Ironwood Electronics

Test socket
0.5 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 Electronics test socket with a P-P196 contact. 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 (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 into 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 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.

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

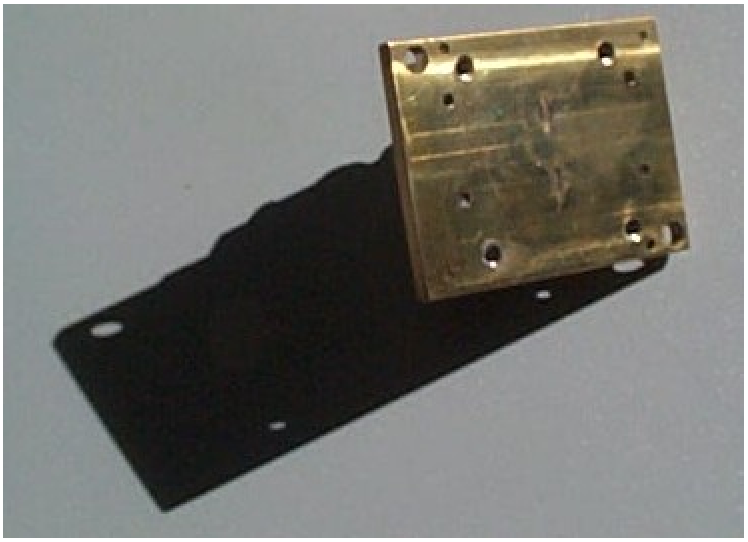


Figure 1 test socket base plate example

Figure 2 DUT plate

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

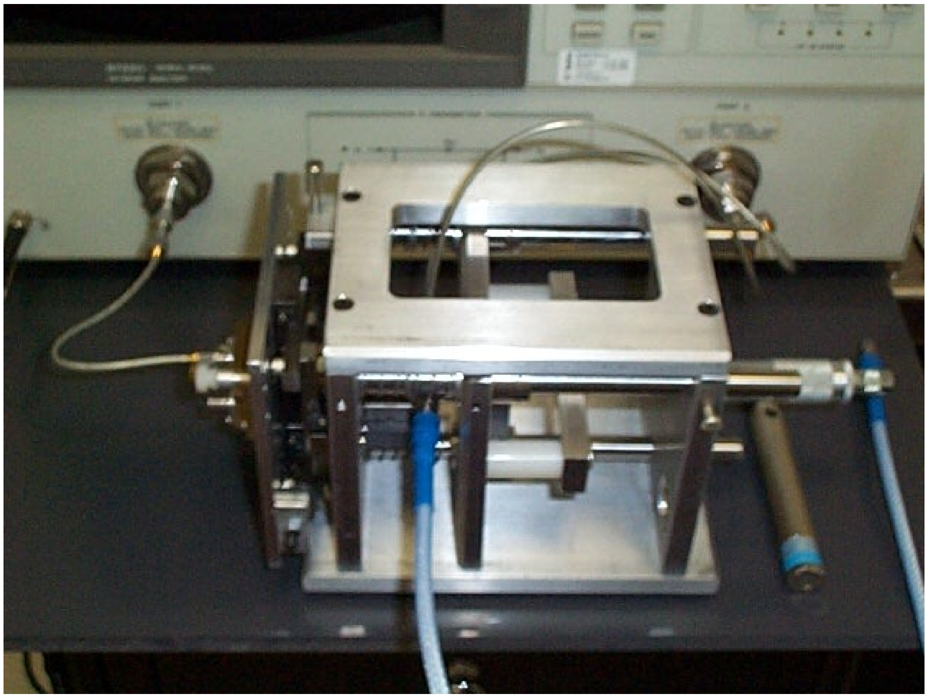
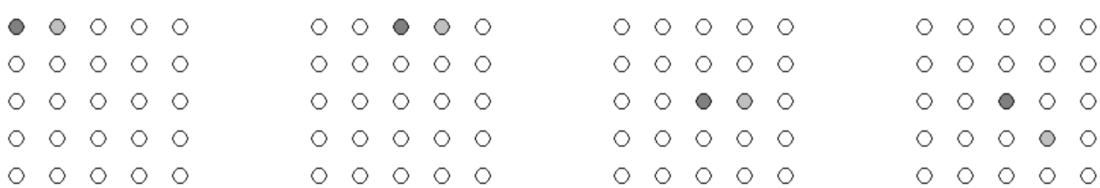


Figure 3 Test fixture

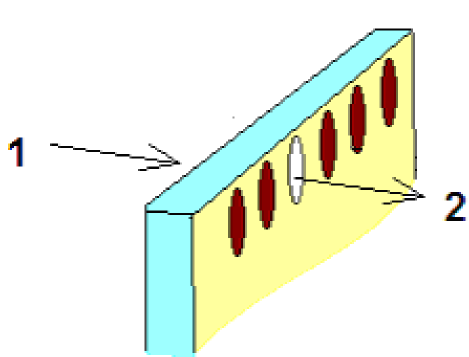
This fixture provides for independent X,Y and Z control of the components relative to each other. X, Y and angular alignment is established once at the beginning of a test series and then kept constant. Z (depth) alignment is measured via micrometer and is established according to specifications for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

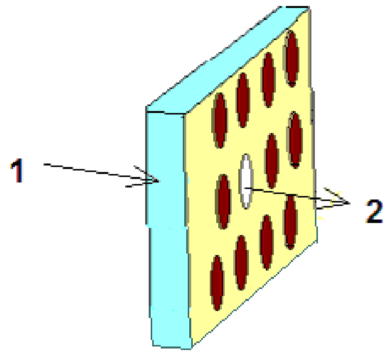
Connections to the VNA are made with high quality coaxial cables with K connectors.

Site assignments are from left to right CORNER, EDGE, FIELD, DIAGONAL:



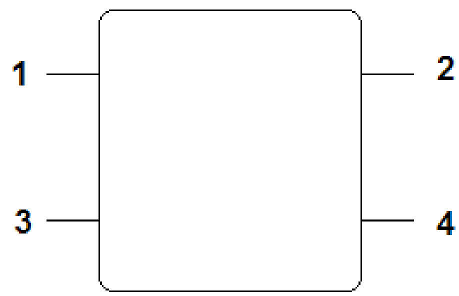
For G-S-G and G-S-S-G measurements, the ports are named as follows:





Single row DUTs

Multi-row DUTS



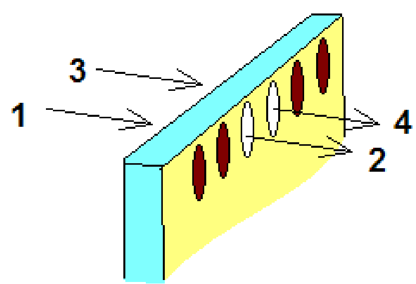


Figure 4 Ports for the G-S-G and G-S-S-G measurements

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

Measurements G-S-G

Time domain

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

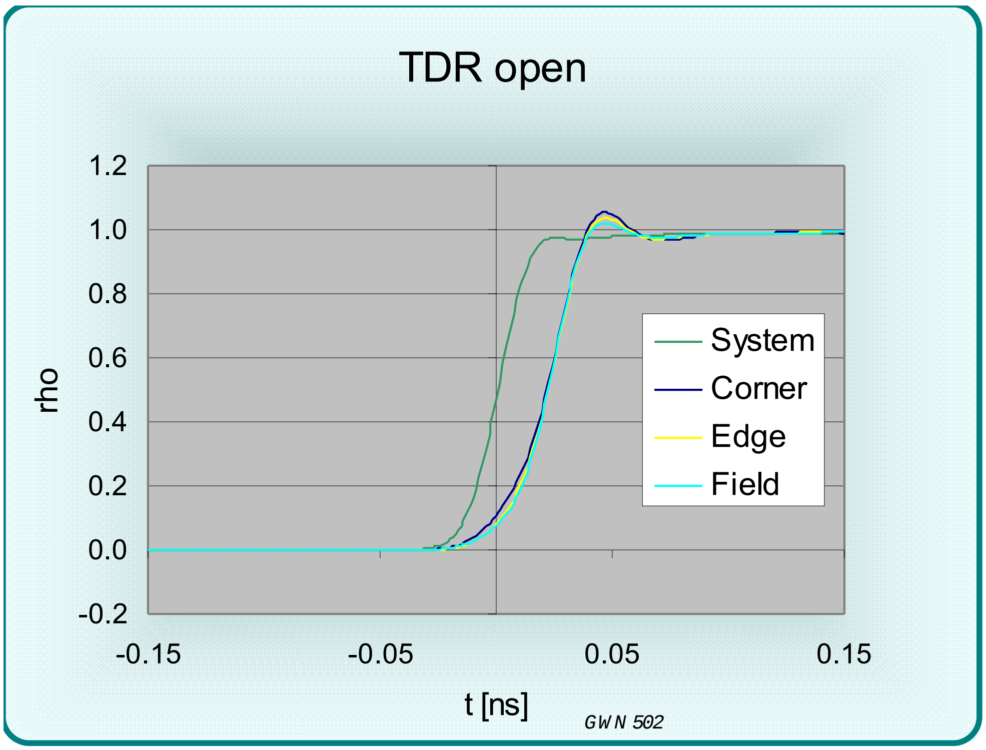


Figure 5 TDR signal from an OPEN circuited test socket

The reflected signals from the test socket (rightmost traces) show only a small deviation in shape from the original waveform (leftmost trace). The risetime is about 34.5, 33.0 and 31.5 ps for corner, edge and field, respectively and is almost the same as that of the system with the open probe (27.0 ps). Electrical pin length is about 10.5, 10.5 and 10.5 ps, respectively (one way).

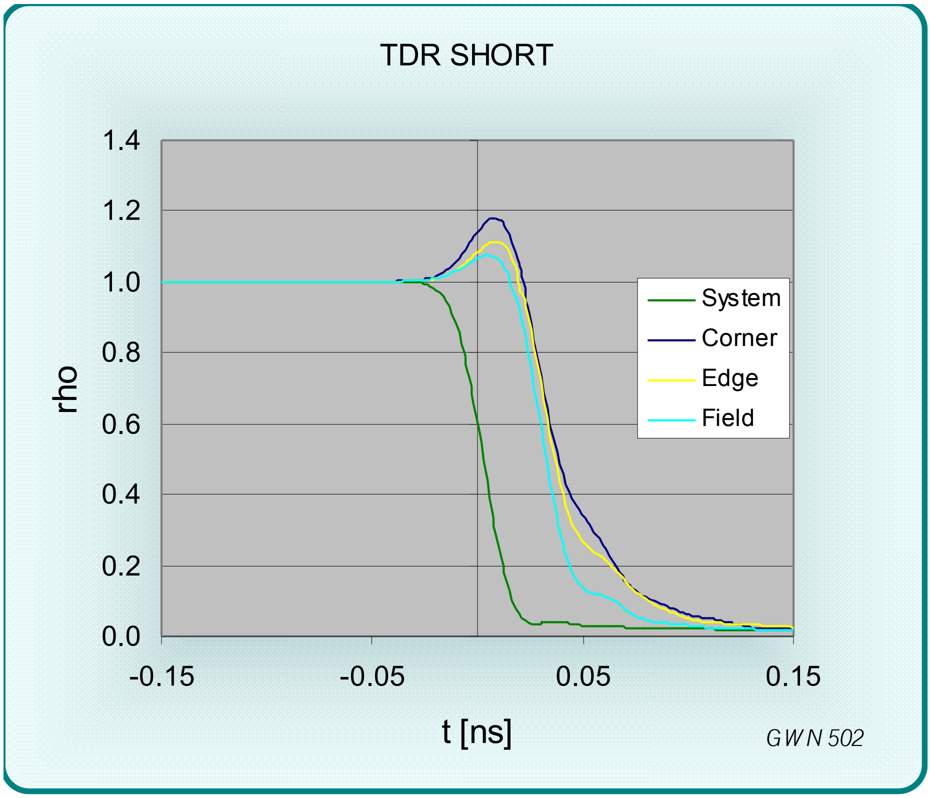


Figure 6 TDR signal from a SHORT circuited test socket

For the short circuited test socket the fall time is about 58.5, 57.0and 43.5 ps for corner, edge and field, respectively. There is a noticeable increase over the system risetime of 27.0 ps for the corner case because of the foot, which is caused by the high impedance level.

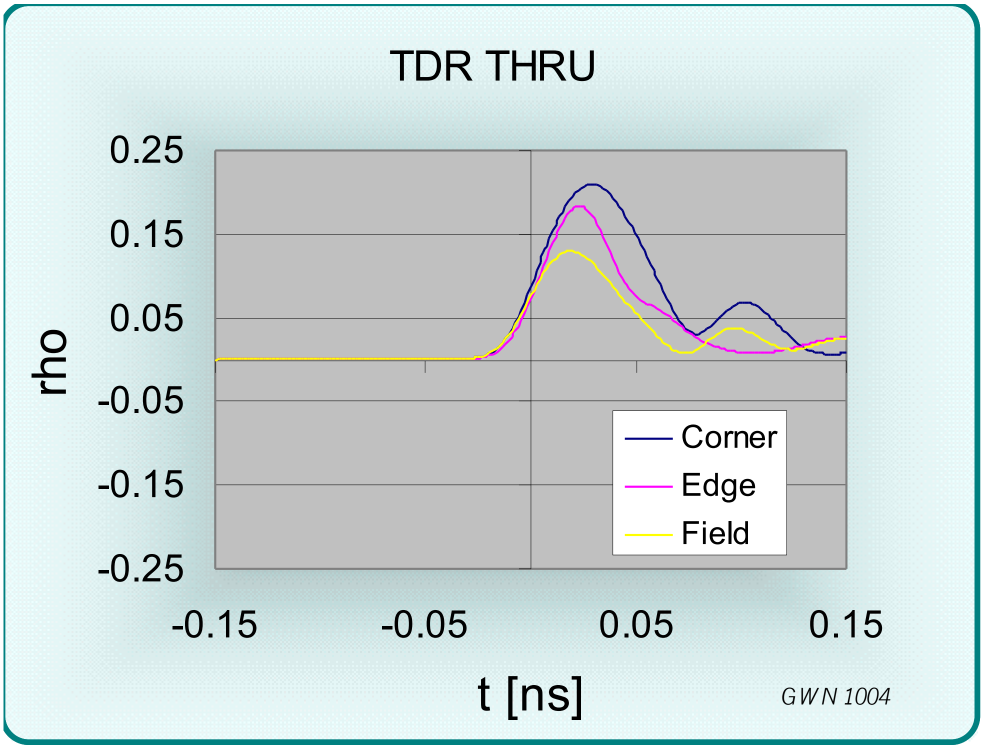


Figure 7 TDR measurement into a 50 Ohm probe

The thru TDR response shows an inductive response. The peak corresponds to an impedance of 76.5, 72.5 and 64.9 Ohms for corner, edge and field, respectively and is noticeably larger than 50 Ohms for the corner connection.

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

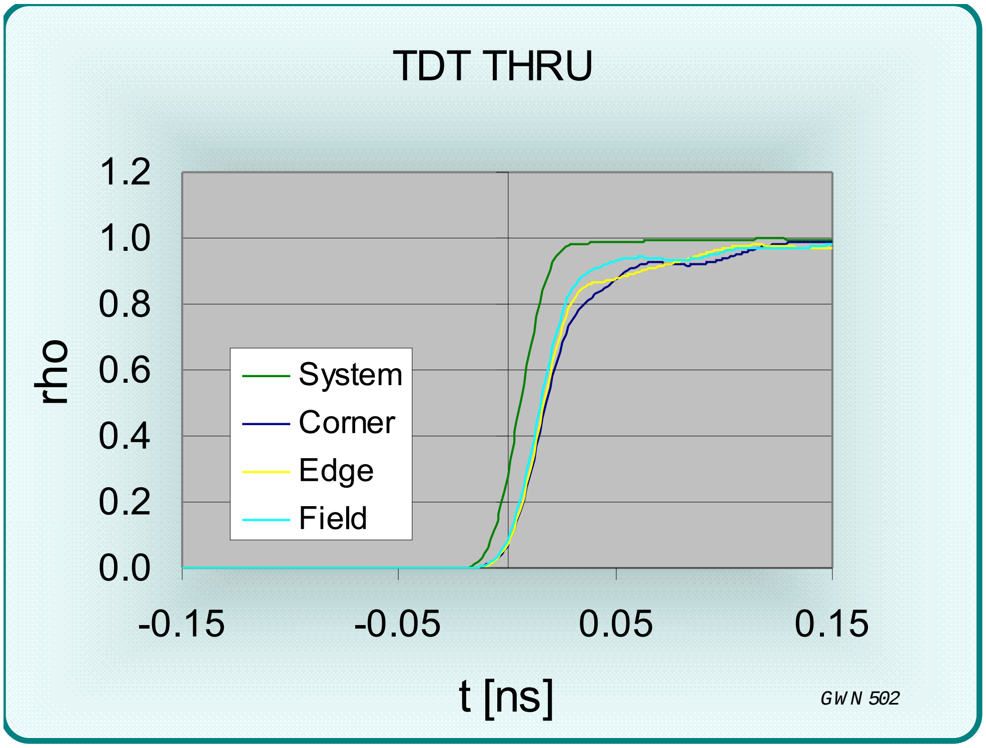


Figure 8 TDT measurement

The TDT measurements for transmission show a small contribution to risetime from the pin array (10-90% RT = 51.0, 45.0 and 33.0 ps for corner, edge and field, respectively, the system risetime is 25.5 ps). The added delay at the 50% point is 12.0, 10.5 and 10.5 ps, respectively. There is no significant signal distortion. If the 20%-80% values are extracted, the risetimes are only 27.0, 21.0 and 21.0 ps, respectively vs. 16.5 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).

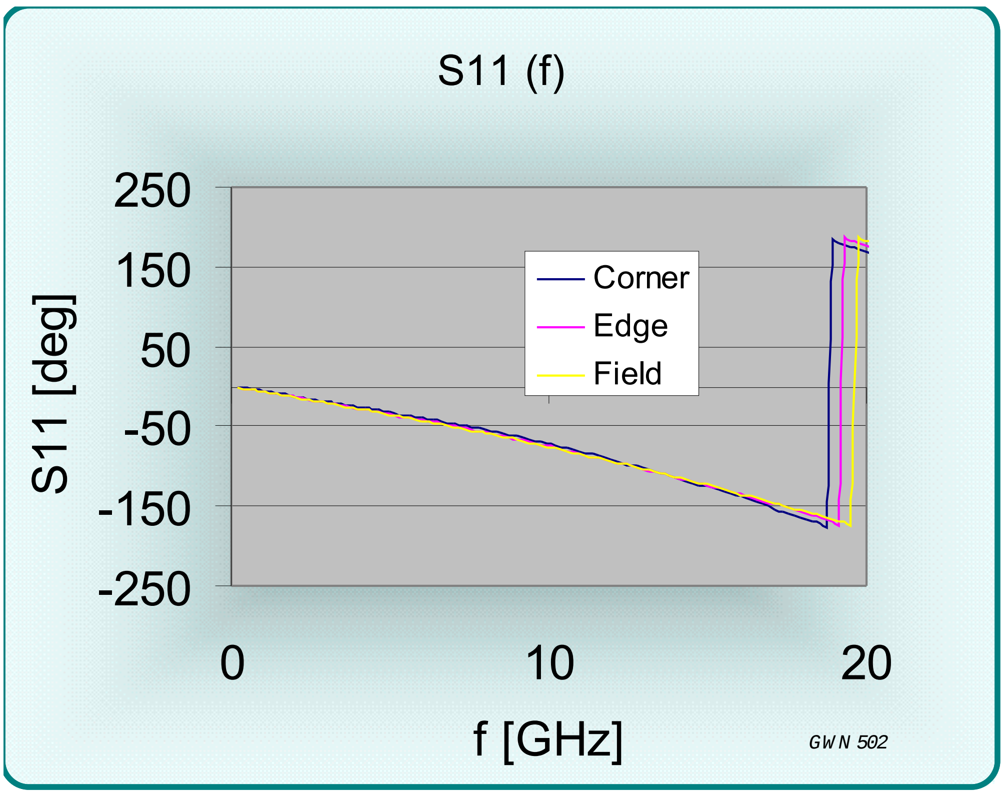


Figure 9 S11 phase (f) for the open circuited signal pin

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.

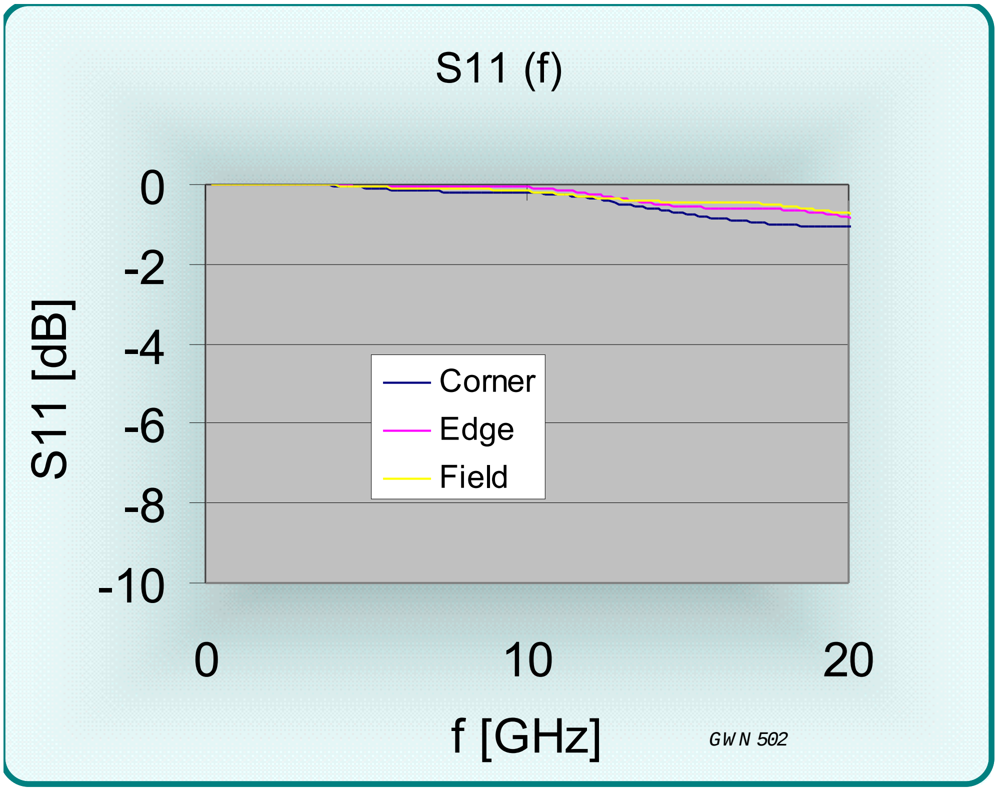


Figure 10 S11 magnitude (f) for the open circuited signal pin

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.

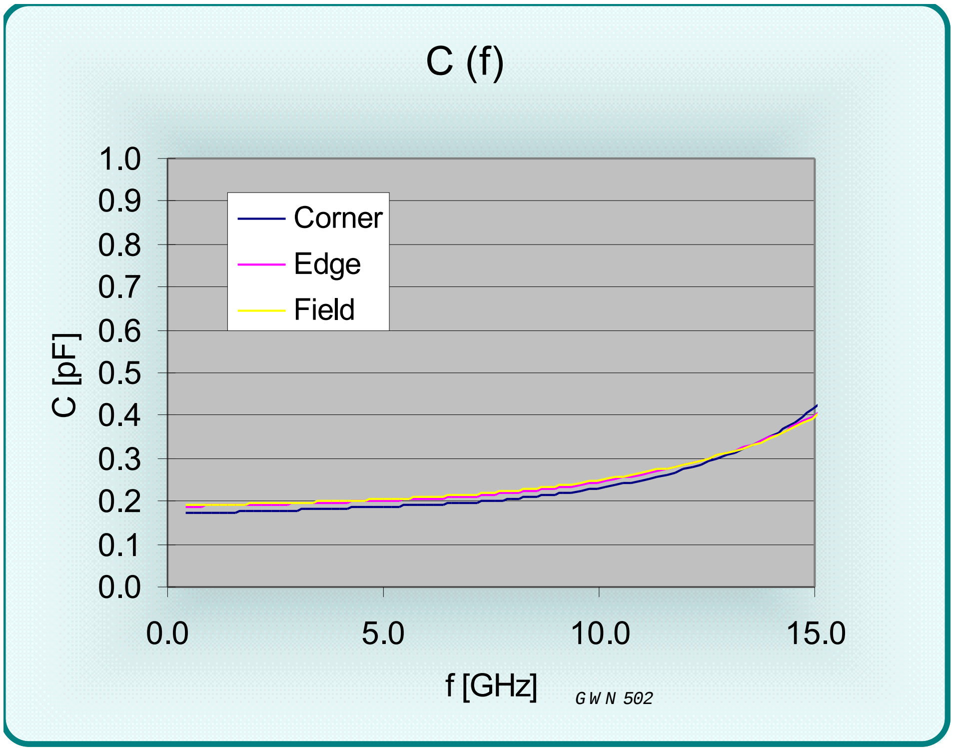


Figure 11 C(f) for the open circuited signal pin

Capacitance is 0.17, 0.190 and 0.193 pF for corner, edge and field, respectively, at low frequencies. The rise in capacitance toward 17 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 only 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.

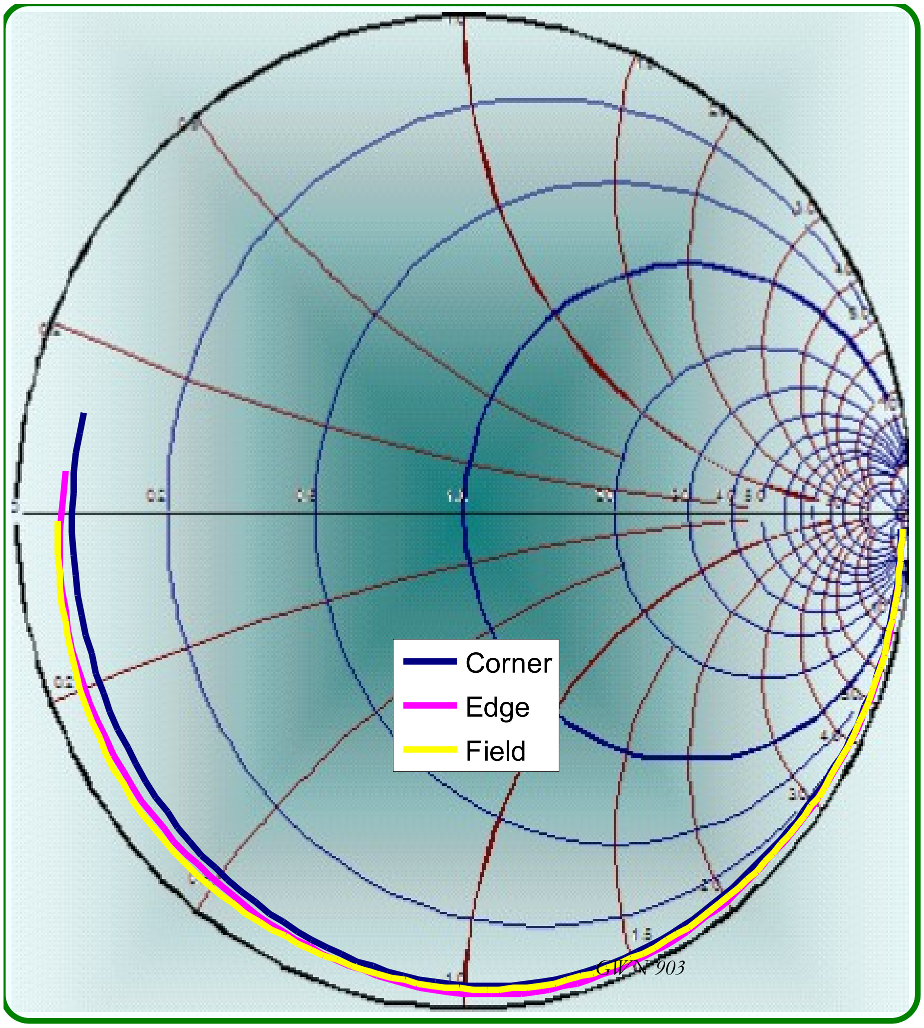


Figure 12 Reflections from the open circuited test socket

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 test socket. Calibration was established with a short placed at the end of the coax probe.

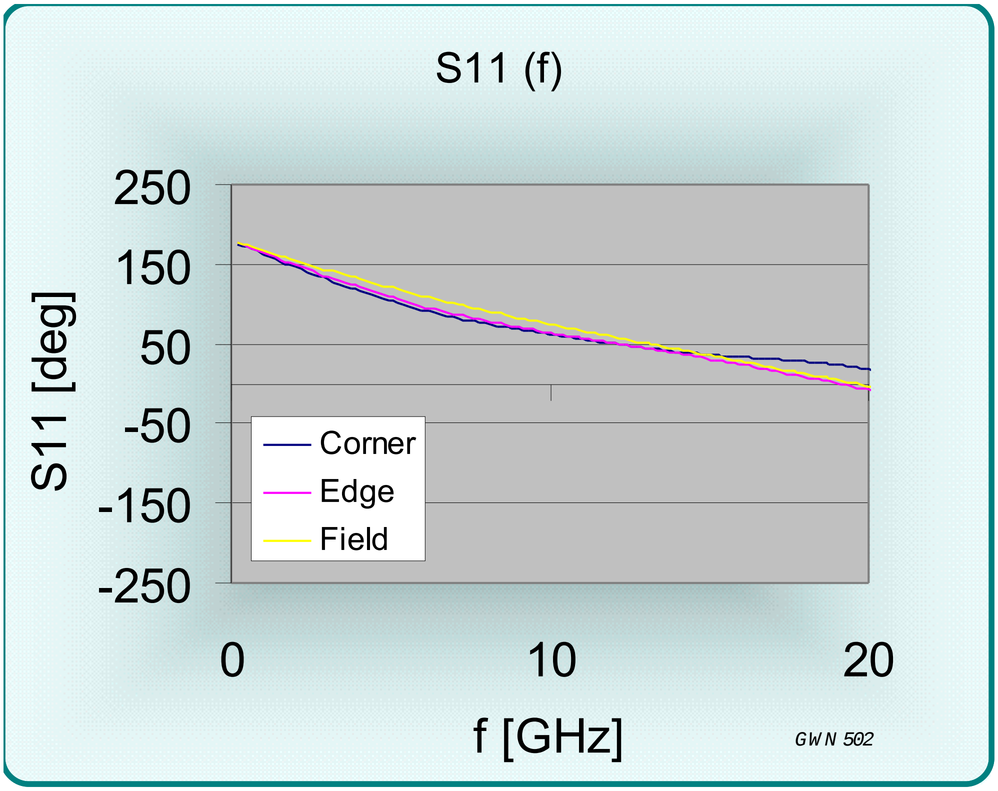


Figure 13 S11 phase (f) for the short circuited case

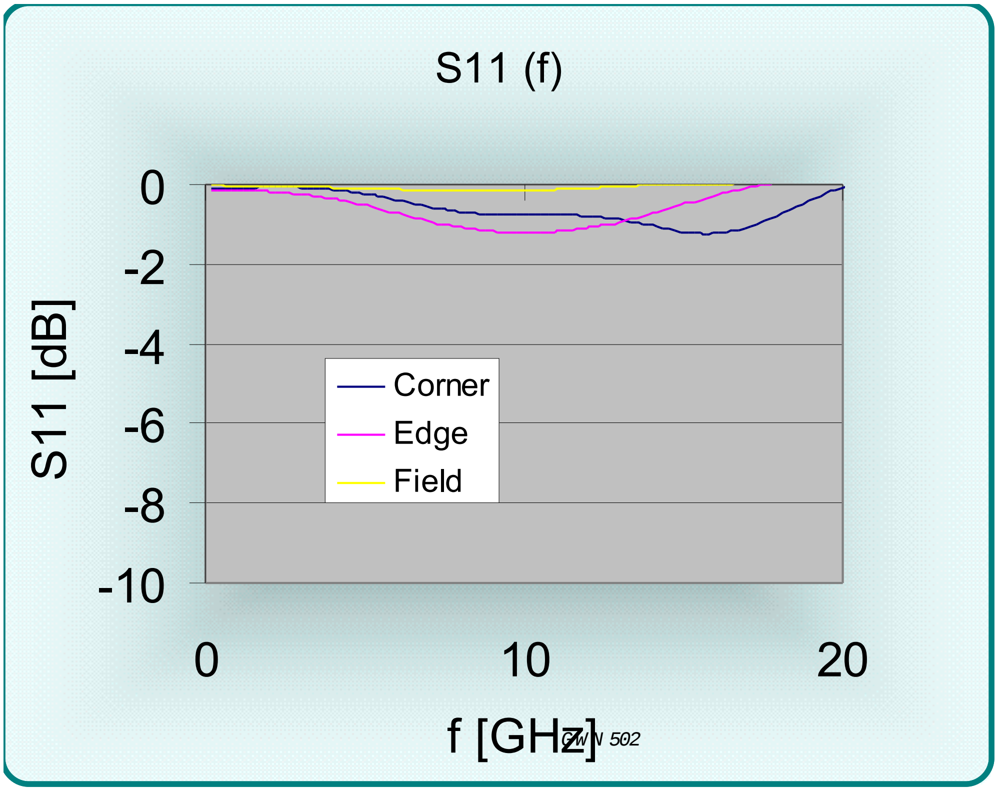


Figure 14 S11 magnitude (f) for the short circuited case

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

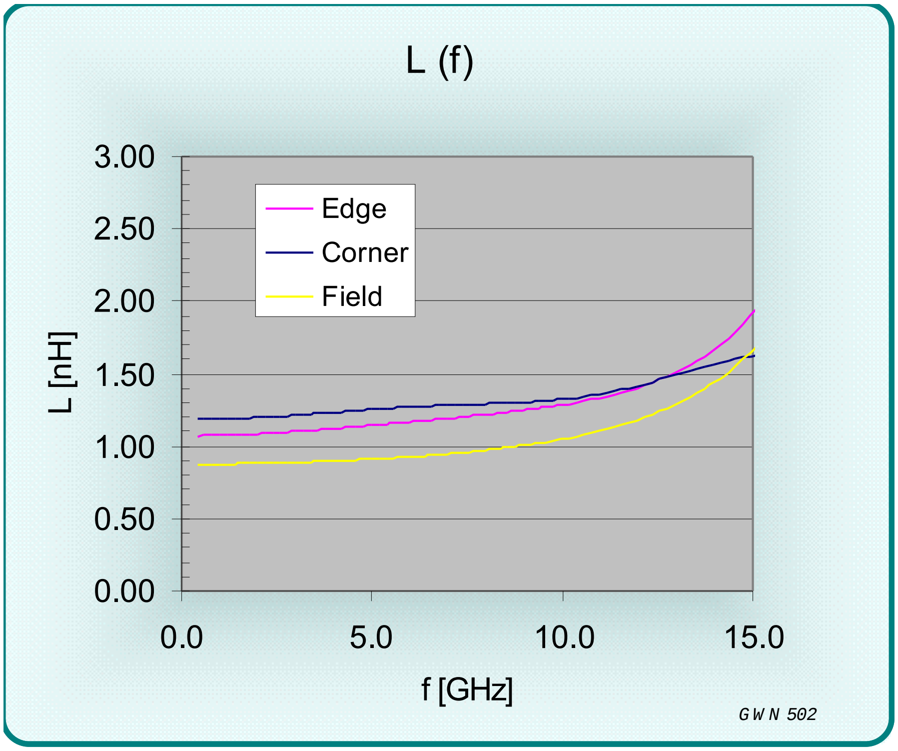


Figure 15 L(f) for the test socket

The phase change corresponds to an inductance of 1.19, 1.08 and 0.88 nH for corner, edge and field, respectively, at low frequencies. Toward 15 GHz inductance increases. Again, at these frequencies, the transmission line nature of the arrangement must be taken into account.

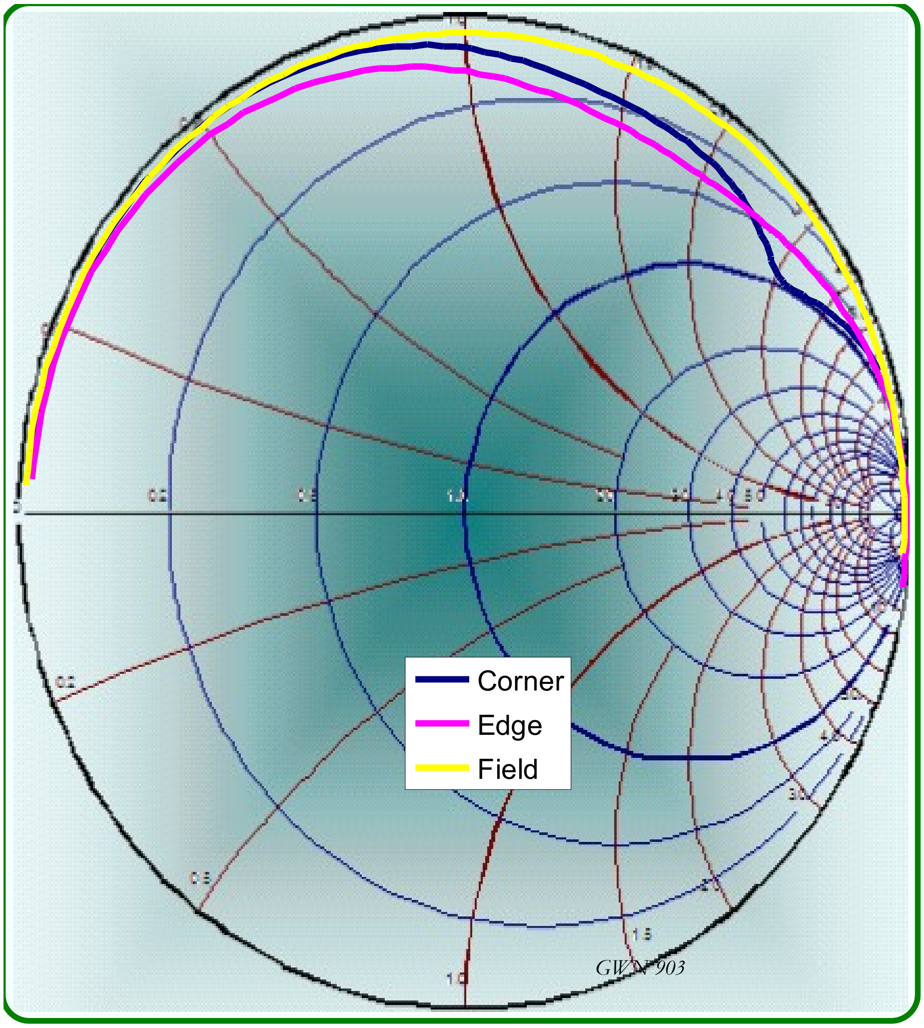


Figure 16 Short circuit response in the Smith chart

Only a small amount of loss at elevated frequencies 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.

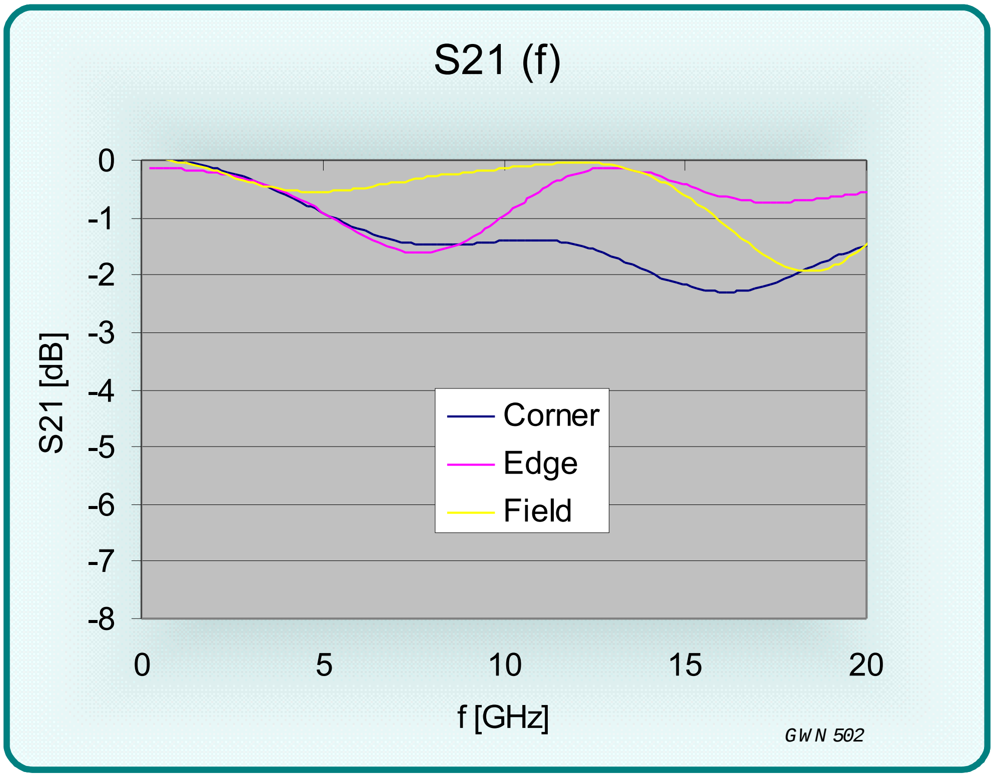


Figure 17 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 5.2, 5.2 and 15.7 GHz for corner, edge and field locations. The 3 dB point is not reached before 20 GHz.

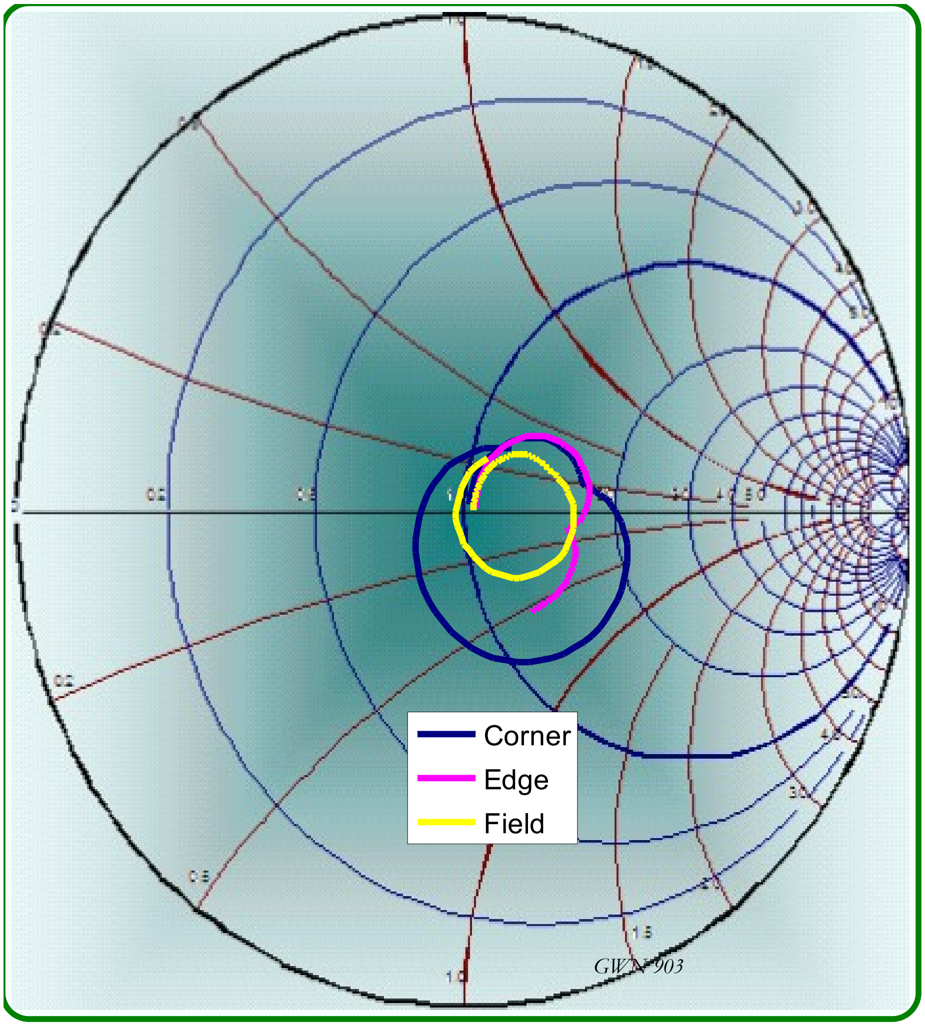


Figure 18 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows a good match with some reactive components toward 20 GHz.

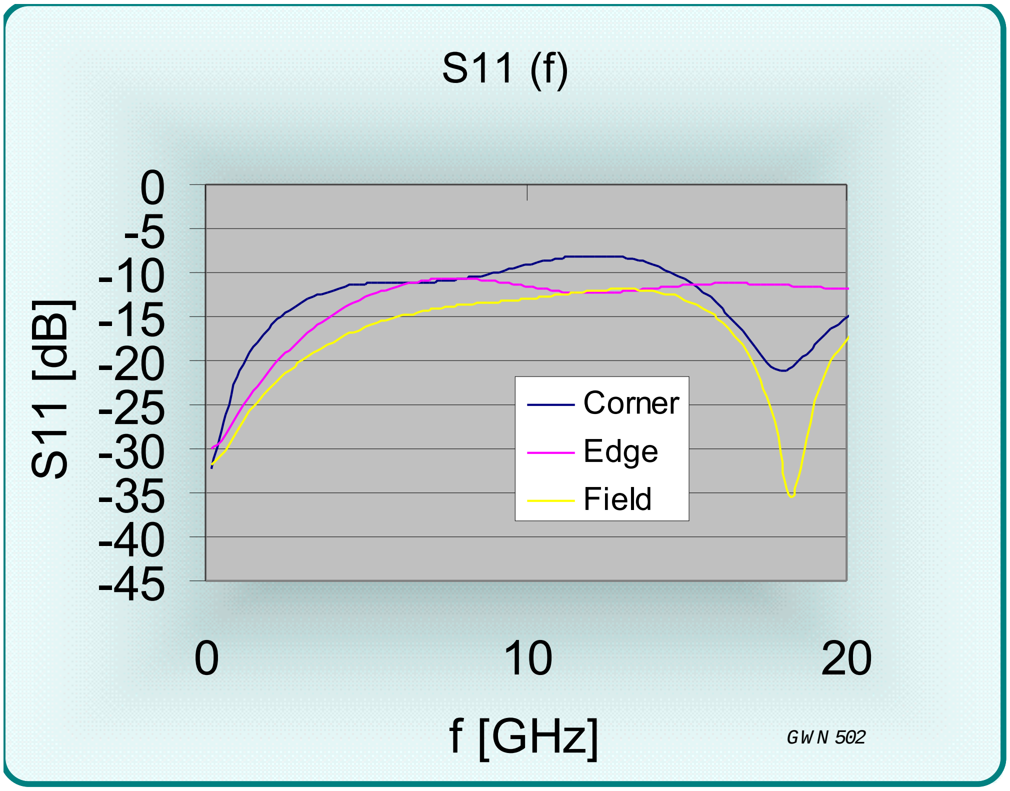


Figure 19 S11 magnitude (f) for the thru measurement into a 50 Ohm probe

The value of the return loss for the thru measurement is lowest for the field configuration since its characteristic impedance is closest to 50 Ohms.

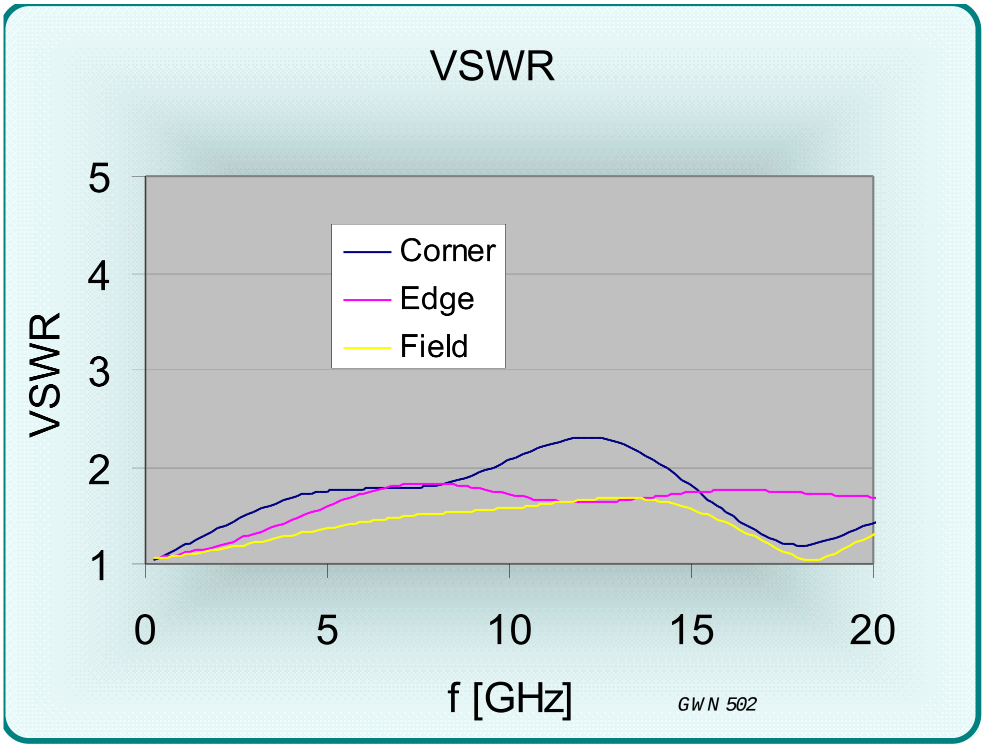


Figure 20 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 9.5 GHz for the corner connection and 20 GHz for edge and field locations.

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:

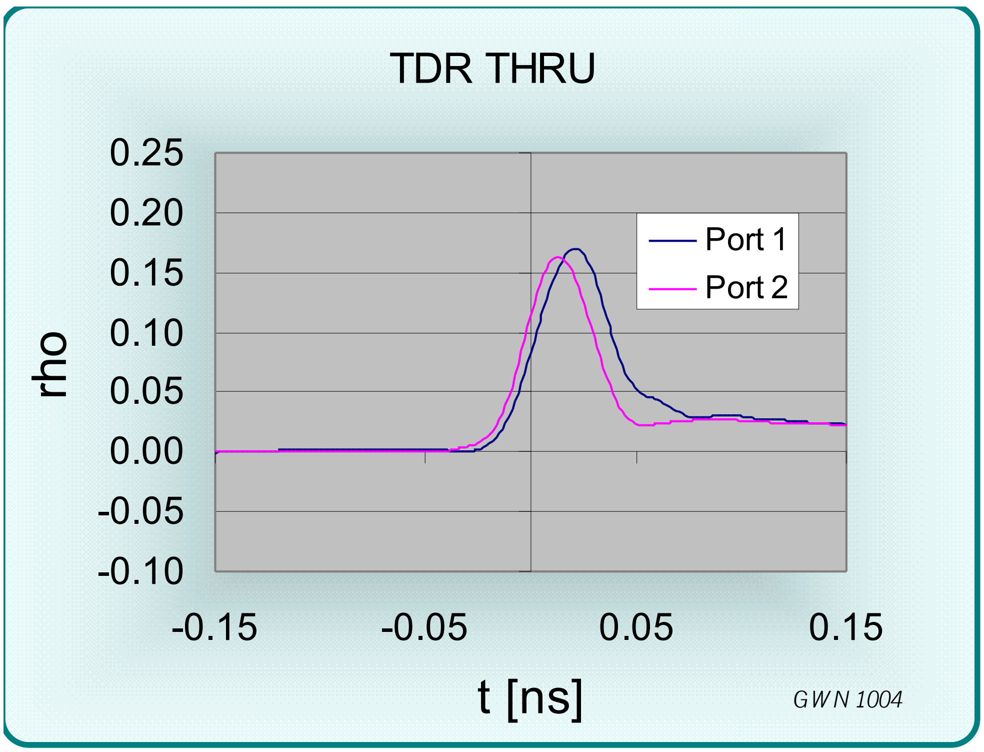


Figure 21 TDR through DUT into a terminated probe

The thru TDR measurement from port 1 to port 2 shows an inductive response. The peak corresponds to a transmission line impedance of 70.5 Ohms. This is noticeably larger than the system impedance and higher than in the G-S-G case for the field location, most likely because of the fact that one of the adjacent pins is not grounded.

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

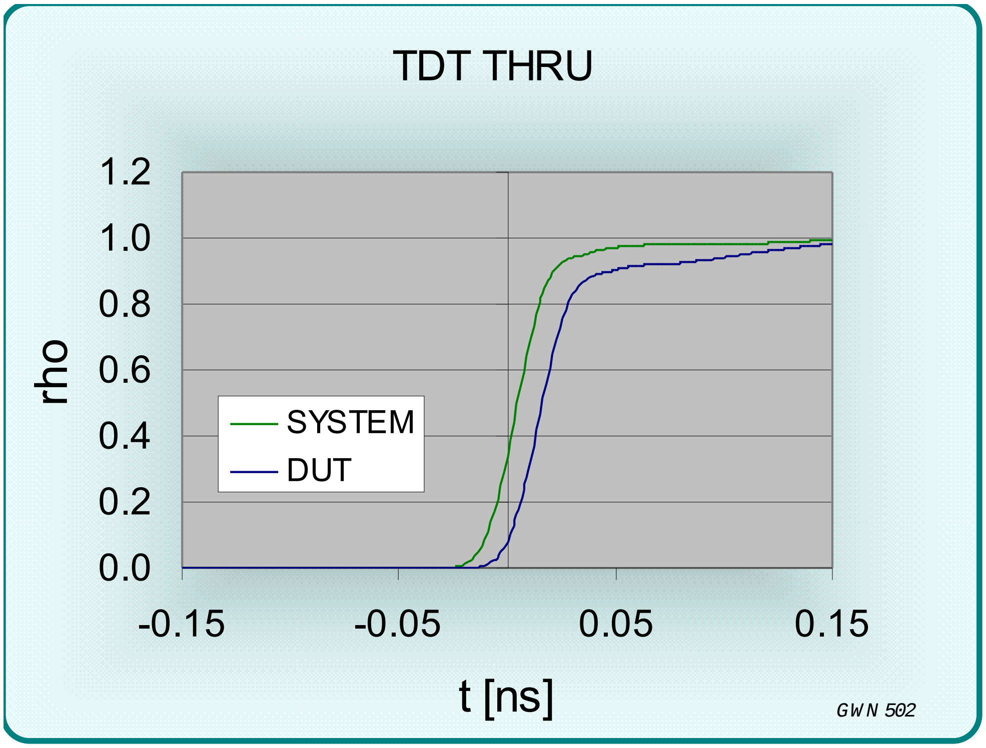


Figure 22 TDT measurement

The TDT measurements for transmission shows a small contribution to risetime from the pin array (10-90% RT = 37.5 ps) as the system risetime (30.0 ps). The added delay at the 50% point is 10.5 ps. The 20%-80% values are 19.5 ps and 19.5 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.

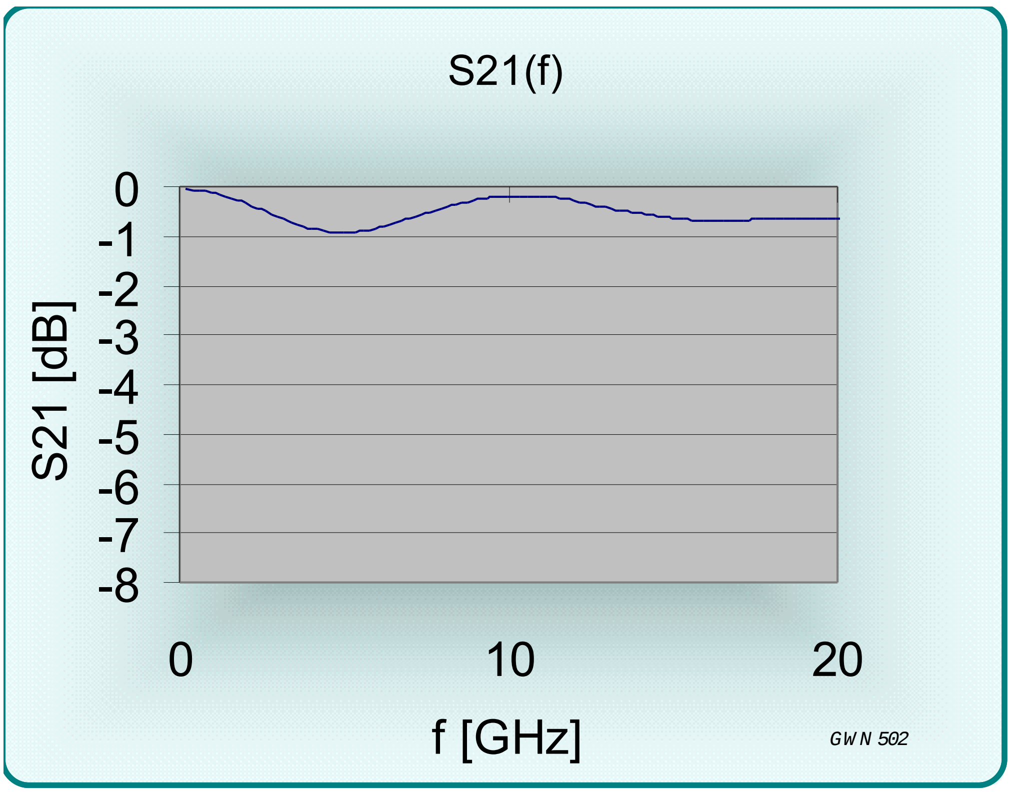


Figure 23 Insertion loss S21 (f) and S12 (f)

Insertion loss is less than 1 dB to 20 GHz.

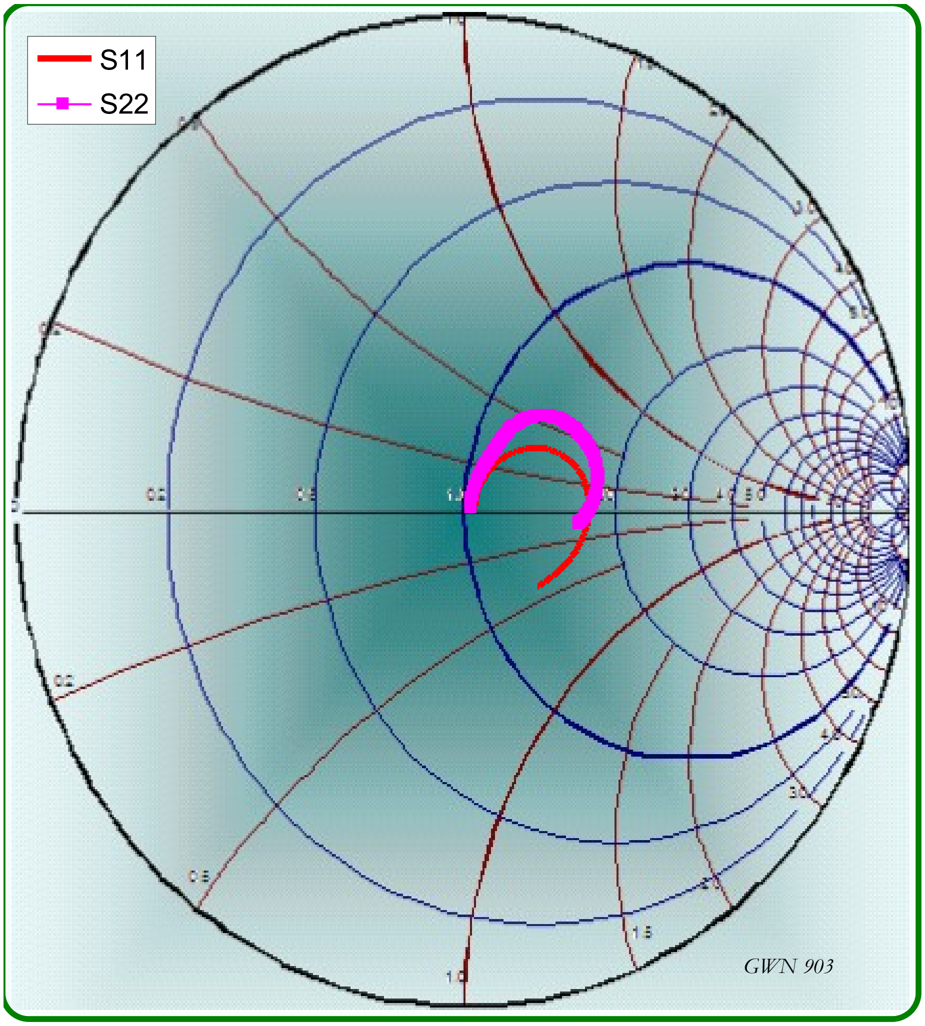


Figure 24 Smith chart for the thru measurement into a 50 Ohm probe

The Smith chart for the thru measurements shows a good match with some reactive components.

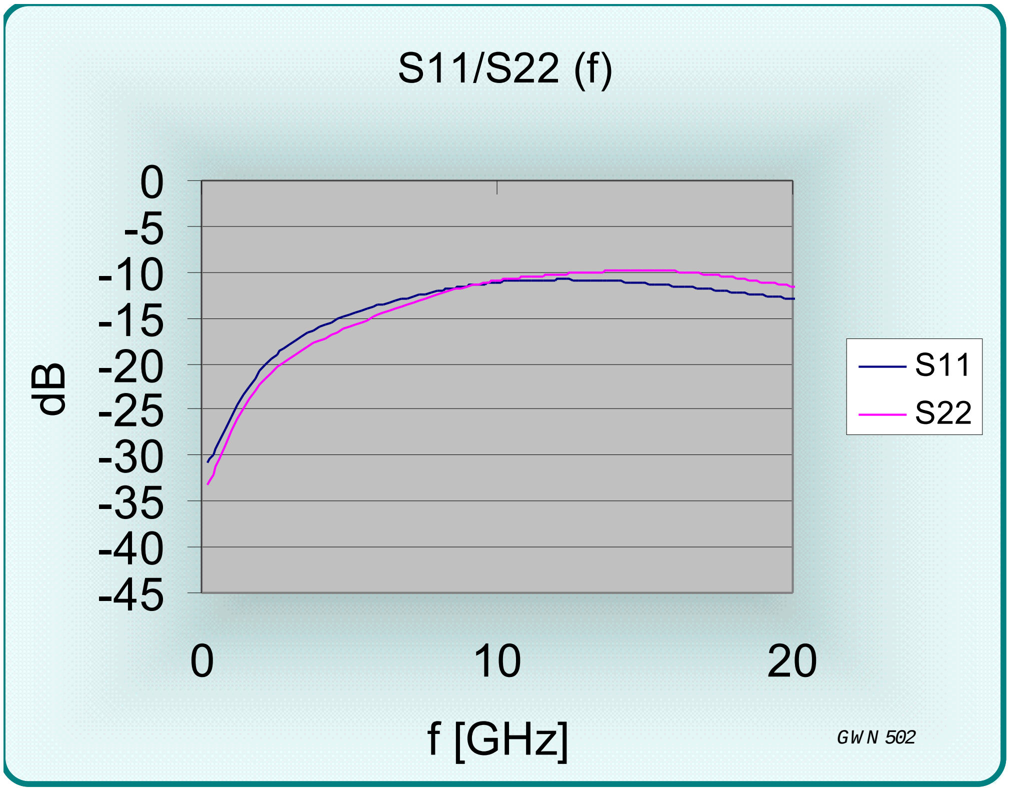


Figure 25 S11 magnitude (f) for the thru measurements into a 50 Ohm probe

The value of the return loss for the thru measurement reaches -20 dB at 2 GHz (S11) and 3 GHz (S22). It does not exceed -10 dB before 20 GHz.

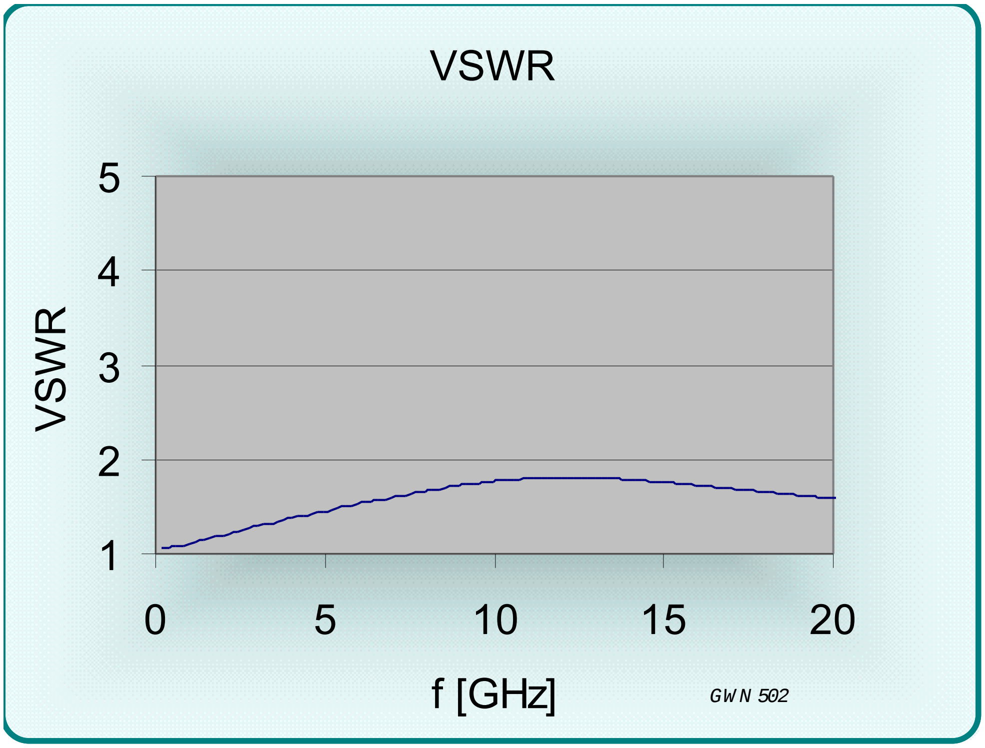


Figure 26 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to 20 GHz.

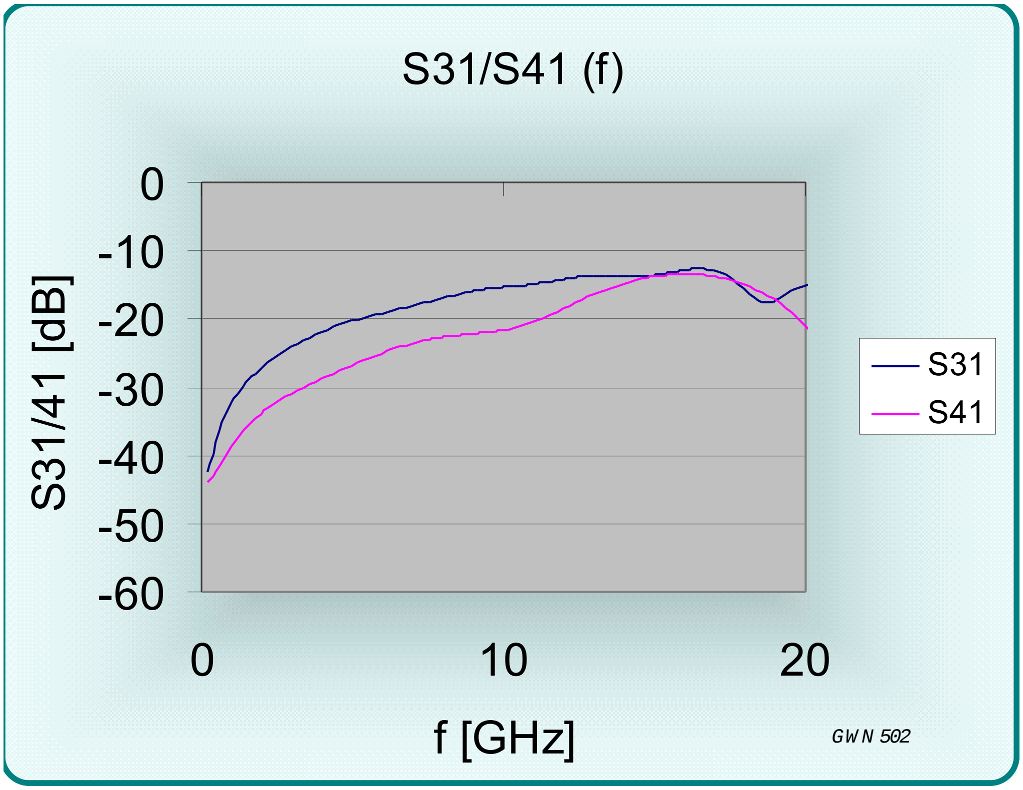


Figure 27 Crosstalk as a function of frequency

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 5.2 GHz (S31) and 11 GHz (S41). The level of signal never reaches -10 dB in the frequency range of interest.

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 0.050, 0.046, 0.032 and 0.020 pF and a mutual inductance of 0.34, 0.25, 0.17 and 0.084 nH for corner, edge field and diagonal sites, respectively.

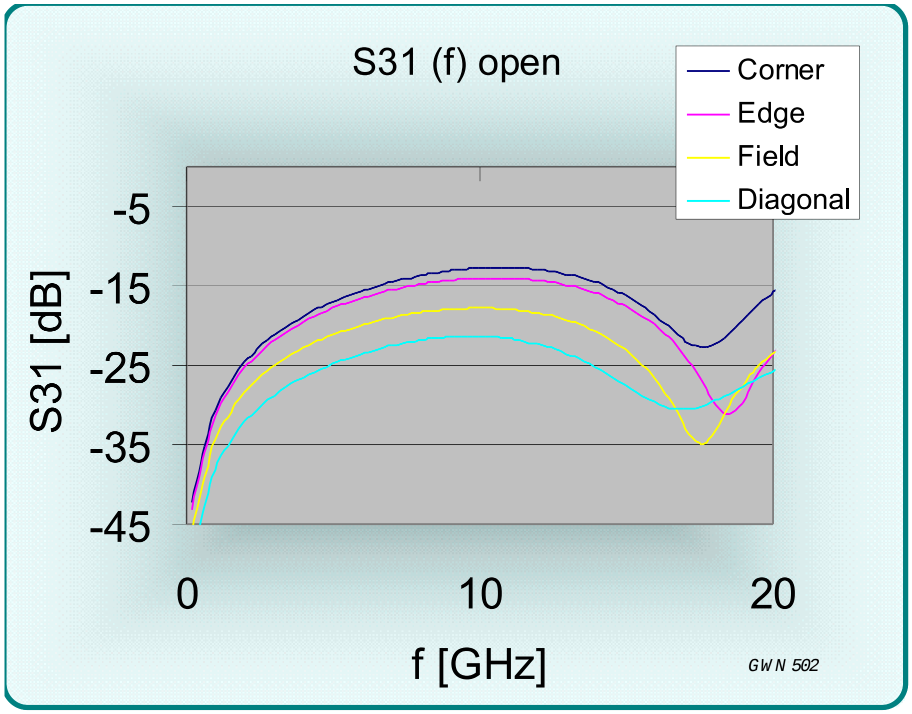


Figure 28 Open circuit crosstalk from port 1 to port 3

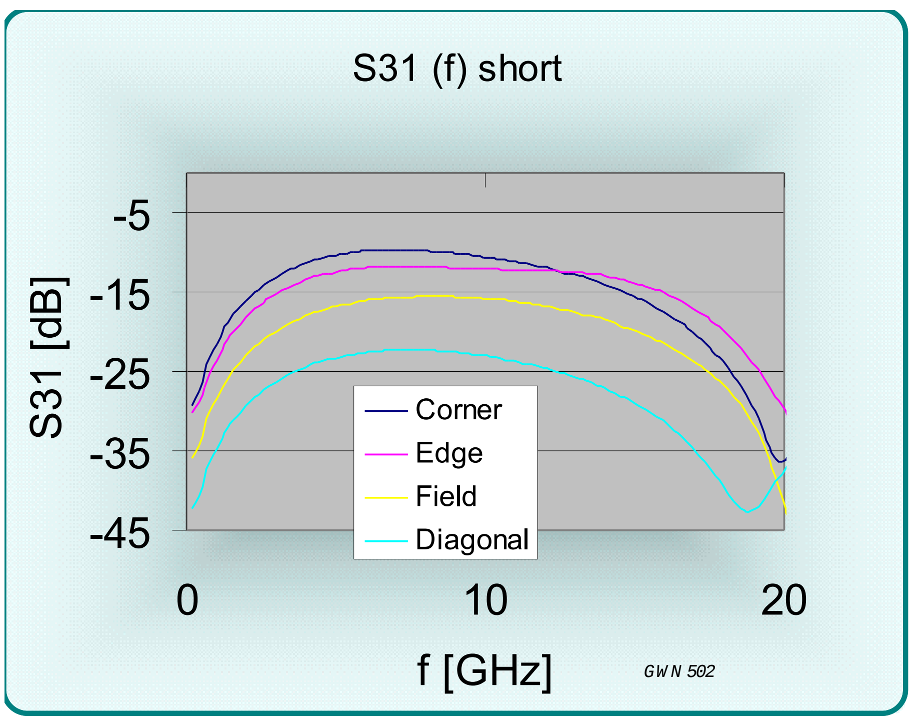


Figure 29 Short circuit crosstalk from port 1 to port 3

SPICE Models

A lumped element SPICE model for the Ironwood Electronics test socket in G-S-G configuration is shown below:

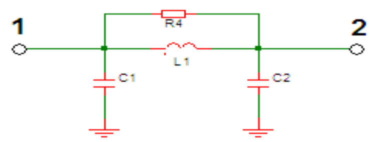


Figure 30 Lumped element SPICE model

The resistance value (R4) approximates the loss term encountered.
The values for the elements are

Site		C1		C2		L1	
Corner		0.087	pF	0.087	pF	1.19	nH
Edge		0.095	pF	0.095	pF	1.08	nH
Field		0.097	pF	0.097	pF	0.88	nH
Diagonal		0.097	pF	0.097	pF	0.88	nH

Toward the cutoff frequency of the Pi section the lumped element model becomes invalid. This happens above 16 GHz for the above model. Hence, the second model developed is a transmission line model:

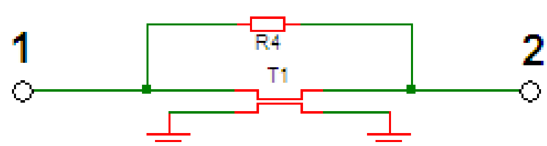


Figure 31 Transmission line model for the test socket

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

	Zo		L		R4	
Corner	82.6	Ω	14.4	ps	500	Ω
Edge	75.3	Ω	14.3	ps	2000	Ω
Field	67.4	Ω	13.0	ps	2000	Ω

Time domain

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

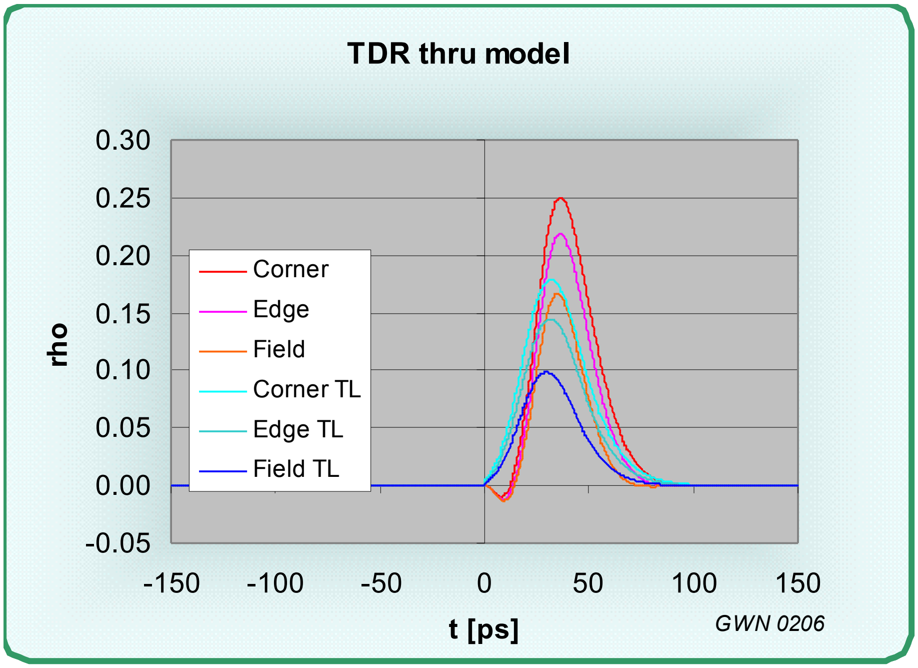


Figure 32 TDR model results

The transmission line models are better suited to the time domain simulation than the lumped element models since the latter causes a slight downward response before the inductive peak. This is due to the two capacitors in the Pi section equivalent circuit.

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

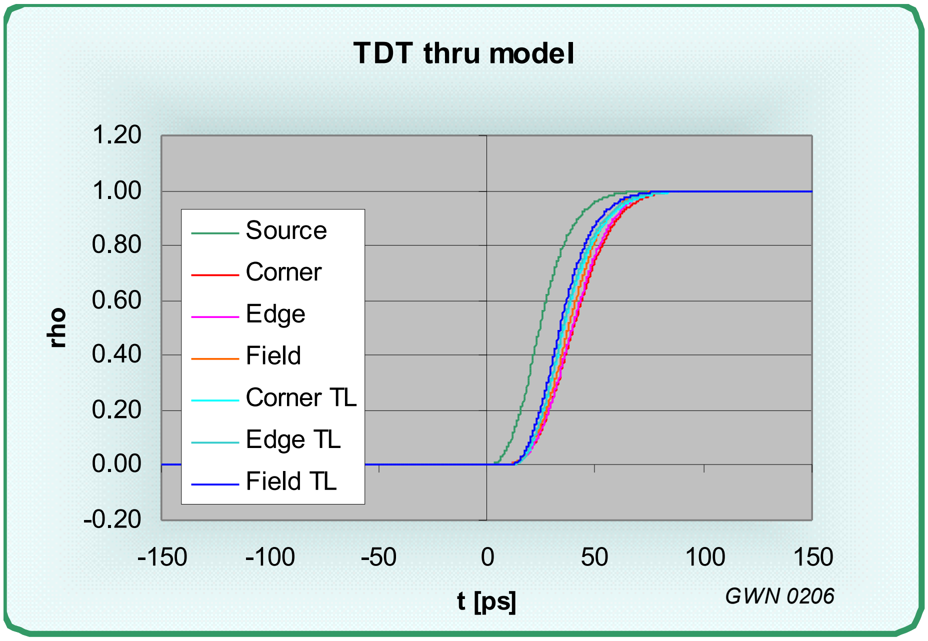


Figure 33 TDT model

The risetime for the transmission line cases are 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.

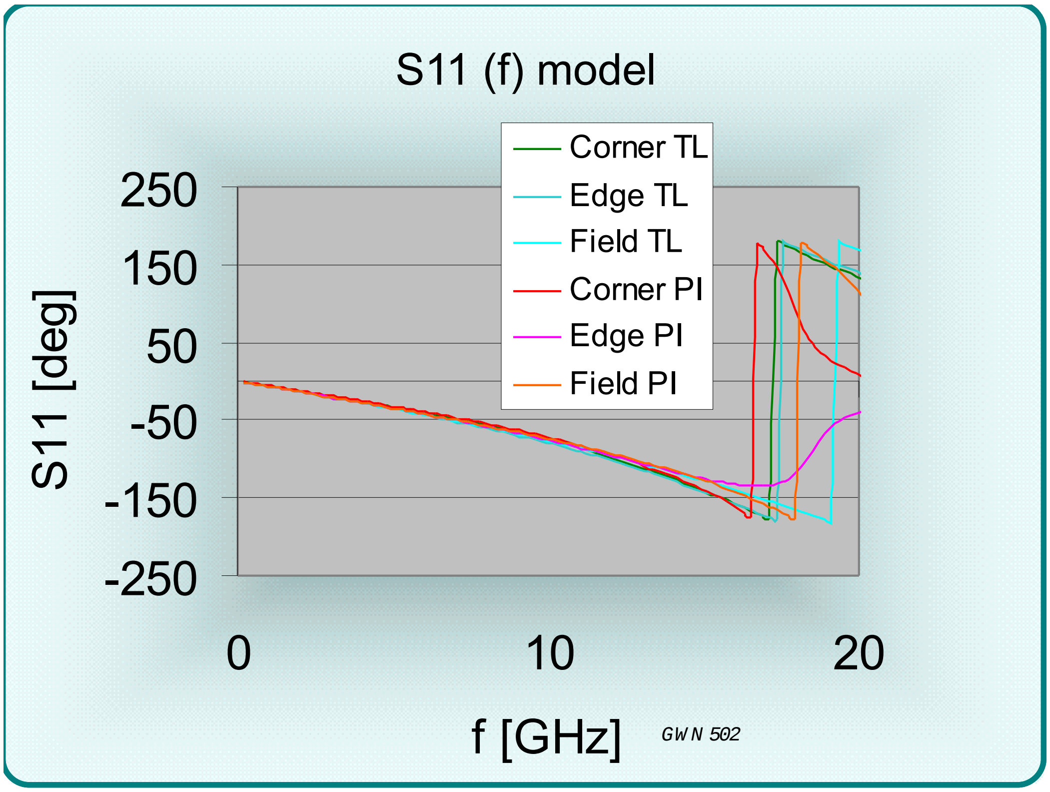


Figure 34 S11 phase (f) for open circuited case

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 16 GHz.

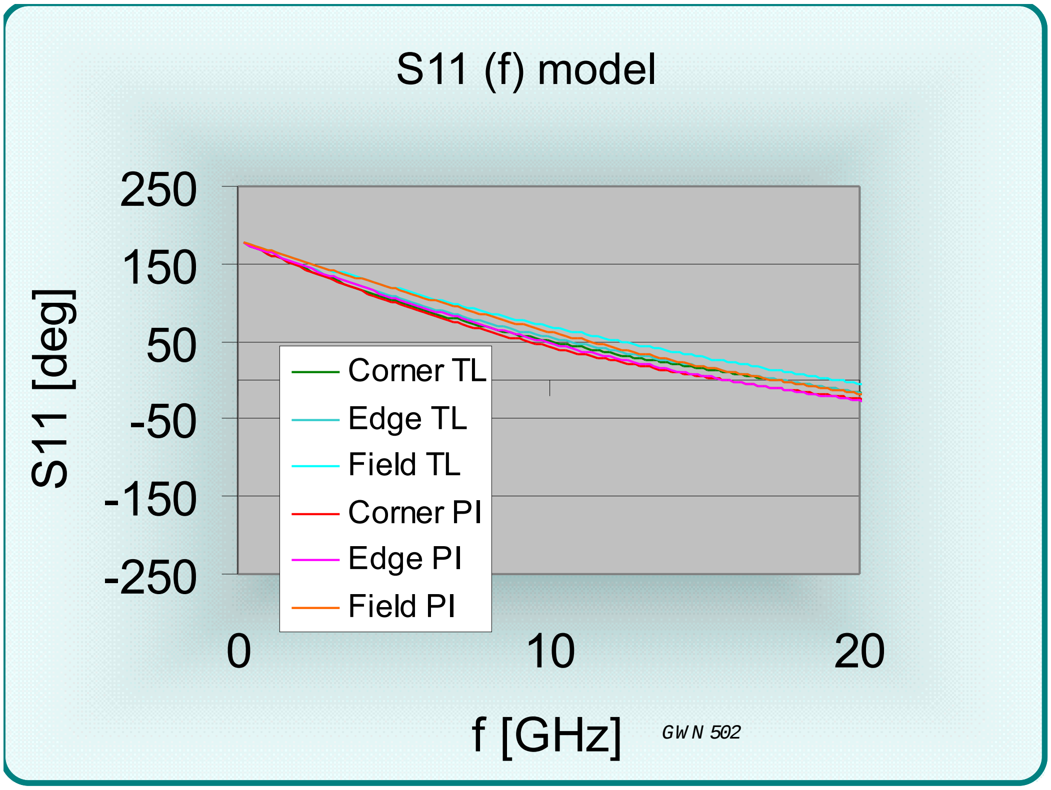


Figure 35 S11 phase response (short circuit)

The short circuit phase evolution with frequency is also comparable to that actually measured. Again, the lumped element model is not valid beyond about 16 GHz.

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.

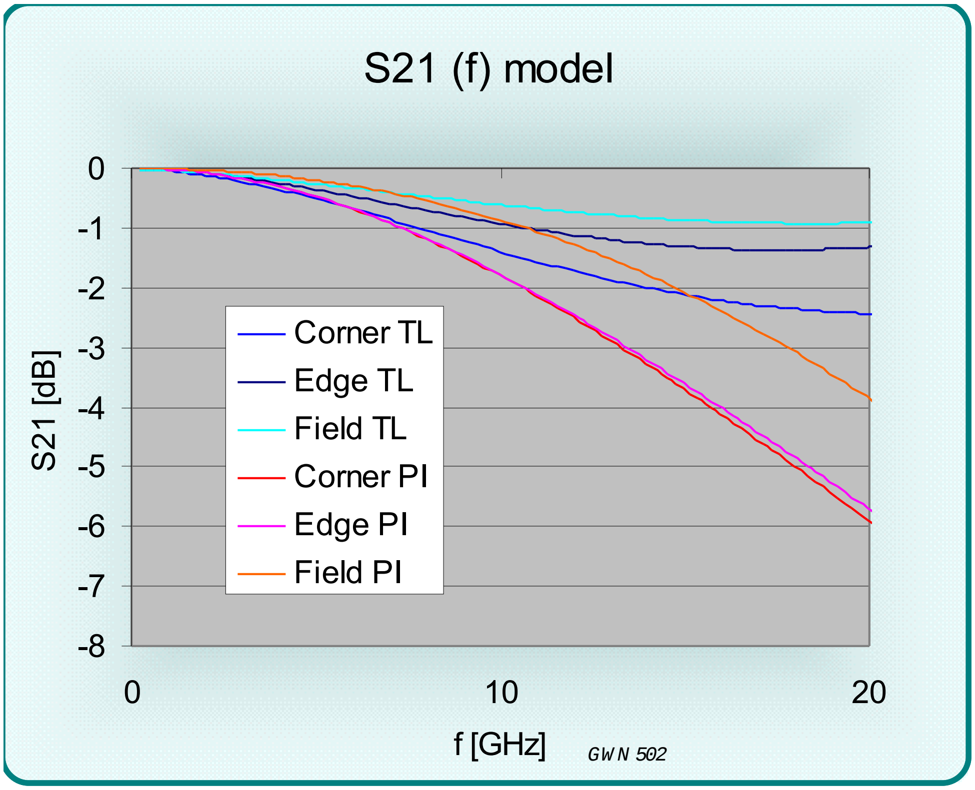


Figure 36 Insertion loss as a function of frequency

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.

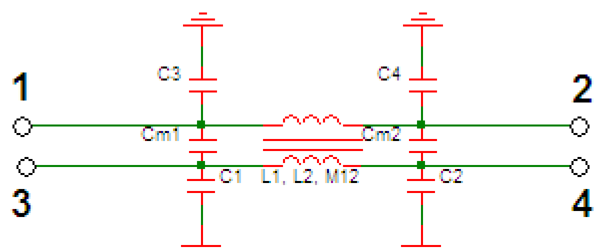


Figure 37 Equivalent circuit for G-S-S-G (mutual coupling)

The values for this model are:

Site	C1,2,3,4		Cm1, Cm2		L1, L2	M12	
Corner	0.087		0.025	pF	1.19	0.336	nH
Edge	0.095		0.023	pF	1.08	0.270	nH
Field	0.097		0.016	pF	0.88	0.153	nH
Diagonal	0.097		0.010	pF	0.88	0.074	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:

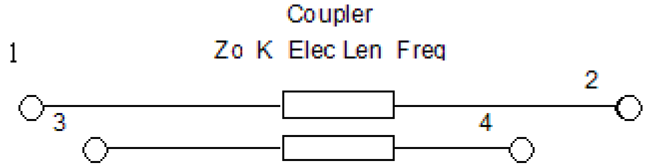


Figure 38 Transmission line equivalent circuit for crosstalk

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

Site	Zo		td		K	180 deg	@
Corner	76.5	Ω	12	ps	0.28	47.6	GHz
Edge	72.5	Ω	10.5	ps	0.17	76.19	GHz
Field	64.9	Ω	10.5	ps	0.10	95.238	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.

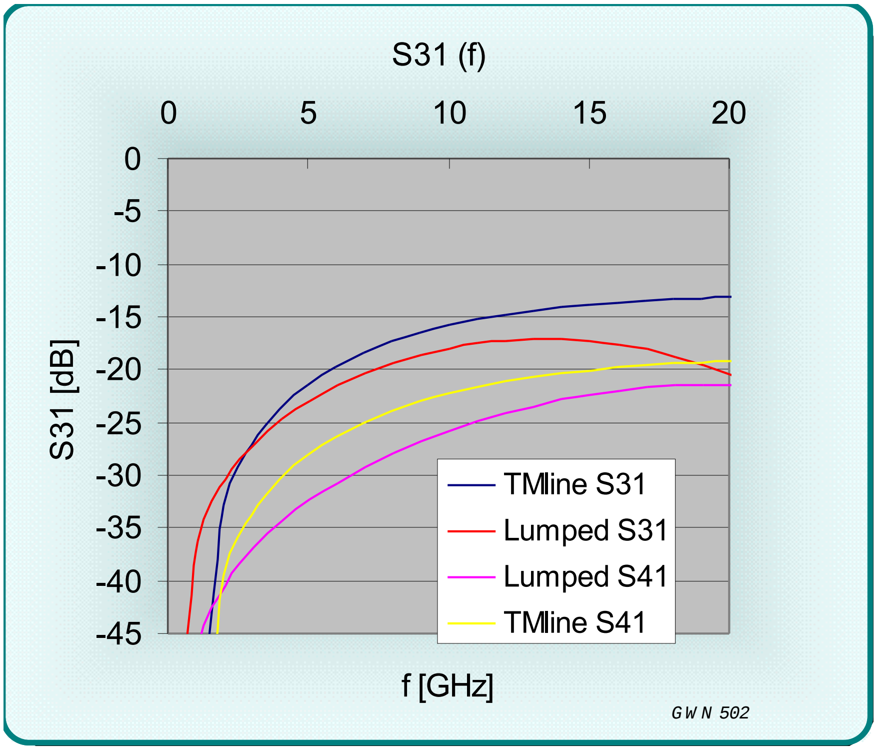


Figure 39 Crosstalk S31 and S41 [dB] as a function of frequency

Ironwood Electronics

Test socket

0.5 mm pitch

5/23/06

Measurement results:

	Corner	Edge	Field	
Delay	12	10.5	10.5	ps
Risetime open	34.5	33	31.5	ps
Risetime short	58.5	57	43.5	ps
Risetime thru, 50Ω	51	45	33	ps
Insertion loss (1dB)	5.2	5.2	15.7	GHz
Insertion loss (3dB)	>20	>20	>20	GHz
VSWR (2:1)	9.50	>20	>20	GHz

PI equivalent circuit component values:

Site		C1		C2		L1	
Corner		0.087	pF	0.087	pF	1.19	nH
Edge		0.095	pF	0.095	pF	1.08	nH
Field		0.097	pF	0.097	pF	0.88	nH
Diagonal		0.097	pF	0.097	pF	0.88	nH

Mutual component values:

Site		Cm12		M12	
Corner		0.025	pF	0.34	nH
Edge		0.023	pF	0.27	nH
Field		0.016	pF	0.15	nH
Diagonal		0.010	pF	0.07	nH

Transmission line equivalent circuit values:

Site	Zo		td	
Corner	76.5	Ω	12	ps
Edge	72.5	Ω	10.5	ps
Field	64.9	Ω	10.5	ps