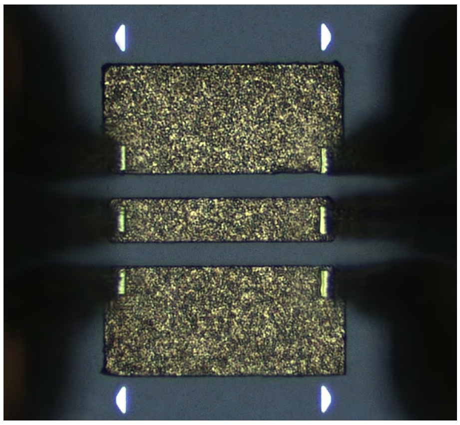
TCS-050-100-W Calibration Substrate

The MPI TITAN™ TCS-050-100-W is the industry-first commercially-available calibration substrate designed according to the recommendations developed by the PlanarCal Consortium of twelve European organizations [1, 2]. It enables the probe tip benchmark calibration and the calibration uncertainty estimation for frequencies up to and including 325 GHz. The TCS-050-100-W is the only commercially-available calibration substrate with an established traceability chain for the coplanar elements and the probe tip calibration to the National Metrology Institute (NMI) references [3].

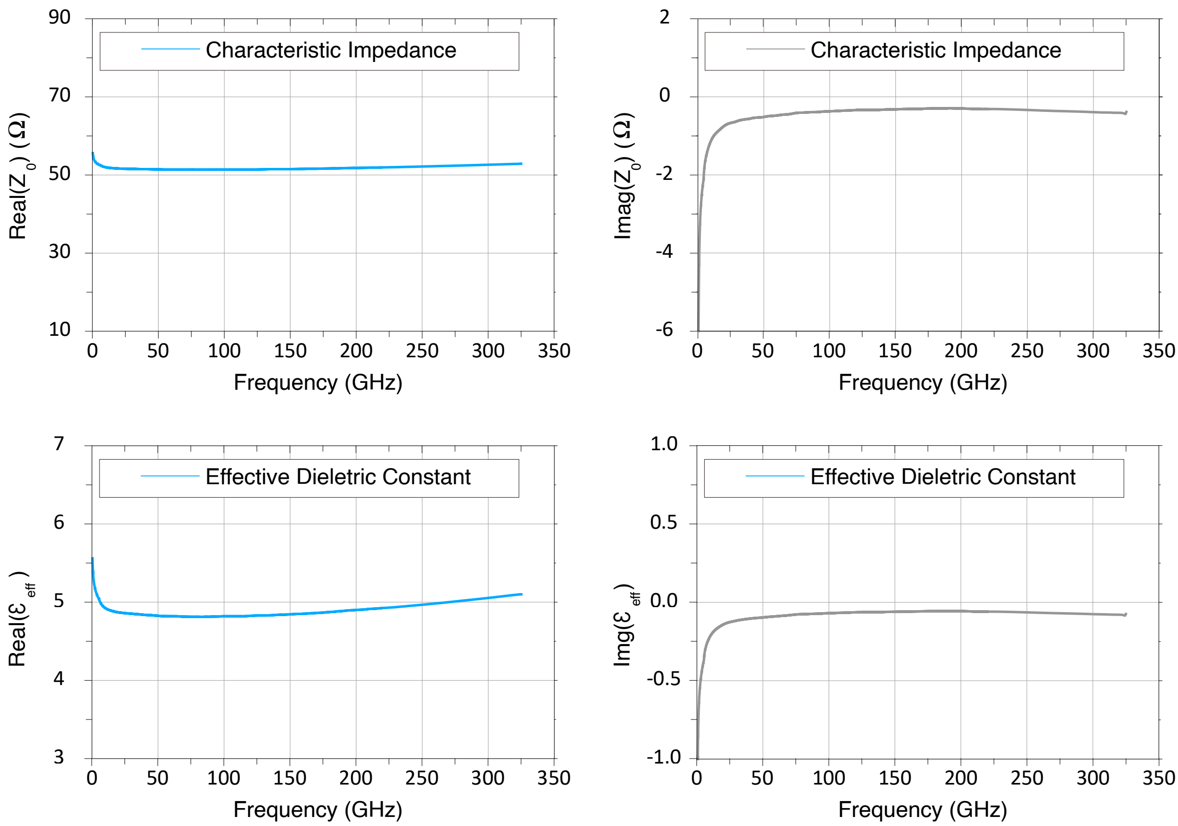
The TCS-050-100-W calibration substrate is designed to provide accurate probe tip calibration of MPI TITAN™ RF Probe family with Ground-Signal-Ground (GSG) probe tips and accommodates probe pitches from 50 µm to 100 µm. It supports the industry-standard Short-Open-Load-Thru (SOLT/TOSM) calibration method, as well as advanced Thru-Match-Reflect (TMR/LRM), Thru-Match-Reflect-Reflect (TMRR) and the NIST multiline Thru-Line-Reflect (mTRL) calibration methods.

The TCS-050-100-W calibration substrate contains eleven groups of lumped standard elements, as well as the complete set of coplanar transmission lines for the NIST multiline TRL calibration good for use up to 325 GHz. It also includes 3 dB, 6 dB, and 10 dB symmetrical attenuators for the S- and RF noise parameters calibration verification in a wide frequency range.



T110A-GSG050-RC probes in separation on the TCS-050-100-W Thru standard after 10µm overtravel contact.

TYPICAL ELECTRICAL FIGURES



Typical characteristic impedance and the effective dielectric constant of the TCS-050-100-W line standard measured using the method of National Institute of Standards and Technology (NIST, Boulder, CO, USA) [4, 5].

SUBSTRATE CHARACTERISTICS

Material	Alumina
Size	16.5 x 12.5 mm
Thickness	254 µm
Design or standards	Coplanar
Probe configuration	GSG
Supported probe pitch	50 to 100 µm
Number of lumped standard groups	11
Number of calibration and verification lines	5
Calibration verification elements	yes
Supported calibration methods	SOLT, LRM, TMR, TMRR and multiline TRL
Typical resistance of the load	50 Ω
Typical load trimming accuracy error	± 0.3 %
Open standard	Au pads on substrate
Recommended overtravel for TITAN™ probes	10 µm

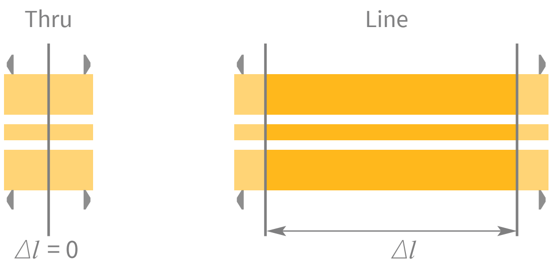
ELECTRICAL CHARACTERISTICS OF CPW LINE STANDARDS

Nominal capacitance per unit length, pF/cm	1.44
Nominal characteristic impedance @20 GHz	50 Ω
Effective dielectric constant @20 GHz, real part	4.9
Velocity factor @20 GHz	0.452
Parameters of the simplified model of line losses	
Reference loss, dB	0.54
Reference delay, ps	18
Reference frequency, GHz	60
Electrical length of line, ps	
Thru	1.10
Line 1 (0104)	2.65
Line 2 (0204)	4.50
Line 3 (0304)	8.70
Line 4 (0205)	18.00
Line 5 (0105)	38.50

MULTI-LINE TRL

The Multi-line TRL calibration kit can be easily designed and fabricated using the same semiconductor process as the DUT. Customized "On-wafer" multi-line TRL calibration kits eliminate the need for de-embedding the DUT measurement results from parasitic impedances of the device contact pads. The multi-line TRL is the only method that delivers trustable calibration results at measurement frequencies above 220 GHz.

The TRL algorithm always treats the thru standards as a zero-length line. The length of each next line standards Δl is, therefore, defined with the respect to the length of the thru. When operating the MPI MP80-DX, the operator simply needs to zero-out the digital micrometer after the initial adjustment of the RF probes, i.e., on the thru standard. Next, the distance between RF probes can be easily re-adjusted to the required value of Δl with the precision better than 1 µm. As a result, MPI MP80-DX has boosted the accuracy and repeatability of the multi-line TRL system calibration even for inexperienced operators while reducing set up times.



The TRL definition of the Δl for line standards

The MP80-DX MicroPositioner with the digital micrometer on the X-axis.

Standard type, (ID)	Physical length, µm	Effective length l, µm	Δl, µm
Thru	182	150	0
Line 1 (0104)	392	360	210
Line 2 (0204)	642	610	460
Line 3 (0304)	1207	1175	1025
Line 4 (0205)	2457	2425	2275
Line 5 (0105)	5232	5200	5050

Recommended frequency band specifications for transmission lines with approximately 30…150 degree phase delay vs. the Thru standard. Use the values below for VNA-embedded CalKit definition standards for TRL calibrations. You may also use MPI's QAlibria® software to check for alternative or in-between frequency band configurations in addition to the minimum and maximum bands provided below.

	fmin, GHz	fmax, GHz
Thru	0	325
Line 1 (0104)	60	240
Line 2 (0204)	30	110
Line 3 (0304)	15	50
Line 4 (0205)	5	20
Line 5 (0105)	2.5	10

PROBE PLANARIZATION

MPI TITAN™ RF probes deliver excellent and real time visibility of the tip contacts, due to the unique protrusion tip design. Accurate positioning of the RF probe on calibration standards or DUT pads is now even possible for inexperienced operators.

TITAN™ probes are very robust; however, excessive over travel can damage them. Use care when lowering probe. To planarize the probe, we recommend using the bare gold area of the calibration substrate or the dedicated contact substrate PN TCS-1 (Figure 1).

While monitoring the probe tips under a high resolution microscope, adjust the Z height to bring the probe tips into contact with the surface. The probe is in contact with surface when the probe tips begin to skate forward. After contacting the surface, raise the probe and check the probe marks. If the probe tips are parallel to the pad surface, you should see a uniform probe mark for each tip (Figure 2). If the probe tips are not parallel to surface (Figure 3), rotate planarity knob on positioner and recheck probe marks (Figure 4). This may take several att-empts.

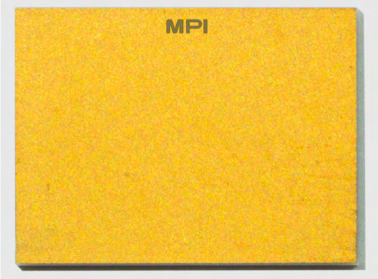


Figure 1. TITAN™ Probe contact substrate TCS-1.

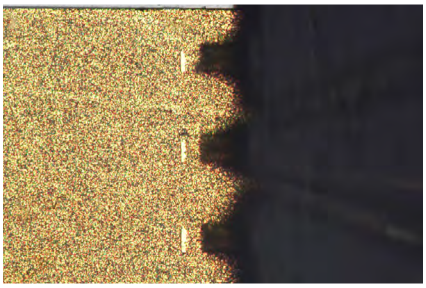


Figure 2. Image of probe marks of Planarized probe.

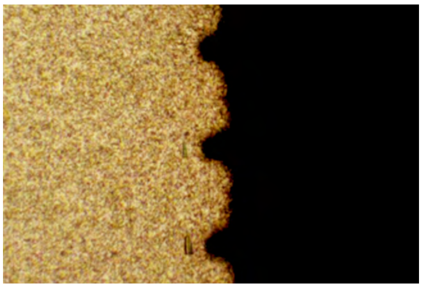


Figure 3. Image of probe that is not parallel to surface.

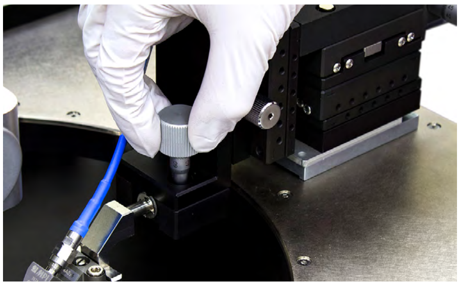
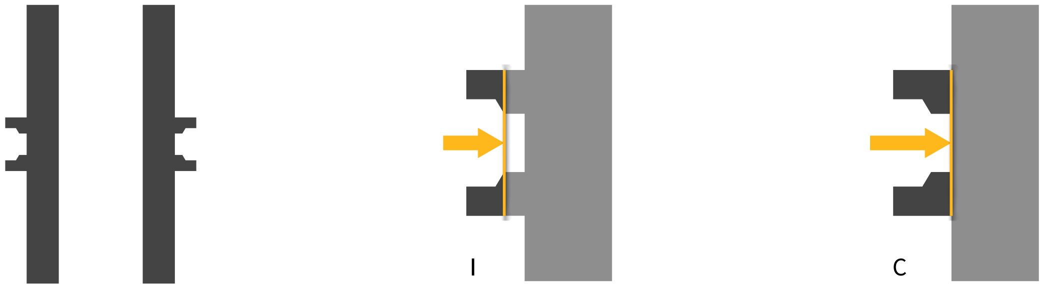


Figure 4. Planarization of TITAN™ Probes.

GUIDELINES FOR ALIGNMENT MARKS

The TITAN™ probe alignment elements help an operator accurately adjust the probe-to-probe spacing as well as set the recommended probe overtravel on a manual probe system. Probe spacing defines the equivalent length of the Thru standard that is essential for precise definition of the measurement plane of a calibrated system.

The recommended probe overtravel guarantees consistent probe contact, repeatable measurement data of calibration standards and thus reliable system calibration results. At the same time, it minimizes unnecessary damage of the standard usually caused by excessive probe overtravel. Thus, the use of proper probe alignment not only increases calibration repeatability and reproducibility, but it substantially increases the lifetime of the calibration standards which reduces the cost of test.



Alignment marks | Initial probe contact position reference "I" | Final probe contact position "C" reference with overtravel applied

PROBE ALIGNMENT PROCEDURE

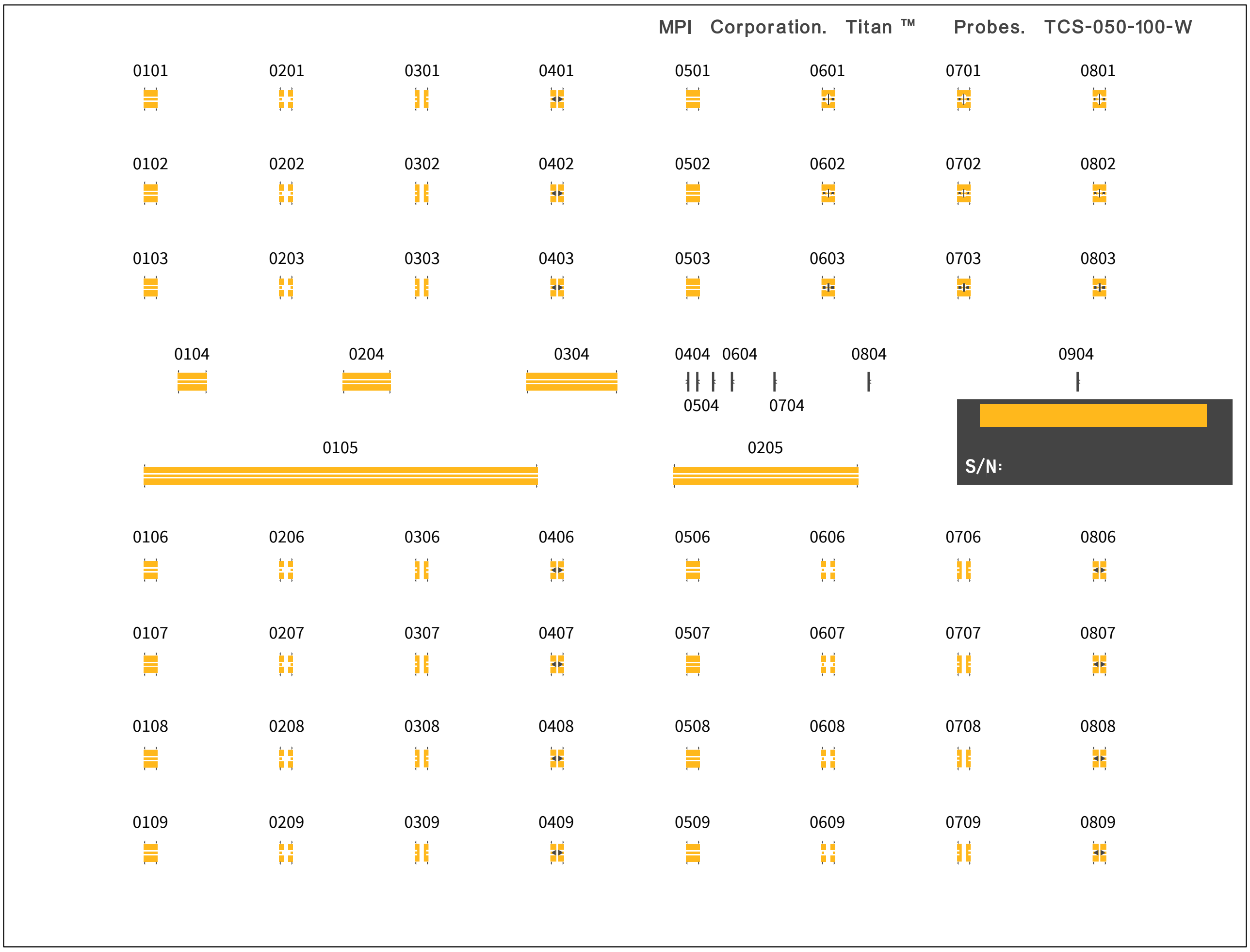
Step.1 Move the edge of the probe tips to reference plane X, as shown on the Figure 5 (left) and Figure 6 (left).
Step.2 Adjust probe height using the Z-knob of the RF positioner bringing the probe into contact with ceramic surface until the probe tips begin to skate forward.
Step.3 Apply overtravel by further adjustment of probe height using the Z-knob of the probe on the positioner until the edges of the probe tips reached the reference plane Y, as shown on the Figure 5 (right) and Figure 6 (right).

The resulting probe position corresponds to the 150 µm (or 1.1 ps) effective length of the Thru standard.

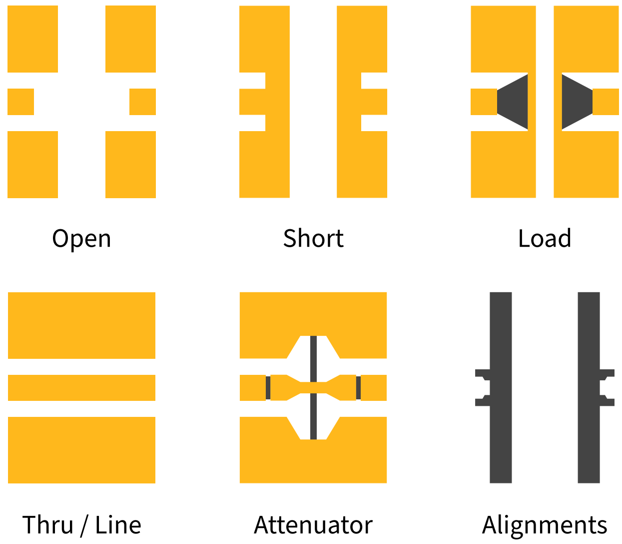
Figure 5. Image shows correct alignment and placement of TITAN™ Probe with standard 30 µm probe tip width.

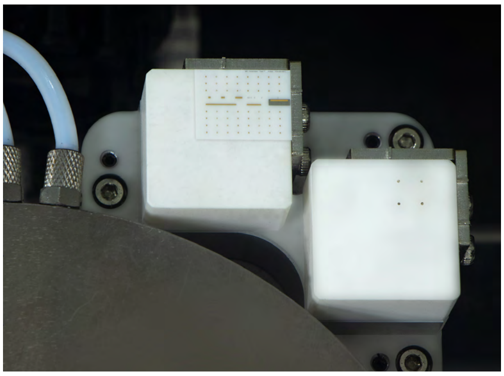
Figure 6. Image shows correct alignment and placement of TITAN™ RC Probe with optional Reduced Contact 20 µm probe tip width.

SUBSTRATE LAYOUT



STANDARD ELEMENTS





TCS-050-100-W calibration substrate on the ceramic AUX chuck of TS200 manual system.

THRU STANDARDS

ID	Type	X µm	Y µm	Location Reference	Spacing µm	Length µm
0101	THRU	-7200	3750	0404	150	182
0102	THRU	-7200	2500	0404	150	182
0103	THRU	-7200	1250	0404	150	182
0106	THRU	-7200	-2500	0404	150	182
0107	THRU	-7200	-3750	0404	150	182
0108	THRU	-7200	-5000	0404	150	182
0109	THRU	-7200	-6250	0404	150	182
0501	THRU	0	3750	0404	150	182
0502	THRU	0	2500	0404	150	182
0503	THRU	0	1250	0404	150	182
0506	THRU	0	-2500	0404	150	182
0507	THRU	0	-3750	0404	150	182
0508	THRU	0	-5000	0404	150	182
0509	THRU	0	-6250	0404	150	182

LINE STANDARDS

ID	Type	X µm	Y µm	Location Reference	Spacing µm	Length µm	Δl	Note
0104	LINE 1	-6750	0	0404	360	392	210	mTRL
0204	LINE 2	-4558	0	0404	610	642	460	mTRL
0304	LINE 3	-2116	0	0404	1175	1207	1025	mTRL
0205	LINE 4	-168	-1250	0404	2425	2457	2275	mTRL
0105	LINE 5	-7200	-1250	0404	5200	5232	5050	mTRL

LOAD STANDARDS

ID	Type	X µm	Y µm	Location Reference	Spacing µm
0401	LOAD	-1800	3750	0404	150
0402	LOAD	-1800	2500	0404	150
0403	LOAD	-1800	1250	0404	150
0406	LOAD	-1800	-2500	0404	150
0407	LOAD	-1800	-3750	0404	150
0408	LOAD	-1800	-5000	0404	150
0409	LOAD	-1800	-6250	0404	150
0806	LOAD	5400	-2500	0404	150
0807	LOAD	5400	-3750	0404	150
0808	LOAD	5400	-5000	0404	150
0809	LOAD	5400	-6250	0404	150

ATTENUATOR STANDARDS

ID	Type	Attenuation	X µm	Y µm	Location Ref.	Spacing µm
0601	ATTENUATOR	3 dB	1800	3750	0404	150
0602	ATTENUATOR	6 dB	1800	2500	0404	150
0603	ATTENUATOR	10 dB	1800	1250	0404	150
0701	ATTENUATOR	3 dB	3600	3750	0404	150
0702	ATTENUATOR	6 dB	3600	2500	0404	150
0703	ATTENUATOR	10 dB	3600	1250	0404	150
0801	ATTENUATOR	3 dB	5400	3750	0404	150
0802	ATTENUATOR	6 dB	5400	2500	0404	150
0803	ATTENUATOR	10 dB	5400	1250	0404	150

SHORT STANDARDS

ID	Type	X µm	Y µm	Location Reference	Spacing µm
0301	SHORT	-3600	3750	0404	150
0302	SHORT	-3600	2500	0404	150
0303	SHORT	-3600	1250	0404	150
0306	SHORT	-3600	-2500	0404	150
0307	SHORT	-3600	-3750	0404	150
0308	SHORT	-3600	-5000	0404	150
0309	SHORT	-3600	-6250	0404	150
0706	SHORT	3600	-2500	0404	150
0707	SHORT	3600	-3750	0404	150
0708	SHORT	3600	-5000	0404	150
0709	SHORT	3600	-6250	0404	150

OPEN STANDARDS

ID	Type	X µm	Y µm	Location Reference	Spacing µm
0201	OPEN	-5400	3750	0404	150
0202	OPEN	-5400	2500	0404	150
0203	OPEN	-5400	1250	0404	150
0206	OPEN	-5400	-2500	0404	150
0207	OPEN	-5400	-3750	0404	150
0208	OPEN	-5400	-5000	0404	150
0209	OPEN	-5400	-6250	0404	150
0606	OPEN	1800	-2500	0404	150
0607	OPEN	1800	-3750	0404	150
0608	OPEN	1800	-5000	0404	150
0609	OPEN	1800	-6250	0404	150

ELECTRICAL MODELS OF CALIBRATION STANDARDS

Probe model	Pitch	C-Open, fF	L-Short, pH	L-Load, pH
T220A	50	4.8	12.0	5.2
	75	5.0	12.0	6.0
	90	5.3	12.0	7.1
	100	5.5	12.0	8.0
TITAN™	50	3.7	8.8	6.0
	75	4.3	11.5	6.1
	90	4.4	13.0	6.5
	100	4.4	14.0	7.0
TITAN™ RC Reduced Contact	50	3.7	9.0	6.0
	75	4.3	14.0	7.0
	90	4.5	14.1	7.6
	100	4.5	13.0	8.0

Some VNA models do not support the serial R-L model of the Load standard impedance shown in the chart above. Alternatively, the reactance component of the Load impedance can be modeled over a line with a given delay (Offset Delay) and the characteristic impedance (Offset Impedance, Zoff) different to the system reference impedance Zo of 50 Ohm. See below.

Probe model	Pitch	R-Load, Ohm	Offset Impedance, Zoff, Ohm	Offset Delay, pS
T220A	50	50	500	0.01051
	75	50	500	0.01212
	90	50	500	0.01425
	100	50	500	0.01616
TITAN™	50	50	500	0.01212
	75	50	500	0.01232
	90	50	500	0.01322
	100	50	500	0.01414
TITAN™ RC Reduced Contact	50	50	500	0.01212
	75	50	500	0.01414
	90	50	500	0.01535
	100	50	500	0.01616

REFERENCES

[1] M. Spirito, U. Arz, G. N. Phung, F. J. Schmückle, W. Heinrich, and R. Lozar, "Guidelines for the design of calibration substrates, including the suppression of parasitic modes for frequencies up to and including 325 GHz," in "EMPIR 14IND02 – PlanarCal," Physikalisch-Technische Bundesanstalt (PTB), 2018.

[2] A. Rumiantsev, R. Doerner, and G. N. Phung, "Calibration Substrate Design for Accurate mm-Wave Probe-Tip Calibration," in 2020 94th ARFTG Microwave Measurement Symposium (ARFTG), 26-29 Jan. 2020, pp. 1-4.

[3] U. Arz, G.-N. Phung, and A. Rumiantsev, "Traceable Lumped-Element Calibrations up to 110 GHz on Commercial Calibration Substrates", ARFTG-100th, Jan. 2023, pp. 1-4.

[4] R. B. Marks and D. F. Williams, "Characteristic impedance determination using propagation constant measurement," IEEE Microwave and Guided Wave Letters, vol. 1, pp. 141-143, June 1991.

[5] D. F. Williams and R. B. Marks, "Transmission line capacitance measurement," Microwave and Guided Wave Letters, IEEE, vol. 1, pp. 243-245, 1991.

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