Ironwood Electronics

Giga-snap BGA100B-41 test socket
1.00 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 Ironwood Giga-snap BGA100B-41 test 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 20 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 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.

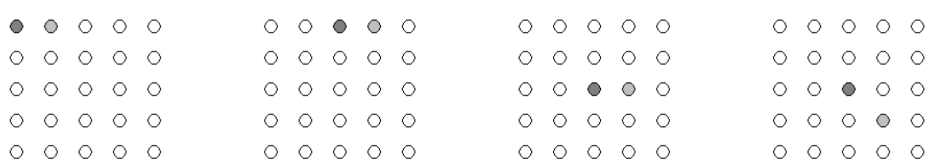
Time domain measurements are obtained via Fourier transform from VNA tests. These measurements reveal the type of discontinuities at the interfaces plus contacts and establish bounds for digital system risetime and clock speeds.

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 Giga-snap BGA100B-41 test 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 determined for all cases.

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

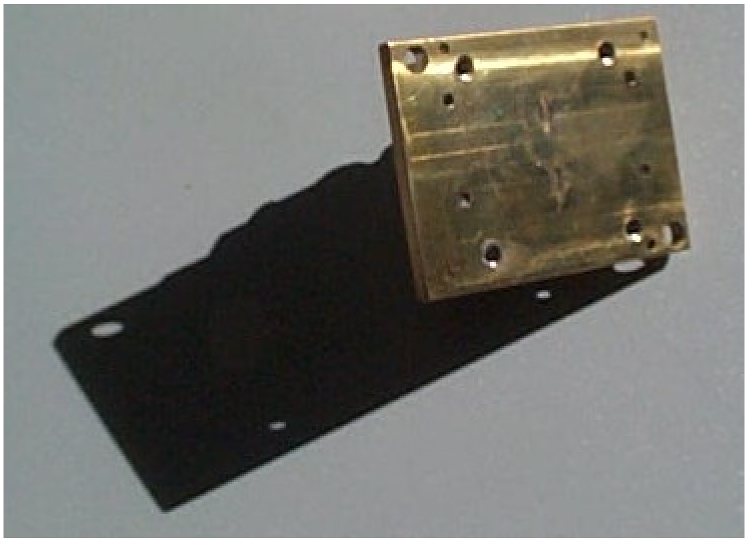


Figure 1 Giga-snap BGA100B-41 test socket base plate example

Figure 2 DUT plate

The Giga-snap BGA100B-41 test socket and base plate as well as the DUT plate are then mounted in a test fixture as shown in Fig. 3:

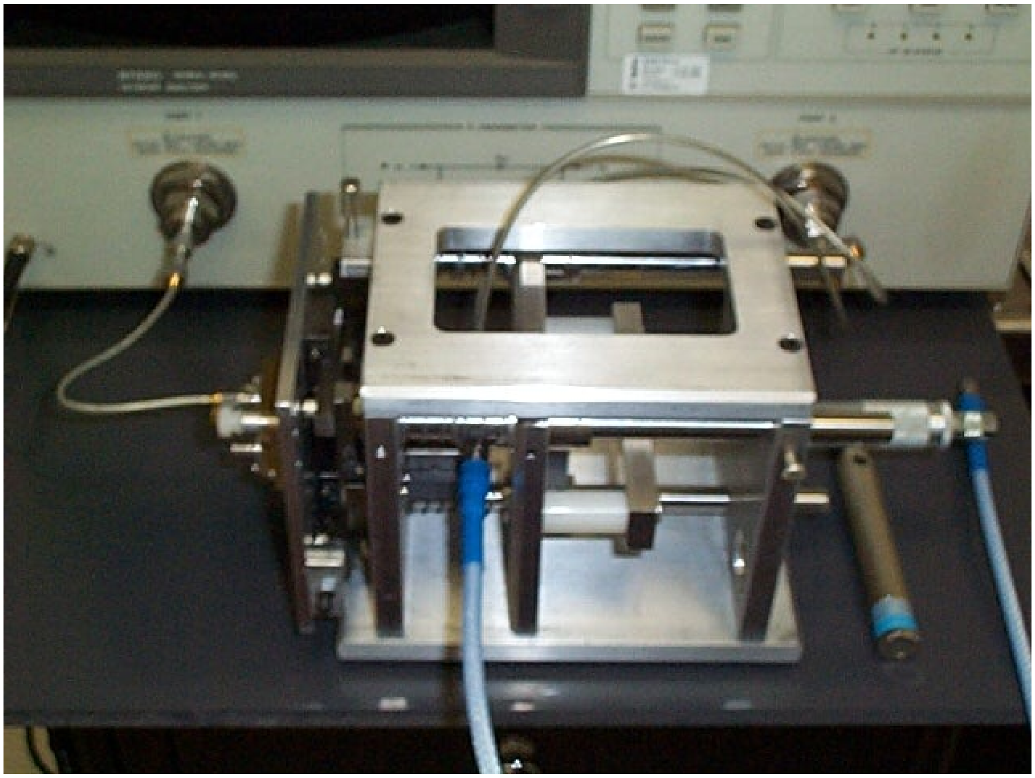


Figure 3 Test fixture

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:

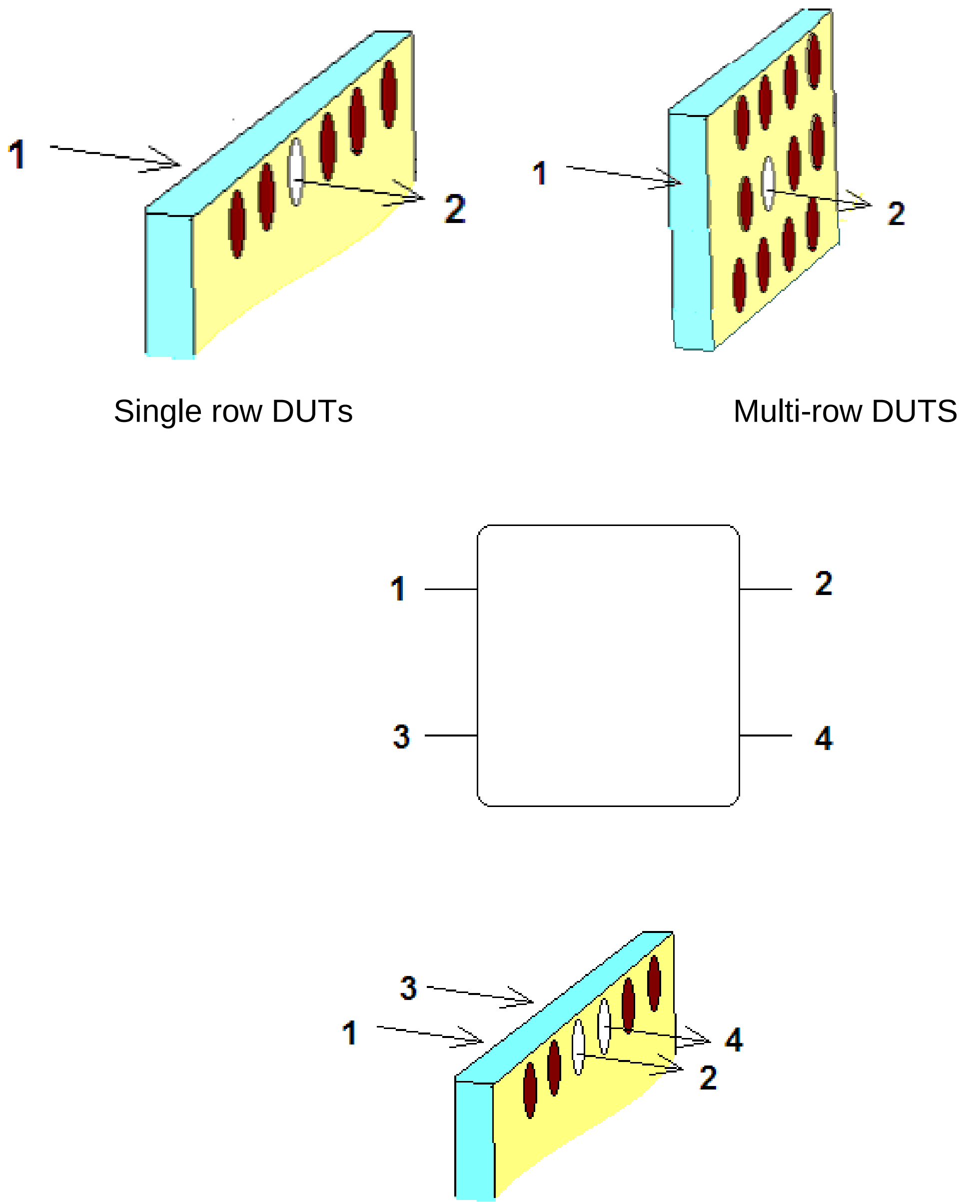


Figure 4 Ports for the G-S-G and G-S-S-G measurements

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:

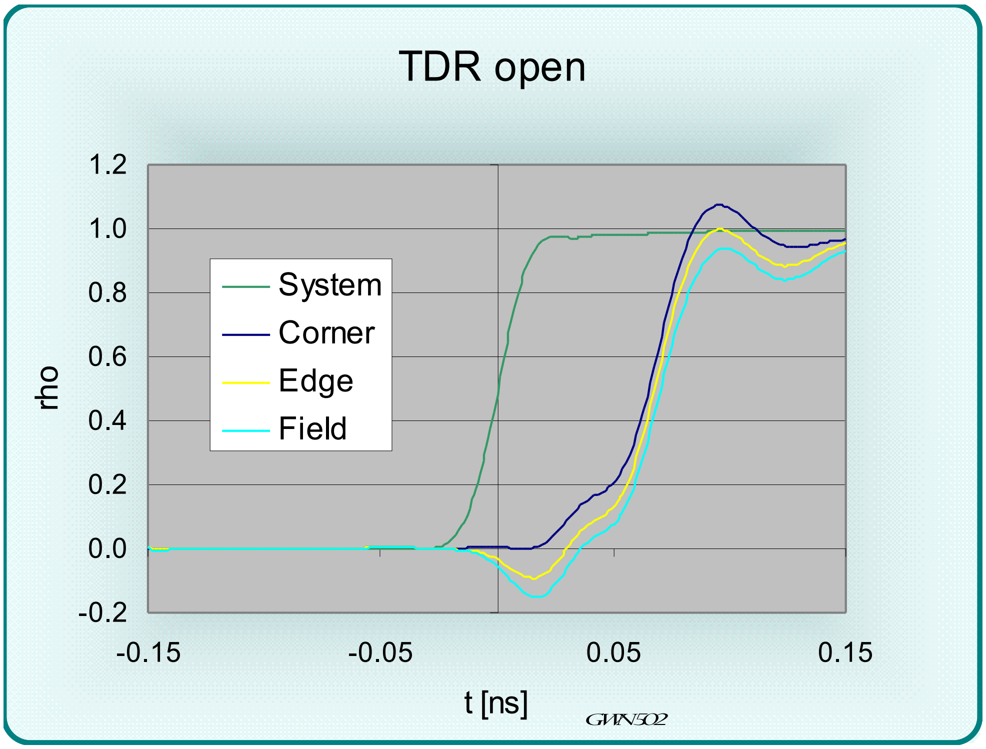


Figure 5 TDR signal from an OPEN circuited Giga-snap BGA100B-41 test socket

The reflected signals from the Giga-snap BGA100B-41 test socket (rightmost traces) show only a small deviation in shape from the original waveform (leftmost trace). The risetime is about 46.5, 37.5 and 33.0 ps for corner, edge and field, respectively and is somewhat larger than that of the system with the open probe (25.5 ps). Electrical pin length is about 32.3, 33.0 and 33.8 ps, respectively (one way).

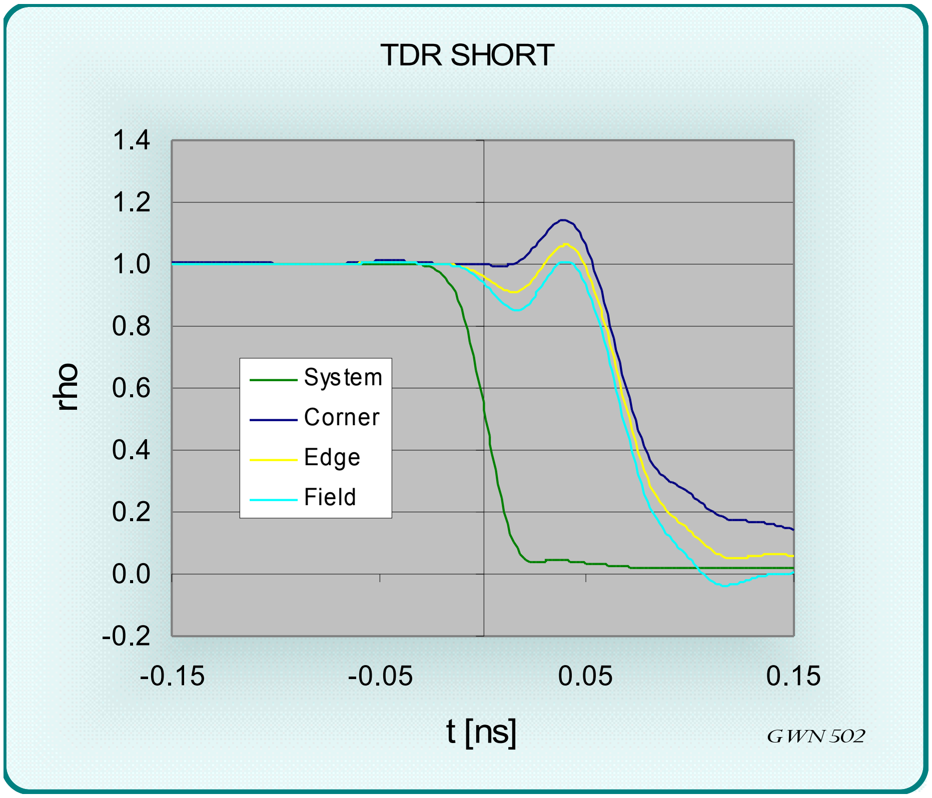


Figure 6 TDR signal from a SHORT circuited Giga-snap BGA100B-41 test socket

For the short circuited Giga-snap BGA100B-41 test socket the fall time is about 88.5, 49.5 and 85.5 ps for corner, edge and field, respectively. There is an increase over the system risetime of 27.0 ps caused by the contact impedance levels.

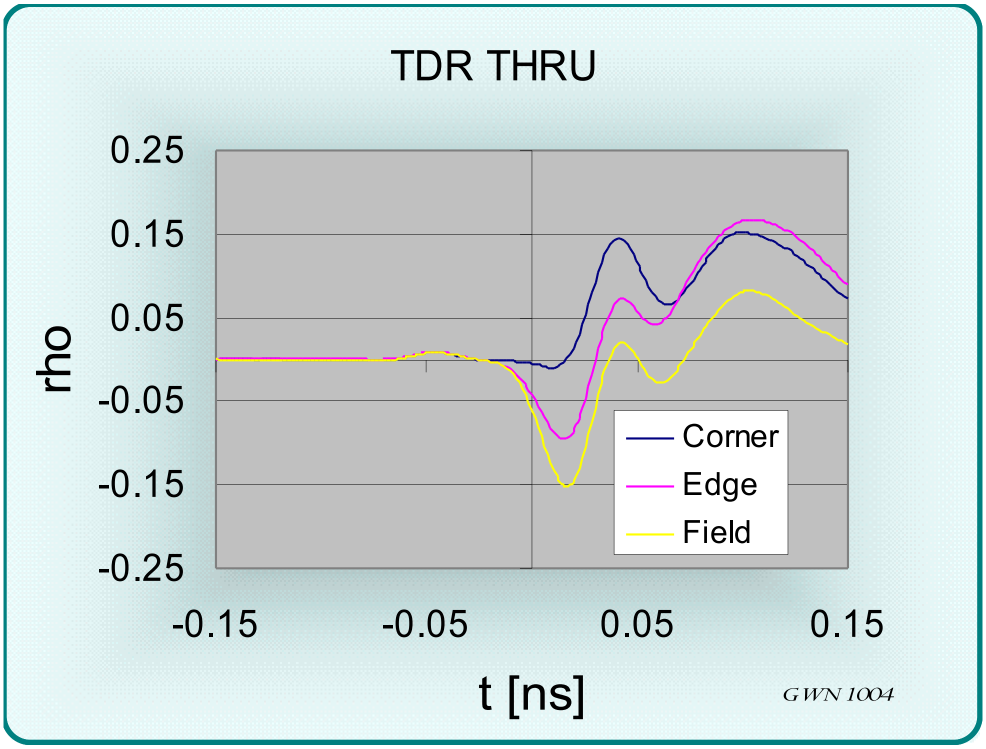


Figure 7 TDR measurement into a 50 Ohm probe

The thru TDR measurement shows both an inductive response and a capacitive response. The peaks correspond to an impedance of 67.9, 70.1 and 58.9 Ohms for corner, edge and field, respectively. The corresponding low values are 49.0, 41.3 and 36.8 Ohms.

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

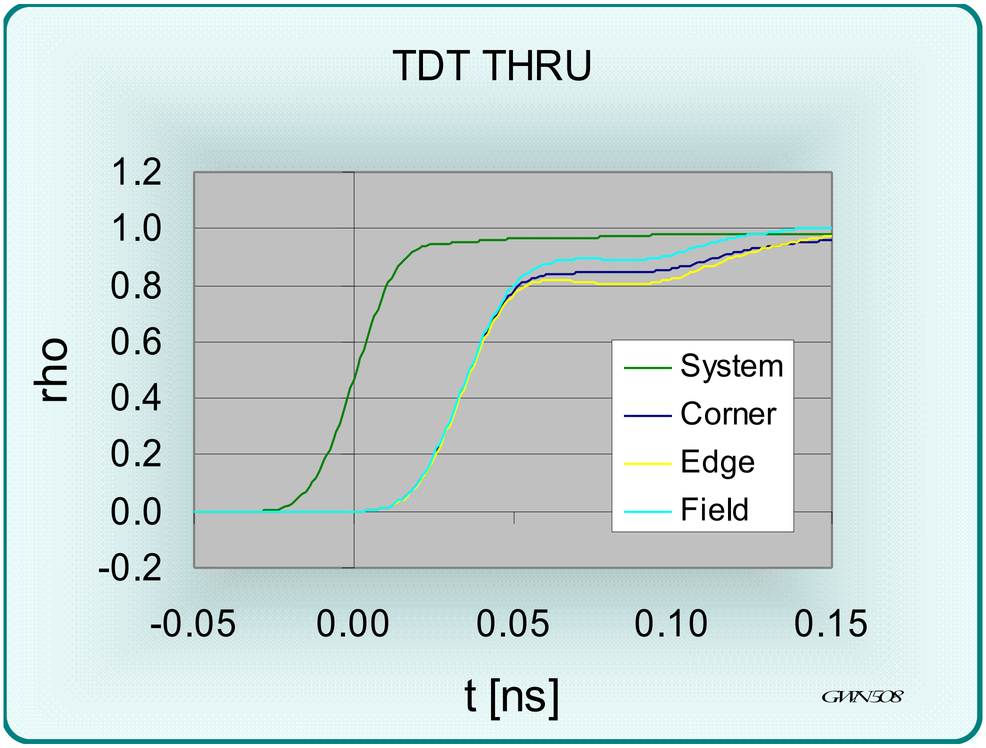


Figure 8 TDT measurement

The TDT measurements for transmission show a contribution to risetime from the pin array (10-90% RT = 81.0, 93.0 and 78.0 ps for corner, edge and field, respectively, the system risetime is 28.5 ps). The added delay values at the 50% point are 35.2, 35.6 and 35.7 ps, respectively. If the 20%-80% values are extracted, the risetimes are only 24.0, 25.5 and 24.0 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).

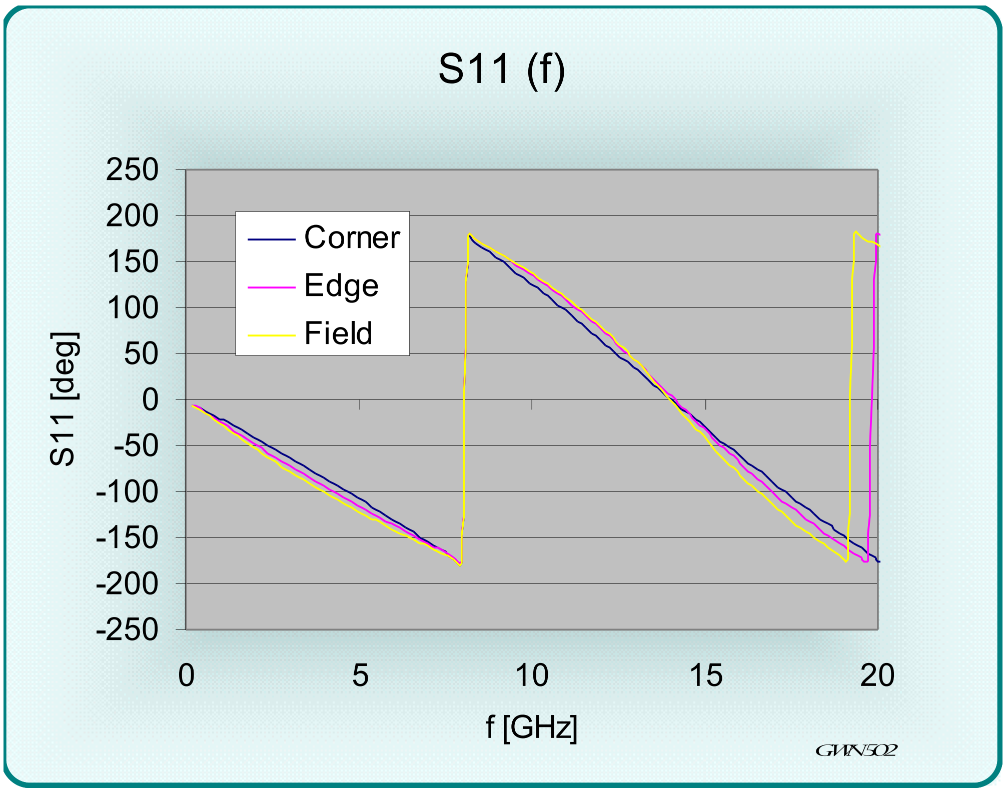


Figure 9 S11 phase (f) for the open circuited signal pin

There are no aberrations in the response. The 360 degree jump is due to the network analyzer data presentation. It rolls over values greater than +/- 180 degrees.

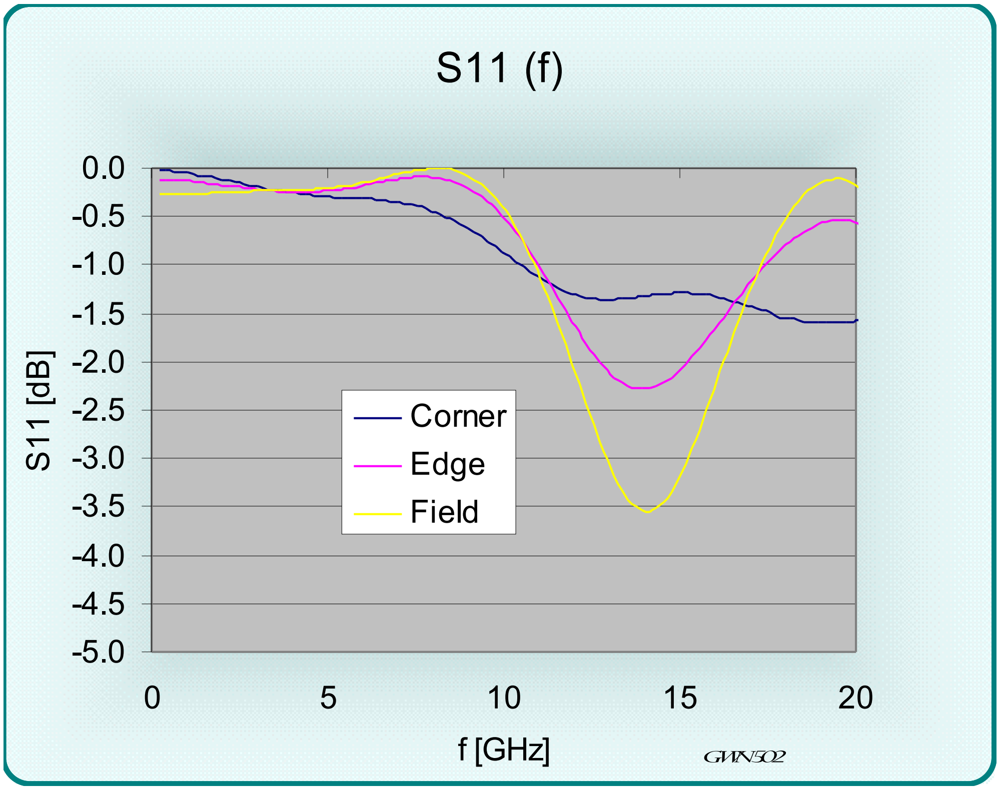


Figure 10 S11 magnitude (f) for the open circuited signal pin

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

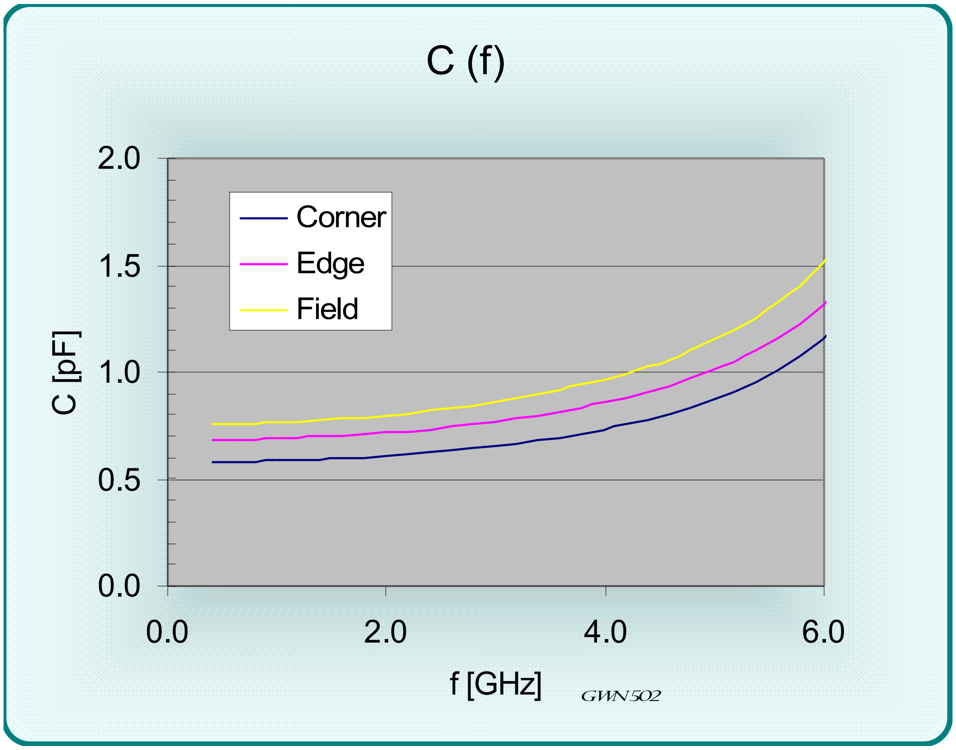


Figure 11 C(f) for the open circuited signal pin

Capacitance is 0.60, 0.70 and 0.78 pF for corner, edge and field, respectively, at low frequencies. The rise in capacitance toward 7 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 of a lumped capacitor is not valid anymore. Instead, a transmission line model must be applied. 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 maximum frequency is 20 GHz.

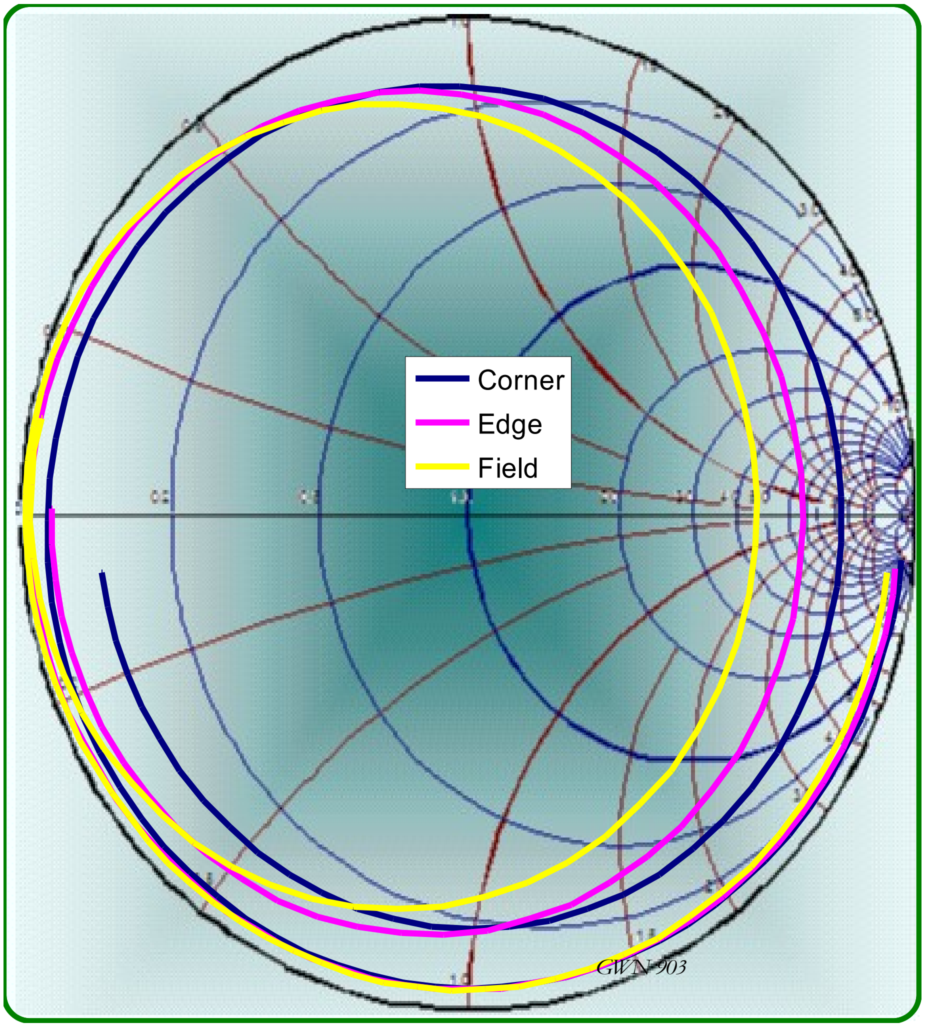


Figure 12 Reflections from the open circuited Giga-snap BGA100B-41 test socket

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 Giga-snap BGA100B-41 test socket. Calibration was established with a short placed at the end of the coax probe.

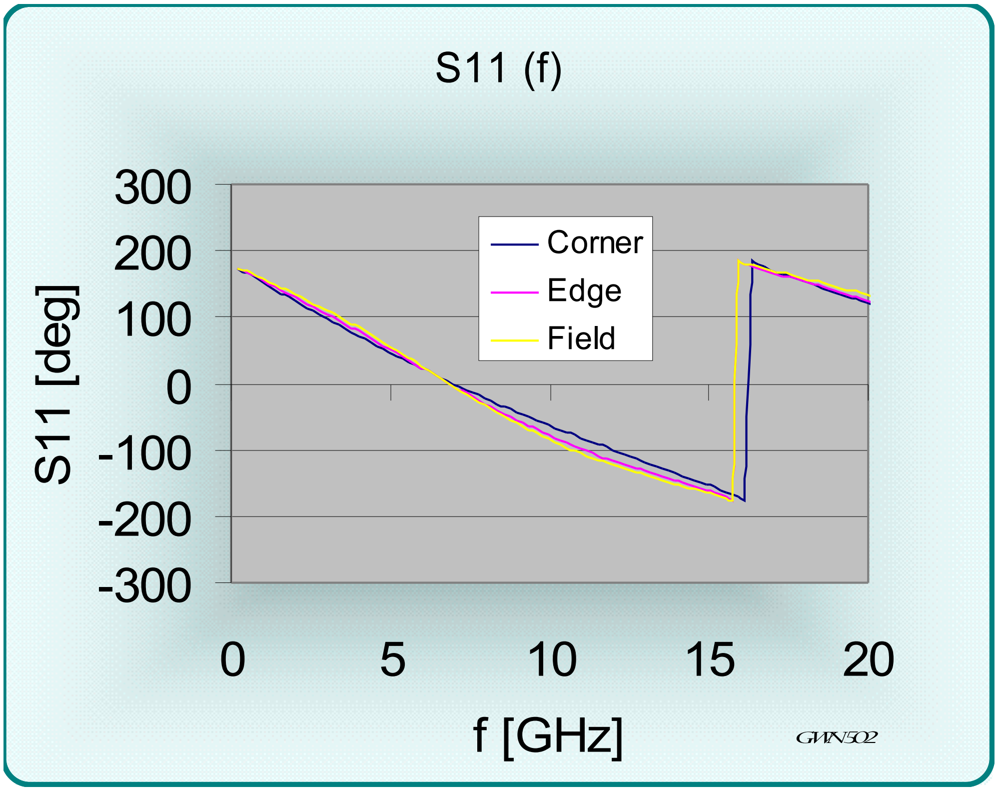


Figure 13 S11 phase (f) for the short circuited case

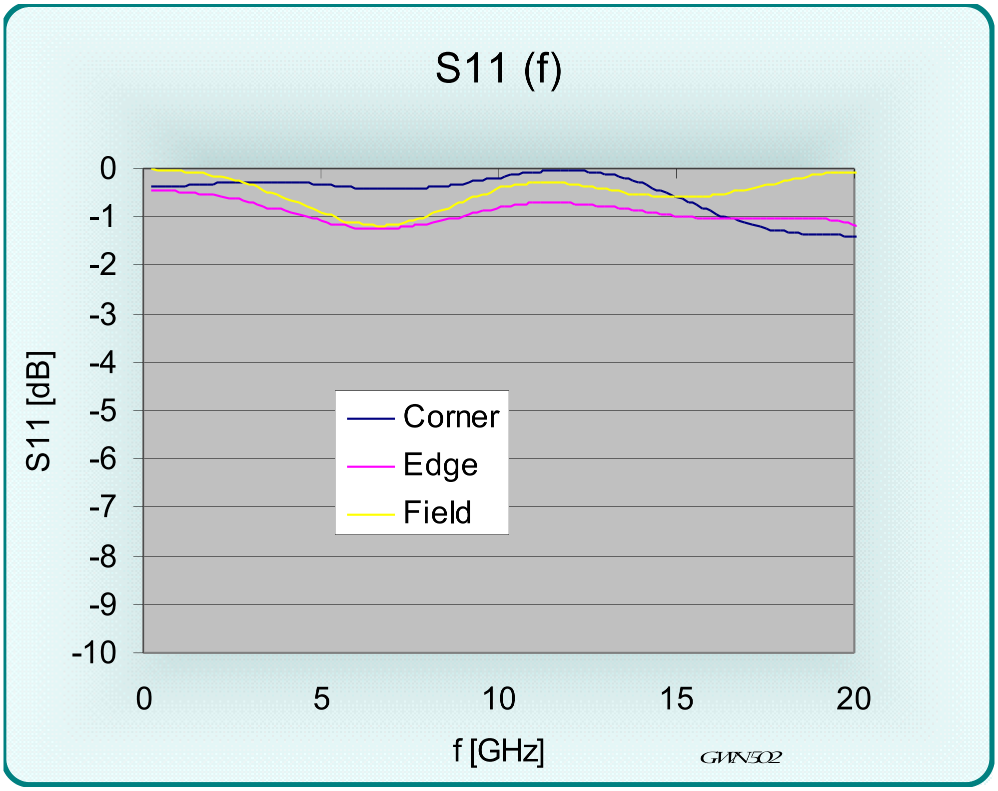


Figure 14 S11 magnitude (f) for the short circuited case

Some S11 return loss exists, likely the result of loss, radiation and resonances.

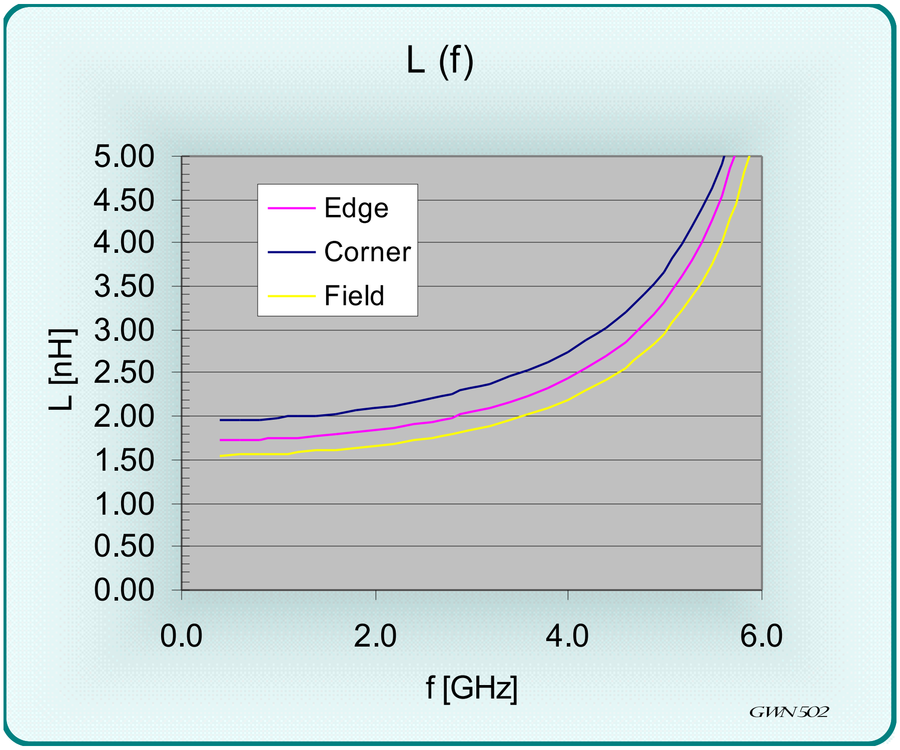


Figure 15 L(f) for the Giga-snap BGA100B-41 test socket

The phase change corresponds to an inductance of 2.03, 1.79 and 1.62 nH for corner, edge and field, respectively, at low frequencies. Toward 6 GHz inductance increases. At these frequencies, the transmission line nature of the connection must be taken into account.

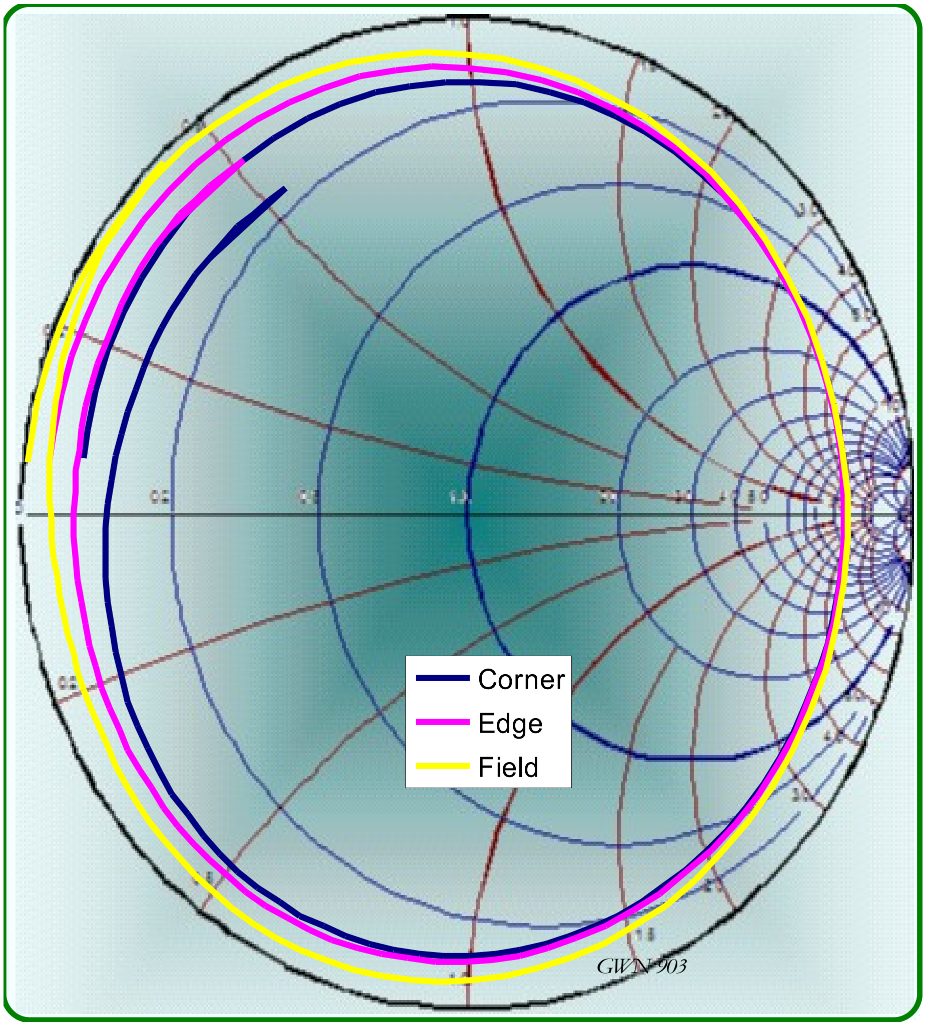


Figure 16 Short circuit response in the Smith chart

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

An insertion loss measurement is shown below for the frequency range of 50 MHz to 20 GHz.

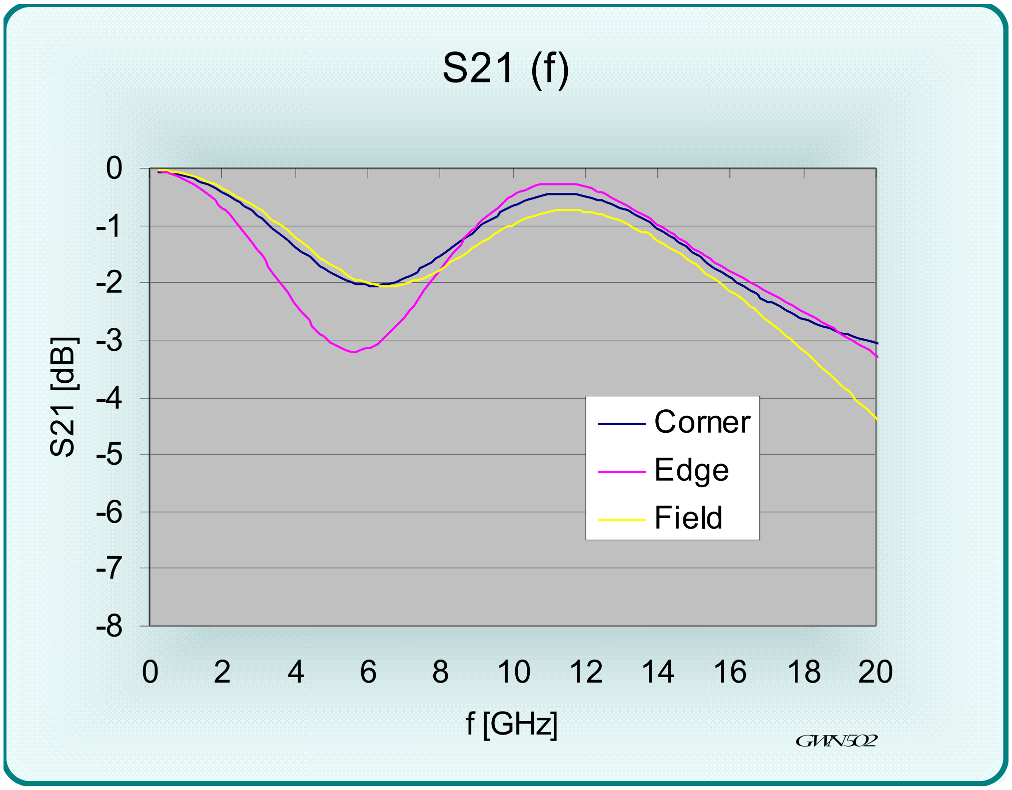


Figure 17 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 3.2, 2.4 and 3.6 GHz (corner, edge, field). The 3 dB point is not reached before 19.7, 4.8 and 17.5 GHz.

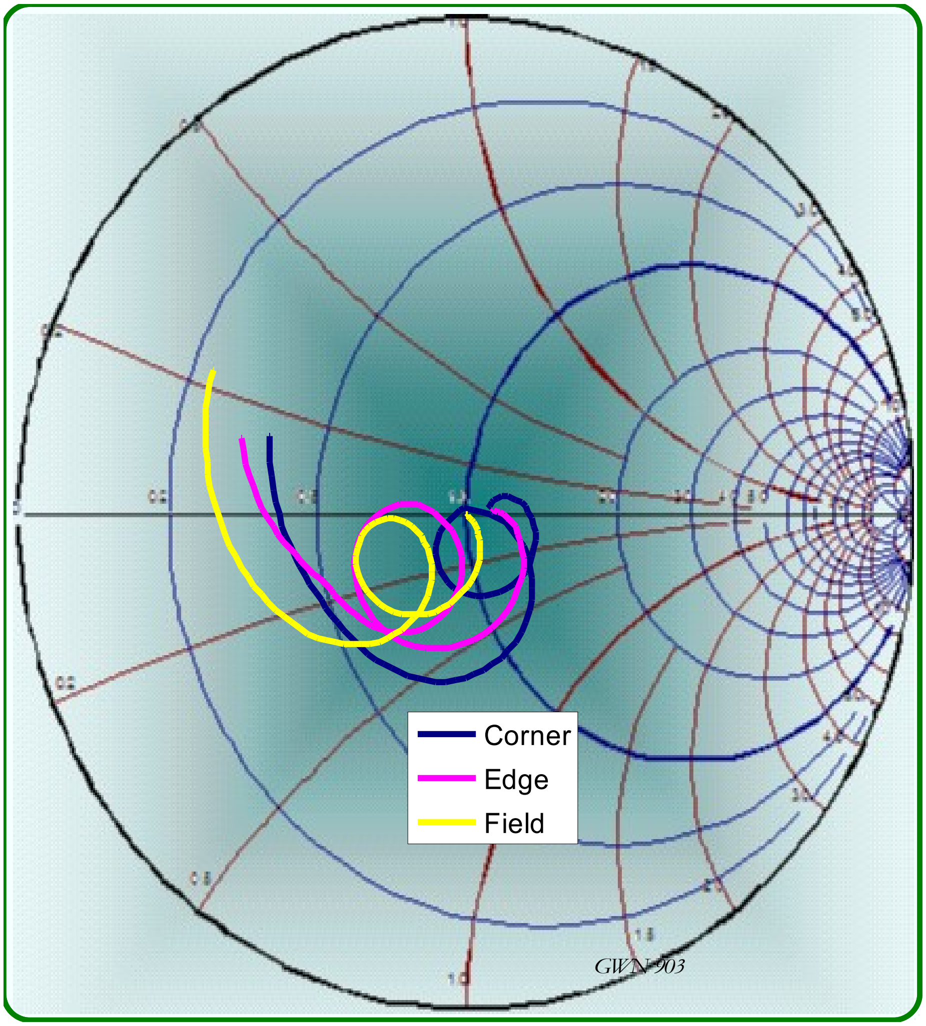


Figure 18 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for thru measurements shows a good match at low frequencies. At higher frequencies reactive components become apparent.

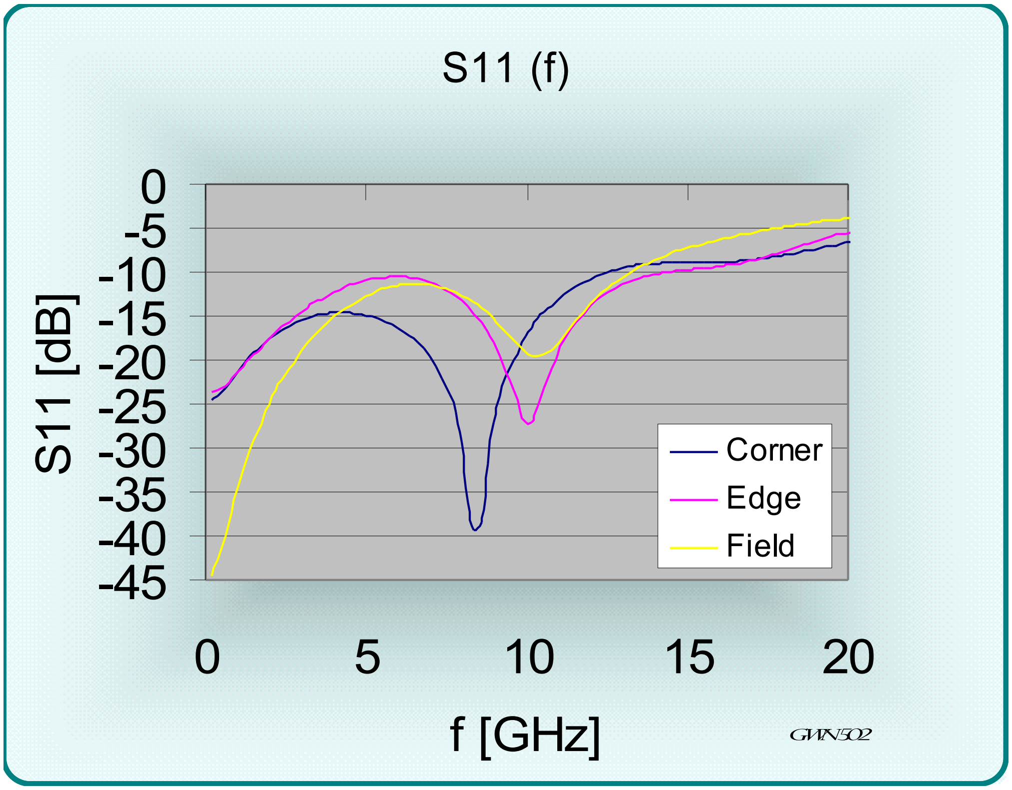


Figure 19 S11 magnitude (f) for the thru measurement into a 50 Ohm probe

Return loss reaches -20 dB at 1.2 GHz, 10.8 GHz and 2.6 GHz for corner, edge and field sites. The corresponding -10 dB frequencies are 12.4, 14.3 and 13.2 GHz.

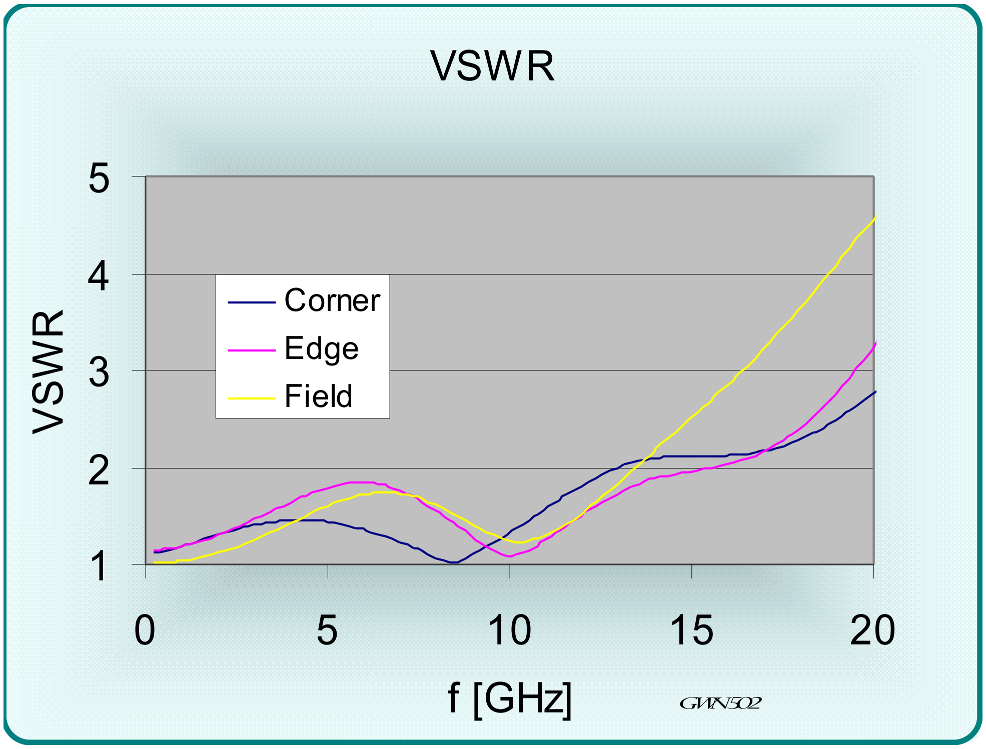


Figure 20 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 13.0, 15.5 and 13.3 GHz (corner, edge, field).

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:

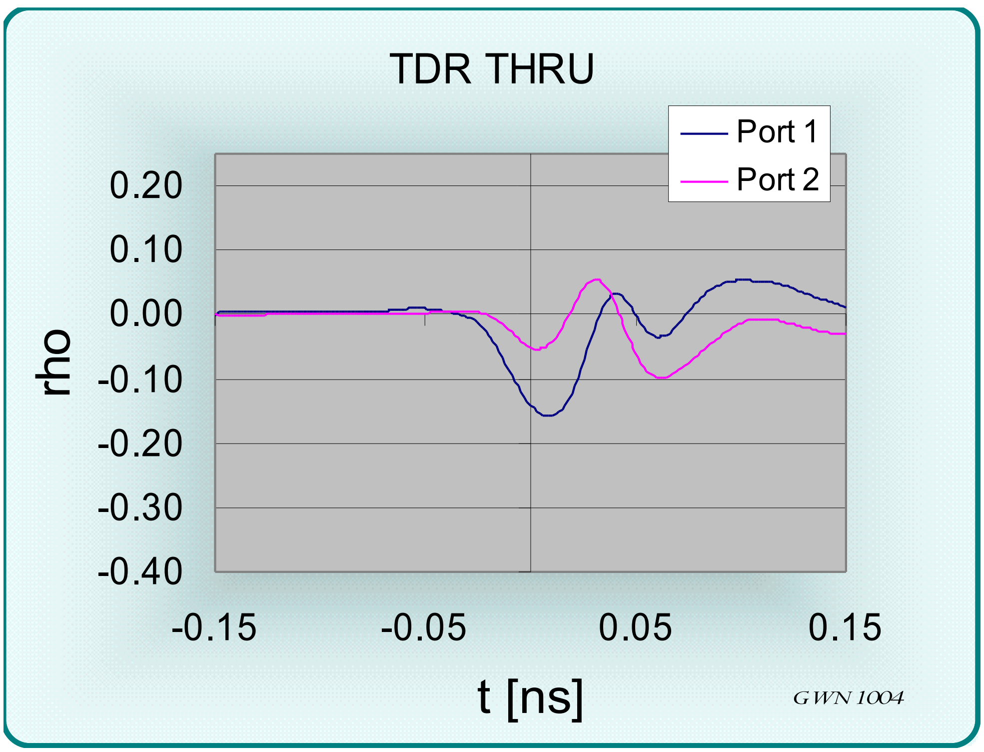


Figure 21 TDR through DUT into a terminated probe

The thru TDR measurement from port 1 to port 2 shows both capacitive and inductive responses. The low peak corresponds to a transmission line impedance of 36.3 Ohms.

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

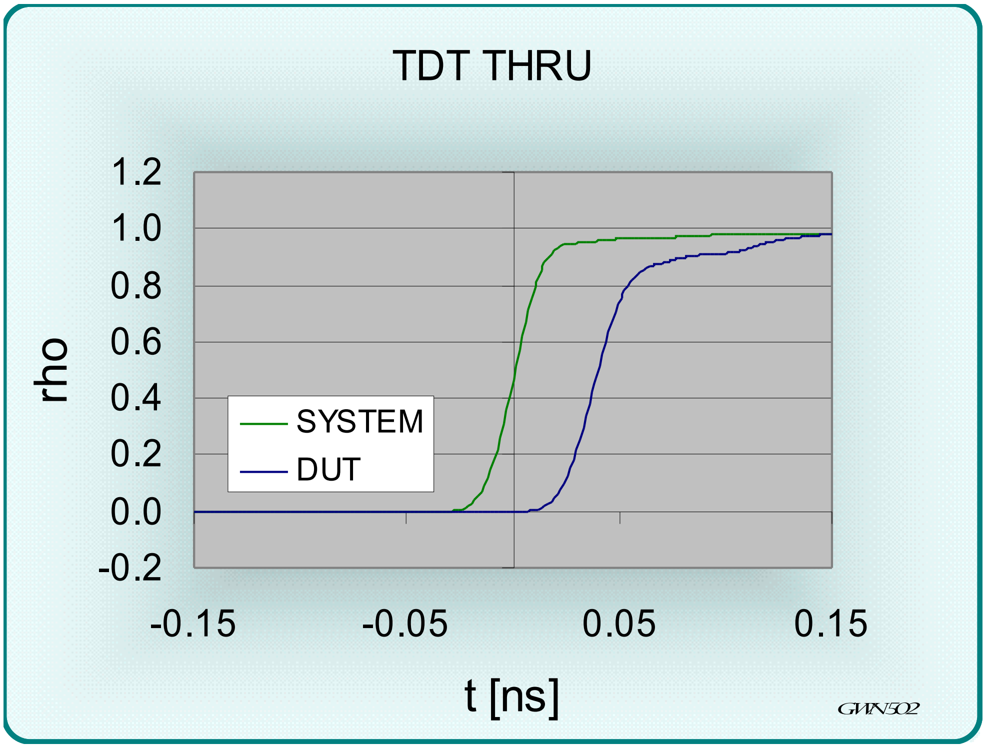


Figure 22 TDT measurement

The TDT measurements for transmission shows a small contribution to risetime from the pin array (10-90% RT = 48.0 ps) as the system risetime (28.5 ps). The added delay at the 50% point is 39.0 ps. The 20%-80% values are 24.0 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.

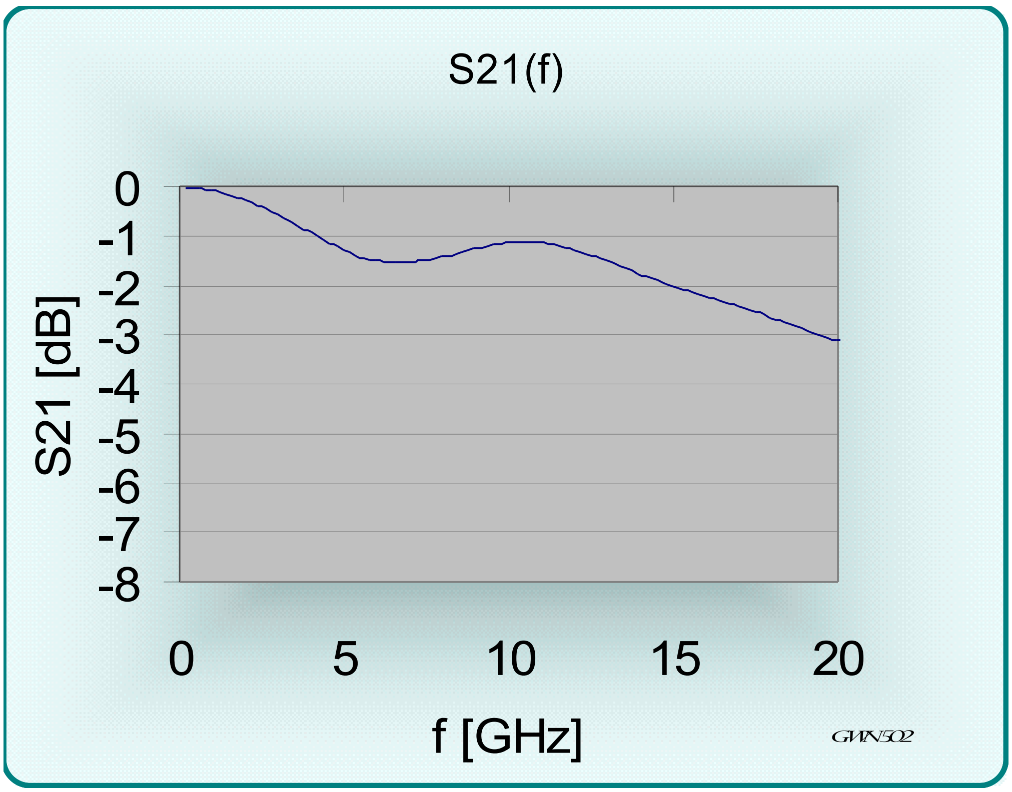


Figure 23 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 4.0 GHz. The 3 dB point is not reached before 19.3 GHz.

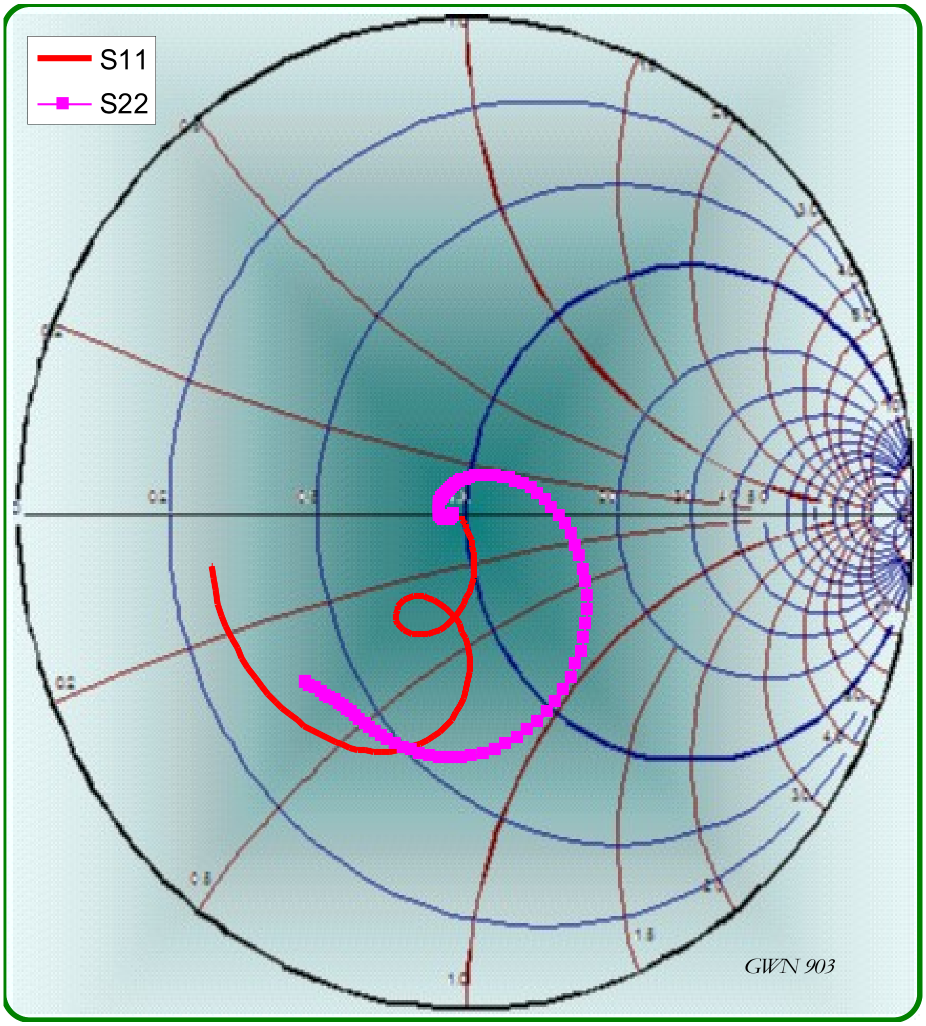


Figure 24 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows a good match at low frequencies with some reactive components as frequency increases.

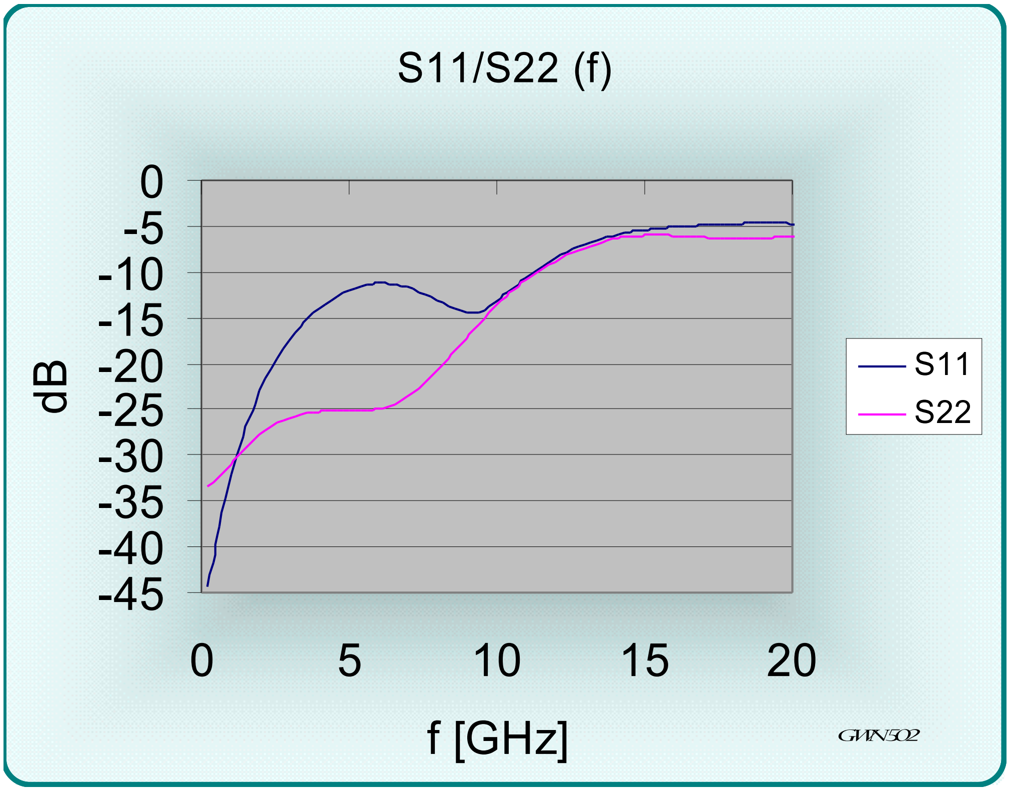


Figure 25 S11 magnitude (f) for the thru measurements into a 50 Ohm probe

The value of the return loss for the thru measurement reaches -20 dB at 2.4 GHz (S11) and 8.2 GHz (S22). It does not exceed -10 dB before 11.2 GHz and 11.4 GHz, respectively.

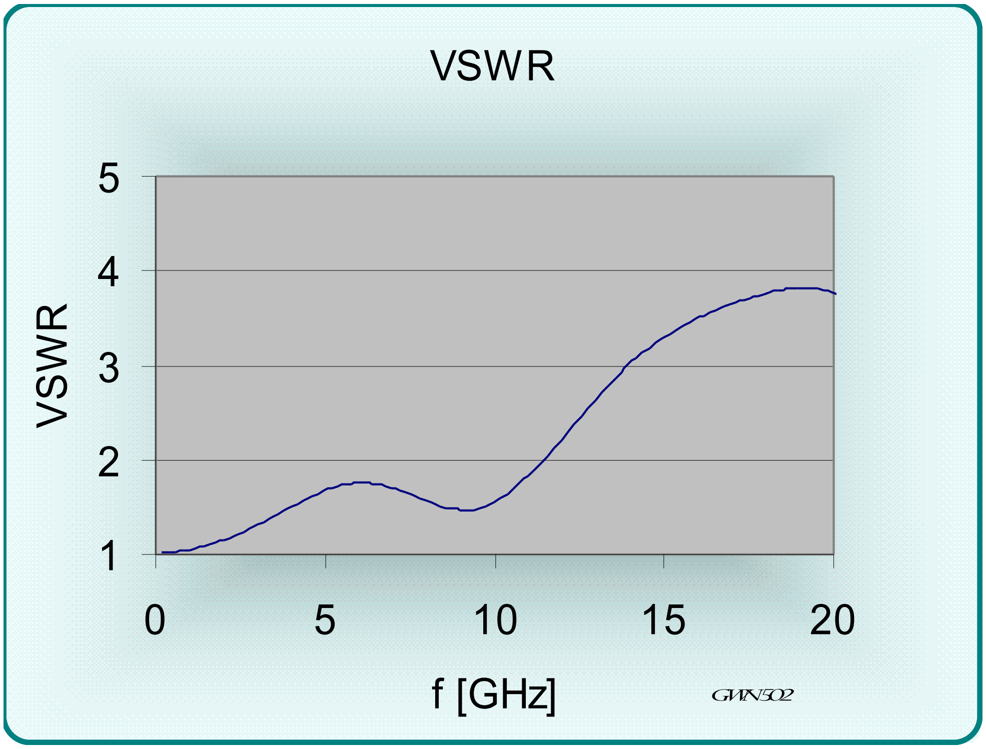


Figure 26 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 11.4 GHz.

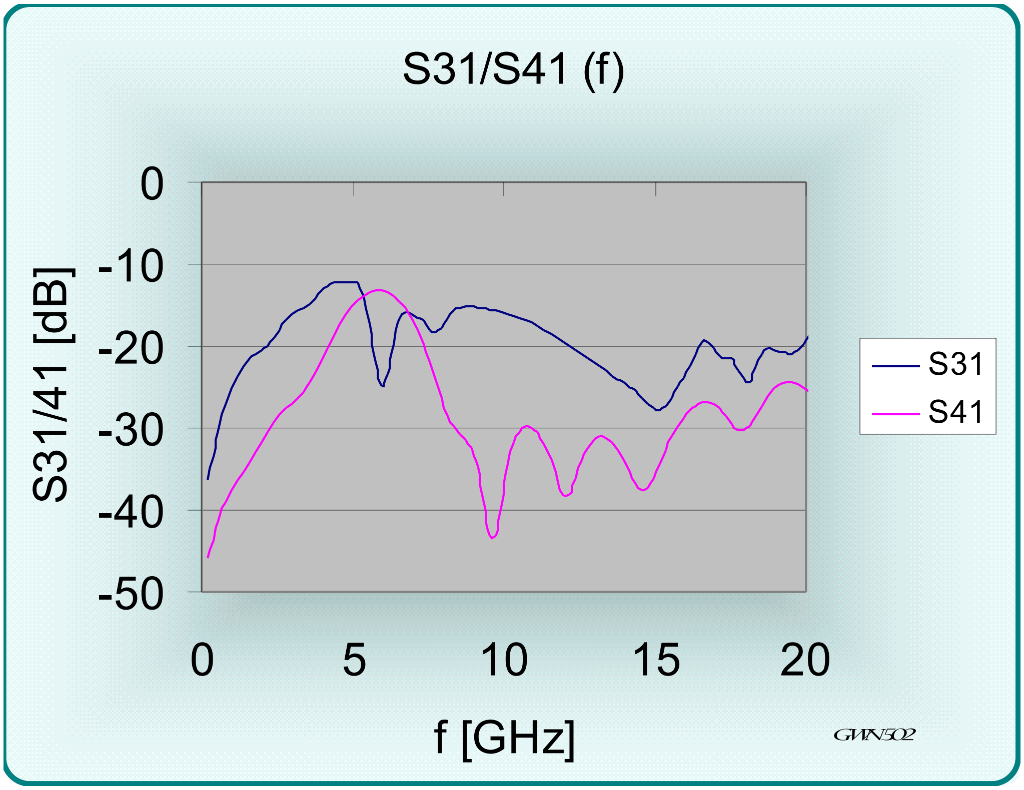


Figure 27 Crosstalk as a function of frequency

The graph shows forward crosstalk from port 1 to port 4 (S41, far end crosstalk {FEXT}) and backward crosstalk from port 1 to the adjacent terminal (port 3, S31, near end crosstalk {NEXT}). The -20 dB point is reached at 2.0 GHz (S31) and not before 4.2 GHz (S41). Not before 20.1 GHz (S31) and 20.1 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 0.167, 0.165, 0.124 and 0.024 pF and a mutual inductance of 0.48, 0.42, 0.29 and 0.056 nH for corner, edge field and diagonal sites, respectively.

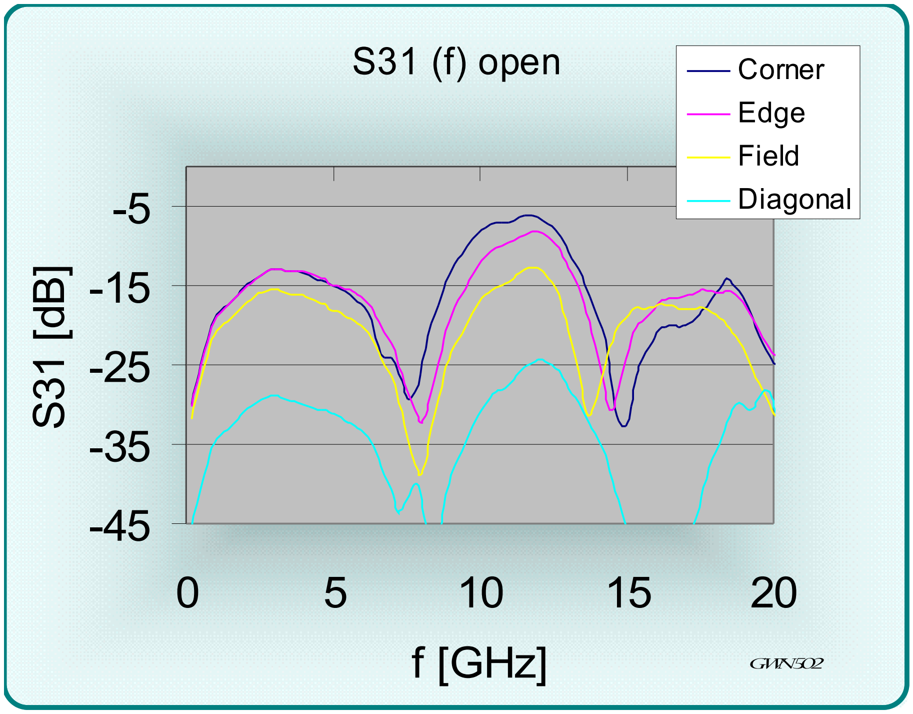


Figure 28 Open circuit crosstalk from port 1 to port 3

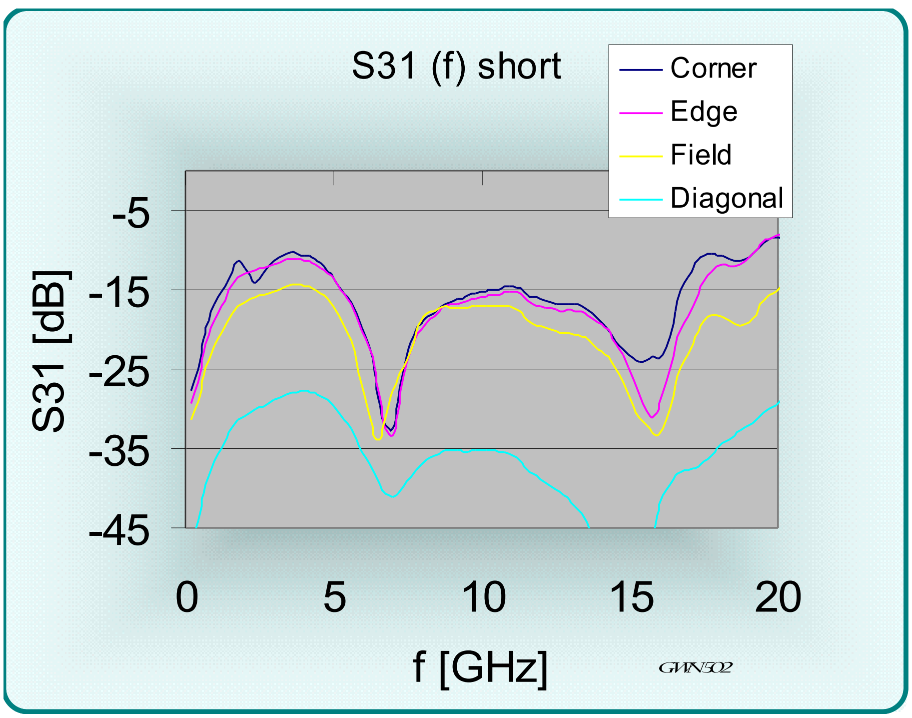


Figure 29 Short circuit crosstalk from port 1 to port 3

SPICE Models

A lumped element SPICE model for the Ironwood Giga-snap BGA100B-41 test socket in G-S-G configuration is shown below:

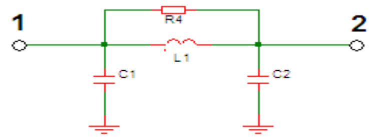


Figure 30 Lumped element SPICE model

The resistance value (R4) approximates the loss term encountered. It should be noted that the lumped element representation is valid only for low frequencies of perhaps 2 GHz. An accurate representation at higher frequencies requires the use of the provided 7th order SPICE model (see .cir files).

The values for the simple model are

Site	Cg=C1+C2			L1		R4	
Corner		0.596	pF	2.03	nH	400	Ohms
Edge		0.701	pF	1.79	nH	400	Ohms
Field		0.779	pF	1.62	nH	400	Ohms
Diagonal		0.779	pF	1.62	nH	400	Ohms

A second simple model developed is a transmission line model. Again, this is only valid at low frequencies. For elevated frequencies the multi-pole circuit files must be used.

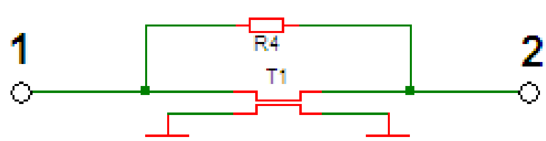


Figure 31 Transmission line model for the Giga-snap BGA100B-41 test socket

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

	Zo		L		R4	
Corner	58.4	Ω	34.8	ps	400	Ω
Edge	50.5	Ω	35.4	ps	400	Ω
Field	45.5	Ω	35.5	ps	400	Ω

Time domain

The TDR simulation for the simple models are as indicated below:

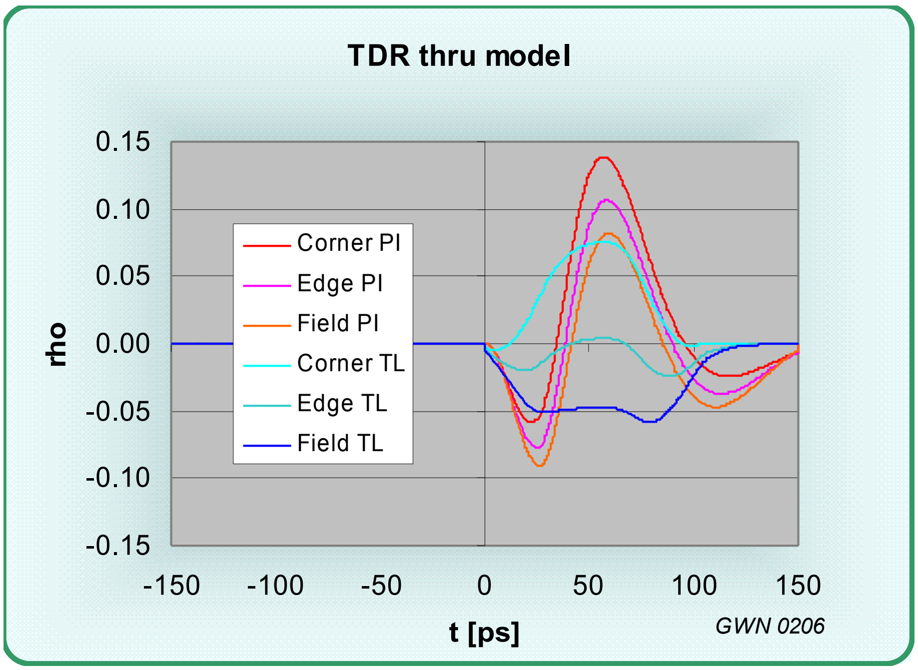


Figure 32 TDR model results

The results demonstrate the limits of the simple model. The simulation for the multi-pole model shows much better agreement with the measurement:

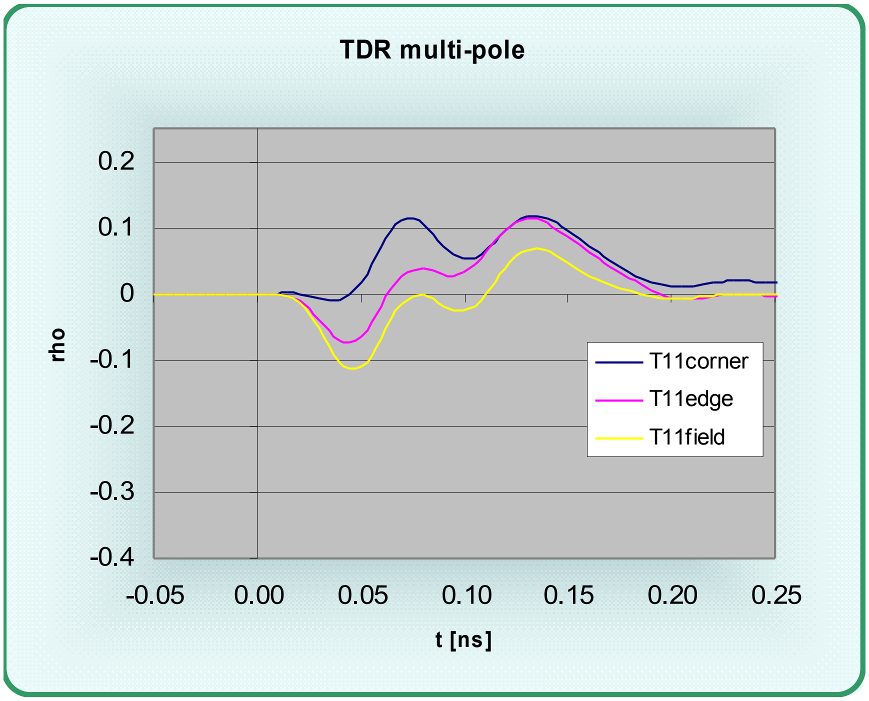


Figure 33 TDR model results (multi-pole)

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

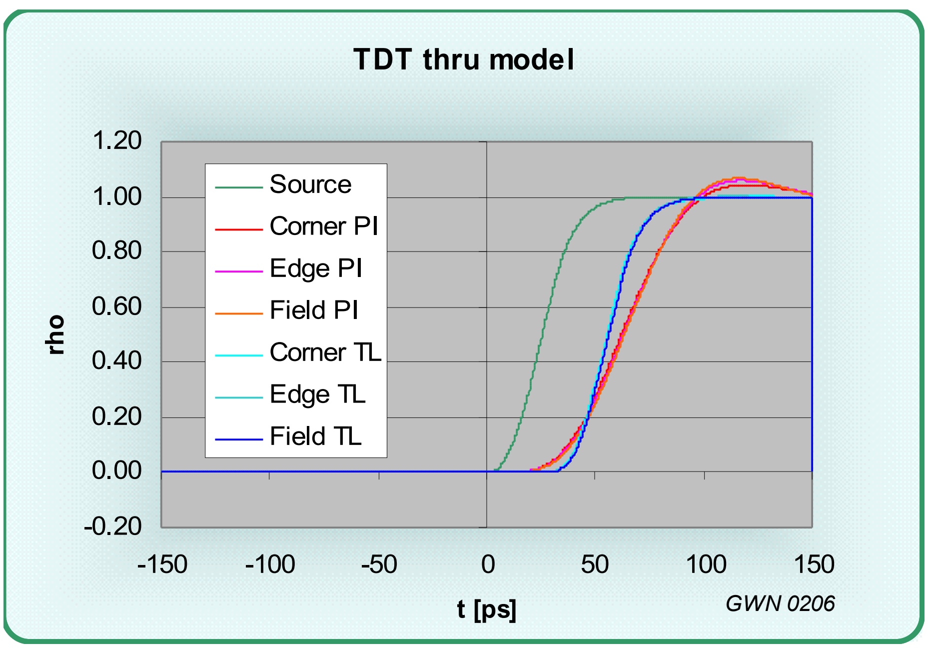


Figure 34 Simple TDT model

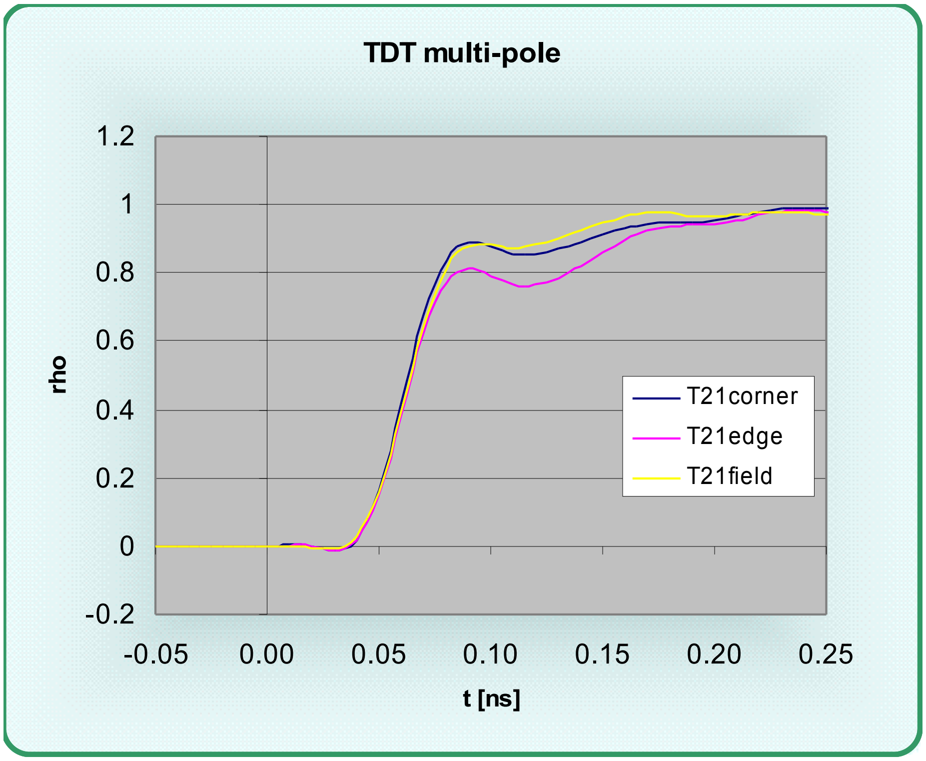


Figure 35 Multi-pole TDT model

Frequency domain

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

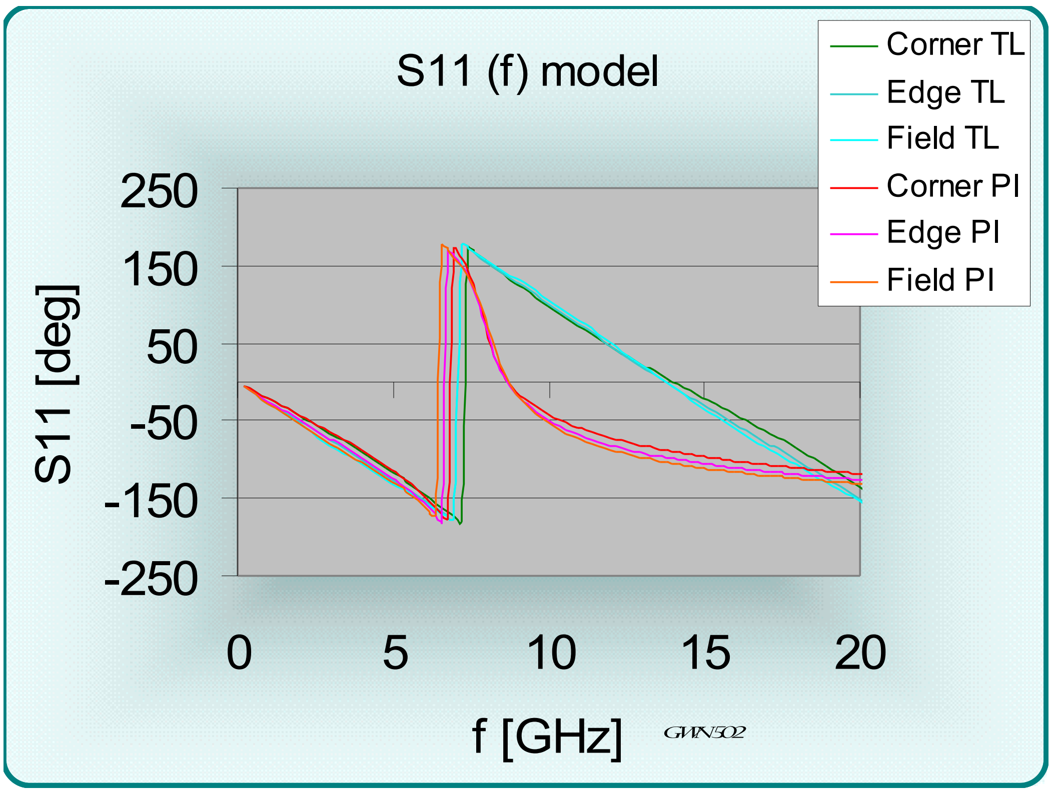


Figure 36 S11 phase (f) for open circuited case (simple model)

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 7 GHz.

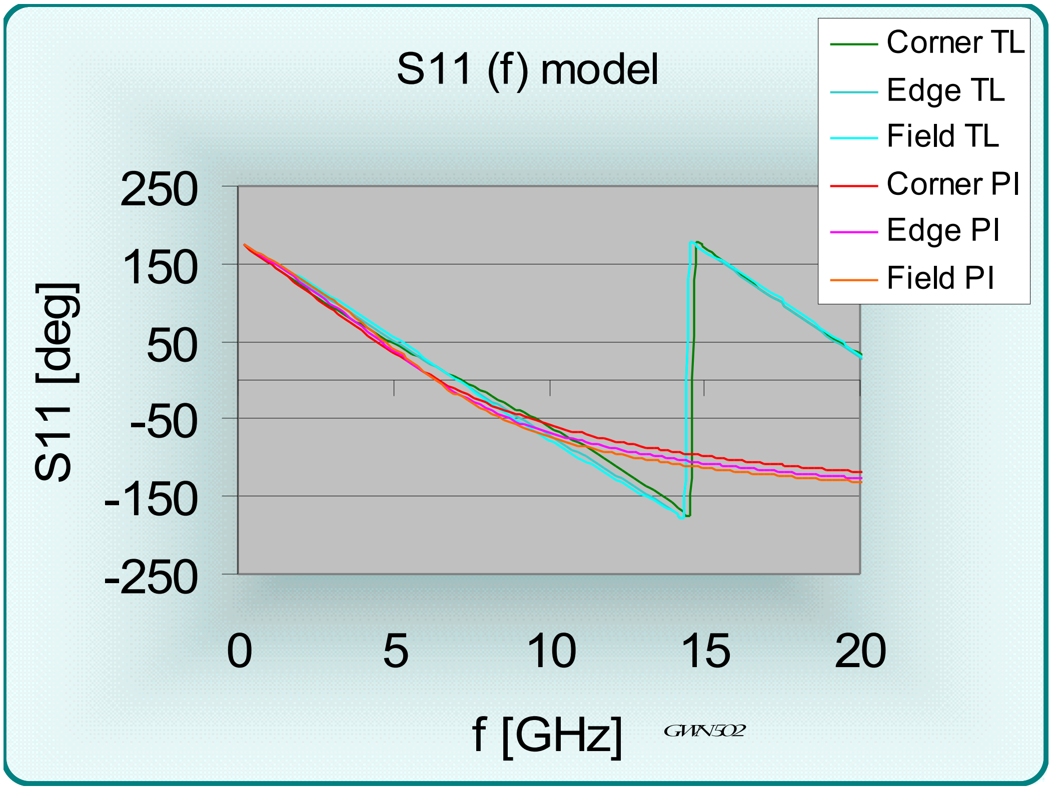


Figure 37 S11 phase response (short circuit)

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, insertion loss increases significantly. The transmission line model does not suffer from this shortcoming.

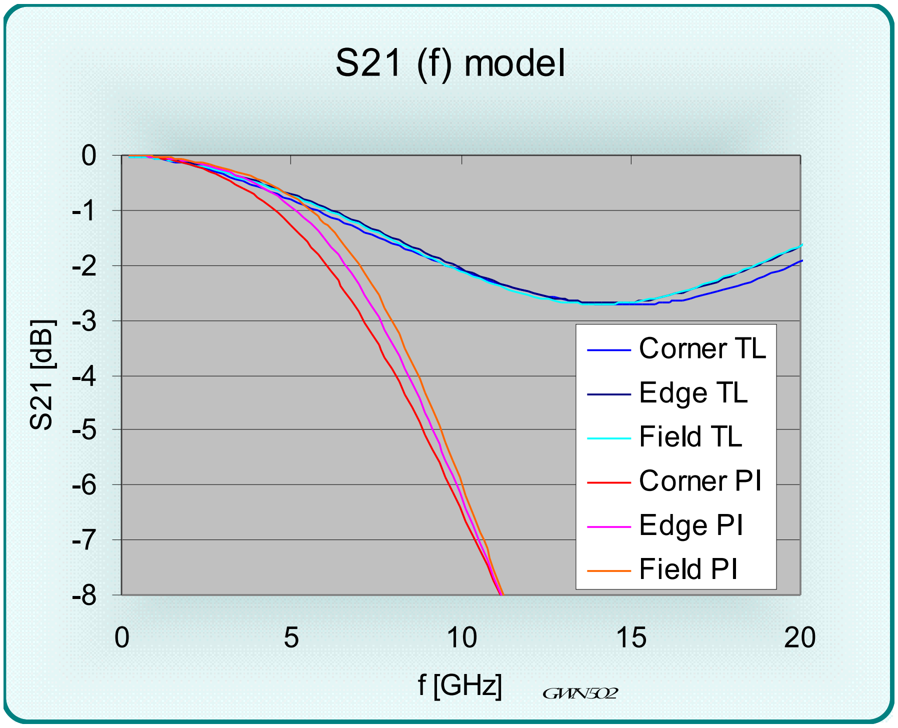


Figure 38 Insertion loss as a function of frequency (simple model)

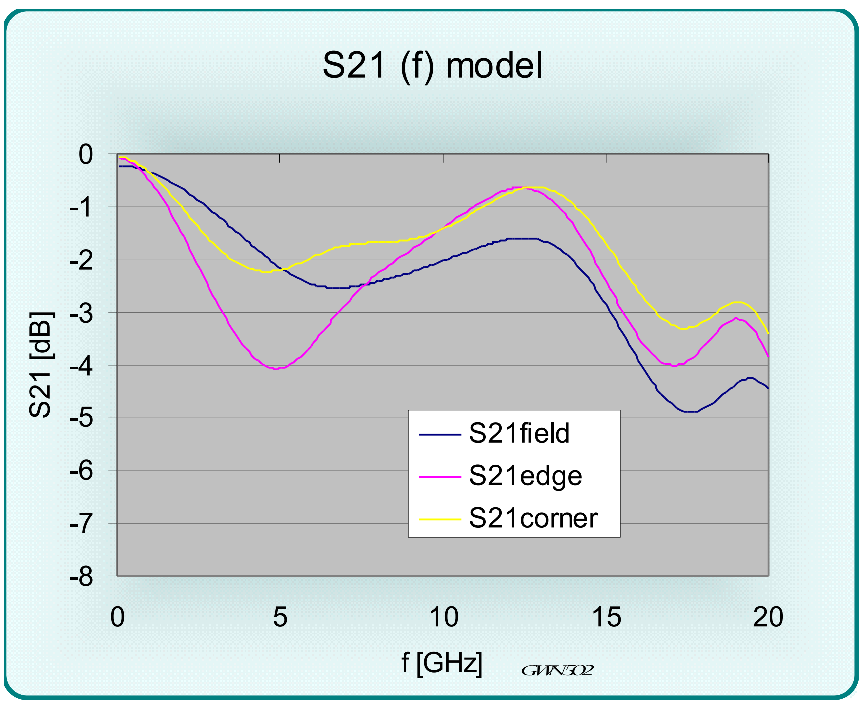


Figure 39 Insertion loss as a function of frequency (multi-pole model)

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

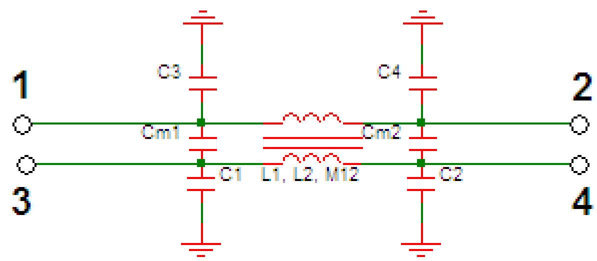


Figure 40 Equivalent circuit for G-S-S-G (mutual coupling)

The values for this model are:

Site	C1,2,3,4		Cm1,Cm2		L1, L2	M	
Corner	0.298		0.084	pF	2.03	0.476	nH
Edge	0.350		0.083	pF	1.79	0.422	nH
Field	0.389		0.062	pF	1.62	0.292	nH
Diagonal	0.389		0.012	pF	1.62	0.056	nH

The corresponding simple transmission line model is shown below:

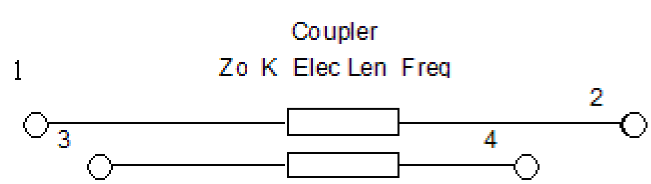


Figure 41 Transmission line equivalent circuit for crosstalk

The model shows two coupled transmission lines with the respective in- and outputs. Its elements are Z_o, L_{el}, k and $f_{(180deg)}$:

Field	36.8	Ω	35.7	ps	0.18	12.8	GHz

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

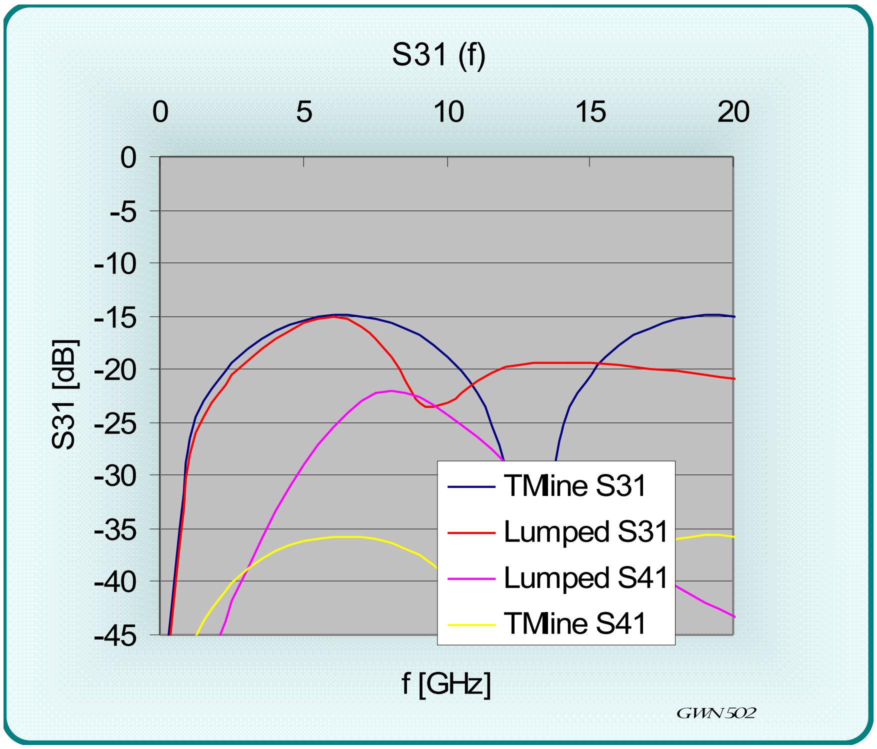


Figure 42 Crosstalk S31 and S41 [dB] as a function of frequency

Both models are limited in maximum frequency to a maximum of about 3 GHz.

The forward crosstalk is underestimated. This is of relatively little consequence because of the low levels of crosstalk present at these low frequencies.

Summary sheet

Ironwood Electronics

Giga-snap BGA100B-41 test socket

1.00 mm pitch

8/11/2009

Measurement results:

	Corner	Edge	Field	
Delay	35.2	35.6	35.7	ps
Risetime open	46.5	37.5	33	ps
Risetime short	88.5	49.5	85.5	ps
Risetime thru, 50Ω	81	93	78	ps
Insertion loss (1dB)	3.2	2.4	3.6	GHz
Insertion loss (3dB)	19.73	4.78	17.53	GHz
VSWR (2:1)	12.95	15.54	13.35	GHz

PI equivalent circuit component values:

Site	Cg=C1+C2			L1		R4	
Corner		0.596	pF	2.03	nH	400	Ohms
Edge		0.701	pF	1.79	nH	400	Ohms
Field		0.779	pF	1.62	nH	400	Ohms
Diagonal		0.779	pF	1.62	nH	400	Ohms

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

Mutual component values:

Site		Cm		M	
Corner		0.167	pF	0.476	nH
Edge		0.165	pF	0.422	nH
Field		0.124	pF	0.292	nH
Diagonal		0.024	pF	0.056	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	67.9	Ω	35.2	ps
Edge	70.1	Ω	35.6	ps
Field	36.8	Ω	35.7	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.