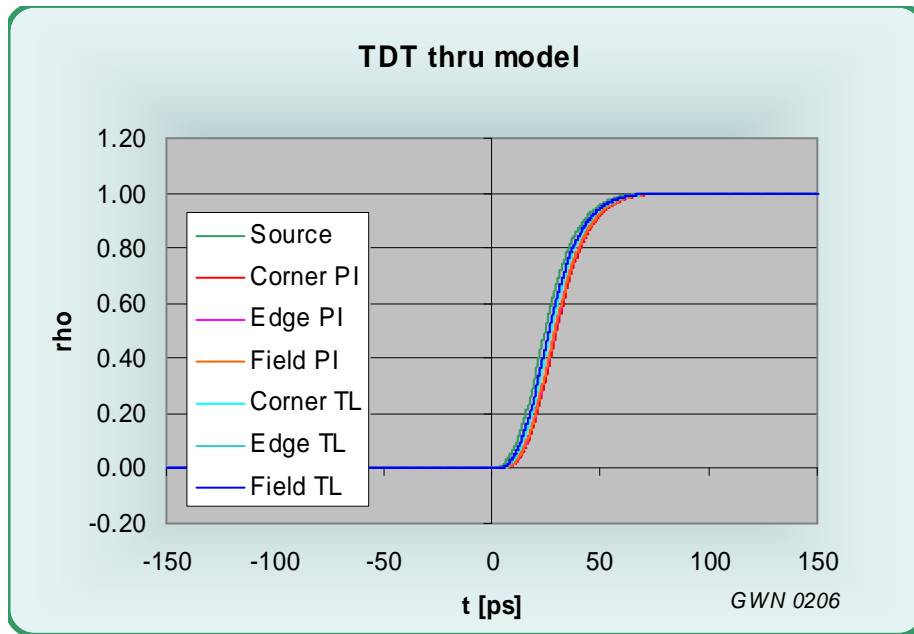


Figure 33 TDT model

The risetime for the transmission line case is 32.5 ps and 27.5 ps for the generator in the model. This situation is comparable to that obtained in the measurement.

Frequency domain

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

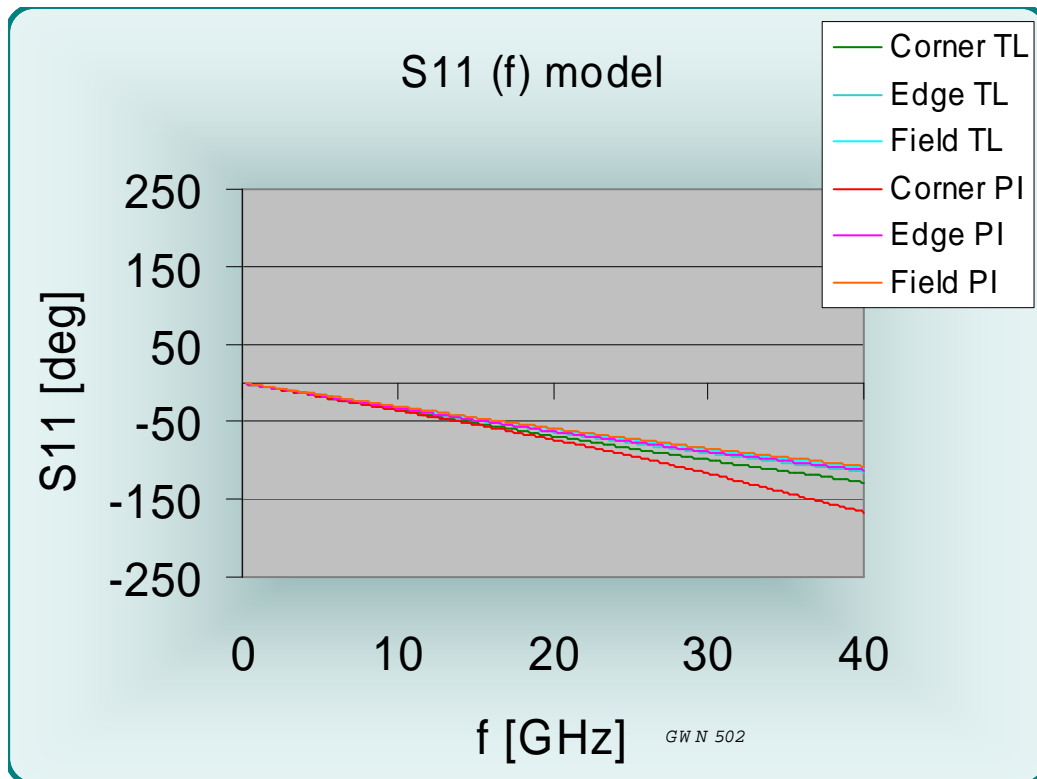


Figure 34 S11 phase (f) for open circuited case

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.

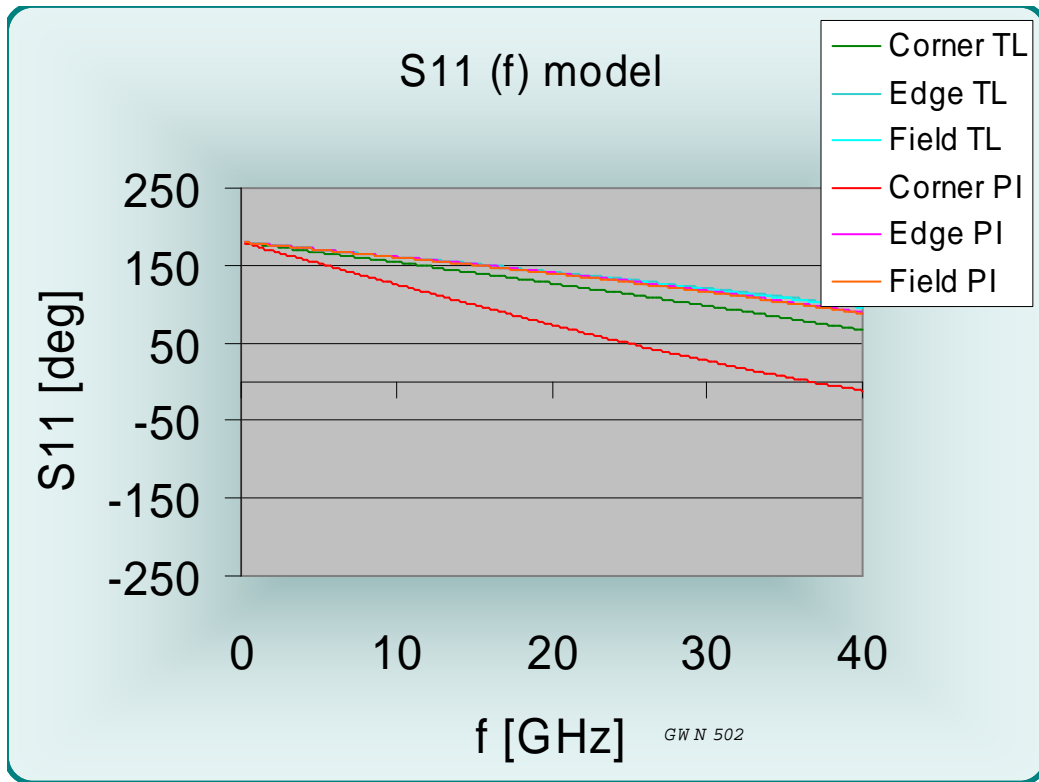


Figure 35 S11 phase response (short circuit)

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.

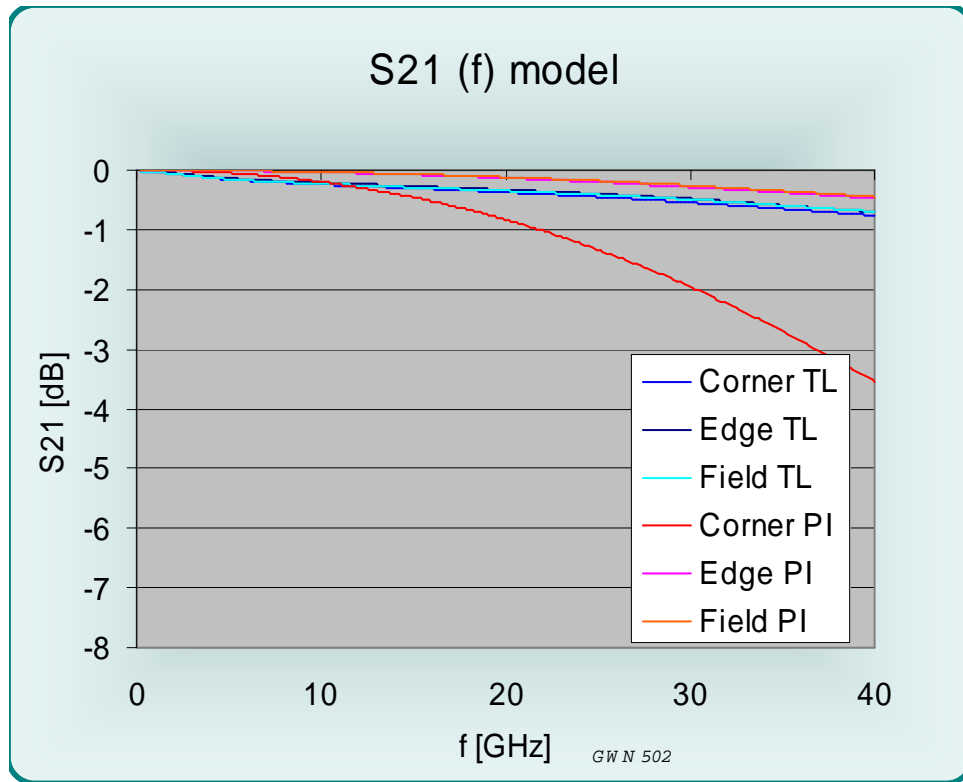


Figure 36 Insertion loss as a function of frequency

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.

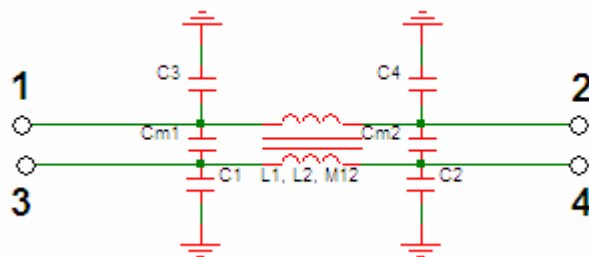


Figure 37 Equivalent circuit for G-S-S-G (mutual coupling)

The values for this model are:

Site	C1,2,3,4	Cm1, Cm2	L1, L2	M
Corner	0.098	0.005 pF	0.38	0.062 nH
Edge	0.092	0.005 pF	0.33	0.041 nH
Field	0.085	0.004 pF	0.34	0.026 nH
Diagonal	0.085	0.001 pF	0.34	0.015 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 (field site only):

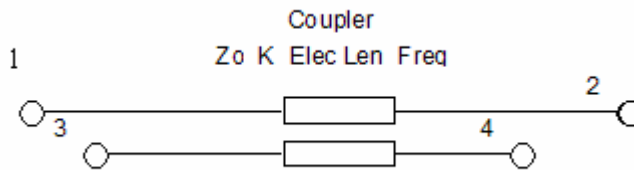


Figure 38 Transmission line equivalent circuit for crosstalk

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

Field	56.7	Ω	3	ps	0.19	166.7	GHz
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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.

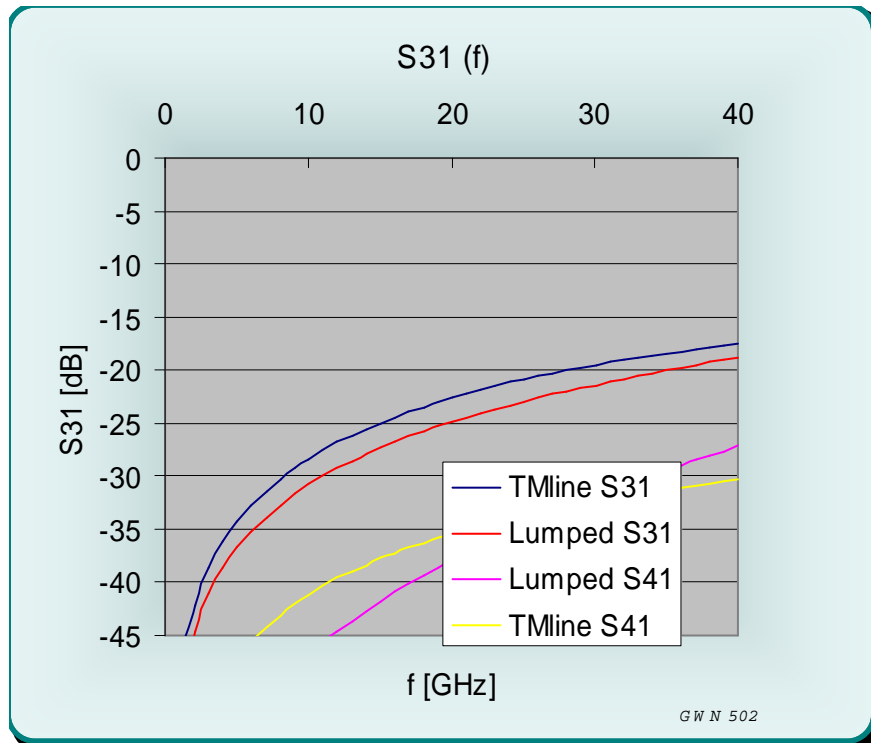


Figure 39 Crosstalk S31 and S41 [dB] as a function of frequency

Summary sheet

Paricon Technologies

BGA socket
0.50 mm pitch

8/22/2007

Measurement results:

	Corner	Edge	Field	
Delay	3	3	3	ps
Risetime open	27	27	27	ps
Risetime short	28.5	28.5	28.5	ps
Risetime thru, 50 Ω	30	30	30	ps
Insertion loss (1dB)	40.0	40.0	40.0	GHz
Insertion loss (3dB)	40.05	40.05	40.05	GHz
VSWR (2:1)	40.05	40.05	40.05	GHz

PI equivalent circuit component values:

Site	Cg=C1+C2		L1		R4	
Corner	0.098	pF	0.18	nH	300	Ohms
Edge	0.092	pF	0.13	nH	300	Ohms
Field	0.085	pF	0.13	nH	300	Ohms
Diagonal	0.085	pF	0.13	nH	300	Ohms

It should be noted that there are 2 capacitors in the PI equivalent circuit. Each of them has half the value listed here. Capacitance values do not follow expectation, possibly because different numbers of vertical conductor columns are being contacted.

Mutual component values:

Site	Cm		M	
Corner	0.010	pF	0.062	nH
Edge	0.010	pF	0.041	nH
Field	0.009	pF	0.026	nH
Diagonal	0.003	pF	0.015	nH

It should be noted that there are 2 capacitors in the PI equivalent circuit. Each of them has half the value listed here.

Transmission line equivalent circuit values:

Site	Zo		td	
Corner	56.5	Ω	3	ps
Edge	57.2	Ω	3	ps
Field	56.7	Ω	3	ps

The impedance listed is that observed in the time domain measurements. It is different than that calculated from the measured L,C parameters because of the limited time domain signal risetime.