PRELIMINARY

Plastronics

H057 spring probe

0.80 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 Plastronics H057 spring probe. 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.

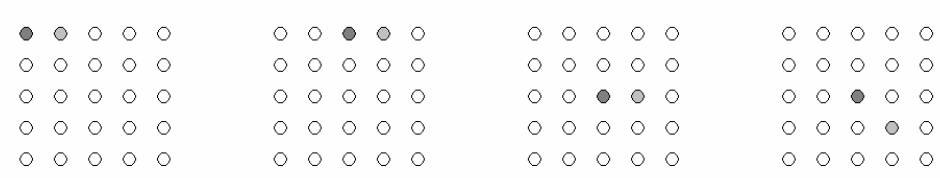
Time domain measurements are obtained via Fourier transform from VNA tests. These measurements reveal the type of discontinuities at the interfaces plus contacts and establish bounds for digital system risetime and clock speeds.

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 H057 spring probe 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:

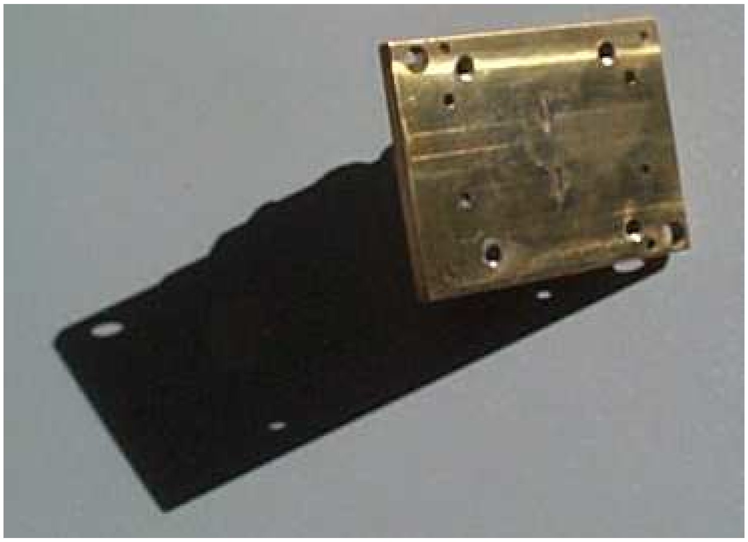


Figure 1 H057 spring probe base plate example

Figure 2 DUT plate

The H057 spring probes in their socket and base plate as well as the DUT plate are then mounted in a test fixture as shown in Fig. 3:

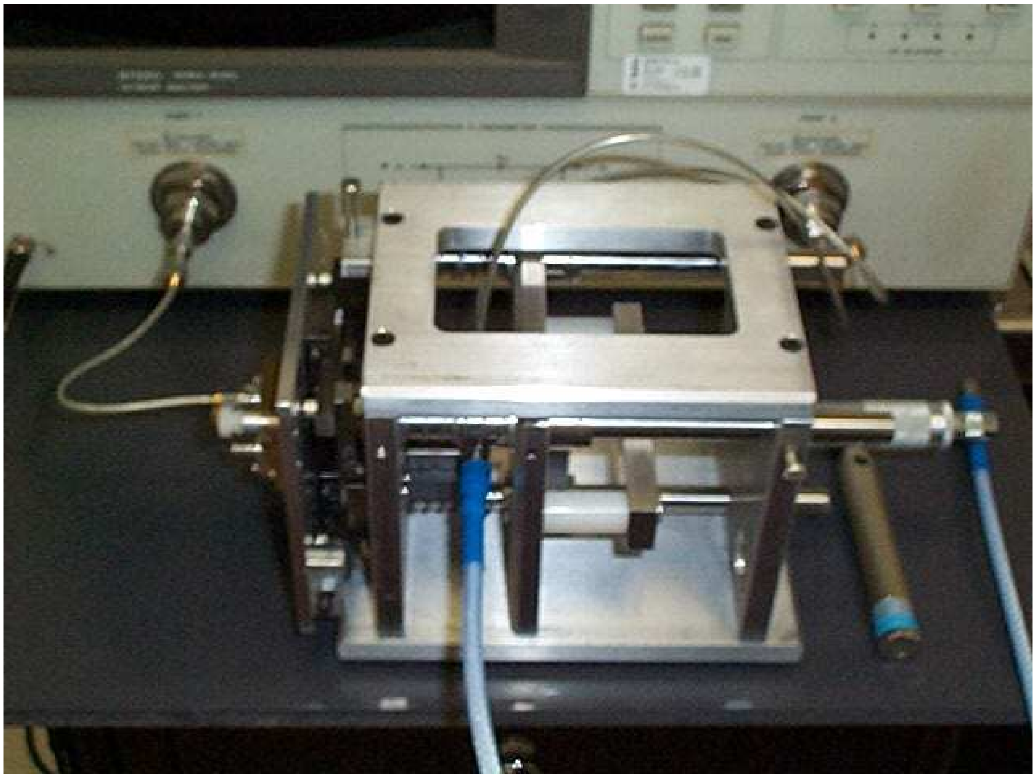
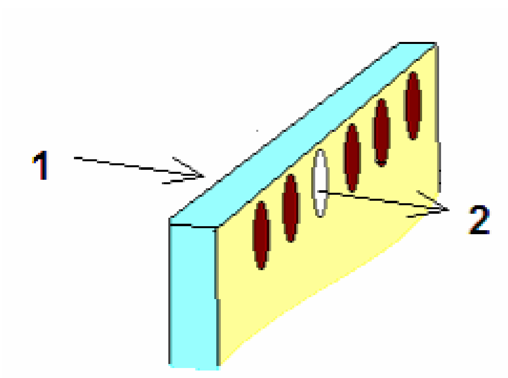


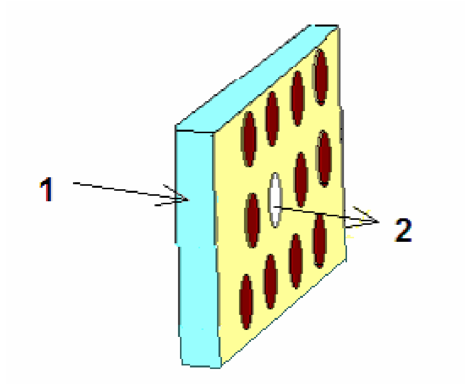
Figure 3 Test fixture

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.

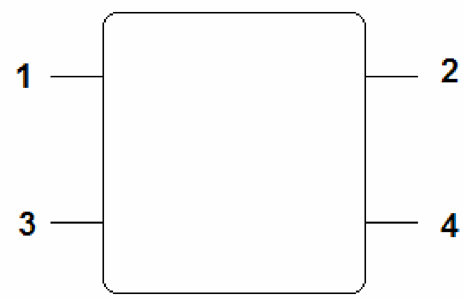
For G-S-G and G-S-S-G measurements, the ports are named as follows:





Single row DUTs

Multi-row DUTS



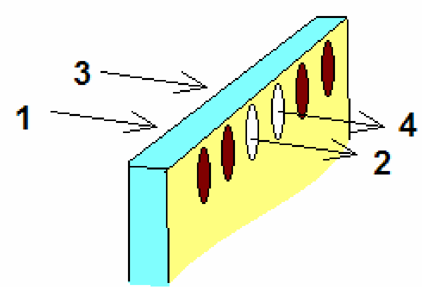


Figure 4 Ports for the G-S-G and G-S-S-G measurements

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:

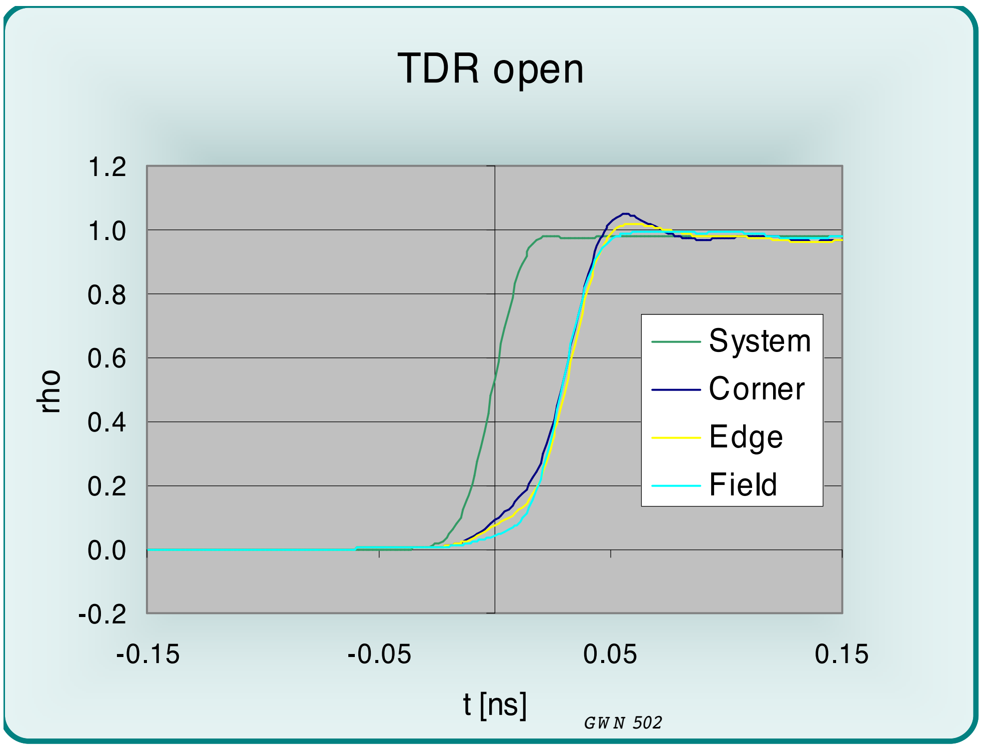


Figure 5 TDR signal from an OPEN circuited H057 array

The reflected signals from the H057 array (rightmost traces) show only a small deviation in shape from the original waveform (leftmost trace). The risetime is about 40.5, 37.5 and 30.0 ps for corner, edge and field, respectively and is somewhat larger than that of the system with the open probe (27.0 ps). Electrical pin length is about 14.3, 15.0 and 15.0 ps, respectively (one way).

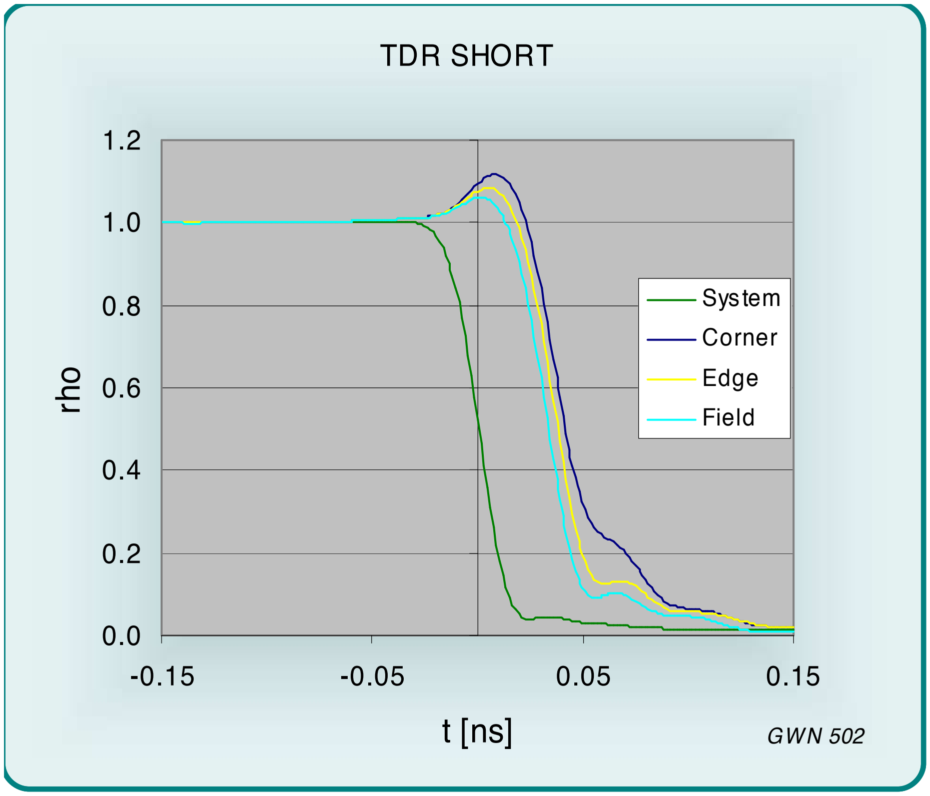


Figure 6 TDR signal from a SHORT circuited H057 array

For the short circuited H057 array the fall time is about 57.0, 55.5 and 31.5 ps for corner, edge and field, respectively. There is a small increase over the system risetime of 27.0 ps caused by the contact impedance levels.

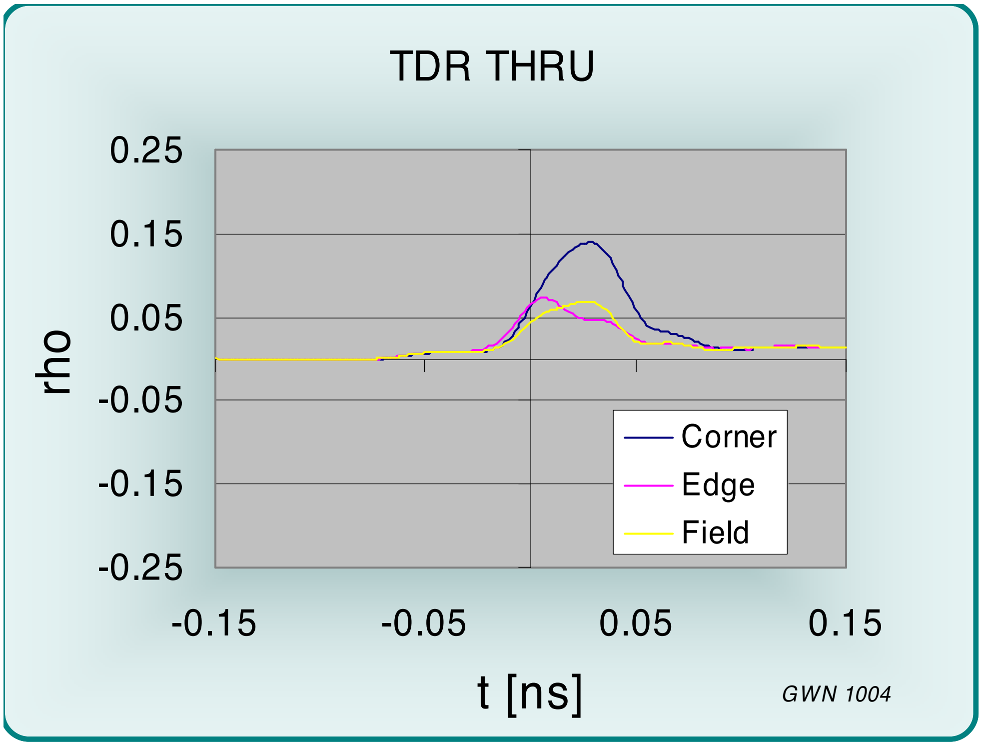


Figure 7 TDR measurement into a 50 Ohm probe

The thru TDR measurement shows both an inductive response and a capacitive response. The peaks correspond to an impedance of 66.1, 57.8 and 57.4 Ohms for corner, edge and field, respectively.

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

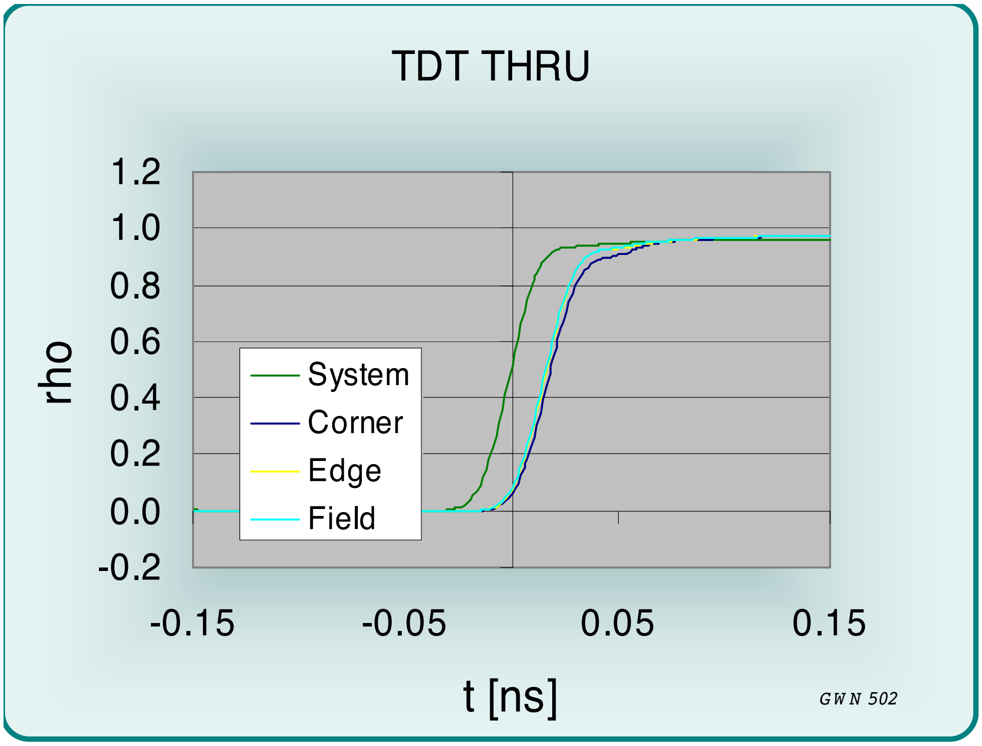


Figure 8 TDT measurement

The TDT measurements for transmission show almost the same risetime from the pin array (10-90% RT = 36.0, 31.5 and 31.5 ps for corner, edge and field, respectively, the system risetime is 27.0 ps). The added delay values at the 50% point are 18.0, 16.5 and 16.5 ps, respectively. There is no signal distortion. If the 20%-80% values are extracted, the risetimes are only 21.0, 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).

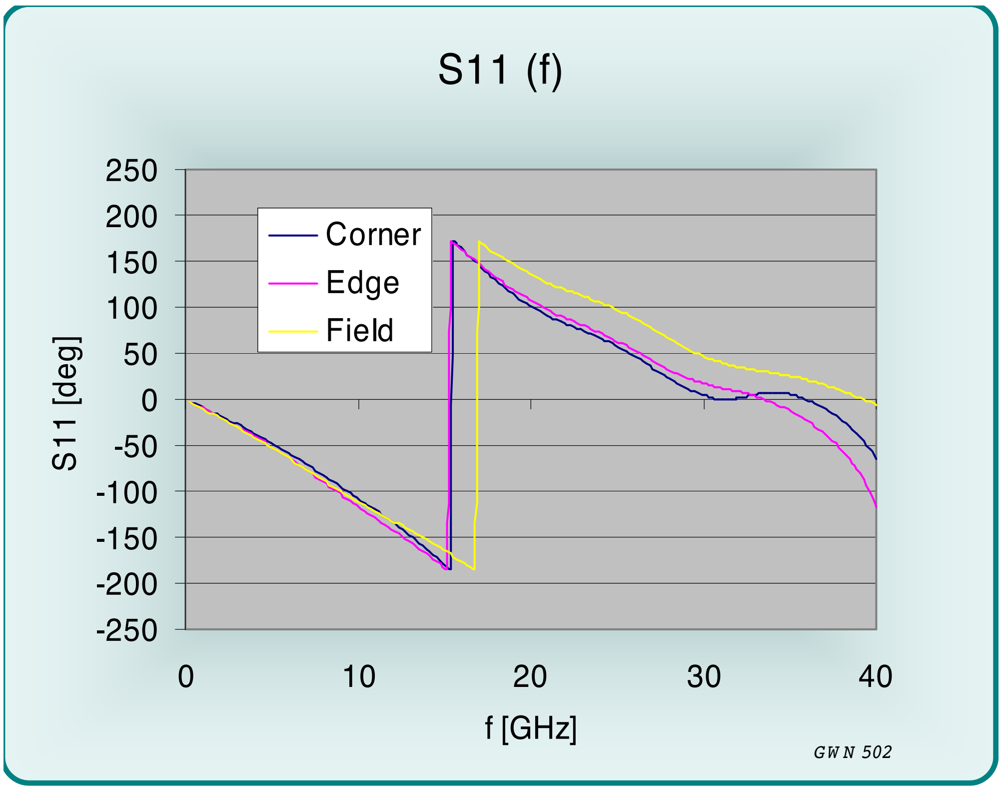


Figure 9 S11 phase (f) for the open circuited signal pin

There are no aberrations in the response. The 360 degree jump is due to the network analyzer data presentation.

It rolls over values greater than +/- 180 degrees.

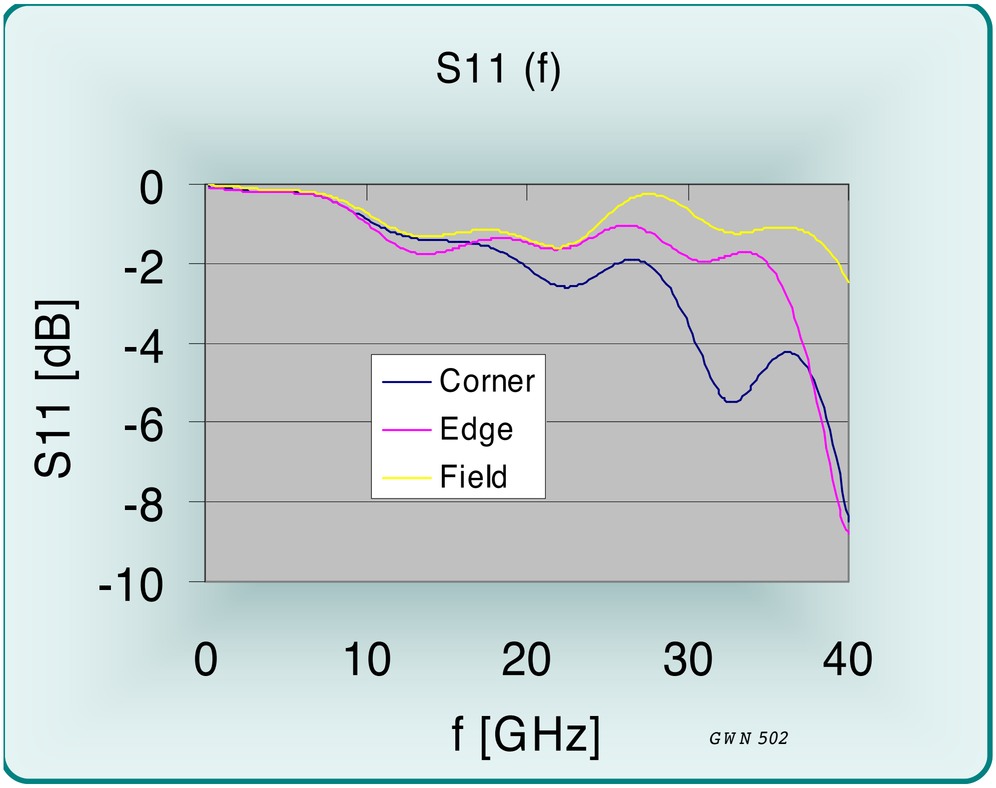


Figure 10 S11 magnitude (f) for the open circuited signal pin

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

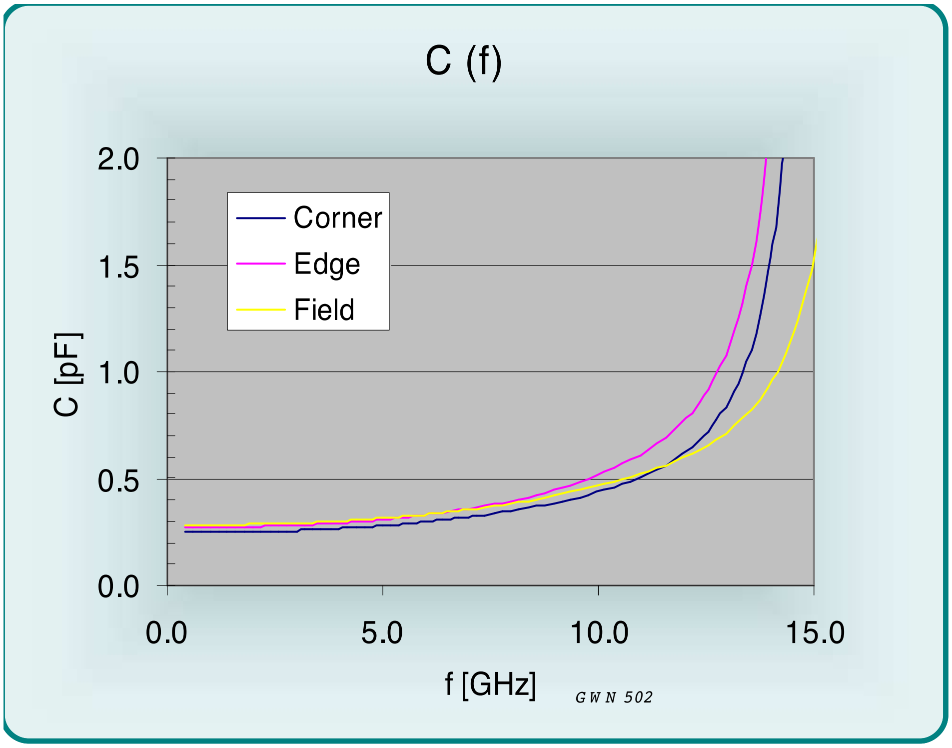


Figure 11 C(f) for the open circuited signal pin

Capacitance is 0.25, 0.27 and 0.28 pF for corner, edge and field, respectively, at low frequencies. The rise in capacitance toward 14 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 significant resonances. A small amount of loss is present, especially toward 40 GHz.

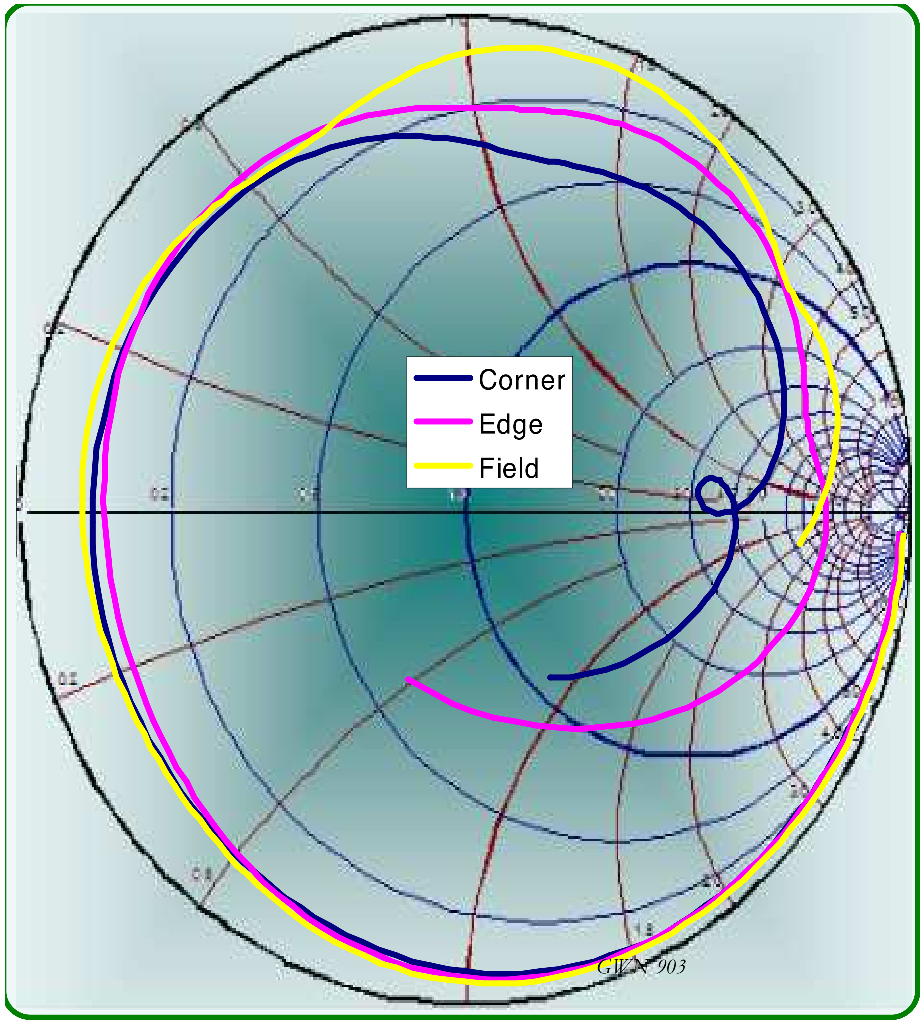


Figure 12 Reflections from the open circuited H057 array

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 H057 array. Calibration was established with a short placed at the end of the coax probe.

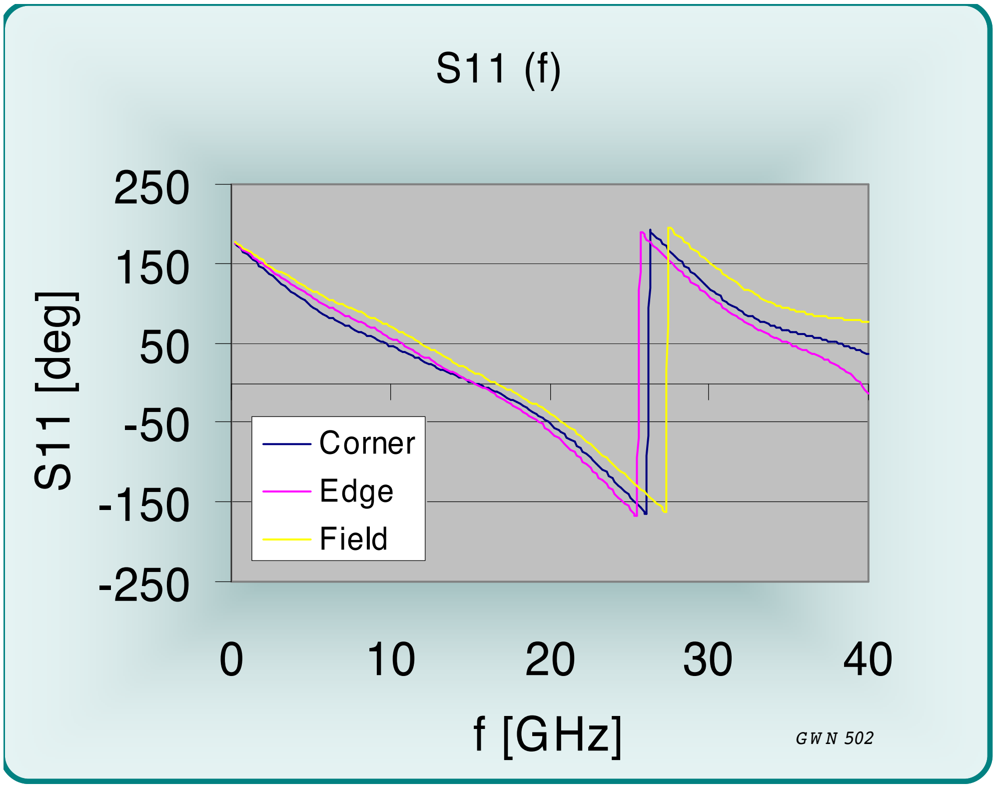


Figure 13 S11 phase (f) for the short circuited case

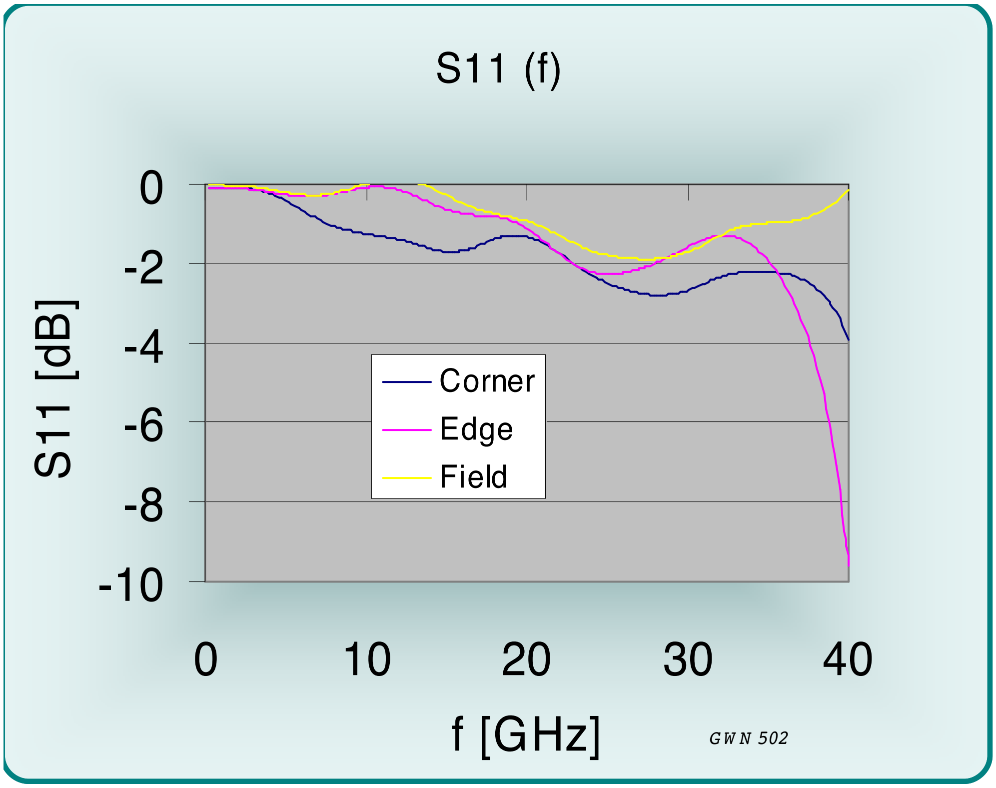


Figure 14 S11 magnitude (f) for the short circuited case

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

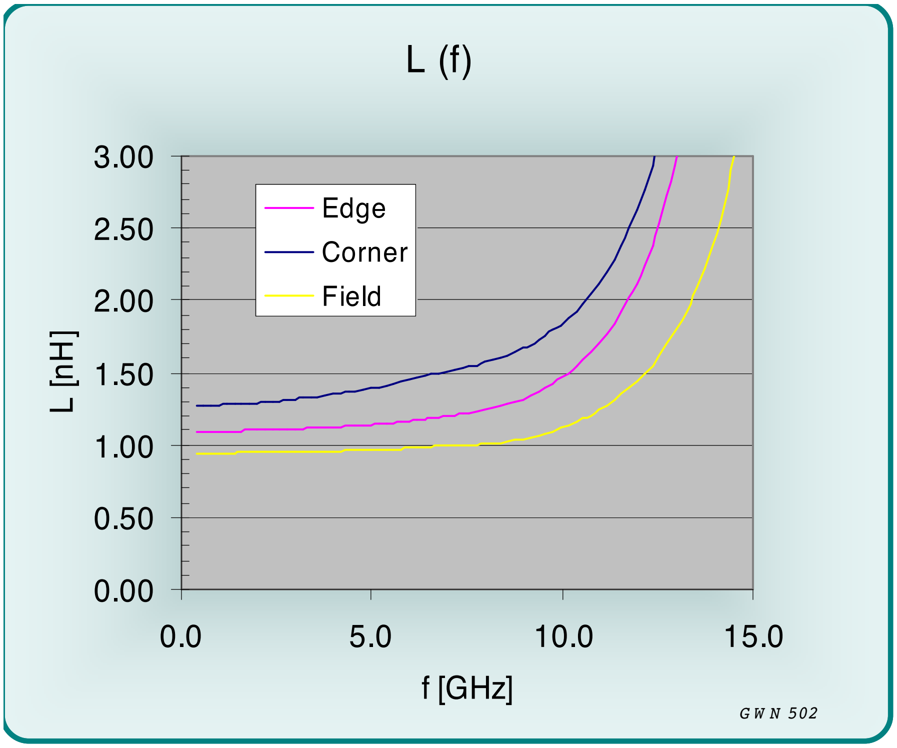


Figure 15 L(f) for the H057 array

The phase change corresponds to an inductance of 1.28, 1.10 and 0.95 nH for corner, edge and field, respectively, at low frequencies. Toward 14 GHz inductance increases. At these frequencies, the transmission line nature of the arrangement must be taken into account.

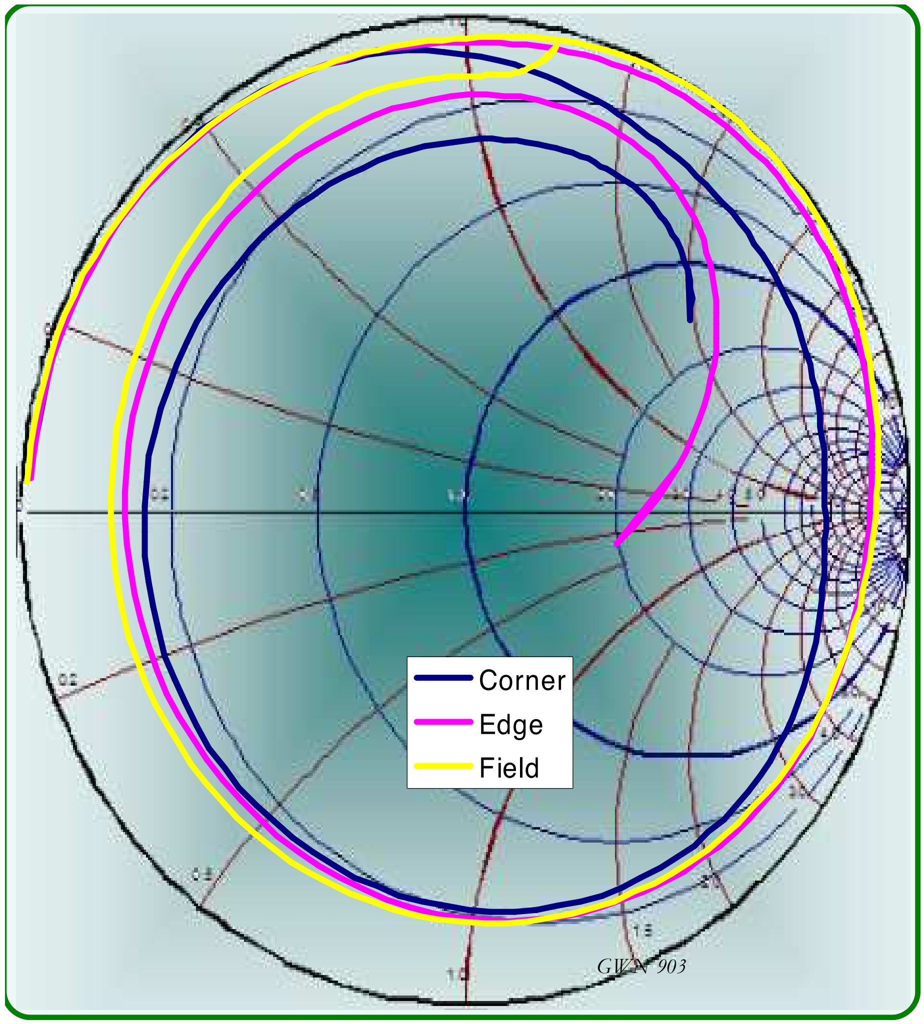


Figure 16 Short circuit response in the Smith chart

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

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

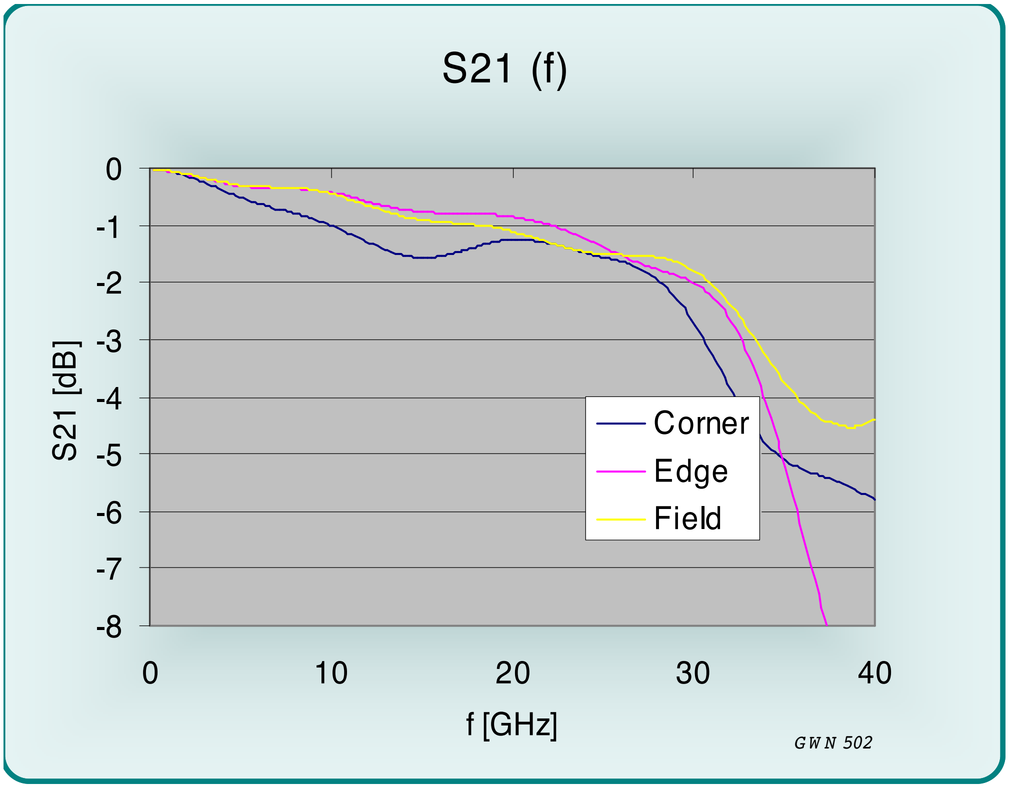


Figure 17 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 10.0, 22.1 and 18.1 GHz (corner, edge, field). The 3 dB point is not reached before 30.5, 32.5 and 33.3 GHz.

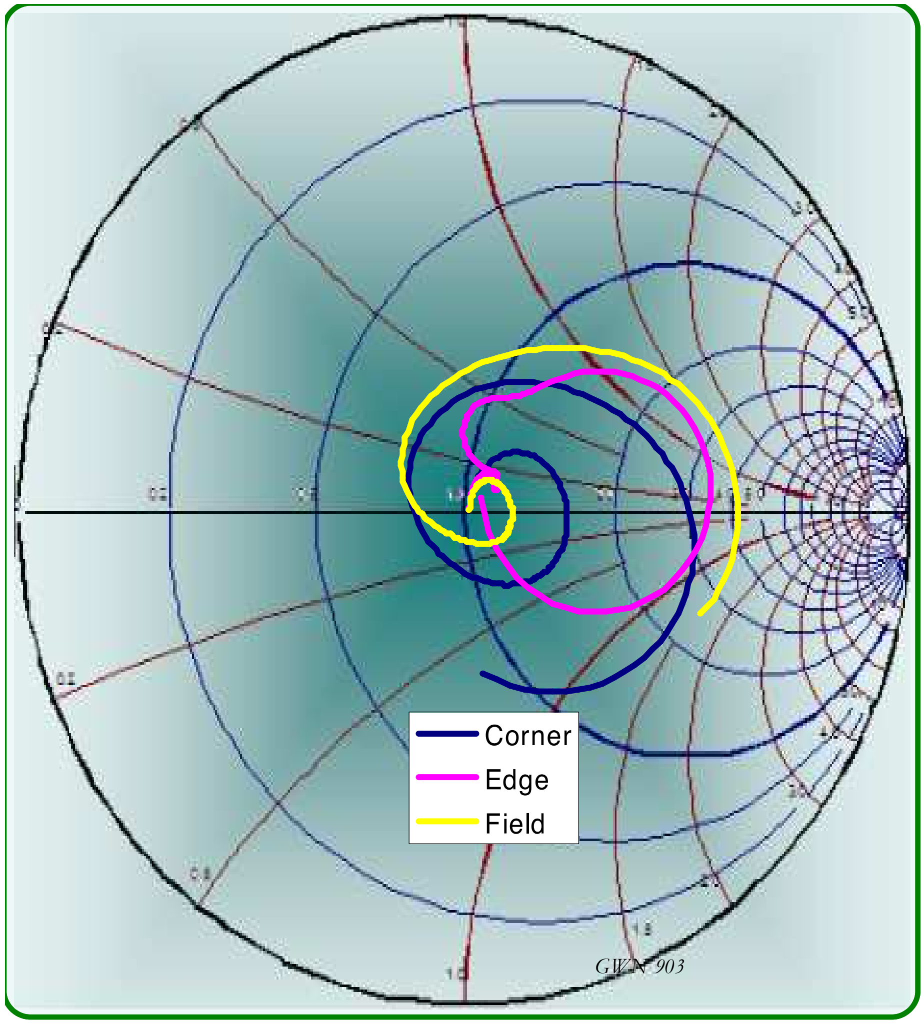


Figure 18 Smith chart for the thru measurement into a 50 Ohm probe

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

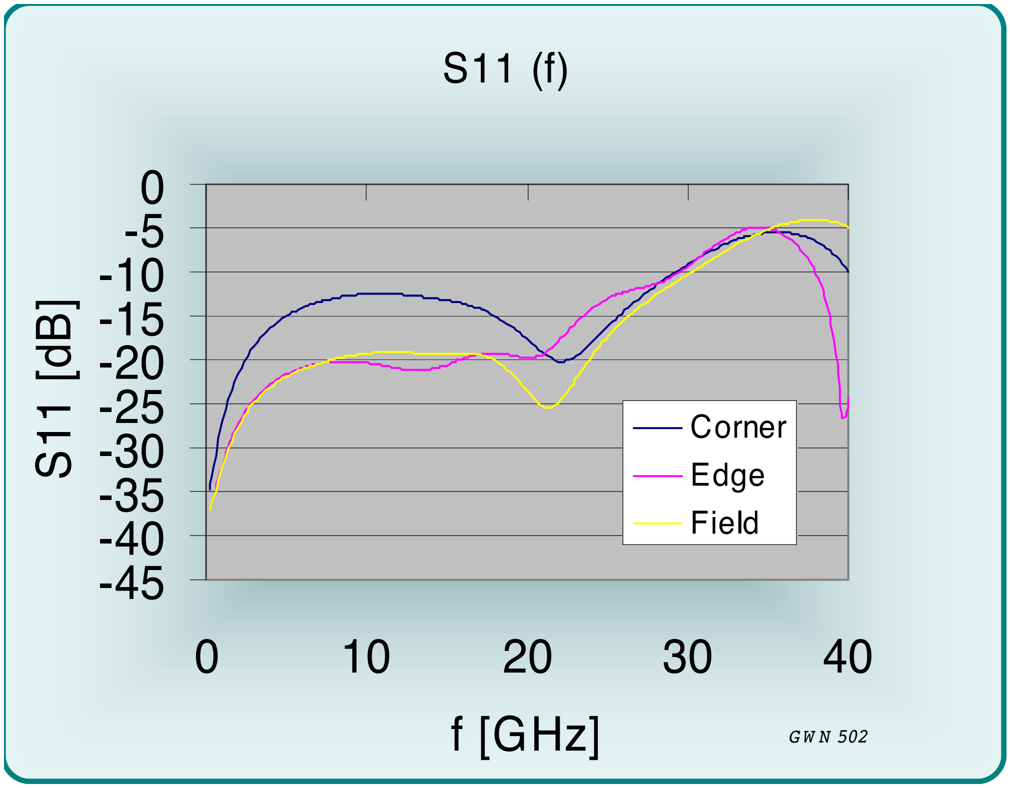


Figure 19 S11 magnitude (f) for the thru measurement into a 50 Ohm probe

Return loss reaches -20 dB at 2.4 GHz, 15.7 GHz and 23.7 GHz for corner, edge and field sites. The corresponding -10 dB frequencies are 29.1, 29.5 and 30.1 GHz. The level of the return loss for the thru measurement is lowest for the field configuration since its characteristic impedance is closest to 50 Ohms.

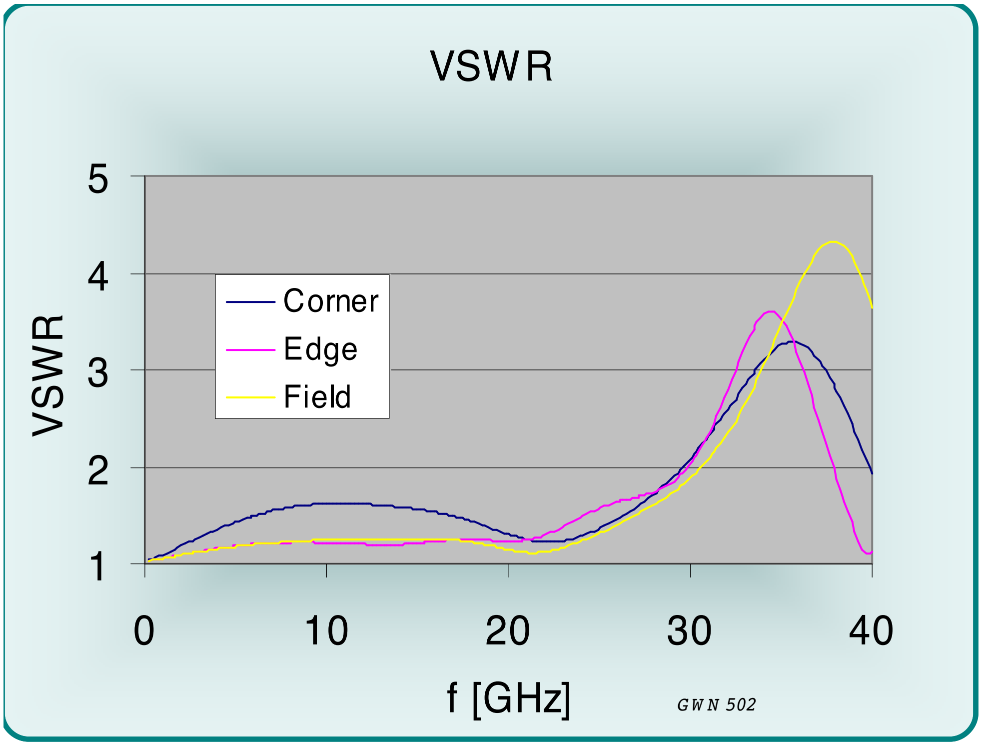


Figure 20 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 29.5, 29.7 and 30.5 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:

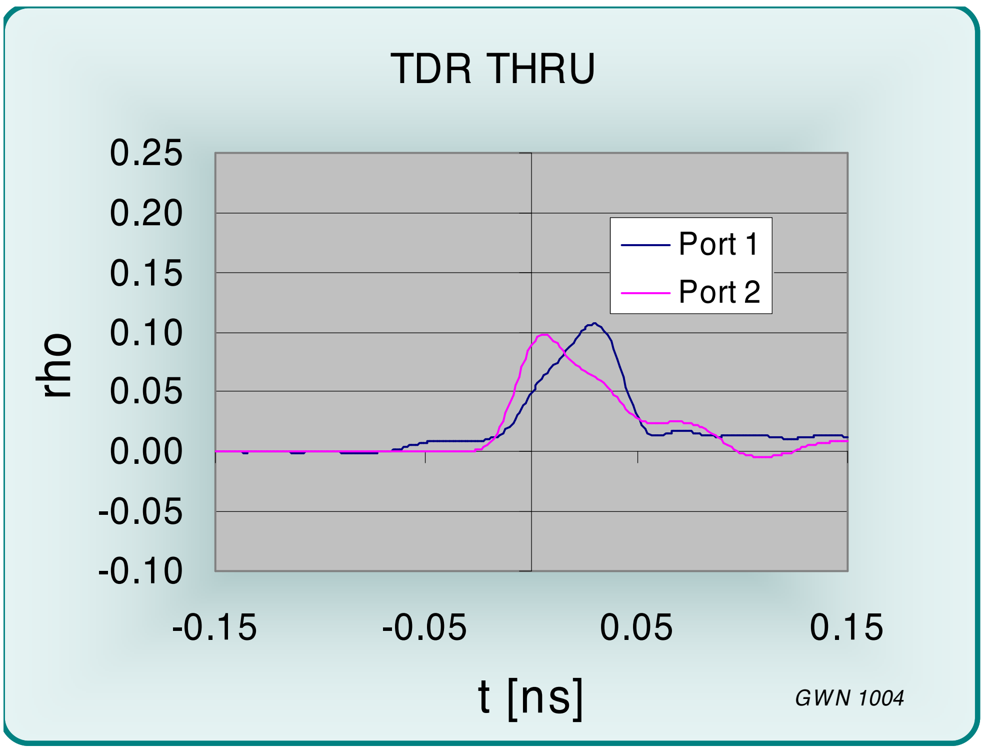


Figure 21 TDR through DUT into a terminated probe

The thru TDR measurement from port 1 to port 2 shows an inductive response. The low peak corresponds to a transmission line impedance of 62.0 Ohms. This is higher than in the G-S-G case since 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:

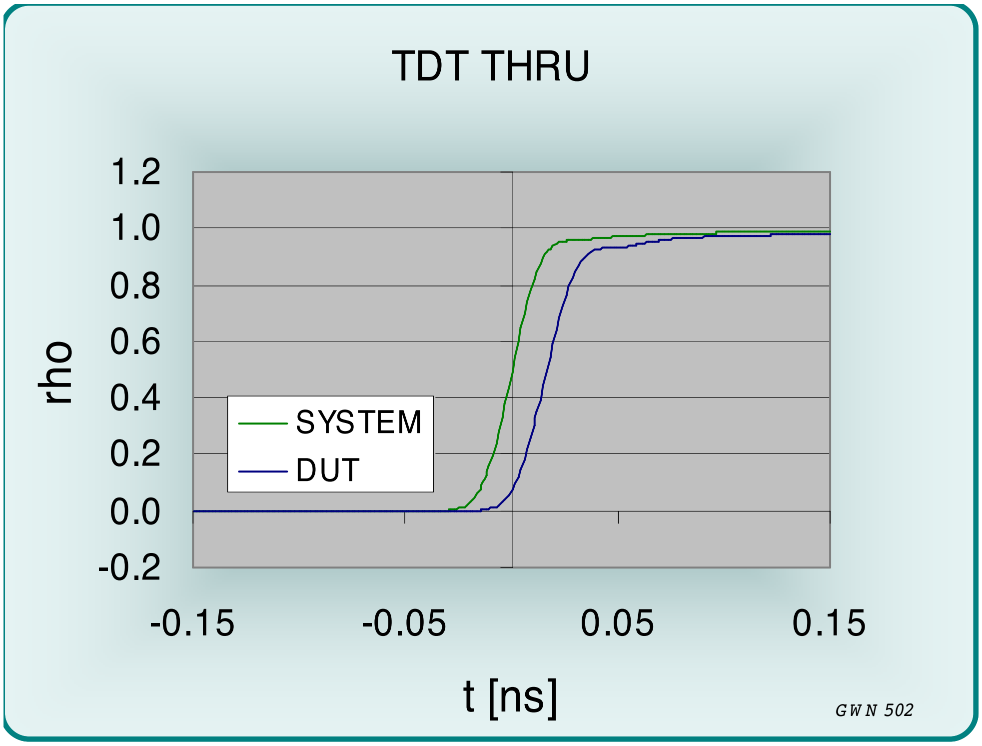


Figure 22 TDT measurement

The TDT measurements for transmission shows almost the same risetime from the pin array (10-90% RT = 30.0 ps) as the system risetime (28.5 ps). The added delay at the 50% point is 15.0 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.

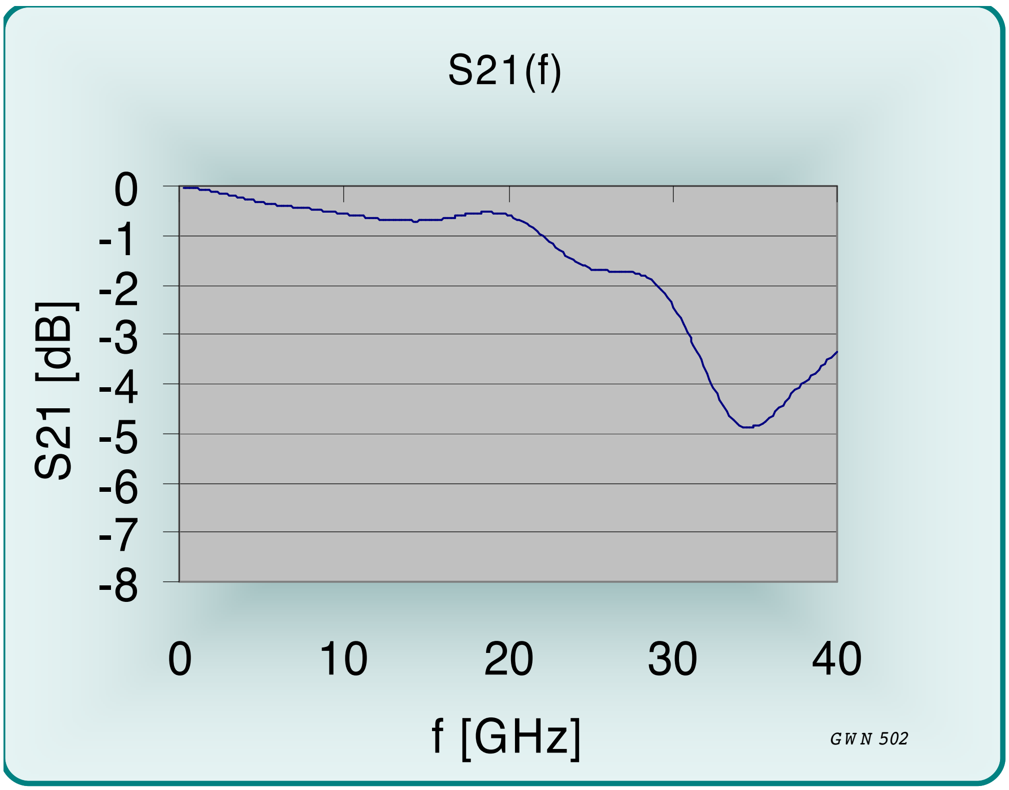


Figure 23 Insertion loss S21 (f)

Insertion loss is less than 1 dB to about 21.9 GHz. The 3 dB point is not reached before 30.9 GHz.

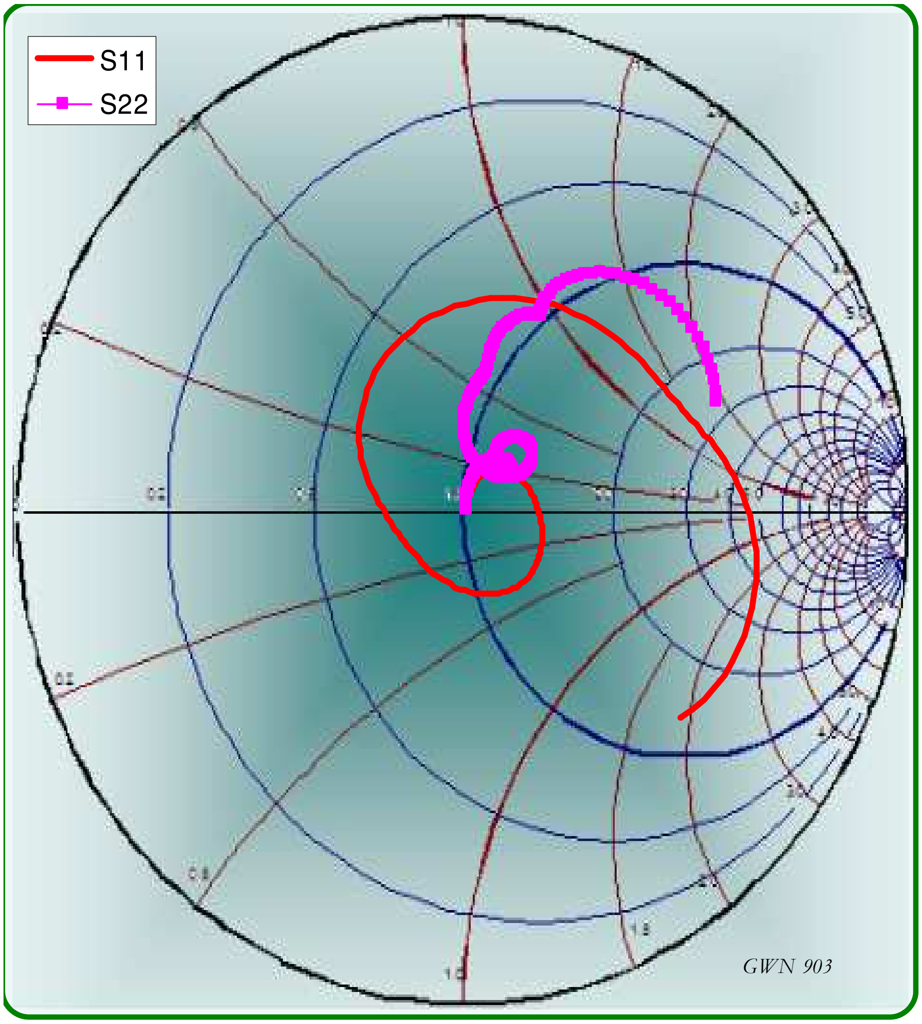


Figure 24 Smith chart for the thru measurement into a 50 Ohm probe

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

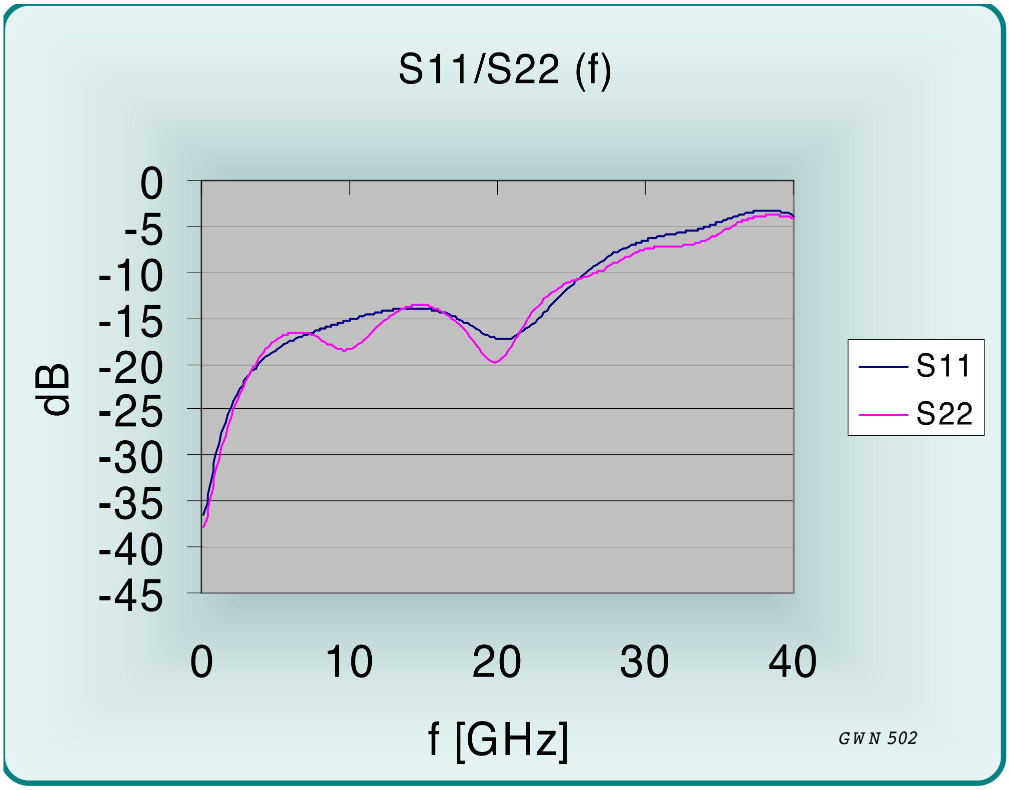


Figure 25 S11 magnitude (f) for the thru measurements into a 50 Ohm probe

The value of the return loss for the thru measurement reaches -20 dB at 3.8 GHz (S11) and 3.6 GHz (S22). It does not exceed -10 dB before 25.9 GHz and 26.7 GHz, respectively.

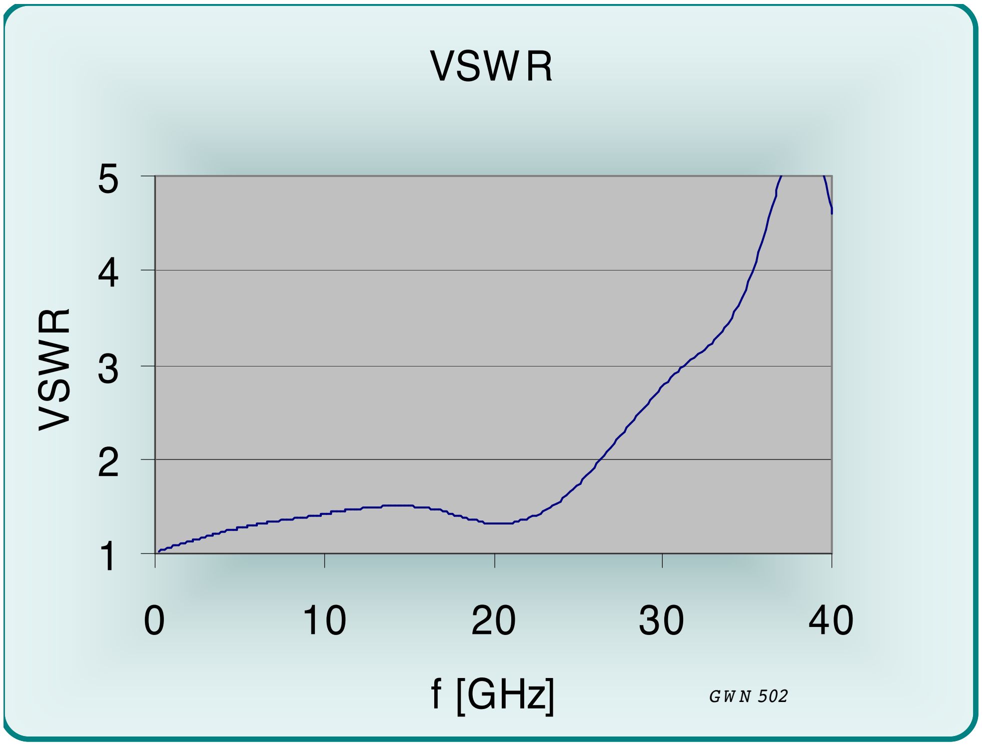


Figure 26 Standing wave ratio VSWR (f) [1 / div.]

The VSWR remains below 2 : 1 to a frequency of 26.3 GHz.

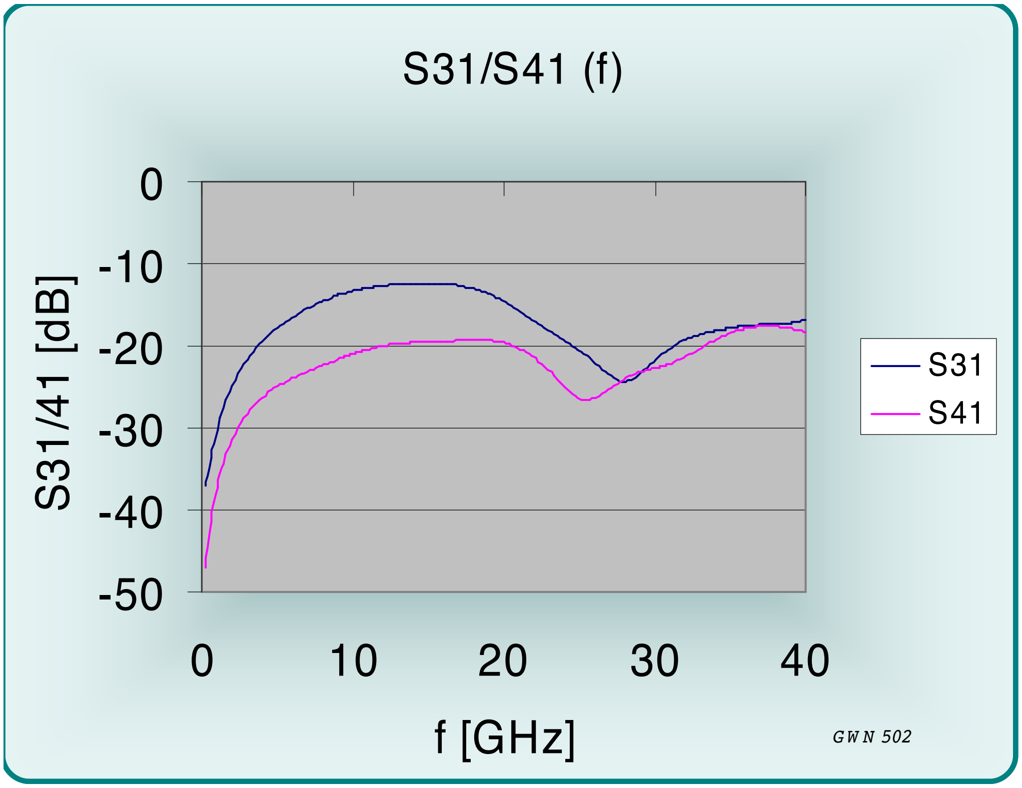


Figure 27 Crosstalk as a function of frequency

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 3.6 GHz (S31) and not before 12.0 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 0.054, 0.050, 0.048 and 0.039 pF and a mutual inductance of 0.41, 0.25, 0.16 and 0.050 nH for corner, edge field and diagonal sites, respectively.

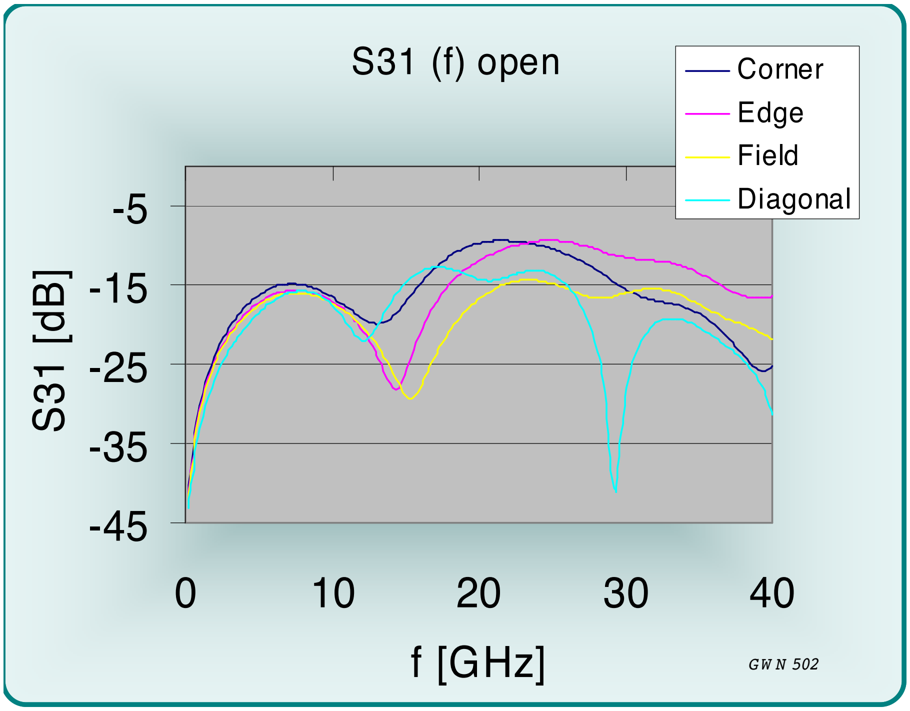


Figure 28 Open circuit crosstalk from port 1 to port 3

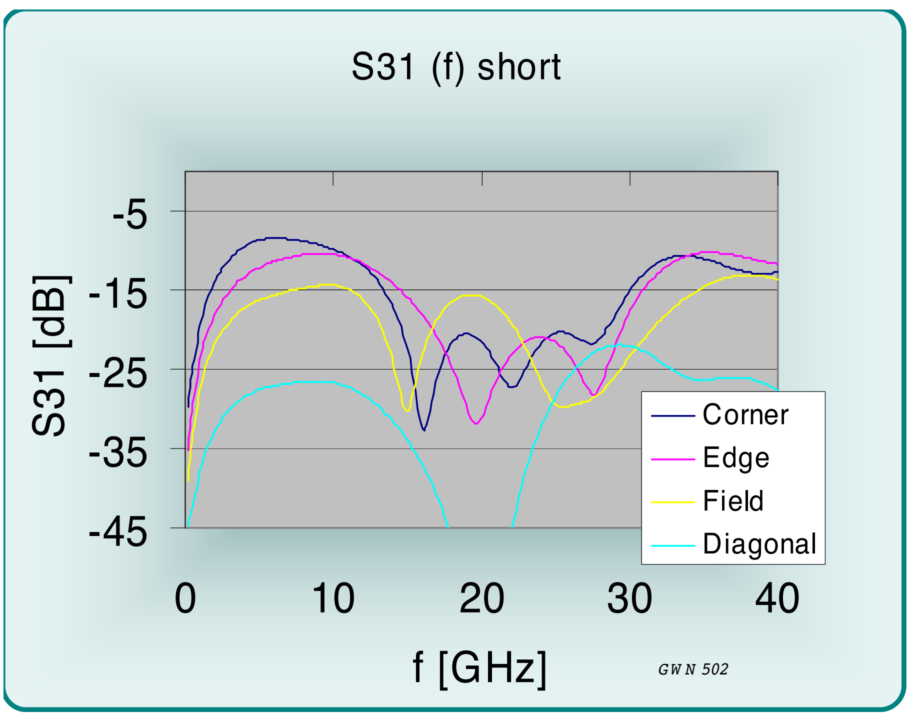


Figure 29 Short circuit crosstalk from port 1 to port 3

SPICE Models

A lumped element SPICE model for the Plastronics H057 array in G-S-G configuration is shown below:

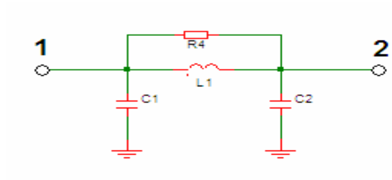


Figure 30 Lumped element SPICE model

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

The values for the elements are

Site	Cg=C1+C2			L1		R4	
Corner		0.251	pF	1.28	nH	1000	Ohms
Edge		0.273	pF	1.10	nH	1000	Ohms
Field		0.284	pF	0.95	nH	1000	Ohms
Diagonal		0.284	pF	0.95	nH	1000	Ohms

Toward the cutoff frequency of the Pi section the lumped element model becomes invalid. This happens above 13 GHz for the above model. Hence, the second model developed is a transmission line model:

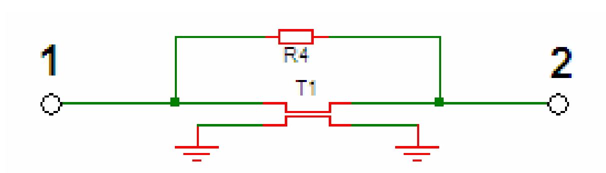


Figure 31 Transmission line model for the H057 array

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

	Zo		L		R4	
Corner	71.5	Ω	17.95	ps	1000	Ω
Edge	63.4	Ω	17.31	ps	1000	Ω
Field	57.8	Ω	16.40	ps	1000	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.

The lumped model does not remain valid at high frequencies. Alternatives are to split this model into multiple sections with the same total capacitance and inductance or to use a transmission line model.

Time domain

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

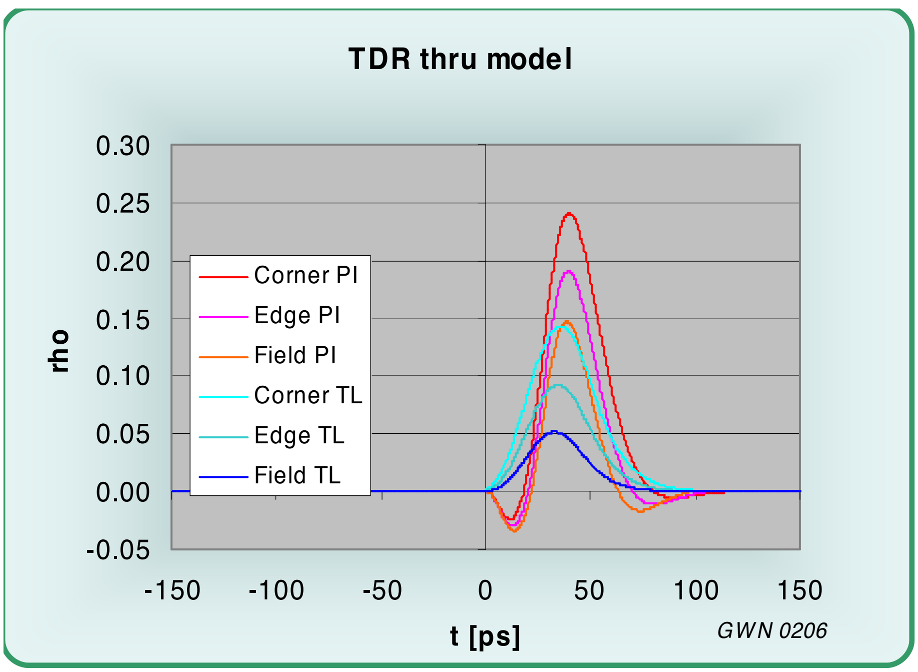


Figure 32 TDR model results

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:

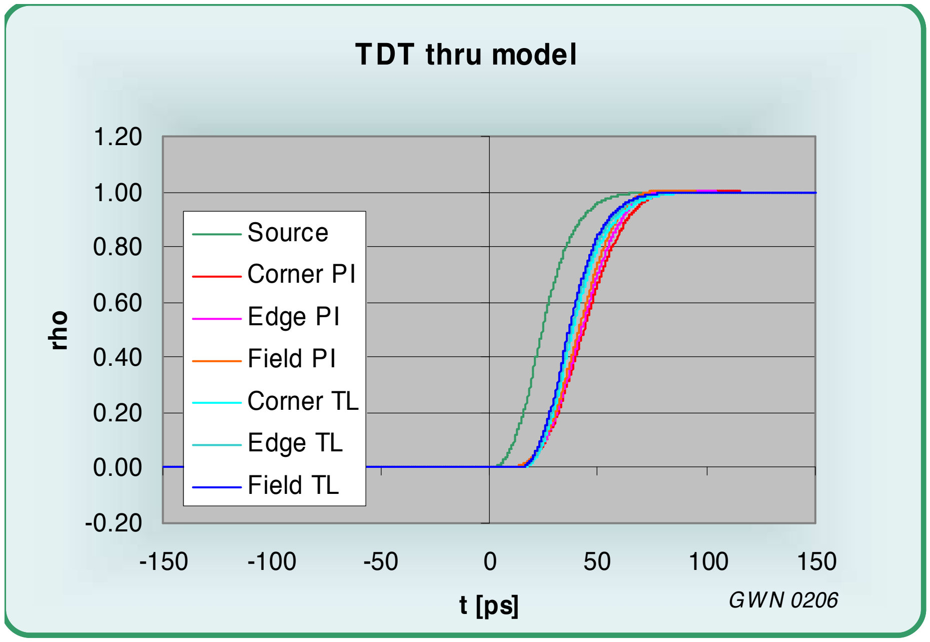


Figure 33 TDT model

The risetime for the transmission line case is 32.5, 32.5 and 30.0 ps respectively 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.

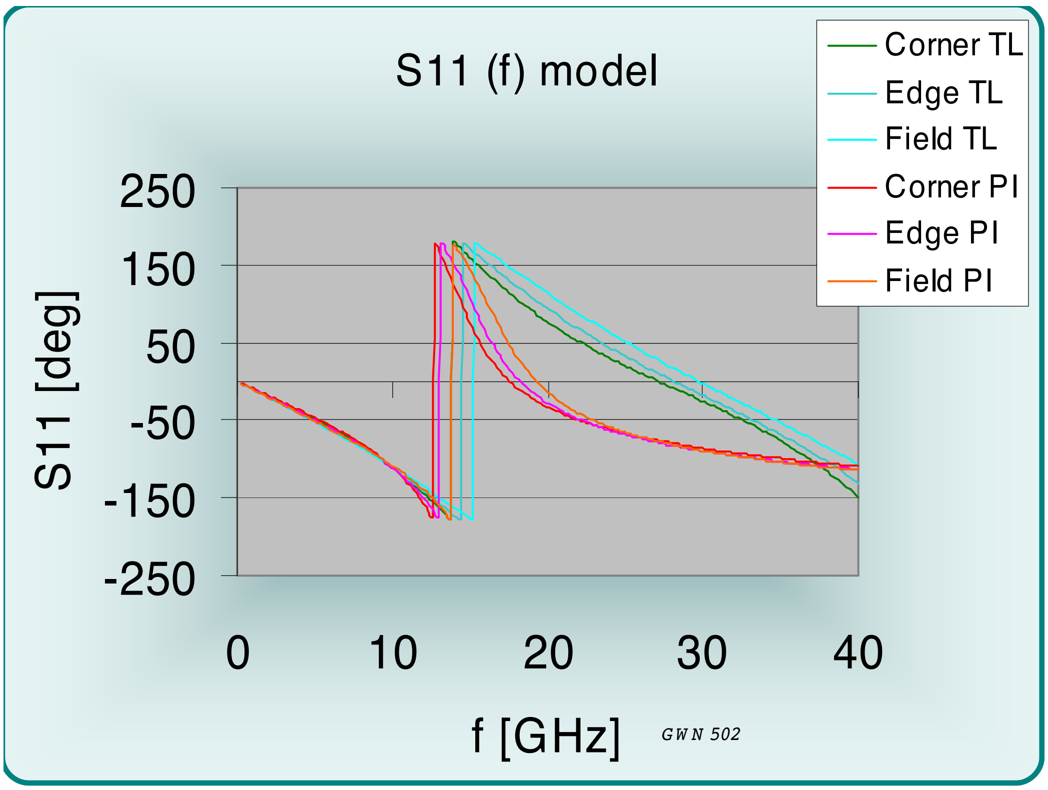


Figure 34 S11 phase (f) for open circuited case

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 13 GHz.

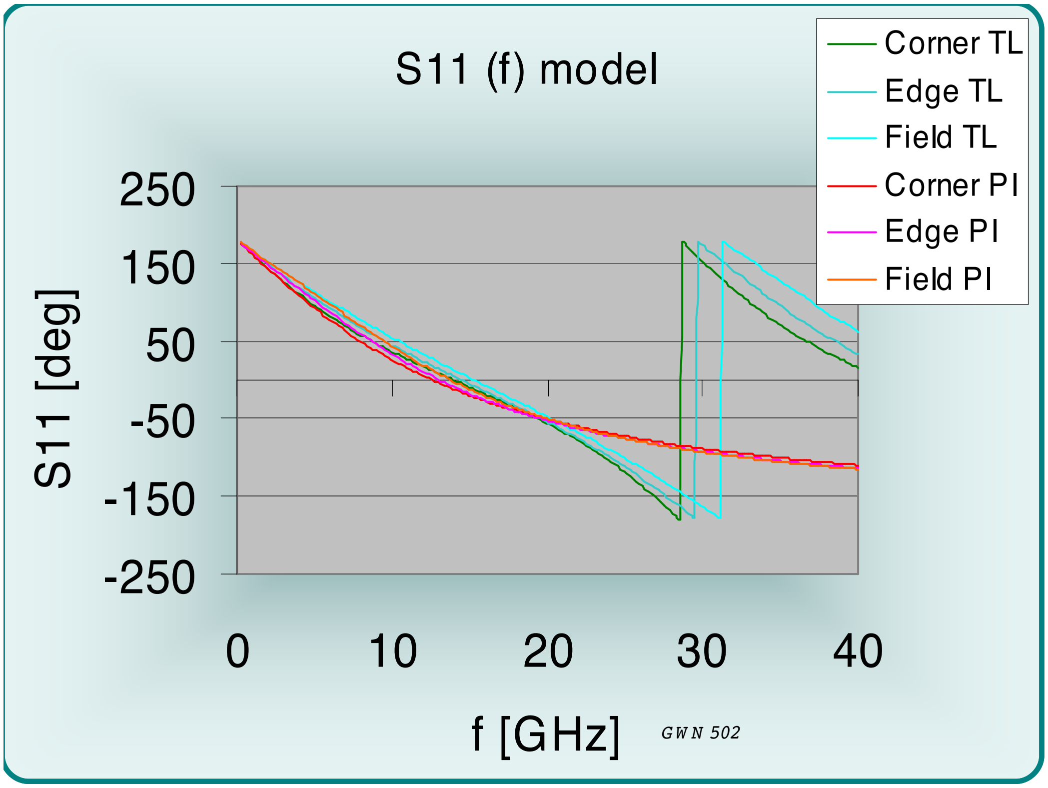


Figure 35 S11 phase response (short circuit)

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

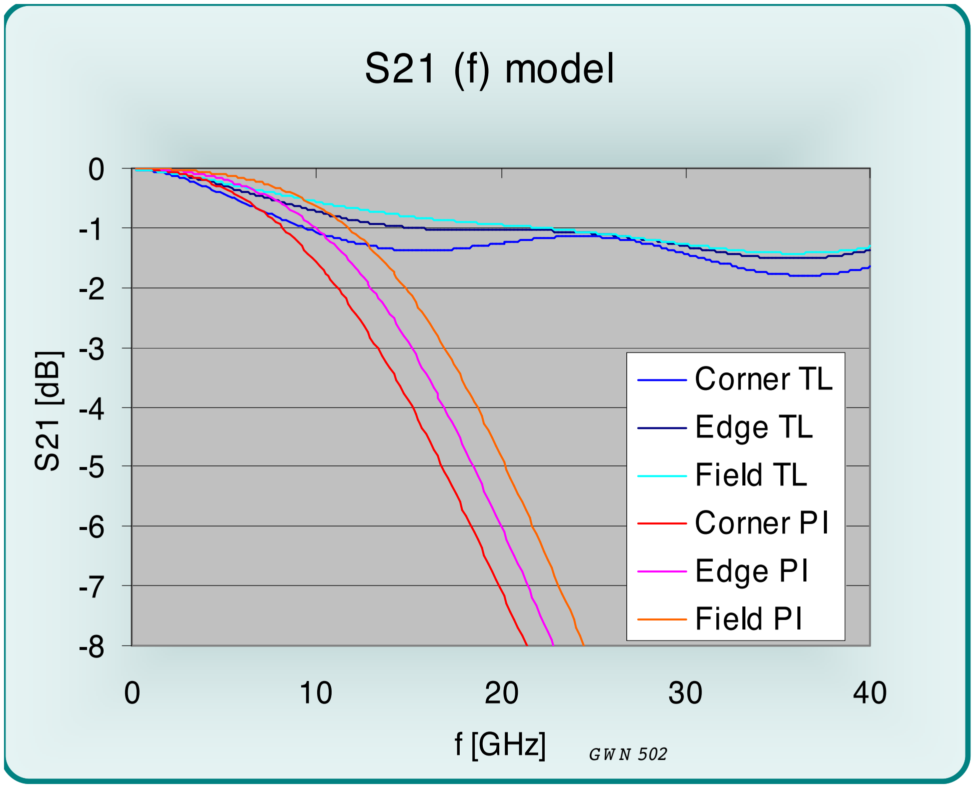


Figure 36 Insertion loss as a function of frequency

The lumped element frequency domain model used for evaluating the mutual elements also consists of the 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.

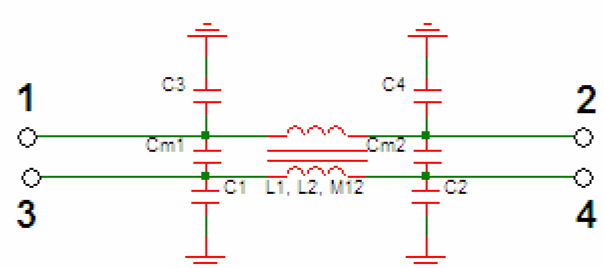


Figure 37 Equivalent circuit for G-S-S-G (mutual coupling)

The values for this model are:

Site	C1,2,3,4		Cm1,Cm2		L1, L2	M	
Corner	0.125		0.027	pF	1.28	0.405	nH
Edge	0.136		0.025	pF	1.10	0.247	nH
Field	0.142		0.024	pF	0.95	0.160	nH
Diagonal	0.142		0.019	pF	0.95	0.050	nH

The lumped model does not remain valid at high frequencies. Alternatives are a split of the lumped model into multiple sections, e.g. three sections with 1/3 the values for the total capacitance or inductance each or the use of a transmission line model with coupled transmission lines and added loss terms as shown below (field site only):

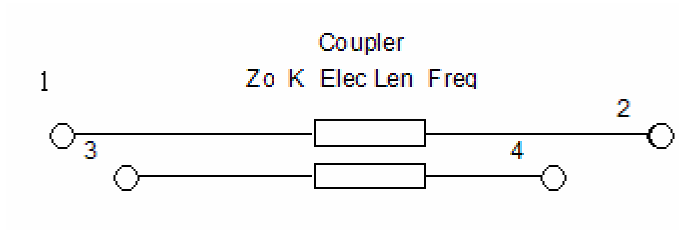


Figure 38 Transmission line equivalent circuit for crosstalk

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

Field	57.4	Ω	16.5	ps	0.17	33.3	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.

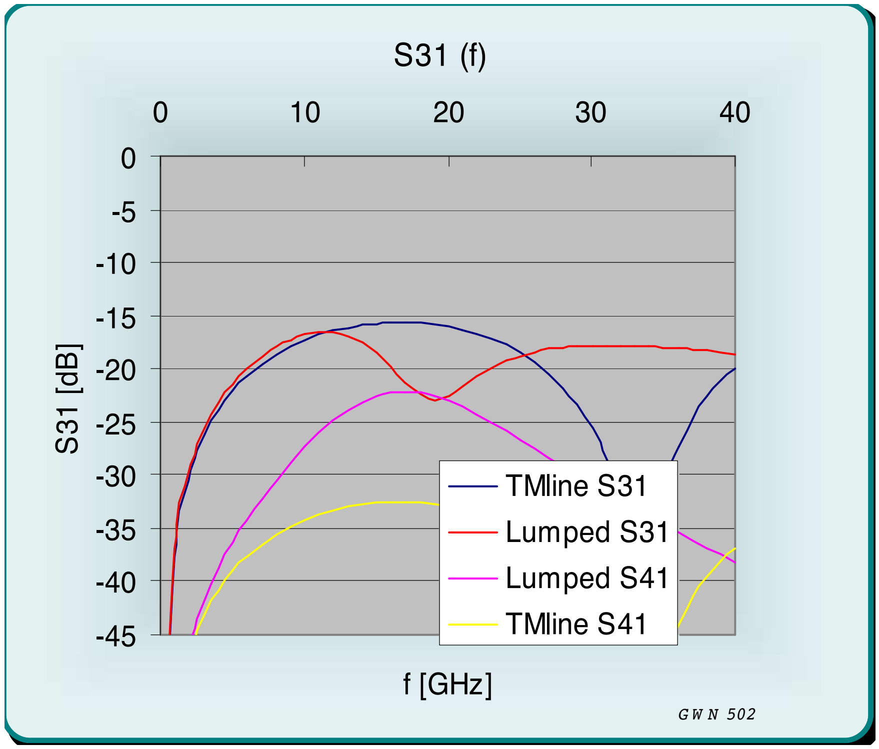


Figure 39 Crosstalk S31 and S41 [dB] as a function of frequency

Both models are limited to a maximum frequency of about 20 GHz.

The model underestimates crosstalk slightly. For the forward crosstalk this is of little consequence, however, since the overall level is low to begin with.

PRELIMINARY

Summary sheet

Plastronics

H057 spring probe
0.80 mm pitch

8/6/2008

Measurement results:

	Corner	Edge	Field	
Delay	18	16.5	16.5	ps
Risetime open	40.5	37.5	30	ps
Risetime short	57	55.5	31.5	ps
Risetime thru, 50Ω	36	31.5	31.5	ps
Insertion loss (1dB)	10.0	22.1	18.1	GHz
Insertion loss (3dB)	30.49	32.48	32.48	GHz
VSWR (2:1)	29.49	29.69	30.49	GHz

PI equivalent circuit component values:

Site	Cg=C1+C2			L1		R4	
Corner		0.251	pF	1.28	nH	1000	Ohms
Edge		0.273	pF	1.10	nH	1000	Ohms
Field		0.284	pF	0.95	nH	1000	Ohms
Diagonal		0.284	pF	0.95	nH	1000	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		0.054	pF	0.405	nH
Edge		0.050	pF	0.247	nH
Field		0.048	pF	0.160	nH
Diagonal		0.039	pF	0.050	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	66.1	Ω	18	ps
Edge	57.8	Ω	16.5	ps
Field	57.4	Ω	16.5	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.