

An Interlaboratory Comparison of Vector Network Analyzer Measurements

Speaker: Dr. Li Pi Su

US Army Primary Standards Laboratory
AMSAM-TMD-S
Redstone Arsenal, AL 35898-5000
Phone (256) 955-6137/Fax (256) 842-8551
E-mail: lipi.su@redstone.army.mil

Authors: Dr. Li Pi Su, George Walden and Van Black
U.S. Army Primary Standards Laboratory

Abstract

This paper will report on an interlaboratory comparison (ILC) of measurements performed on Vector Network Analyzers (VNAs). The ILC was conducted with the three primary standards laboratories of the U.S. Department of Defense and the National Institute of Standards and Technology (NIST). This provided an appraisal of the capabilities and degree of equivalence of the participant laboratories to perform coaxial Type N 1-port VNA measurements accurately and consistently. This also demonstrated proficiency of VNA operators in the context that they can produce measurement results consistent with other comparable laboratories.

1. Introduction

In accordance with the guideline provided by NCSLI RP-15, *Guide to Laboratory Intercomparisons* [2], and ISO/CASCO 331, *Proficiency Testing by Interlaboratory Comparisons* [3], the objective of this interlaboratory comparison is to provide an appraisal of the capabilities and degree of equivalence of the participant laboratories to perform coaxial Type N 1-port Vector Network Analyzer (VNA) measurements accurately and consistently. A secondary objective of this ILC is to demonstrate proficiency of VNA operators in the context that they can produce measurement results consistent with other comparable laboratories, some of which may be accredited in this measurement parameter.

2. Participants

The participants of this ILC included the Electronics and Electrical Engineering Laboratory of NIST and the three primary standards laboratories of the United States Department of Defense (DoD). They are the Air Force Primary Standards Laboratory (AFPSL), the Navy Primary Standards Laboratory (NPSL), and the Army Primary Standards Laboratory (APSL). The APSL coordinated the ILC and performed the analysis.

3. ILC Measurement Parameters and Artifacts

The participating laboratories measured a set of coaxial Type N 1-port devices at the following 23 frequencies: 50, 200, 400, 600, and 800 MHz, and 1.0 to 18.0 GHz in 1 GHz increments. The devices¹ consisted of the Maury Microwave model 2561A, 2561G, 2562A and 2562G series male and female precision Type N mismatch standards. The manufacturer's specifications for these devices are as follows:

Type N Mismatches Standards

Nominal VSWR	Model		Accuracy		
	Female	Male	DC - 8.0 GHz	8.0 - 12.4 GHz	12.4 - 18.0 GHz
1.05:1	2561A	2562A	±0.05	±0.05	±0.08
2.00:1	2561G	2562G	±0.12	±0.12	±0.22

4. Procedures

The APSL served as the pivot laboratory and ILC Coordinator. The APSL also provided the artifacts to be measured, analyzed the data, and reported the results. The four coaxial Type N 1-port devices were new from the manufacturer.

4.1. The pivot laboratory performed the initial measurements of the artifacts.

4.2. The devices then were sent to the remaining laboratories in a circular (serial) fashion, in order to minimize disruption of the participants' normal work schedule.

4.3. Measurement Details. The complex S_{11} (magnitude and phase) of each device was measured on 3 separate occasions by each laboratory. Each occasion consisted of 3 measurements of each device, with the devices disconnected and reconnected at approximate 120° axial rotations. The participants were free to determine the details of how those measurements were made (e.g., VNA averaging, etc.), according to their normal measurement procedures. However, the VNA should have been recalibrated for each of the 3 occasions, preferably on 3 different days.

4.4. Data Submission. When the participating laboratories completed their portion of the measurements their results were sent to the Coordinator in either Microsoft Excel spreadsheet or text file format (comma- or tab-delimited). The VNA data were submitted in polar form, with magnitudes expressed to at least 4 decimal places and phases in degrees to at least 3 decimal places.

¹ Reference to commercial products, their sources, or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products by the participating laboratories.

4.5. The pivot laboratory performed the final measurement of the artifacts: Measurements were taken before and after the devices were cleaned. Then these measurements were compared with the initial dataset to check for stability and drift.

4.6. The data processor analyzed the data from all participants using suitable statistical techniques. The data processor prepared a draft ILC final report and distributed it to all participants for comment or concurrence. After a suitable review period, the resulting data were issued in a final ILC report to all participants. A courtesy concurrence of all participants was obtained to release the results to the public.

5. Analysis and Results

A-Measurements were made on an HP Model 8510C VNA using the sliding load calibration technique. B-Measurements were also made on an HP Model 8510C VNA. The VNA was calibrated with an HP Model 85054B calibration kit, and the calibration was verified with a NIST-calibrated HP Model 2561L verification kit. C-Measurements were made on an HP model 8510C VNA. The VNA was calibrated with a set of 5 air line standards, shorts and 50 ohm terminations using the NIST-developed multical software. D-Measurements were made on an HP Model 8510C VNA with an 85054B cal kit. The data submitted by participants were displayed on Excel spreadsheets by model and participants. The examples included in 5.1 to 5.6 are the best and worst case as a group.

5.1. A secondary objective of this ILC is to demonstrate proficiency of VNA operators in the context that the participants can produce measurement results consistent with other comparable laboratories. As such, 4 NEW devices were not calibrated by NIST before the APSL performed the measurements. See Tables 1 and 2.

5.2. ILC Ending Check Measurements. After the pivot lab received the devices from the last participant, the devices were measured before cleaning and then again after cleaning. See Tables 3 and 4 and Charts 1, 2, 3, and 4.

5.3. The manufacturer's specifications for the magnitude of S_{11} of these four devices are used as the respective devices' baseline. The manufacturer's specifications do not include specifications for phase.

5.4. All the magnitude measurements are within the manufacturer's specifications. The examples included here are the best and worst case as a group. See S_{11} Magnitude Measurements, Charts 5 and 6.

5.5. Almost all of the (S_{11} Magnitude – Group Mean S_{11} Magnitude) are within two standard deviations of the participants' measurements. See (S_{11} - Mean S_{11}) Magnitude Charts, Charts 7 and 8.

5.6. The phase measurements are not as well behaved as those of the magnitudes. There were some outliers. See S_{11} Phase Measurements Charts and (S_{11} Phase - Mean S_{11} Phase) Charts, Charts 9, 10, 11 and 12.

5.7. It is worth mentioning that the magnitude and phase measurements of the pivot laboratory on the 1.05:1 VSWR model 2561A and 2562A devices demonstrated some significant shifts between the starting measurements and ending measurements. See Tables 3 and 4 and Charts 1, 2, 3, and 4.

6. Conclusion and Recommendations

In general, both magnitude and phase measurements among all participants were consistent and the magnitudes were within the manufacturer's specifications. We also noted that the differences between the two ending measurements were negligible (i.e., before and after cleaning). This is evidence that the four devices were very well kept by all participants. Although the shifts on the 1.05:1 VSWR model 2561A and 2562A devices were not unexpected, we were not able to determine when the shifts occurred. Additional analysis may determine the source of these significant drifts.

7. References

1. *General Requirement for the Competence of Testing and Calibration Laboratories*, ISO/IEC 17025, 1st Edition, 15 December 1999.
2. *Guide to Laboratory Intercomparisons*, NCSLI RP-15, March 1999.
3. *Proficiency Testing by Interlaboratory Comparisons*, ISO/CASCO 331, Guide 43, November 1996.

8. Acknowledgement

The APSL acknowledges the participation and cooperation of the NIST Electronics and Electrical Engineering Laboratory, the Air Force Primary Standards Laboratory, and the Navy Primary Standards Laboratory in this study. We thank all participants for their contributions of time and expertise. Without their support, the results obtained would not have been possible.

Type N 1-Port Coaxial Reflection S ₁₁ Magnitude @ 2.00 VSWR/2562G-8314														
FREQ(GHz)	A#1	A#2	A#3	B#1	B#2	B#3	C#1	C#2	C#3	D#1	D#2	D#3	Mean	STDEV
0.05	0.33800	0.33790	0.33760	0.33888	0.33872	0.33816	0.33900	0.33900	0.33930	0.33880	0.33873	0.33898	0.33859	0.00053
0.20	0.33660	0.33660	0.33670	0.33777	0.33771	0.33742	0.33700	0.33700	0.33710	0.33782	0.33789	0.33805	0.33731	0.00053
0.40	0.33550	0.33570	0.33580	0.33710	0.33706	0.33638	0.33620	0.33650	0.33650	0.33684	0.33702	0.33716	0.33648	0.00058
0.60	0.33490	0.33500	0.33500	0.33674	0.33667	0.33607	0.33590	0.33610	0.33620	0.33656	0.33667	0.33663	0.33604	0.00070
0.80	0.33460	0.33430	0.33440	0.33647	0.33642	0.33585	0.33580	0.33590	0.33590	0.33660	0.33648	0.33665	0.33578	0.00087
1.00	0.33370	0.33410	0.33370	0.33619	0.33612	0.33552	0.33620	0.33600	0.33580	0.33619	0.33620	0.33633	0.33551	0.00104
2.00	0.33210	0.33210	0.33130	0.33477	0.33465	0.33412	0.33600	0.33440	0.33500	0.33504	0.33516	0.33539	0.33417	0.00150
3.00	0.32900	0.32910	0.32880	0.33450	0.33438	0.33388	0.33440	0.33260	0.33300	0.33541	0.33579	0.33509	0.33300	0.00259
4.00	0.33310	0.33290	0.33350	0.33463	0.33385	0.33328	0.33470	0.33250	0.33280	0.33436	0.33434	0.33421	0.33368	0.00077
5.00	0.34000	0.34020	0.33930	0.33913	0.33844	0.33805	0.33940	0.33710	0.33690	0.33760	0.33679	0.33752	0.33837	0.00121
6.00	0.34160	0.34270	0.34170	0.34180	0.34072	0.34052	0.34150	0.33990	0.33900	0.34223	0.34218	0.34188	0.34131	0.00107
7.00	0.33670	0.33720	0.33650	0.33540	0.33474	0.33477	0.33600	0.33670	0.33530	0.33926	0.34091	0.33946	0.33691	0.00198
8.00	0.32790	0.32750	0.32900	0.32691	0.32685	0.32651	0.32700	0.32970	0.32830	0.33042	0.33118	0.33084	0.32851	0.00168
9.00	0.33020	0.33070	0.33030	0.32687	0.32761	0.32690	0.32580	0.32980	0.32800	0.32607	0.32355	0.32633	0.32768	0.00220
10.00	0.33910	0.33930	0.33840	0.33474	0.33550	0.33477	0.33190	0.33640	0.33450	0.33175	0.32933	0.33365	0.33495	0.00307
11.00	0.34240	0.34490	0.34410	0.33861	0.33957	0.33901	0.33640	0.34010	0.33830	0.34062	0.33927	0.34079	0.34034	0.00244
12.00	0.33900	0.34290	0.34210	0.33610	0.33713	0.33624	0.33580	0.33820	0.33640	0.33848	0.33891	0.33902	0.33836	0.00228
13.00	0.34090	0.33260	0.33530	0.33118	0.33196	0.33137	0.33210	0.33400	0.33160	0.32848	0.32562	0.32943	0.33204	0.00376
14.00	0.32780	0.32790	0.32710	0.32565	0.32622	0.32597	0.32570	0.32670	0.32340	0.32219	0.31811	0.32379	0.32505	0.00280
15.00	0.32170	0.32210	0.32160	0.31959	0.31984	0.31883	0.31760	0.31920	0.31600	0.31944	0.31898	0.32025	0.31959	0.00174
16.00	0.32360	0.32560	0.32420	0.31983	0.32026	0.31905	0.31830	0.31890	0.31650	0.31972	0.32198	0.32017	0.32068	0.00266
17.00	0.34110	0.34290	0.34170	0.33787	0.33809	0.33666	0.33740	0.33690	0.33450	0.33255	0.33238	0.33215	0.33702	0.00365
18.00	0.36530	0.36500	0.36410	0.36675	0.36745	0.36579	0.36540	0.36610	0.36340	0.36254	0.36015	0.35936	0.36428	0.00252

Table 1. Type N 1-Port Coaxial Reflection S₁₁ Magnitude @ 2.00 VSWR/2562G-8314

Type N 1-Port Coaxial Reflection S ₁₁ Magnitude @ 1.05 VSWR/2561A-8289														
FREQ(GHz)	A#1	A#2	A#3	B#1	B#2	B#3	C#1	C#2	C#3	D#1	D#2	D#3	Mean	STDEV
0.05	0.02080	0.02090	0.02110	0.02548	0.02555	0.02544	0.02220	0.02170	0.02230	0.02126	0.02109	0.02117	0.02242	0.00191
0.20	0.02050	0.02050	0.02080	0.02523	0.02525	0.02529	0.02150	0.02090	0.02120	0.02088	0.02088	0.02085	0.02198	0.00199
0.40	0.02130	0.02090	0.02080	0.02554	0.02549	0.02543	0.02210	0.02170	0.02230	0.02123	0.02146	0.02125	0.02246	0.00188
0.60	0.02190	0.02180	0.02190	0.02619	0.02620	0.02605	0.02310	0.02290	0.02330	0.02246	0.02239	0.02227	0.02337	0.00174
0.80	0.02290	0.02280	0.02340	0.02708	0.02701	0.02678	0.02460	0.02410	0.02460	0.02374	0.02338	0.02349	0.02449	0.00159
1.00	0.02390	0.02360	0.02410	0.02800	0.02798	0.02770	0.02550	0.02530	0.02550	0.02477	0.02446	0.02465	0.02545	0.00159
2.00	0.02790	0.02760	0.02840	0.03163	0.03146	0.03130	0.02890	0.02880	0.02940	0.02851	0.04127	0.02827	0.03029	0.00373
3.00	0.03000	0.03030	0.02980	0.03013	0.03005	0.03016	0.02800	0.02800	0.02890	0.02969	0.02975	0.02933	0.02951	0.00080
4.00	0.03030	0.03050	0.02980	0.03068	0.03070	0.03093	0.02950	0.03000	0.03020	0.03042	0.03106	0.02962	0.03031	0.00050
5.00	0.02700	0.02670	0.02660	0.03452	0.03438	0.03464	0.03550	0.03630	0.03650	0.03475	0.03466	0.03389	0.03295	0.00381
6.00	0.02680	0.02690	0.02660	0.03449	0.03397	0.03410	0.03540	0.03610	0.03620	0.03506	0.03314	0.03408	0.03274	0.00371
7.00	0.03040	0.03050	0.03070	0.02609	0.02559	0.02555	0.02390	0.02420	0.02320	0.02567	0.02327	0.02538	0.02620	0.00278
8.00	0.02670	0.02690	0.02610	0.01894	0.01873	0.01870	0.01480	0.01470	0.01510	0.01703	0.01755	0.01677	0.01934	0.00460
9.00	0.01360	0.01310	0.01360	0.02682	0.02681	0.02722	0.02830	0.02900	0.03010	0.02649	0.02891	0.02553	0.02412	0.00657
10.00	0.01960	0.01960	0.01980	0.03379	0.03396	0.03438	0.03630	0.03670	0.03730	0.03416	0.03590	0.03369	0.03126	0.00710
11.00	0.03700	0.03750	0.03800	0.03139	0.03130	0.03167	0.02980	0.03050	0.02910	0.03168	0.03389	0.03100	0.03274	0.00310
12.00	0.04110	0.04150	0.04080	0.02721	0.02666	0.02712	0.02150	0.02150	0.01950	0.02597	0.02535	0.02555	0.02865	0.00792
13.00	0.02730	0.02770	0.02790	0.02927	0.02896	0.02979	0.02880	0.02980	0.02930	0.02789	0.02903	0.02733	0.02859	0.00092
14.00	0.00220	0.00160	0.00160	0.02684	0.02685	0.02711	0.03090	0.03140	0.02900	0.02731	0.03303	0.02636	0.02202	0.01237
15.00	0.02170	0.02280	0.02240	0.01233	0.01201	0.01155	0.01530	0.01600	0.01100	0.01355	0.02312	0.01268	0.01620	0.00488
16.00	0.03120	0.03200	0.03150	0.01759	0.01687	0.01794	0.01390	0.01400	0.02130	0.01496	0.01462	0.01329	0.01993	0.00736
17.00	0.02280	0.02300	0.02320	0.04003	0.03965	0.04021	0.04000	0.04040	0.04410	0.03725	0.03067	0.03458	0.03466	0.00778
18.00	0.01100	0.01020	0.01130	0.04784	0.04693	0.04738	0.05000	0.05020	0.04820	0.04588	0.03328	0.04472	0.03724	0.01651

Table 2. Type N 1-Port Coaxial Reflection S₁₁ Magnitude @ 1.05 VSWR/2561A-8289

Type N 1-Port Coaxial Reflection S ₁₁ Magnitude and Phase Shifts @ 2.00 VSWR/2561G-8299												
FREQ (GHz)	June 04 Meas = J04M		Before Clean Meas=BCM		BCM - J04M		After Clean Meas= ACM		ACM - J04M		BCM - ACM	
	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE
0.05	0.33905	176.46	0.33881	176.40	-0.00024	-0.06	0.33876	176.45	-0.00028	-0.01	0.00005	-0.05
0.20	0.33855	166.00	0.33817	165.95	-0.00039	-0.06	0.33820	165.99	-0.00036	-0.02	-0.00003	-0.04
0.40	0.33824	152.17	0.33781	152.11	-0.00043	-0.06	0.33771	152.15	-0.00053	-0.02	0.00010	-0.05
0.60	0.33814	138.31	0.33774	138.27	-0.00040	-0.04	0.33758	138.30	-0.00056	-0.01	0.00016	-0.03
0.80	0.33817	124.50	0.33769	124.45	-0.00047	-0.05	0.33769	124.50	-0.00048	-0.01	0.00000	-0.04
1.00	0.33823	110.73	0.33784	110.66	-0.00039	-0.07	0.33768	110.74	-0.00054	0.01	0.00015	-0.08
2.00	0.33836	41.92	0.33778	41.88	-0.00058	-0.04	0.33763	41.94	-0.00073	0.02	0.00015	-0.06
3.00	0.33624	-27.35	0.33553	-27.26	-0.00071	0.09	0.33528	-27.16	-0.00096	0.19	0.00026	-0.10
4.00	0.33820	-97.16	0.33666	-97.26	-0.00154	-0.09	0.33640	-97.13	-0.00181	0.03	0.00027	-0.13
5.00	0.34400	-166.45	0.34394	-166.64	-0.00006	-0.19	0.34351	-166.52	-0.00048	-0.07	0.00043	-0.12
6.00	0.34703	125.17	0.34824	125.32	0.00121	0.14	0.34788	125.41	0.00085	0.24	0.00036	-0.10
7.00	0.34213	55.90	0.34195	56.40	-0.00017	0.50	0.34181	56.48	-0.00032	0.58	0.00015	-0.08
8.00	0.33528	-15.76	0.33354	-15.45	-0.00174	0.31	0.33367	-15.26	-0.00161	0.50	-0.00013	-0.19
9.00	0.33472	-88.57	0.33488	-88.59	0.00016	-0.01	0.33471	-88.40	-0.00001	0.18	0.00017	-0.19
10.00	0.33612	-160.63	0.33836	-160.45	0.00225	0.18	0.33771	-160.18	0.00160	0.44	0.00065	-0.26
11.00	0.33030	126.57	0.33081	127.31	0.00050	0.75	0.33006	127.55	-0.00024	0.99	0.00074	-0.24
12.00	0.32246	51.37	0.32103	51.94	-0.00143	0.57	0.32004	52.08	-0.00242	0.71	0.00099	-0.14
13.00	0.32126	-24.76	0.32125	-24.69	-0.00001	0.07	0.32052	-24.42	-0.00074	0.34	0.00073	-0.27
14.00	0.31660	-99.59	0.31946	-99.10	0.00286	0.49	0.31887	-98.79	0.00227	0.80	0.00059	-0.31
15.00	0.30109	-176.65	0.30190	-175.69	0.00080	0.97	0.30103	-175.16	-0.00006	1.50	0.00086	-0.53
16.00	0.29888	100.60	0.29666	101.45	-0.00222	0.84	0.29527	102.00	-0.00362	1.39	0.00140	-0.55
17.00	0.33237	19.54	0.33230	19.87	-0.00008	0.32	0.33078	20.38	-0.00159	0.84	0.00151	-0.51
18.00	0.37083	-55.96	0.37350	-54.98	0.00267	0.98	0.37240	-54.68	0.00157	1.29	0.00110	-0.31

Table 3. Type N 1-Port Coaxial Reflection S₁₁ Magnitude and Phase Shifts @ 2.00 VSWR/2561G-8299

Type N 1-Port Coaxial Reflection S ₁₁ Magnitude & Phase Shifts @ 1.05 VSWR/2562A-8300												
FREQ(GHz)	June 04 Meas = J04M		Before Clean Meas=BCM		BCM - J04M		After Clean Meas=ACM		ACM - J04M		BCM - ACM	
	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE	MAGNITUDE	PHASE
0.05	0.02280	174.49	0.02244	175.11	-0.00036	0.62	0.02233	174.44	-0.00047	-0.05	0.00011	0.67
0.20	0.02268	159.48	0.02220	159.32	-0.00049	-0.16	0.02225	158.96	-0.00043	-0.52	-0.00006	0.36
0.40	0.02265	139.91	0.02282	138.74	0.00016	-1.16	0.02251	138.22	-0.00014	-1.68	0.00030	0.52
0.60	0.02293	120.29	0.02295	118.15	0.00002	-2.14	0.02282	117.62	-0.00012	-2.67	0.00014	0.53
0.80	0.02330	101.16	0.02341	97.41	0.00012	-3.75	0.02319	97.19	-0.00010	-3.97	0.00022	0.22
1.00	0.02371	82.47	0.02386	77.47	0.00015	-5.00	0.02355	76.96	-0.00016	-5.51	0.00031	0.51
2.00	0.02445	-10.00	0.02322	-21.31	-0.00123	-11.31	0.02326	-21.54	-0.00119	-11.54	-0.00004	0.23
3.00	0.02317	-102.16	0.02092	-112.42	-0.00225	-10.26	0.02044	-112.65	-0.00273	-10.49	0.00048	0.23
4.00	0.02115	156.04	0.02102	149.54	-0.00013	-6.50	0.02068	149.51	-0.00047	-6.53	0.00034	0.03
5.00	0.02499	64.39	0.02910	60.57	0.00411	-3.82	0.02868	60.48	0.00368	-3.91	0.00043	0.09
6.00	0.02867	-13.73	0.03245	-18.96	0.00378	-5.23	0.03263	-19.53	0.00396	-5.80	-0.00018	0.57
7.00	0.02620	-90.86	0.02794	-97.53	0.00174	-6.67	0.02940	-99.08	0.00320	-8.22	-0.00146	1.55
8.00	0.02004	-177.63	0.02234	165.31	0.00230	342.94	0.02369	166.61	0.00365	344.24	-0.00136	-1.30
9.00	0.01846	75.62	0.02482	56.05	0.00636	-19.57	0.02566	59.76	0.00720	-15.86	-0.00084	-3.71
10.00	0.02419	-23.69	0.03239	-35.54	0.00821	-11.86	0.03271	-33.44	0.00852	-9.76	-0.00031	-2.10
11.00	0.02891	-112.61	0.03648	-117.93	0.00757	-5.31	0.03640	-119.01	0.00749	-6.40	0.00008	1.09
12.00	0.03116	162.03	0.03739	157.30	0.00622	-4.73	0.03772	154.52	0.00656	-7.51	-0.00034	2.78
13.00	0.03253	77.39	0.03705	71.33	0.00451	-6.06	0.03872	70.81	0.00619	-6.58	-0.00168	0.52
14.00	0.03206	-2.22	0.03471	-10.02	0.00265	-7.80	0.03725	-8.95	0.00519	-6.73	-0.00254	-1.07
15.00	0.02711	-80.10	0.02988	-92.33	0.00276	-12.23	0.03069	-89.01	0.00358	-8.91	-0.00081	-3.32
16.00	0.01909	-172.70	0.02398	169.86	0.00489	342.55	0.02398	172.34	0.00489	345.04	0.00000	-2.49
17.00	0.02394	64.63	0.03296	63.19	0.00902	-1.45	0.03308	64.17	0.00914	-0.47	-0.00013	-0.98
18.00	0.05083	-22.75	0.05973	-19.71	0.00890	3.04	0.05972	-19.94	0.00889	2.81	0.00001	0.23

Table 4. Type N 1-Port Coaxial Reflection S₁₁ Magnitude & Phase Shifts @ 1.05 VSWR/2562A-8300

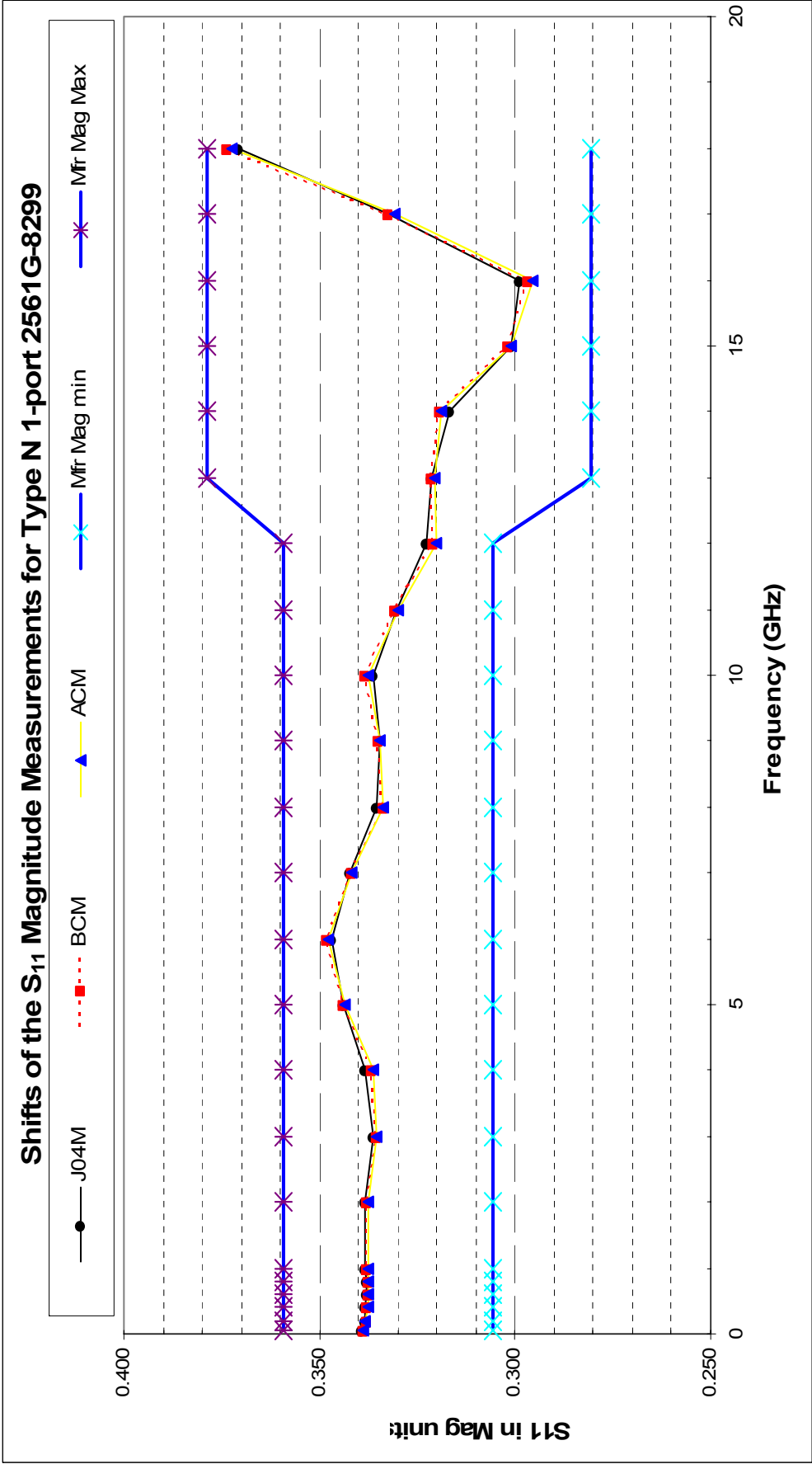


Chart 1. Shifts of the S_{11} Magnitude Measurements for Type N 1-port 2561G-8299

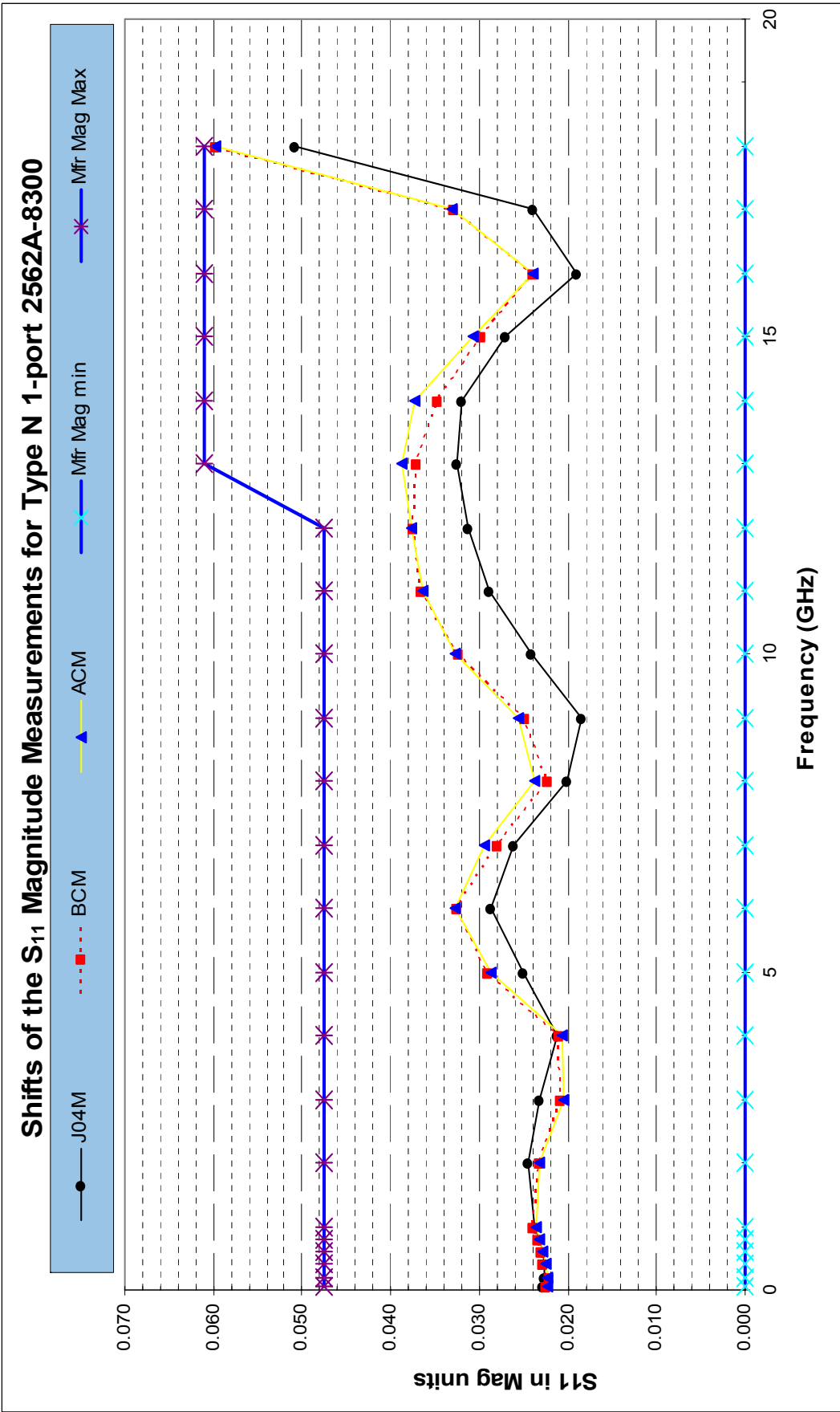


Chart 2. Shifts of the S_{11} Magnitude Measurements for Type N 1-port 2562A-8300

Shifts of the S_{11} Phase Measurements for Type N 1-port 2561G-8299

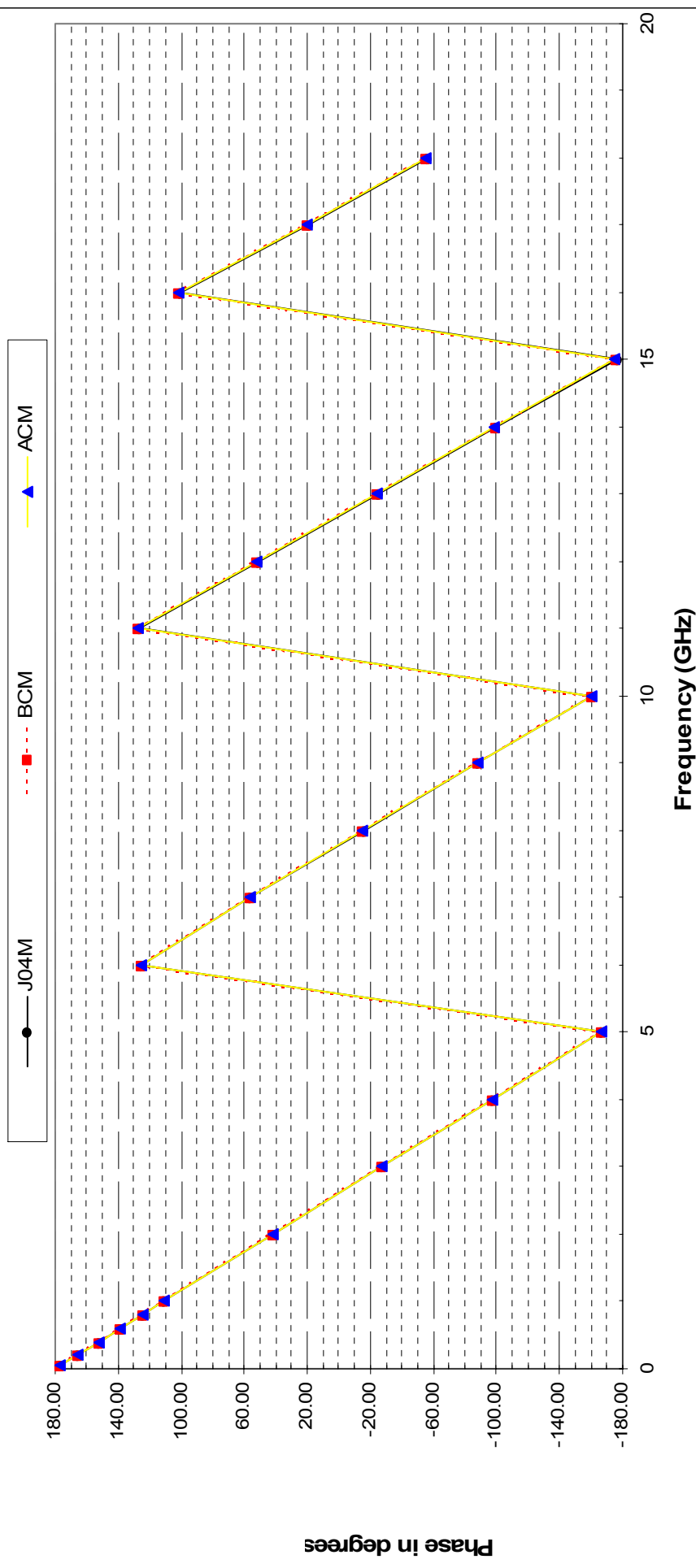


Chart 3. Shifts of the S_{11} Phase Measurements for Type N 1-port 2561G-8299

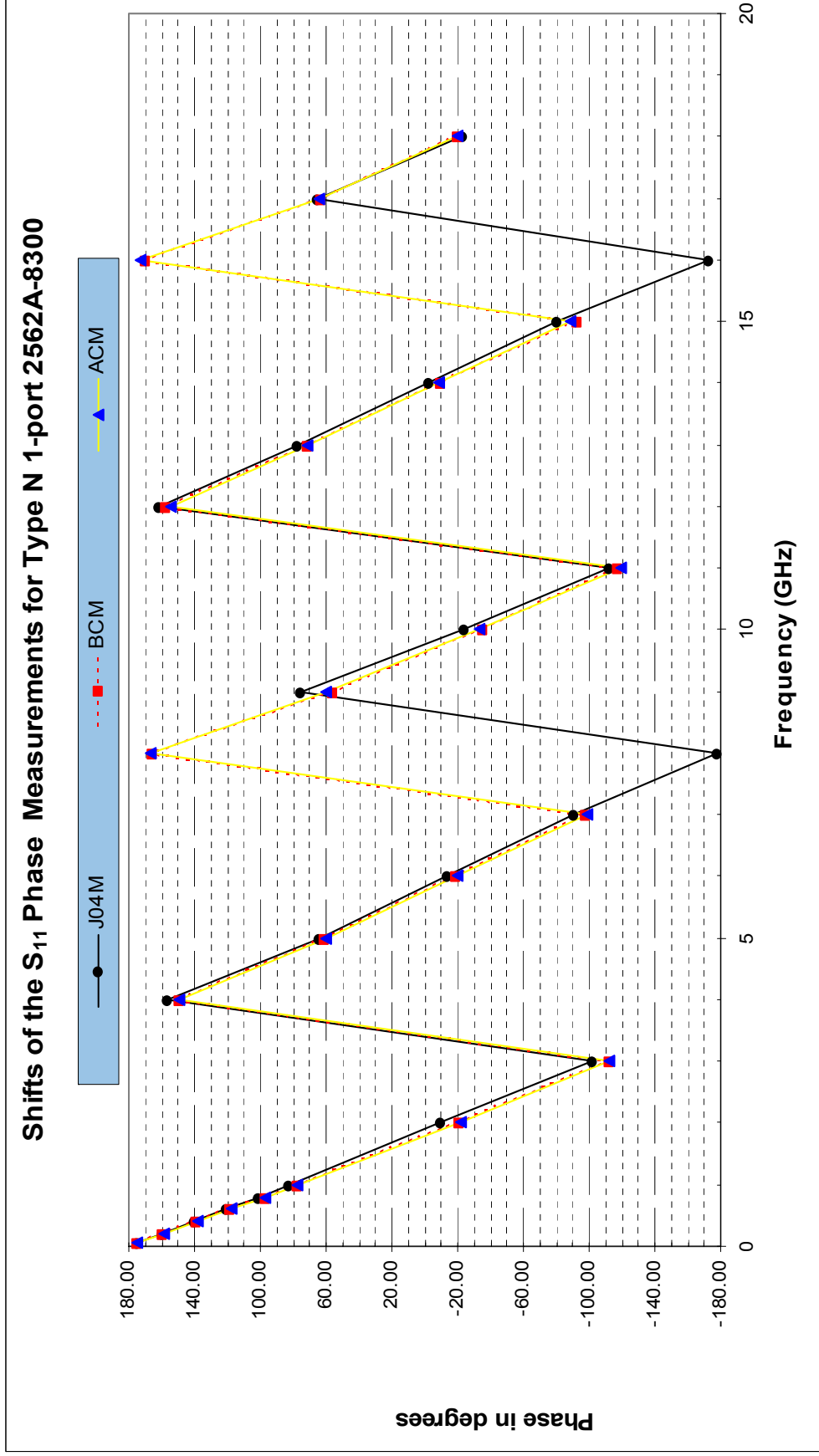


Chart 4. Shifts of the S_{11} Phase Measurements for Type N 1-port 2562A-8300

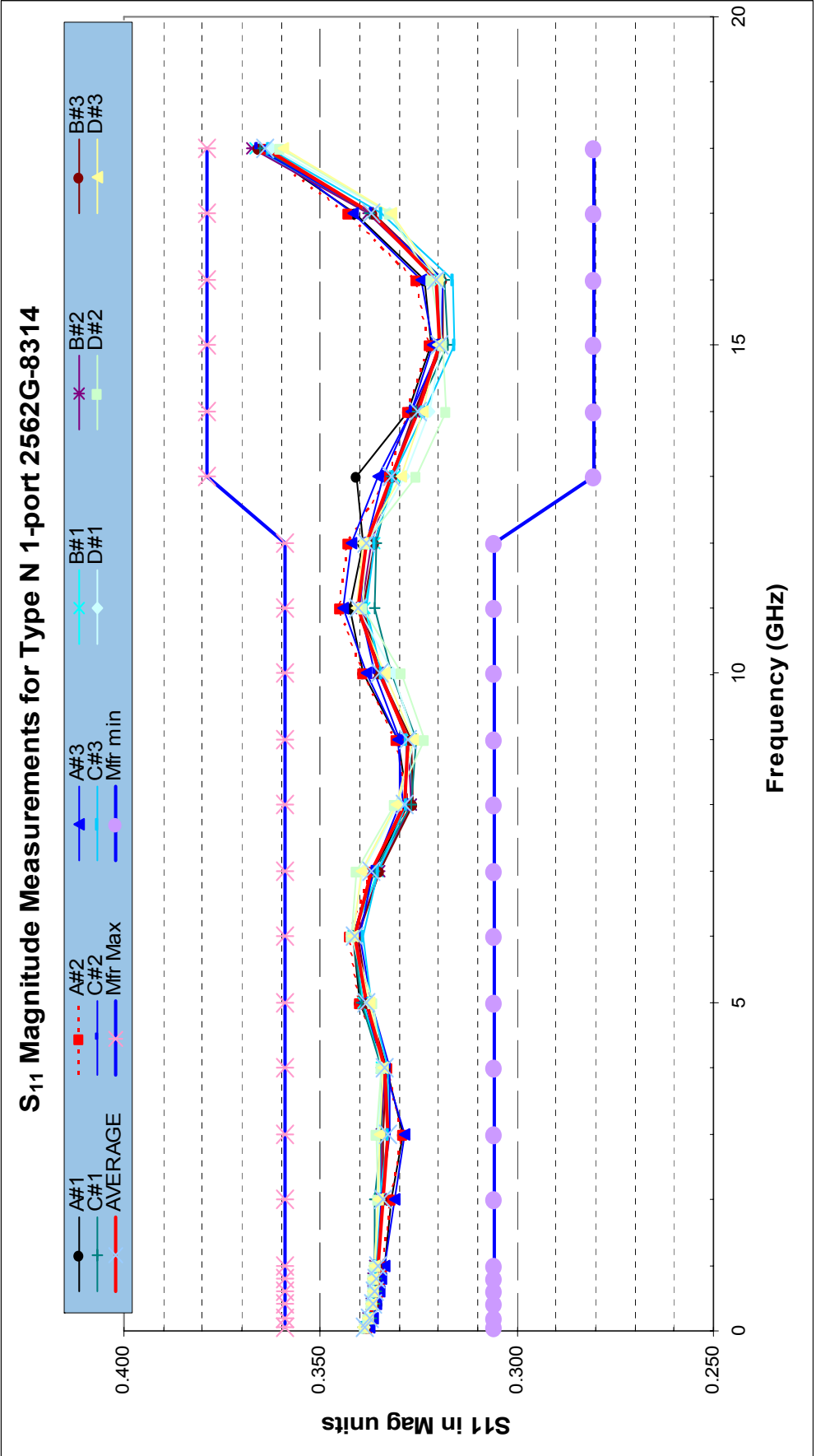


Chart 5. S₁₁ Magnitude Measurements for Type N 1-port 2562G-8314

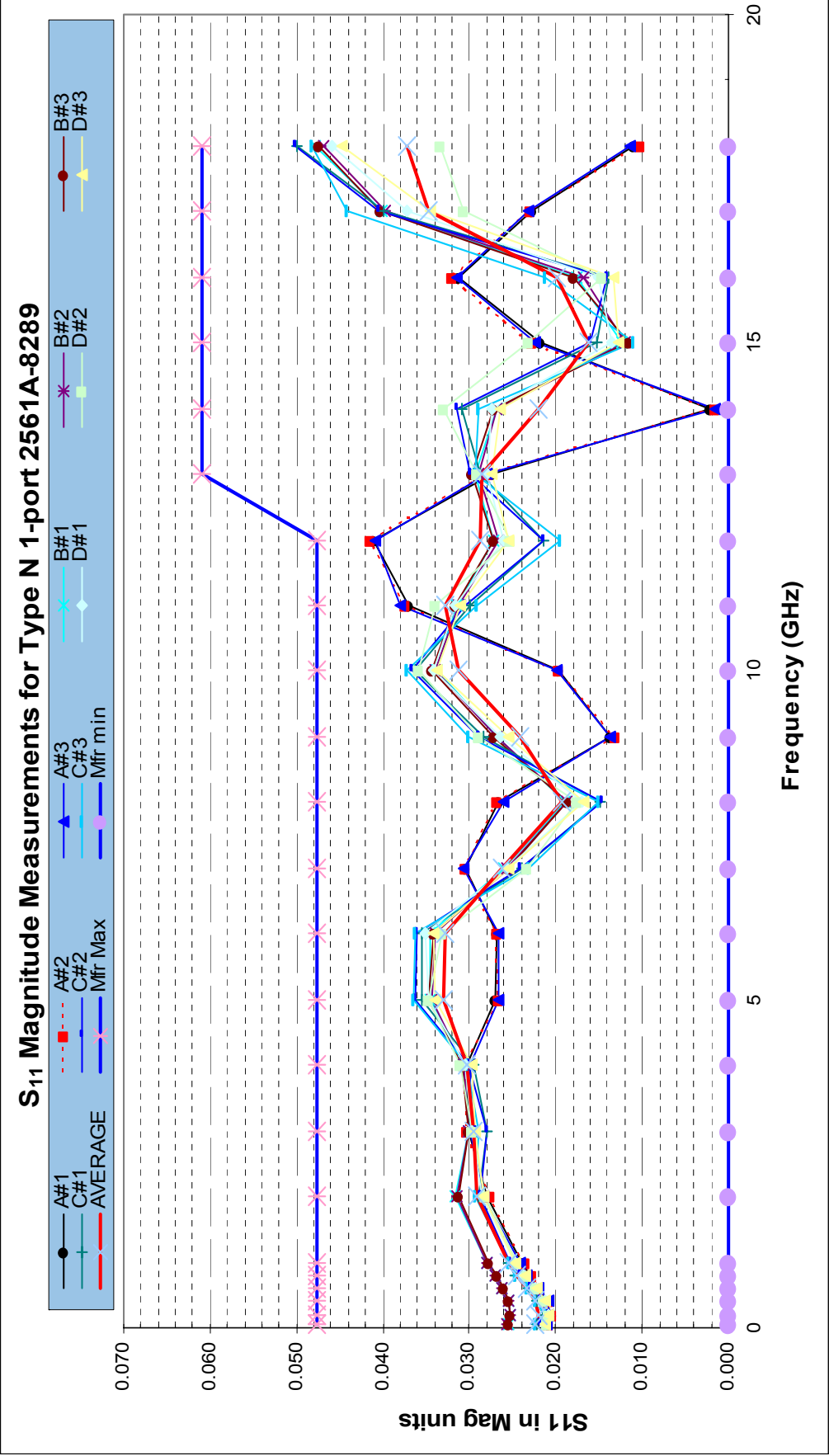


Chart 6. S₁₁ Magnitude Measurements for Type N 1-port 2561A-8289

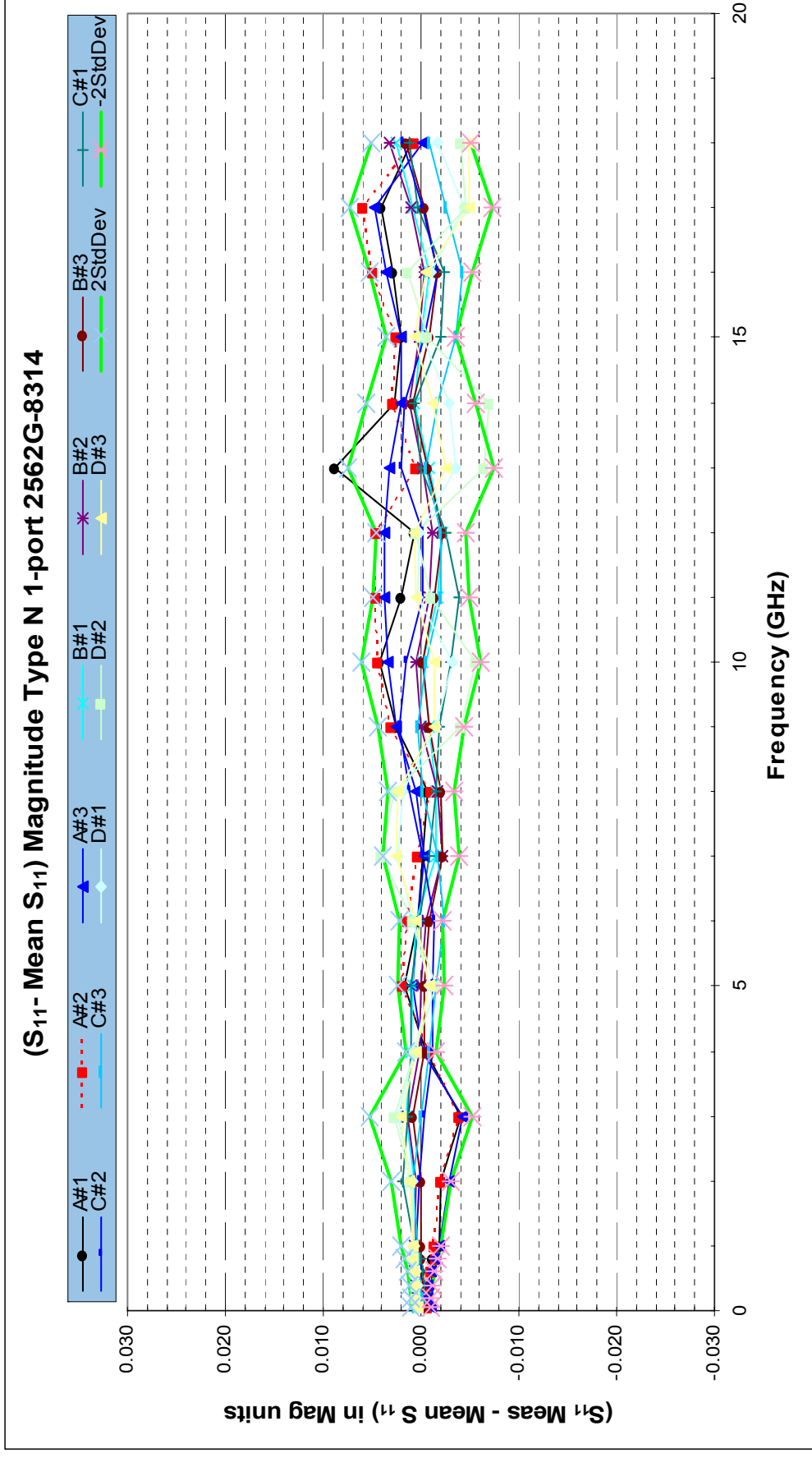


Chart 7. (S_{11} - Mean S_{11}) Magnitude Type N 1-port 2562G-8314

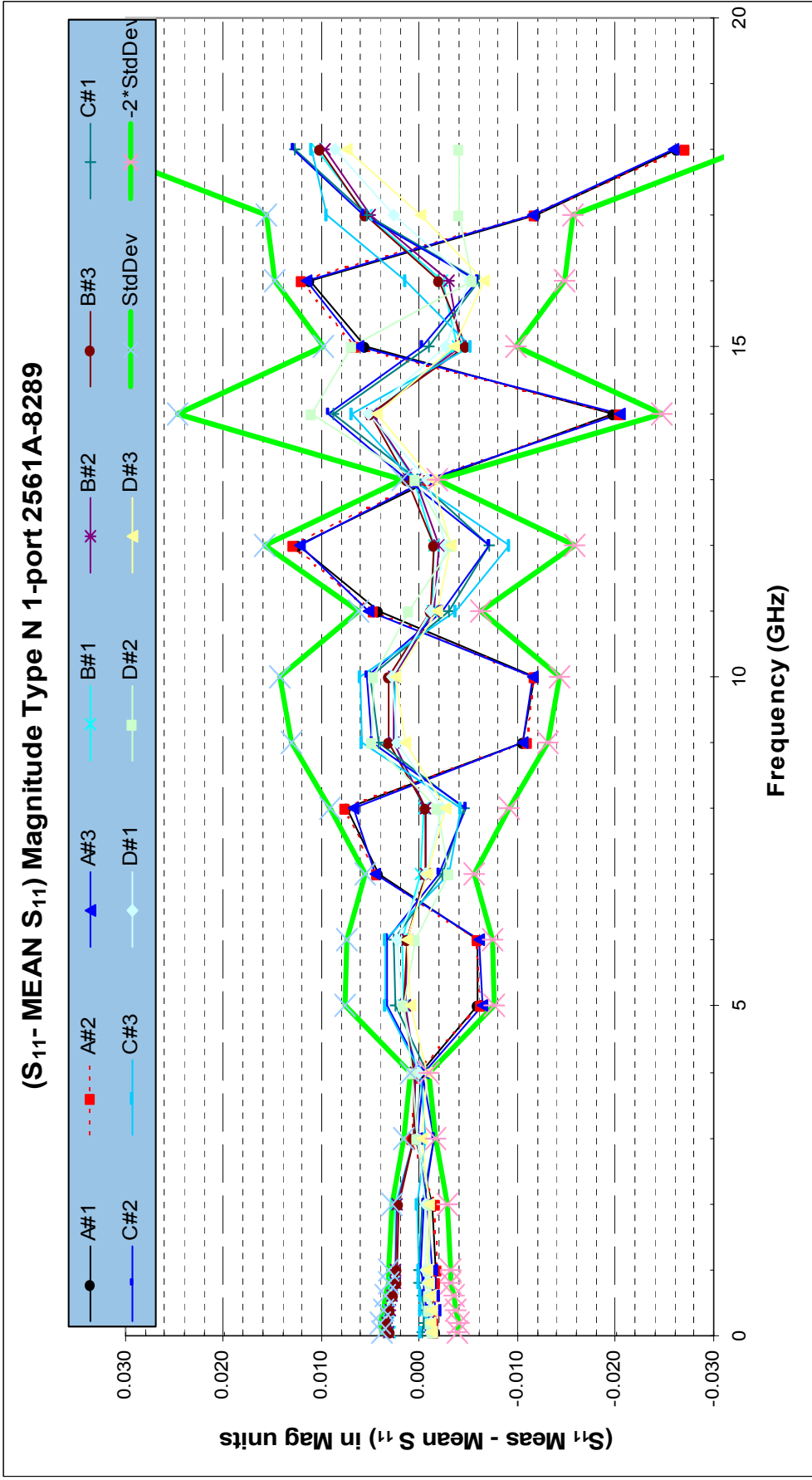


Chart 8. (S_{11} - MEAN S_{11}) Magnitude Type N 1-port 2561A-8289

S_{11} Phase Measurements for Type N 1-port 2562G-8314

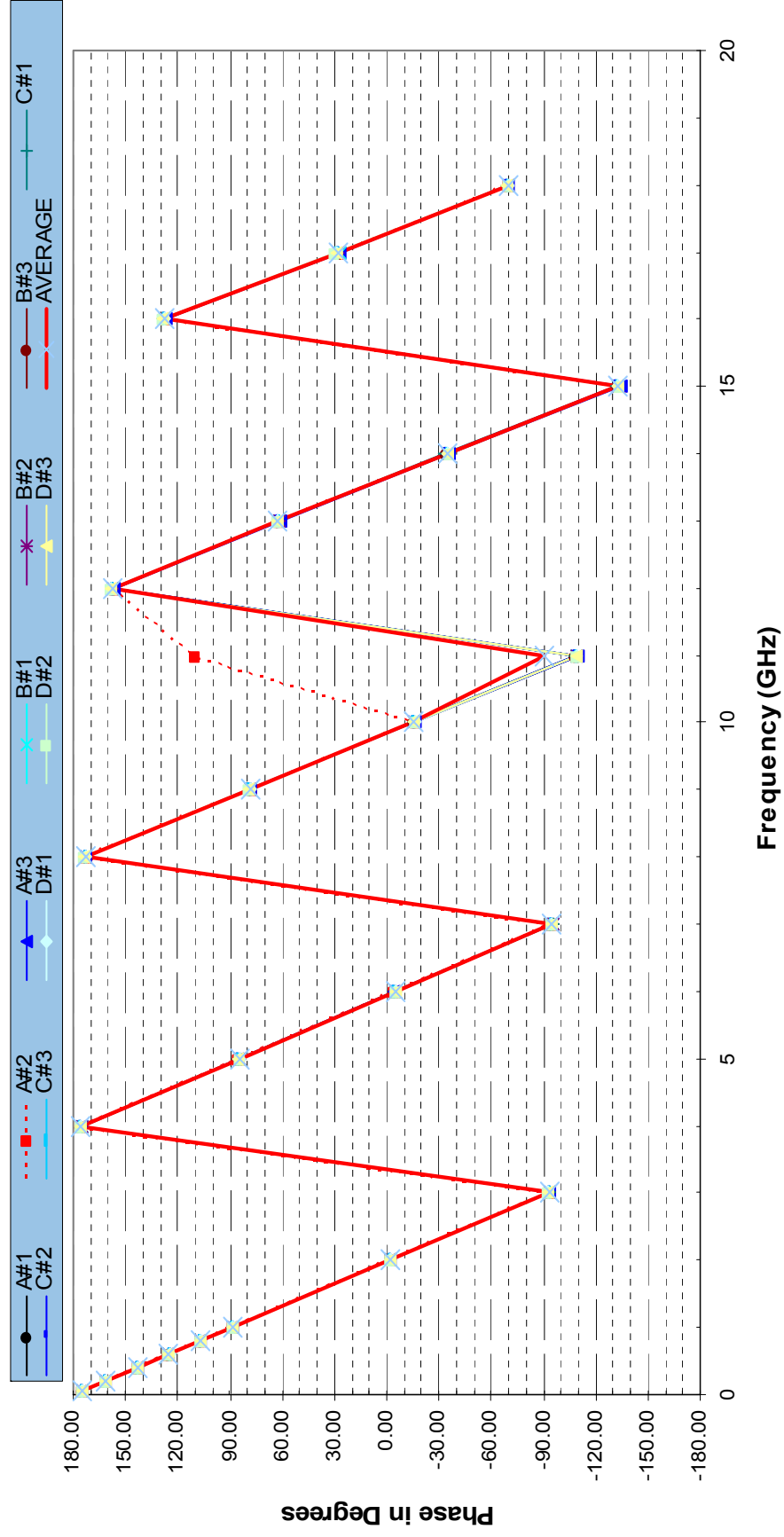


Chart 9. S_{11} Phase Measurements for Type N 1-port 2562G-8314

S_{11} Phase Measurements for Type N 1-port 2561A-8289

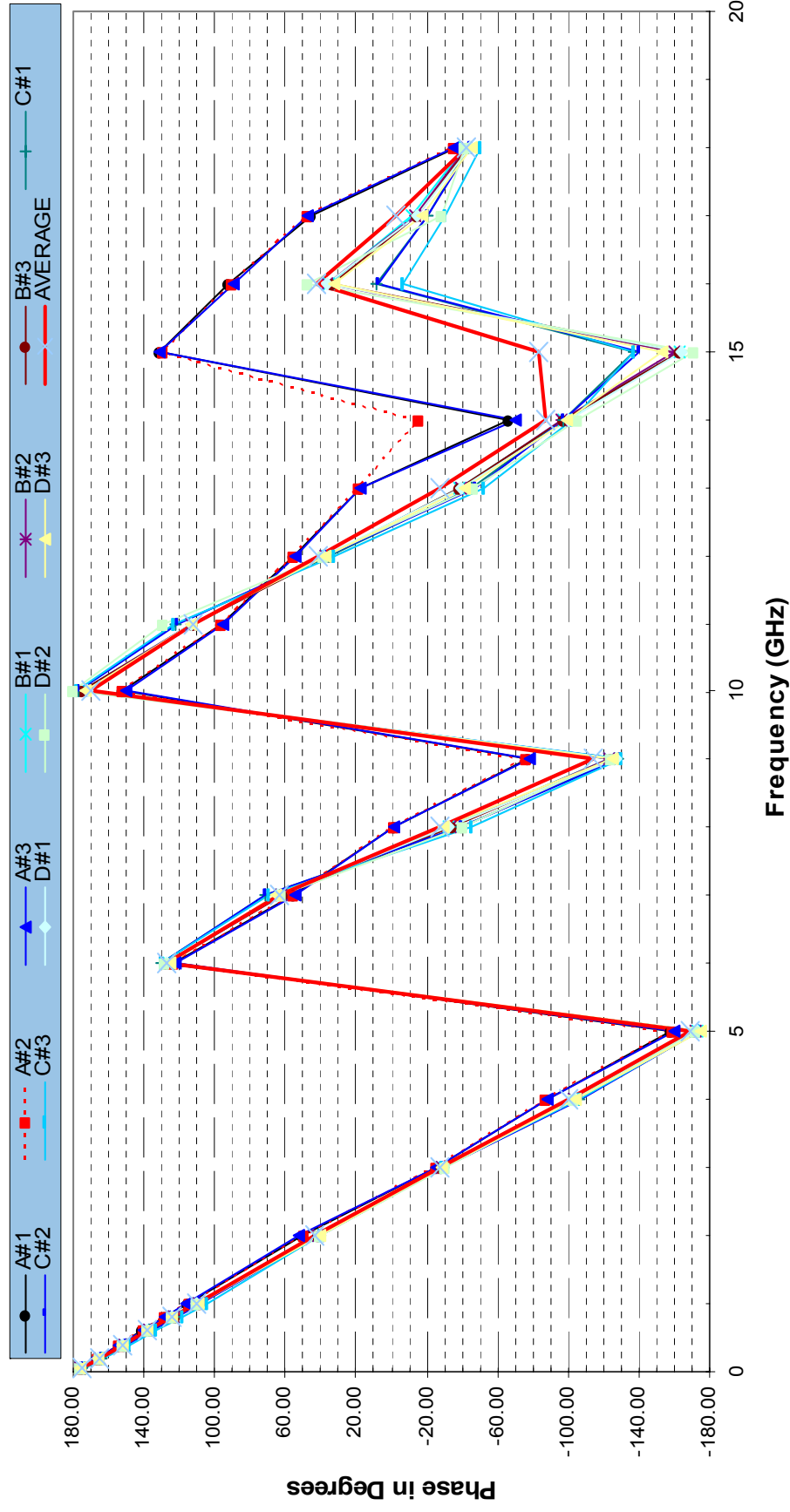


Chart 10. S_{11} Phase Measurements for Type N 1-port 2561A-8289

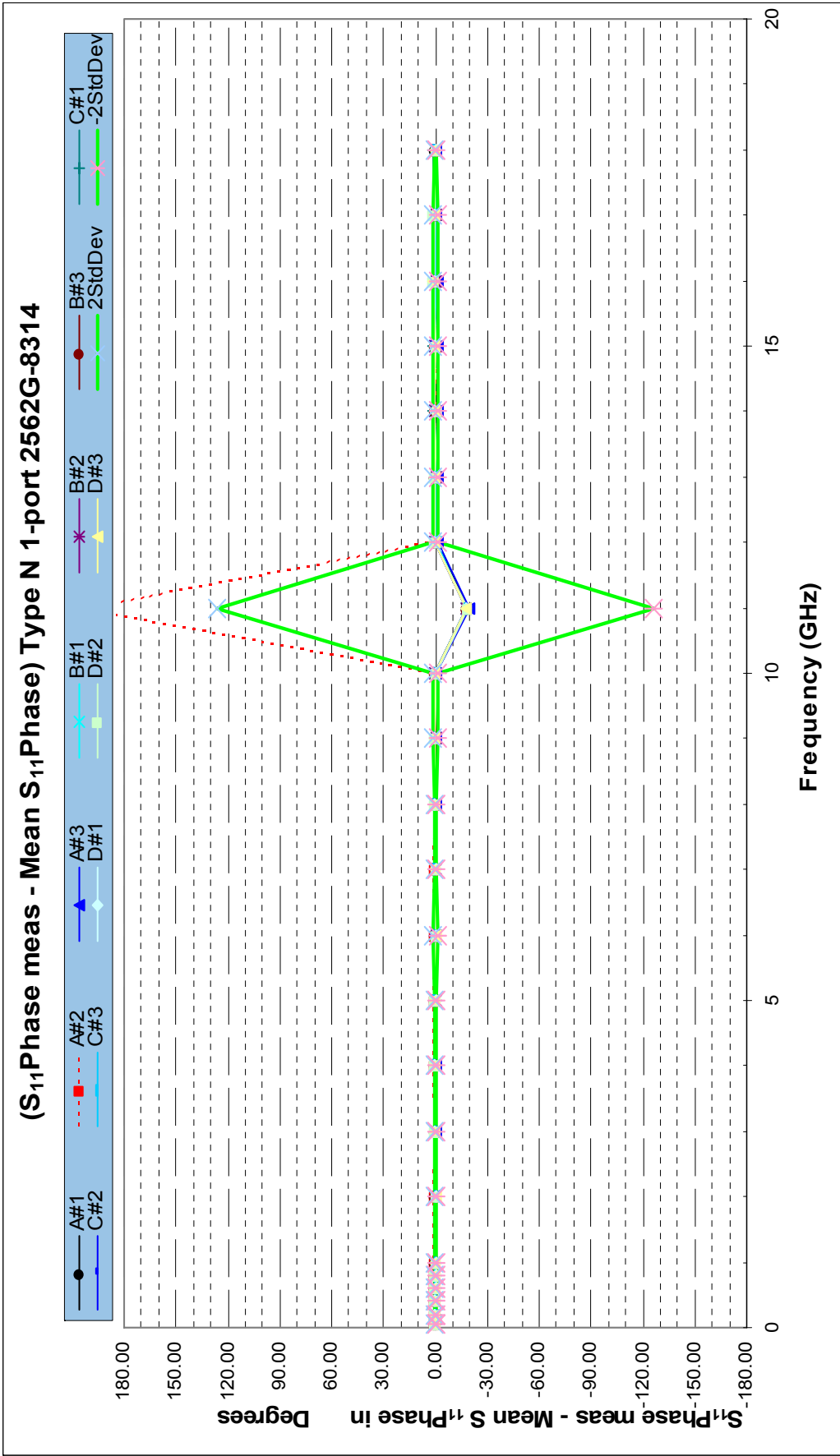


Chart 11. (S₁₁Phase meas - Mean S₁₁Phase) Type N 1-port 2562G-8314

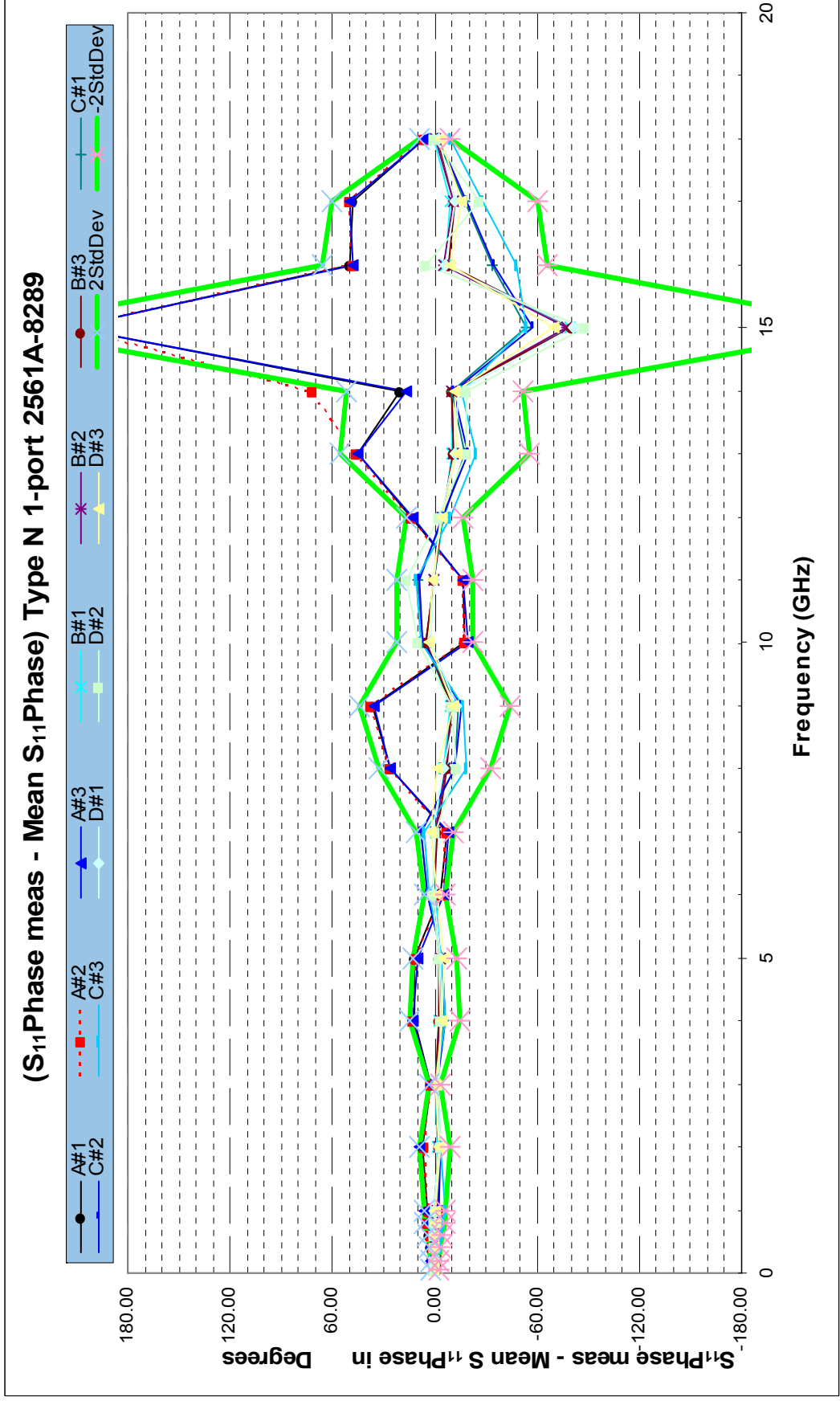


Chart 12. (S₁₁Phase meas - Mean S₁₁Phase) Type N 1-port 2561A-8289