
DC-50 GHz Variable Attenuator: S-parameters

Application Note #44 — Rev. A

HMMC-1002

I. Introduction

The HMMC-1002 is a voltage variable attenuator that operates from DC to 50 GHz. This application note consists of tables of s-parameter data at the following attenuation levels:

Minimum

7 dB

12 dB

17 dB

22 dB

27 dB

Maximum

The s-parameters cover the frequency range of 1.5 - 26.5 GHz and were obtained from on-wafer measurements.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]
Minimum Attenuation Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-32.4	0.024	-79.91	-0.9	0.900	-12.55	-0.9	0.900	-12.99	-32.2	0.024	-79.41
2.0	-28.3	0.038	-80.77	-0.9	0.906	-16.98	-0.9	0.906	-17.43	-28.7	0.037	-80.83
2.5	-27.7	0.041	-91.93	-0.9	0.902	-20.94	-0.9	0.902	-21.32	-27.9	0.040	-90.45
3.0	-26.7	0.046	-106.79	-1.0	0.894	-25.08	-1.0	0.894	-25.45	-26.8	0.046	-107.55
3.5	-25.1	0.056	-105.68	-0.9	0.900	-29.30	-0.9	0.900	-29.65	-25.4	0.054	-106.02
4.0	-23.8	0.064	-114.10	-1.0	0.896	-33.59	-1.0	0.896	-33.91	-24.2	0.062	-114.64
4.5	-23.4	0.067	-122.48	-1.0	0.890	-37.53	-1.0	0.890	-37.86	-23.6	0.066	-123.20
5.0	-22.7	0.073	-125.90	-1.0	0.891	-41.60	-1.0	0.891	-41.93	-23.0	0.071	-128.27
5.5	-22.0	0.080	-133.64	-1.0	0.886	-45.72	-1.0	0.886	-46.05	-22.3	0.077	-135.06
6.0	-21.8	0.081	-138.35	-1.1	0.885	-49.62	-1.1	0.885	-49.92	-21.9	0.080	-139.75
6.5	-21.4	0.085	-141.58	-1.1	0.885	-53.57	-1.1	0.885	-53.87	-21.6	0.083	-145.06
7.0	-20.9	0.090	-146.84	-1.1	0.884	-57.71	-1.1	0.884	-57.99	-21.0	0.089	-148.97
7.5	-20.8	0.091	-150.80	-1.1	0.884	-61.65	-1.1	0.884	-61.88	-20.9	0.090	-153.07
8.0	-20.5	0.095	-156.01	-1.1	0.881	-65.73	-1.1	0.881	-65.94	-20.6	0.093	-158.61
8.5	-20.2	0.098	-159.27	-1.1	0.882	-69.88	-1.1	0.882	-70.09	-20.3	0.097	-162.51
9.0	-20.2	0.098	-162.75	-1.1	0.881	-73.72	-1.1	0.881	-73.91	-20.3	0.096	-166.86
9.5	-19.9	0.101	-166.92	-1.1	0.881	-77.71	-1.1	0.881	-77.88	-20.2	0.098	-171.38
10.0	-19.6	0.105	-169.81	-1.1	0.882	-81.91	-1.1	0.882	-82.08	-19.8	0.102	-174.32
10.5	-19.2	0.109	-173.53	-1.1	0.885	-86.16	-1.1	0.885	-86.32	-19.5	0.105	-176.50
11.0	-19.1	0.111	-178.96	-1.1	0.883	-90.49	-1.1	0.883	-90.60	-19.4	0.108	177.58
11.5	-19.2	0.110	176.41	-1.1	0.882	-94.58	-1.1	0.882	-94.71	-19.3	0.108	172.65
12.0	-19.2	0.110	170.54	-1.1	0.879	-98.78	-1.1	0.878	-98.90	-19.2	0.109	166.06
12.5	-19.1	0.111	166.06	-1.1	0.876	-102.86	-1.1	0.876	-102.95	-19.1	0.111	160.48
13.0	-19.1	0.111	160.92	-1.2	0.875	-106.96	-1.2	0.874	-107.02	-19.0	0.112	155.03
13.5	-19.3	0.108	154.24	-1.2	0.872	-110.98	-1.2	0.872	-111.02	-19.2	0.109	149.54
14.0	-19.8	0.102	150.79	-1.2	0.872	-115.01	-1.2	0.871	-115.00	-19.4	0.107	145.92
14.5	-20.1	0.098	146.10	-1.2	0.873	-119.08	-1.2	0.872	-119.07	-19.7	0.104	141.11
15.0	-20.5	0.094	141.23	-1.2	0.873	-123.24	-1.2	0.872	-123.20	-20.6	0.093	134.72
15.5	-21.3	0.086	135.73	-1.2	0.873	-127.37	-1.2	0.872	-127.35	-21.1	0.088	130.51
16.0	-21.6	0.083	133.46	-1.2	0.872	-131.50	-1.2	0.872	-131.49	-21.3	0.086	124.23
16.5	-21.9	0.080	127.49	-1.2	0.872	-135.73	-1.2	0.872	-135.66	-22.2	0.077	117.24
17.0	-22.7	0.074	121.62	-1.2	0.873	-139.84	-1.2	0.872	-139.81	-22.8	0.073	117.36
17.5	-23.3	0.068	117.18	-1.2	0.872	-144.15	-1.2	0.872	-144.06	-22.9	0.072	112.91
18.0	-24.5	0.060	109.20	-1.2	0.872	-148.36	-1.2	0.872	-148.25	-24.5	0.059	103.88
18.5	-26.3	0.049	103.38	-1.2	0.872	-152.72	-1.2	0.872	-152.54	-26.2	0.049	103.19
19.0	-28.1	0.039	99.64	-1.2	0.871	-156.91	-1.2	0.870	-156.72	-26.9	0.045	95.31
19.5	-30.1	0.031	89.69	-1.2	0.872	-161.25	-1.2	0.872	-161.00	-28.9	0.036	75.49
20.0	-33.1	0.022	82.15	-1.2	0.872	-165.59	-1.2	0.872	-165.39	-31.3	0.027	71.08
20.5	-35.2	0.017	75.55	-1.2	0.870	-169.97	-1.2	0.870	-169.75	-31.5	0.027	66.08
21.0	-37.6	0.013	47.99	-1.2	0.868	-174.37	-1.2	0.867	-174.11	-34.7	0.018	40.82
21.5	-37.0	0.014	-21.01	-1.3	0.865	-178.66	-1.3	0.864	-178.40	-38.7	0.012	-16.47
22.0	-33.4	0.022	-67.73	-1.3	0.862	177.02	-1.3	0.861	177.30	-36.2	0.016	-73.89
22.5	-30.5	0.030	-84.67	-1.3	0.860	172.72	-1.3	0.860	173.03	-30.4	0.030	-85.37
23.0	-27.7	0.041	-93.23	-1.3	0.857	168.30	-1.3	0.857	168.64	-27.1	0.044	-92.81
23.5	-26.2	0.049	-102.67	-1.4	0.855	164.01	-1.4	0.854	164.38	-25.7	0.052	-98.65
24.0	-25.0	0.056	-105.38	-1.4	0.853	159.72	-1.4	0.854	160.03	-24.6	0.059	-103.15
24.5	-23.3	0.068	-110.85	-1.4	0.852	155.34	-1.4	0.851	155.75	-23.6	0.066	-111.08
25.0	-22.2	0.078	-118.27	-1.4	0.850	150.93	-1.4	0.849	151.37	-22.7	0.074	-120.04
25.5	-21.0	0.089	-119.77	-1.5	0.846	146.55	-1.5	0.845	146.97	-21.1	0.089	-125.82
26.0	-19.4	0.107	-124.67	-1.5	0.843	142.22	-1.5	0.842	142.69	-19.7	0.104	-128.84
26.5	-18.5	0.118	-133.37	-1.5	0.840	137.79	-1.5	0.838	138.34	-18.6	0.117	-135.28

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$

S-Parameters ($T_A = 25^\circ\text{C}$)[†]

7 dB Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-31.7	0.026	-133.48	-7.0	0.445	-12.45	-7.1	0.442	-12.87	-34.2	0.020	-62.83
2.0	-29.4	0.034	-124.60	-7.0	0.448	-16.94	-7.0	0.446	-17.33	-31.2	0.027	-70.54
2.5	-28.0	0.040	-126.77	-7.0	0.446	-20.85	-7.0	0.445	-21.19	-30.9	0.028	-83.54
3.0	-26.5	0.047	-133.28	-7.1	0.440	-24.92	-7.1	0.441	-25.27	-30.4	0.030	-102.95
3.5	-25.3	0.054	-132.40	-7.1	0.444	-29.13	-7.0	0.444	-29.47	-28.9	0.036	-102.02
4.0	-24.0	0.063	-136.46	-7.1	0.444	-33.45	-7.1	0.443	-33.71	-27.5	0.042	-108.92
4.5	-23.3	0.068	-142.66	-7.1	0.442	-37.33	-7.1	0.440	-37.60	-27.0	0.045	-117.20
5.0	-22.6	0.074	-145.50	-7.1	0.443	-41.38	-7.1	0.441	-41.66	-26.3	0.048	-124.45
5.5	-21.8	0.081	-151.09	-7.1	0.440	-45.42	-7.1	0.439	-45.71	-25.8	0.051	-133.32
6.0	-21.4	0.085	-155.51	-7.1	0.440	-49.26	-7.1	0.440	-49.51	-25.3	0.054	-139.91
6.5	-21.0	0.090	-159.52	-7.1	0.440	-53.22	-7.1	0.440	-53.50	-24.9	0.057	-145.93
7.0	-20.5	0.094	-164.29	-7.1	0.442	-57.30	-7.1	0.441	-57.52	-24.5	0.059	-149.84
7.5	-20.3	0.097	-168.87	-7.1	0.443	-61.19	-7.1	0.442	-61.36	-24.3	0.061	-155.13
8.0	-19.9	0.101	-173.67	-7.1	0.443	-65.26	-7.1	0.442	-65.43	-24.1	0.063	-161.85
8.5	-19.7	0.104	-177.88	-7.1	0.443	-69.32	-7.1	0.443	-69.51	-23.8	0.064	-167.87
9.0	-19.5	0.106	177.51	-7.1	0.444	-73.16	-7.1	0.444	-73.35	-23.7	0.065	-173.83
9.5	-19.3	0.108	173.02	-7.0	0.445	-77.19	-7.0	0.445	-77.30	-23.6	0.066	179.78
10.0	-19.1	0.111	169.14	-7.0	0.448	-81.35	-7.0	0.448	-81.47	-23.5	0.067	175.92
10.5	-18.9	0.114	164.39	-6.9	0.452	-85.58	-6.9	0.451	-85.68	-23.4	0.067	171.85
11.0	-18.8	0.115	159.09	-6.9	0.453	-89.87	-6.9	0.452	-89.96	-23.4	0.068	165.31
11.5	-18.7	0.116	153.20	-6.9	0.454	-94.05	-6.9	0.453	-94.13	-23.4	0.067	157.56
12.0	-18.7	0.116	147.52	-6.8	0.455	-98.29	-6.8	0.455	-98.38	-23.4	0.067	149.38
12.5	-18.7	0.116	142.06	-6.8	0.457	-102.52	-6.8	0.456	-102.59	-23.3	0.068	143.29
13.0	-18.8	0.115	136.75	-6.8	0.459	-106.82	-6.8	0.458	-106.81	-23.0	0.071	136.07
13.5	-18.8	0.115	130.29	-6.7	0.461	-111.04	-6.7	0.460	-111.07	-23.3	0.068	129.08
14.0	-19.1	0.111	124.35	-6.7	0.464	-115.38	-6.7	0.462	-115.30	-23.6	0.066	124.16
14.5	-19.4	0.108	118.25	-6.6	0.466	-119.70	-6.6	0.465	-119.65	-23.8	0.064	114.91
15.0	-19.5	0.105	110.93	-6.6	0.469	-124.19	-6.6	0.468	-124.13	-24.8	0.058	102.14
15.5	-20.0	0.100	103.55	-6.5	0.472	-128.74	-6.5	0.472	-128.67	-25.5	0.053	93.19
16.0	-20.3	0.096	97.82	-6.5	0.474	-133.33	-6.5	0.474	-133.22	-25.1	0.056	81.73
16.5	-20.5	0.095	90.04	-6.4	0.477	-138.01	-6.4	0.476	-137.88	-25.5	0.053	66.45
17.0	-21.0	0.089	81.14	-6.4	0.480	-142.68	-6.4	0.478	-142.56	-26.7	0.046	60.41
17.5	-21.5	0.084	73.80	-6.3	0.482	-147.51	-6.4	0.481	-147.35	-26.6	0.047	51.29
18.0	-21.9	0.080	63.47	-6.3	0.484	-152.27	-6.3	0.483	-152.17	-26.6	0.047	29.19
18.5	-22.6	0.074	51.21	-6.3	0.485	-157.27	-6.3	0.484	-157.05	-27.2	0.044	9.98
19.0	-23.4	0.068	40.08	-6.3	0.485	-162.14	-6.3	0.485	-161.92	-26.3	0.048	0.34
19.5	-23.5	0.067	26.90	-6.3	0.486	-167.11	-6.3	0.485	-166.87	-24.4	0.060	-14.48
20.0	-23.8	0.064	12.23	-6.3	0.485	-172.15	-6.3	0.485	-171.81	-24.2	0.061	-27.73
20.5	-24.4	0.060	-0.21	-6.3	0.485	-177.14	-6.3	0.484	-176.93	-24.1	0.063	-35.42
21.0	-24.3	0.061	-13.13	-6.3	0.484	177.71	-6.3	0.483	178.04	-23.0	0.071	-46.75
21.5	-23.7	0.065	-29.11	-6.3	0.483	172.49	-6.3	0.481	172.98	-21.9	0.080	-62.94
22.0	-23.5	0.067	-45.90	-6.4	0.481	167.49	-6.4	0.479	167.95	-21.2	0.087	-73.73
22.5	-23.1	0.070	-58.05	-6.4	0.478	162.50	-6.4	0.477	162.90	-20.0	0.100	-81.17
23.0	-22.2	0.078	-69.50	-6.5	0.475	157.38	-6.5	0.473	157.77	-19.0	0.112	-88.97
23.5	-21.8	0.081	-81.43	-6.5	0.472	152.44	-6.6	0.470	152.84	-18.6	0.117	-94.78
24.0	-21.4	0.085	-88.79	-6.6	0.468	147.42	-6.6	0.467	147.86	-18.4	0.121	-99.91
24.5	-20.5	0.094	-97.89	-6.7	0.464	142.38	-6.7	0.463	142.82	-18.1	0.124	-107.23
25.0	-20.0	0.100	-107.42	-6.7	0.460	137.44	-6.8	0.459	137.84	-17.7	0.131	-114.95
25.5	-19.3	0.108	-113.04	-6.8	0.456	132.31	-6.8	0.455	132.85	-17.0	0.141	-121.42
26.0	-18.3	0.122	-120.78	-6.9	0.451	127.52	-6.9	0.451	127.93	-16.2	0.154	-126.40
26.5	-17.9	0.127	-130.62	-7.0	0.448	122.42	-7.0	0.447	123.25	-15.8	0.162	-133.60

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]

12 dB Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-33.6	0.021	-53.93	-12.1	0.249	-10.07	-12.1	0.249	-10.51	-25.8	0.051	-22.77
2.0	-31.6	0.026	-64.99	-12.0	0.251	-13.80	-12.0	0.251	-14.24	-25.3	0.055	-30.51
2.5	-30.8	0.029	-72.88	-12.0	0.251	-16.91	-12.0	0.251	-17.25	-25.6	0.053	-37.04
3.0	-29.8	0.032	-83.92	-12.0	0.250	-20.39	-12.0	0.250	-20.71	-26.1	0.050	-45.87
3.5	-28.5	0.038	-89.43	-11.9	0.253	-23.84	-11.9	0.253	-24.14	-25.4	0.054	-51.16
4.0	-27.5	0.042	-97.44	-11.9	0.254	-27.43	-11.9	0.253	-27.76	-24.9	0.057	-58.78
4.5	-26.9	0.045	-105.04	-11.9	0.254	-30.68	-11.9	0.254	-31.02	-24.9	0.057	-65.78
5.0	-26.2	0.049	-111.06	-11.8	0.256	-34.09	-11.9	0.256	-34.39	-24.9	0.057	-72.37
5.5	-25.5	0.053	-118.16	-11.8	0.257	-37.64	-11.8	0.256	-37.89	-25.0	0.056	-80.12
6.0	-25.2	0.055	-123.23	-11.8	0.258	-40.89	-11.8	0.258	-41.14	-25.1	0.056	-87.51
6.5	-24.7	0.058	-128.32	-11.7	0.261	-44.31	-11.7	0.261	-44.59	-25.0	0.056	-93.98
7.0	-24.3	0.061	-133.95	-11.6	0.264	-47.88	-11.6	0.263	-48.16	-24.7	0.058	-98.33
7.5	-24.1	0.063	-138.86	-11.5	0.266	-51.32	-11.5	0.266	-51.54	-24.7	0.058	-103.93
8.0	-23.7	0.065	-144.00	-11.4	0.268	-54.97	-11.4	0.268	-55.21	-24.7	0.058	-110.28
8.5	-23.5	0.067	-148.78	-11.3	0.272	-58.72	-11.3	0.272	-58.92	-24.9	0.057	-115.72
9.0	-23.3	0.068	-153.11	-11.2	0.274	-62.34	-11.2	0.275	-62.50	-25.1	0.056	-122.37
9.5	-23.1	0.070	-158.11	-11.1	0.278	-66.09	-11.1	0.278	-66.20	-25.2	0.055	-128.38
10.0	-22.9	0.071	-162.19	-11.0	0.282	-69.91	-11.0	0.282	-70.09	-25.2	0.055	-132.67
10.5	-22.7	0.073	-167.22	-10.9	0.286	-73.89	-10.9	0.286	-74.04	-25.2	0.055	-136.05
11.0	-22.7	0.073	-172.08	-10.7	0.290	-78.07	-10.7	0.290	-78.21	-25.5	0.053	-140.96
11.5	-22.7	0.073	-178.23	-10.7	0.293	-82.20	-10.7	0.293	-82.28	-25.9	0.051	-147.32
12.0	-22.9	0.072	176.38	-10.5	0.297	-86.40	-10.5	0.297	-86.49	-26.5	0.047	-154.19
12.5	-23.0	0.070	171.00	-10.4	0.300	-90.68	-10.4	0.300	-90.71	-26.6	0.047	-161.11
13.0	-23.2	0.069	166.58	-10.3	0.304	-94.96	-10.3	0.304	-94.99	-26.8	0.046	-170.40
13.5	-23.4	0.068	160.64	-10.3	0.307	-99.31	-10.3	0.307	-99.30	-27.6	0.042	-174.67
14.0	-23.9	0.064	155.79	-10.2	0.310	-103.66	-10.2	0.310	-103.64	-27.9	0.040	-176.74
14.5	-24.4	0.060	151.23	-10.0	0.315	-108.10	-10.1	0.314	-108.10	-29.2	0.035	177.17
15.0	-25.0	0.056	144.29	-9.9	0.318	-112.71	-10.0	0.318	-112.72	-32.1	0.025	178.33
15.5	-26.1	0.050	138.76	-9.8	0.322	-117.43	-9.9	0.322	-117.38	-33.7	0.021	-178.19
16.0	-26.7	0.046	135.21	-9.8	0.324	-122.12	-9.8	0.324	-122.08	-36.8	0.014	166.10
16.5	-27.4	0.043	126.61	-9.7	0.327	-127.03	-9.7	0.327	-126.87	-46.0	0.005	-161.69
17.0	-29.0	0.036	119.83	-9.6	0.330	-131.82	-9.6	0.329	-131.77	-39.6	0.010	-132.92
17.5	-30.6	0.030	117.13	-9.6	0.332	-136.82	-9.6	0.331	-136.72	-41.1	0.009	-125.88
18.0	-32.7	0.023	107.40	-9.5	0.333	-141.68	-9.6	0.333	-141.63	-35.2	0.017	-82.10
18.5	-37.6	0.013	93.67	-9.5	0.334	-146.84	-9.5	0.334	-146.66	-31.2	0.028	-86.33
19.0	-44.9	0.006	74.04	-9.5	0.334	-151.84	-9.5	0.335	-151.58	-30.1	0.031	-82.48
19.5	-43.9	0.006	-15.07	-9.5	0.336	-156.87	-9.5	0.335	-156.58	-27.5	0.042	-74.44
20.0	-37.2	0.014	-60.95	-9.5	0.335	-161.91	-9.5	0.334	-161.61	-26.1	0.049	-83.47
20.5	-34.2	0.020	-81.46	-9.5	0.334	-167.06	-9.5	0.334	-166.83	-25.9	0.050	-87.49
21.0	-31.7	0.026	-88.61	-9.5	0.334	-172.15	-9.6	0.333	-171.90	-24.3	0.061	-91.17
21.5	-28.8	0.036	-92.93	-9.6	0.332	-177.23	-9.6	0.332	-176.87	-22.4	0.076	-100.05
22.0	-26.8	0.046	-103.07	-9.6	0.330	177.77	-9.6	0.330	178.02	-21.5	0.084	-106.22
22.5	-25.7	0.052	-108.68	-9.7	0.328	172.66	-9.7	0.329	173.17	-20.4	0.096	-108.46
23.0	-24.4	0.060	-112.93	-9.7	0.326	167.59	-9.8	0.325	168.05	-19.6	0.105	-112.20
23.5	-23.4	0.068	-119.81	-9.8	0.324	162.56	-9.8	0.323	163.07	-19.1	0.110	-116.22
24.0	-22.9	0.071	-123.47	-9.9	0.321	157.82	-9.9	0.321	158.21	-19.2	0.110	-119.75
24.5	-21.9	0.080	-127.14	-9.9	0.319	152.93	-9.9	0.318	153.23	-18.7	0.116	-126.15
25.0	-21.3	0.086	-133.52	-10.0	0.316	147.87	-10.0	0.315	148.25	-18.3	0.121	-131.70
25.5	-20.6	0.093	-136.20	-10.1	0.313	143.14	-10.1	0.314	143.41	-17.8	0.129	-135.59
26.0	-19.5	0.106	-139.82	-10.2	0.310	138.03	-10.2	0.310	138.60	-17.0	0.141	-139.73
26.5	-19.0	0.112	-147.80	-10.3	0.306	133.00	-10.2	0.307	133.97	-16.5	0.150	-143.85

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]

17 dB Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-32.4	0.024	-50.09	-17.2	0.138	-8.27	-17.2	0.138	-8.74	-26.1	0.049	-26.48
2.0	-30.8	0.029	-60.95	-17.1	0.140	-11.45	-17.1	0.140	-11.98	-25.6	0.052	-34.56
2.5	-29.9	0.032	-69.35	-17.1	0.140	-14.05	-17.0	0.140	-14.41	-25.8	0.051	-42.67
3.0	-28.9	0.036	-78.53	-17.0	0.140	-17.13	-17.0	0.140	-17.49	-26.0	0.050	-51.92
3.5	-27.7	0.041	-84.43	-16.9	0.142	-20.14	-16.9	0.142	-20.37	-25.3	0.054	-57.49
4.0	-26.7	0.046	-91.79	-16.9	0.143	-23.28	-16.9	0.143	-23.61	-24.7	0.058	-65.09
4.5	-26.0	0.050	-98.45	-16.8	0.144	-26.12	-16.8	0.144	-26.48	-24.3	0.061	-72.34
5.0	-25.3	0.054	-104.73	-16.7	0.146	-29.17	-16.7	0.146	-29.50	-24.2	0.062	-79.31
5.5	-24.6	0.059	-110.45	-16.6	0.147	-32.36	-16.6	0.147	-32.71	-24.1	0.063	-86.87
6.0	-24.1	0.062	-115.51	-16.5	0.149	-35.32	-16.5	0.149	-35.73	-23.8	0.064	-94.13
6.5	-23.6	0.066	-120.30	-16.4	0.151	-38.59	-16.4	0.151	-38.91	-23.6	0.066	-100.64
7.0	-23.1	0.070	-125.22	-16.3	0.154	-41.99	-16.3	0.154	-42.18	-23.2	0.069	-104.82
7.5	-22.8	0.072	-129.81	-16.2	0.156	-45.22	-16.1	0.156	-45.46	-23.0	0.071	-110.19
8.0	-22.4	0.076	-134.22	-16.0	0.158	-48.75	-16.0	0.158	-48.97	-22.9	0.072	-116.22
8.5	-22.1	0.078	-138.17	-15.9	0.160	-52.41	-15.9	0.161	-52.52	-22.8	0.073	-121.27
9.0	-21.9	0.081	-142.39	-15.8	0.163	-55.95	-15.8	0.163	-56.13	-22.7	0.074	-127.42
9.5	-21.6	0.084	-146.56	-15.6	0.166	-59.74	-15.6	0.166	-59.83	-22.6	0.074	-132.64
10.0	-21.3	0.086	-150.33	-15.5	0.169	-63.50	-15.5	0.169	-63.67	-22.4	0.076	-136.28
10.5	-21.1	0.088	-154.47	-15.3	0.171	-67.47	-15.3	0.172	-67.53	-22.3	0.076	-140.08
11.0	-21.0	0.089	-158.18	-15.2	0.175	-71.68	-15.2	0.174	-71.69	-22.4	0.076	-144.18
11.5	-20.9	0.090	-162.73	-15.1	0.177	-75.84	-15.0	0.177	-75.98	-22.4	0.076	-149.25
12.0	-20.9	0.090	-166.58	-15.0	0.179	-80.11	-14.9	0.179	-80.20	-22.5	0.075	-154.15
12.5	-20.9	0.090	-170.28	-14.8	0.181	-84.55	-14.8	0.181	-84.44	-22.4	0.076	-159.37
13.0	-20.8	0.091	-173.07	-14.7	0.183	-88.85	-14.7	0.183	-88.74	-22.3	0.077	-165.55
13.5	-20.8	0.091	-177.07	-14.7	0.185	-93.13	-14.7	0.185	-93.13	-22.4	0.076	-168.58
14.0	-20.9	0.090	-179.58	-14.6	0.187	-97.65	-14.6	0.187	-97.67	-22.2	0.077	-170.46
14.5	-21.0	0.090	177.58	-14.5	0.189	-102.08	-14.5	0.189	-102.02	-22.6	0.074	-174.30
15.0	-21.1	0.088	173.89	-14.4	0.190	-106.71	-14.4	0.190	-106.76	-23.5	0.067	-174.42
15.5	-21.4	0.086	171.92	-14.4	0.192	-111.41	-14.3	0.192	-111.41	-23.5	0.067	-175.32
16.0	-21.3	0.086	169.86	-14.3	0.194	-116.14	-14.3	0.193	-116.05	-23.9	0.064	178.56
16.5	-21.4	0.085	165.87	-14.2	0.194	-120.95	-14.3	0.194	-120.81	-24.7	0.058	178.31
17.0	-21.8	0.082	164.18	-14.2	0.194	-125.48	-14.2	0.194	-125.48	-23.9	0.064	179.37
17.5	-21.8	0.082	163.30	-14.2	0.195	-130.45	-14.2	0.195	-130.35	-23.8	0.064	174.95
18.0	-22.0	0.079	160.82	-14.2	0.195	-135.22	-14.2	0.195	-135.04	-24.5	0.060	177.57
18.5	-22.4	0.076	161.14	-14.2	0.195	-140.25	-14.2	0.195	-139.93	-24.2	0.062	-178.49
19.0	-22.6	0.074	160.61	-14.2	0.195	-144.93	-14.2	0.195	-144.64	-24.6	0.059	177.34
19.5	-23.0	0.071	158.54	-14.2	0.195	-149.78	-14.2	0.194	-149.53	-25.7	0.052	179.18
20.0	-23.2	0.069	159.63	-14.3	0.194	-154.60	-14.3	0.194	-154.22	-25.2	0.055	-179.54
20.5	-22.9	0.072	159.74	-14.3	0.193	-159.30	-14.3	0.193	-159.01	-24.9	0.057	174.28
21.0	-23.0	0.071	158.31	-14.4	0.192	-164.51	-14.4	0.191	-164.02	-25.1	0.056	176.83
21.5	-23.1	0.070	159.42	-14.4	0.191	-169.07	-14.4	0.190	-168.65	-24.0	0.063	-177.68
22.0	-22.6	0.074	161.06	-14.5	0.189	-173.87	-14.5	0.189	-173.56	-23.4	0.067	-177.57
22.5	-22.7	0.073	158.65	-14.5	0.188	-178.60	-14.5	0.188	-178.42	-23.5	0.067	-173.66
23.0	-22.7	0.073	159.39	-14.6	0.187	176.65	-14.6	0.185	176.76	-23.1	0.070	-172.30
23.5	-22.4	0.076	158.48	-14.7	0.184	171.40	-14.7	0.184	172.15	-23.0	0.071	-174.91
24.0	-22.4	0.076	155.14	-14.8	0.182	166.94	-14.8	0.182	167.46	-23.3	0.068	179.85
24.5	-22.4	0.076	156.00	-14.9	0.180	162.07	-14.9	0.179	162.83	-22.9	0.072	176.96
25.0	-22.0	0.079	155.01	-14.9	0.179	157.43	-15.0	0.179	158.05	-22.4	0.076	175.05
25.5	-22.4	0.076	153.82	-15.1	0.176	152.75	-15.1	0.176	153.00	-22.0	0.080	176.11
26.0	-22.0	0.079	158.21	-15.2	0.174	148.05	-15.2	0.174	148.77	-21.5	0.084	177.06
26.5	-21.4	0.085	155.00	-15.3	0.172	142.97	-15.3	0.172	144.30	-20.8	0.091	177.45

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]

22 dB Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-34.2	0.020	-90.85	-21.9	0.080	-8.60	-21.9	0.081	-9.05	-29.9	0.032	-45.15
2.0	-31.6	0.026	-94.43	-21.8	0.081	-12.11	-21.8	0.082	-12.50	-28.7	0.037	-55.32
2.5	-29.9	0.032	-98.90	-21.8	0.082	-14.63	-21.8	0.082	-15.12	-28.2	0.039	-66.51
3.0	-28.3	0.038	-103.35	-21.8	0.082	-17.98	-21.8	0.082	-18.29	-27.5	0.042	-77.07
3.5	-26.9	0.045	-106.22	-21.7	0.082	-21.01	-21.7	0.082	-21.41	-26.4	0.048	-81.88
4.0	-25.7	0.052	-110.32	-21.7	0.082	-24.21	-21.7	0.083	-24.70	-25.3	0.055	-88.04
4.5	-24.6	0.059	-114.56	-21.7	0.082	-27.26	-21.6	0.083	-27.88	-24.4	0.060	-94.56
5.0	-23.8	0.064	-118.94	-21.6	0.084	-30.39	-21.6	0.084	-30.78	-23.8	0.064	-101.07
5.5	-23.0	0.071	-122.80	-21.5	0.084	-33.90	-21.5	0.084	-34.26	-23.3	0.068	-107.27
6.0	-22.4	0.076	-126.33	-21.5	0.084	-36.91	-21.5	0.084	-37.20	-22.7	0.074	-113.36
6.5	-21.7	0.082	-129.77	-21.4	0.085	-40.23	-21.4	0.085	-40.50	-22.1	0.078	-118.64
7.0	-21.2	0.087	-133.58	-21.3	0.086	-43.68	-21.3	0.086	-43.93	-21.6	0.084	-122.04
7.5	-20.7	0.092	-137.11	-21.3	0.086	-46.82	-21.2	0.087	-47.19	-21.1	0.088	-126.26
8.0	-20.3	0.097	-140.34	-21.2	0.087	-50.56	-21.2	0.087	-50.76	-20.7	0.092	-130.95
8.5	-19.9	0.101	-143.61	-21.1	0.088	-54.04	-21.1	0.088	-54.32	-20.4	0.096	-135.22
9.0	-19.5	0.106	-146.68	-21.1	0.088	-57.56	-21.1	0.088	-57.99	-20.0	0.100	-139.80
9.5	-19.1	0.111	-150.15	-21.0	0.089	-61.29	-21.0	0.089	-61.35	-19.7	0.103	-143.95
10.0	-18.7	0.116	-153.26	-20.9	0.090	-64.93	-20.9	0.090	-65.11	-19.4	0.107	-147.09
10.5	-18.4	0.120	-156.65	-20.8	0.091	-68.82	-20.8	0.091	-68.97	-19.1	0.111	-150.53
11.0	-18.1	0.124	-159.79	-20.8	0.091	-72.66	-20.8	0.091	-72.85	-18.9	0.114	-154.03
11.5	-17.9	0.127	-163.24	-20.7	0.092	-76.85	-20.7	0.092	-76.97	-18.7	0.117	-157.98
12.0	-17.7	0.130	-166.53	-20.7	0.092	-80.99	-20.7	0.092	-81.01	-18.5	0.119	-162.01
12.5	-17.5	0.133	-169.58	-20.7	0.092	-84.74	-20.7	0.092	-85.08	-18.1	0.124	-166.07
13.0	-17.3	0.136	-172.16	-20.7	0.092	-89.06	-20.7	0.092	-88.79	-17.8	0.128	-170.87
13.5	-17.1	0.140	-175.55	-20.7	0.093	-92.99	-20.7	0.092	-93.03	-17.7	0.131	-173.68
14.0	-16.9	0.142	-178.31	-20.7	0.093	-97.16	-20.7	0.093	-97.06	-17.4	0.136	-175.87
14.5	-16.7	0.146	179.00	-20.6	0.093	-101.02	-20.7	0.092	-100.96	-17.3	0.136	-179.60
15.0	-16.6	0.148	175.56	-20.6	0.093	-105.32	-20.7	0.093	-105.31	-17.5	0.134	178.27
15.5	-16.5	0.149	172.93	-20.6	0.093	-109.36	-20.6	0.093	-109.59	-17.3	0.137	175.91
16.0	-16.3	0.154	170.22	-20.7	0.093	-113.98	-20.7	0.092	-113.70	-17.2	0.138	170.75
16.5	-16.1	0.156	166.31	-20.7	0.092	-118.04	-20.7	0.092	-117.93	-17.3	0.136	168.25
17.0	-16.1	0.156	163.75	-20.7	0.092	-122.28	-20.7	0.092	-122.26	-16.8	0.144	166.91
17.5	-15.9	0.160	161.45	-20.8	0.091	-126.91	-20.8	0.092	-126.57	-16.5	0.150	162.32
18.0	-15.9	0.161	157.96	-20.8	0.091	-131.11	-20.8	0.091	-130.94	-16.7	0.146	160.22
18.5	-15.9	0.161	155.75	-20.9	0.090	-135.14	-20.9	0.090	-135.19	-16.5	0.149	159.08
19.0	-15.8	0.162	152.85	-21.0	0.090	-139.64	-21.0	0.089	-139.43	-16.5	0.150	154.40
19.5	-15.8	0.162	149.38	-21.0	0.089	-143.72	-21.1	0.089	-143.73	-16.8	0.144	150.83
20.0	-15.8	0.162	147.03	-21.1	0.088	-148.16	-21.2	0.087	-148.03	-16.6	0.148	148.55
20.5	-15.6	0.165	144.67	-21.2	0.087	-152.46	-21.2	0.087	-152.23	-16.3	0.154	143.80
21.0	-15.5	0.167	141.31	-21.2	0.087	-157.06	-21.3	0.086	-156.71	-16.4	0.152	141.05
21.5	-15.6	0.166	138.85	-21.4	0.085	-161.15	-21.3	0.086	-160.57	-16.3	0.153	141.09
22.0	-15.4	0.169	136.95	-21.5	0.084	-165.43	-21.5	0.085	-165.18	-16.2	0.155	139.16
22.5	-15.4	0.171	133.52	-21.6	0.083	-169.61	-21.6	0.083	-169.40	-16.4	0.151	136.62
23.0	-15.5	0.169	130.57	-21.7	0.082	-174.34	-21.7	0.082	-173.93	-16.5	0.150	134.79
23.5	-15.4	0.171	127.93	-21.7	0.082	-178.65	-21.9	0.080	-178.10	-16.5	0.149	130.57
24.0	-15.3	0.171	123.85	-21.9	0.080	177.42	-22.0	0.079	178.47	-16.4	0.152	125.38
24.5	-15.4	0.169	121.52	-22.1	0.078	173.41	-22.1	0.078	173.79	-16.3	0.153	122.27
25.0	-15.3	0.171	118.60	-22.3	0.077	169.50	-22.2	0.077	169.52	-16.2	0.154	119.55
25.5	-15.5	0.167	115.22	-22.4	0.076	164.97	-22.5	0.075	165.50	-16.3	0.153	117.91
26.0	-15.7	0.164	114.56	-22.6	0.074	160.76	-22.5	0.075	162.00	-16.5	0.149	117.27
26.5	-15.5	0.168	111.85	-22.3	0.076	155.73	-22.8	0.073	156.61	-16.6	0.148	116.14

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]

27 dB Setting

Freq. (GHz)	S ₁₁			S ₂₁			S ₁₂			S ₂₂		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-29.7	0.033	-54.14	-26.6	0.047	-10.26	-26.6	0.047	-10.81	-28.4	0.038	-45.02
2.0	-28.2	0.039	-65.10	-26.6	0.047	-14.58	-26.6	0.047	-15.05	-27.2	0.044	-55.34
2.5	-26.9	0.045	-73.49	-26.6	0.047	-17.47	-26.6	0.047	-17.90	-26.4	0.048	-64.94
3.0	-25.7	0.052	-80.80	-26.7	0.046	-21.59	-26.7	0.046	-21.84	-25.5	0.053	-73.76
3.5	-24.5	0.060	-86.75	-26.7	0.046	-25.12	-26.7	0.046	-25.45	-24.5	0.060	-79.61
4.0	-23.4	0.068	-92.82	-26.8	0.046	-28.65	-26.8	0.046	-29.04	-23.4	0.067	-86.47
4.5	-22.5	0.075	-98.22	-26.9	0.045	-32.25	-26.8	0.046	-32.59	-22.6	0.074	-92.85
5.0	-21.7	0.082	-103.35	-26.9	0.045	-35.42	-26.9	0.045	-35.77	-21.9	0.080	-98.79
5.5	-20.9	0.090	-108.48	-27.0	0.045	-38.91	-27.0	0.045	-39.44	-21.2	0.087	-104.13
6.0	-20.3	0.096	-112.61	-27.1	0.044	-42.22	-27.1	0.044	-42.42	-20.6	0.094	-109.43
6.5	-19.6	0.104	-116.77	-27.2	0.044	-45.33	-27.1	0.044	-45.91	-20.0	0.100	-114.52
7.0	-19.1	0.111	-121.01	-27.2	0.044	-48.63	-27.2	0.044	-49.04	-19.4	0.107	-118.30
7.5	-18.6	0.118	-124.88	-27.3	0.043	-51.98	-27.2	0.044	-52.34	-18.9	0.114	-122.59
8.0	-18.1	0.125	-128.74	-27.3	0.043	-55.33	-27.3	0.043	-55.64	-18.4	0.120	-126.93
8.5	-17.6	0.131	-132.38	-27.3	0.043	-58.61	-27.3	0.043	-58.79	-18.0	0.126	-130.85
9.0	-17.2	0.138	-135.93	-27.5	0.042	-62.19	-27.4	0.042	-61.95	-17.5	0.133	-135.11
9.5	-16.7	0.146	-139.61	-27.5	0.042	-65.01	-27.5	0.042	-65.38	-17.1	0.139	-139.03
10.0	-16.3	0.153	-143.20	-27.6	0.042	-68.68	-27.6	0.042	-68.37	-16.7	0.146	-142.60
10.5	-16.0	0.159	-146.88	-27.6	0.042	-71.77	-27.6	0.042	-71.87	-16.4	0.152	-146.10
11.0	-15.6	0.165	-150.33	-27.6	0.042	-75.38	-27.6	0.042	-75.21	-16.1	0.157	-149.65
11.5	-15.3	0.171	-153.99	-27.7	0.041	-78.66	-27.7	0.041	-78.91	-15.7	0.163	-153.54
12.0	-15.1	0.176	-157.48	-27.8	0.041	-82.35	-27.8	0.041	-82.39	-15.5	0.168	-157.52
12.5	-14.8	0.181	-160.82	-27.9	0.040	-85.43	-27.9	0.040	-85.83	-15.1	0.176	-161.62
13.0	-14.5	0.188	-163.97	-28.0	0.040	-88.91	-28.0	0.040	-89.08	-14.8	0.183	-166.21
13.5	-14.2	0.194	-167.57	-28.1	0.039	-92.10	-28.1	0.039	-92.04	-14.5	0.188	-169.35
14.0	-14.0	0.200	-170.77	-28.1	0.039	-95.36	-28.2	0.039	-95.40	-14.2	0.196	-171.93
14.5	-13.7	0.206	-173.98	-28.2	0.039	-98.81	-28.2	0.039	-98.89	-14.0	0.200	-175.66
15.0	-13.5	0.210	-177.56	-28.4	0.038	-102.01	-28.3	0.038	-102.45	-14.0	0.200	-178.31
15.5	-13.4	0.215	179.35	-28.4	0.038	-106.00	-28.4	0.038	-106.13	-13.7	0.206	178.89
16.0	-13.1	0.222	176.01	-28.5	0.038	-109.62	-28.5	0.038	-108.91	-13.5	0.210	174.14
16.5	-12.9	0.226	171.85	-28.6	0.037	-113.05	-28.5	0.037	-113.14	-13.5	0.211	171.03
17.0	-12.8	0.229	168.93	-28.7	0.037	-117.04	-28.8	0.036	-116.73	-13.1	0.222	168.64
17.5	-12.6	0.235	165.97	-28.8	0.036	-120.46	-28.8	0.036	-119.86	-12.7	0.230	164.12
18.0	-12.5	0.238	162.30	-28.9	0.036	-123.37	-28.9	0.036	-122.88	-12.8	0.230	161.35
18.5	-12.4	0.240	159.32	-29.0	0.036	-126.93	-29.1	0.035	-127.24	-12.5	0.236	159.31
19.0	-12.2	0.244	156.23	-29.2	0.035	-130.42	-29.4	0.034	-130.48	-12.4	0.240	154.76
19.5	-12.2	0.246	152.35	-29.4	0.034	-134.67	-29.3	0.034	-134.11	-12.5	0.236	150.89
20.0	-12.1	0.248	149.38	-29.6	0.033	-136.99	-29.6	0.033	-137.04	-12.3	0.242	148.07
20.5	-11.9	0.254	146.43	-29.7	0.033	-140.40	-29.7	0.033	-140.66	-12.1	0.250	143.38
21.0	-11.8	0.257	142.75	-29.7	0.033	-143.73	-29.9	0.032	-143.44	-12.1	0.250	140.17
21.5	-11.7	0.259	139.93	-29.9	0.032	-147.71	-30.0	0.032	-147.56	-11.9	0.253	138.70
22.0	-11.6	0.264	137.10	-30.0	0.032	-151.37	-30.1	0.031	-151.05	-11.8	0.258	135.76
22.5	-11.5	0.267	133.38	-30.1	0.031	-155.38	-30.2	0.031	-155.32	-11.9	0.255	132.62
23.0	-11.5	0.267	130.08	-30.4	0.030	-159.18	-30.5	0.030	-158.50	-11.9	0.254	129.84
23.5	-11.4	0.271	126.94	-30.9	0.028	-163.11	-30.8	0.029	-162.47	-11.8	0.258	125.60
24.0	-11.3	0.273	122.73	-31.1	0.028	-163.24	-31.0	0.028	-162.98	-11.7	0.261	121.01
24.5	-11.3	0.273	119.45	-31.1	0.028	-167.40	-31.2	0.027	-167.44	-11.5	0.265	117.55
25.0	-11.2	0.276	116.26	-31.3	0.027	-170.26	-31.4	0.027	-169.27	-11.5	0.267	114.68
25.5	-11.3	0.274	112.67	-31.4	0.027	-172.12	-31.6	0.026	-172.77	-11.5	0.268	111.78
26.0	-11.4	0.270	110.68	-31.3	0.027	-175.30	-31.5	0.026	-174.71	-11.5	0.265	109.39
26.5	-11.2	0.277	107.68	-31.8	0.026	-179.15	-31.6	0.026	179.62	-11.5	0.265	107.35

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.

S-Parameters ($T_A = 25^\circ\text{C}$)[†]
Maximum Attenuation Setting

Freq. (GHz)	S_{11}			S_{21}			S_{12}			S_{22}		
	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang	dB	Mag	Ang
1.5	-35.5	0.017	-45.03	-34.2	0.019	-20.62	-34.2	0.019	-21.26	-34.5	0.019	-40.99
2.0	-33.7	0.021	-53.40	-34.4	0.019	-27.84	-34.4	0.019	-28.25	-33.0	0.022	-47.85
2.5	-32.4	0.024	-60.24	-34.9	0.018	-32.95	-34.8	0.018	-32.74	-32.0	0.025	-55.30
3.0	-30.8	0.029	-66.34	-35.4	0.017	-39.49	-35.3	0.017	-39.39	-30.7	0.029	-62.65
3.5	-29.3	0.034	-72.12	-35.8	0.016	-43.89	-35.8	0.016	-44.08	-29.4	0.034	-67.57
4.0	-28.1	0.039	-78.06	-36.4	0.015	-49.72	-36.4	0.015	-49.21	-28.2	0.039	-74.80
4.5	-27.0	0.045	-83.60	-36.9	0.014	-53.72	-36.9	0.014	-53.33	-27.2	0.044	-80.99
5.0	-26.0	0.050	-88.99	-37.5	0.013	-56.49	-37.6	0.013	-56.74	-26.4	0.048	-86.67
5.5	-25.2	0.055	-93.88	-38.1	0.012	-60.32	-38.2	0.012	-60.52	-25.6	0.053	-91.73
6.0	-24.5	0.060	-97.83	-38.7	0.012	-63.08	-38.7	0.012	-63.16	-24.7	0.058	-97.12
6.5	-23.7	0.065	-102.06	-39.4	0.011	-65.17	-39.3	0.011	-66.01	-24.0	0.063	-102.18
7.0	-23.0	0.070	-106.26	-39.8	0.010	-67.23	-39.7	0.010	-67.40	-23.3	0.068	-105.74
7.5	-22.4	0.076	-109.81	-40.4	0.010	-69.29	-40.3	0.010	-68.99	-22.7	0.073	-109.59
8.0	-21.8	0.081	-113.65	-40.8	0.009	-71.22	-40.9	0.009	-72.16	-22.1	0.078	-113.78
8.5	-21.3	0.086	-117.01	-41.3	0.009	-70.53	-41.3	0.009	-73.16	-21.6	0.083	-117.53
9.0	-20.7	0.092	-120.51	-41.6	0.008	-73.91	-41.9	0.008	-74.26	-21.0	0.089	-121.52
9.5	-20.2	0.098	-124.14	-42.2	0.008	-74.29	-42.3	0.008	-73.61	-20.5	0.094	-125.33
10.0	-19.7	0.103	-127.67	-42.4	0.008	-74.30	-42.6	0.007	-76.89	-20.1	0.099	-128.70
10.5	-19.3	0.109	-131.34	-42.6	0.007	-74.64	-42.9	0.007	-74.92	-19.6	0.105	-131.99
11.0	-18.9	0.114	-134.48	-43.1	0.007	-78.58	-43.0	0.007	-79.12	-19.2	0.110	-135.13
11.5	-18.5	0.119	-138.03	-43.3	0.007	-80.26	-43.3	0.007	-80.03	-18.8	0.115	-138.74
12.0	-18.2	0.123	-141.37	-44.0	0.006	-80.42	-44.0	0.006	-79.83	-18.4	0.120	-142.54
12.5	-17.9	0.128	-144.54	-44.0	0.006	-82.94	-44.4	0.006	-83.30	-17.9	0.127	-146.71
13.0	-17.4	0.135	-147.55	-44.6	0.006	-80.73	-44.9	0.006	-80.30	-17.5	0.133	-151.72
13.5	-17.1	0.140	-151.01	-45.0	0.006	-82.04	-45.0	0.006	-81.57	-17.2	0.138	-154.75
14.0	-16.7	0.146	-153.96	-45.2	0.006	-85.97	-45.7	0.005	-83.93	-16.7	0.146	-157.22
14.5	-16.4	0.152	-157.02	-45.4	0.005	-86.18	-45.5	0.005	-83.65	-16.5	0.150	-160.69
15.0	-16.1	0.156	-160.51	-45.5	0.005	-86.22	-45.7	0.005	-89.14	-16.4	0.152	-162.56
15.5	-15.8	0.161	-163.33	-46.2	0.005	-86.48	-45.7	0.005	-86.09	-16.0	0.159	-165.20
16.0	-15.5	0.169	-166.78	-46.0	0.005	-92.00	-46.4	0.005	-86.68	-15.8	0.163	-170.12
16.5	-15.2	0.173	-170.90	-46.6	0.005	-86.68	-46.6	0.005	-91.57	-15.7	0.165	-172.67
17.0	-15.0	0.178	-173.64	-47.1	0.004	-87.87	-47.3	0.004	-89.78	-15.0	0.178	-175.38
17.5	-14.7	0.184	-176.80	-47.5	0.004	-90.48	-48.0	0.004	-95.21	-14.6	0.186	179.92
18.0	-14.5	0.189	179.54	-48.0	0.004	-91.90	-47.7	0.004	-91.41	-14.5	0.188	177.66
18.5	-14.3	0.192	177.03	-48.4	0.004	-94.49	-48.0	0.004	-94.12	-14.1	0.196	175.61
19.0	-14.1	0.198	173.99	-49.1	0.004	-90.74	-49.1	0.004	-93.13	-14.0	0.200	170.91
19.5	-13.9	0.201	170.13	-50.2	0.003	-92.43	-49.4	0.003	-92.81	-14.1	0.198	167.58
20.0	-13.8	0.205	167.30	-50.8	0.003	-90.49	-50.5	0.003	-87.23	-13.7	0.206	164.58
20.5	-13.4	0.213	164.18	-50.8	0.003	-94.39	-49.6	0.003	-96.59	-13.4	0.214	159.59
21.0	-13.2	0.218	160.36	-50.8	0.003	-76.60	-52.0	0.002	-88.19	-13.2	0.218	156.61
21.5	-13.1	0.222	157.66	-50.2	0.003	-84.67	-50.8	0.003	-80.23	-12.9	0.226	155.12
22.0	-12.8	0.229	154.70	-51.7	0.003	-88.37	-50.2	0.003	-86.00	-12.6	0.233	152.24
22.5	-12.6	0.235	150.86	-51.1	0.003	-74.62	-52.4	0.002	-91.70	-12.6	0.234	149.17
23.0	-12.5	0.238	147.74	-52.0	0.002	-82.05	-52.8	0.002	-81.03	-12.5	0.236	146.52
23.5	-12.3	0.243	144.23	-55.4	0.002	-59.19	-55.4	0.002	-60.95	-12.3	0.242	142.37
24.0	-12.1	0.248	140.01	-52.8	0.002	-46.46	-51.4	0.003	-52.16	-12.2	0.246	137.36
24.5	-12.0	0.250	137.00	-53.2	0.002	-41.25	-49.1	0.004	-54.31	-12.0	0.253	133.76
25.0	-11.8	0.256	133.44	-50.5	0.003	-42.24	-48.2	0.004	-51.62	-11.7	0.260	130.40
25.5	-11.8	0.258	129.88	-47.1	0.004	-46.15	-47.5	0.004	-39.32	-11.6	0.263	127.67
26.0	-11.8	0.258	128.34	-47.1	0.004	-46.61	-46.4	0.005	-67.22	-11.5	0.265	125.32
26.5	-11.4	0.269	124.33	-45.4	0.005	-53.16	-46.6	0.005	-63.33	-11.4	0.269	122.97

[†] Data obtained from on-wafer measurements. $T_{\text{chuck}} = 25^\circ\text{C}$.