



# **Agilent 8481A/D Power Sensors**

## **Calibration Guide**

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# Calibration Guide

This Calibration Guide provides calibration procedures for Agilent Technologies 8481A/D Power Sensors being delivered under U.S. Navy Contract Number N00104-07-R-DC15.

Manual Part Number 08481-90175

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Agilent Technologies 8481A/D  
Power Sensors



## INTRODUCTION

### Part 1 Agilent 8481A CAL FACTOR Measurement

The basic operating principle is to transfer the accuracy of a precisely calibrated laboratory standard Power Sensor (called a STANDARD Sensor) to the Power Sensor or device under test (called a DUT Sensor). The calibration system performs calibration factor measurements by first taking a measurement on a STANDARD Sensor traceable to NIST. The results are recorded and used later in the calibration factor calculation. The DUT Sensor is then connected and measured, and calibration factors are calculated using both the recorded results of the STANDARD Sensor and the measured results of the DUT Sensor. Cal factor data is now stored in an array which will be downloaded to the sensor's memory by the EEPROM build routine. Regardless of the model or type of power sensor being tested, the measurement is performed in three steps: (Note: *If an external Network Analyzer [Scaler or vector] is available, the DUT Sensor reflection coefficient is measured and stored prior to system calibration.*)

### Part 2 Agilent 8481A VECTOR ANA Reflection Measurement

The purpose of this test is to measure the Reflection Coefficients of Power Sensors over a frequency range of 10MHz to 18GHz. The test system consists of the 8510C Vector Network analyzer system and the 8360B Signal Source. S-Parameter Test Set 8515A along with Cal Kit 85052C are also used. If a Scalar Network Analyzer is used, measured reflection coefficient contains magnitude data only. If a Vector Network Analyzer is used, measured reflection coefficient contains magnitude and phase data. The test starts with a list of input frequencies defined according to the DUT model. These input frequencies are input to the Network Analyzer and a S11 measurement is performed. This test will run multiple sensors of the same model number. These results will be saved for later use.

### Part 3 Agilent 8481D CAL FACTOR Measurement

The basic operating principle is to transfer the accuracy of a precisely calibrated laboratory standard Power Sensor (called a STANDARD Sensor) to the Power Sensor or device under test (called a DUT Sensor). The calibration system performs calibration factor measurements by first taking a measurement on a STANDARD Sensor traceable to NIST. The results are recorded and used later in the calibration factor calculation. The DUT Sensor is then connected and measured, and calibration factors are calculated using both the recorded results of the STANDARD Sensor and the measured results of the DUT Sensor. Cal factor data is now stored in an array which will be downloaded to the sensor's memory by the EEPROM build routine. Regardless of the model or type of power sensor being tested, the measurement is performed in three steps: (Note: *If an external Network Analyzer [Scaler or vector] is available, the DUT Sensor reflection coefficient is measured and stored prior to system calibration.*)

#### Part 4 Agilent 8481D VECTOR ANA Reflection Measurement

The purpose of this test is to measure the Reflection Coefficients of Power Sensors over a frequency range of 10MHz to 18GHz. The test system consists of the 8510C Vector Network analyzer system and the 8360B Signal Source. S-Parameter Test Set 8515A along with Cal Kit 85052C are also used. If a Scalar Network Analyzer is used, measured reflection coefficient contains magnitude data only. If a Vector Network Analyzer is used, measured reflection coefficient contains magnitude and phase data. The test starts with a list of input frequencies defined according to the DUT model. These input frequencies are input to the Network Analyzer and a S11 measurement is performed. This test will run multiple sensors of the same model number. These results will be saved for later use.

#### Test Equipment Required

The following test equipment is required to perform some of the tests in this Calibration Guide:

- Agilent 8360B Signal Source
- Agilent 8510C Vector Network Analyzer
- Agilent 8515A Test Set with 85052C Calibration Kit

# **PART 1**

**Agilent 8481A CAL FACTOR Measurement**





## Performance Test Support Document

Test Name : Agilent 8481A CAL FACTOR Measurement Revision C

### Specification:

Frequency	Sum of Uncertainties +/- (%)
10MHz to <2GHz	0.7
2GHz to <12GHz	0.7 - 1.1
12GHz to 18GHz	1.2 - 1.5

### Description:

The basic operating principle is to transfer the accuracy of a precisely calibrated laboratory standard Power Sensor (called a STANDARD Sensor) to the Power Sensor or device under test (called a DUT Sensor). The calibration system performs calibration factor measurements by first taking a measurement on a STANDARD Sensor traceable to NIST. The results are recorded and used later in the calibration factor calculation. The DUT Sensor is then connected and measured, and calibration factors are calculated using both the recorded results of the STANDARD Sensor and the measured results of the DUT Sensor. Cal factor data is now stored in an array which will be downloaded to the sensor's memory by the EEPROM build routine. Regardless of the model or type of power sensor being tested, the measurement is performed in three steps: *(note-if an external Network Analyzer [Scaler or vector] is available, the DUT Sensor reflection coefficient is measured and stored prior to system calibration.)*

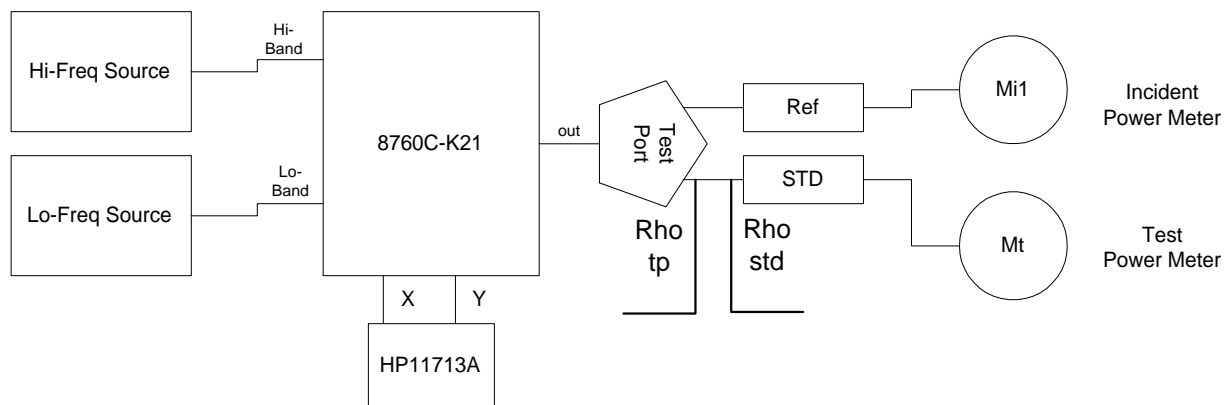
1. SYSTEM CALIBRATION: The source output is measured and adjusted to the correct level using the STANDARD Sensor. A measurement is then performed on both the STANDARD and REFERENCE Sensors to establish the incident power level. This sequence is repeated at all frequencies being measured.
2. SYSTEM VERIFICATION (optional): the system calibration is verified using a second Standards Lab Calibrated Power Sensor (Called a VERIFICATION Sensor).
3. DUT MEASUREMENT: The measurement is repeated with the DUT sensor in place of the STANDARD Sensor. The REFERENCE Sensor is used to compensate for variations that occur in the source output power level.

If the DUT Sensor reflection coefficient was not previously measured and stored, the system uncertainty is based on reflection coefficient values specified by the data sheet for the DUT Sensor model, and the report and label will provide calibration factor data only. If the DUT Sensor reflection coefficient was previously measured and stored, the measured reflection data is used to reduce or correct system uncertainty due to mismatch. In this case, the report provides effective efficiency, calibration factor, and reflection data. The label provides both calibration factor and reflection data. This test will run multiple sensors of the same model number. These results will be saved by serial number for later use.

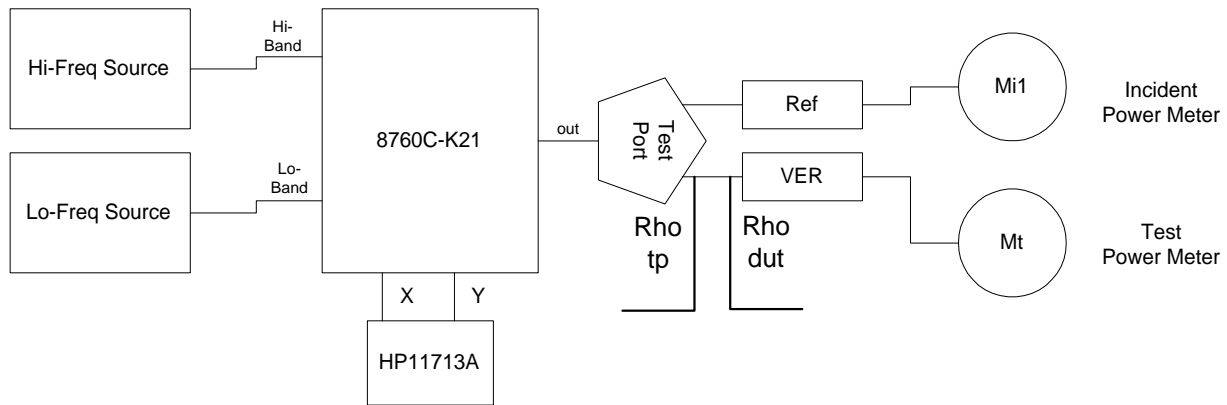
**Equipment:** (include cables and connectors)

Instrument	Critical Specifications (for this test)	Recommended Model
<b>Signal Sources</b>		
<b>Synthesized Sweeper</b>	Frequency:10 MHz to 18GHz	Agilent 83650B Agilent 8350B
<b>Power Meters</b>		
<b>Power Meter</b>	Dual Channel	Agilent E4419B
<b>Miscellaneous Devices</b>		
<b>Hi-Band Cable</b>	Hi-freq source to 8760C input connection	Agilent 8120-4948
<b>RF Interface</b>	Frequency:100KHz to 26.5MHz	Agilent 8760C-K21
<b>8760C output adapter</b>	3.5(f) to 3.5(f) 8760C output adapter	Agilent 5061-5311
<b>8760C output cable</b>	3.5(m) to 3.5(m) cable	Agilent 11500E
<b>Type N Adapter</b>	SMA(f) to Type N(m) Splitter input	Agilent 1250-1250
<b>Power Splitter</b>	10MHz to 18GHz/-30dBm to +20dBm	Agilent 11667A-H04
<b>Atten/Switch Driver</b>		Agilent 11713A
<b>Reference Sensor</b>	10MHz to 18GHz/-30dBm to +20dBm	Agilent 8481A
<b>Standard Sensor</b>	10MHz to 18GHz /-30dBm to +20dBm	Agilent 8481A-H84
<b>Verification Sensor</b>	10MHz to 18GHz /-30dBm to +20dBm	Agilent 8481A-H84

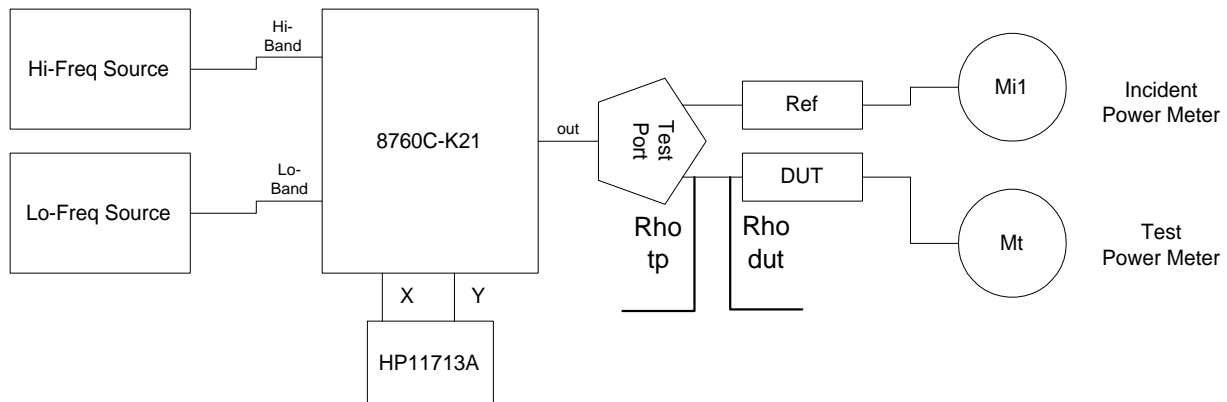
**Figure 1a System Calibration Setup**



**Figure 1b System Verification Setup**



**Figure 1c DUT Measurement Setup**



**Test Frequency list:**

10MHz, 30MHz, 50MHz, 100MHz, 300MHz, 500MHz, 1GHz to 12GHz(1GHz steps), 12.4GHz, 13GHz to 18GHz(1GHz steps).

**Test Procedure:**

**System Calibration**

1. Use Figure 1a, to set up equipment for System Calibration.
2. Preset all test equipment.
3. Set the 11713A to switch the HI band input of the 8760C-K21 directly to the RF output of the 8760C-K21.

4. Zero and Calibrate the REFERENCE Sensor to the E4419B power meter (Chan B).
5. Connect the REFERENCE Sensor to the Ref arm of the Power Splitter.
6. Set the Cal factor for the REFERENCE sensor to 100%.
7. Zero and Calibrate the STANDARD Sensor to the E4419B power meter (ChanA).
8. Connect the STANDARD Sensor to the Test arm of the Power Splitter.
9. Set the Source frequency to the next test freq. in the frequency list (10MHz).
10. Set the appropriate Cal factor for the STANDARD Sensor.
11. Set the Source output power to desired calibration power (0 dBm).
12. Adjust the Source output power until the Std power meter reads +/- .1dB of desired power.
13. Record readings for E4419B ChanA(x), ChanB(x) , and the Source power setting[freqx].
14. Divide ChanB(x)/ChanA(x) save this ratio as calRatio[freqx].
15. Repeat steps 9 through 14 for the remaining frequencies in the freq. list.

**System Verification** (optional)

16. Use Figure 1b, to set up equipment for System Verification.
17. Zero and Calibrate the VERIFICATION Sensor to the E4419B power meter (ChanA).
18. Connect the VERIFICATION Sensor to the Test arm of the Power Splitter.
19. Set the Source frequency to the next freq. in the frequency list (10MHz 1<sup>st</sup> time).
20. Set the Cal factor to 100%.
21. Adjust the source output power according to Source power setting[freqx] and ChanB(x).
22. Record readings for E4419B ChanA(x) and ChanB(x).
23. Divide ChanB(x)/ChanA(x) save this ratio as dutRatio[freqx].
24. Repeat steps 19 through 23 for the remaining frequencies in the freq. list.
25.  $DutData.data[freqx]=calRatio[freqx]/dutRatio[freqx]$ .
26. If vector reflection data exist for both the Power Splitter and the STANDARD perform mismatch correction *see section 4*; **a)** Convert the reflection magnitude and phase data of the Splitter and the STANDARD to rectangular using radians *see section 4.1*; **b)** Combine the complex numbers for the Splitter and the STANDARD *see section 4.2*; **c)** Normalize the complex result *see section 4.3*; **d)** Convert the complex result back to polar *see section 4.4*; **e)** Square result  $stdmatchCor[freqx]^2$ ; **f)** Perform correction :  $corData.data[freqx]=DutData.data[freqx]/stdmatchCor[freqx]$ .
27. If vector reflection data exist for both the Power Splitter and the VERIFICATION perform mismatch correction *see section 4*; **a)** Convert the reflection magnitude and phase data of the Splitter and the VERIFICATION to rectangular using radians *see section 4.1*; **b)** Combine the complex numbers for the Splitter and the VERIFICATION *see section 4.2*; **c)** Normalize the complex result *see section 4.3*; **d)** Convert the complex result back to polar *see section 4.4*; **e)** Square the result  $dutmatchCor[freqx]^2$ ; **f)** Perform correction:  $corData[freqx]=(corData.data[freqx]) \times (dutmatchCor[freqx])$ .
28. If vector or Scaler reflection data exist for the VERIFICATION, calculate  $U_{mm}$  by:  

$$U_{mm}=200 \times (\rho_{tp\_unc} \times (\rho_{std} + \rho_{dut})) + (\rho_{tp} \times (\rho_{std\_unc} + \rho_{dut\_unc}))$$
29. If no reflection data exist for the VERIFICATION, calculate  $U_{mm}$  by:  

$$U_{mm} = 200 \times ((\rho_{tp\_unc} \times \rho_{std}) + (\rho_{std\_unc} \times \rho_{tp})) + 100 \times (1+(\rho_{tp} \times \rho_{dut})^2 - 1$$

30. Calculate system uncertainty  $U_{cf} = \text{SQrt}(U_{std}^2 + U_{mm}^2 + U_{ran}^2 + U_{sys}^2)$  refer to the Measurement Uncertainty analysis section for an explanation of these terms.
31. Find the min and max data points of corData[freq] data array.
32. All data must be between 85% and 110% or else the unit fails.
33. Normalize the 50MHz point to 100% and apply the offset to shift the overall response curve.
34. Compare the corData[freqx] data to the VERIFICATION cf[freqx]. The difference should be less than  $\text{SQrt}(U_{cf}^2 + U_{cfver}^2)$ . If this is true then the system verified correct. If not run the verification over again.

### Dut Measurement

35. Use Figure 1c, to set up equipment for Dut Measurement.
36. Repeat steps 16 through 32 but substitute the DUT Sensor for VERIFICATION.
37. Save all data to an array which contains: (Frequency and Cal factor in percentage,). This array will be used in the EEPROM build.
38. Repeat steps 36 and 37 for the remaining 8481A sensors to be tested.

### **Measurement Uncertainty Analysis:**

#### **1.0 Measurand**

The measurand is the calibration factor  $K_b$  of the sensor under test.

#### **2.0 Measurement Equation**

Express mathematically the relationship between the measurand Y and the input quantities  $X_i$ .

$$Y = f(X_1 + X_2 + \dots + X_i)$$

Example:

The calibration factor  $K_b$ , is defined as:

$$K_b = K_s \times (M_t/M_s) \times (M_{i1}/M_{i2}) \times ((1 - \text{Rho}_{tp} \times \text{Rho}_{dut})^2 / (1 - \text{Rho}_{tp} \times \text{Rho}_{std})^2)$$

where,

$K_b$  is the cal factor of the DUT sensor.

$K_s$  is the cal factor of the STANDARD sensor.

$M_t$  is the reading of the DUT sensor.

$M_s$  is the reading of the STANDARD sensor.

$M_{i1}$  is the reading of the REFERENCE while measuring the STANDARD sensor.

$M_{i2}$  is the reading of the REFERENCE while measuring the DUT sensor.

$\text{Rho}_{tp}$  is the test port match of the power splitter.

$\text{Rho}_{dut}$  is the reflection coefficient of the DUT sensor.

$\text{Rho}_{std}$  is the reflection coefficient of the STANDARD sensor.

### 3.0 Uncertainty Equation

$$U_{cf} = \sqrt{U_{std}^2 + U_{mm}^2 + U_{ran}^2 + U_{sys}^2}$$

Where,

$U_{cf}$  is the uncertainty of  $K_b$

$U_{std}$  is the uncertainty of the STANDARD cal factor

$U_{mm}$  is total mismatch uncertainty:

For Vector or Scalar Analyzers  $U_{mm} =$

$$200 \times (UncRho_{tp} \times (Rho_{std} + Rho_{dut})) + (Rho_{tp} \times (UncRho_{std} + UncRho_{dut}))$$

For no Analyzer  $U_{mm} =$

$$200 \times ((UncRho_{tp} \times Rho_{std}) + (UncRho_{std} \times Rho_{tp})) + 100 \times (1 + (Rho_{tp} \times Rho_{dut})^2) \div 1$$

where  $UncRho_{tp}$  is the uncertainty of the test port match for the splitter.

$UncRho_{std}$  is the uncertainty of the reflection coefficient for the STANDARD sensor.

$UncRho_{dut}$  is the uncertainty of the reflection coefficient for the DUT sensor.

$U_{ran}$  is uncertainty associated with random drift and connector repeatability errors of the System and the DUT sensor (measured by making more than 1 connection of Specifying data sheet values.

$U_{sys}$  is system uncertainty calculated by taking the total (RSS) of the following errors:

$$\sqrt{P_{mt}^2 + P_{mr}^2 + M_{uc}^2 + P_{mc1}^2 + P_{mc2}^2 + D_t^2 + D_r^2 + Z_s^2 + N_1^2 + N_2^2 + P_{cal}^2}$$

### 3.1 Sensitivity Coefficient ( $C_i$ )

By inspection the sensitivity coefficients are 1

### 3.2 Covariance

All variables are independent, the covariance is 0

### 3.3 Standard Uncertainty ( $U_{xi}$ )

Uncertainty expressed as a standard deviation.

Example:

All the standard uncertainties listed in this section are Type B standard uncertainties.

### 3.4 Combined Standard Uncertainty Tables

Show an example of all uncertainty contributions in a table along with their probability distribution.

**Total Uncertainty Budget**

Symbol	Source of Uncertainty	Value +/- %	Probability distribution	Divisor (SF)	Uxi +/-%
U <sub>std</sub>	Standard Cal Factor		Gaussian	2	
U <sub>mm</sub>	Total Mismatch	$ \Gamma_g $ $ \Gamma_s $	Uniform	(1)	
U <sub>ran</sub>	Random drift/connections	.5%	Gaussian	2	.25%
(P <sub>mt</sub> )	Test power meter instrumentation	.5%	Rectangular	$\sqrt{3}$	.29%
(P <sub>mr</sub> )	Ref power meter instrumentation	.5%	Rectangular	$\sqrt{3}$	.29%
(M <sub>uc</sub> )	50Mhz Ref Mismatch	$ \Gamma_g =0.024$ $ \Gamma_s =0.048$	Uniform	(1)	.081%
(P <sub>mc1</sub> )	Ref Cal Uncert STD	.5%	Rectangular	$\sqrt{3}$	.29%
(P <sub>mc2</sub> )	Ref Cal Uncert DUT	.5%	Rectangular	$\sqrt{3}$	.29%
(D <sub>t</sub> )	Test power meter drift	+/-10nW	Rectangular	$\sqrt{3}$	.00058%
(D <sub>r</sub> )	Ref power meter drift	+/-10nW	Rectangular	$\sqrt{3}$	.00058%
(Z <sub>s</sub> )	Zero Set	+/-50nW	Rectangular	$\sqrt{3}$	.0000%
(N <sub>1</sub> )	Noise STD meter	+/-110nW	Rectangular	$\sqrt{3}$	.0000%
(N <sub>2</sub> )	Noise REF meter	+/-110nW	Rectangular	$\sqrt{3}$	.0000%
(P <sub>cal</sub> )	Calibrator output power	.9%	Gaussian	2	.45%
U <sub>sys</sub>	Combined uncertainty-RSSed				.739%
U <sub>cf</sub>	Overall combined uncertainty-RSSed				
	Expanded uncertainty		K=2		

## **4.0 Conversion Equations**

### **4.1 Polar to Rectangular conversion using Radians**

$$\text{Ang\_rad} = \text{Angle} / 57.2957795$$

$$\text{Real} = \text{Mag} \times \text{COS}(\text{Ang\_rad})$$

$$\text{Imaginary} = \text{Mag} \times \text{SIN}(\text{Ang\_rad})$$

### **4.2 Combine complex data for the SPLITTER AND SENSOR**

$$\text{Real} = (\text{Real\_splitter} \times \text{Real\_sensor}) - (\text{imaginary\_splitter} \times \text{imaginary\_sensor})$$

$$\text{Imaginary} = (\text{Real\_splitter} \times \text{imaginary\_sensor}) + (\text{Real\_sensor} \times \text{imaginary\_splitter})$$

### **4.3 Normalize Complex result**

$$\text{Real} = (1 - \text{Real\_complex})$$

$$\text{Imaginary} = (0 - \text{imaginary\_complex})$$

### **4.4 Convert rectangular complex to polar**

$$\text{Mag} = \text{SQRT}(\text{Real\_complex}^2 + \text{Imaginary\_complex}^2)$$

$$\text{Denom} = \text{Real\_complex} + \text{Mag}$$

$$\text{If Denom} = 0 \text{ Then Angle} = 180$$

$$\text{If Denom} \neq 0 \text{ Then Angle} = 2 \times \text{ARCTAN}(\text{Imaginary\_complex} / \text{Denom}) \times 57.2957795$$



## **PART 2**

**Agilent 8481A VECTOR ANA Reflection Measurement**



## Performance Test Support Document

**Test Name : Agilent 8481A VECTOR ANA Reflection Measurement Rev C**

### Specification:

Frequency	Specification SWR(Rho)
10MHz to <30MHz	<1.40 (0.166)
30MHz to <50MHz	<1.18 (0.083)
50MHz to <2GHz	<1.10 (0.048)
2GHz to <12.4GHz	<1.18 (0.083)
12.4GHz to 18GHz	<1.28 (0.123)

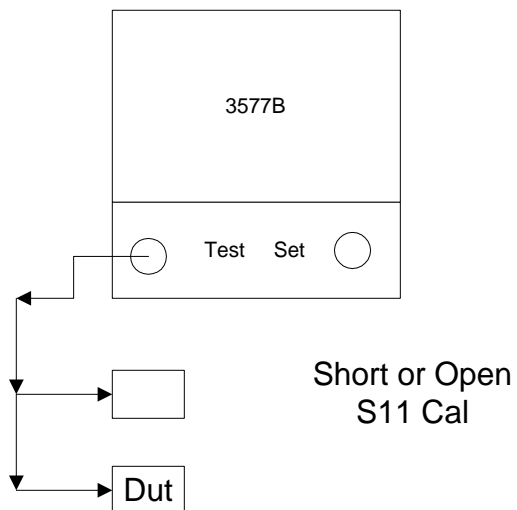
### Description:

The purpose of this test is to measure the Reflection Coefficients of Power Sensors over a frequency range of 10MHz to 18GHz. The test system consists of the 8510C Vector Network analyzer system and the 8360B Signal Source. S-Parameter Test Set 8515A along with Cal Kit 85052C are also used. If a Scalar Network Analyzer is used, measured reflection coefficient contains magnitude data only. If a Vector Network Analyzer is used, measured reflection coefficient contains magnitude and phase data. The test starts with a list of input frequencies defined according to the DUT model. These input frequencies are input to the Network Analyzer and a S11 measurement is performed. This test will run multiple sensors of the same model number. These results will be saved for later use.

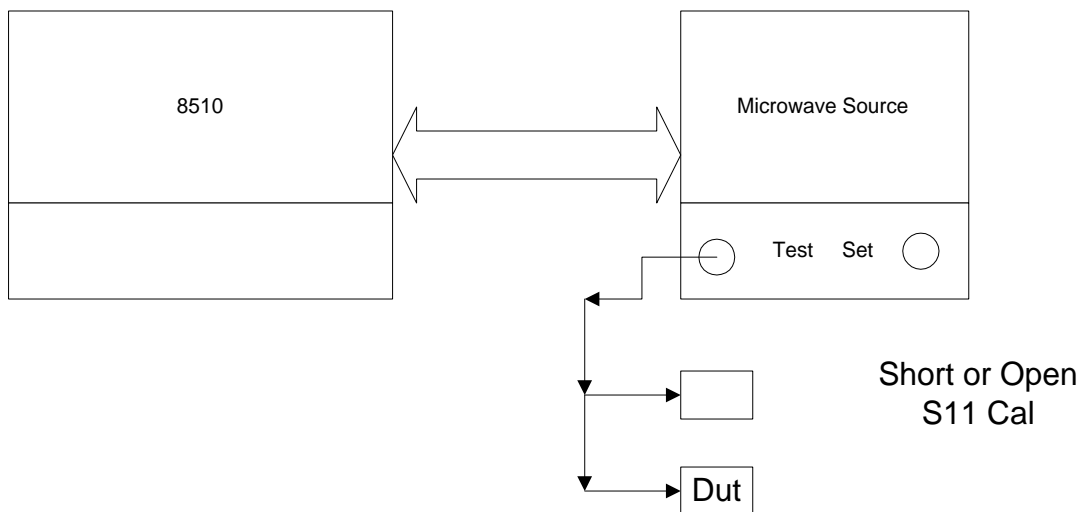
### Equipment: *(include cables and connectors)*

Instrument	Critical Specifications (for this test)	Recommended Model
<b>Signal Sources</b>		
<b>Synthesized Sweeper</b>	Frequency:10 MHz to 18 GHz	Agilent 83650B
<b>Analyzers</b>		
<b>Network Analyzer</b>	Frequency:100KHz to 50MHz Substitution 50MHz to 18 GHz	Agilent 3577A/B Agilent 8751A Agilent 8510C
<b>Miscellaneous Devices</b>		
<b>S-Parameter Test Sets</b>	Directivity>40dB /Test Port Match<1.07	Agilent35677A(3577A/ B)
<b>Cal Kits</b>	$i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ}$ $i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} <1.$ Agilent quality	Agilent 87511A(8751A) Agilent 8515A(8510C) Agilent35678A(3577A/ B)
<b>Adapter Set</b>	3.5 to Type N (8515A)	Agilent 85032B(8751A) Agilent 85054D(8510C) Agilent 85130C

**Figure 1a Vector Reflection Test Setup, <50MHz**



**Figure 1b Vector Reflection Test Setup, >50MHz**



## Test Procedure:

1. Use Figure 1, to set up equipment.
2. Preset the UUT and all test equipment.
3. Initialize the test equipment parameters as follows:

### Network Analyzer

Parameter	Setting
Channel [1]	Chan 1 S <sub>11</sub>
Channel [1]	LIN mkr on POLAR
Channel [2]	Chan 2 S <sub>21</sub>
# TRACE POINTS	201
Start frequency	10MHz(low band) or 50MHz(high band)
Stop frequency	50MHz(low band) or 18GHz(high band)
Power Level	0dBm

4. Perform reflection calibration of the Analyzer using the Cal kit
  - A) Press [S<sub>11</sub>] [CAL] CAL 1, CALIBRATE: S<sub>11</sub> 1-PORT.
  - B) At Port 1, connect a shielded open circuit.
  - C) When the trace is correct, press (S<sub>11</sub>): OPEN. Open circuit data is measured.
  - D) At Port 1, connect a short circuit.
  - E) When the trace is correct, press (S<sub>11</sub>): SHORT. Short circuit data is measured.
  - F) Press (S<sub>11</sub>): LOADS to present the loads menu. If the frequency sweep crosses 2 GHz, then both the LOWBAND and SLIDING loads, or the BROADBAND load must be used.
  - G) At Port 1 connect a fixed load.
  - H) When the trace is correct, press LOWBAND. Load data is measured.
  - I) At Port 1, connect a sliding load.
  - J) Move sliding element to the first index mark; then, when the trace is correct, press SLIDE IS SET. Load data is measured.
  - K) Repeat 5 to 8 times each time moving the sliding element to the next index mark, then pressing SLIDE IS SET.
  - L) Press SLIDING LOAD DONE.
  - M) Press DONE LOADS. If the message ADDITIONAL STANDARDS NEEDED appears, then the loads were not specified for the current frequency range (for

example, only the LOWBAND load was used for a sweep that crossed 2 GHz).

- N) Press SAVE 1-PORT CAL then select CAL SET 1. (Error coefficients are computed and stored; Cal menu is displayed with CORRECTION ON).
  - O) Corrected S<sub>11</sub> trace is displayed.
  - P) Connect the test device.
  - Q) Measure S<sub>11</sub>.
5. Connect the DUT to port 1 of the S-Parameter test set.
  6. Press [MARKER] and position to read S-Parameter. The magnitude is given in linear terms ( $\rho$ ) and an angle  $\angle\phi$ , in degrees.
  7. Compare the data with the spec and save to a file.

## Measurement Uncertainty Analysis:

### 1.0 Measurand

The measurand is the Reflection Coefficient of the Power Sensor as measured by the Network Analyzer.

### 2.0 Measurement Equation

Express mathematically the relationship between the measurand Y and the input quantities X<sub>i</sub>.

$$Y = f(X_1 + X_2 + \dots + X_i)$$

Example:

The Reflection Coefficient, Y, is defined as:

$$Y = (\text{Power}_{\text{refl}}/\text{Power}_{\text{inc}})$$

where,

Power<sub>refl</sub> is the reflected power.

Power<sub>inc</sub> is the power incident to the DUT.

### 3.0 Uncertainty Equation

The total uncertainty is taken from the Measurement Uncertainty curves of the Network Analyzer in use. Refer to the Network Analyzer's documentation for more information on the measurement uncertainty equations and the uncertainty terms.

$$U_{\text{rho}} = A + (C * \text{Rho}^2)$$

Where,

U<sub>rho</sub> is the uncertainty of Rho

A is directivity

C is source match

Rho is the measured rho of DUT

### **3.1 Sensitivity Coefficient ( $C_i$ )**

By inspection the sensitivity coefficients are 1

### **3.2 Covariance**

All variables are independent, the covariance is 0

### **3.3 Standard Uncertainty ( $U_{x_i}$ )**

Uncertainty expressed as a standard deviation.

Example:

All the standard uncertainties listed in this section are Type B standard uncertainties. The value of each standard uncertainty is determined by the DUT and Analyzer system specifications, documented in the User's/Calibration Guides

### 3.4 Combined Standard Uncertainty Tables

Show an example of all uncertainty contributions in a table along with their probability distribution.

#### Total Uncertainty Budget

Symbol	Source of Uncertainty	Value	C * Rho <sup>2</sup>	Combined Std Unc +/- A+(C*Rho <sup>2</sup> )
A	Directivity(3577A/B) 10MHz to 50MHz	.01(40)		
	Directivity(8510C) .045GHz to 2GHz	.004(48)		
	2GHz to 8GHz	.003(50)		
	8GHz to 20GHz	.003(50)		
	20GHz to 26.5GHz	.003(50)		
C	Sour match(3577A/B) 10MHz to 50MHz	.032(30)		
	Source match(8510) .045GHz to 2GHz	.01(40)		
	2GHz to 8GHz	.003(50)		
	8GHz to 20GHz	.003(50)		
	20GHz to 26.5GHz	.003(50)		
Rho	8481A Rho Spec: 10MHz to <30MHz	.166	.000882	.010882
	30MHz to <50MHz	.083	.00022	.01022
	50MHz to <2GHz	.048	.0000069	.00401
	2GHz to <12.4GHz	.083	.000021	.00402
	12.4GHz to 18GHz	.123	0.000045	.00405



## **PART 3**

### **Agilent 8481D CAL FACTOR Measurement**



## Performance Test Support Document

Test Name : Agilent 8481D CAL FACTOR Measurement Revision C

### Specification:

Frequency	Sum of Uncertainties +/- (%)
10MHz to <2GHz	0.8
2GHz to <12GHz	0.8 - 1.2
12GHz to 18GHz	1.2 -1.5

### Description:

The basic operating principle is to transfer the accuracy of a precisely calibrated laboratory standard Power Sensor (called a STANDARD Sensor) to the Power Sensor or device under test (called a DUT Sensor). The calibration system performs calibration factor measurements by first taking a measurement on a STANDARD Sensor traceable to NIST. The results are recorded and used later in the calibration factor calculation. The DUT Sensor is then connected and measured, and calibration factors are calculated using both the recorded results of the STANDARD Sensor and the measured results of the DUT Sensor. Cal factor data is now stored in an array which will be downloaded to the sensor's memory by the EEPROM build routine. Regardless of the model or type of power sensor being tested, the measurement is performed in three steps: *(note-if an external Network Analyzer [Scaler or vector] is available, the DUT Sensor reflection coefficient is measured and stored prior to system calibration.)*

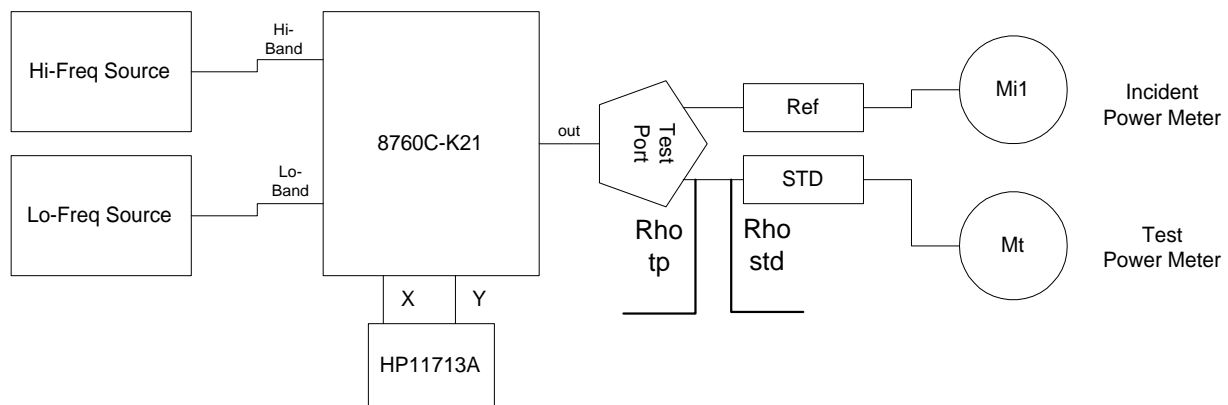
1. SYSTEM CALIBRATION: The source output is measured and adjusted to the correct level using the STANDARD Sensor. A measurement is then performed on both the STANDARD and REFERENCE Sensors to establish the incident power level. This sequence is repeated at all frequencies being measured.
2. SYSTEM VERIFICATION (optional): the system calibration is verified using a second Standards Lab Calibrated Power Sensor (Called a VERIFICATION Sensor).
3. DUT MEASUREMENT: The measurement is repeated with the DUT sensor in place of the STANDARD Sensor. The REFERENCE Sensor is used to compensate for variations that occur in the source output power level.

If the DUT Sensor reflection coefficient was not previously measured and stored, the system uncertainty is based on reflection coefficient values specified by the data sheet for the DUT Sensor model, and the report and label will provide calibration factor data only. If the DUT Sensor reflection coefficient was previously measured and stored, the measured reflection data is used to reduce or correct system uncertainty due to mismatch. In this case, the report provides effective efficiency, calibration factor, and reflection data. The label provides both calibration factor and reflection data. This test will run multiple sensors of the same model number. These results will be saved by serial number for later use.

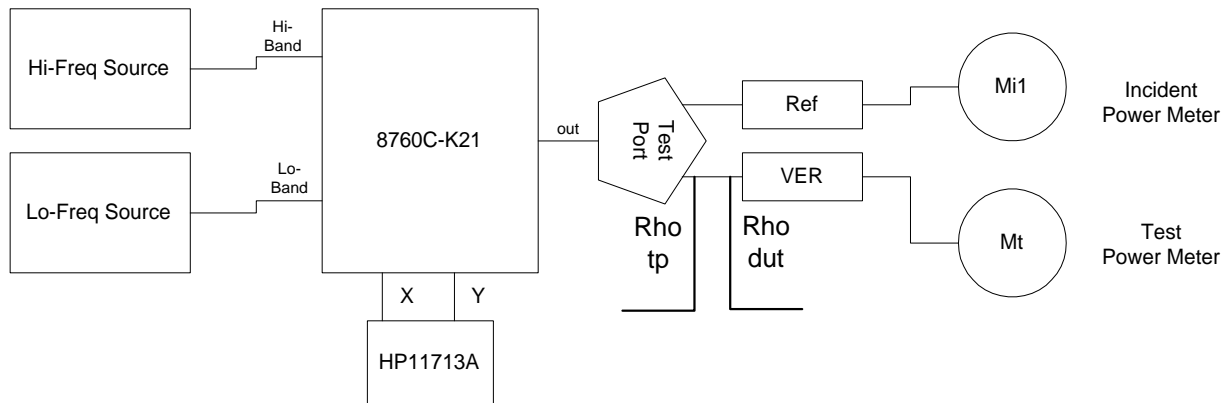
**Equipment:** (include cables and connectors)

Instrument	Critical Specifications (for this test)	Recommended Model
<b>Signal Sources</b>		
<b>Synthesized Sweeper</b>	Frequency:10 MHz to 18GHz	Agilent 83650B Agilent 8350B
<b>Power Meters</b>		
<b>Power Meter</b>	Dual Channel	Agilent E4419B
<b>Miscellaneous Devices</b>		
<b>Hi-Band Cable</b>	Hi-freq source to 8760C input connection	Agilent 8120-4948
<b>RF Interface</b>	Frequency:100KHz to 26.5MHz	Agilent 8760C-K21
<b>8760C output adapter</b>	3.5(f) to 3.5(f) 8760C output adapter	Agilent 5061-5311
<b>8760C output cable</b>	3.5(m) to 3.5(m) cable	Agilent 11500E
<b>Type N Adapter</b>	SMA(f) to Type N(m) Splitter input	Agilent 1250-1250
<b>Power Splitter</b>	10MHz to 18GHz/-30dBm to +20dBm	Agilent 11667A-H04
<b>Atten/Switch Driver</b>		Agilent 11713A
<b>Reference Sensor</b>	10MHz to 18GHz/-30dBm to +20dBm	Agilent 8481D
<b>Standard Sensor</b>	10MHz to 18GHz /-30dBm to +20dBm	Agilent 8481D-H84
<b>Verification Sensor</b>	10MHz to 18GHz /-30dBm to +20dBm	Agilent 8481D-H84
<b>30dBm Fix Attenuator</b>	50MHz / 0dBm Only	Agilent 11708A

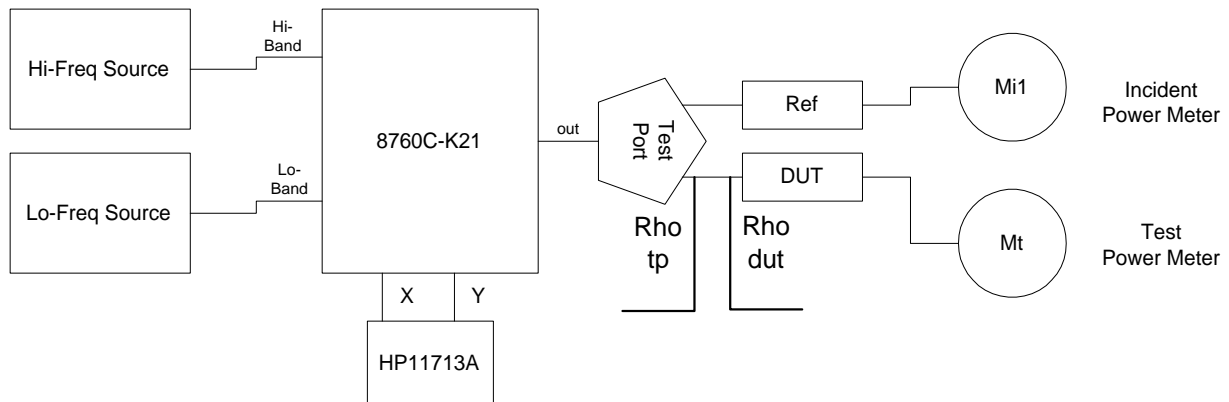
**Figure 1a System Calibration Setup**



**Figure 1b System Verification Setup**



**Figure 1c DUT Measurement Setup**



**Test Frequency list:**

10MHz, 30MHz, 50MHz, 100MHz, 300MHz, 500MHz, 1GHz to 12GHz(1GHz steps), 12.4GHz, 13GHz to 18GHz(1GHz steps).

**Test Procedure:**

**System Calibration**

1. Use Figure 1a, to set up equipment for System Calibration.
2. Preset all test equipment.
3. Set the 11713A to switch the HI band input of the 8760C-K21 directly to the RF output of the 8760C-K21.

4. Connect the 11708A 30dBm fix attenuator to the power meter reference port.
5. Zero and Calibrate the REFERENCE Sensor to the E4419B power meter (Chan B).
6. Connect the REFERENCE Sensor to the Ref arm of the Power Splitter.
7. Set the Cal factor for the REFERENCE sensor to 100%.
8. Zero and Calibrate the STANDARD Sensor to the E4419B power meter (ChanA).
9. Connect the STANDARD Sensor to the Test arm of the Power Splitter.
10. Set the Source frequency to the next test freq. in the frequency list (10MHz).
11. Set the appropriate Cal factor for the STANDARD Sensor.
12. Set the Source output power to desired calibration power -30dBm.
13. Adjust the Source output power until the Std power meter reads +/- .1dB of desired power.
14. Record readings for E4419B ChanA(x), ChanB(x) , and the Source power setting[freqx].
15. Divide ChanB(x)/ChanA(x) save this ratio as calRatio[freqx].
16. Repeat steps 9 through 14 for the remaining frequencies in the freq. list.

#### **System Verification** (optional)

17. Use Figure 1b, to set up equipment for System Verification.
18. Zero and Calibrate the VERIFICATION Sensor to the E4419B power meter (ChanA).
19. Connect the VERIFICATION Sensor to the Test arm of the Power Splitter.
20. Set the Source frequency to the next freq. in the frequency list (10MHz 1<sup>st</sup> time).
21. Set the Cal factor to 100%.
22. Adjust the source output power according to Source power setting[freqx] and ChanB(x).
23. Record readings for E4419B ChanA(x) and ChanB(x).
24. Divide ChanB(x)/ChanA(x) save this ratio as dutRatio[freqx].
25. Repeat steps 19 through 23 for the remaining frequencies in the freq. list.
26.  $DutData.data[freqx]=calRatio[freqx]/dutRatio[freqx]$ .
27. If vector reflection data exist for both the Power Splitter and the STANDARD perform mismatch correction *see section 4*; **a)** Convert the reflection magnitude and phase data of the Splitter and the STANDARD to rectangular using radians *see section 4.1*; **b)** Combine the complex numbers for the Splitter and the STANDARD *see section 4.2*; **c)** Normalize the complex result *see section 4.3*; **d)** Convert the complex result back to polar *see section 4.4*; **e)** Square result  $stdmatchCor[freqx]^2$ ; **f)** Perform correction :  $corData.data[freqx]=DutData.data[freqx]/stdmatchCor[freqx]$ .
28. If vector reflection data exist for both the Power Splitter and the VERIFICATION perform mismatch correction *see section 4*; **a)** Convert the reflection magnitude and phase data of the Splitter and the VERIFICATION to rectangular using radians *see section 4.1*; **b)** Combine the complex numbers for the Splitter and the VERIFICATION *see section 4.2*; **c)** Normalize the complex result *see section 4.3*; **d)** Convert the complex result back to polar *see section 4.4*; **e)** Square the result  $dutmatchCor[freqx]^2$ ; **f)** Perform correction:  $corData[freqx]=(corData.data[freqx]) \times (dutmatchCor[freqx])$ .
29. If vector or Scaler reflection data exist for the VERIFICATION, calculate Umm by:  
 $U_{mm}=200 \times (\rho_{tp\_unc} \times (\rho_{std} + \rho_{dut})) + (\rho_{tp} \times (\rho_{std\_unc} + \rho_{dut\_unc}))$ .
30. If no reflection data exist for the VERIFICATION, calculate Umm by:

$$U_{mm} = 200 \times ((\rho_{tp\_unc} \times \rho_{std}) + (\rho_{std\_unc} \times \rho_{tp})) + 100 \times (1 + (\rho_{tp} \times \rho_{dut})^2) - 1$$

31. Calculate system uncertainty  $U_{cf} = \text{SQRT}(U_{std}^2 + U_{mm}^2 + U_{ran}^2 + U_{sys}^2)$  refer to the Measurement Uncertainty analysis section for an explanation of these terms.
32. Find the min and max data points of corData[freq] data array.
33. All data must be between 85% and 110% or else the unit fails.
34. Normalize the 50MHz point to 100% and apply the offset to shift the overall response curve.
35. Compare the corData[freqx] data to the VERIFICATION cf[freqx]. The difference should be less than  $\text{SQRT}(U_{cf}^2 + U_{cver}^2)$ . If this is true then the system verified correct. If not run the verification over again.

### Dut Measurement

36. Use Figure 1c, to set up equipment for Dut Measurement.
37. Repeat steps 16 through 32 but substitute the DUT Sensor for VERIFICATION.
38. Save all data to an array which contains: (Frequency and Cal factor in percentage,). This array will be used in the EEPROM build.
39. Repeat steps 36 and 37 for the remaining 8481D sensors to be tested.

### **Measurement Uncertainty Analysis:**

#### **1.0 Measurand**

The measurand is the calibration factor  $K_b$  of the sensor under test.

#### **2.0 Measurement Equation**

Express mathematically the relationship between the measurand  $Y$  and the input quantities  $X_i$ .

$$Y = f(X_1 + X_2 + \dots + X_i)$$

Example:

The calibration factor  $K_b$ , is defined as:

$$K_b = K_s \times (M_t/M_s) \times (M_{i1}/M_{i2}) \times ((1 - \rho_{tp} \times \rho_{dut})^2 / (1 - \rho_{tp} \times \rho_{std})^2)$$

where,

$K_b$  is the cal factor of the DUT sensor.

$K_s$  is the cal factor of the STANDARD sensor.

$M_t$  is the reading of the DUT sensor.

$M_s$  is the reading of the STANDARD sensor.

$M_{i1}$  is the reading of the REFERENCE while measuring the STANDARD sensor.

$M_{i2}$  is the reading of the REFERENCE while measuring the DUT sensor.

$\rho_{tp}$  is the test port match of the power splitter.

$\rho_{dut}$  is the reflection coefficient of the DUT sensor.

$\rho_{std}$  is the reflection coefficient of the STANDARD sensor.

### 3.0 Uncertainty Equation

$$U_{cf} = \sqrt{U_{std}^2 + U_{mm}^2 + U_{ran}^2 + U_{sys}^2}$$

Where,

$U_{cf}$  is the uncertainty of  $K_b$

$U_{std}$  is the uncertainty of the STANDARD cal factor

$U_{mm}$  is total mismatch uncertainty:

For Vector or Scalar Analyzers  $U_{mm} =$

$$200 \times (\text{UncRho}_{tp} \times (\text{Rho}_{std} + \text{Rho}_{dut})) + (\text{Rho}_{tp} \times (\text{UncRho}_{std} + \text{UncRho}_{dut}))$$

For no Analyzer  $U_{mm} =$

$$200 \times ((\text{UncRho}_{tp} \times \text{Rho}_{std}) + (\text{UncRho}_{std} \times \text{Rho}_{tp})) + 100 \times (1 + (\text{Rho}_{tp} \times \text{Rho}_{dut})^2) \leq 1$$

where  $\text{UncRho}_{tp}$  is the uncertainty of the test port match for the splitter.

$\text{UncRho}_{std}$  is the uncertainty of the reflection coefficient for the STANDARD sensor.

$\text{UncRho}_{dut}$  is the uncertainty of the reflection coefficient for the DUT sensor.

$U_{ran}$  is uncertainty associated with random drift and connector repeatability errors of the

System and the DUT sensor (measured by making more than 1 connection of

Specifying data sheet values.

$U_{sys}$  is system uncertainty calculated by taking the total (RSS) of the following errors:

$$\sqrt{P_{mt}^2 + P_{mr}^2 + M_{uc}^2 + P_{mc1}^2 + P_{mc2}^2 + D_t^2 + D_r^2 + Z_s^2 + N_1^2 + N_2^2 + P_{cal}^2}$$

### 3.1 Sensitivity Coefficient ( $C_i$ )

By inspection the sensitivity coefficients are 1

### 3.2 Covariance

All variables are independent, the covariance is 0

### 3.3 Standard Uncertainty ( $U_{xi}$ )

Uncertainty expressed as a standard deviation.

Example:

All the standard uncertainties listed in this section are Type B standard uncertainties.

### 3.4 Combined Standard Uncertainty Tables

Show an example of all uncertainty contributions in a table along with their probability distribution.



### Total Uncertainty Budget

Symbol	Source of Uncertainty	Value +/- %	Probability distribution	Divisor (SF)	Uxi +/-
U <sub>std</sub>	Standard Cal Factor		Gaussian	2	
U <sub>mm</sub>	Total Mismatch	$ \Gamma_g $ $ \Gamma_s $	Uniform	(1)	
U <sub>ran</sub>	Random drift/connections	.5%	Gaussian	2	.25%
(P <sub>mt</sub> )	Test power meter instrumentation	.5%	Rectangular	$\sqrt{3}$	.29%
(P <sub>mr</sub> )	Ref power meter instrumentation	.5%	Rectangular	$\sqrt{3}$	.29%
(M <sub>uc</sub> )	50Mhz Ref Mismatch	$ \Gamma_g =0.024$ $ \Gamma_s =0.048$	Uniform	(1)	.081%
(P <sub>mc1</sub> )	Ref Cal Uncert STD	.5%	Rectangular	$\sqrt{3}$	.29%
(P <sub>mc2</sub> )	Ref Cal Uncert DUT	.5%	Rectangular	$\sqrt{3}$	.29%
(D <sub>t</sub> )	Test power meter drift	+/-10nW	Rectangular	$\sqrt{3}$	.00058%
(D <sub>r</sub> )	Ref power meter drift	+/-10nW	Rectangular	$\sqrt{3}$	.00058%
(Z <sub>s</sub> )	Zero Set	+/-50nW	Rectangular	$\sqrt{3}$	.0000%
(N <sub>1</sub> )	Noise STD meter	+/-110nW	Rectangular	$\sqrt{3}$	.0000%
(N <sub>2</sub> )	Noise REF meter	+/-110nW	Rectangular	$\sqrt{3}$	.0000%
(P <sub>cal</sub> )	Calibrator output power	.9%	Gaussian	2	.45%
U <sub>sys</sub>	Combined uncertainty-RSSed				.739%
U <sub>cf</sub>	Overall combined uncertainty-RSSed				
	Expanded uncertainty		K=2		

## 4.0 Conversion Equations

### 4.1 Polar to Rectangular conversion using Radians

$$\text{Ang\_rad} = \text{Angle} / 57.2957795$$

$$\text{Real} = \text{Mag} \times \text{COS}(\text{Ang\_rad})$$

$$\text{Imaginary} = \text{Mag} \times \text{SIN}(\text{Ang\_rad})$$

### 4.2 Combine complex data for the SPLITTER AND SENSOR

$$\text{Real} = (\text{Real\_splitter} \times \text{Real\_sensor}) \pm (\text{imaginary\_splitter} \times \text{imaginary\_sensor})$$

$$\text{Imaginary} = (\text{Real\_splitter} \times \text{imaginary\_sensor}) + (\text{Real\_sensor} \times \text{imaginary\_splitter})$$

### 4.3 Normalize Complex result

$$\text{Real} = (1 - \text{Real\_complex})$$

$$\text{Imaginary} = (0 \pm \text{imaginary\_complex})$$

### 4.4 Convert rectangular complex to polar

$$\text{Mag} = \text{SQRT}(\text{Real\_complex}^2 + \text{Imaginary\_complex}^2)$$

$$\text{Denom} = \text{Real\_complex} + \text{Mag}$$

$$\text{If Denom} = 0 \text{ Then Angle} = 180$$

$$\text{If Denom} \neq 0 \text{ Then Angle} = 2 \times \text{ARCTAN}(\text{Imaginary\_complex} / \text{Denom}) \times 57.2957795$$

## **PART 4**

### **Agilent 8481D VECTOR ANA Reflection Measurement**



## Performance Test Support Document

### Test Name : Agilent 8481D VECTOR ANA Reflection Measurement Rev C

#### Specification:

Frequency	Specification SWR(Rho)
10MHz to <30MHz	<1.40 (0.167)
0.03 GHz to 4GHz	<1.15 (0.070)
4GHz to 10GHz	<1.20 (0.091)
10GHz to 15GHz	<1.30 (0.130)
15GHz to 18GHz	<1.35 (0.112)

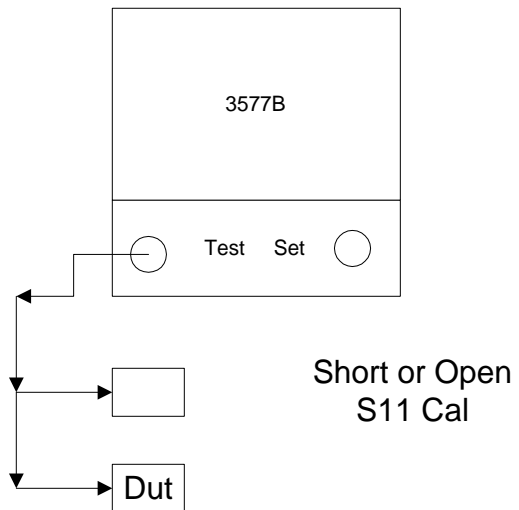
#### Description:

The purpose of this test is to measure the Reflection Coefficients of Power Sensors over a frequency range of 10MHz to 18GHz. The test system consists of the 8510C Vector Network analyzer system and the 8360B Signal Source. S-Parameter Test Set 8515A along with Cal Kit 85052C are also used. If a Scalar Network Analyzer is used, measured reflection coefficient contains magnitude data only. If a Vector Network Analyzer is used, measured reflection coefficient contains magnitude and phase data. The test starts with a list of input frequencies defined according to the DUT model. These input frequencies are input to the Network Analyzer and a S11 measurement is performed. This test will run multiple sensors of the same model number. These results will be saved for later use.

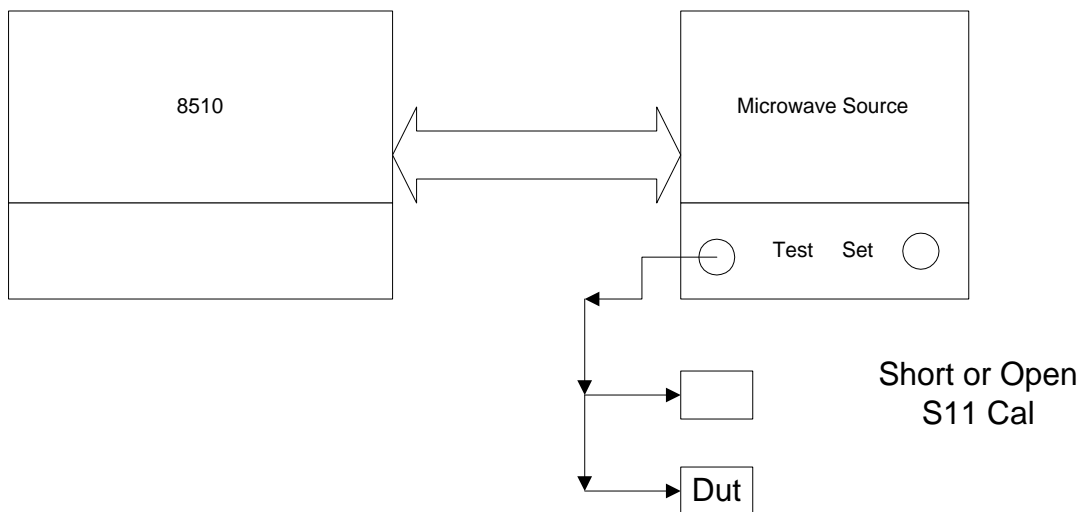
#### Equipment: *(include cables and connectors)*

Instrument	Critical Specifications (for this test)	Recommended Model
<b>Signal Sources</b>		
<b>Synthesized Sweeper</b>	Frequency:10 MHz to 18 GHz	Agilent 83650B
<b>Analyzers</b>		
<b>Network Analyzer</b>	Frequency:100KHz to 50MHz Substitution 50MHz to 18 GHz	Agilent 3577A/B Agilent 8751A Agilent 8510C
<b>Miscellaneous Devices</b>		
<b>S-Parameter Test Sets</b>	Directivity>40dB /Test Port Match<1.07 $i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ}$ $i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} \quad i^{\circ} <1.$	Agilent35677A(3577A/B) Agilent 87511A(8751A) Agilent 8515A(8510C)
<b>Cal Kits</b>	Agilent quality	Agilent35678A(3577A/B) Agilent 85032B(8751A) Agilent 85054D(8510C)
<b>Adapter Set</b>	3.5 to Type N (8515A)	Agilent 85130C

**Figure 1a Vector Reflection Test Setup, <50MHz**



**Figure 1b Vector Reflection Test Setup, >50MHz**



## Test Procedure:

1. Use Figure 1, to set up equipment.
2. Preset the UUT and all test equipment.
3. Initialize the test equipment parameters as follows:

### Network Analyzer

Parameter	Setting
Channel [1]	Chan 1 S <sub>11</sub>
Channel [1]	LIN mkr on POLAR
Channel [2]	Chan 2 S <sub>21</sub>
# TRACE POINTS	201
Start frequency	10MHz(low band) or 50MHz(high band)
Stop frequency	50MHz(low band) or 18GHz(high band)
Power Level	-30dBm

4. Perform reflection calibration of the Analyzer using the Cal kit
  - A) Press [S<sub>11</sub>] [CAL] CAL 1, CALIBRATE: S<sub>11</sub> 1-PORT.
  - B) At Port 1, connect a shielded open circuit.
  - C) When the trace is correct, press (S<sub>11</sub>): OPEN. Open circuit data is measured.
  - D) At Port 1, connect a short circuit.
  - E) When the trace is correct, press (S<sub>11</sub>): SHORT. Short circuit data is measured.
  - F) Press (S<sub>11</sub>): LOADS to present the loads menu. If the frequency sweep crosses 2 GHz, then both the LOWBAND and SLIDING loads, or the BROADBAND load must be used.
  - G) At Port 1 connect a fixed load.
  - H) When the trace is correct, press LOWBAND. Load data is measured.
  - I) At Port 1, connect a sliding load.
  - J) Move sliding element to the first index mark; then, when the trace is correct, press SLIDE IS SET. Load data is measured.
  - K) Repeat 5 to 8 times each time moving the sliding element to the next index mark, then pressing SLIDE IS SET.
  - L) Press SLIDING LOAD DONE.
  - M) Press DONE LOADS. If the message ADDITIONAL STANDARDS NEEDED appears, then the loads were not specified for the current frequency range (for

example, only the LOWBAND load was used for a sweep that crossed 2 GHz).

- N) Press SAVE 1-PORT CAL then select CAL SET 1. (Error coefficients are computed and stored; Cal menu is displayed with CORRECTION ON).
  - O) Corrected S<sub>11</sub> trace is displayed.
  - P) Connect the test device.
  - Q) Measure S<sub>11</sub>.
5. Connect the DUT to port 1 of the S-Parameter test set.
  6. Press [MARKER] and position to read S-Parameter. The magnitude is given in linear terms ( $\rho$ ) and an angle  $\angle\phi$ , in degrees.
  7. Compare the data with the spec and save to a file.

## Measurement Uncertainty Analysis:

### 1.0 Measurand

The measurand is the Reflection Coefficient of the Power Sensor as measured by the Network Analyzer.

### 2.0 Measurement Equation

Express mathematically the relationship between the measurand Y and the input quantities X<sub>i</sub>.

$$Y = f(X_1 + X_2 + \dots + X_i)$$

Example:

The Reflection Coefficient, Y, is defined as:

$$Y = (\text{Power}_{\text{refl}}/\text{Power}_{\text{inc}})$$

where,

Power<sub>refl</sub> is the reflected power.

Power<sub>inc</sub> is the power incident to the DUT.

### 3.0 Uncertainty Equation

The total uncertainty is taken from the Measurement Uncertainty curves of the Network Analyzer in use. Refer to the Network Analyzer's documentation for more information on the measurement uncertainty equations and the uncertainty terms.

$$U_{\text{rho}} = A + (C * \text{Rho}^2)$$

Where,

U<sub>rho</sub> is the uncertainty of Rho



A is directivity

C is source match

Rho is the measured rho of DUT

### **3.1 Sensitivity Coefficient ( $C_i$ )**

By inspection the sensitivity coefficients are 1

### **3.2 Covariance**

All variables are independent, the covariance is 0

### **3.3 Standard Uncertainty ( $U_{x_i}$ )**

Uncertainty expressed as a standard deviation.

Example:

All the standard uncertainties listed in this section are Type B standard uncertainties. The value of each standard uncertainty is determined by the DUT and Analyzer system specifications, documented in the User's/Calibration Guides

### 3.4 Combined Standard Uncertainty Tables

Show an example of all uncertainty contributions in a table along with their probability distribution.

#### Total Uncertainty Budget

Symbol	Source of Uncertainty	Value	C * Rho <sup>2</sup>	Combined Std Unc +/- A+(C*Rho <sup>2</sup> )
A	Directivity(3577A/B) 10MHz to 50MHz	.01(40)		
	Directivity(8510C) .045GHz to 2GHz	.004(48)		
	2GHz to 8GHz	.003(50)		
	8GHz to 20GHz	.003(50)		
	20GHz to 26.5GHz	.003(50)		
C	Sour match(3577A/B) 10MHz to 50MHz	.032(30)		
	Source match(8510) .045GHz to 2GHz	.01(40)		
	2GHz to 8GHz	.003(50)		
	8GHz to 20GHz	.003(50)		
	20GHz to 26.5GHz	.003(50)		
Rho	8481D Rho Spec: 10MHz to <30MHz	.167	.00089	.01089
	0.03GHz to 4GHz	.070	.000015	.00402
	4GHz to 10GHz	.091	.000027	.00403
	10GHz to 15GHz	.130	.000051	.00405
	15GHz to 18GHz	.112	.000038	.00404



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