

NO: SAMM 051(Issue 2, 29 August 2018 replacement
of SAMM 051 dated 8 August 2018)

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LABORATORY LOCATION:
(PERMANENT LABORATORY)
TEKMARK SDN. BHD.
B-G-8, ENDAH PROMENADE
NO. 5, JALAN 3/149E
TAMAN SRI ENDAH
BANDAR BARU SRI PETALING
57000 KUALA LUMPUR
MALAYSIA
FIELD OF CALIBRATION: ELECTRICAL

This laboratory has demonstrated its technical competence to operate in accordance with MS ISO/IEC 17025:2005 (ISO/IEC 17025:2005).

This laboratory's fulfillment of the requirements of ISO/IEC 17025 means the laboratory meets both the technical competence requirements and management system requirements that are necessary for it to consistently deliver technically valid test results and calibrations. The management system requirements in ISO/IEC 17025 are written in language relevant to laboratory operations and operate generally in accordance with the principles of ISO 9001 (see Joint ISO-ILAC-IAF Communiqué dated April 2017).

* The expanded uncertainties are based on an estimated confidence probability of approximately 95% and have a coverage factor of $k=2$ unless stated otherwise.

SCOPE OF CALIBRATION: ELECTRICAL

Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 1. DC Voltage	(0 to 220) mV (0.0 to 2.2) V (0 to 11) V (0 to 22) V (0 to 220) V (0 to 1100) V	6 μ V/ V + 0.4 μ V 3.5 μ V/ V + 0.7 μ V 2.5 μ V/ V + 2.5 μ V 2.5 μ V/ V + 4 μ V 3.5 μ V/ V + 40 μ V 4.5 μ V/ V + 400 μ V	Generation using calibrator model Fluke 5720A
2. AC Voltage	<u>(0.0 to 220) V</u>	(See Matrix A)	

Matrix A AC Voltage Source

Range	Frequency (kHz)							
	0.01 to 0.02	0.02 to 0.04	0.04 to 20	20 to 50	50 to 100	100 to 300	300 to 500	500 to 1000
0 to 2.2mV	220 + 4	85 + 4	75 + 4	180 + 4	460 + 5	900 + 10	1200 + 20	2500 + 20
2.2mV to 22mV	220 + 4	85 + 4	75 + 4	180 + 4	460 + 5	900 + 10	1200 + 20	2500 + 20
22mV to 220mV	220 + 12	85 + 7	75 + 7	180 + 7	420 + 17	750 + 20	1200 + 25	2500 + 45
220mV to 2. V	220 + 40	80 + 15	40 + 8	70 + 10	105 + 30	340 + 80	900 + 200	1500 + 300
2.2V to 22V	220 + 0.4	80 + 0.15	40 + 0.05	70 + 0.1	95 + 0.2	260 + 0.6	900 + 2	1300 + 3.2
22V to 220V	220 + 4	80 + 1.5	47 + 0.6	75 + 1	130 + 2.5	-	-	-

The expanded uncertainties given at above table expressed in μ V/V + μ V for range 2.2 mV to 2.2 V while range 22 V to 220 V expressed in μ V/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 2. AC Voltage (Continued)	<u>(220 to 1100) V</u>	(See Matrix B)	Generation using calibrator model Fluke 5720A & Fluke 5522A
3. DC Current	(0 to 220) μ A (0.0 to 2.2) mA (0 to 22) mA (0 to 220) mA (0.0 to 2.2) A	35 μ A/A + 6 nA 30 μ A/A + 7 nA 30 μ A/A + 40 nA 40 μ A/A + 0.7 μ A 60 μ A/A + 12 μ A	Generation using calibrator model Fluke 5720A
	(2.2 to 2.9) A (2.9 to 10.9) A (10.9 to 20.0) A	0.38 mA/A + 40 μ A 0.50mA/A + 50 μ A 0.55 mA/A + 4.5 mA	Generation using calibrator model Fluke 5522A & Wavetek 9100 (with 10Turn & 50Turn Coil
4. DC Current via Current Coils	(3.2 to 32) A (32 to 105) A (105 to 200) A (16 to 160) A (160 to 525) A (525 to 1000) A	0.60 mA/A + 1.2 mA 0.55 mA/A + 9.4 mA 0.55 mA/A + 45 mA 0.60 mA/A + 5.9 mA 0.55 mA/A + 47 mA 0.55 mA/A + 230 mA	

Matrix B AC Voltage Source (Continued)

Range	Frequency (kHz)							
	0.015 to 0.05	0.045 to 0.05	0.05 to 1	1 to 5	5 to 10	10 to 20	20 to 50	50 to 100
220 V to 250 V	0.26 + 16	0.19 + 2	0.06 + 3.5	0.2 + 6	0.2 + 6	0.25 + 6	0.3 + 6	2 + 50
250 V to 330 V	-	0.19 + 2	0.06 + 3.5	0.2 + 6	0.2 + 6	0.25 + 6	0.3 + 6	2 + 50
330 V to 1020 V	-	0.3 + 10	0.06 + 3.5	0.25 + 10	0.3 + 10	-	-	-
1020 V to 1100 V	-	-	0.06 + 3.5	-	-	-	-	-

The expanded uncertainties given at above table expressed in mV/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 5. AC Current	<u>(0 to 20) A</u>	(See Matrix C)	Generation using calibrator model Fluke5720A, Wavetek 9100

Matrix C AC Current Source

Range	Frequency (kHz)							
	0.01 to 0.02	0.02 to 0.04	0.04 to 1	1 to 3	3 to 5	5 to 10	10 to 20	20 to 30
0 to 32 μ A	0.23 + 0.016	0.14 + 0.01	0.11 to 0.008	0.25 + 0.012	0.25 + 0.012	0.9 + 0.065	2 + 6	2.5 + 9
32 μ A to 220 μ A	0.23 + 0.016	0.14 + 0.01	0.11 + 0.008	0.25 + 0.012	0.25 + 0.012	0.9 + 0.065	2 + 2	2.5 + 3
220 μ A to 320 μ A	0.23 + 0.04	0.14 + 0.035	0.11 + 0.035	0.18 + 0.11	0.18 + 0.11	0.9 + 0.65	2 + 2	2.5 + 3
320 μ A to 2.2mA	0.23 + 0.04	0.14 + 0.035	0.11 + 0.035	0.18 + 0.11	0.18 + 0.11	0.9 + 0.65	2 + 2	2.5 + 3
2.2mA to 3.2mA	0.23 + 0.4	0.14 + 0.35	0.11 + 0.35	0.18 + 0.55	0.18 + 0.55	0.9 + 5	2 + 2	2.5 + 3
3.2mA to 22mA	0.23 + 0.4	0.14 + 0.35	0.11 + 0.35	0.18 + 0.55	0.18 + 0.55	0.9 + 5	2 + 13	2.5 + 23
22mA to 32mA	0.23 + 4	0.14 + 3.5	0.11 + 2.5	0.18 + 3.5	0.18 + 3.5	0.9 + 10	2 + 13	2.5 + 23
32mA to 220mA	0.23 + 4	0.14 + 3.5	0.11 + 2.5	0.18 + 3.5	0.18 + 3.5	0.9 + 10	2 + 64	2 + 96
220mA to 32mA	-	0.24 + 35	0.24 + 35	0.39 + 80	0.39 + 80	6 + 160	2 + 64	2.5 + 96
320mA to 2.2A	-	0.24 + 35	0.24 + 35	0.39 + 80	0.39 + 80	6 + 160	-	-
2.2A to 2.9A	1 + 0.48	1 + 0.48	1 + 0.48	1 + 0.48	2.5 + 2.6	2.5 + 2.6	-	-
3.2A to 10.5A	2 + 3	2 + 3	2 + 3	2 + 3	5 + 10	5 + 10	-	-
10.5A to 20 A	2 + 6.9	2 + 6.9	2 + 6.9	2 + 6.9	5 + 23	5 + 23	-	-

The expanded uncertainties given at above table expressed in mA/A + μ A for range 0 A to 2.2 A while range 2.2 A to 20 A expressed in mA/A + mA

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 6. AC Current via Current Coils	<u>(3.2 to 32.0) A</u> 10 Hz to 100 Hz 100 Hz to 440 Hz <u>(32.0 to 200.0) A</u> 10 Hz to 100 Hz 100 Hz to 440 Hz <u>(16.0 to 160.0) A</u> 10 Hz to 100 Hz <u>(160.0 to 1000.0) A</u> 10 Hz to 65 Hz	2.0 mA/A + 5.5 mA 7.8 mA/A + 27 mA 2.1 mA/A + 90 mA 6.7 mA/A + 0.25 A 2.0 mA/A + 28 mA 2.1 mA/A + 0.45 A	Generation using calibrator model Wavetek 9100 (with 10Turn & 50Turn Coil)
7. Wideband AC Voltage (Frequency from 30Hz to 500 kHz into 50 Ω Termination)	0.3 mV to 1.1 mV 1.1 mV to 3 mV 3 mV to 11 mV 11 mV to 33 mV 33 mV to 110 mV 110 mV to 330 mV 330 mV to 1.1 V 1.1 V to 3.5 V	5 mV/ V + 0.4 μ V 4.5 mV/ V + 1 μ V 3.5 mV/ V + 4 μ V 3 mV/ V + 10 μ V 3 mV/ V + 40 μ V 2.5 mV/ V + 100 μ V 2.5 mV/ V + 400 μ V 2 mV/ V + 500 μ V	Generation using calibrator model Fluke 5720A

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 7. Wideband AC Voltage (Continued) Amplitude Flatness at 1 kHz reference	<u>0.3 mV to 3.5 V</u>	(See Matrix D)	Generation using calibrator model Fluke 5720A

Matrix D Wideband ACV Amplitude Flatness

Range	Volts		
	1.1 mV	3 mV	3.5 V
10 Hz to 30 Hz	3	3	3
30 Hz to 120 Hz	1	1	1
120 Hz to 1.2 kHz	1	1	1
1.2 kHz to 12 kHz	1	1	1
12 kHz to 120 kHz	1	1	1
120 kHz to 1.2 MHz	2 + 3	1 + 3	1 + 3
1.2 MHz to 2 MHz	2 + 3	1 + 3	1 + 3
2 MHz to 10 MHz	4 + 3	1 + 3	2 + 3
10 MHz to 20 MHz	6 + 3	1 + 3	4 + 3
20 MHz to 30 MHz	15 + 15	15 + 15	10 + 3

The calibration uncertainties given at above table expressed in mV/V + μ V

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 8. Resistance Measuring Instrument	(Nominal Value) 0 Ω	40 $\mu\Omega$	Generation using calibrator model Fluke 5720A
	1 Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-1
	1.9 Ω	80 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	10 Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-10
	19 Ω 100 Ω 190 Ω 1 k Ω 1.9 k Ω	21 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 7.5 $\mu\Omega/\Omega$ 7.5 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	10 k Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-10k
	19 k Ω 100 k Ω 190 k Ω 1 M Ω 1.9 M Ω 10 M Ω 19 M Ω 100 M Ω	7.5 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 15 $\mu\Omega/\Omega$ 16 $\mu\Omega/\Omega$ 31 $\mu\Omega/\Omega$ 39 $\mu\Omega/\Omega$ 95 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	(0.0 to 10.9) Ω (11 to 32.9) Ω (33 to 109.9) Ω (110 to 1.09) k Ω (1.1 to 10.9) k Ω (11 to 109) k Ω (110 k to 1.09) M Ω (1.1 to 3.29) M Ω (3.3 to 10.9) M Ω (11 to 32.9) M Ω (33 to 109.9) M Ω (110 to 400) M Ω	0.04 m Ω/Ω + 1 m Ω 0.03 m Ω/Ω + 1.5 m Ω 0.028 m Ω/Ω + 1.4 m Ω 0.028 m Ω/Ω + 2 m Ω 0.028 m Ω/Ω + 0.02 Ω 0.028 m Ω/Ω + + 0.2 Ω 0.032 m Ω/Ω + + 2 Ω 0.06 m Ω/Ω + 30 Ω 0.13 m Ω/Ω + + 50 Ω 0.25 m Ω/Ω + 2.5 k Ω 0.5 m Ω/Ω + 3 k Ω 0.6 m Ω/Ω + 40 k Ω	Generation using calibrator model Fluke 5522A, Wavetek 9100

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 9. Capacitance	<u>Stim Repetition Rate \geq 350Hz</u> (0.5 to 4.0) nF (4.0 to 40.0) nF (40.0nF to 400.0) nF (0.4 to 4.0) μ F (4.0 to 40.0) μ F (40.0 to 400.0) μ F (0.4 to 4.0) mF (4.0 to 40.0) mF	3 mF/F + 15 pF 3 mF/F + 30 pF 3 mF/F + 160 pF 4 mF/F + 1.6 nF 5 mF/F + 16 nF 5 mF/F + 160 nF 5 mF/F + 1.6 μ F 10 mF/F + 60 μ F	
	<u>Stim Repetition Rate 350 to 1.5 kHz</u> (0.5 to 4.0) nF (4.0 to 40.0) nF (40.0 to 400.0) nF (0.4 to 4.0) μ F (4.0 to 40.0) μ F (40.0 to 400.0) μ F (0.4 to 4.0) mF (4.0 to 40.0) mF	6 mF/F + 30 pF 6 mF/F + 60 pF 6 mF/F + 320 pF 8 mF/F + 3.2 nF 10 mF/F + 32 nF 10 mF/F + 320 nF 10 mF/F + 3.2 μ F 20 mF/F + 120 μ F	

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 10. Vertical Amplitude a) Square Peak to Peak 1M Ω Load 50 Ω Load	200 μ V to 100 V 100 μ V Ω to 5 V	2.5 mV/ V + 1 μ V 2.5 mV/ V + 1 μ V	Generation using calibrator model Tek PG506A
b) DC 1M Ω Load 50 Ω Load	0 V to 130 V 4.44 mV to 2.78 V	0.5 mV/ V + 40 μ V 2.0 mV/ V + 40 μ V	Generation using calibrator model Fluke 5522A, Wavetek 9100
11. Time Base	1 ns 2 ns to 5 s	0.5 μ s/s 0.25 μ s/s	Generation using calibrator model Tek TG501A
12. Edge Function a) Output Period b) Rise Time 1M Ω Load 50 Ω Load c) Fall Time	100 ns to 10 ms 10 μ s to 10 ms 100 ns to 10 ms 100 ns to 10 ms	0.25 μ s/s 100 ns 1 ns 1 ns	Generation using calibrator model Wavetek 9100
13. Frequency a) Source	1 μ Hz to 0.5 Hz	5 μ Hz/Hz	Generation using calibrator model DS345
	0.5 Hz to 600 MHz	0.25 μ Hz/Hz	Generation using calibrator model Wavetek 9100
	600 MHz to 1050 MHz	20 mHz/Hz	Generation using calibrator model SG504

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(±)*	Remarks
A. Indicating Meters/ Instruments 13. Frequency (Continued) b) Amplitude	<u>(0.01 to 5.00) V_{pp}</u> 1 μHz to 100 kHz 100 kHz to 20 MHz 20 MHz to 30.2 MHz	47 mV/ V 47 mV/ V 59 mV/ V	Generation using calibrator model DS345
	<u>(5 to 10) V_{pp}</u> 1 μHz to 100 kHz 100 kHz to 20 MHz 20 MHz to 30.2 MHz	23 mV/ V 23 mV/ V 35 mV/ V	
c) Amplitude Flatness at 50 kHz or 6MHz	50 kHz to 100 MHz 100 MHz to 250 MHz	10 mV/ V 20 mV/ V + 100 μV	Generation using calibrator model SG503, Fluke 5522A
reference	250 MHz to 1050 MHz	40 mV/ V	Generation using calibrator model SG504
B. Source 14. DC Voltage	(0 to 100) mV (0 to 1) V (0 to 10) V (0 to 100) V (0 to 1000) V	5.5 μV/ V + 0.3 μV 5.1 μV/ V + 0.3 μV 4.6 μV/ V + 0.5 μV 6.5 μV/ V + 30 μV 6.5 μV/ V + 0.1 mV	Measurement using calibrator model HP3458A, Keithley 2001
15. AC Voltage Source	<u>(0 to 750) V</u>	(See Matrix E)	

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Matrix E AC Voltage Measurement

Range	Frequency (kHz)									
	0.02 to 0.05	0.05 to 0.1	0.1 to 2	2 to 10	10 to 30	30 to 50	50 to 100	100 to 200	200 to 1000	1000 to 2000
200 mV	2.5 + 0.03	0.8 + 0.03	0.5 + 0.03	0.5 + 0.03	0.5 + 0.03	0.6 + 0.03	1.7 + 0.03	5 + 0.05	20 + 0.2	50 + 0.4
2 V	2.5 + 0.3	0.8 + 0.3	0.5 + 0.3	0.5 + 0.3	0.5 + 0.3	0.6 + 0.3	1.7 + 0.3	5 + 0.5	20 + 2	50 + 4
20 V	2.5 + 3	0.8 + 3	0.6 + 3	0.85 + 3	1.2 + 3	1.3 + 3	1.7 + 3	5 + 5	40 + 40	-
200 V	2.5 + 30	0.8 + 30	0.6 + 30	0.85 + 30	1.2 + 30	1.3 + 30	1.7 + 30	-	-	-
750 V	2.7 + 120	1.1 + 120	1.0 + 120	1.3 + 120	1.8 + 120	-	-	-	-	-

The calibration uncertainties given in this table are expressed in mV/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
B. Source 16. DC Current	(0 to 100) μ A (0 to 1) mA (0 to 10) mA (0 to 100) mA (0 to 1) A (0 to 2) A	20 μ A/A + 0.8 nA 20 μ A/A + 5 nA 20 μ A/A + 50 nA 35 μ A/A + 0.5 μ A 105 μ A/A + 10 μ A 900 μ A/A + 40 μ A	Measurement using calibrator model HP3458A, Keithley 2001
	(0 to 10) A	2 mA/A + 0.7 mA	Measurement using calibrator model Fluke 45
17. AC Current	<u>(0 to 10) A</u>	(See Matrix F)	Measurement using calibrator model Keithley 2001, Fluke 45

Matrix F AC Current Measurement

Range	Frequency (kHz)			
	0.02 to 0.05	0.05 to 0.2	0.2 to 1	1 to 10
200 μ A	3.5 + 0.00003	2 + 0.00003	4 + 0.00003	5 + 0.00003
2 mA	3.0 + 0.0003	1.5 + 0.0003	1.2 + 0.0003	1.2 + 0.0003
20 mA	3.0 + 0.003	1.5 + 0.003	1.2 + 0.003	1.2 + 0.003
200 mA	3.0 + 0.03	1.5 + 0.03	1.2 + 0.03	1.2 + 0.03
2 A	3.5 + 0.3	2 + 0.3	3 + 0.3	4.5 + 0.3
10 A	20 + 10	10 + 10	10 + 10	-

The calibration uncertainties given in this table are expressed in mA/A + mA

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
B. Source 18. Resistance	10 Ω 100 Ω 1 k Ω 10 k Ω 100 k Ω 1 M Ω 10 M Ω 100 M Ω	18 $\mu\Omega/\Omega$ + 0.05 m Ω 13 $\mu\Omega/\Omega$ + 0.5 m Ω 11 $\mu\Omega/\Omega$ + 0.5 m Ω 11 $\mu\Omega/\Omega$ + 5 m Ω 11 $\mu\Omega/\Omega$ + 0.05 Ω 15 $\mu\Omega/\Omega$ + 2 Ω 53 $\mu\Omega/\Omega$ + 100 Ω 0.505 m Ω/Ω + 1 k Ω	Measurement using calibrator model HP3458A

Signatories:

1. **Wong Sin Chon**
2. **Ramlah Mamat**
3. **Rafizi Affandi**
4. **K.S. Manikandan**
5. ***Lalyn Soriano Duco**

*Non-resident

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>Generating Equipment</u> 19. DC Current	(0.1 to 1) μ A (1 to 10) μ A (10 to 100) μ A (100 to 1) mA (1 to 10) mA (10 to 100) mA (0.1 to 1) A (1 to 2) A (2 to 5) A (5 to 10) A (10 to 15) A (15 to 20) A (20 to 25) A (25 to 30) A	0.4 nA 1.2 nA 10 nA 100 nA 1.6 μ A 16 μ A 0.26 mA 0.11 mA 0.21 mA 0.4 mA 0.6 mA 1.6 mA 1.7 mA 1.9 mA	Current Shunt method using Guildline 9230A- 30 & Keithley 2001
20. DC High Voltage	1 kV to 10 kV	5 mV/V + 3 V	Measurement using Kikusui 149-10A
21. AC High Voltage	1 kV to 10 kV @ 50 Hz & 60 Hz	10 mV/V + 5 V	Measurement using Kikusui 149-10A

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<u>Measuring Equipment</u>			
22. Earth Tester	0.1 Ω to 100 Ω 100 Ω to 1 M Ω	0.1 m Ω / Ω + 2 m Ω 0.5 m Ω / Ω + 0.05 Ω	Generating using Yokogawa 2793- 01, 2793-03
23. Insulation Tester/ High Voltage Insulation Tester	1 M Ω + 100 M Ω 100 M Ω to 1 G Ω @ up to 5 kV 1 G Ω to 10 G Ω @ up to 5 kV 10 G Ω to 1 T Ω @ up to 5 kV 1 T Ω to 10 T Ω @ up to 5 kV	2 m Ω / Ω 1 m Ω / Ω 2 m Ω / Ω 5 m Ω / Ω 3 m Ω / Ω	Generating using 2793-03 and IET HRRS-Q-5- 100M-5kV
24. Capacitance Meter 4 Wire Configuration	1pF to 1 uF <u>Fixed Value</u> 10 uF 100 uF 1000 uF	0.51 mF/F 0.5 mF/F 0.7 mF/F 4.1 mF/F	Generating using IET 1413, IET SCA-10uF, SCA -100uF and SCA-1000uF
25. Inductance Meter 4 Wire Configuration	Fixed Value 100 uH 1 mH 10 mH 100 mH	2.5 mH/H 1 mH/H 1 mH/H 1 mH/H	Generating using IET 1482-B, 1482-E, 1482-H, 1482-L, and 1482-P

Signatories:

1. **K.S. Manikandan**
2. **Rafizi Affandi**
3. **Liew Sin Chew**
4. *** Lalyn Soriano Duco**

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<u>RF Measuring Equipment</u> 26. RF Power Sensor Calibration Factor	Power Level 1.00 mW, Ref = 50 MHz 50 MHz to 1GHz 2 GHz to 5 GHz 6 GHz to 10 GHz 11 GHz to 18 GHz	1.6 % 1.7 % 1.9 % 2.6 %	Calibration Factor Type-N 50 Ω , Direct Comparison Method using N432A, 8478B, 11667A, NRVS & NRV-Z51
27. RF Measuring Equipment a) Frequency	0.1 Hz to 18 GHz	2.0×10^{-12}	Generating using calibrator model DS345, HP8665A, 68369B ext ref. to EC1S-SO with GPS disciplined
b) RF Power (50 Ω)	<u>-30 dBm to 20 dBm</u> DC to 30 MHz 30 MHz to 6 GHz 6 GHz to 8 GHz 8 GHz to 12.4 GHz 12.4 GHz to 15 GHz 15 GHz to 16 GHz 16 GHz to 18 GHz	0.10 dB 0.08 dB 0.09 dB 0.10 dB 0.12 dB 0.13 dB 0.14 dB	Characterized using 68369B, NRVS and NRV- Z52
<u>Generating Equipment:</u> 28. RF Generating Equipment a) Frequency	0.1 Hz to 18 GHz	2.0×10^{-12}	Measurement using CNT-90 ext ref to EC1S-SO with GPS disciplined
b) RF Power (50 Ω)	<u>-30 dBm to 20 dBm</u> DC to 30 MHz 30 MHz to 6 GHz 6 GHz to 8 GHz 8 GHz to 12.4 GHz 12.4 GHz to 15 GHz 15 GHz to 16 GHz 16 GHz to 18 GHz	0.09 dB 0.07 dB 0.08 dB 0.09 dB 0.11 dB 0.12 dB 0.14 dB	Measurement using NRVS and NRV-Z52

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Schedule

Issue date: 29 August 2018
Valid until: 30 September 2021



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Signatories:

1. Liew Sin Chew
2. Rafizi Affandi
3. Chan Boon Lye
4. K.S Manikandan

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SCOPE OF CALIBRATION: ELECTRICAL

Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>Measuring Instrument</u> 29. RF Measuring Equipment RF Power Meter	<u>Power Level</u> -25 dBm (3.1623 μ W) -20 dBm (10 μ W) -15 dBm (31.6228 μ W) -10 dBm (100 μ W) -5 dBm (316.2278 μ W) 0 dBm (1 mW) 5 dBm (3.1623 mW) 10 dBm (10 mW) 15 dBm (31.6228 mW) 20 dBm (100 mW)	0.020 μ W 0.017 μ W 0.026 μ W 0.02 μ W 0.04 μ W 0.0001 mW 0.0006 mW 0.002 mW 0.007 mW 0.030 mW	Generation using Agilent 11683A- H01 range calibrator, Fluke 5720A calibrator
Reference output	1mW @ 50 MHz	0.004 mW	Agilent N432A, HP 478A-H75 and HP3458A- 002

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SCOPE OF CALIBRATION: ELECTRICAL

Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
30. <u>RF Generating Equipment</u> a) Frequency Modulation Accuracy/Deviation	<p style="text-align: center;"><u>-18 to 30 dBm</u></p> <p>f_c: 250 kHz to 10 MHz f_m: 20 Hz to 10 kHz Δf = 200 Hz to 40 kHz $\beta > 0.2$ $\beta > 1.2$</p> <p>f_c: 10 MHz to 6.6 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 0.45$</p> <p>f_c: 6.6 GHz to 13.2 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 8$</p> <p>f_c: 13.2 GHz to 26.5 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 16$</p>	<p style="text-align: center;">0.015 Hz/Hz 0.010 Hz/Hz</p> <p style="text-align: center;">0.015 Hz/Hz 0.010 Hz/Hz</p> <p style="text-align: center;">0.025 Hz/Hz 0.010 Hz/Hz</p> <p style="text-align: center;">0.038 Hz/Hz 0.010 Hz/Hz</p>	<p style="text-align: center;">N5531S</p> <p>f_c = Carrier Frequency f_m = Modulation Rate Δf = Peak Deviation $\beta = \Delta f/f_m$</p>

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
b) Amplitude Modulation Depth	-18 to 30 dBm f _c : 100 kHz to 10 MHz f _m : 50 Hz to 10 kHz Depth: 5% to 99%	0.0075%/%	N5531S f _c = Carrier Frequency f _m = Modulation Rate
	f _c : 10 MHz to 3 GHz f _m : 50 Hz to 100 kHz Depth: 20% to 99% Depth: 5% to 20%	0.005%/% 0.025%/%	
	f _c : 3 GHz to 26.5 GHz f _m : 50 Hz to 100 kHz Depth: 20% to 99% Depth: 5% to 20%	0.015%/% 0.045%/%	
c) Phase Modulation Accuracy/Deviation	-18 to 30 dBm f _c : 100 kHz to 6.6 GHz $\Delta\phi$: 0.7 rad $\Delta\phi$: 0.3 rad	0.01 rad/rad 0.03 rad/rad	N5531S f _c = Carrier Frequency $\Delta\phi$ = Phase Deviation
	f _c : 6.6 GHz to 13.2 GHz $\Delta\phi$: 2.0 rad $\Delta\phi$: 0.6 rad	0.01 rad/rad 0.03 rad/rad	
	f _c : 13.2 GHz to 26.5 GHz $\Delta\phi$: 4.0 rad $\Delta\phi$: 1.2 rad	0.01 rad/rad 0.03 rad/rad	

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
d) Frequency Modulation Distortion	f_m : 20Hz to 1 kHz f_c : 1 MHz to 6.6 GHz Δf = 500 Hz to 2.0 kHz $\Delta f \geq 2.0$ kHz f_c : 6.6 GHz to 13.2 GHz $\Delta f \geq 2.3$ kHz $\Delta f \geq 4.5$ kHz f_c : 13.2 GHz to 26.5 GHz $\Delta f \geq 2.7$ kHz $\Delta f \geq 6.0$ kHz	 0.12 %/% + 0.3% 0.12 %/% + 0.1% 0.12 %/% + 0.3% 0.12 %/% + 0.1% 0.12 %/% + 0.3% 0.12 %/% + 0.1%	 N5531S f_c = Carrier Frequency f_m = Modulation Rate Δf = Deviation
e) Amplitude Modulation Distortion	0.01% to 100% f_m : 20 Hz to 1 kHz f_c : 100 kHz to 10 MHz Depth > 1% Depth > 3% f_c : 10 MHz to 26.5 GHz Depth > 1% Depth > 3%	 0.12 %/% + 0.8% 0.12 %/% + 0.3% 0.12 %/% + 1.0% 0.12 %/% + 0.4%	 N5531S f_c = Carrier Frequency f_m = Modulation Rate

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
f) Phase Modulation Distortion	<p><u>-18 to 30 dBm</u></p> <p>f_c: 100 kHz to 6.6 GHz f_m: 20 Hz to 500 Hz $\Delta\phi > 0.8$ rad $\Delta\phi > 2.5$ rad</p> <p>f_c: 1 MHz to 6.6 GHz f_m: 500 Hz to 1 kHz $\Delta\phi > 0.4$ rad $\Delta\phi > 1.0$ rad</p> <p>f_c: 6.6 GHz to 13.2 GHz f_m: 20 Hz to 500 Hz $\Delta\phi > 1.8$ rad $\Delta\phi > 5.5$ rad</p> <p>f_c: 6.6 GHz to 13.2 GHz f_m: 500 Hz to 1 kHz $\Delta\phi > 0.8$ rad $\Delta\phi > 2.5$ rad</p> <p>f_c: 13.2 GHz to 26.5 GHz f_m: 20 Hz to 500 Hz $\Delta\phi > 3.5$ rad $\Delta\phi > 10.0$ rad</p> <p>f_c: 13.2 GHz to 26.5 GHz f_m: 500 Hz to 1 kHz $\Delta\phi > 1.2$ rad $\Delta\phi > 4.0$ rad</p>	<p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p> <p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p> <p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p> <p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p> <p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p> <p>0.0012 %/% + 0.3% 0.0012 %/% + 0.1%</p>	<p>N5531S</p> <p>f_c = Carrier Frequency f_m = Modulation Rate $\Delta\phi$ = Phase Deviation</p>

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
g) Modulation Rate	100 kHz to 26.5 GHz		
Amplitude Modulation	$\Delta f \geq 2.3$ kHz $f_m \leq 100$ kHz	0.078 Hz	N5531S
Frequency Modulation	$\beta \geq 0.01$ $f_m \leq 200$ kHz	0.096 Hz	$f_m =$ Modulation Rate $\beta = \Delta f/f_m$
Phase Modulation	$\beta \geq 0.01$ $f_m \leq 20$ kHz	0.064 Hz	
h) Tuned RF Level	(See Matrix G & H)		N5531S (Option 1DS) with N5532B Sensor Module (Option 526)

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Matrix G: Tuned RF Level (Pre-amplifier ON)		
	Calibration Measurements Capability (dB)	
Level Range	30 MHz to 2 GHz	2 GHz to 3.05 GHz
10 to 16 dBm	0.25	0.36
0 to 10 dBm	0.24	0.36
-10 to 0 dBm	0.24	0.35
-20 to -10 dBm	0.24	0.36
-30 to -20 dBm	0.25	0.36
-40 to -30 dBm	0.25	0.37
-50 to -40 dBm	0.26	0.38
-60 to -50 dBm	0.27	0.38
-70 to -60 dBm	0.27	0.39
-80 to -70 dBm	0.28	0.40
-90 to -80 dBm	0.29	0.40
-100 to -90 dBm	0.29	0.41
-110 to -100 dBm	0.30	0.41
-120 to -110 dBm	0.30	0.42
-130 to -120 dBm	0.45	0.56
-140 to -130 dBm	0.86	0.98

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Matrix H: Tuned RF Level (Pre-amplifier OFF)				
	Calibration Measurements Capability (dB)			
Level Range	3.05 GHz to 6.6 GHz	6.6 GHz to 13.2 GHz	13.2 GHz to 18 GHz	18 GHz to 26.5 GHz
10 to 16 dBm	0.36	0.36	0.36	0.45
0 to 10 dBm	0.36	0.36	0.36	0.45
-10 to 0 dBm	0.35	0.35	0.35	0.44
-20 to -10 dBm	0.36	0.36	0.36	0.45
-30 to -20 dBm	0.36	0.36	0.36	0.45
-40 to -30 dBm	0.37	0.37	0.37	0.46
-50 to -40 dBm	0.38	0.38	0.38	0.47
-60 to -50 dBm	0.38	0.38	0.38	0.47
-70 to -60 dBm	0.37	0.39	0.39	0.48
-80 to -70 dBm	0.40	0.40	0.40	0.49
-90 to -80 dBm	0.40	0.40	0.40	0.49
-100 to -90 dBm	0.41	0.41	0.54	0.63
-110 to -100 dBm	0.41	0.55	0.96	1.05
-120 to -110 dBm	0.56	1.67		
-130 to -120 dBm	0.97			

Signatories:

1. **K.S. Manikandan**
2. **Liew Sin Chew**
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SCOPE OF CALIBRATION: ELECTRICAL**SITE: CATEGORY I**

Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 1. DC Voltage	(0 to 220) mV (0.0 to 2.2) V (0 to 11) V (0 to 22) V (0 to 220) V (0 to 1100) V	6 μ V/ V + 0.4 μ V 3.5 μ V/ V + 0.7 μ V 2.5 μ V/ V + 2.5 μ V 2.5 μ V/ V + 4 μ V 3.5 μ V/ V + 40 μ V 4.5 μ V/ V + 400 μ V	Generation using calibrator model Fluke 5720A
2. AC Voltage	<u>(0.0 to 220) V</u>	(See Matrix I)	

Matrix I AC Voltage Source

Range	Frequency (kHz)							
	0.01 to 0.02	0.02 to 0.04	0.04 to 20	20 to 50	50 to 100	100 to 300	300 to 500	500 to 1000
0 to 2.2mV	220 + 4	85 + 4	75 + 4	180 + 4	460 + 5	900 + 10	1200 + 20	2500 + 20
2.2mV to 22mV	220 + 4	85 + 4	75 + 4	180 + 4	460 + 5	900 + 10	1200 + 20	2500 + 20
22mV to 220mV	220 + 12	85 + 7	75 + 7	180 + 7	420 + 17	750 + 20	1200 + 25	2500 + 45
220mV to 2.2 V	220 + 40	80 + 15	40 + 8	70 + 10	105 + 30	340 + 80	900 + 200	1500 + 300
2.2V to 22V	220 + 0.4	80 + 0.15	40 + 0.05	70 + 0.1	95 + 0.2	260 + 0.6	900 + 2	1300 + 3.2
22V to 220V	220 + 4	80 + 1.5	47 + 0.6	75 + 1	130 + 2.5	-	-	-

The expanded uncertainties given at above table expressed in μ V/V + μ V for range 2.2 mV to 2.2 V while range 22 V to 220 V expressed in μ V/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 2. AC Voltage (Continued) 3. DC Current	(220 to 1100) V	(See Matrix J)	Generation using calibrator model Fluke 5720A, Fluke 5522A
	(0 to 220) μ A (0.0 to 2.2) mA (0 to 22) mA (0 to 220) mA (0.0 to 2.2) A	35 μ A/A + 6 nA 30 μ A/A + 7 nA 30 μ A/A + 40 nA 40 μ A/A + 0.7 μ A 60 μ A/A + 12 μ A	
	(2.2 to 2.9) A (2.9 to 10.9) A (10.9 to 20.0) A	0.38 mA/A + 40 μ A 0.50mA/A + 50 μ A 0.55 mA/A + 4.5 mA	Generation using calibrator model Fluke 5522A, Wavetek 9100 (with 10Turn & 50Turn Coil)
4. DC Current via Current Coils	(3.2 to 32) A (32 to 105) A (105 to 200) A (16 to 160) A (160 to 525) A (525 to 1000) A	0.60 mA/A + 1.2 mA 0.55 mA/A + 9.4 mA 0.55 mA/A + 45 mA 0.60 mA/A + 5.9 mA 0.55 mA/A + 47 mA 0.55 mA/A + 230 mA	

Matrix J AC Voltage Source (Continued)

Range	Frequency (kHz)							
	0.015 to 0.05	0.045 to 0.05	0.05 to 1	1 to 5	5 to 10	10 to 20	20 to 50	50 to 100
220 V to 250 V	0.26 + 16	0.19 + 2	0.06 + 3.5	0.2 + 6	0.2 + 6	0.25 + 6	0.3 + 6	2 + 50
250 V to 330 V	-	0.19 + 2	0.06 + 3.5	0.2 + 6	0.2 + 6	0.25 + 6	0.3 + 6	2 + 50
330 V to 1020 V	-	0.3 + 10	0.06 + 3.5	0.25 + 10	0.3 + 10	-	-	-
1020 V to 1100 V	-	-	0.06 + 3.5	-	-	-	-	-

The expanded uncertainties given in above table are expressed in mV/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/Instruments 5. AC Current	<u>(0 to 20) A</u>	(See Matrix K)	Generation using calibrator model Fluke5720A, Wavetek 9100

Matrix K AC Current Source

Range	Frequency (kHz)							
	0.01 to 0.02	0.02 to 0.04	0.04 to 1	1 to 3	3 to 5	5 to 10	10 to 20	20 to 30
0 to 32 μ A	0.23 + 0.016	0.14 + 0.01	0.11 to 0.008	0.25 + 0.012	0.25 + 0.012	0.9 + 0.065	2 + 6	2.5 + 9
32 μ A to 220 μ A	0.23 + 0.016	0.14 + 0.01	0.11 + 0.008	0.25 + 0.012	0.25 + 0.012	0.9 + 0.065	2 + 2	2.5 + 3
220 μ A to 320 μ A	0.23 + 0.04	0.14 + 0.035	0.11 + 0.035	0.18 + 0.11	0.18 + 0.11	0.9 + 0.65	2 + 2	2.5 + 3
320 μ A to 2.2mA	0.23 + 0.04	0.14 + 0.035	0.11 + 0.035	0.18 + 0.11	0.18 + 0.11	0.9 + 0.65	2 + 2	2.5 + 3
2.2mA to 3.2mA	0.23 + 0.4	0.14 + 0.35	0.11 + 0.35	0.18 + 0.55	0.18 + 0.55	0.9 + 5	2 + 2	2.5 + 3
3.2mA to 22mA	0.23 + 0.4	0.14 + 0.35	0.11 + 0.35	0.18 + 0.55	0.18 + 0.55	0.9 + 5	2 + 13	2.5 + 23
22mA to 32mA	0.23 + 4	0.14 + 3.5	0.11 + 2.5	0.18 + 3.5	0.18 + 3.5	0.9 + 10	2 + 13	2.5 + 23
32mA to 220mA	0.23 + 4	0.14 + 3.5	0.11 + 2.5	0.18 + 3.5	0.18 + 3.5	0.9 + 10	2 + 64	2 + 96
220mA to 32mA	-	0.24 + 35	0.24 + 35	0.39 + 80	0.39 + 80	6 + 160	2 + 64	2.5 + 96
320mA to 2.2A	-	0.24 + 35	0.24 + 35	0.39 + 80	0.39 + 80	6 + 160	-	-
2.2A to 3.2A	1 + 0.48	1 + 0.48	1 + 0.48	1 + 0.48	2.5 + 2.6	2.5 + 2.6	-	-
3.2A to 10.5A	2 + 3	2 + 3	2 + 3	2 + 3	5 + 10	5 + 10	-	-
10.5A to 20 A	2 + 6.9	2 + 6.9	2 + 6.9	2 + 6.9	5 + 23	5 + 23	-	-

The expanded uncertainties given at above table expressed in mA/A + μ A for range 0 A to 2.2 A while range 2.2 A to 20 A expressed in mA/A + mA

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/Instruments 6. AC Current via Current Coils	<u>(3.2 to 32.0) A</u> 10 Hz to 100 Hz 100 Hz to 440 Hz <u>(32.0 to 200.0) A</u> 10 Hz to 100 Hz 100 Hz to 440 Hz <u>(16.0 to 160.0) A</u> 10 Hz to 100 Hz <u>(160.0 to 1000.0) A</u> 10 Hz to 65 Hz	2.0 mA/A + 5.5 mA 7.8 mA/A + 27 mA 2.1 mA/A + 90 mA 6.7 mA/A + 0.25 A 2.0 mA/A + 28 mA 2.1 mA/A + 0.45 A	Generation using calibrator model Wavetek 9100 (10Turn & 50Turn Coil)
7. Wideband AC Voltage (Frequency from 30Hz To 500 kHz into 50 Ω Temperature	0.3 mV to 1.1 mV 1.1 mV to 3 mV 3 mV to 11 mV 11 mV to 33 mV 33 mV to 110 mV 110 mV to 330 mV 330 mV to 1.1 V 1.1 V to 3.5 V	5 mV/ V + 0.4 μ V 4.5 mV/ V + 1 μ V 3.5 mV/ V + 4 μ V 3 mV/ V + 10 μ V 3 mV/ V + 40 μ V 2.5 mV/ V + 100 μ V 2.5 mV/ V + 400 μ V 2 mV/ V + 500 μ V	Generation using calibrator model Fluke 5720A

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 7. Wideband AC Voltage (Continued) Amplitude Flatness at 1 kHz Reference	<u>(0.3 mV to 3.5) V</u>	(See Matrix L)	Generation using calibrator model Fluke 5720A

Matrix L Wideband ACV Amplitude Flatness

Range	Volts		
	1.1 mV	3 mV	3.5 V
10 Hz to 30 Hz	3	3	3
30 Hz to 120 Hz	1	1	1
120 Hz to 1.2 kHz	1	1	1
1.2 kHz to 12 kHz	1	1	1
12 kHz to 120 kHz	1	1	1
120 kHz to 1.2 MHz	2 + 3	1 + 3	1 + 3
1.2 MHz to 2 MHz	2 + 3	1 + 3	1 + 3
2 MHz to 10 MHz	4 + 3	1 + 3	2 + 3
10 MHz to 20 MHz	6 + 3	1 + 3	4 + 3
20 MHz to 30 MHz	15 + 15	15 + 15	10 + 3

The calibration uncertainties given at above table expressed in mV/V + μ V

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 8. Resistance Measuring Instrument	(Nominal Value) 0 Ω	40 $\mu\Omega$	Generation using calibrator model Fluke 5720A
	1 Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-1
	1.9 Ω	80 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	10 Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-10
	19 Ω 100 Ω 190 Ω 1 k Ω 1.9 k Ω	21 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 7.5 $\mu\Omega/\Omega$ 7.5 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	10 k Ω	4 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 742A-10k
	19 k Ω 100 k Ω 190 k Ω 1 M Ω 1.9 M Ω 10 M Ω 19 M Ω 100 M Ω	7.5 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 9 $\mu\Omega/\Omega$ 15 $\mu\Omega/\Omega$ 16 $\mu\Omega/\Omega$ 31 $\mu\Omega/\Omega$ 39 $\mu\Omega/\Omega$ 95 $\mu\Omega/\Omega$	Generation using calibrator model Fluke 5720A
	0.0 Ω to 10.9 Ω 11 to 32.9 Ω 33 to 109.9 Ω 110 to 1.09 k Ω 1.1 to 10.9 k Ω 11 to 109 k Ω 110 k to 1.09 M Ω 1.1 to 3.29 M Ω 3.3 to 10.9 M Ω 11 to 32.9 M Ω 33 to 109.9 M Ω 110 to 400 M Ω	0.04 m Ω/Ω + 1 m Ω 0.03 m Ω/Ω + 1.5 m Ω 0.028 m Ω/Ω + 1.4 m Ω 0.028 m Ω/Ω + 2 m Ω 0.028 m Ω/Ω + 0.02 Ω 0.028 m Ω/Ω + 0.2 Ω 0.032 m Ω/Ω + 2 Ω 0.06 m Ω/Ω + 30 Ω 0.13 m Ω/Ω + 50 Ω 0.25 m Ω/Ω + 2.5 k Ω 0.5 m Ω/Ω + 3 k Ω 0.6 m Ω/Ω + 40 k Ω	Generation using calibrator mode Fluke 5522A, Wavetek 9100

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 9. Capacitance	<u>Stim Repetition Rate \leq 350Hz</u> 0.5 to 4.0 nF 4.0 to 40.0 nF 40.0nF to 400.0 nF 0.4 to 4.0 μ F 4.0 to 40.0 μ F 40.0 to 400.0 μ F 0.4 to 4.0 mF 4.0 to 40.0 mF	3 mF/F + 15 pF 3 mF/F + 30 pF 3 mF/F + 160 pF 4 mF/F + 1.6 nF 5 mF/F + 16 nF 5 mF/F + 160 nF 5 mF/F + 1.6 μ F 10 mF/F + 60 μ F	
	<u>Stim Repetition Rate 350 to 1.5 kHz</u> 0.5 to 4.0 nF 4.0 to 40.0 nF 40.0 to 400.0 nF 0.4 to 4.0 μ F 4.0 to 40.0 μ F 40.0 to 400.0 μ F 0.4 to 4.0 mF 4.0 to 40.0 mF	6 mF/F + 30 pF 6 mF/F + 60 pF 6 mF/F + 320 pF 8 mF/F + 3.2 nF 10 mF/F + 32 nF 10 mF/F + 320 nF 10 mF/F + 3.2 μ F 20 mF/F + 120 μ F	

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 10. Vertical Amplitude a) Square Peak to Peak 1M Ω Load 50 Ω Load	200 μ V to 100 V 100 μ V Ω to 5 V	2.5 mV/ V + 1 μ V 2.5 mV/ V + 1 μ V	Generation using calibrator model Tek PG506A
b) DC 1M Ω Load 50 Ω Load	0 V to 130 V 4.44 mV to 2.78 V	0.5 mV/ V + 40 μ V 2.0 mV/ V + 40 μ V	Generation using calibrator model Fluke 5522A, Wavetek 9100
11. Time Base	1 ns 2 ns to 5 s	0.5 μ s/s 0.25 μ s/s	Generation using calibrator model Tek TG501A
12. Edge Function a) Output Period b) Rise Time 1M Ω Load 50 Ω Load c) Fall Time	100 ns to 10 ms 10 μ s to 10 ms 100 ns to 10 ms 100 ns to 10 ms	0.25 μ s/s 100 ns 1 ns 1 ns	Generation using calibrator model Wavetek 9100
13. Frequency a) Source	1 μ Hz to 0.5 Hz	5 μ Hz/Hz	Generation using calibrator model DS345
	0.5 Hz to 600 MHz	0.25 μ Hz/Hz	Generation using calibrator model Wavetek 9100
	600 MHz to 1050 MHz	20 mHz/Hz	Generation using calibrator model SG504

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
A. Indicating Meters/ Instruments 13. Frequency (Continued) b) Amplitude	(0.01 to 5.00) V _{pp} 1 μ Hz to 100 kHz 100 kHz to 20 MHz 20 MHz to 30.2 MHz	47 mV/ V 47 mV/ V 59 mV/ V	Generation using calibrator model DS345
	(5 to 10) V _{pp} 1 μ Hz to 100 kHz 100 kHz to 20 MHz 20 MHz to 30.2 MHz	23 mV/ V 23 mV/ V 35 mV/ V	
c) Amplitude Flatness at 50 kHz or 6MHz reference	50 kHz to 100 MHz 100 MHz to 250 MHz	10 mV/ V 20 mV/ V + 100 μ V	Generation using calibrator model SG503, Fluke 5522A
	250 MHz to 1050 MHz	40 mV/ V	Generation using calibrator model SG504
B. Source 14. DC Voltage 15. AC Voltage Source	(0 to 100) mV (0 to 1) V (0 to 10) V (0 to 100) V (0 to 1000) V (0 to 750) V	5.5 μ V/ V + 0.3 μ V 5.1 μ V/ V + 0.3 μ V 4.6 μ V/ V + 0.5 μ V 6.5 μ V/ V + 30 μ V 6.5 μ V/ V + 0.1 mV (See Matrix M)	Measurement using calibrator model HP3458A, Keithley 2001

Matrix M AC Voltage Measurement

Range	Frequency (kHz)									
	0.02 to 0.05	0.05 to 0.1	0.1 to 2	2 to 10	10 to 30	30 to 50	50 to 100	100 to 200	200 to 1000	1000 to 2000
200 mV	2.5 + 0.03	0.8 + 0.03	0.5 + 0.03	0.5 + 0.03	0.5 + 0.03	0.6 + 0.03	1.7 + 0.03	5 + 0.05	20 + 0.2	50 + 0.4
2 V	2.5 + 0.3	0.8 + 0.3	0.5 + 0.3	0.5 + 0.3	0.5 + 0.3	0.6 + 0.3	1.7 + 0.3	5 + 0.5	20 + 2	50 + 4
20 V	2.5 + 3	0.8 + 3	0.6 + 3	0.85 + 3	1.2 + 3	1.3 + 3	1.7 + 3	5 + 5	40 + 40	-
200 V	2.5 + 30	0.8 + 30	0.6 + 30	0.85 + 30	1.2 + 30	1.3 + 30	1.7 + 30	-	-	-
750 V	2.7 + 120	1.1 + 120	1.0 + 120	1.3 + 120	1.8 + 120	-	-	-	-	-

The calibration uncertainties given in this table are expressed in mV/V + mV

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
B. Source 16. DC Current	(0 to 100) μ A (0 to 1) mA (0 to 10) mA (0 to 100) mA (0 to 1) A (0 to 2) A	20 μ A/A + 0.8 nA 20 μ A/A + 5 nA 20 μ A/A + 50 nA 35 μ A/A + 0.5 μ A 105 μ A/A + 10 μ A 900 μ A/A + 40 μ A	Measurement using calibrator model HP3458A, Keithley 2001
	(0 to 10) A	2 mA/A + 0.7 mA	Measurement using calibrator model Fluke 45
17. AC Current	<u>(0 to 10) A</u>	(See Matrix N)	Measurement using calibrator model Keithley 2001, Fluke 45

Matrix N AC Current Measurement

Range	Frequency (kHz)			
	0.02 to 0.05	0.05 to 0.2	0.2 to 1	1 to 10
200 μA	3.5 + 0.00003	2 + 0.00003	4 + 0.00003	5 + 0.00003
2 mA	3.0 + 0.0003	1.5 + 0.0003	1.2 + 0.0003	1.2 + 0.0003
20 mA	3.0 + 0.003	1.5 + 0.003	1.2 + 0.003	1.2 + 0.003
200 mA	3.0 + 0.03	1.5 + 0.03	1.2 + 0.03	1.2 + 0.03
2 A	3.5 + 0.3	2 + 0.3	3 + 0.3	4.5 + 0.3
10 A	20 + 10	10 + 10	10 + 10	-

The calibration uncertainties given in this table are expressed in mA/A + mA

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
B. Source 18. Resistance	10 Ω 100 Ω 1 k Ω 10 k Ω 100 k Ω 1 M Ω 10 M Ω 100 M Ω	18 $\mu\Omega/\Omega$ + 0.05 m Ω 13 $\mu\Omega/\Omega$ + 0.5 m Ω 11 $\mu\Omega/\Omega$ + 0.5 m Ω 11 $\mu\Omega/\Omega$ + 5 m Ω 11 $\mu\Omega/\Omega$ + 0.05 Ω 15 $\mu\Omega/\Omega$ + 2 Ω 53 $\mu\Omega/\Omega$ + 100 Ω 0.505 m Ω/Ω + 1 k Ω	Measurement using calibrator model HP3458A

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>Generating Equipment</u> 19. DC Current	(0.1 to 1) μ A (1 to 10) μ A (10 to 100) μ A (100 to 1) mA (1 to 10) mA (10 to 100) mA (0.1 to 1) A (1 to 2) A (2 to 5) A (5 to 10) A (10 to 15) A (15 to 20) A (20 to 25) A (25 to 30) A	0.4 nA 1.2 nA 10 nA 100 nA 1.6 μ A 16 μ A 0.26 mA 0.11 mA 0.21 mA 0.4 mA 0.6 mA 1.6 mA 1.7 mA 1.9 mA	Current Shunt method using Guildline 9230A- 30 & Keithley 2001
20. DC High Voltage	1 kV to 10 kV	5 mV/V + 3 V	Measurement using Kikusui 149-10A
21. AC High Voltage	1 kV to 10 kV @ 50 Hz & 60 Hz	10 mV/V + 5 V	Measurement using Kikusui 149-10A

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>Measuring Instrument</u>			
22. Earth Tester	0.1 Ω to 100 Ω 100 Ω to 1 M Ω	0.1 m Ω / Ω + 2 m Ω 0.5 m Ω / Ω + 0.05 Ω	Generating using Yokogawa 2793- 01 and 2793-03
23. Insulation Tester/High Voltage Insulation Tester	1 M Ω to 100 M Ω 100 M Ω to 1 G Ω @ up to 5 kV 1 G Ω to 10 G Ω @ up to 5 kV 10 G Ω to 1 T Ω @ up to 5 kV 1 T Ω to 10 Ω T @ up to 5 kV	2 m Ω / Ω 1 m Ω / Ω 2 m Ω / Ω 5 m Ω / Ω 3 m Ω / Ω	Generating using Yokogawa 2793 03 and IET HRRS-Q-5- 100M-5 kV
24. Capacitance Meter 4-wire Configuration	1 pF to 1 μ F <u>Fixed value</u> 10 μ F 100 μ F 1000 μ F	0.51 mF/F 0.5 mF/F 0.7 mF/F 4.1 mF/F	Generating using IET 1413, IET SCA-10 μ F, SCA-100 μ F and SCA-1000 μ F
25. Inductance Meter 4-wire Configuration	<u>Fixed Value</u> 100 μ H 1 mH 10 mH 100 mH	2.5 mH/H 1 mH/H 1 mH/H 1 mH/H	Generating using IET 1482- B, 1482-E, 1482-H, 1482-L and 1482-P

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>RF Measuring Equipment</u> 26. RF Power Sensor Calibration Factor	<u>Power Level</u> 1.00 mW, Ref = 50 MHz 50 MHz to 1GHz 2 GHz to 5 GHz 6 GHz to 10 GHz 11 GHz to 18 GHz	1.6 % 1.7 % 1.9 % 2.6 %	Calibration Factor Type-N 50 Ω , Direct Comparison Method using N432A, 8478B, 11667A, NRVS & NRV-Z51
<u>27. RF Measuring Equipment</u> a) Frequency	0.1 Hz to 18 GHz	1.0×10^{-7}	Generating using calibrator model DS345, HP8665A, 68369B ext ref. to CNT90
b) RF Power (50 Ω)	<u>-30 dBm to 20 dBm</u> DC to 30 MHz 30 MHz to 6 GHz 6 GHz to 8 GHz 8 GHz to 12.4 GHz 12.4 GHz to 15 GHz 15 GHz to 16 GHz 16 GHz to 18 GHz	0.10 dB 0.08 dB 0.09 dB 0.10 dB 0.12 dB 0.13 dB 0.14 dB	Characterized using 68369B, NRVS and NRV- Z52
<u>Generating Equipment;</u> 28. RF Generating Equipment			
a) Frequency	0.1 Hz to 18 GHz	1.0×10^{-7}	Measurement using CNT-90
b) RF Power (50 Ω)	<u>-30 dBm to 20 dBm</u> DC to 30 MHz 30 MHz to 6 GHz 6 GHz to 8 GHz 8 GHz to 12.4 GHz 12.4 GHz to 15 GHz 15 GHz to 16 GHz 16 GHz to 18 GHz	0.09 dB 0.07 dB 0.08 dB 0.09 dB 0.11 dB 0.12 dB 0.14 dB	Measurement using NRVS and NRV-Z52

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FIELD OF CALIBRATION: ELECTRICAL

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<u>Measuring Instrument</u> 29. RF Measuring Equipment RF Power Meter	<u>Power Level</u> -25 dBm (3.1623 μ W) -20 dBm (10 μ W) -15 dBm (31.6228 μ W) -10 dBm (100 μ W) -5 dBm (316.2278 μ W) 0 dBm (1 mW) 5 dBm (3.1623 mW) 10 dBm (10 mW) 15 dBm (31.6228 mW) 20 dBm (100 mW)	0.020 μ W 0.017 μ W 0.026 μ W 0.02 μ W 0.04 μ W 0.0001 mW 0.0006 mW 0.002 mW 0.007 mW 0.030 mW	Generation using Agilent 11683A- H01 range calibrator, Fluke 5720A calibrator
	1mW @ 50 MHz	0.004 mW	Agilent N432A, HP 478A-H75 and HP3458A- 002

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
<p>30. <u>RF Generating Instrument</u></p> <p>a) Frequency Modulation Accuracy/Deviation</p>	<p><u>-18 to 30 dBm</u></p> <p>f_c: 250 kHz to 10 MHz f_m: 20 Hz to 10 kHz Δf = 200 Hz to 40 kHz $\beta > 0.2$ $\beta > 1.2$</p> <p>f_c: 10 MHz to 6.6 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 0.45$</p> <p>f_c: 6.6 GHz to 13.2 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 8$</p> <p>f_c: 13.2 GHz to 26.5 GHz f_m: 50 Hz to 200 kHz Δf = 250 Hz to 400 kHz $\beta > 0.2$ $\beta > 16$</p>	<p>0.015 Hz/Hz 0.010 Hz/Hz</p> <p>0.015 Hz/Hz 0.010 Hz/Hz</p> <p>0.025 Hz/Hz 0.010 Hz/Hz</p> <p>0.038 Hz/Hz 0.010 Hz/Hz</p>	<p>N5531S</p> <p>f_c = Carrier Frequency f_m = Modulation Rate Δf = Peak Deviation $\beta = \Delta f / f_m$</p>

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
b) Amplitude Modulation Depth	<u>-18 to 30 dBm</u> f_c : 100 kHz to 10 MHz f_m : 50 Hz to 10 kHz Depth: 5% to 99% f_c : 10 MHz to 3 GHz f_m : 50 Hz to 100 kHz Depth: 20% to 99% Depth: 5% to 20% f_c : 3 GHz to 26.5 GHz f_m : 50 Hz to 100 kHz Depth: 20% to 99% Depth: 5% to 20%	 0.0075 %/% 0.005 %/% 0.025 %/% 0.015 %/% 0.045 %/%	 N5531S f_c = Carrier Frequency f_m = Modulation Rate
c) Phase Modulation Accuracy/Deviation	<u>-18 to 30 dBm</u> f_c : 100 kHz to 6.6 GHz $\Delta\phi$: 0.7 rad $\Delta\phi$: 0.3 rad f_c : 6.6 GHz to 13.2 GHz $\Delta\phi$: 2.0 rad $\Delta\phi$: 0.6 rad f_c : 13.2 GHz to 26.5 GHz $\Delta\phi$: 4.0 rad $\Delta\phi$: 1.2 rad	 0.01 rad/rad 0.03 rad/rad 0.01 rad/rad 0.03 rad/rad 0.01 rad/rad 0.03 rad/rad	 N5531S f_c = Carrier Frequency $\Delta\phi$ = Phase Deviation

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
d) Frequency Modulation Distortion	f_m : 20 Hz to 1 kHz f_c : 1 MHz to 6.6 GHz $\Delta f = 500$ Hz to 2.0 kHz $\Delta f \geq 2.0$ kHz f_c : 6.6 GHz to 13.2 GHz $\Delta f \geq 2.3$ kHz $\Delta f \geq 4.5$ kHz f_c : 13.2 GHz to 26.5 GHz $\Delta f \geq 2.7$ kHz $\Delta f \geq 6.0$ kHz	 0.12 %/% + 0.3 % 0.12 %/% + 0.1 % 0.12 %/% + 0.3 % 0.12 %/% + 0.1 % 0.12 %/% + 0.3 % 0.12 %/% + 0.1 %	 N5531S f_c = Carrier Frequency f_m = Modulation Rate Δf = Deviation
e) Amplitude Modulation Distortion	0.01% to 100% f_m : 20 Hz to 1 kHz f_c : 100 kHz to 10 MHz Depth > 1% Depth > 3% f_c : 10 MHz to 26.5 GHz Depth > 1% Depth > 3%	 0.12 %/% + 0.8% 0.12 %/% + 0.3% 0.12 %/% + 1.0% 0.12 %/% + 0.4 %	 N5531S f_c = Carrier Frequency f_m = Modulation Rate

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
RF Generating Instrument (f) Phase Modulation Distortion	-18 to 30 dBm		
	f _c : 100 kHz to 6.6 GHz f _m : 20 Hz to 500 Hz $\Delta\phi > 0.8$ rad $\Delta\phi > 2.5$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	
	f _c : 1 MHz to 6.6 GHz f _m : 500 Hz to 1 kHz $\Delta\phi > 0.4$ rad $\Delta\phi > 1.0$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	
	f _c : 6.6 GHz to 13.2 GHz f _m : 20 Hz to 500 Hz $\Delta\phi > 1.8$ rad $\Delta\phi > 5.5$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	
	f _c : 6.6 GHz to 13.2 GHz f _m : 500 Hz to 1 kHz $\Delta\phi > 0.8$ rad $\Delta\phi > 2.5$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	
	f _c : 13.2 GHz to 26.5 GHz f _m : 20 Hz to 500 Hz $\Delta\phi > 3.5$ rad $\Delta\phi > 10.0$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	
	f _c : 13.2 GHz to 26.5 GHz f _m : 500 Hz to 1 kHz $\Delta\phi > 1.2$ rad $\Delta\phi > 4.0$ rad	0.0012 %/% + 0.3 % 0.0012 %/% + 0.1 %	

N5531S
f_c = Carrier Frequency
f_m = Modulation Rate
 $\Delta\phi$ = Phase Deviation

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Instrument Calibrated/ Measurement Parameter	Range	Calibration and Measurement Capability Expressed as an Uncertainty(\pm)*	Remarks
(g) Modulation rate	<u>100 kHz to 26.5 GHz</u>		
Amplitude Modulation	$\Delta f \geq 2.3$ kHz $f_m \leq 100$ kHz	0.078 Hz	N5531S $f_m =$ Modulation Rate $\beta = \Delta f/f_m$
Frequency Modulation	$\beta \geq 0.01$ $f_m \leq 200$ kHz	0.096 Hz	
Phase Modulation	$\beta \geq 0.01$ $f_m \leq 200$ kHz	0.064 Hz	
(h) Tuned RF Level	(See Matrix O & P)		N5531S (Option 1DS) with N5532B Sensor Module (Option 526)

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Matrix O: Tuned RF Level (Pre-amplifier ON)		
	Calibration Measurements Capability (dB)	
Level Range	30 MHz to 2 GHz	2 GHz to 3.05 GHz
10 to 16 dBm	0.25	0.36
0 to 10 dBm	0.24	0.36
-10 to 0 dBm	0.24	0.35
-20 to -10 dBm	0.24	0.36
-30 to -20 dBm	0.25	0.36
-40 to -30 dBm	0.25	0.37
-50 to -40 dBm	0.26	0.38
-60 to -50 dBm	0.27	0.38
-70 to -60 dBm	0.27	0.39
-80 to -70 dBm	0.28	0.40
-90 to -80 dBm	0.29	0.40
-100 to -90 dBm	0.29	0.41
-110 to -100 dBm	0.30	0.41
-120 to -110 dBm	0.30	0.42
-130 to -120 dBm	0.45	0.56
-140 to -130 dBm	0.86	0.98

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Matrix P: Tuned RF Level (Pre-amplifier OFF)				
	Calibration Measurements Capability (dB)			
Level Range	3.05 GHz to 6.6 GHz	6.6 GHz to 13.2 GHz	13.2 GHz to 18 GHz	18 GHz to 26.5 GHz
10 to 16 dBm	0.36	0.36	0.36	0.45
0 to 10 dBm	0.36	0.36	0.36	0.45
-10 to 0 dBm	0.35	0.35	0.35	0.44
-20 to -10 dBm	0.36	0.36	0.36	0.45
-30 to -20 dBm	0.36	0.36	0.36	0.45
-40 to -30 dBm	0.37	0.37	0.37	0.46
-50 to -40 dBm	0.38	0.38	0.38	0.47
-60 to -50 dBm	0.38	0.38	0.38	0.47
-70 to -60 dBm	0.37	0.39	0.39	0.48
-80 to -70 dBm	0.40	0.40	0.40	0.49
-90 to -80 dBm	0.40	0.40	0.40	0.49
-100 to -90 dBm	0.41	0.41	0.54	0.63
-110 to -100 dBm	0.41	0.55	0.96	1.05
-120 to -110 dBm	0.56	1.67		
-130 to -120 dBm	0.97			

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