HEWLETT PACKARD

OPERATION

MODEL 4191A
RF IMPEDANCE ANALYZER

(Including Options 002 and 004)

SERIAL NUMBERS

This manual applies directly to instruments with serial numbers prefixed 2515J.

With changes described in Section VII, this manual also applies to instruments with serial numbers prefixed 1930J.

For additional important information about serial numbers, see INSTRUMENTS COVERED BY MANUAL in Section I.

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PREFACE

In response to the demand for new impedance measuring instruments which can contribute to the development of high quality devices operating in the radio frequency region, to the increased depth of research of electronic materials, to rf circuit design and to efficient experimental evaluation in production quality control, Hewlett-Packard has developed the Model 4191A RF Impedance Analyzer.

The 4191A's extended measurement capabilities deliver the advantages of certain rf impedance measurements beyond the level of pre-existing instruments. Its improved accuracy, high resolution, multiple measurement parameter capability and wide range are innovations beyond the prevailing concepts in rf impedance measurements. Microprocessor based instrument design provides fully automatic measurement and ease of operation (embodied in the control functions which are all accessible through the keyboard). In addition, new 4191A operability enhances both reliability and efficiency in all its measurement applications.

SECTION I
GENERAL INFORMATION

1-1. INTRODUCTION.

1-2. This operation and service manual contains the information required to install, operate, test, adjust and repair the Hewlett-Packard Model 4191A RF Impedance Analyzer. Figure 1-1 shows the instrument and supplied accessories. This section covers specifications, instrument identification, description, options, accessories, and other basic information.

1-3. Listed on the title page of this manual is a microfiche part number. This number can be used to order 4 x 6 inch microfilm transparencies of the manual. Each microfiche contains up to 60 photo-duplicates of the manual pages. The microfiche package also includes the latest manual changes supplement as well as all pertinent service notes. To order an additional manual, use the part number listed on the title page of this manual.

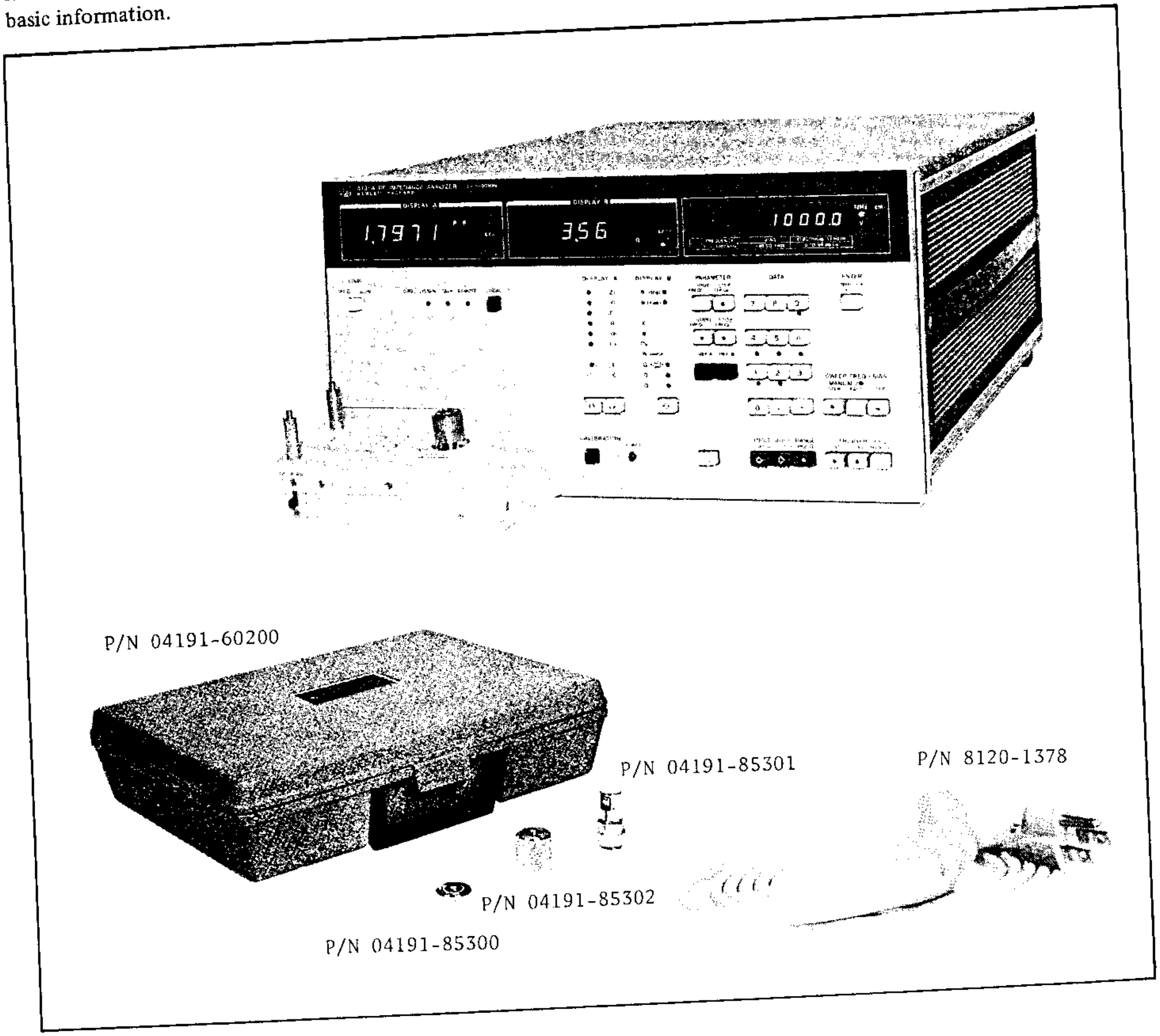


Figure 1-1. Model 4191A and Accessories.

1-4. ABOUT THE MODEL 4191A.

MULTIPLE PARAMETER FEATURES

The HP Model 4191A RF Impedance Analyzer is a fully automatic, high performance test instrument designed to measure diverse impedance parameter values of electronic devices and materials at extended frequencies ranging from MF to the UHF region. The 4191A measures resistance (R), reactance (X), conductance (G), susceptance (B), inductance (L), capacitance (C), dissipation factor (D), quality factor (Q) and, in addition, the absolute values of impedance (|Z|) and admittance (|Y|), along with phase angle (θ) over wide frequency and measurement ranges at high speed. Furthermore, the 4191A can make reflection parameter measurements (absolute value |Γ| with phase angle θ, real Γx and imaginary part Γy) of the sample which is terminated at a single 50Ω test port. These multiple measurement parameters of the 4191A enable straight forward measurement of the desired parameter values obviating the necessity of complex parameter conversion cal- culations which are usually time-consuming processes in RF vector measurements.

TEST FREQUENCY (1-1000 MHz)

Measurement frequency is keyboard controlled at 100 kHz resolution from 1 MHz to 500 MHz and at 200 kHz resolution for the higher frequencies (to 1000 MHz). Optionally, the frequency is selectable at 100 Hz resolution for the same frequency range (200 Hz resolution for frequencies above 500 MHz). The internal synthesizer test frequency signal is accurate to 3 ppm which satisfies stability and spectral purity requirments for measure- ment of resonators, high selectivity filtering devices and other components. The built-in test signal source also provides swept frequency measurement convenience (a feature of the 4191A). The 4191A is capable of dual mode digital sweep operations – linear and logarithmic sweep measurements in response to start, stop and step parameters pro- grammed through its control keys. By the use of an external signal source of higher fre- quency resolution, the test frequency can be exactly tuned to the desired test frequency, for example, the resonance point of a crystal resonator.

WIDE RANGE CAPABILITIES

The measurement ranges were established with respect to acceptable measurement result inaccuracies. The practicable measurement range for impedance and resistance spans 100 mΩ to 20 kΩ, admittance from 100 μS to 10S, conductance from 20 μS to 10S, in- ductance from 0.1 nH to 5 mH, capacitance from 0.1 pF to 1 μF, all of which are depend- ent on the test frequency, and reflection coefficient from .0000 to ±1.0000. Either react- ance, susceptance, equivalent series resistance, conductance, dissipation factor, quality factor or phase angle can be selected as subordinate choices to the |Z|, |Y|, R, G, L, C or Γ measurement. The practicable range for reactance is from 100 mΩ to 20 kΩ, suscept- ance and conductance from 20 μS to 10S, equivalent series resistance from 100 mΩ to 20 kΩ, dissipation factor and quality factor from 0.001 to 1000, and phase angle from ±0.01° to ±180.00°.

HIGH SPEED OR AVERAGING

The two measurement display sections provide simultaneous readouts for the selected measurement parameters by 4-1/2 digit numeric segments along with appropriate units. In normal mode operation, the 4191A displays a running average of the five preceding measurements at about an 800 ms measuring rate. A high speed measurement mode implements the instantaneous display of measurement data taken at about 250 ms.

HIGH ACCURACY

The basic accuracy is 1% for measurements of nearly 50Ω impedance elements, and the instrument has an improved accuracy over its full range. The 4191A must be calibrated at the desired frequency range or for the entire frequency range before taking measurements. The calibration is performed under automatic settings of both the test parameter and frequency(ies) using three kinds of reference terminations (supplied accessories). As a result of such automatic calibration, the measurement accuracy is optimized and the frequency of periodic maintenance can be reduced.

OPERABILITY

Microprocessor based design of the hardware pushes this universal impedance analyzer towards simple operation yet adds advanced performance. Desired test parameters are fully programmable through the front panel control keys or by HP-IB control capability furnished in the standard unit. Two delta (Δ) key functions eliminate the inconvenience of deviation measurement calculations. These arithmetic functions make possible the direct readout of the measured values minus a reference value or of the percentage that the measurement deviates from the reference. The reference value can be taken from either the measurement of a reference sample or from program data input. The microprocesser augments the high reliability design of the 4191A. Convenient operational diagnosis is feasible by merely pressing a panel pushbutton. This confirms functional operation of the instrument. Ease of operation is further enhanced by the "save" function for continuous memorization of control settings sustained by battery memory backup capability. A continuous memory also preserves the auto-calibration data and saves calibration time prior to measurements.

INTERNAL BIAS

Internal dc bias up to ±40V by keyboard control action and swept voltage bias provide convenience for bias applications. Precise voltage setting capability enables control of bias voltage in constant 10mV minimum steps (to 40V) with basic voltage accuracy of 0.1%. The programmability and ease of control by keyboard action provide new dc bias operability obviating the need of an external bias supply and a bias controller.

FLEXIBILITY AND EXTENDED USE

The versatility and operability of the 4191A are maximized by the availability of versatile test fixtures. The installation of options which can provide high resolution test frequency and analog recorder output capabilities – both of which can be combined in one unit, augment these capabilities. Test fixtures are designed with careful consideration for enhancing the reliability of measurement across broad frequency and impedance ranges. The high resolution test frequency option multiplies the frequency resolution of the synthesizer test signal source by 1000 times. Analog recorder output permits the graphic recording of measurement data on an X-Y recorder in swept frequency/bias measurements. In reflection parameter measurements (in particular), the recorder output can draw swept parameter data on a Smith Chart.

1-5. SPECIFICATIONS.

1-6. Complete specifications of the Model 4191A Impedance Analyzer are given in Table 1-1. These specifications are the performance standards or limits against which the instrument is tested. The test procedures for the specifications are covered in Section IV Performance Tests. Table 1-2 lists supplemental performance characteristics. Supplemental performance characteristics are not specifications but are typical characteristics included as additional information for the operator. When the 4191A RF Impedance Analyzer is shipped from the factory, it meets the specifications listed in Table 1-1.

1-7. SAFETY CONSIDERATIONS.

1-8. The Model 4191A RF Impedance Analyzer has been designed to conform to the safety requirements of an IEC (International Electromechanical Committee) Safety Class I instrument and is shipped from the factory in a safe condition.

1-9. This operating and service manual contains information, cautions, and warnings which must be followed by the user to ensure safe operation and to maintain the instrument in a safe condition.

1-10. INSTRUMENTS COVERED BY MANUAL.

1-11. Hewlett-Packard uses a two-section nine character serial number which is marked on the serial number plate (Figure 1-2) attached to the instrument rear panel. The first four digits and the letter are the serial prefix and the last five digits are the suffix. The letter placed between the two sections identifies country where instrument was manufactured. The prefix is the same for all identical instruments; it changes only when a change is made to the instrument. The suffix, however, is assigned sequentially and is different for each instrument. The contents of this manual apply to instruments with the serial number prefix(es) listed under SERIAL NUMBERS on the title page.

1-12. An instrument manufactured after the printing of this manual may have a serial number prefix that is not listed on the title page. This unlisted serial number prefix indicates the instrument is different from those described in this manual. The manual for this new instrument may be accompanied by a yellow Manual Changes supplement or have a different manual part number. This supplement contains "change information" that explains how to adapt the manual to the newer instrument.

1-13. In addition to change information, the supplement may contain information for correcting errors (called Errata) in the manual. To keep this manual as current and accurate as possible, Hewlett-Packard recommends that you periodically request the latest Manual Changes supplement. The supplement for this manual is identified with this manual's print date and part number, both of which appear on the manual's title page. Complementary copies of the supplement are available from Hewlett-Packard. If the serial prefix or number of an instrument is lower than that on the title page of this manual, see Section VII Manual Changes.

1-14. For information concerning a serial number prefix that is not listed on the title page or in the Manual Change supplement, contact your nearest Hewlett-Packard office.

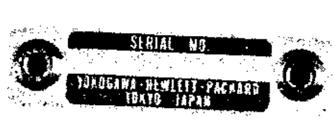


Figure 1-2. Serial Number Plate.

Table 1-1. Specifications (Sheet 1 of 5).

SPECIFICATIONS

Parameters Measured:

Z Y Γ	θ (radian/degree)
R	X
G	B
Γx	Γy
L C	R , G , D , Q

Δ (unit deviation) and Δ% (percent deviation) for all parameters.

Test Signal (Internal): 1 to 1000 MHz

Characteristics[1]	1–500 MHz	500–1000 MHz
Level (50Ω load)	-20±3 dBm	-20±3 dBm
Frequency Resolution	100 kHz	200 kHz
Frequency Accuracy at 23°C	3 ppm	3 ppm

1. After 40 minute warm-up, Temperature: 23°C±5°C.

External Test Signal:

Frequency : 1 MHz to 1000 MHz
Input Level : 0 dBm typ., -3 to +3 dBm.
(Test level: -17 to -23 dBm at 50Ω load)

Sweep Characteristics:

Sweep mode :

Auto: Single sweep from programmed start to stop frequency (or in reverse direction). Sweep pause at desired frequency step is feasible.

Manual: Bidirectional step shift (up-down) of frequency between start and stop frequencies.

Sweep span: Maximum 1 MHz to 1000 MHz, selectable in 100 kHz minimum frequency step intervals.

Frequency step:

Linear sweep: Selectable in 100 kHz minimum step frequency intervals (to 999 MHz).

Logarithmic sweep: A total of 50 step frequencies (51 spot frequencies) automatically selected at logarithmically regular intervals, minimum 100 kHz (rounds off fractional frequency to 100 kHz).

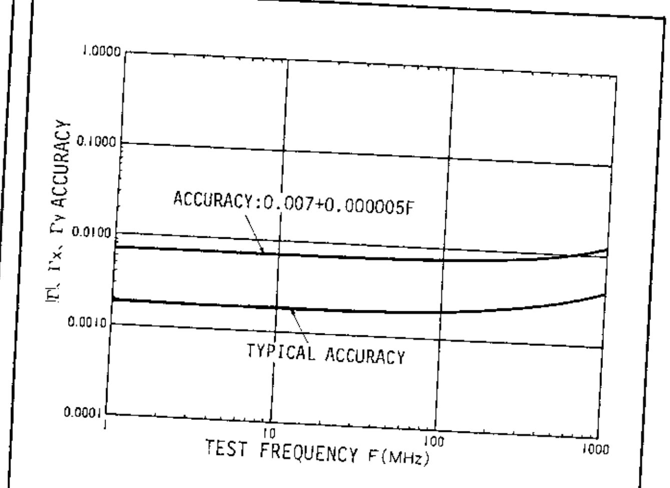
Fast sweep: Manual sweep by 10 times programmed step frequency intervals in linear sweep mode, or by 1/5 of frequency points in logarithmic sweep mode.

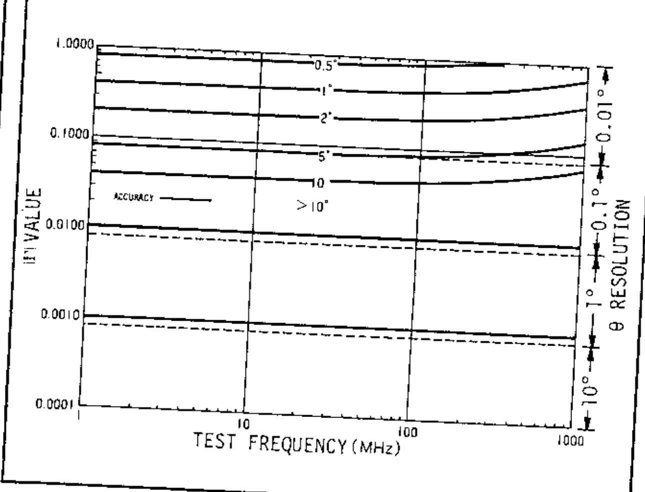
Measurement Accuracy and Resolution:

Accuracies apply under the following measurement operating conditions:

1) Specifies reflection coefficient accuracy (|Γ| - θ and Γx - Γy measurement accuracies). Accuracies for other parameter measurements are given as typical values in Supplemental Performance Characteristics.
2) Warm-up time: at least 40 minutes.
3) Auto-calibration properly completed using standard reference terminations.
4) Measurement frequency identical to auto-calibration frequency points (51 spots).
5) Environmental temperature:
23°C ± 5°C (allows temperature variation).
0°C ~ 55°C (at the constant temperature at which auto-calibration is completed).
6) Measurement taken at UNKNOWN connector (without using test port extension).

Table 1-1. Specifications (Sheet 2 of 5).





Measurement Range:

|Γ|, Γx, Γy : 0.0001 to 1.0000
θ : 0.00 to ±180.00°
(0 to ±π radian)

Display: 4-1/2 digit maximum, simultaneous display of two parameter values, maximum display 19999. (Number of display digits changes depending on measurement frequency and range).

Digit Shift: Number of desired display digits (less than the maximum display digits) is selectable by control key.

Range Modes: Auto and Hold.

Measurement Terminal: Single test port, APC-7 connector terminal.

Deviation Measurement: A measurement display value or a desired value entered by DATA input keys can be stored as a reference value. Next, pressing Δ or Δ% button enables the difference between the referenced value and subsequent result to be displayed. (Deviation spread in counts is −19999 to 19999 or from −1999.9% to 1999.9%).

Electrical Length Correction: The effects in phase of the reflection coefficient particular to the test fixture used can be automatically corrected by entering electrical length number of the test fixture with DATA input keys.
Input data range: 0 to 99.99cm

Automatic Calibration: Memorizes measurement results of reference termination impedances and automatically performs corrections to optimize measurement accuracy in subsequent measurements.

Reference termination impedances: 0Ω, 50Ω and 0S.

Calibration frequency: 51 spot frequencies automatically selected from within the frequency range of 1MHz to 1000MHz or of programmed start to stop frequencies.

Calibration data at frequencies other than the selected calibration frequency points are obtained by using cubic interpolation approximations.

Self Test: Performs cyclic operation of internal function tests and displays diagnostic code sets (when any abnormality is detected).

Internal Bias: Internal dc bias source manually or remotely controllable from 0V to ± 40V in 10mV (minimum) steps.

Bias control range and accuracy (23°C ± 5°C):

Bias Voltage Control Range	Accuracy
−40.00V —— 40.00V	±(0.1% of setting +10mV)*

* ± (0.4% + 20mV) at 0°C to 55°C

Bias output characteristics:
1390Ω ± 10%, 7.2mA max. (±10%).

Table 1-1. Specifications (Sheet 3 of 5).

Control: Manual control by front panel keys or remote control by HP-IB controller. Bias voltage sweep is also feasible.

Sweep characteristics:

Sweep Mode:

Auto: Single sweep from programed start to stop voltages or in reverse direction. Sweep pause at desired voltage step is feasible.

Manual: Bidirectional step shift (up-down) of bias voltage between start and stop bias voltages.

Sweep span: Maxium −40 to +40V (linear sweep). Maximum +0.01 to +40V (logarithmic sweep). Selectable in 0.01V minimum voltage step intervals.

Voltage step:

Linear sweep: Selectable in 0.01V (minimum) step voltage intervals (to ± 40V).

Logarithmic sweep: A total of 50 step voltages (51 spot voltages) automatically selected at logarithmically regular intervals, minimum 0.01V (rounds off fractional voltage to 0.01V).

Fast sweep: Manual sweep at 10 times programmed step voltage intervals in linear sweep mode, or by 1/5 of voltage points in logarithmic sweep mode.

DC bias monitor: Bias voltage monitor output (common to external dc bias input), BNC connector, output impedance 1kΩ ± 10%.

Save Function: Continuous memorization of one or two desired control settings states powered by stand-by battery. Memorized setting data is preserved in event that instrument loses operating power and can be restored as actual control setting anytime by pressing control keys. Memorizes the following data and control settings:

1) Front panel pushbutton control settings (except SELF TEST function).
2) Automatic calibration data (restored just after the instrument is turned on).
3) Reference values in deviation measurement.

External DC Bias: External DC bias input connector on rear panel (common to internal dc bias voltage monitor connector), maximum ± 40V.
Bias input characteristics: 390Ω ± 10%, 100mA max.

Trigger: Internal, external and manual.

HP–IB INTERFACE: Remote control and data output via the HP-IB (based on IEEE-Std-488 and ANSI-MC1.1).

Remotely controllable functions:

1) DISPLAY A functions (|Z|, |Y|, |Γ|, R, G, Γx, L and C).
2) DISPLAY B functions (θ, X, B, Γy, R, G, D and Q).
3) Test signal frequency (SPOT).
4) Frequency sweep functions (START, STOP and STEP frequencies, LOG SWEEP, MANUAL STEP, AUTO START, PAUSE and SWEEP ABORT).
5) Deviation functions (Δ, Δ%, REF A, REF B, and STORE DSPL A/B).
6) High speed.
7) Range hold.
8) Digit shift (DSPL A and DSPL B).
9) Electrical length.
10) Open capacitance.
11) Automatic calibration.
12) Save functions (SAVE 1, SAVE 2, RCL 1 and RCL 2).
13) Self test.
14) Trigger.
15) DC bias voltage (SPOT).
16) Bias voltage sweep functions (START, STOP and STEP voltages, LOG SWEEP, MANUAL STEP, AUTO START, PAUSE and SWEEP ABORT).
17) X-Y recorder control functions (LL, UR and INTRPL) (option 004 only).

Table 1-1. Specifications (Sheet 4 of 5).

Data output:
1) |Z|, |Y| or |Γ| with θ; R with X; G with B; Γx with Γy; L or C with R, G, D or Q.
2) Test frequency in swept frequency measurement.
3) Frequency in automatic calibration.
4) Bias voltage in swept bias voltage measurement.

Internal function allowable subsets:
SH1, AH1, T5, L4, SR1, RL1, DC1 and DT1.

Data output format: Either of two formats may be selected (switchable on rear panel).

Format A.
1. Stationary (fixed) frequency/bias measurement:

```
␣XXX±NNN.NNE±NN,XXX±NNN.NNE±NN(CR)(LF)
1234     5     6789     10        11
```

2. Swept frequency/bias measurement or auto-calibration:

```
␣X±NNNN.NNNN,XXX±NNN.NNE±NN,XXX±NNN.NNE±NN(CR)(LF)
1 12    13   6234     5     6789     10        11
```

Format B.
1. Stationary (fixed) frequency/bias measurement:

```
␣XXX±NNN.NNE±NN(CR)(LF)
1234     5        11
XXX±NNN.NNE±NN(CR)(LF)
789     10        11
```

2. Swept frequency/bias measurement or auto-calibration:

```
␣X±NNNN.NNNN(CR)(LF)
1 12    13     11
XXX±NNN.NNE±NN(CR)(LF)
234     5         11
XXX±NNN.NNE±NN(CR)(LF)
789     10        11
```

(1) Space.
(2) Data status of DISPLAY A.
(3) Function of DISPLAY A or calibration condition.
(4) Deviation measurement mode of DISPLAY A.
(5) Value of DISPLAY A (decimal point position is coincident with display).
(6) Comma (data delimiter).
(7) Data status of DISPLAY B.
(8) Function of DISPLAY B or calibration condition.
(9) Deviation measurement mode of DISPLAY B.
(10) Value of DISPLAY B (decimal point position is coincident with display).
(11) Data terminator.
(12) Sweep parameter.
(13) Measurement frequency or bias voltage (decimal point position is coincident with display).

GENERAL

Operating Temperature and Humidity:
0°C to 55°C at 95% RH (to 40°C).

Power Requirements: 100/120/220V ±10%, 240V +5% -10%, 48-66Hz.

Power Consumption: 150VA max with any option.

Dimensions:
425.5 (W) x 230 (H) x 574 (D) mm
(16-3/4" x 9-1/16" x 22-5/8")

Weight: Approximately 24 kg (Std).

Table 1-1. Specifications (Sheet 5 of 5).

OPTIONS

Option 002: Provides test signal frequencies selectable at 100 Hz resolution to 500 MHz and at 200 Hz resolution to 1000 MHz.

Option 004: Analog voltage outputs for graphically recording sweep measurement data on an X-Y recorder. Three channel BNC output connectors on rear panel.

DISPLAY A connector: Outputs voltage proportional to three lesser significant digit numbers of DISPLAY A display outputs (1 mV/count).

DISPLAY B connector: Outputs voltage proportional to DISPLAY B display outputs in the same manner as that for DISPLAY A connector outputs.

FREQ/BIAS connector: Outputs voltage proportional to test frequency or bias voltage as:
Start frequency/voltage : 0V
Stop frequency/voltage : 1V

Reference recorder voltages:
Lower Left (LL) : 0, 0, 0 V
Upper Right (UR) : +1, +1, +1V

Voltage accuracy: ± (0.5% + 2 mV) at 23°C ± 5°C
± (1% + 5 mV) at 0°C to 55°C

Interpolation function: Smoothing of recorder outputs by arithmetic interpolation of measurement data, selectable by control key.

Option 907: Front handle kit, for front handle installation

Option 908: Rack flange kit, for mounting in IEC standard rack.

Option 909: Rack flange & handle kit, for rack mounting and handle installation.

Option 910: Extra operating manual.

Option 91S: Extra service manual.

ACCESSORIES

Accessories Supplied:

Reference terminations for calibrating the 4191A. Three kinds of terminations are included:

0 Ω reference termination (short), (HP P/N 04191-85300).
50 Ω reference termination, (HP P/N 04191-85301).
0S reference termination (open), (HP P/N 04191-85302).

Additionally, accessory box (HP P/N 04191-60200) which accommodates these terminations and all the available test fixtures is furnished.

Operating booklet (HP P/N 04191-90100).

Power Cord (HP P/N 8120-1378).

Accessories Available:

Accessories, other than primary accessories, are outlined in Table 1-2.

16091A: Coaxial Fixture set, direct coupled, two types of sample holders, coaxial termination structure, with APC-7 connectors. For mounting cylindrical sample piece in inner cavity chamber. Usable on all 4191A ranges to 1000 MHz.

16092A: Spring Clip Fixture, direct coupled, for holding axial or radial lead components or leadless chip elements. Either slide clip contact or twin clip contacts can be attached on the terminal deck with APC-7 connector. Usable on all ranges at frequencies below 500 MHz.

16093A: Binding Post Fixture, direct coupled, two binding posts on terminal deck with APC-7 connector, for holding axial or radial lead components, 7 mm terminal post interval. Usable on all ranges at frequencies below 250 MHz.

16093B: Binding Post Fixture, direct coupled, three binding posts (including a guard terminal) on terminal deck with APC-7 connector, 18 mm terminal post interval (15 mm to guard). Usable on all ranges at frequencies below 125 MHz.

16094A: Probe fixture, two-needle probe adapter, compatible with APC-7 connector test cable, for in-circuit testing of components, variable needle span (15 mm max.). Useable on all ranges at frequencies below 125 MHz.

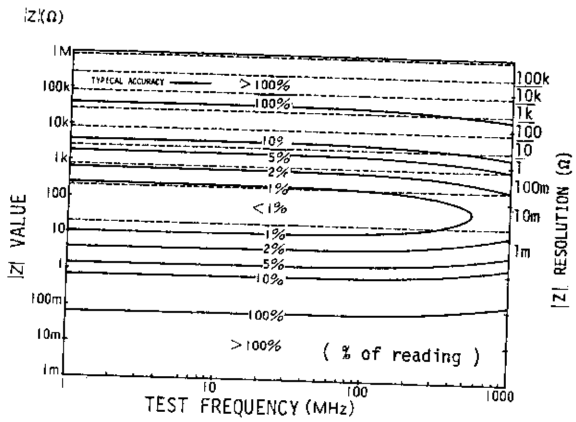
Table 1-2. Supplemental Performance Characteristics (Sheet 1 of 3).

SUPPLEMENTAL PERFORMANCE CHARACTERISTICS

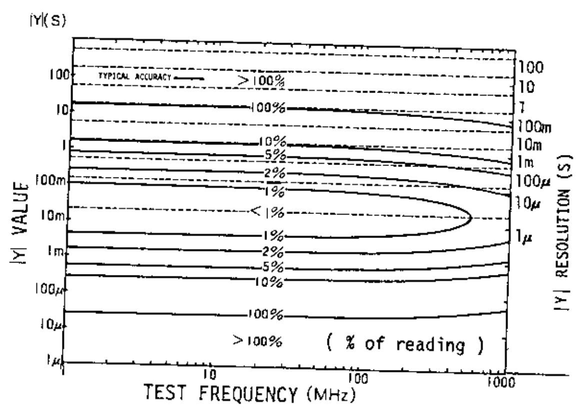
Measurement accuracy:

|Z| − θ, |Y| − θ measurement

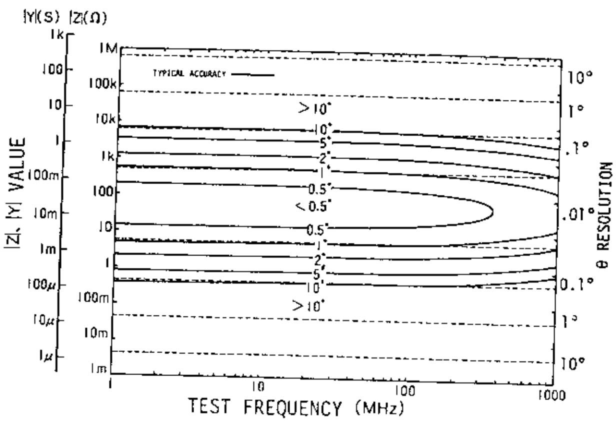
○ |Z| accuracy at θ = 45°:



○ |Y| accuracy at θ = 45°:

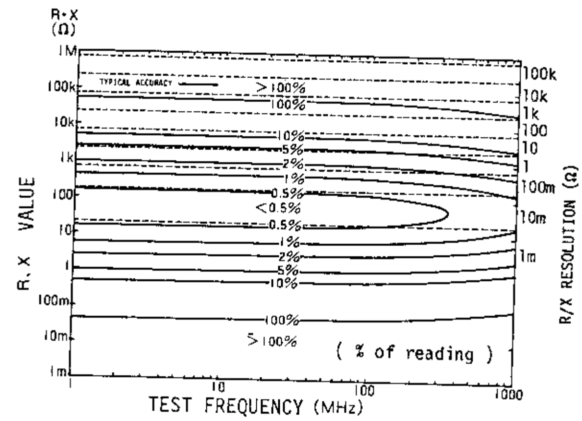


○ θ accuracy at θ = 45°:

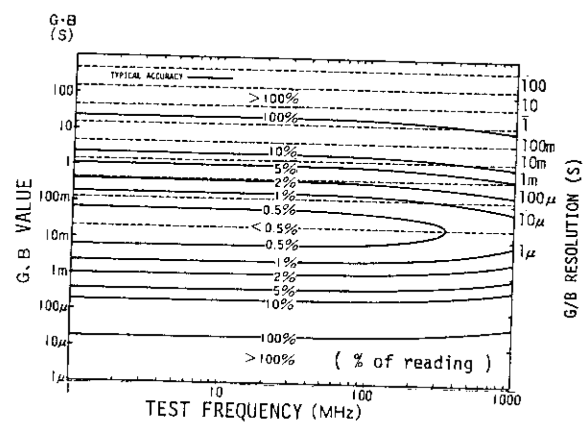


R-X, G-B measurement

○ R-X accuracy at D = 1:



○ G-B accuracy at D = 1:



L-R/G/D/Q, C-R/G/D/Q measurement:

○ L accuracy at D ≤ 0.01:

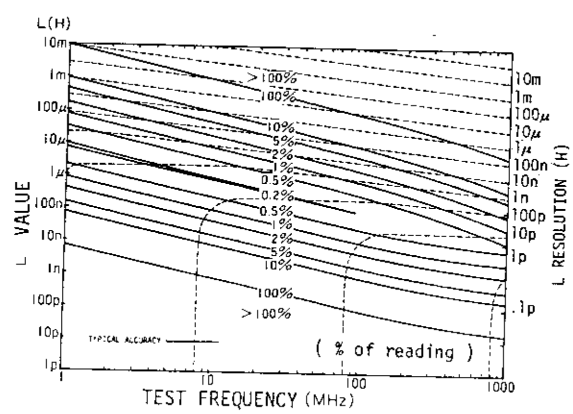
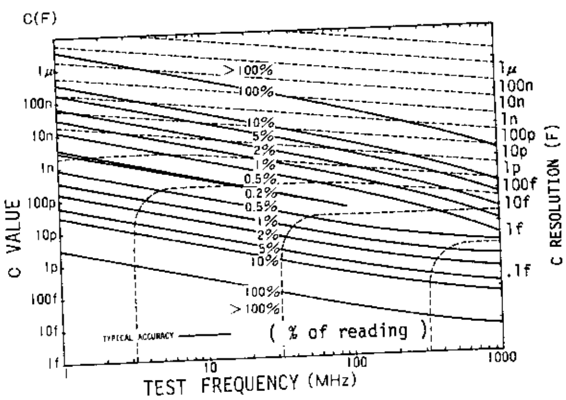


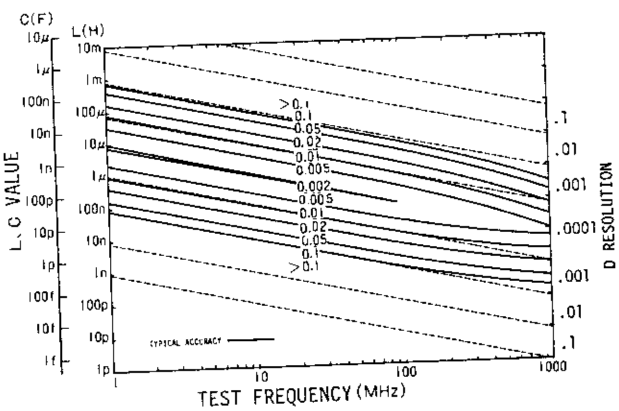
Table 1-2. Supplemental Performance Characteristics (Sheet 2 of 3).

o C accuracy at D ≤ 0.01:



D (=1/Q) measurement range: 0.0001 to 1000

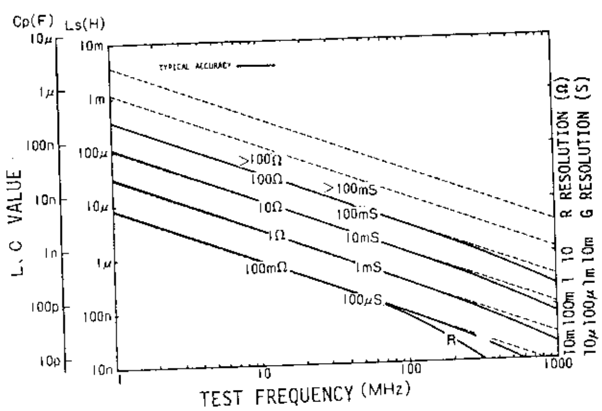
o D (=1/Q) accuracy at D ≤ 0.01:



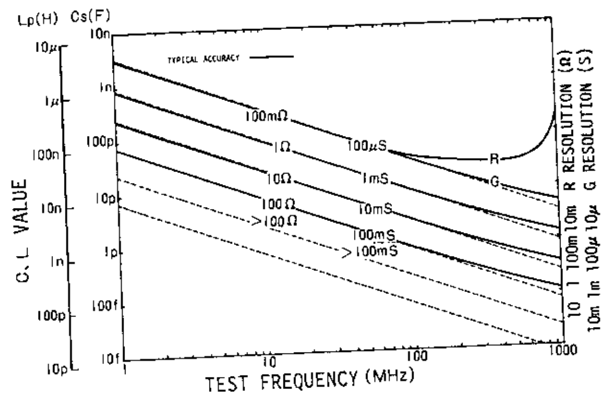
R measurement range: 20mΩ to 100kΩ

G measurement range: 10μS to 50S

o (L-)R, (C-)G accuracies at D ≤ 0.01:



o (C-)R, (L-)G accuracies at D ≤ 0.01:



|Γ|−θ and Γx−Γy accuracy temperature coefficient:

|Γ| : 0.0001/°C (23 ± 5°C)

: 0.0004 (1 + 0.001 f)/°C (0 ~ 55°C)

θ : 0.0001/|Γ| radian/°C (23 ± 5°C)

: 0.0004 (1 + 0.001 f)/|Γ| radian/°C (0 ~ 55°C)

(f = measurement frequency in MHz)

Γx, Γy: $1/\sqrt{2}$ times the temperature coefficient of |Γ|

Test Signal:

Characteristics[1]	1−500MHz	500−1000MHz
Frequency Stability	0.2ppm/C°	0.2ppm/C°
Harmonics, THD	<−30dB[2]	<−30dB[2]
Residual FM	<30Hz[3,4]	< 60Hz[3]
Spurious Level	<−30dB[2]	<−30dB[2]

1. After 40 minute warm-up, Temperature: 23°C ± 5°C
2. Level below fundamental.
3. Averaged rms deviation at 3kHz bandwidth.
4. <15Hz at 250MHz and below.

Test signal settling time

Time for test signal to settle when measurement frequency is changed.

Less than 200ms

Sweep time

Frequency sweep:

Linear sweep:

Number of sweep steps x 1.1 seconds (typical).

Logarithmic sweep:

58 seconds for 50 steps (typical).

Table 1-2. Supplemental Performance Characteristics (Sheet 3 of 3).

Bias voltage sweep:
Linear sweep:
Number of sweep steps x 0.84 seconds (typical).
Logarithmic sweep:
44 seconds for 50 steps (typical).

Measurement time

Normal mode: Less than 800ms
(Displays arithmetic running average of five preceding measurement values.)

High speed mode: Less than 250ms
(Displays measured values for each trigger.)

Auto-calibration time

Approximately 48 seconds for each reference termination impedance.

Bias voltage settling time

Internal bias: Less than 100ms
External bias: Less than 10ms

Open capacitance compensation

Typical open stray capacitance (0.082 pF) of *UNKNOWN connector is continuously memorized for subtracting from measured values. The memorized capacitance value can be temporarily changed by concealed controls.

Input capacitance value range: 0 to 1.000 pF

*APC-7 connector

AVAILABLE ACCESSORIES

[Accessories and parts associated with options or which are usable for special applications or as spares. For primary accessories, refer to Table 1-1 Specifications.]

RF connector for external signal source:
HP Part Number 04191-65001

HP-IB Interface Cable: HP 10631A (1m)
HP 10631B (2m)
HP 10631C (4m)
HP 10631D (0.5m)

Front Handle Kit:
Kit Part Number 5061-0091

Rack Flange Kit:
Kit Part Number 5061-0079

Rack Flange Handle Kit:
Kit Part Number 5061-0085

Line Fuse:
HP Part Number 2110-0304 (100/120V)
HP Part Number 2110-0360 (220/240V)

Internal power supply fuses:

HP Part Number	Rating	Use
2110-0003	3A	+ 5V
2110-0055	4A	+ 5V
2110-0094	1.25A	+12V
2110-0094	1.25A	-12V
2110-0004	0.25A	+46V
2110-0004	0.25A	-46V
2110-0513	0.125A	+36V
2110-0513	0.125A	-36V

Protective fuse (for dc bias):
HP Part Number 2110-0011 (0.062A)

Service Parts

APC-7 connector center spring contact:
HP Part Number 1250-0907

Exchange tool : HP 11591A

1-15. OPTIONS.

1-16. Options are standard modifications to instrument that implement user's special requirements for minor functional changes. A total of seven options for the Model 4191A are available for adding the following capabilities:

Option 002: High Resolution Test Frequency. Test frequency selectable at 100Hz resolution to 500MHz and at 200Hz resolution to 1000MHz.

Option 004: X-Y Recorder Output: Analog output for graphic recording of measurement data (with an X-Y recorder).

Options 907, 908 and 909 are handle or rack mount kits. See paragraph 1-22 for details.

Options 910 and 91S add the following to provide an extra manual or additional information on the 4191A:

Option 910: Extra Operating Manual
Option 91S: Extra Service Manual

Note: Options 002 and 004 can be simultaneously installed in a 4191A unit.

A brief description for each option is given in the paragraphs below.

1-17. OPTION 002.

1-18. The 4191A Option 002 provides test frequency selection capability at the high resolution of 100Hz in frequency range of 1MHz to 500MHz and at 200Hz resolution to 1000MHz frequency instead of standard frequency resolution.

1-19. OPTION 004.

1-20. The 4191A Option 004 provides analog recorder outputs for graphically recording measurement data in swept frequency (or bias voltage) measurements. Two, from among the three output connectors, provide voltages directly proportional to the three lesser significant digit numbers of the respective measurement display outputs (DISPLAY A and DISPLAY B) in the ratio of 1mV to one count. The other output connector affords a voltage of 0 to 1 volt in proportion to the swept frequency (bias voltage) from start to stop frequency (voltage).

1-21. OTHER OPTIONS.

1-22. The following options provide the mechanical parts necessary for rack mounting and hand carrying:

Option 907: Front Handle Kit. Furnishes carrying handles for both ends of front panel.

Option 908: Rack Flange Kit. Furnishes flanges for rack mounting for both ends of front panel.

Option 909: Rack Flange and Front Handle Kit. Furnishes both front handles and rack flanges for instrument.

Installation procedures for these options are detailed in Section II.

1-23. The 4191A Option 910 adds an extra copy of the operating manual and Option 91S provides a service manual.

1-24. ACCESSORIES SUPPLIED.

1-25. Figure 1-1 shows the HP Model 4191A Impedance Analyzer, three reference terminations (HP Part Numbers 04191-85300, -85301 and -85302) with accessory box (HP Part Number 04191-60200), and power cord (HP Part Number 8120-1378). The reference terminations, accessory box and power cord are furnished accessories. Additionally, a fuse (HP Part Number 2110-0304 or 2110-0306) is supplied as a service part.

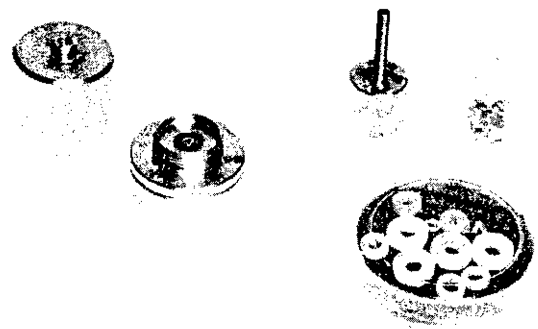
1-26. ACCESSORIES AVAILABLE.

1-27. For certain measurements and for convenience in connecting sample, four styles of test fixtures are available. Each accessory is designed to meet the various measurement requirements and types of DUT. All accessories were developed with careful consideration to accuracy, reliability and ease of measurement. Primary accessory model numbers and names are listed in Table 1-1 (other associated accessories are listed in Table 1-2). A brief description for each of these test fixtures is given in Table 1-3.

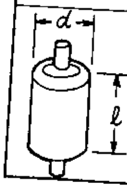
Table 1-3 Accessories Available (sheet 1 of 3).

Model	Description

HP16091A Coaxial Fixtures.



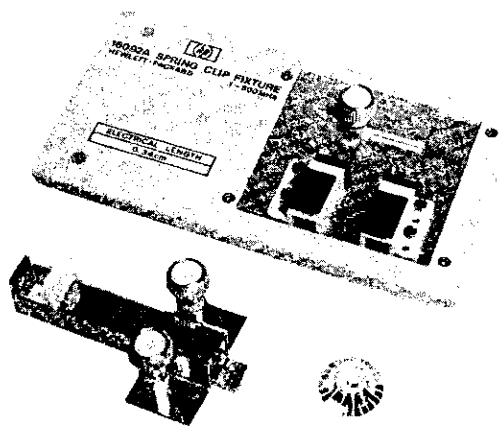
Test Fixtures (coaxial termination type) for holding a piece of sample material or a small component. Screw-mount sample holders accommodate a cylindrical sample in their respective inner chambers. Two kinds of fixtures fit samples dimensions given below:

Sample	Fixture	Max. dimensions	
	04191-85302	d	7 mm
		ℓ	20 mm
	16091-60012	d	10 mm
		ℓ	20 mm

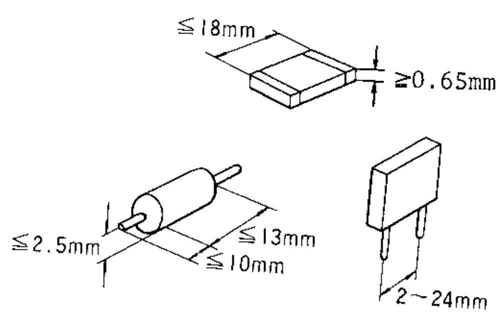
Usable frequency range: DC to 1000MHz.
Electrical length: 1.87 cm (typ.).
Maximum applied dc bias voltage: ± 40V.

Note: The 16091A fixture of 7mm inner diameter (P/N 04191-85302) is actually the same as the 0S standard termination. Thus, this fixture is not supplied with the 16091A fixture set since the furnished 0S termination can be used.

HP16092A Spring Clip Fixture.



Test Fixture (direct attachment type) for measurement of both axial and radial lead components and lead-less chip elements. Spring clip contacts are capable of holding samples of dimensions given below:



A combined slide gauge provides direct readouts of the physical length of the sample tested.
Usable frequency range: DC to 500MHz.
Electrical length : 0.34cm (typ.).
Maximum applied dc bias voltage: ± 40V.

Table 1-3 Accessories Available (sheet 2 of 3).

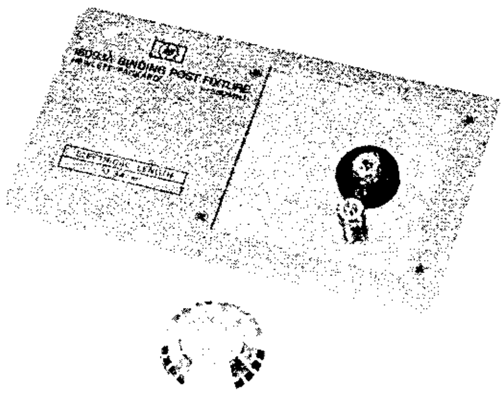
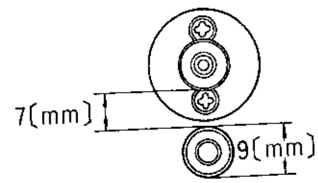
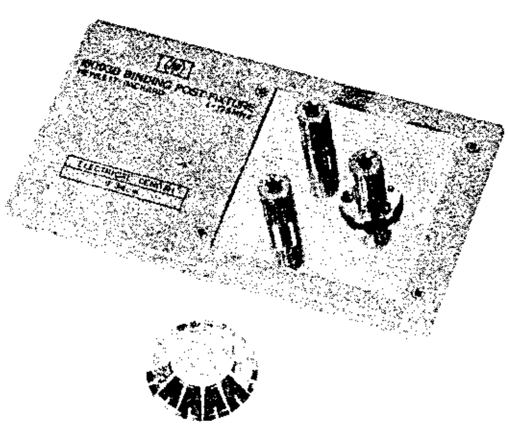
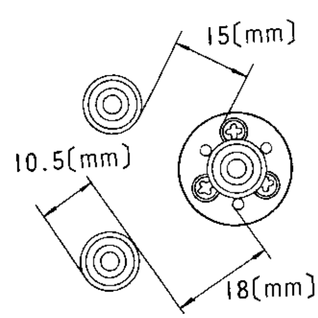
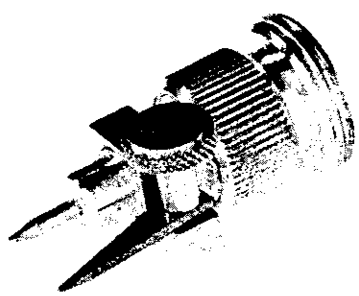
Model	Description
HP16093A Binding Post Fixture 	Test Fixtures (direct attachment type) for measurement of both axial and radial lead miniature components. Two binding post terminals at an interval of 7mm on the terminal deck ensure optimum contact of terminals and sample leads.  Usable frequency range: DC to 250MHz. Electrical length : 0.34cm (typ.). Maximum applied dc bias voltage: ± 40V.
HP16093B Binding Post Fixture 	Test Fixture (direct attachment type) for general measurement of both axial and radial lead components. Three binding post terminals are located on the terminal deck as shown below:  Usable frequency range: DC to 125MHz. Electrical length : 0.34cm (typ.). Maximum applied dc bias voltage: ± 40V.

Table 1-3 Accessories Available (sheet 3 of 3).

Model	Description
HP16094A Probe Fixture 	Test Fixture for measurement of circuit impedances and components mounted on circuit assemblies. The probe adapter unit can be attached at the tip of an extension line connected to the test port. The probe connector fits APC-7 connector of a coaxial test cable or a flexible air line. Probe needle interval is variable from 1mm to 15mm. Electrical length compensation in the instrument must be adjusted for probe cable length (refer to paragraph 3-44). Useable frequency range: DC to 125MHz. Electrical length : 2.32 cm (typ.). Maximum applied dc bias voltage: ±40V.

SECTION II
INSTALLATION

2-1. INTRODUCTION.

2-2. This section provides installation instructions for the Model 4191A Impedance Analyzer. The section also includes information on initial inspection and damage claims, preparation for using the 4191A, packaging, storage, and shipment.

2-3. INITIAL INSPECTION.

2-4. The 4191A Impedance Analyzer, as shipped from the factory, meets all the specifications listed in Table 1-1. On receipt, inspect the shipping container for damage. If the shipping container or cushioning material is damaged, notify the carrier as well as the Hewlett-Packard office and be sure to keep the shipping materials for carrier's inspection until the contents of the shipment have been checked for completeness and the instrument has been checked mechanically and electrically. The contents of the shipment should be as shown in Figure 1-1. The procedures for checking the general electrical operation are given in Section III (Paragraph 3-5 Self Test) and the procedures for checking the 4191A Impedance Analyzer against its specifications are given in Section IV. Firstly, do the self test. If the 4191A Impedance Analyzer is electrically questionable, then do the Performance Tests to determine whether the 4191A has failed or not. If contents are incomplete, if there is mechanical damage or defects (scratches, dents, broken switches, etc.) or if the performance does not meet the self test or performance tests, notify the nearest Hewlett-Packard office (see list at back of this manual). The HP office will arrange for repair or replacement without waiting for claim settlement.

2-5. PREPARATION FOR USE.

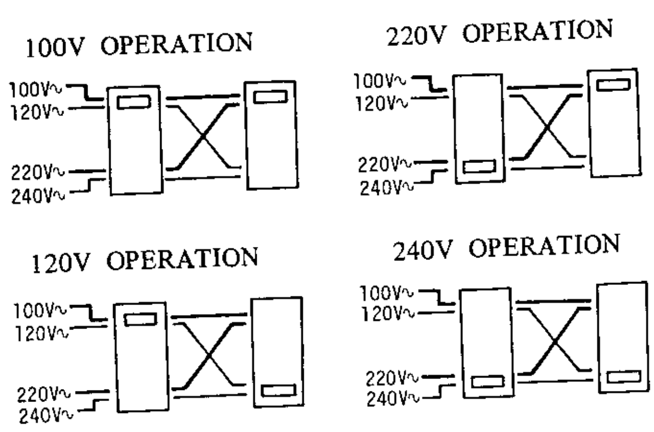
2-6. POWER REQUIREMENTS.

2-7. The 4191A requires a power source of 100, 120, 220 Volts ac ±10%, or 240 Volts ac +5%−10%, 48 to 66 Hz single phase; power consumption is 150 VA maximum.

WARNING:
If this instrument is to be energized via an external autotransformer for voltage reduction, be sure that the common terminal of the instrument is connected to the earth pole of the power source.

2-8. LINE VOLTAGE AND FUSE SELECTION.

Caution: **Before turning the 4191A line switch to on, verify that the instrument is set to the voltage of the power supplied.**

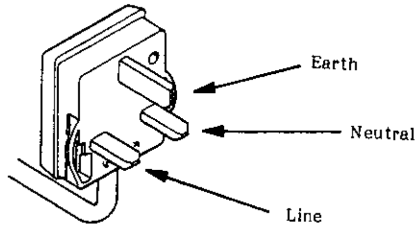


FUSE SELECTION

Operating voltage	Fuse ratings	Fuse Part No.
100V 120V	1.5 A Slow Blow	2110-0304
220V 240V	0.75A Slow Blow	2110-0360

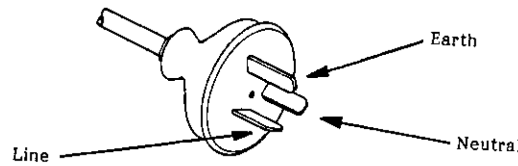
Figure 2-1. Line Voltage and Fuse Selection.

OPTION 900 — United Kingdom



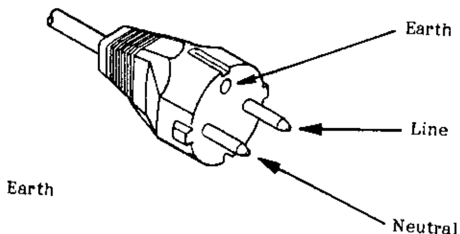
Plug : BS 1363A, 250V
Cable : HP 8120-1351

OPTION 901 — Australia/New Zealand



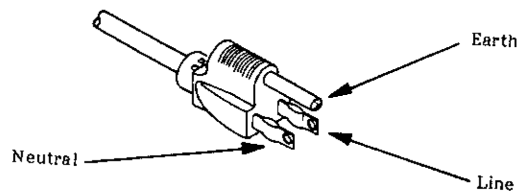
Plug : NZSS 198/AS C112, 250V
Cable : HP 8120-1369

OPTION 902 — European Continent



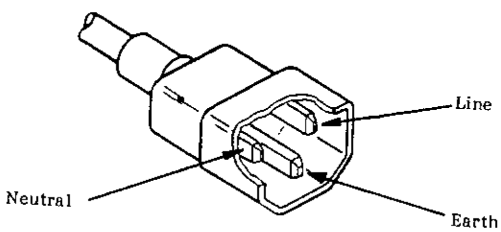
Plug : CEE-VII, 250V
Cable : HP 8120-1689

OPTION 903 — U.S./Canada



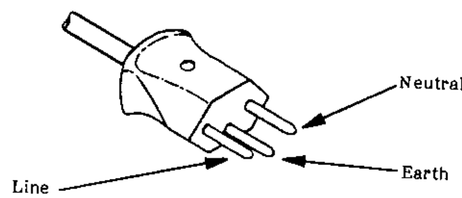
Plug : NEMA 5-15P, 125V, 15A
Cable : HP 8120-1378

OPTION 905* — Any country



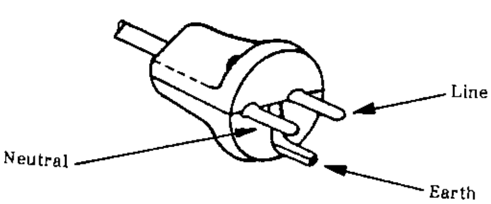
Plug : CEE 22-VI, 250V
Cable : HP 8120-1396

OPTION 906 — Switzerland



Plug : SEV 1011.1959-24507 Type 12, 250V
Cable : HP 8120-2104

OPTION 912 — Denmark



Plug : DHCR 107, 220V
Cable : HP 8120-2956

* Plug option 905 is frequently used for interconnecting system components and peripherals.

NOTE: Each option number includes a 'family' of cords and connectors of various materials and plug body configurations (straight, 90° etc.)

Figure 2-2. Power Cables Supplied

2-9. Figure 2-1 provides instructions for line voltage and fuse selection. The line voltage selection switch and the proper fuse are factory installed for 100 or 120 volts ac operation.

Caution:

1. **Use proper fuse for line voltage selected.**
2. **Make sure that only fuses for the required rated current and of the specified type are used for replacement. The use of mended fuses and the short-circuiting of fuse-holders must be avoided.**

2-10. POWER CABLE.

2-11. To protect operating personnel, the National Electrical Manufactures Association (NEMA) recommends that the instrument panel and cabinet be grounded. The Model 4191A is equipped with a three-conductor power cable which, when plugged into an appropriate receptacle, grounds the instrument. The offset pin on the power cable is the ground wire.

2-12. To preserve the protection feature when operating the instrument from a two contact outlet, use a three prong to two prong adapter (HP Part No. 1251-8196) and connect the green grounding tab on the adapter to power line ground.

Caution:

The mains plug must only be inserted in a socket outlet provided with a protective earth contact. The protective action must not be negated by the use of an extension cord (POWER CABLE) without protective conductor (GROUNDING).

2-13. Figure 2-2 shows the available power cords, which may be used in various countries including the standard power cord furnished with the instrument. HP Part number, applicable standards for power plug, power cord color, electrical characteristics and countries using each power cord are listed in the figure. If assistance is needed for selecting the correct power cable, contact nearest Hewlett-Packard office.

2-14. INTERCONNECTIONS.

2-15. When external bias is to be used, set rear panel DC BIAS INT EXT switch to EXT position. The output of the external dc bias source should be connected to EXT INPUT/INT MONITOR connector. For coupling the 4191A with an external controller and/or output device using HP-IB interface capability (IEEE-488-1975), connect HP-IB interface cable between rear panel HP-IB connectors of the instruments.

2-16. OPERATING ENVIRONMENT.

2-17. Temperature. The instrument may be operated in temperatures from 0°C to +55°C.

2-18. Humidity. The instrument may be operated in environments with relative humidities to 95% to 40°C. However, the instrument should be protected from temperature extremes which cause condensation within the instrument.

2-19. INSTALLATION INSTRUCTIONS.

2-20. The HP Model 4191A can be operated on the bench or in a rack mount. The 4191A is ready for bench operation as shipped from the factory. For bench operation, a two-leg instrument stand is used. For use, the instrument stands are designed to be pulled towards the front of instrument.

2-21. INSTALLATION OF OPTIONS 907, 908 and 909.

2-22. The 4191A can be installed in a rack and be operated as a component of a measurement system. Rack mounting information for the 4191A is presented in Figure 2-3.

2-23. STORAGE AND SHIPMENT.

2-24. ENVIRONMENT.

2-25. The instrument may be stored or shipped in environments within the following limits:

Temperature	-55°C to +65°C
Humidity	to 95%
Altitude	50,000 ft

The instrument should be protected from temperature extremes which cause condensation inside the instrument.

2-26. PACKAGING.

2-27. Original Packaging. Containers and materials identical to those used in factory packaging are available through Hewlett-Packard offices. If the instrument is being returned to Hewlett-Packard for servicing, attach a tag indicating the type of service required, return address, model number, and full serial number. Also mark the container FRAGILE to assure careful handling. In any correspondence, refer to the instrument by model number and full serial number.

2-28. Other Packaging. The following general instructions should be used for re-packing with commercially available materials:

a. Wrap instrument in heavy paper or plastic. If shipping to Hewlett-Packard office or service center, attach tag indicating type of service required, return address, model number, and full serial number.

b. Use strong shipping container. A double-wall carton made of 350 pound test material is adequate.

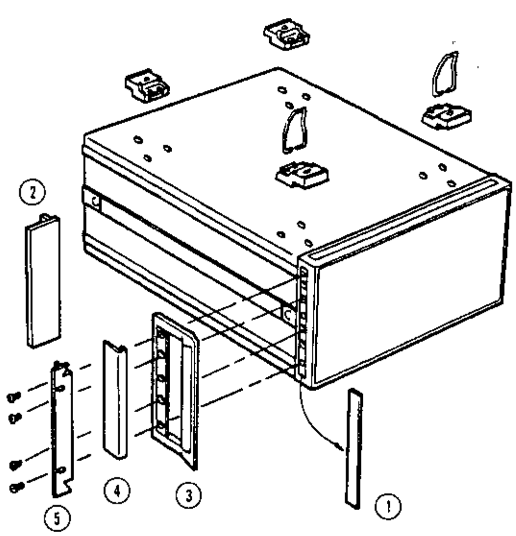
c. Use enough shock absorbing material (3 to 4 inch layer) around all sides of instrument to provide firm cushion and prevent movement inside container. Protect control panel with cardboard.

d. Seal shipping container securely.

e. Mark shipping container FRAGILE to ensure careful handling.

f. In any correspondence, refer to instrument by model number and full serial number.

Option	Description	Kit Part Number
907	Handle Kit	5061-9691
908	Rack Flange Kit	5061-9679
909	Rack Flange & Handle Kit	5061-9685



1. Remove adhesive-backed trim strips ① from side at right and left front of instrument.

2. HANDLE INSTALLATION : Attach front handle ③ to sides at right and left front of instrument with screws provided and attach trim ④ to handle.

3. RACK MOUNTING : Attach rack mount flange ② to sides at right and left front of instrument with screws provided.

4. HANDLE AND RACK MOUNTING : Attach front handle ③ and rack mount flange ⑤ together to sides at right and left front of instrument with screws provided.

5. When rack mounting (3 and 4 above), remove all four feet (lift bar at inner side of foot, and slide foot toward the bar).

Figure 2-3. Rack Mount Kits.

SECTION III
OPERATION

3-1. INTRODUCTION.

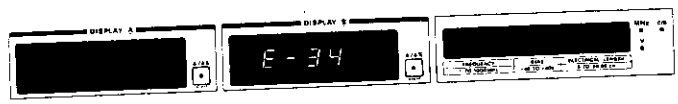
3-2. This manual section provides the operating instructions for acquainting the user with the Model 4191A RF Impedance Analyzer. Instructions for panel controls, functions, operating procedures, basic measuring techniques for the various applications, operational check of the fundamental electrical functions and option information are included in this section. Operating precautions given throughout the text should be carefully observed.

3-3. PANEL FEATURES.

3-4. Front and rear panel features for the 4191A are described in Figures 3-1 and 3-2. Reference numbers in the photos are keyed to the associated descriptions. Other detailed information for panel displays and controls is covered in paragraphs 3-5 and those which follow.

3-5. SELF TEST

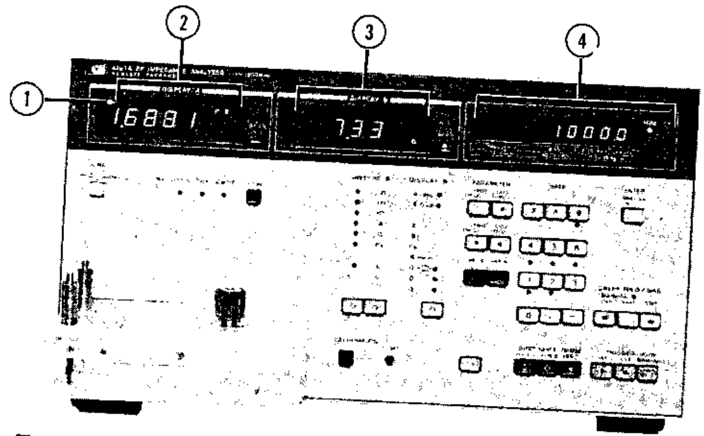
3-6. The 4191A has self-diagnostic functions which are automatically performed or can be done any time desired to confirm the normal operation of the instrument. During the diagnostic test, the instrument is checked for normal operation of the memorized measurement sequences stored in the internal program memory. This automatic test is initially performed each time the LINE button is pushed to turn instrument on. If any abnormality is detected, one of the sixteen error message codes among E-20 through 23, E-30 through 40 or E-50 is displayed in DISPLAY B as illustrated below:



When no abnormality is detected during the diagnostic test routine, the DISPLAY B is normally blank. SELF TEST function key on the front panel allows the diagnostic test to be done at any desired time. Pressing blue key and the SELF TEST key activates the self diagnostic function (same as the initial automatic test). If a failure is not detected, the alphabetic annunciation figure "PASS" is displayed in DISPLAY B. This test is repeated until these keys are again pushed to release the SELF TEST.

Note: Display outputs other than those given in DISPLAY B section have no meaning in diagnostic test results.

DISPLAYS



(1) **Trigger Lamp**: Turns on during sample measuring period. Turns off during period when instrument is not taking measurement. There is thus one lamp turn-on-and-off cycle per measurement. When TRIGGER (14) is set to INT (pushbutton lamp lights), the trigger lamp flashes repeatedly at internal measuring rate.

(2) **DISPLAY A**: Displays absolute values of vector impedance, admittance, or reflection coefficient or, alternately, resistance, conductance, real part of reflection coefficient, inductance, or capacitance values ($|Z|$, $|Y|$, $|\Gamma|$, R, G, Γx, L or C) in a maximum 4-1/2 digit decimal number from 0000 to 19999 (the number of digits change depending on instrument control settings). Simultaneously, decimal point and appropriate unit are displayed to indicate the multiple and the base parameter quantity of the measured sample value.

If measurement is not achieved because of incorrect panel control settings or because of an inappropriate sample value, an alphabetic annunciation figure (either -OF- or E-06)appears. Otherwise, during the CALIBRATION (18) function, a "CAL" or "Conn", figure is presented in the display.

(3) **DISPLAY B**: Displays phase angle, reactance, susceptance, imaginary part of vector reflection coefficient, resistance, conductance, dissipation factor or quality factor value (θ, X, B, Γy, R, G, D or Q) in a maximum 4-1/2 digit decimal number from 0000 to 19999 (the number of digits change depending on instrument control settings) along with decimal point and appropriate unit.

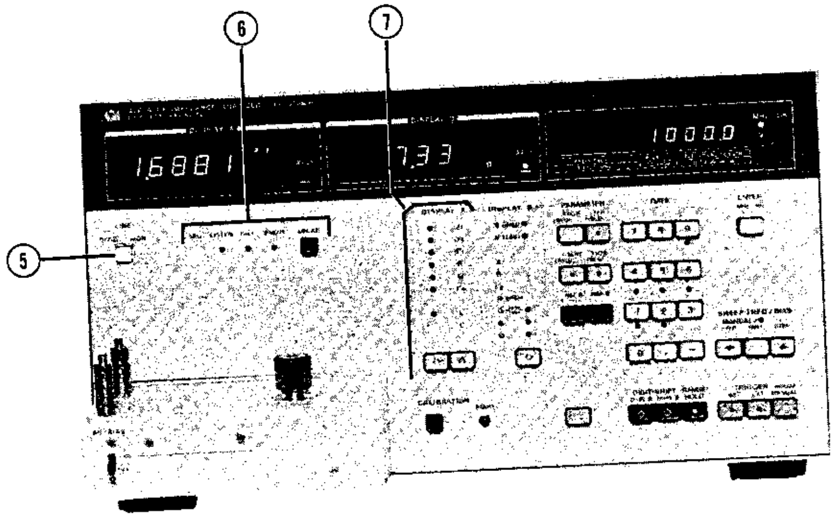
If measurement is not achieved, an error annunciation figure (either -OF- or E-06) appears similar to that given in DISPLAY A. During the calibration function, either "0Ω", "0S", "50Ω" or "END" annunciation display is provided in conjunction with the indications in DISPLAY A (2). Test results for diagnostic SELF TEST (24) are also displayed.

(4) **Test Parameter Data Display**: Displays spot test frequency, swept frequency measurement parameters (start, stop and step frequencies), test fixture electrical length or reference value (for deviation measurement) to be employed in the measurement in maximum 5 digit decimal number including decimal point. Spot bias voltage and swept voltage bias parameter data (start, stop and step voltage setting data) are also contained in the selectable parameter data displays. The appropriate unit (MHz, cm or V) is indicated by unit lamp indicator adjacent to the numeric display.

If option 002 is installed, the test frequency display expands to a maximum of 7 digits. If an inappropriate test parameter input operation is made, -OF- or one of eleven error annunciation displays (E-01 to E-12 except E-10) provides specific information about the nature of the operating error.

Figure 3-1. Front Panel Features (Sheet 1 of 9).

BASIC CONTROLS



(5) **LINE ON/OFF**: Turns instrument on and readies instrument for measurement.

(6) **HP-IB Status Indicators and LOCAL key**: Four LED lamps for SRQ, LISTEN, TALK and REMOTE indicate the status of interface between the 4191A and HP-IB controller. LOCAL key enables front panel control instead of remote control from HP-IB line (when controller does not set the instrument to local lockout status).

(7) **DISPLAY A function selector and indicators**: Two pushbutton keys select the primary measurement parameter to be measured from among a total of eight parameters shown in the indicator above the selector keys.

[⇩] (down) key selects the parameter positioned next lower in the stack (than the indicated parameter) to be selected each time the key is pushed. [⇧] (up) key selects the next upper stack parameter in like manner.

An appropriate indicator lamp lights to indicate the selected parameter.

Parameters measured:

|Z|: Absolute value of vector impedance (|Z|) together with phase angle (θ) in degrees or radians. The combination of these two parameter values is the vector impedance expression (|Z| $\angle\theta$) of the sample.

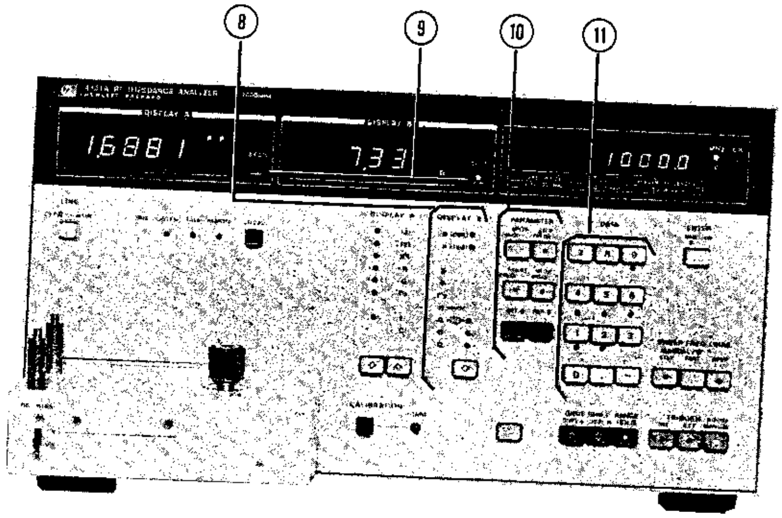
|Y|: Absolute value of vector admittance (|Y|) together with phase angle (θ) in degrees or radians as the vector admittance expression (|Y| $\angle\theta$) of the sample.

|Γ|: Absolute value of vector reflection coefficient of the sample which is terminated in 50Ω UNKNOWN test port (31). Phase angle (θ) is simultaneously selectable in degrees or radians as representation of the vector reflection coefficient (|Γ| $\angle\theta$).

R: Resistance (R) together with reactance (X). These two parameter values represent the real and imaginary components, respectively, of the vector impedance ($Z = R + jX$) of the sample.

Figure 3-1. Front Panel Features (Sheet 2 of 9).

BASIC CONTROLS



G: Conductance (G) together with susceptance (B). These two parameter values represent the real and imaginary components, respectively, of the vector admittance (Y = G + jB) of the sample.

Γx: Real part (Γx) of vector reflection coefficient together with imaginary part (Γy). These two parameter values are a complex number expression of the vector reflection coefficient (Γ = Γx + jΓy) of the sample.

L: Inductance together with subordinate parameter – equivalent series resistance (R), parallel conductance (G), dissipation factor (D) or quality factor (Q).

C: Capacitance together with one of the subordinate measurement parameters (same as those available for inductance measurement).

Note: Parameter selection circles from bottom to top (or top to bottom) as long as the same directional ([⇩] or [⇧]) key is pressed (that is, it moves in the same direction).

(8) **DISPLAY B function selector and indicator:** [⇩] (down) key selects the subordinate measurement parameter to be simultaneously combined with the primary parameter (set by the DISPLAY A function selector (7)). The parameter positioned next lower than the indicated parameter in the stack is selected each time the key is pushed. Parameter choice circles from top to bottom and back to top. The indicator lamp lit identifies the selected parameter.

θ (deg): Phase angle (θ) in degrees together with impedance (|Z|), admittance (|Y|) or reflection coefficient (|Γ|) measurement.

θ (rad): Phase angle (θ) in radians instead of degrees.

X: Reactance (X) together with resistance (R) measurement.

B: Susceptance (B) together with conductance (G) measurement.

Γy: Imaginary part (Γy) with real part (Γx) of vector reflection coefficient measurement.

Figure 3-1. Front Panel Features (Sheet 3 of 9).

BASIC CONTROLS

R: Resistance (R) together with inductance (L) or capacitance (C) measurement in a series equivalent circuit representation of the sample.

G: Conductance (G) together with inductance (L) or capacitance (C) measurement in a parallel equivalent circuit representation of the sample.

D: Dissipation factor (D) together with inductance (L) or capacitance (C) measurement.

Q: Quality factor together with inductance (L) or capacitance (C) measurement.

(9) Δ/Δ%: These keys enable taking deviation measurements, respectively, for DISPLAY A and DISPLAY B parameter values. Measurement range is automatically fixed during the period from initiation to the release of deviation measurement.

Δ (delta): Difference between the measured value of the sample under test and previously stored reference value is displayed by pressing this key. The deviation calculation follows the formula:

$$A - B$$

Where, A is measured value of the sample. B is reference value.

Δ%: The difference in percent deviation of a measured value from the reference value is displayed (this function is enabled by pressing [Blue] key prior to pressing this button). The percent deviation calculation follows the formula:

$$\frac{A - B}{B} \times 100(\%)$$

(10) **PARAMETER – SPOT, STEP, START, STOP FREQ and REF A, REF B**: These keys assign the parameters for the test frequency parameter data and reference values which are input numerically by DATA input keys (11).

SPOT: A spot frequency is entered by successively setting a frequency number with DATA keys.

STEP: A step interval frequency for a swept frequency measurement is entered by successively setting a frequency number. This function is automatically deactivated when LOG SWEEP (28) mode of function is set.

START: A frequency for sweep start point in a swept frequency measurement is entered by successively setting a frequency number.

STOP: A frequency for sweep stop point in a swept frequency measurement is entered by successively setting a frequency number.

REF A: A reference value for DISPLAY A parameter in deviation measurements is entered by successively setting a reference number.

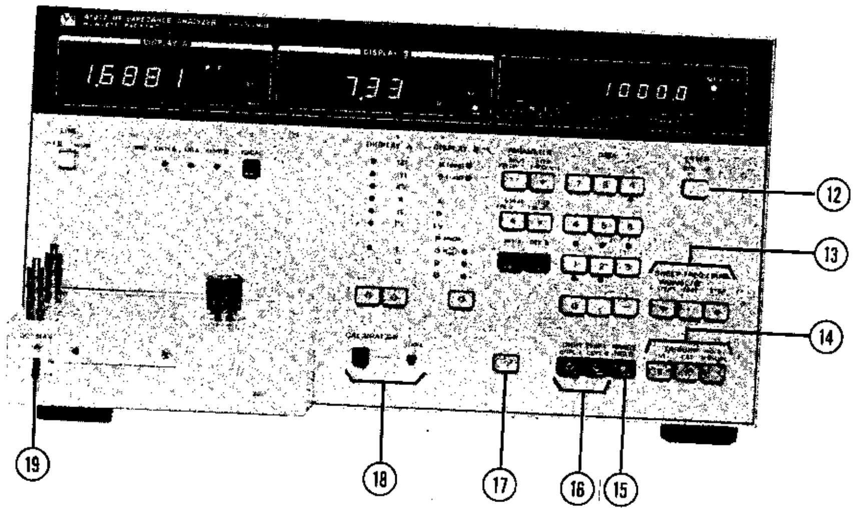
REF B: A reference value for DISPLAY B parameter is entered similarly to that for DISPLAY A parameter.

To change or to release the function, press another PARAMETER key.

(11) **DATA input keys**: These numeric keys set the values of the test frequency (1.0 to 1000.0 MHz, or 1.0000 to 1000.0000 MHz in an Option 002 unit), electrical length (0.00 to 99.99 cm) or reference (for deviation measurements) employed in the measurement in conjunction with PARAMETER (10) key. The input data is displayed in Test Parameter Data Display (4). These keys have other control functions which are denoted by blue labels above each individual key on the panel.

Figure 3-1. Front Panel Features (Sheet 4 of 9).

BASIC CONTROLS



(12) **ENTER**: This key actuates the instrument to read test parameter data set by the PARAMETER (10) and DATA (11) input keys. A test frequency, an electrical length or dc bias voltage input data can be actuated as an instrument control setting just after this key is pushed.

(13) **SWEEP FREQ/BIAS (MANUAL)**: In a swept frequency measurement, the test frequency shifts to a lower or higher frequency, respectively, at the step frequency intervals (previously programmed) each time the STEP [⇩] or [⇧] key is pushed. The test frequency continues to shift digitally as long as either of these keys is being depressed and held. When the STEP key is pressed simultaneously with FAST key, the step frequency interval is expanded to ten times the programmed value (in linear sweep mode) or to one-fifth the frequency points (in logarithmic sweep mode). Consequently, the test frequency is swept in a shorter time (at a sacrifice of frequency resolution in the measurement results). These keys also function to provide similar control input demands for a swept voltage bias measurement.

(14) **TRIGGER**: These keys select trigger mode for triggering measurement (Internal, External or Hold/Manual):

INT: Internal trigger signal enables instrument to make repeated automatic measurements at a measuring rate of approximately 800 ms (250 ms in high speed mode).

EXT: Measurement is triggered by external trigger signal through rear panel EXT TRIGGER input connector.

HOLD/MANUAL: Measurement is triggered each time this key is pushed. Measurement data is held until the key is again pushed.

(15) **RANGE HOLD**: This key fixes measurement range (even if sample is changed). Otherwise, the range is automatically fixed when DIGIT SHIFT (16) key is pushed or when a deviation or a swept frequency/bias measurement is being taken.

Figure 3-1. Front Panel Features (Sheet 5 of 9).

BASIC CONTROLS

16 **DIGIT SHIFT DSPL A and DSPL B**: Numeric figures of the display output in DISPLAY A (2) shifts in a left-to-right direction by one character each time DSPL A key is pushed. Thus, display output is extinguished in this order beginning with the least significant digit. DISPL B key actuates the display output of DISPLAY B (3) in like manner. Measurement range is concurrently held with the first stroke of the key. Fractional parts below the least significant digit (LSD) displayed are automatically rounded to the LSD. When the instrument is equipped with Option 004, this function enables analog recorder output proportionate to the appropriate three element digit numbers of the display output. This function is released by pressing RANGE HOLD (15) key.

17 **Blue key**: This key is pressed prior to pressing a blue label function key to interchange a normal key function with a blue label function.

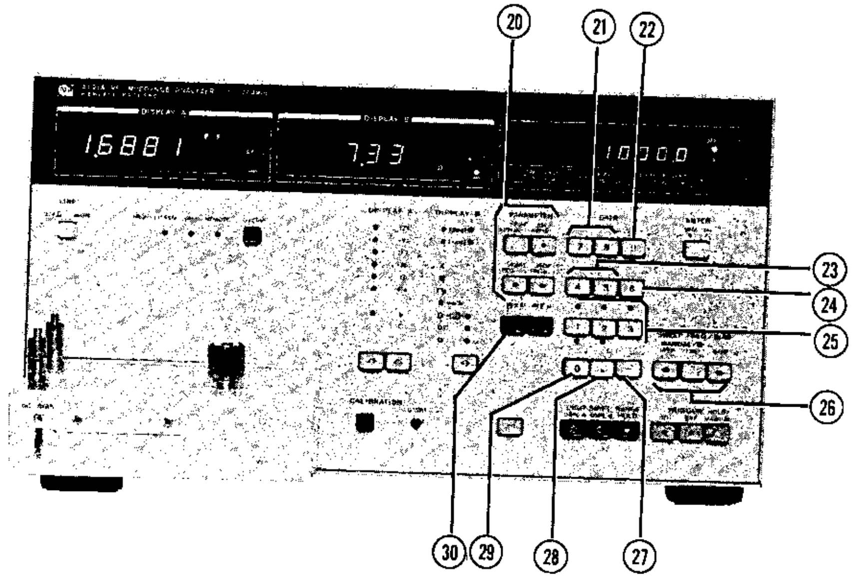
18 **CALIBRATION**: This key performs automatic calibration in accordance with the self calibration program routine memorized in the instrument. Calibration is done by taking measurements with three kinds of standard terminations (0Ω, 0S and 50Ω, which are supplied accessories) at a total of 51 spot frequencies. During the calibration mode of operation, indications for the standard termination to be connected to UNKNOWN (31) are timely given on displays. Concurrently, other functions, unnecessary for the calibration, are deactivated. If calibration data is not being memorized, the instrument must initially be calibrated to optimize subsequent measurements after the power is turned on. This function is released by again pressing the key (after the calibration is completed).

START button – This pushbutton starts calibration subroutine running when an appropriate termination (0Ω, 0S or 50Ω) is connected.

19 **DC BIAS switch**: This switch is set to ON to enable application of an internal or external dc bias voltage to the sample connected at UNKNOWN (31), and is set to OFF to disable bias application when dc bias is not needed.

Figure 3-1. Front Panel Features (Sheet 6 of 9).

BLUE LABEL FUNCTIONS



The blue label functions are secondary selectable modes of dual function keys and require that the [Blue] key be pressed beforehand to activate the desired mode.

(20) **PARAMETER – SPOT, STEP, START, STOP BIAS**: These keys assign the parameters of bias parameter data similar to the functions for setting test frequency parameters (as described in item (10)). Spot bias voltage or the voltage value for step interval, start or stop points to be employed for swept bias voltage measurement are entered by successively setting the voltage number through DATA input keys (11). To release the function, press another PARAMETER key.

(21) **SAVE 1 and SAVE 2**: These keys continuously memorize the desired front panel control settings including reference values for deviation measurement and electrical length input value. SAVE 1 and SAVE 2 keys are individually capable of memorizing different settings. Sweep mode (AUTO/manual, linear/LOG SWEEP), self test and analog recorder output function (Option 004) settings can not be stored in the memory.

(22) **STORE DSPL A/B**: This key simultaneously memorizes both measured values of the sample displayed in DISPLAY A (2) and DISPLAY B (3) as reference values for a deviation measurement.

(23) **RCL 1 and RCL 2**: These keys recall the panel control settings memorized by the SAVE 1 or SAVE 2 function (21).

(24) **SELF TEST**: This key performs an automatic check for diagnosing the functional operation of the instrument. An indicator lamp above the key lights during the test. The diagnostic test repeats until this key is again pushed to release the SELF TEST (after pressing [Blue] key). If the instrument is faulty, an error message code appears in DISPLAY B (3) to identify the point where the abnormality is occurring.

(25) **X-Y RECORDER function**: (Option 004 only). These keys provide for analog recorder reference output voltages for X-Y

Figure 3-1. Front Panel Features (Sheet 7 of 9).

BLUE LABEL FUNCTIONS

recorder full scale and zero scale adjustments, and additionally, the capability to smooth recorder output in swept frequency (or swept voltage bias) measurement. An indicator lamp above each individual key lights to indicate that the function is set. These functions are released by again pressing the key (after pressing [Blue] key):

INTRPL: Graphic recording or recorder output is automatically smoothed by arithmetic interpolations of the measured values when this key is pressed.

LL: Provides a reference voltage (0V) for recorder zero scale adjustment for each rear panel recorder output (A, B and C). Positions recorder pen at lower left corner of the scale area.

UR: Provides a reference voltage (1V) for recorder full scale adjustment. Positions recorder pen at upper right corner of the scale area.

(26) **SWEEP FREQ/BIAS (AUTO)**: These keys control implementation of an auto sweep mode of operation. START [⇧] key starts a single swept frequency measurement from a lower frequency towards upper frequency in the previously programmed sweep range (Start and Stop frequencies). [⇩] key moves the frequency sweep in a lower direction (from a higher frequency towards a lower frequency). When either of these keys is pushed, the AUTO indicator lamp above the keys lights to indicate that the instrument is set to auto sweep mode of operation. PAUSE key temporarily stops sweep frequency at a desired frequency step point until either [⇧] or [⇩] key is again pushed (after pressing [Blue] key).

These keys also function for a swept voltage bias measurement in like manner.

During swept measurement mode of operation, functions, other than these controls, are automatically deactivated. The swept measurement is released when the measurement is completed or when SWEEP ABORT key (27) is pressed (after pressing [Blue] key).

(27) **SWEEP ABORT**: This key releases auto sweep frequency (bias voltage) measurement and activates a stationary frequency measurement at the frequency (voltage) point where the sweep mode is released.

(28) **LOG SWEEP**: Swept frequency measurement sweeps the 51 spot (50 step) frequencies which are automatically selected at logarithmically regular frequency intervals over the range of the programmed start to stop frequencies. Step frequency program input data has no effect on the measurement.

Logarithmic sweep is also feasible in swept voltage bias measurement. An indicator lamp above the key lights to indicate that this function is set. This function is released by again pressing the key (after pressing [Blue] key).

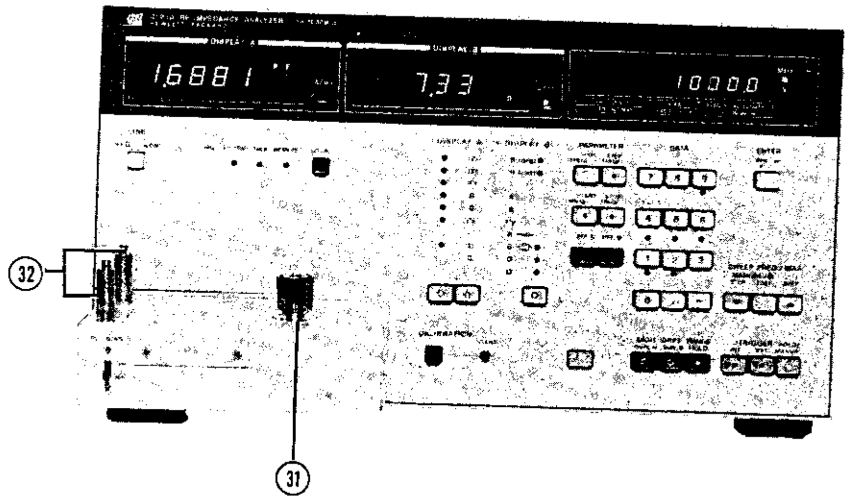
(29) **HIGH SPEED**: This key provides display output of measured values at an accelerated measuring rate of approximately 250ms. The high speed measurement is achieved at the sacrifice of the averaging measurements (averages five measurements) with its resultant improved stability for readouts on the lowest or highest measurement ranges. An indicator lamp above the key lights to indicate that this function is set.

This function is released by again pressing the key (after pressing [Blue] key).

(30) **ELEC LG**: This key is pushed to enter an electrical length number particular to the test fixture used (before taking measurements). An appropriate electrical length number must be successively inputted through DATA keys (11) (electrical length is indispensable in optimizing measurements).

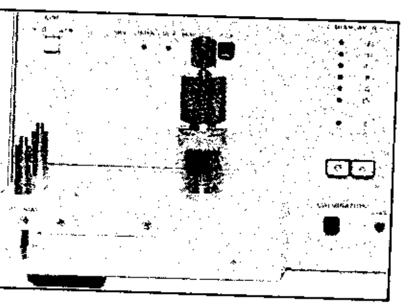
Figure 3-1. Front Panel Features (Sheet 8 of 9).

UNKNOWN CONNECTOR

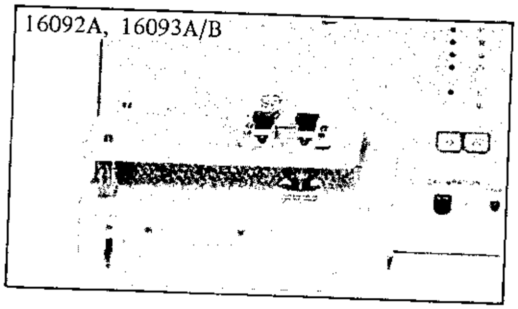


(31) **UNKNOWN connector:** This connector provides the capability for connecting and installing an accessory test fixture specially matched to the 4191A or a user-built test fixture. The APC-7 connector test port, of two terminal configuration, has a characteristic impedance of 50Ω which is equal to the base impedance in reflection coefficient measurements. This base impedance represents the reference in the normalized impedance calculations for multiple parameter derivations.

16091A



16092A, 16093A/B



(32) **Test Fixture Mounting Posts:** These two mounting posts help to securely install the test fixture in conjunction with the UNKNOWN (31) connector. The mounting posts fit twin holes on the 16092A, 16093A or 16093B Test Fixture terminal decks for firm installation (not used for 16091A and 16094A).

TEST FIXTURE INSTALLATION

Accessory test fixture installations on the UNKNOWN terminal deck are illustrated at left:

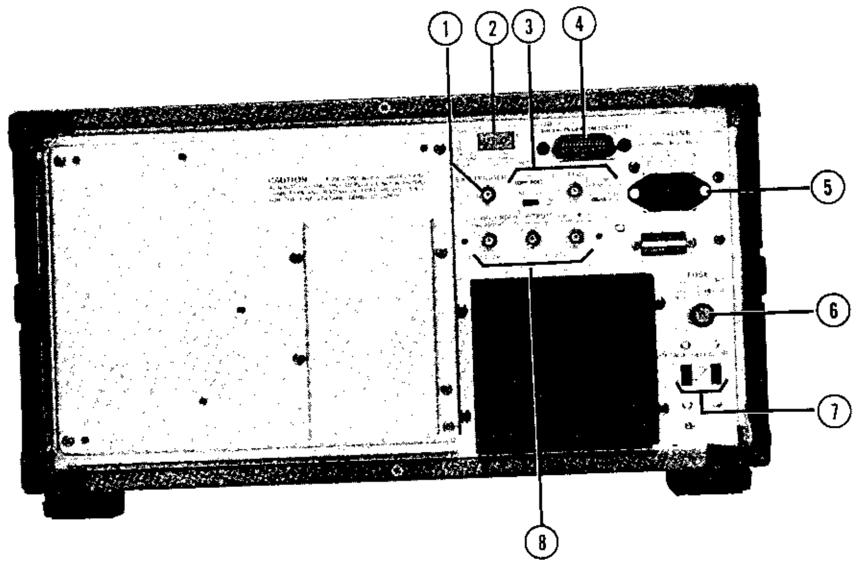
16091A Coaxial Fixtures:
The coaxial fixture is installed on the UNKNOWN connector with a special coaxial adapter (for interconnecting the two connectors). The coaxial adapter protects the UNKNOWN connector contact surface from any damage incident to attachment of sample.

16092A Spring Clip Fixture,
16093A/B Binding Post Fixtures:
A connector coupling screw on the underside of the test fixture terminal deck is coupled to the UNKNOWN connector. The test fixture mounting posts of the 4191A are set into the twin locating holes at the corner of the deck.

Note: For detailed instructions for usage of test fixtures, refer to paragraphs entitled "DUT CONNECTION" (pages 3-31 through 3-35).

Figure 3-1. Front Panel Features (Sheet 9 of 9).

REAR PANEL FUNCTIONS



(1) **EXT TRIGGER Connector:** This connector is used for externally triggering the instrument by inputting an external trigger signal. TRIGGER key on front panel should be set to EXT.

(2) **HP-IB Address Switch:** This switch sets the HP-IB address number for the instrument and, additionally, data output format, and control capability to Talk Only or to Addressable.

(3) **DC BIAS Selector Switch and Connector:**

INT EXT switch: This switch selects between internal or an external dc bias source:

INT - Internal dc bias voltage is applied to the sample.

EXT- External dc bias voltage can be applied to the sample up to a maximum of ± 40 volts through EXT INPUT/INT MONITOR connector.

EXT INPUT/INT MONITOR connector: External dc bias voltage can be applied to sample up to a maximum of 40 volts (100 mA max) through this connector. When internal dc bias is used, the bias voltage can be monitored by connecting a voltmeter (DVM) to this connector.

Input impedance: 390Ω ± 10%.

(4) **HP-IB Connector:** HP-IB interface cable can be connected to this connector to intercommunicate with other HP-IB devices through the bus line cable.

(5) **~ LINE Input receptacle:** AC power cord is connected to this receptacle and ac power line.

(6) **FUSE Holder:** Instrument power-line fuse is installed in this holder.

(7) **VOLTAGE SELECTOR Switches:** These switches select appropriate ac operating power voltage from among 100, 120, 220V ± 10% and 240V +5% - 10%, 48-66Hz.

(8) **RECORDER OUTPUTS (OPT 004) Connector:** With Option 004, these connectors output analog voltages in proportion to measurement display outputs and test frequency (or internal dc bias voltage) for graphically recording a sweep measurement with an X-Y recorder.

Figure 3-2. Rear Panel Features (Sheet 1 of 2).

REAR PANEL FUNCTIONS

FREQ/BIAS Connector: Outputs analog voltage in proportion to test frequency or internal dc bias voltage from 0V at start frequency (voltage) to 1V at stop frequency (voltage) point. The output voltage is proportional to the logarithm of the frequency (voltage) when LOG SWEEP function is set.

DISPLAY B Connector: Outputs analog voltage in proportion to the three lesser significant digit numbers of DISPLAY B display output (1 mV per 1 count of display from −999 to 999 counts).

DISPLAY A Connector: Outputs analog voltage in proportion to DISPLAY A display outputs in the same manner as for DISPLAY B connector output.

Figure 3-2. Rear Panel Features (Sheet 2 of 2).

3-7. MEASUREMENT FUNCTIONS.

3-8. The model 4191A makes simultaneous measurement of two independent, complementary parameters in each measurement cycle. This combination of measurement parameters represent both the resistive and reactive characteristics of the sample. A total of 16 measurement parameters (two among them are duplicates) constitute the 14 selectable combinations of the parameters. These measurement functions are classified, for display purpose, into two groups: DISPLAY A and DISPLAY B functions.

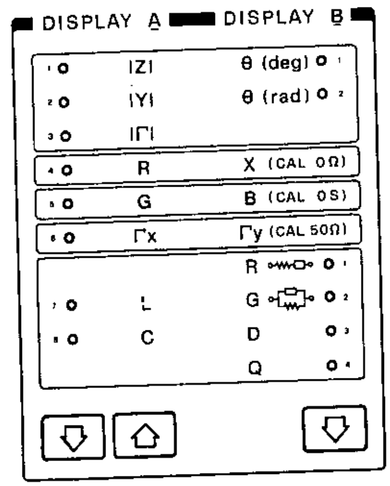
DISPLAY A function group comprises primary measurement parameters including those tabulated below:

DISPLAY A functions	
|Z|	Absolute value of vector impedance.
|Y|	Absolute value of vector admittance.
|Γ|	Absolute value of vector reflection coefficient.
R	Resistance.
G	Conductance.
Γx	Real part of vector reflection coefficient.
L	Inductance.
C	Capacitance.

Measured values are displayed in DISPLAY A section at top left on the front panel.

DISPLAY B functions include a group of subordinate parameters, the availability of which are partially dependent on the primary function selected. The measurement parameters included in the DISPLAY B functions are listed in the tabulation below:

DISPLAY B functions	
θ (deg)	Phase angle in degrees.
θ (rad)	Phase angle in radians.
X	Reactance.
B	Susceptance.
Γy	Imaginary part of vector reflection coefficient.
R (series symbol)	Equivalent series resistance.
G (parallel symbol)	Parallel conductance.
D	Dissipation factor.
Q	Quality factor.



The relationship of the combinability of subordinate parameters to major measurement parameters are represented in the function indicator on the front panel (these panel markings are shown in above-right figure). The DISPLAY B parameters selectable together with the DISPLAY A function are discriminated by rectangular block lines outlining the parameter labels. That is, the divisions shown for the particular function indicator signify the available combinations of the measurement parameters (as defined below):

	Combinable functions				
DISPLAY A	|Z|, |Y|, |Γ|	R	G	Γx	L, C
DISPLAY B	θ(deg), θ(rad)	X	B	Γy	R, G, D, Q

Measured values are displayed in DISPLAY B section (at top center of the front panel).

3-9. DEVIATION MEASUREMENT FUNCTION.

3-10. The 4191A is capable of deviation measurements associated with both DISPLAY A and DISPLAY B functions. This function enables displaying unit deviation or percent deviation of the sample values from a reference value stored in the internal memory. When the store mode operation is enabled, the instrument memorizes the measured values for DISPLAY A and/or DISPLAY B parameters, or otherwise the data input numbers as the reference value(s). The difference between the subsequent measurement and the reference value is displayed in the form of a subtraction as a Δ (delta) measurement or as a percent deviation Δ% (delta percent) measurement. The deviation measurement procedure is described in Figure 3-8.

3-11. DISPLAYS.

3-12. Two primary display sections and a subdisplay section provide visual data output of measurement results as well as of the test parameter values employed for the measurement.

1. DISPLAY A

DISPLAY A provides a readout of the measured impedance, admittance, reflection coefficient (absolute values) as well as for resistance, conductance, the real part of vector reflection coefficient, and the inductance or capacitance values (|Z|, |Y|, |Γ|, R, G, Γx, L or C) in a maximum 4-1/2 digit decimal number with decimal point and appropriate unit. The trigger lamp located at the left in display flashes in synchronism with measuring rate.

If the sample value exceeds full count display number on the selected range or an inappropriate DIGIT SHIFT control setting is set, an -OF- (Over Flow) figure appears in this display. If an inappropriate panel control operation is made, an error annunciation figure E-06 (Error 6) is displayed until the erroneous measurement arrangement is corrected (refer to Table 3-6 for the annunciation display meanings). When an auto-calibration needs to be performed, "CAL" (CALibration) or "Conn" (Connect) annunciation display provides an instruction for the succeeding calibration procedure in association with collateral indications in DISPLAY B.

2. DISPALY B

DISPLAY B gives subordinate measurement data such as phase angle (θ) in |Z|, |Y| or |Γ| measurements; reactance (X) in R measurements; susceptance (B) in G measurements; imaginary part of vector reflection coefficient (Γy) in conjunction with real Γx measurements; equivalent series resistance, parallel conductance dissipation factor or quality factor (R, G, D or Q) in L or C measurements.

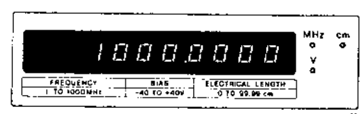
If sample value for selected DISPLAY B function is inappropriate or if an incorrect panel control operation is made, an -OF- or an error annunciation figure is displayed similar to that which appears in DISPLAY A. During calibration function, an "0Ω", "0S", "50Ω" or "END" figure appears providing information relevant to the display in DISPLAY A. When a diagnostic SELF TEST is performed, displays of the test results are exclusively provided in DISPLAY B.

3. Test Parameter Data Display

Test Parameter Data Display at front panel upper right provides readouts for the test parameter values that correspond with those particular data input operations, and affords a selectable display of the data for the test parameter settings employed in the measurement. These display parameter data are:

- Spot test frequency
- Sweep frequency parameters (start, stop and step frequencies)
- Spot bias voltage
- Sweep bias voltage parameters (start, stop and step frequencies)
- Electrical length value
- Reference values (in deviation measurements)

The display is given in a maximum 4-1/2 digit decimal number along with an adjacent unit indication (MHz, cm or V) at the right side. Option 002 unit offers a maximum 7 digit readout to permit the full digits of the test frequency setting number to be displayed at 0.0001 MHz resolution. An example is given below:



If an unacceptable input parameter number is set or if an inappropriate control operation is made, -OF- or an error message (E-01 to E-12 except E-10) is displayed until the control input demand is automatically released or the erroneous measurement setup is corrected.

3-13. DIGIT SHIFT.

3-14. DIGIT SHIFT control function permits the number of display digits for DISPLAY A and DISPLAY B to be independently set as desired instead of an automatic setting for the optimum number of digits (selectable number of display digits can not exceed those of an automatic setting). The numeric figures of the display output move to the right by one character each time the DIGIT SHIFT DSPL A or DSPL B [▷] key is pushed. The primary usage of this function is to proportion the analog recorder output to an appropriate three element digit number output of the display. For detailed information on the recorder output, refer to paragraph 3-56.

3-15. TEST FREQUENCY SIGNAL

3-16. The sinusoidal wave test signal incident on the test sample is fed at a signal level of −14 dBm (approximately 45 mV rms) from the internal frequency synthesizer signal source with 3 ppm frequency accuracy. The programmable, microprocessor controlled, synthesizer signal source provides sweep frequency measurement capability with a simple key board operating procedure. Coupling the powerful control and computation capability of an external calculating instrument (HP desktop computer) through the HP-IB line, enables the 4191A to make more creative, sophisticated use of the swept measurement functions. A control program will permit, for example, an automatic search for the resonance points of a sample device in the test frequency range and provides measurement readouts of the resonant frequencies, impedance values of the extremes, quality factor for each individual resonance and other useful analysis data. The controllable test frequency and sweep frequency parameters of the internal test signal are shown in Table 3-1.

Table 3-1. Test Frequency Setting Ranges.

Instrument option		Standard	Opt. 002
Spot frequency		1.0 – 1000.0 MHz	1.0000 – 1000.0000 MHz
Sweep frequency parameters	Step	0.1 – 999.0 MHz	0.0001 – 999.0000 MHz
	Start	1.0 – 1000.0 MHz	1.0000 – 1000.0000 MHz
	Stop	1.0 – 1000.0 MHz	1.0000 – 1000.0000 MHz
Frequency resolution	≤500 MHz	100 kHz	100 Hz
	>500 MHz	200 kHz	200 Hz

Test Signal Settling Time.
It takes about 200 milliseconds (maximum) for the test signal to stabilize after changing frequency. In swept frequency measurements, this settling time is automatically set before a measurement can be taken (at each sweep step frequency).

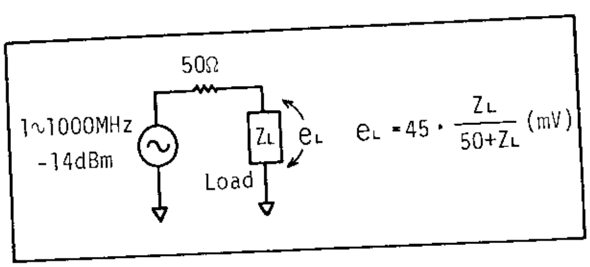


Figure 3-3. Test Signal Level.

3-17. RANGING

3-18. The 4191A measures sample values on one range for whichever measurement parameter is selected. Each of the selectable measurement parameters is derived from reflection coefficient measurements using parameter conversion calculations (performed by the 4191A). The reflection coefficients are always measured as values in the range of $|\Gamma| = 0$ and $|\Gamma| = 1$ for any impedance element (from 0Ω to infinity – ∞ Ω). Thus, measurement values are covered by one reflection coefficient range and range control function need not be provided.

However, autoranging control is seemingly performed for display output purposes in measurements of parameter values except for reflection coefficients. When the delta (Δ/Δ%) function is set to perform deviation measurements, the display output value range is automatically fixed. RANGE HOLD key function allows fixing the multiplier and decimal point displays to represent measured values in the desired display format.

Note: To supplement the outline of the ranging described above, refer to the expanded explanation of 4191A measurement principle (page 3-19).

3-19. MEASUREMENT RANGES

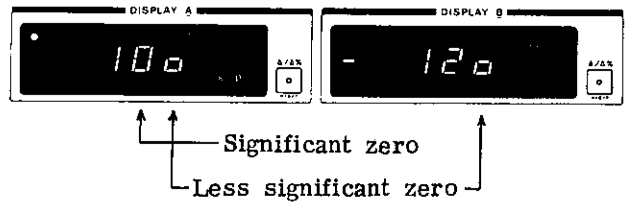
3-20. The 4191A is, in measurement principle, capable of measuring samples of all impedance values from zero to infinity (∞ ohms) as the measurement parameter values are translated from reflection coefficient measurements. However, the practical measurement range is defined in relation to accuracy and resolution both of which are reduced in the both low and high impedance regions. The practicable measurement range is therefore dependent on the accuracy requirements of the measurement purpose. Figure 3-4 shows each parameter measurement range in which sample values can be measured at accuracies better than ± 5%.

Because the reflection coefficient parameter measurement capability spans its entire range ($|\Gamma| = 0$ and $|\Gamma| = 1$) at almost constant accuracy at any test frequency, a reflection coefficient range graph is omitted.

3-21. MEASUREMENT RESOLUTION

3-22. In reflection coefficient (|Γ|-θ, Γx-Γy) measurements, measurement display outputs are provided at a 4 digit constant resolution from 0.0000 to 1.0000 over the entire test frequency range. As other parameter values are calculated from the measured reflection coefficient values, the resolution for these parameter measurements depends on the number of significant digits developed in the parameter conversion calculation results. The significant digits of converted parameter values decrease as reflection coefficient values increase (near 1). The 4191A automatically changes the number of display digits to provide appropriate measurement readouts in conjuntion with the resolution and measurement inaccuracy. Additionally, to facilitate reading the significance of the display outputs, the 4191A differentiates between the lesser significant digits displayed and the more significant digit display outputs (see note below).

Note: *Numeric segments of lesser significant display digits indicate zero figures. The lesser significant digit data (zero) are represented by small zeroes (o) figure to differentiate them from significant figures which are represented by large zeroes (0).*



(Less significant digit data identifies the meaningless numbers related to the uncertainty of the measurement result.)

When a high impedance sample is measured, the measurement readout displays, other than for reflection coefficients, will skip some numbers owing to the change in significant digits. For example, an impedance value of sample which is somewhat greater than 150 kΩ is displayed as either 15o kΩ or 2oo kΩ (the values 16o, 17o, 18o, and 19o kΩ are not displayed). This skip in readout display also occurs when a measurement is taken for high dissipation factor or high quality factor values.

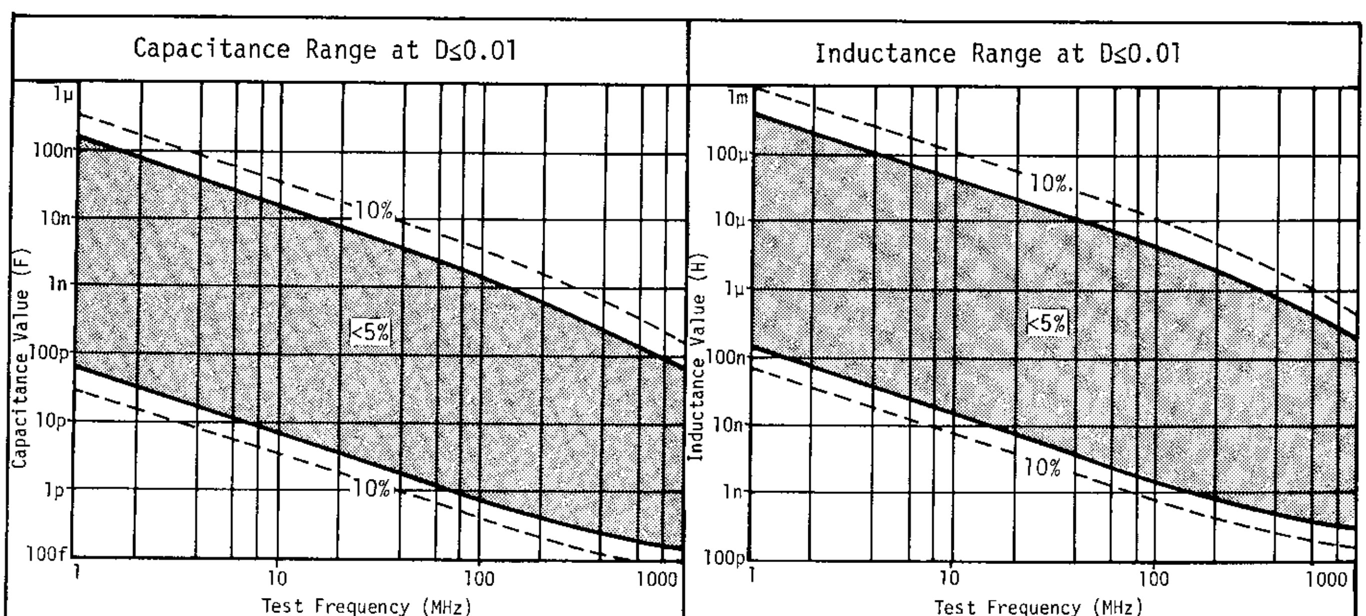


Figure 3-4. Measurement Ranges (Sheet 1 of 2).

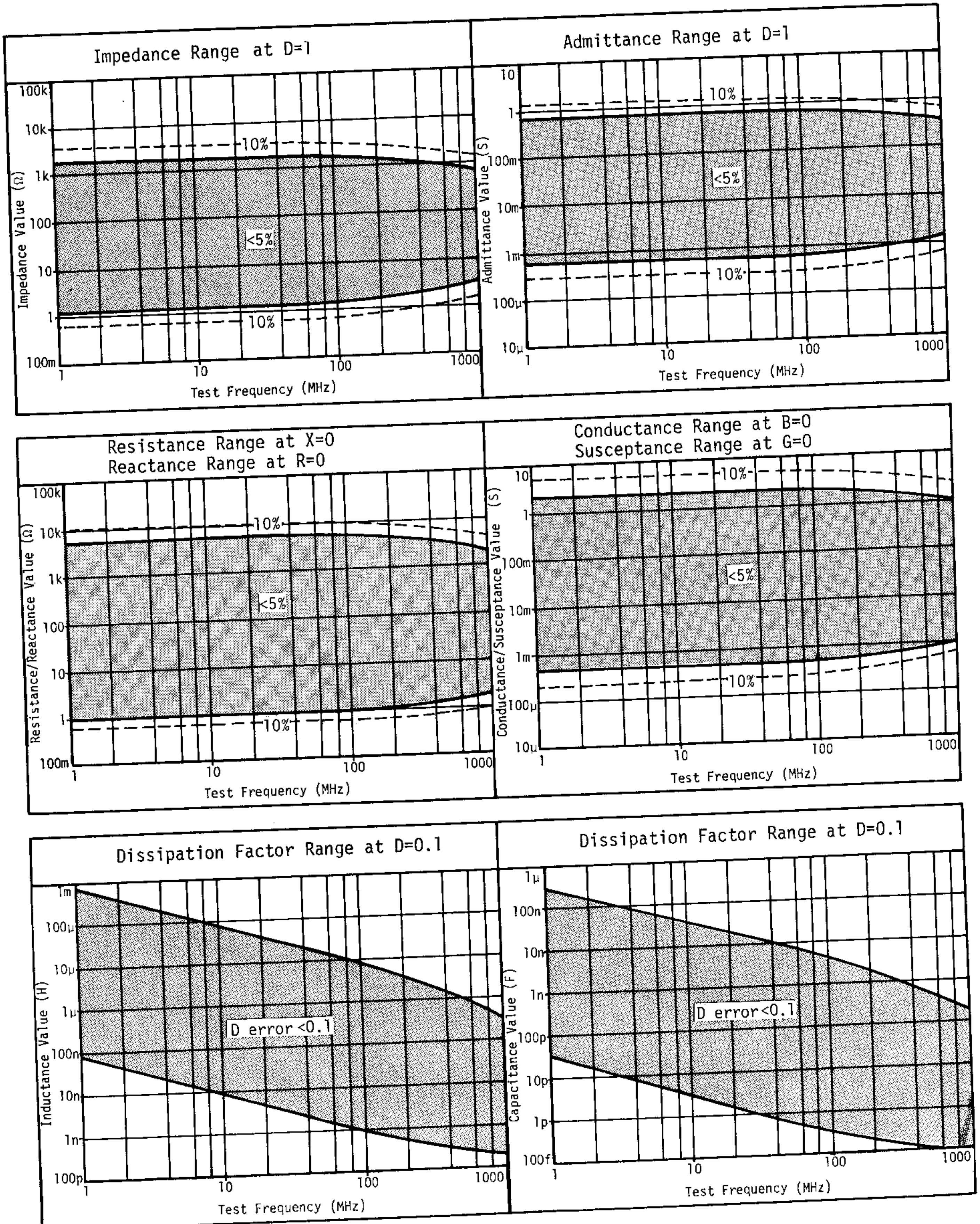


Figure 3-4. Measurement Ranges (Sheet 2 of 2).

3-23. CIRCUIT MODE

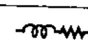
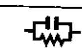
3-24. An impedance element can be represented by a simple equivalent circuit comprised of resistive and reactive elements each connected in series with or in parallel with the other. This representation is possible by either of the equivalents (series or parallel) because both have identical impedances at the selected measurement frequency by properly establishing the values of the equivalent circuit elements.

The 4191A employs an equivalent measurement circuit which is predetermined for each of the selectable combinations for both DISPLAY A and DISPLAY B measurement parameters. The display outputs are given as the resistive and reactive element values in the equivalent circuit for each measurement parameter set as shown in Table 3-2.

Parameter values for a component measured in a parallel equivalent circuit and that measured in a series equivalent circuit are different from each other. The difference in measured values is related to the loss factor of the sample to be measured. If no series resistance or parallel conductance is present, the two equivalent circuits are identical.

However, the sample value measured in a parallel measurement circuit can be correlated with that of a series circuit by a simple conversion formula which considers the effect of dissipation factor. See Table 3-3. The dissipation factor of a component always has the same value at a given frequency for both parallel and series equivalents.

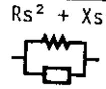
Table 3-2. Measurement Circuit Mode.

DISPLAY A	DISPLAY B	Circuit Mode
R	X	
G	B	
L	G	
	R, D, Q	
C	R	
	G, D, Q	

Note: Impedance, admittance, reflection coefficient and phase angle values are identical for both the series and parallel equivalent circuit representations. Such equivalents are thus omitted.

Table 3-3. Parallel-Series Equivalent Circuit Conversion.

jXs Rs

 ≈ 

$$\frac{Rs}{Rs^2 + Xs^2} = G$$

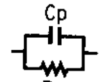
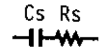
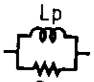
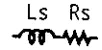
$$-j\frac{Xs}{Rs^2 + Xs^2} = jB$$

$$Zs = Rs + jXs \qquad Yp = \frac{1}{Zp} = G + jB$$

$$(Ds = Rs/Xs) \qquad (Dp = G/B = Rs/Xs)$$

When the conditions for the above equations are satisfied, the parallel and series circuits have equal impedance (at a particular frequency point). Note that the dissipation factor is the same in both equivalent circuit representations.

Dissipation Factor Equations.

	Circuit Mode	Dissipation Factor	Conversion to other modes
C	Cp  Rp	$D = \frac{1}{2\pi fCpRp} = \frac{1}{Q}$	$Cs = (1 + D^2)\,Cp$ $Rs = \frac{D^2}{1 + D^2}\,Rp$
C	Cs Rs 	$D = 2\pi fCsRs = \frac{1}{Q}$	$Cp = \frac{1}{1 + D^2}\,Cs$ $Rp = \frac{1 + D^2}{D^2}\,Rs$
L	Lp  Rp	$D = \frac{2\pi fLp}{Rp} = \frac{1}{Q}$	$Ls = \frac{1}{1 + D^2}\,Lp$ $Rs = \frac{D^2}{1 + D^2}\,Rp$
L	Ls Rs 	$D = \frac{Rs}{2\pi fLs} = \frac{1}{Q}$	$Lp = (1 + D^2)\,Ls$ $Rp = \frac{1 + D^2}{D^2}\,Rs$

THE 4191A MEASUREMENT PRINCIPLES

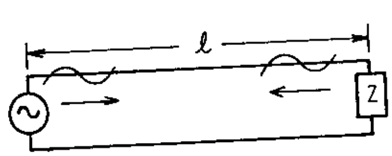
RF impedance measuring techniques necessitate a distinctly different architecture from the design techniques popularly used in the circuitry and mechanical composition of a low frequency (kilohertz region) LCR measuring instrument; (these include considerations for such elements as the test cables, the auto-balancing bridge circuit and other critical design areas).

Residual impedances, phase shift, propagation losses and other unwanted effects incident to "lumped constant measuring circuit" configurations are indeterminable factors in rf vector measurements. These effects increase with test frequency causing unacceptable, significant measurement errors to occur and narrow the practicable measurement and frequency ranges.

Thus, a vector measurement in the rf region is more conveniently handled by a "distributed constant measuring circuit" arrangement. Its advantage is that an equality in characteristics of the circuit over a broad frequency range can be realized; and, consequently, that the vector test signal detected can be exactly represented by a simple mathematic form with respect to the measuring circuit.

Instead of the usual vector-voltage-current-ratio measurement method (useable at low frequencies), the reflection and/or transmission coefficient parameter values are measured to obtain the desired characteristics of the sample.

The 4191A applies a measurement frequency test signal to the sample which is terminated at the test port and detects the vector-voltage-ratio of the reflected wave to the incident wave from/to the sample to measure the reflection coefficient. The reflection coefficient Γ is defined as:



$$\Gamma = \frac{V_{ref}}{V_{inc}} = \Gamma_x + j\Gamma_y$$

$$= |\Gamma| (\cos\theta + j\sin\theta) = |\Gamma| \angle \theta$$

Where, Vref is voltage of the reflected wave.
Vinc is voltage of the incident wave.

As the phases of both the incident and reflected waves differ at each point on the test signal propagation line (measuring circuit), the reflection coefficient is a function of the propagation line length. The reflection coefficient measured at distance ℓ from the termination point is represented as:

$$\Gamma_\ell = \Gamma e^{-2j\beta\ell} \quad (\beta = \frac{2\pi}{\lambda} = \frac{\omega}{c})$$

Where, λ is wave length of the test signal in the propagation line.
Γ is reflection coefficient value when ℓ = 0.

Note: *Attenuation coefficient of the test signal propagation line is neglected in this discussion.*

In practice, the measuring point where the reference terminations are connected for auto-calibration (normally the UNKNOWN connector contact surface) is taken as the reference of the line length ℓ.

Therefore the ℓ value corresponds to the propagation line length between the test port and the contact point of the sample to be tested. The ℓ value of the particular test fixture used is provided as the electrical length value in the performance characteristics data and is entered at the keyboard before taking measurements.

All measurement results automatically compensate for the electrical length effect of the test fixture using correction calculations based on the above equation.

The reflection coefficient value and the impedance value of the sample is interrelated, each with the other, by the following formulas:

$$\Gamma = \frac{Z_r - 1}{Z_r + 1}$$

$$Z_r = \frac{1 + \Gamma}{1 - \Gamma}$$

Where, Zr is normalized impedance of the sample defined as: $Z_r = Z_x/Z_0$

The base impedance Zo is identical with the characteristic impedance of the test port, that is, 50Ω.

The impedance value of the sample can therefore be derived as:

$$Zx = Zo\,\frac{1+\Gamma}{1-\Gamma}\ (\Omega)$$

$$= |Z|\,(\cos\theta + j\sin\theta) = |Z|\angle\theta$$

$$= R + jX$$

Resistance (R) and reactance (X) sample values are derived as:

$$R = Zo\,\frac{1-\Gamma x^2 - \Gamma y^2}{(1-\Gamma x)^2 + \Gamma y^2}$$

$$X = Zo\,\frac{2\Gamma y}{(1-\Gamma x)^2 + \Gamma y^2}$$

Other measurement parameter values are calculated from the resistive and/or reactive component(s) of the impedance value.

Measurement Parameter Relationships

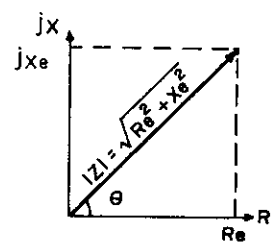
Vector impedance and vector reflection coefficient values are represented in orthogonal or polar coordinates as follows:

$$\Gamma = \Gamma x + j\Gamma y = |\Gamma|(\cos\phi + j\sin\phi)$$

$$= |\Gamma|\angle\phi \qquad |\Gamma| = \sqrt{\Gamma x^2 + \Gamma y^2}$$

$$Z = R + jX = |Z|\,(\cos\theta + j\sin\theta)$$

$$= |Z|\angle\theta \qquad Z = \sqrt{R^2 + X^2}$$



Measured reflection coefficient values and impedance values are correlated by the following equations:

$$\Gamma = \frac{Zx - Zo}{Zx + Zo} \qquad Zx = Zo\,\frac{1+\Gamma}{1-\Gamma}$$

Where, Zx is impedance value of sample.
Zo is characteristic impedance of the measurement circuit.

Because 4191A measurement circuit impedance is 50Ω, the above equations can be represented as:

$$\Gamma = \frac{Zx - 50}{Zx + 50} = \frac{Zr - 1}{Zr + 1}$$

$$Zx = 50\cdot\frac{1+\Gamma}{1-\Gamma}$$

Where, Zr (normalized impedance) is given as:

$$Zr = Zx/Zo = Zx/50 = \frac{R}{50} + \frac{jX}{50} = Rr + jXr$$

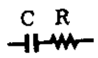
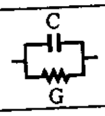
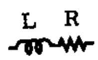
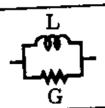
$$\Gamma x = \frac{Rr^2 + Xr^2 - 1}{(Rr+1)^2 + Xr^2} \qquad \Gamma y = \frac{2Xr}{(Rr+1)^2 + Xr^2}$$

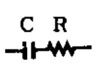
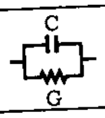
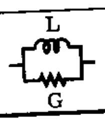
$$R = 50\,\frac{1-\Gamma x^2 - \Gamma y^2}{(1-\Gamma x)^2 + \Gamma y^2} \qquad X = 50\,\frac{2\Gamma y}{(1-\Gamma x)^2 + \Gamma y^2}$$

Other measurement parameter values are correlated with the resistance and reactance values by the equations tabulated below:

DISPLAY A Parameters		DISPLAY B Parameters	
|Z|	$\sqrt{R^2+X^2}$	θ	$\tan^{-1}\frac{X}{R}$
|Y|	$\frac{1}{\sqrt{R^2+X^2}}$	θ	$\tan^{-1}\frac{X}{R}\ \left(=\tan^{-1}\frac{B}{G}\right)$
G	$\frac{R}{R^2+X^2}$	B	$\frac{X}{R^2+X^2}$
L	$\frac{R^2+X^2}{2\pi fX}\ \left(=\frac{1}{2\pi fB}\right)$	G	$\frac{R}{R^2+X^2}$
	$\frac{X}{2\pi f}$	R	R
		D,Q	$\frac{R}{X}\ \left(=\frac{1}{Q}\right)$
C	$\frac{1}{2\pi fX}$	R	R
	$\frac{X}{2\pi f(R^2+X^2)}\ \left(=\frac{B}{2\pi f}\right)$	G	$\frac{R}{R^2+X^2}$
		D,Q	$\frac{R}{X}\ \left(=\frac{1}{Q}\right)$

Table 3-4. Parameter Conversion Formulas

Sample	DISPLAY A parameters					
	$\|Z\|$	$\|Y\|$	R	G	L	C
	$\sqrt{\frac{1}{\omega^2 C^2} + R^2}$	$\frac{\omega C}{\sqrt{1 + \omega^2 C^2 R^2}}$	R	$\frac{\omega^2 C^2 R}{1 + \omega^2 C^2 R^2}$	——	C*
	$\frac{1}{\sqrt{\omega^2 C^2 + G^2}}$	$\sqrt{\omega^2 C^2 + G^2}$	$\frac{G}{G^2 + \omega^2 C^2}$	G	——	C*
	$\sqrt{\omega^2 L^2 + R^2}$	$\frac{1}{\sqrt{\omega^2 L^2 + R^2}}$	R	$\frac{R}{R^2 + \omega^2 L^2}$	L*	——
	$\frac{\omega L}{\sqrt{1 + \omega^2 L^2 G^2}}$	$\sqrt{\frac{1}{\omega^2 L^2} + G^2}$	$\frac{\omega^2 L^2 G}{1 + \omega^2 L^2 G^2}$	G	L*	——

Sample	DISPLAY B parameters					
	θ	X	B	R	G	D (1/Q)
	$-\tan^{-1}\frac{1}{\omega CR}$	$-\frac{1}{\omega C}$	$\frac{\omega C}{1 + \omega^2 C^2 R^2}$	R	$\frac{\omega^2 C^2 R}{1 + \omega^2 C^2 R^2}$	ωCR
	$-\tan^{-1}\frac{\omega C}{G}$	$-\frac{\omega C}{G^2 + \omega^2 C^2}$	ωC	$\frac{G}{G^2 + \omega^2 C^2}$	G	$\frac{G}{\omega C}$
	$\tan^{-1}\frac{\omega L}{R}$	ωL	$-\frac{\omega L}{R^2 + \omega^2 L^2}$	R	$\frac{R}{R^2 + \omega^2 L^2}$	$\frac{R}{\omega L}$
	$\tan^{-1}\frac{1}{\omega LG}$	$\frac{\omega L}{1 + \omega^2 L^2 G^2}$	$-\frac{1}{\omega L}$	$\frac{\omega^2 L^2 G}{1 + \omega^2 L^2 G^2}$	G	ωLG

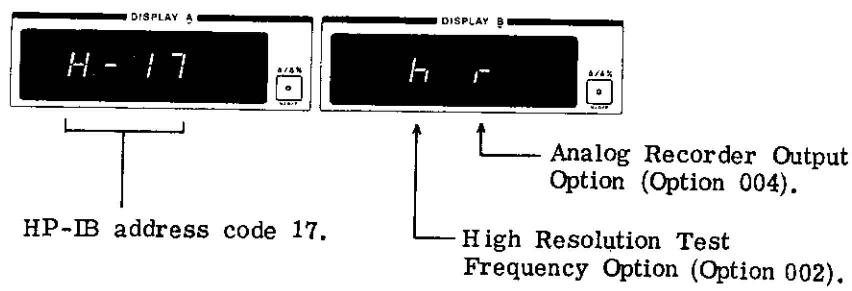
* Note: Measured value for measurement circuit mode is same as equivalent circuit of sample.

INITIAL MODE SETTINGS

Initial impedance analyzer operation begins with an automatic self diagnostic test which checks functional operation of the instrument when the instrument is turned on. This test is accomplished within 1 second. If any abnormality is detected in the diagnostic test period, an error message figure will appear in DISPLAY B and/or the sequential operation will not proceed to the next option annunciation display.

OPTION ANNUNCIATIONS

The instrument first displays the HP-IB address number to be used when interfacing with other HP-IB equipment. Simultaneously, installed option content is, if Option 002 and/or 004 is installed, displayed in the front panel display to let users know what option is available in the instrument. The HP-IB address number and option annunciation are respectively given in abbreviated code as illustrated below:



10 MINUTE WARM-UP

An internal timer delays instrument operation for the 10 minute warm-up time needed to stabilize the temperature controlled circuit block in the instrument. During the preparatory warm-up operation, the option annunciation figures are continuously displayed. If any panel control key is pressed before the 10 minutes warm-up time is complete, an error message figure (E-07) will appear in Test Parameter Data Display.

Notes: 1. *Perform a running warm-up of at least 40 minutes to settle instrument into its specified performance.*

2. *If ac operating power is momentarily lost after warm-up, the measurement can be resumed by passing over the initial warm-up time. To omit the regular warm-up time, press any arbitrary panel control key (E-07 will be displayed), and again press a key. The instrument will proceed to its initial control settings.*

Figure 3-5. Initial Mode Settings (Sheet 1 of 3).

INITIAL MODE SETTINGS

INITIAL CONTROL SETTINGS

The 4191A front panel control key functions and test parameter data are automatically set as follows:

DISPLAY A function	|Z|
DISPLAY B function	θ (deg)
Δ/Δ% (DISPLAY A)	off
Δ/Δ% (DISPLAY B)	off
SPOT FREQ	1.0 MHz
STEP FREQ	1.0 MHz
START FREQ	1.0 MHz
STOP FREQ	1000.0 MHz
REF A	0Ω (|Z|)
REF B	0 deg (θ)
ELEC LG	.00 cm
SELF TEST	off
HIGH SPEED	off
LOG SWEEP	off
TRIGGER	INT
RANGE HOLD	off
CALIBRATION	off
SPOT BIAS	0V
STEP BIAS	.01V
START BIAS	-40V
STOP BIAS	40V

INITIAL CALIBRATION

Calibration data for the entire 4191A frequency range (1MHz to 1000MHz) is present in the instrument's continuous memory (when the instrument is shipped from factory). Accordingly, the instrument can usually begin taking measurements using these initial control settings. Thus, the impedance value of a sample can be measured by merely connecting the sample (using an appropriate test fixture) at the memorized 1MHz test frequency.

If a CAL annunciation figure appears in DISPLAY A and/or DISPLAY B, such display indicates that the instrument is in either of the following states:

1. Auto-calibration data memorized by instrument is for a defined frequency range which does not include the spot frequency (1MHz). That is, the spot frequency is out of the calibrated (and memorized) frequency range.

2. Calibration data has been lost (owing to incomplete calibration or because memory backup battery is exhausted).

Figure 3-5. Initial Mode Settings (Sheet 2 of 3).

INITIAL MODE SETTINGS

REQUIRED OPERATION

Set the upper limit frequency number of the desired test frequency range with the DATA input keys and, next, press ENTER key.

(Example) Upper limit frequency = 100 MHz

Key strokes: [1] [0] [0] [MHz V cm]

Note: If PARAMETER SPOT FREQ/BIAS key indicator lamp is not lighted, first press this key.

Check whether the CAL annunciation display occurs or not. Next, set the lower limit test frequency number in like manner.

If CAL annunciation is displayed when either the upper or lower frequency limit is set, the instrument must be recalibrated to cover a frequency range which includes the desired test frequencies. The auto-calibration procedure is described in the paragraph which follows.

Note

For optimum calibration accuracy, it is recommended that the instrument be calibrated at the specific frequency range used rather than for the full range.

Figure 3-5. Initial Mode Settings (Sheet 3 of 3).

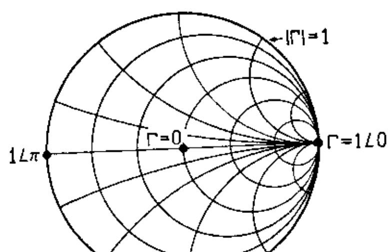
INITIAL AUTO-CALIBRATION

GENERAL

To optimize measurements, the 4191A must initially have memorized automatic calibration data for the entire test frequency range to be used before beginning measurements. By pressing CALIBRATION key, the 4191A goes into its automatic calibration operating mode. Through the calibration routine, trial measurements with definitive reference terminations* (0Ω, 0S and 50Ω) are made to calculate the correction factors based on measurement deviation results from the reference values. The 4191A memorizes its own calibration data and applies appropriate corrections to all measurements. The instrument's intelligent microprocessor capabilities do the memorization and produce the necessary sophisticated correction computations at high speed for each measurement. Consequently, any constitutional errors, particular to the instrument, are eliminated from any subsequent measurement results almost to the level of the inaccuracies inherent in the reference terminations.

*Note: *The reference terminations are supplied accessories (HP part numbers are 04191-85300 for 0Ω, 04191-85301 for 50Ω, and 04191-85302 for 0S termination).*

Note: *The 0Ω, 0S and 50Ω reference termination devices provide references for exact $\Gamma = 1\angle\pi$, $1\angle 0$ and 0 reflection coefficient representations, respectively. On a Smith Chart plane, these reference points represent the intersections on the circumference of the $|\Gamma| = 1$ circle, the R axis $(x = 0)$, and the center of the chart. Auto-calibration optimizes measurements using these references so that measured values are exactly coordinated with the proper points on the chart. The virtual (supposed) coordinated system of the instrument, related to measurements, is compensated for any possible distortion and, consequently, any measurement parameter value can be represented correctly by the optimized coordinate.*



Calibration Points on Smith Chart

ACCURACY AND TRACEABILITY

The above discussion emphasizes that the 4191A measurement accuracy substantially depends on the accuracies of the standard terminations used. In practice, the comprehensive accuracies of the standards is dominant in both actual and specified measurement accuracies of the instrument. Thus, the measurement accuracy is further enhanced if high quality terminations, that is, more idealistic reference terminations which embody high standard impedance accuracies, are available and used.

As a result of the preparatory calibrations with the use of standards whose values are certifiable by national standard/calibration entities, definite traceability for the 4191A to NBS, NRC or other, equivalent, standards groups is provided.

INITIAL AUTO-CALIBRATION

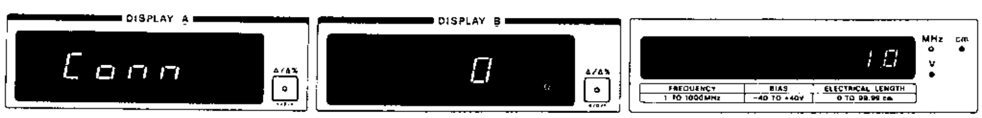
CALIBRATION PROCEDURE

Auto-calibration of the 4191A instrument is performed by using reference terminations under automatic settings of the measurement parameter (reflection coefficient) and of the test frequency as it sweeps the programmed frequency range. This paragraph firstly describes the basic calibration procedure for calibrating the instrument over its entire test frequency range and, secondly, describes selective calibration (for a defined frequency range):

1. Depress LINE button to turn instrument on.
   After the 10 minute warm-up time is fulfilled, the instrument controls are automatically set (initial control settings).

2. Press CALIBRATION key (key lamp lights).
   Instrument controls are automatically set as follows:
   DISPLAY A and DISPLAY B .... R-X
   CALIBRATION .... on
   Start frequency .... 1.0 MHz
   Stop frequency .... 1000.0 MHz
   TRIGGER .... INT
   (Measurement parameters are now, in actuality, set to an $\Gamma x - \Gamma y$ measurement.)

   The indicator lamps for the above functions (except for start and stop frequencies) and SPOT FREQ/BIAS key lamp light. Concurrently, "Conn" "0Ω" figures appear in the displays to indicate that the 0Ω reference termination should be connected to UNKNOWN connector, as illustrated below:



> *Note*
>
> *The above "Conn 0Ω" annunciation figure does not appear when complete calibration data, used in previous measurements, has been memorized. Also, the "Conn 0S" and "Conn 50Ω" annunciation figures (steps 7 and 11) are not displayed.*

0Ω CALIBRATION

3. Rotate UNKNOWN connector coupling nut clockwise until the coupling sleeve screw fully protrudes.

   Caution: **Do not touch the terminal contact surface with fingers (to maintain optimum electrical contact).**

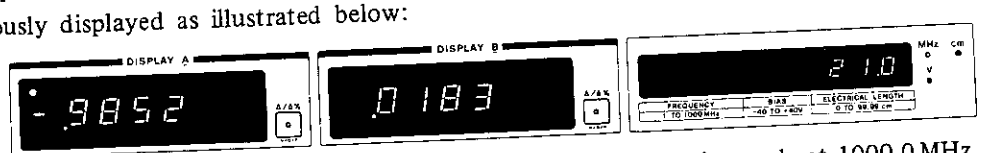
4. Carefully couple the 0Ω termination to the UNKNOWN connector so that each is face-to-face with the other.

   Caution: **Carefully handle the termination so as not to impair its precision contact surface.**

INITIAL AUTO-CALIBRATION

5. Rotate the 0Ω termination cap nut clockwise until it is firm (termination is mated with the UNKNOWN connector).

6. Press CALIBRATION START button.
Test frequency display succeedingly changes in a higher frequency direction in the order of the programmed 51 spot frequencies (which are automatically predetermined in regular *20MHz frequency intervals to 1000MHz). Measurement data taken for the 0Ω termination is simultaneously displayed as illustrated below:

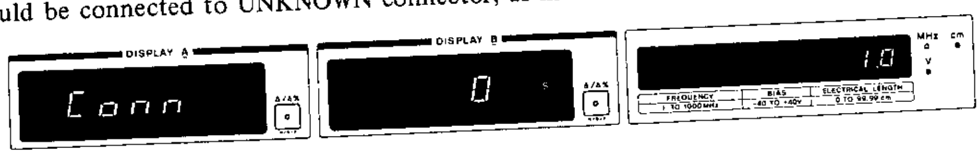


After an interval of approximately 50 seconds, the 0Ω calibration ends at 1000.0MHz test frequency.

**Note:* *19.98MHz for option 002 units.*

0S CALIBRATION

7. "Conn" "0S" figures appear in the displays to indicate that the 0S standard termination should be connected to UNKNOWN connector, as illustrated below:



Measurement parameter indication changes as follows:
DISPLAY A and DISPLAY B .... G-B

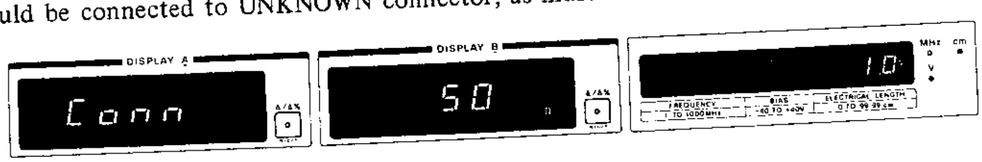
8. Rotate the 0Ω termination cap nut counter-clockwise and remove the 0Ω termination.

9. Carefully couple the 0S reference termination to the UNKNOWN connector and rotate the termination cap nut clockwise until it firmly mates with the connector.

10. Press CALIBRATION START button.
Test frequency display is reset to 1MHz and restarts (succeedingly shifting in the higher frequency direction). Measurement data (Γx and Γy values) for the 0S termination is displayed similar to that for 0Ω calibration. The 0S calibration ends at the 1000.0MHz test frequency approximately 50 seconds from the start.

50Ω CALIBRATION

11. "Conn" "50Ω" figures appear in the displays to indicate that the 50Ω reference termination should be connected to UNKNOWN connector, as illustrated below:



Measurement parameter indication changes as follows:
DISPLAY A and DISPLAY B .... Γx-Γy

INITIAL AUTO-CALIBRATION

12. Rotate the 0S termination cap nut counter-clockwise and remove the termination.

13. Rotate 50Ω reference termination coupling nut counter-clockwise (as viewed from contact side) until the coupling sleeve screw is at its innermost free position.

14. Carefully couple the 50Ω reference termination to the UNKNOWN connector and rotate the termination coupling nut clockwise until it firmly mates with the connector.

15. Press CALIBRATION START button.
Test frequency display is reset to 1MHz and restarts (succeedingly shifting to higher frequencies). Measurement data (Γx and Γy values) for the 50Ω termination is displayed similar to that for 0Ω and 0S calibrations. The 50Ω calibration ends after approximately 50 seconds. Concluding "CAL" "END" annunciation figures appear in the displays to indicate that the calibration is completed.

16. To release the calibration function, press CALIBRATION button. The instrument is automatically set to |Z|-θ (deg) measurement mode of operation.

Caution: After use, keep the termination coupling sleeve screw protruding to prevent the termination surface from possible impairment.

Notes:

1. *If calibration can not be achieved for either 0Ω, 0S or 50Ω standard, "CAL END" annunciation display will not appear.*
2. *Correction factors at frequencies other than at the calibration frequency points are automatically calculated using cubic interpolation approximations.*
3. *Typical value of the UNKNOWN connector stray capacitance (0.082pF) is continuously memorized in the internal memory and is used for the correction factor calculations (with nothing connected to the UNKNOWN, the 4191A thus displays approximately 0.08pF).*
4. *Electrical length input data has no effect on the calibration results.*
5. *The calibration data displayed for the individual terminations are approximately equal to the values listed in the table below:*

Termination	0Ω	0S	50Ω
DISPLAY A	-0.7~-1.1	0.7~1.1	-0.07~0.07
DISPLAY B	-0.5~ 0.5	-0.5~0.5	-0.07~0.07

If a displayed value exceeds the normal value range, check the UNKNOWN connector and the termination connector surfaces for dirt. For critical test limits, refer to paragraph 4-15.

Note

The calibration data is stored in the internal memory and retained by virtue of the battery memory backup capability (until new calibration data is taken and stored to update the previously memorized data).

INITIAL AUTO-CALIBRATION

SELECTIVE CALIBRATION

If a calibration fails to be achieved or if it is desired to calibrate in a particular test frequency range (using narrower calibration frequency step intervals), the calibration can be again performed with respect to the 0Ω, 0S or 50Ω reference impedance terminations (separately) or to the desired frequency range.

Note: If the CALIBRATION function is released before the calibration completed, the memory of memorized calibration data is lost and the instrument must be again calibrated for all reference terminations.

- **0Ω, 0S or 50Ω Calibration.**
When the instrument needs to be calibrated at the 0Ω reference impedance, perform the following procedures:

1. Connect the 0Ω reference termination to the UNKNOWN connector.
2. Set measurement parameter to R-X by pressing DISPLAY A parameter selector (⇧ ⇩) keys.
3. Press CALIBRATION START button.

   0S and 50Ω calibration procedures are similar to the above 0Ω calibration procedures. Set measurement parameter to G-B or Γx-Γy in accord with the calibration setup procedures summarized in the tabulation below:

Individual Termination Calibration Setup Procedures.

Reference termination	Operating procedure		
	1	2	3
0Ω	Connect reference termination	Select R-X	Press START ●
0S		Select G-B	Press START ●
50Ω		Select Γx-Γy	Press START ●

- **Calibration on a defined frequency range.**
To define the calibration frequency range, set its bottom and top frequencies as the Start and Stop frequencies, respectively, in accord with the following procedure:

Setting upper limit frequency.

1. Press PARAMETER STOP FREQ/BIAS key.
2. Set the upper limit frequency number (in MHz) of the desired calibration frequency range with the DATA input keys. The frequency setting is displayed in Test Parameter Data display.
3. Press ENTER key.

INITIAL AUTO-CALIBRATION

Setting lower limit frequency.

1. Press PARAMETER START FREQ/BIAS key.
2. Set the lower limit frequency number (in MHz) of the desired calibration frequency range with the DATA input keys.
3. Press ENTER key.

Press CALIBRATION key to activate calibration function.

Notes: 1. *Step frequency is automatically determined so as to total 50 steps (51 calibration frequency points) at regular frequency intervals from the start to stop frequencies (and can not be selected manually).*

2. *When LOG SWEEP function is set (LOG SWEEP key is pressed after pressing* [Blue] *key), the calibration frequency points are taken at logarithmically regular frequency intervals.*

3. *If measurement is attempted at a test frequency out of the defined calibration frequency range, a CAL (CALibration) annunciation figure appears in DISPLAY A or DISPLAY B.*

4. *Setting the START and STOP frequencies to an identical value allows calibration in a shorter time for measurement at that particular SPOT frequency.*

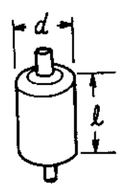
5. *When the calibration frequency range is narrower than 5MHz (5kHz for option 002), the number of calibration frequency points decreases, owing to the minimum selectable step frequency.*

DUT CONNECTION – WITH 16091A

The 16091A Coaxial Termination Fixture set offers a sample holding capability specifically suitable for making accurate measurements at high frequencies. Two types of fixtures are included in the fixture set to provide flexibility and wide adaptability to various sizes of samples.

Each fixture is coupled to the UNKNOWN test port with the sample device mounted in its inner cavity chamber. Owing to this unique construction, the sample to be tested can be measured immediately at the test port. This decreases, to a great extent, the residual parameters of the component leads and of the measuring circuits. Additionally, the complete shielding effect of the test fixture, a cavity chamber prevents measurement errors sometimes contributed by the free radiation of the test signal from the sample. This 16091A fixture, consequently, features high accuracy with a useable frequency range beyond 1000MHz.

The 16091A fixture set is suited to the measurement of lead-less material samples or small size, axial lead components whose leads can be shortened. The maximum dimensions of the sample which the test fixture can accommodate are shown in the tabulation below:

Sample	Fixture	Maximum dimensions	
	04191-85302	d l	7 mm 20 mm
	16091-60012	d l	10 mm 20 mm

Sample mounting procedure

1) Rotate the 4191A UNKNOWN connector coupling nut counter-clockwise until the coupling sleeve screw is at its innermost free position.

2) Attach the 16091A special coaxial coupling adapter to the UNKNOWN connector.

   Caution:
   Be sure to use the coupling adapter to protect the precision-built UNKNOWN connector from possible damage.

3) Set the test sample and the movable, skirted, electrode onto the coupling adapter as illustrated below:

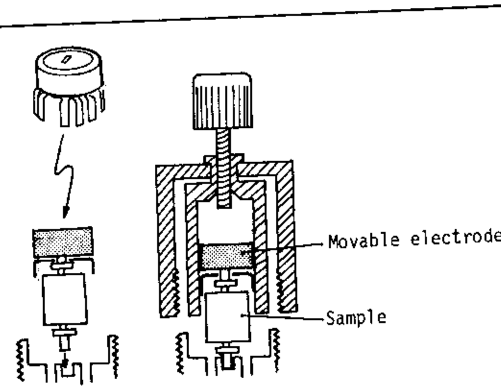


Figure 3-6. DUT Connection (Sheet 1 of 7).

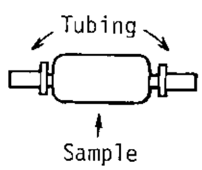
DUT CONNECTION – WITH 16091A

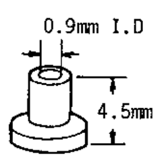
4) Carefully couple the coaxial fixture (housing the test sample) to the coupling adapter attached to the UNKNOWN connector. Rotate the coaxial fixture coupling nut clockwise until it is snug.

5) Insert the electrode adjustment screw into the head spindle of the coaxial fixture used (see illustration). Rotate the adjustment screw knob clockwise until the click stop knob begins to idle.

Notes:

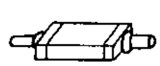
1. *To properly set test sample into the coaxial fixture chamber, solder miniature tubing (disposable part supplied) near the element on the sample leads. Cut off the excess portion of the leads. See illustration below:*





Tubing dimensions

2. *For lead-less chip components, solder tubing directly to the electrodes of the sample.*



Chip component

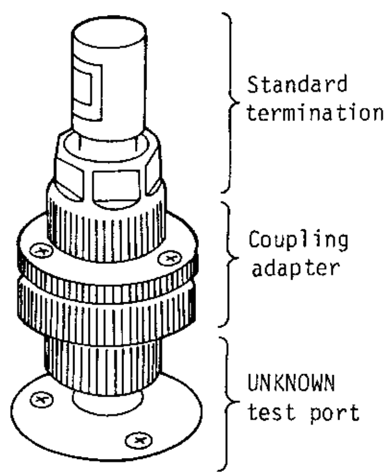
Model 16091A Residual Parameters

Stray C	Residual L	Residual R	Stray G
0.082pF	*0.0nH	*0mΩ	0μS

*When auto-calibration is performed at the protective connection port of the coaxial coupling adapter.

3. *Set Electrical Length input data to 1.87 cm.*

4. *To optimize measurement accuracy with respect to the 16091A test fixture, perform auto-calibration at the protective connection port of the coaxial adapter attached to the UNKNOWN.*
Set Electrical Length input data to 0.00 cm. (This calibration data is specific to the coaxial adapter of the 16091A used. Therefore, the instrument must be re-calibrated exclusive of the adapter when another type of test fixture is used).



Model 16091 A accessories:

Coupling adapter:	P/N 16091-60010
Ratchet screw:	P/N 16091-60011
Movable electrodes:	P/N 16091-60014 (10mm)
	P/N 16091-60013 (7mm)
Tubing:	P/N 16091-60023 (200ea. 16091-24023, in a plastic case)

Figure 3-6. DUT Connection (Sheet 2 of 7).

DUT CONNECTION – WITH 16092A

The 16092A Spring Clip Test Fixture provides a convenient capability for easily connecting and disconnecting samples and has a broad useable frequency operating range up to 500 MHz. Two types of spring contact assemblies (furnished) permit selecting the fixture configuration appropriate to the shape of the sample. The slide clip contact assembly is designed specifically for holding lead-less chip components such as chip capacitors. The twin clip contact assembly is suited for measuring general radial lead components and axial short lead components. Its ground contact, which is slidable on the fixture deck, permits proper adjustment of the distance between sample lead contacts. The contact distance can be gauged with the 1 mm pitch scale on the deck (maximum measurable device dimension = 13 mm). Appropriate sample connection procedures are outlined below:

Chip components

1) Rotate the 4191A UNKNOWN connector coupling nut counter-clockwise until the coupling sleeve screw is at its innermost free position.

2) Couple the connector coupling screw on the underside of the 16092A test fixture deck to the 4191A UNKNOWN connector, and set the test fixture mounting posts of the 4191A into the twin holes at the corners of the deck.

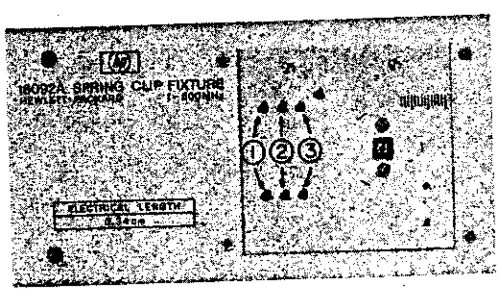
3) Rotate the UNKNOWN connector coupling nut counter-clockwise until it is firm.

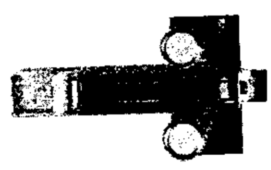
4) Attach the slide clip contact assembly to the test fixture deck ((1), (2) or (3)) with the captive screws provided (see illustration below).
Use deck positioning holes appropriate to size of sample to be measured.

5) Securely attach the contact assembly to the deck with the two captive knob screws.

6) Pull spring slide contact back and clip in sample.

Note: Set electrical length input data to 0.34 cm.





Slide clip contact assembly

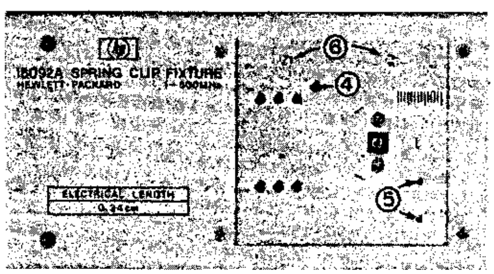
Figure 3-6. DUT Connection (Sheet 3 of 7).

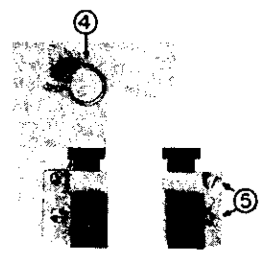
DUT CONNECTION – WITH 16092A

Short lead radial and axial lead components

1) Perform steps 1, 2 and 3 of the above procedure to install the 16092A test fixture deck to the 4191A.
2) Attach single clip module of the twin clip contact assembly to the test fixture deck with its two retaining screws (screw into deck positioning holes ⑤ – see illustration).
3) Attach ground contact slide module of the twin clip contact assembly so that its slide guide mounts on the two guide posts ⑥ of the deck.
4) Fasten contact module on the deck with its knob screw and leave screw loose.
5) Set an appropriate contact distance and tighten contact module to deck with its knob screw.
6) Press spring clip lever down and clip in sample.

Note: Set electrical length input data to 0.34 cm.





Twin clip contact assembly

Model 16092A Residual Parameters

Stray C	1.1 pF
Residual L	1.3 nH
Residual R	See graph
Stray G	See graph

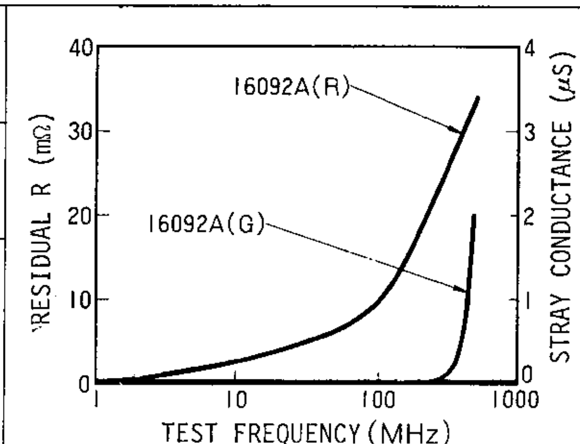
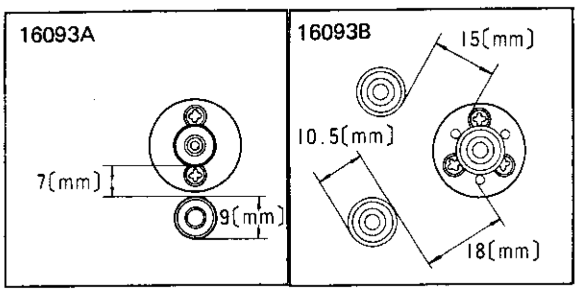


Figure 3-6. DUT Connection (Sheet 4 of 7).

DUT CONNECTION
– WITH 16093A/B

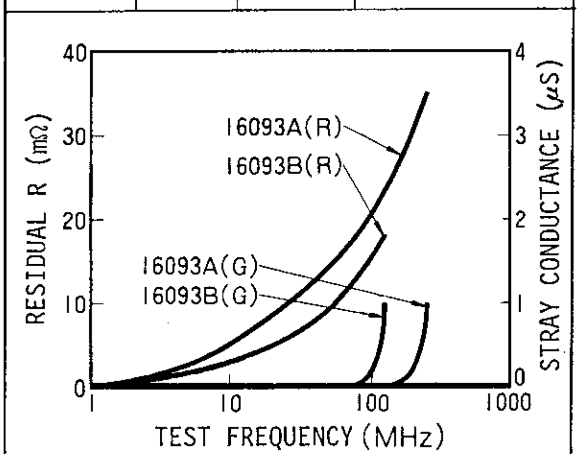
The 16093A/B Binding Post Test Fixtures are suited for the measurement of relatively large size, axial and radial lead components or devices which do not fit the 16091A or 16092A. The 16093A is provided with two small binding post measurement terminals set at 7 mm intervals on the terminal deck. These short post terminals afford the advantage of low stray capacitance with low stray conductance and, therefore, offer a broad, useable frequency operating range (up to 250 MHz). The 16093B employs a common type three binding post terminal arrangement which includes an extra guard post terminal. The measurement terminal interval is 15 mm (the terminal configuration is same as that of the current HP Q meter). The 16093B is suitable for the measurement of relatively high value capacitors, high value inductors and resistor samples at frequencies below 125 MHz.

Terminal Structures



Model 16093A/B Residual Parameters

	Stray C	Residual L	Residual R	Stray G
16093A	1.8 pF	1.8 nH	See graph below	
16093B	5.5 pF	1.4 nH		



Installation and DUT connection procedure:

1) Rotate the 4191A UNKNOWN connector coupling nut counter-clockwise until the coupling sleeve screw is at its innermost free position.

2) Couple the connector coupling screw on the underside of the 16093A (or 16093B) test fixture deck to the 4191A UNKNOWN connector, and set the test fixture mounting posts of the 4191A into the twin holes at the corners of the deck.

3) Rotate the UNKNOWN connector coupling nut counter-clockwise until it is firm.

4) Loosen binding post terminal nut and connect sample leads. Tighten the nut. For samples with banana plugs, plug the banana plugs into the binding post terminal holes.

Notes:

1. *Set electrical length input data to 0.34 cm (identical for both 16093A and 16093B).*

2. *A special, skirted, grounding terminator furnished with both the 16093A and B provides an optimum shorting configuration for test fixture terminals. For the use of these terminators, refer to paragraph 3-37.*

Figure 3-6. DUT Connection (Sheet 5 of 7).

DUT CONNECTION
– WITH 16094A

The 16094A Probe Test Fixture provides probing capability for measuring circuit impedances and components mounted on circuit assemblies. The 16094A permits easy access to test point locations when it is attached to an appropriate test cable (connected to the 4191A test port). This probe fixture unit can be combined with a coaxial test cable or flexible air line which has an APC-7 connector. The probe needles (consisting of sense and ground terminals) permit setting to appropriate distances from 1mm (min.) to 15 mm (max.) for fitting dimensions of device/material to be measured. The 16094A is suitable for measurements at frequencies below 125MHz.

Note: Use of a probe cable requires that the electrical length compensator of the instrument be adjusted to optimize measurement accuracy at that particular measurement configuration. Replace the normal electrical length compensator cable with a longer cable appropriate to the probe cable used. For the electrical length compensation adjustment method, refer to paragraph 3-44.

Installation and measurement setup procedure:

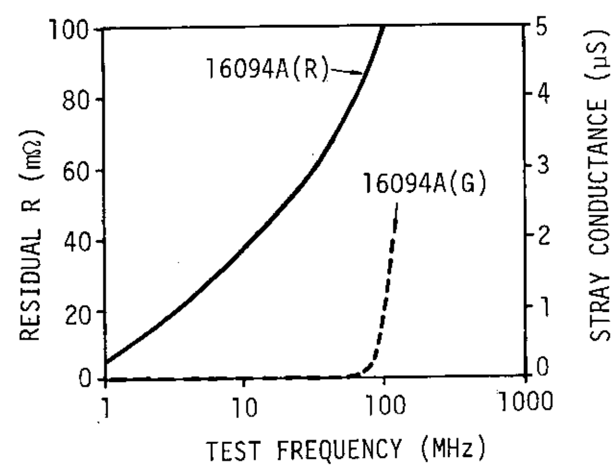
1) Build the electrical length compensator cable appropriate to the probe cable (or air line) used and install it in place of the normal compensator cable.
2) Rotate the UNKNOWN connector coupling nut clockwise until the coupling sleeve screw fully protrudes.
3) Couple the probe cable connector coupling nut to the 4191A UNKNOWN connector and rotate the coupling nut clockwise until it is snug
4) Connect reference termination at the tip of the probe cable and perform auto-calibration for each of the 0Ω, 0S and 50Ω termination impedances.
5) Disconnect reference termination and connect 16094A (at the tip of test cable).

   Notes:
   1. *Set electrical length input data to 2.32 cm.*
   2. *A bent coaxial probe cable causes a slight change in its physical and electrical length from that in its straight form. This has a low order effect on the measured reflection coefficient phase angle and this effect increases at high frequencies. To maximize measurement accuracy, the auto-calibration should be performed with the cable shape (form) near that used in the actual measurement.*

Figure 3-6. DUT Connection (Sheet 6 of 7).

Model 16094A Residual Parameters

Stray C	*1.0 pF	See graph (right)
Residual L	5 nH	
Residual R	See graph	
Stray G	See graph	



* Typical value when needles are set at a distance of 15 mm.

Note: The 16094A Probe Fixture causes, as do other general hand held probes, unavoidable change in contact resistance and stray admittance depending on the contact pressure applied and the tilt of the probe at the measurement object. Accordingly, consideration of exact residual parameter values is not practicable.

Associated accessory:

Coaxial cable with APC-7 connector (62 cm long): P/N 8120-2291

Model 11605A Flexible Arm (maximum extendability 64.8 cm).

Figure 3-6. DUT Connection (Sheet 7 of 7).

Initial mode settings.

Attach desired test fixture to UNKNOWN.

Enter ELECTRICAL LENGTH number.

Select DISPLAY A parameter.

Select DISPLAY B parameter.

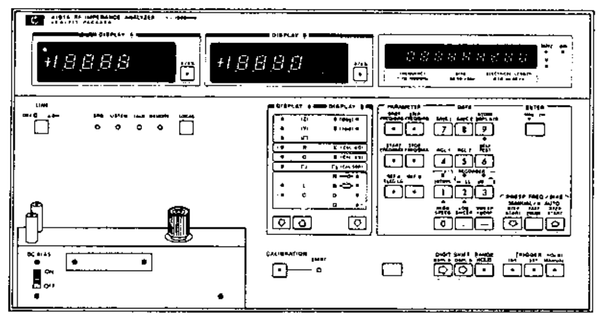
Set SPOT FREQUENCY.

Connect sample to test fixture.

Read display output.

BASIC OPERATING PROCEDURE

Basic operating procedures for measuring general components and electronic materials at a desired frequency point are described in these paragraphs. Instructions and operating procedures for semiconductor measurements, deviation measurements, swept frequency applications, with external dc bias or with an external test signal source are provided in separate paragraphs, including information for the appropriate setup arrangement and the special care needed for making a reliable measurement.



PROCEDURE

1. Press LINE button to turn instrument on. In accordance with instructions in "Initial Mode Settings" (Figure 3-5), prepare to take measurements with the 4191A. The preparatory operations include the following sequential operating procedures and prerequisite setups:

    1) Option annunciation
    2) 10 minute warm-up
    3) Initial control settings
    4) Initial calibration (as necessary)

2. If initial calibration is performed and is complete, release the calibration function by pressing CALIBRATION key (key lamp is extinguished).

    Note: Test frequency (Spot frequency) stays at the frequency point where the calibration ended. Verify that trigger lamp continues flashing.

3. Attach a 16092A, 16093A or 16093B Test Fixture on the 4191A test fixture installation deck mounting posts with UNKNOWN connector. If the 16091A Coaxial Fixture is used, attach its special coaxial coupling adapter to UNKNOWN connector. Attachment and mounting procedures are described in Figure 3-6.

Figure 3-7. Basic Operating Procedure (Sheet 1 of 2).

4. Press [Blue] key and then ELEC LG key to activate electrical length data input function. Enter the electrical length number particular for the installed test fixture through the DATA input keys, then press ENTER key.

   (Example) Electrical length = 0.34 cm.

   Key strokes [blue] [REF A / ELEC LG ∘] [.] [3] [4] [MHz cm V]

   An electrical length setting number of .34 will be displayed in Test Parameter Data Display.

   Note: *If an undesired number has been set by an inadvertent key stroke or if it is needed to change the input data, repeat the key stroke procedure using appropriate number value.*

5. Select the desired DISPLAY A parameter by pushing [⇧] or [⇩] (up-down) key. Parameter indicator lamp lights on the selected parameter.

6. If necessary, select the desired DISPLAY B parameter (compatible with the DISPLAY A parameter selected in step 5) by pressing [⇩] key.

7. Press PARAMETER SPOT FREQ/BIAS key to activate test frequency setting function. Enter the desired test frequency number through the DATA input keys. Press ENTER key.

   (Example) Test frequency 10.7 MHz.

   Key strokes [SPOT FREQ/BIAS ∘] [1] [0] [.] [7] [MHz cm V]

   A test frequency setting of 10.7 will be displayed in Test Parameter Data Display.

   Note: *The test frequency can be set for 0.1MHz minimum step resolution in the standard unit and for 0.0001 MHz step resolution in option 002 units (0.2 MHz and 0.0002 MHz for frequencies above 500 MHz).*

8. Connect the sample to be tested to Test Fixture.

   Note: *The appropriate sample holding method for each individual accessory test fixture is outlined in Figure 3-6.*

   Caution: Do not connect a charged capacitor as DUT or internal circuitry may be damaged.

9. The 4191A will automatically display measured values of unknown.

   Notes: *1. If -OF- display occurs, the sample value exceeds measurement range limit of the selected measurement parameter. In such an occurrence, select another measurement parameter capable of being measured for the sample tested (the reflection coefficient or a reciprocal parameter, for example, |Y| instead of |Z| or D instead of Q).*

   2. If an error annunciation display occurs, try again to set the instrument using appropriate procedure. Annunciation display meanings are summarized in Table 3-6.

   3. If it is desired to change test frequency, key in new frequency value with DATA input keys. If SPOT FREQ/BIAS key lamp is lit, this key need not be pressed.

Figure 3-7. Basic Operating Procedure (Sheet 2 of 2).

DEVIATION MEASUREMENT

When many components of similar value are to be tested, it is sometimes more practicable to measure the difference between the value of the sample and a predetermined reference value. Besides, when the measurement purpose is to observe sample values versus the variance of the sample per degree temperature, unit time or other test variables, a direct measurement of this difference makes examination much more meaningful and easier. The deviation measurement function permits such repetitive calculations of the difference between the reference and each individual sample and displays those results instead of the sample values. The 4191A can make a deviation measurement for either or both DISPLAY A and/or DISPLAY B parameter measurements. Reference value(s) can be taken from a measurement for a reference sample or from input data through the DATA keys.

PROCEDURE

1. Perform appropriate procedures to make a normal measurement for the sample(s) to be tested in accord with the Basic Operating Procedure (refer to Figure 3-7).

Setting reference value

2. Enter reference value(s) for DISPLAY A and/or DISPLAY B parameter deviation measurements using procedure A or B described below:

A: Reference sample data input.

a. Connect the reference sample to Test Fixture and take one measurement of the sample.

b. Press [Blue] key, then press STORE DSPL A/B key.

Key strokes [blue] [9] (STORE DSPL A/B)

B: Reference value data input.

a. Press REF A key to enable memorizing reference value for DISPLAY A parameter. If a deviation measurement is desired for a DISPLAY B parameter only, press REF B function key.

Note: When reference value data has not previously been memorized for the selected measurement parameter, an Err-06 annunciation figure will appear in Test Parameter Data Display. This error message display disappears simultaneously with the first DATA key stroke for entering a reference value.

b. Set reference value number on the Test Parameter Data Display through the DATA input keys.

c. Press ENTER key.

(Example) Reference value 20.5 (Ω).

Key strokes [○] (REF A ELEC LG) [2] [0] [.] [5] [ ] (MHz cm V)

Figure 3-8. Deviation Measurement (Sheet 1 of 2).

d. If necessary, set reference value number for DISPLAY B parameter similar to that for DISPLAY A.

Deviation mode selection

3. Activate Δ/Δ% function to make deviation or percent deviation measurement for the desired measurement parameter using procedure A or B described below:

A: Deviation measurement (Δ)

Press Δ/Δ% key located alongside either DISPLAY A or DISPLAY B (or press both keys) to initiate deviation measurement for the sample(s) to be tested.

The deviation calculation follows the equation below:

$$D = M - R$$

Where, D is deviation to be displayed.
M is measured value of the sample.
R is reference value.

B: Percent deviation measurement (Δ%)

Press [Blue] key, then press Δ/Δ% key located alongside either DISPLAY A or DISPLAY B (or press both keys).
The percent deviation calculation follows the equation below:

$$D = \frac{M - R}{R} \times 100\,(\%)$$

Where, variables D, M and R are the same as those in procedure A above.

Release

4. To release the Δ or Δ% function mode of operation, again press the delta key(s):

Δ : Key stroke [Δ/Δ% ○ N/O/P]

Δ%: Key strokes [blue] [Δ/Δ% ○ N/O/P]

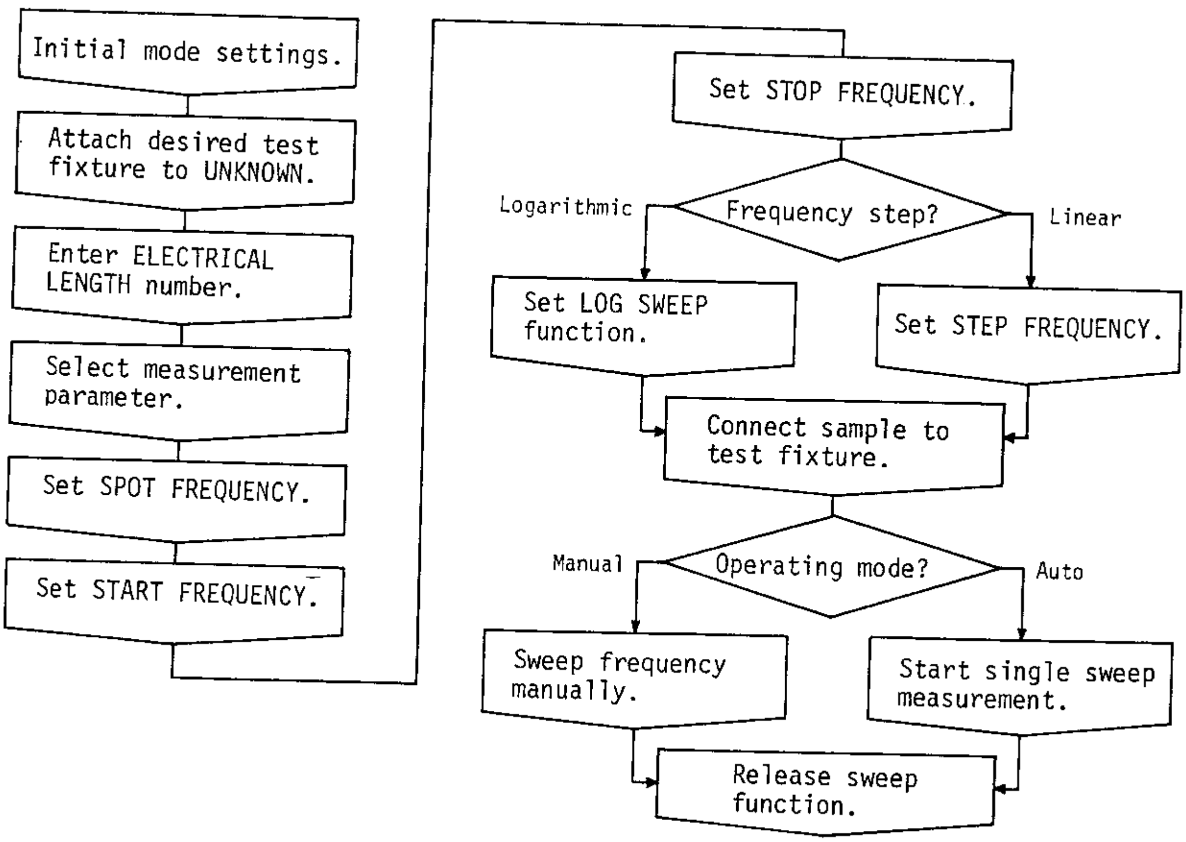
Notes: 1. When the Δ/Δ% function key is pressed, the measurement range is automatically fixed (RANGE HOLD key lamp lights). The range hold function continues holding the range even after the deviation measurement function is released. To restore to auto ranging mode of operation, again press RANGE HOLD key.

2. The reference input data can be monitored on the Test Parameter Data Display by pressing REF A or REF B key.

Figure 3-8. Deviation Measurement (Sheet 2 of 2).

SWEPT FREQUENCY MEASUREMENT

A swept frequency measurement permits measuring sample values over a band of test frequencies and, in addition, offers other useful data which can be obtained only by an examination of the variations in sample values relative to its dependency on the measurement frequency. Some swept measurement advantages are, for example, that it provides significant clues in analyzing the properties of material, that it enables the detection of behavior peculiarities of samples and, that it facilitates the evaluation of quality or of the performance limits of devices. This paragraph describes the procedures for making a swept frequency measurement using the digital frequency sweep capability of the 4191A.



PROCEDURE

1. Press LINE button to turn instrument on.
2. In accordance with instructions in "Initial Mode Settings" (Figure 3-5), prepare to take measurements with the 4191A.
3. Set 4191A controls and do measurement setup according to Basic Operating Procedures (Figure 3-7) steps 3 through 7.

Figure 3-9. Auto-sweep Frequency Measurement (Sheet 1 of 5).

START FREQUENCY

4. Press PARAMETER START FREQ/BIAS key.
Set the lowest (bottom) frequency number of the desired sweep frequency range with DATA input keys. Press ENTER key.

(Example) Start frequency = 5.0MHz

Key strokes [START FREQ/BIAS ∘] [5] [MHz cm V]

A start frequency setting of 5.0 is displayed in Test Parameter Data Display.

Note: All sweep frequency parameter values can be set with 0.1MHz minimum step resolution in the standard unit and with 0.0001MHz step resolution in Option 002 units.

STOP FREQUENCY

5. Press PARAMETER STOP FREQ/BIAS key.
Set the highest (top) frequency number of the desired sweep frequency range with DATA input keys. Press ENTER key.

(Example) Stop frequency = 600.0 MHz

Key strokes [STOP FREQ/BIAS ∘] [6] [0] [0] [MHz cm V]

A stop frequency setting of 600.0 is displayed in Test Parameter Data Display.

STEP FREQUENCY

6. Perform procedure a or b depending on the desired sweep mode.

– LINEAR SWEEP –

a. Press PARAMETER STEP FREQ/BIAS key.
Set the desired step interval frequency number with DATA input keys.
Press ENTER key.

Note: Measurement is taken, in turn, at the frequency points arranged at the regular step frequency intervals while the swept frequency measurement proceeds.

(Example) Step frequency = 2.5 MHz

Key strokes [STEP FREQ/BIAS ∘] [2] [.] [5] [MHz cm V]

A step frequency setting of 2.5 is displayed in Test Parameter Data Display.

Figure 3-9. Auto-sweep Frequency Measurement (Sheet 2 of 5).

Note: When step frequency setting is 0.1 MHz (100 Hz in Option 002 unit), the test frequency is swept in 0.2 MHz (200 Hz) step intervals at frequencies above 500 MHz (because maximum frequency resolution qualifies the useable step frequency).

– LOGARITHMIC SWEEP –

b. PRESS [Blue] key to actuate the blue label function. Next press LOG SWEEP key (DATA input decimal point key). An indicator lamp above the key lights.

Key strokes [blue] [LOG SWEEP .]

Note: Logarithmically swept frequency measurements are taken at a total of 51 frequency points which are automatically selected at logarithmically regular frequency intervals in the start and stop setting frequency range (STEP FREQ function is deactivated).

CORRECTION OF FREQUENCY SETTING

If an undesired frequency number has been set by an inadvertent key strokes or if it is needed to change a preset frequency, repeat the procedure for entering start, stop or step frequencies (steps 4, 5, or 6) using correct frequency number. Logarithmic sweep mode of function can be released by again pressing the [Blue] key and LOG SWEEP key.

Note: If either the start, stop or step frequency input number exceeds the selectable frequency range limits, an error annunciation figure appears in Test Parameter Data Display and the inappropriate control input demand is automatically released.

7. Connect the sample to be tested to Test Fixture.

MANUAL or AUTOMATIC SWEEP

– (MANUAL SWEEP) –

8. Press SWEEP FREQ/BIAS STEP [⇧] or [⇩] key to initiate measurement. Pressing and holding the STEP [⇧] or [⇩] key advances the sweep frequency measurement to a higher or lower frequency direction (from the programmed spot frequency), respectively. If the spot frequency is outside the programmed sweep range, E-04 annunciation is displayed. The test frequency can also be shifted in step frequency intervals each time the key is pushed. A reverse direction sweep is also feasible.

Figure 3-9. Auto-sweep Frequency Measurement (Sheet 3 of 5).

Note: When FAST key is pressed simultaneously with the STEP [△] or [▽] key, the step frequency interval is expanded to ten times its programmed value in linear sweep mode or to one-fifth the frequency points in logarithmic sweep mode.

—(AUTO SWEEP)—

9. Press [Blue] key, then press SWEEP FREQ/BIAS [△] or [▽] key to initiate an automatic sweep frequency measurement.

   Key strokes [blue] [△] or [blue] [▽]

   AUTO sweep indicator lamp above the [△] key lights simultaneously and stays lit while the auto sweep mode of function is being set. Pressing [△] key starts a single sweep frequency measurement from the programmed start frequency (bottom frequency) in the higher frequency direction. The frequency sweep ends at the stop frequency point (top frequency of the sweep range).
   Pressing [▽] key advances frequency sweep in the reverse direction (from the top frequency towards a lower frequency).

   Note: RANGE HOLD function is automatically set.

   Swept test frequency is displayed in the test parameter data display.

   SWEEP PAUSE

   If it is needed to temporarily stop the swept frequency measurement at the desired frequency step point, press [Blue] key, then press PAUSE key. To restart the measurements, again press [△] or [▽] key after pressing [Blue] key.
   The test frequency is successively swept.

   Note: Sweep parameter value and sweep mode settings (linear, logarithmic, auto or manual) can be changed when the PAUSE function is set.
   Pressing [△] or [▽] key sweeps frequency manually ("AUTO" sweep indicator lamp stays lit until SWEEP ABORT key is pressed or until the frequency reaches start or stop frequency point).
   While automatic sweep advances, panel control keys except for SWEEP FREQ/BIAS and SWEEP ABORT keys are deactivated.

Figure 3-9. Auto-sweep Frequency Measurement (Sheet 4 of 5).

SWEEP ABORT

Auto-sweep frequency measurement of operation is automatically released when a single swept measurement ends. To release the swept frequency mode of operation before the measurement is complete, press [Blue] key, then press SWEEP ABORT key.

Key strokes: [blue] [SWEEP ABORT —]

Note: SPOT frequency is automatically set to the frequency point where the swept frequency measurement function is released.

Figure 3-9. Auto-sweep Frequency Measurement (Sheet 5 of 5).

CONTINUOUS MEMORIZATION OF CONTROL SETTINGS (SAVE FUNCTION)

The 4191A's continuous memory capability permits retaining the memory of desired instrument control settings. Front panel control settings which are especially used for a particular application or are frequently used can be memorized by the instrument for repeated use of the same settings. Stored memory data for the control settings are continuously held in event the instrument loses its operating power.

Note: Auto-calibration data prerequisite to measurements, test parameter values for sweep measurements and reference values in deviation measurements are also stored in the continuous memory.

The memorized control settings and test parameter input data can, at anytime, be again set into the instrument as its actual settings by merely pressing two control keys. Two pairs of SAVE and RCL functions allow one or two kinds of such specific settings to be independently memorized and restored. For storing the desired settings in the memory, proceed as follows:

1) Set front panel controls and test parameter input data as appropriate for making the desired measurement.

2) Press [Blue] key and, next, press SAVE 1 or SAVE 2 key. The instrument has now memorized this particular set of control settings.

3) To restore the memorized control settings in place of temporary setting, press [Blue] key and, next, press RCL 1 or RCL 2 key (to actuate memory of SAVE 1 or SAVE 2 function, respectively).

Note: Auto-calibration data is automatically stored in the memory in place of the preceding calibration data each time the calibration is newly implemented (irrespective of the SAVE function).

STAND-BY BATTERY

Rechargeable stand-by batteries provide long term memory protection. The installed batteries have the following capabilities:

Operating time: Battery operating time, capable of continuously protecting the memory, is 3000 hours (typical) after a full charge.

Recharge: Rechargeable to full rate in 72 hours after battery voltage falls below the operating low limit.

Lifetime: 5 years (at 25°C)
The batteries are being charged anytime the instrument is being operated from an AC power line (LINE button is depressed).

3-25. ACCURACY

3-26. Accuracies for all measurement parameters are dependent on the impedance accuracies of the reference terminations (0Ω, 0S and 50Ω) employed for initial auto-calibration. The total possible instrument error consists of the errors related to instrument performance limitations and the calibration errors which are dominated by the particular quality of the individual reference terminations. For achieving the best accuracy of the instrument, the special coaxial terminations furnished with the 4191A were all developed with careful consideration for both their impedance accuracy and frequency dependency and are ready for use as calibration standards. The 50Ω termination (HP Part No. 04191-85301) of the accessory Reference Termination Set, for example, embodies as its typical vector reflection coefficient, a value of 0 and an accuracy to within ±(0.0025 + j0.00025) at any test frequency when it is connected to the UNKNOWN connector. The specified 4191A accuracy is subject to calibration of the instrument with the three reference terminations supplied.

Note:
The accuracies are typical values that apply when calibration is done with the supplied accessory terminations (vector reflection coefficient accuracies specify the coefficient in maximum test limit values). If other terminations which have more accurate reference impedance values are available, the measurement accuracies can be enhanced.

3-27. The 4191A accuracies, as shown in Table 1-2, are graphic representations of each measurement parameter. The accuracy graphs, other than the reflection coefficient graph, show a characteristic common to all the measurement parameters. The reason for this common characteristic is explained as follows:

The relationship of the reflection coefficient value to the impedance value of the sample is graphically represented in Figure 3-10. To simplify the discussion, the reflection coefficient curve given in the graph presupposes that the sample is resistive. As indicated by the graph, the variation in reflection coefficient values being detected per difference (ratio) in sample impedance becomes smaller at both higher and lower impedance values referenced to 50Ω (note: for both low and high impedance values, $|\Gamma| \approx 1$). Thus the accuracy is optimum for measurements of nearly 50Ω impedance ($|\Gamma| \approx 0$). Towards both the higher and lower impedances, the accuracy drops at a continuous gradient to the ends of the practicable range limits.

3-28. The 4191A accuracies are specified under the following measurement operating conditions:

1) Specifies reflection coefficient accuracy ($|\Gamma| - \theta$ and $\Gamma x - \Gamma y$ measurement accuracies). Accuracies for other parameter measurements are given as typical values in supplemental performance characteristics.
2) Warm-up time: at least 40 minutes.
3) Auto-calibration properly completed using standard reference terminations.
4) Test frequencies identical to auto-calibration frequency points (51 spots).
5) Environmental temperature:
   23°C ± 5°C (allows temperature variation).
   0°C to 55°C (at the constant temperature at which auto-calibration is completed).
6) Measurement taken at UNKNOWN connector (without using test port extension).

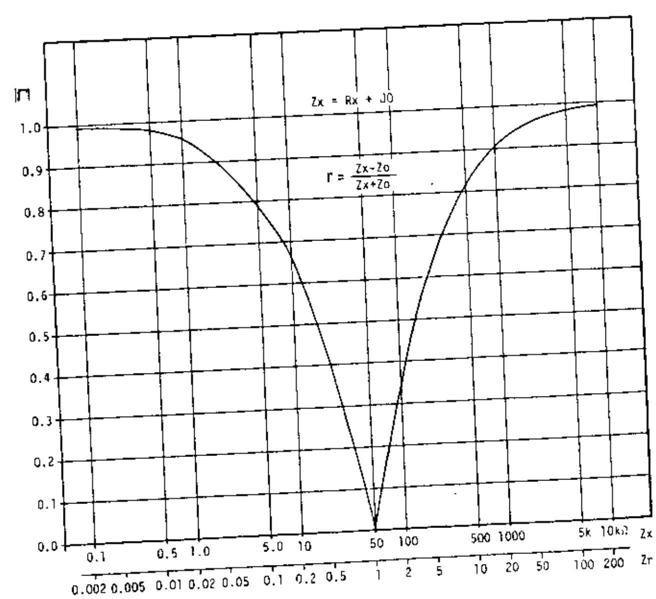


Figure 3-10. Relationship of Reflection Coefficient to Impedance.

3-29. ACTUAL MEASURING CIRCUIT.

3-30. The measuring circuit for connecting a test sample to the UNKNOWN test port (that is, test fixture) actually becomes part of the sample which the instrument measures. Furthermore, component leads, which should essentially be of negligibly low impedance, also influence the measured sample values because of the presence of certain parasitic impedances. Diverse parasitic impedances existing in the measuring circuit between the UNKNOWN test port and the unknown device affect the measurement result. These parasitic impedances are present as resistive or reactive factors in parallel or in series with the sample device. Furthermore, in the high frequency region, the equivalent electrical length of the measuring circuit, including component leads, rotates the measured impedance vector as function of the test signal wavelength. Let's discuss these effects which increase measurement uncertainties.

3-31. RESIDUAL PARAMETER EFFECTS.

3-32. Figure 3-11 shows an equivalent circuit model of the measuring circuit which includes unknown component and parasitic parameters (usually called residual parameters). These residual parameter effects cause two kinds of measurement errors, which are described in the paragraphs below.

1) Simple additive errors

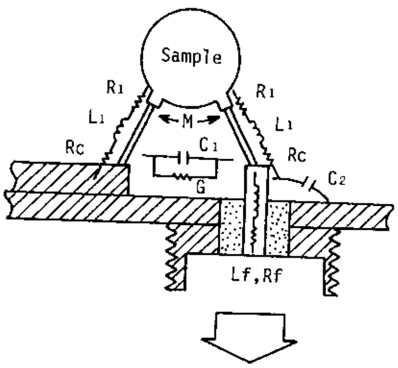
When a component having a low value is measured at relatively low frequencies, the measured value becomes the sum of the sample value and the residual parameter values. The effects of the residual factors are:

$$C_m = C_x + C_{st}$$
$$L_m = L_x + L_{res}$$
$$R_m = R_x + R_{res}$$
$$G_m = G_x + G_{res}$$

where, subscripts are:

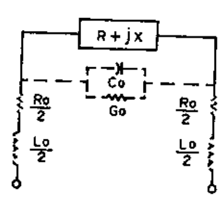
- m : measured value
- x : value of sample
- st : stray capacitance
- res : residual inductance (residual resistance) (residual conductance)

Residual resistance and conductance affect dissipation factor and quality factor measurements because they are included in the measured values as an additional loss.



R_l: Lead resistance
R_c: Contact resistance
R_f: Residual resistance of test fixture
L_l: Lead inductance
L_f: Residual inductance of test fixture
C_1, C_2: Stray capacitance
G : Residual conductance
M : Mutual inductance

Simplified Equivalent Circuit Model



Measured impedance R + jX is :

$$R = \frac{R(1 + RGo) + GoX^2}{(1 - \omega CoX + RGo)^2 + (\omega RCo + GoX)^2} + Ro$$

$$jX = j\left\{\frac{X(1 - \omega CoX) - \omega CoR^2}{(1 - \omega CoX + RGo)^2 + (\omega RCo + GoX)^2} + \omega Lo\right\}$$

Figure 3-11. Residual Parameters in the Measuring Circuit.

2) **Reactive parameter interaction**

Generally, residual inductance resonates with the capacitance of sample (series resonance) and stray capacitance resonates with inductance of sample (parallel resonance), respectively, at a specific high frequency. Thus, the impedance of sample will have some extremes corresponding to the resonant peaks as shown in Figure 3-12. The presence of residual inductance and stray capacitance causes measurement errors as the phase of the measured (reflected) test signal varies over the broad frequency region about the resonant frequencies. Additional errors due to this resonance increase in proportion to the square of the measurement frequency (below resonant frequency) and can be theoretically approximated by the following equations:

$$Lm \approx \frac{Lx}{1 - \omega^2 Lx\, Cst} \quad \text{or} \quad \frac{Lm - Lx}{Lm} \approx \omega^2 Lx\, Cst$$

$$Cm \approx \frac{Cx}{1 - \omega^2 Cx\, Lres} \quad \text{or} \quad \frac{Cm - Cx}{Cm} \approx \omega^2 Cx\, Lres$$

where, ω = $2\pi f$ (f: test frequency)
Cx = Capacitance value of sample
Lx = Inductance value of sample

At the resonant frequency, the phase angle of the measured impedance vector is 0° (resistive impedance). If the test frequency exceeds the resonant frequency point, the measured inductance or capacitance of sample becomes a negative value. In such frequency region, the residual inductance or stray capacitance dominates the actual measurement value.

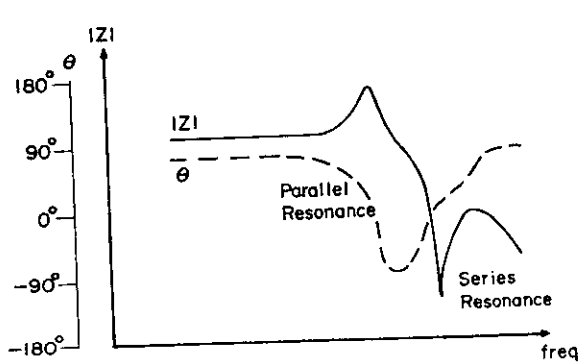


Figure 3-12. Effect of Resonance in Sample (example).

3-33. CHARACTERISTICS OF TEST FIXTURES

1) Electrical Length

The test fixtures are basically composed of two major components – a coaxial coupling terminal and contact electrodes (terminals) combined in one unit. The electrical length value specified for each type of the fixtures are calculated for the coaxial coupling terminal and does not include the electronic factors in the electrodes.

As the coaxial coupling terminal section of the fixtures is a "distributed constant" circuit design (50Ω), this fixture section is virtually an extension of the test port. The inherent effect in the coaxial coupling terminal on the phase of the measured reflection coefficient value is represented by the electrical length value particular to the test fixture. On the other hand, the contact section, that is, the spring clip contacts (16092A) and binding post terminals (16093A) have individually different characteristics from the 50Ω "distributed constant" test port.

2) Residual Parameters

The contact electrode (terminal) section can not be deemed as part of the "distributed constant" measuring circuit. The portion of the measurement circuit length which includes the test fixture contacts and sample leads will also cause a phase shift in the measured reflection coefficient vector. Then, how should this effect be considered?

Generally, the "electrical length" concept should apply to lines of equable "distributed constant" characteristics such as coaxial lines and parallel feeder lines. The phase shift due to the signal propagation length of the contacts or terminals can be considered to be a virtual increase in the residual inductance of the fixture. Actually, this effect can not be easily discriminated from the residual inductance effect. Various effects in the test fixture contacts and terminals are considered as residual impedance factors which contribute to measurement errors.

The coaxial terminals of the fixtures also have measurement signal propagation losses in addition to rotating the phase of the signal. As a correction calculation performed on the basis of the electrical length input value (by the 4191A) does not compensate for the residual loss factors in the coaxial coupling terminal, these propagation losses contribute to measurement errors (in particular, in low impedance measurements). The residual factors in test fixtures are illustrated in Figure 3-11.

Measured sample values may differ depending on the test fixture employed for the measurement. The difference in measurement results will increase in both low impedance (below 100mΩ) and high impedance (above 100Ω) measurements. However, all of those differences may occur unless measurements are properly corrected for the residual impedances inherent in the test fixture used.

3-34. CONSIDERATIONS IN CERTAIN MEASUREMENTS

3-35. To minimize measurement uncertainties, considerations should be taken for decreasing the residual parameters to the lowest possible magnitude. To further reduce the residual parameter effect contributing to measurement errors, various correction methods and calculations can be used with respect to the measured sample value. These are outlined below:

1) Component lead impedance is a lower value for a shorter lead length. Connect sample to test fixture contacts (terminals) so that lead length is minimum.

2) Additional measurement errors due to residual parameters inherent in the test fixture can be compensated for by using correction calculations. When the effects are simple additive errors, a subtraction measurement should be used. The practical correction method for these kinds of errors is outlined in paragraph 3-37.

Note:
Basically, an attempt to correct the measured values for all existing residual parameter effects is not practicable. This is because some parameters, such as lead impedance and stray capacitance, are peculiar to the component measured. Their values depend on component lead length and on the distance between the sample and test fixture. The measurement results, then, are substantially the sample values including the parasitic impedances present under the conditions necessary to connect and hold the sample.

3-36. ELIMINATION OF RESIDUAL PARAMETER EFFECTS IN TEST FIXTURE

3-37. The measuring circuit for dealing with an impedance vector in the rf region employs a two terminal DUT connection configuration. Since the two terminal connection method includes composite residual impedances in its measuring circuit arrangement, its applicability in precise, low frequency impedance measurements is limited to a narrow range in both sample value and frequency. On the other hand, for measurements at rf test signal frequencies, the two terminal method has the advantages of accuracy with ease of handling which comes with the simplicity of the DUT connection arrangement. Contact resistance, distributed admittance (stray capacitance and conductance) and electrode impedance (residual resistance and inductance) of the test fixture used still affect the measurement in the rf region. The additional measurement errors inherent in the test fixture should be considered when evaluating actual measurement accuracy. The residual parameter effects are outlined in paragraph 3-32.

All 4191A accessory test fixtures are designed with careful consideration of the residuals to ensure minimum incremental measurement error. The characteristics of these fixtures exhibit low level residual impedances and broad usable frequency ranges as well terminal structures suitable for the particular use of the individual fixture. Reliability of the measurement can be further enhanced if proper compensation is made for the residual impedances peculiar to the test fixture used. Typical residual parameter values for each individual test fixture are given in Figure 3-6. The compensation subtracts the error value from the measured values using appropriate correction calculations for the given residual parameter data (refer to paragraph 3-32).

Note: The 16091A Coaxial Fixtures need no compensation.

3-38. Actual values of the residuals can be approximately ascertained by taking measurements when the test fixture terminals (contacts) are appropriately terminated in their short or open conditions. To facilitate shorting the fixture at minimum impedance, a special grounding terminator is furnished with each of the 16092A and 16093A/B Test Fixtures.

1) **Distributed admittance**
For stray capacitance and distributed conductance, take a measurement in the C-G (capacitance-conductance) mode with nothing connected to the test fixture. When the 16092A Spring Clip Test Fixture is used, set contact distance near to the dimension of the sample to be mounted in the fixture.

2) **Electrode impedance**
Residual resistance and inductance are measured in the L-R (inductance-series resistance) mode when the test fixture is short-circuited.
16092A: Remove slide clip contact (twin clip contact) assembly from the test fixture deck. Attach the special grounding electrode, with its concave side down, to test fixture positive contact post with its screw.
16093A/B: Remove binding post nut of the drive potential (positive) terminal and attach the special grounding electrode with its concave side down. Tighten the electrode to the terminal with the binding post nut.

Note: The measured resistance and inductance values are approximate values of the electrode impedance.

The measured residual parameter values can be offset from the measurement readouts for a sample of like parameter measurements. The deviation (Δ) function facilitates the subtraction measurement. Store the measured residual parameter values as reference values of the deviation measurement. The deviation provides display outputs of correct sample values as the measured value minus the memorized residual parameter value. This correction method can only eliminate the simple additive errors.

Note: The residual factors can be cancelled only for like parameter measurements (for example, stray capacitance can be subtracted only in capacitance measurements).

Measurement errors due to interaction of residual reactive elements, which increase in proportion to the square of the test frequency, can not be cancelled by the method outlined above.

3-39. UNKNOWN TERMINAL CONVERSION.

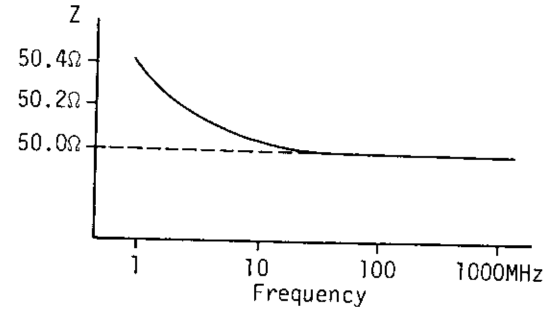
3-40. When the measurement objective is to test communication devices such as rf circuit modules and antennas, an appropriate terminal conversion adapter is sometimes needed to interconnect such a device to the UNKNOWN connector. To adapt the test port to N type, BNC, SMA (SMB, SMC), GR900, GR874 or other type connectors of the device to be measured, attach an adequate terminal converter to the UNKNOWN connector. Possible insertion losses, phase shift and/or a reflection of the test signal in the terminal converter used are all undesirable factors which contribute to incremental measurement errors. The effects of these error factors can be eliminated from the measurement results by performing an auto-calibration with the precise terminations combinable with the terminal converter. The terminations used should be of an impedance accuracy equivalent to the accessory reference terminations in the required calibration frequency range. If the test port needs to be extended (in addition to the conversion of the UNKNOWN connector), perform an auto-calibration at the tip of the extension line (refer to paragraph 3-44 for extension of the test port).

Note:

1. *If appropriate precise terminations with the desired coupling connectors are unavailable, calibrate the instrument with the reference terminations and then attach the terminal converter. Enter the rated value or the measured value of the electrical length for the terminal converter. To minimize incremental measurement errors, use a terminal converter which has a low inherent VSWR* value.*

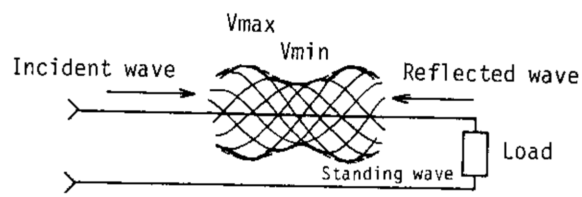
   **VSWR value of terminal converter causes, if not properly compensated, additional measurement error increase.*

2. *Generally, characteristic impedances of terminal converters (also, ordinary connectors and lines) vary their values in the relatively low frequency region. Figure 3-13 shows an example of terminal converter impedance characteristics. At low frequencies, the impedance increases as the frequency decreases. The impedance approaches a constant value (nominal value) at higher frequencies.*



3-41. STANDING WAVE RATIO MEASUREMENT.

3-42. An incident wave traveling along a propagation line toward the load interferes with the returned wave as the result of partial reflection at the load. This interference of the incident and reflected waves produces a standing wave which is distributed along the line. To represent the magnitude of the standing wave, a VSWR (Voltage Standing Wave Ratio) value is used. The VSWR is defined as the ratio of the amplitude at the antinode to the wave node of the standing wave.

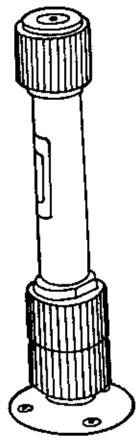


$$VSWR = \frac{V_{max}}{V_{min}}$$

The VSWR measurement is popular, in particular, for evaluations of antenna efficiency. As the magnitude of the standing wave depends on the density of the reflected wave, the VSWR values correlate with the reflection coefficient values. This relationship is represented by the following equation:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (\geq 1)$$

when $|\Gamma|$ value is 0, a reflected wave is not produced and, thus the VSWR value is 1.



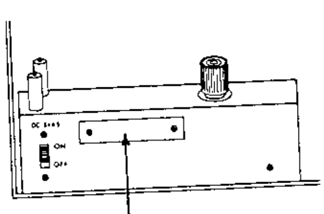
3-43. EXTENSION OF TEST PORT

3-44. Occasionally the test port needs to be extended to the DUT measurement point such as when measuring coaxial switches, wide band attenuators, antennas, rf amplifiers, integrated microcircuits, semiconductor devices and other devices which cannot be directly connected to the UNKNOWN connector or to the accessory test fixture. In these cases, the measurement can be accomplished with a simple modification to the procedure and to the setup arrangement without the need for correction calculations to the measured values for the effects of the test port extension. The operating procedure, here outlined, is an example using a 50Ω air line extention.

Notes:

1. *To minimize any drop in measurement accuracy, the air line used must have a VSWR (voltage standing wave ratio) value of 1 at a high accuracy when it is connected to the UNKNOWN connector. Any impedance mismatch incident to the connection causes measurement error, to a certain extent, to increase.*
2. *Test port should not be extended more than 1 m.*

When an air line extension whose electrical length number (rated value) is ℓ is connected to the UNKNOWN connector, perform the following procedures to take a measurement of the sample connected to the other end of the air line:



Electrical length compensator.
(inside panel).

Electrical length compensation

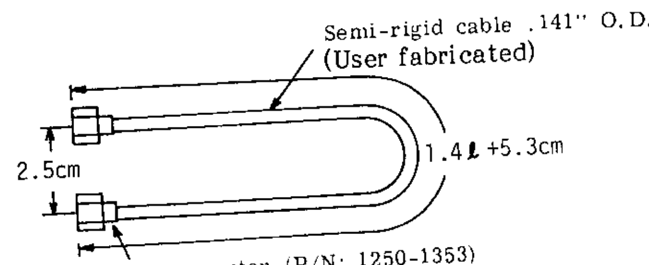
When the electrical length (ℓ) of the air line extension exceeds either 1/8 wavelength of the test frequency signal or 10 cm (approximately), calibration error increases because of a phase shift in the test signal (incident and reflected waves) propagating in the air line. Thus, measurement error increases. It appears as an artificial undulating fluctuation of reflection coefficients in the normal frequency-reflection coefficient locus.

To minimize the measurement errors, a semi-rigid cable electrical length compensator housed in the test fixture installation deck is interchanged with a longer cable assembly:

1) Prepare semi-rigid cable with miniature SMA connectors measuring 1.4ℓ long plus 5.3 cm as illustrated.
2) Remove the two retaining screws and remove blind panel on the deck. The semi-rigid cable compensator will appear in the panel hole.
3) Loosen rigid cable connector coupling nuts (two) and pull cable out.
4) Connect the long semi-rigid cable in place of the existing cable assembly. The blind panel can not be attached while the extended compensation cable is being used.

Note: *The 1.4ℓ length is the product of two times ℓ (sum of air line electrical length for an incident wave and that of the reflected wave) multiplied by the ratio of the wavelength in semi-rigid cable to that in a vacuum (approximately 0.7). Thus, the electrical length of the semi-rigid cable compensator is equivalent to that of an air line extension.*

The cable length of the semi-rigid cable compensator need not be a precisely calculated value (within ±2 cm).



Semi-rigid cable E/L compensator.

Calibration

Perform auto-calibration with each termination (0Ω, 0S and 50Ω) connected to the air line extension.

Electrical length data input

Enter the electrical length number of the test fixture connected to the air line (the value for the air line should not be used).

Note: *When reflection coefficient (Γ_o), measured at the UNKNOWN connector, is taken as a reference, the reflection coefficient measured at the air line end is theoretically represented by the following equation:*

$$\Gamma_\ell = \Gamma_o e^{-2(\alpha + j\beta)\ell}$$

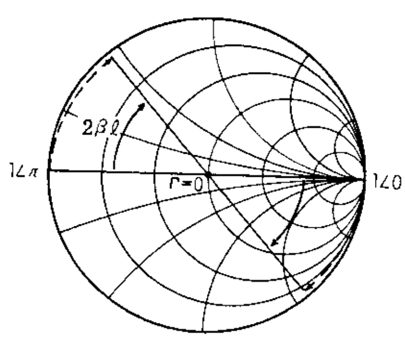
Where, phase constant β is

$$\beta = \frac{2\pi}{\lambda} \quad (\lambda = \text{test signal wavelength})$$

α is the attenuation coefficient of the air line.

The above equation indicates that the magnitude of the vector reflection coefficient is attenuated by $e^{-2\alpha\ell}$ as well as its phase angle shifts by $2\beta\ell = 4\pi\ell/\lambda$ (radians).

When a calibration is performed at the end of the air line, the reflection coefficients $1\angle 0$ (0Ω) and $1\angle\pi$ (0S) references shift by the attenuation and the phase angle ($2\beta\ell$) as illustrated in the Smith Chart below:



As the auto-calibration detects both the attenuation and the phase shift, measured values are automatically compensated for these effects in the air line extension.

However, a large shift in the phase angle increases compensation errors. The semi-rigid cable electrical length compensator acts to cancel the effects of the air line extension by modifying the measuring circuit.

CONFIRMATION OF PROPER ELECTRICAL LENGTH COMPENSATION

A user constructed electrical length compensator can be easily checked to determine whether it can fit the extended measurement circuit. Proceed as follows:

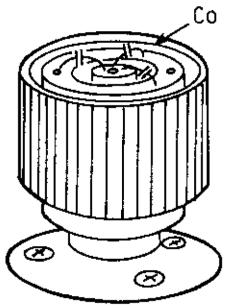
1) Perform auto-calibration for the desired test frequency range without using air line extension.
2) Connect air line extension to be used and the electrical length compensator to the 4191A.
3) Set the 4191A function to $|\Gamma| - \theta$ measurement mode.
4) With 0S standard termination connected at the tip of the air line extension, perform a swept frequency measurement at 20MHz step frequency intervals (in the calibrated frequency range).
5) Monitor DISPLAY B display outputs. The display readouts should be within -00.00 ± 90 degrees at any step frequency point. If a displayed value exceeds 90.00 counts, a shorter electrical length compensator should be used and, if it exceeds a negative 90.00 counts, a longer compensator cable will provide a more appropriate compensation magnitude.

Note

MEASUREMENT WITHOUT
E/L COMPENSATOR

If measurement condition allows using the test frequencies identical to the auto-calibration frequency points, it is possible to make accurate measurements without replacing the electrical length compensator. Perform as follows :

1) Connect reference termination at the tip of the extended test port and perform the auto-calibration for each of the 0Ω, 0S and 50Ω termination impedances.
2) Connect test fixture at the tip of the extension line.
3) Enter the specified electrical length value for the test fixture used.
4) Select the desired test frequencies from among the auto-calibration frequencies and perform measurements.



3-45. SETTING OPEN CAPACITANCE DATA

3-46. To eliminate the effects of stray capacitance present at the center and outer conductors of the UNKNOWN connector from the parameter values measured, the stray capacitance value is used in the error correction calculations which are based on auto-calibration data. The 4191A stores a typical capacitance value of the "open" connector--0.082 pF in its continuous memory.

When the open capacitance value is changed from its typical value by using a terminal converter or when special test apparatus is connected to the UNKNOWN, a new appropriate value can be temporarily memorized to be used instead of the programmed value. A concealed-open capacitance input function allows setting the capacitance value up to 1.000 pF in 0.001 pF (minimum) steps.

Note: The open capacitance data should not be changed to a different value for each accessory test fixture. The typical stray capacitance value of the test fixture should be considered as a residual factor contributing to measurement error.

PROCEDURE

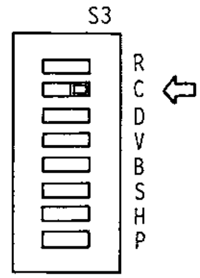
1) Push LINE button to turn instrument off.

2) Loosen top cover retaining screw at rear center of the cover and remove top cover.

3) Turn the two captive fasteners of the top shielding panel 90 degrees counter-clockwise to unlock the panel. The fasteners are located at the front side of the panel.

4) Lift up front side of the hinged top shielding panel on its hinged pivots. Set panel at its rear stop position. Note the major circuit board at the underside of the panel.

5) Change the second bit switch of switch S3 (labeled "C" on the circuit board) to its opposite position as illustrated below:



Caution: Do not change other bit switch positions.

6) Push LINE button to turn instrument on and perform 10 minute warm-up.

7) Press front panel [Blue] key. Next, press REF B key.

8) Set the appropriate capacitance value (≤1 pF) with DATA input keys. Press ENTER key. This enters the capacitance input value.

The volatile memory of the capacitance input data is lost when the instrument is turned off.

Note: The open capacitance value can also be set by HP-IB control/data input command.

3-47. INTERNAL DC BIAS (0−± 40V)

3-48. The 4191A is equipped with an internal programmable dc bias supply controllable from 0.00V to ± 40.00V. This provides step bias voltage control in 10mV increments over the entire controllable range as well as providing an accurate voltage setting capability (±0.1%) to facilitate up-to-date utility in uses which demand precision bias voltage control such as in applications for the analysis of material properties and semiconductor testing. The bias can be programmed and bias parameters memorized, further enhancing utility of the internal bias supply.

In step bias control or bias voltage sweep measurement applications, programmed bias control provides for automatic measurements without the necessity of an external bias source and bias controller.

Bias voltage setting and bias parameter programming can be done either at panel control keys or via an HP-IB controller. This paragraph describes operating procedures for the internal dc bias supply when using panel control keys. For dc bias applications using HP-IB control, refer to paragraph 3-59 HP-IB Compatibility.

Table 3-5. Bias Voltage Setting Ranges.

Spot bias voltage		−40.00 − 40.00V
Sweep bias voltage parameters	Step	0.01 − 40.00V
	Start	−40.00* − 40.00V
	Stop	−40.00* − 40.00V

*Note: *When LOG SWEEP function is used, both the Start and Stop voltage settings should be positive values (above 0.01 volts). Stop voltage should be higher than Start voltage value.*

Note

When a conductive sample is to be measured, actual dc bias voltage applied to sample is lower because of internal loading of bias circuit (approximately 1.4kΩ). A maximum current of 7.2mA can flow through sample which has a low resistance (about 0Ω).

PREPARATIONS FOR DC BIAS OPERATION

Caution: Set dc bias switch to its off position.

1. Press LINE button to turn instrument on.
2. Set 4191A controls and do measurement setup according to Basic Operating Procedures (Figure 3-7 steps 1 through 9).
3. Set rear panel DC BIAS INT EXT switch to its INT position.
4. Set DC BIAS switch on the 4191A test fixture installation deck to its ON position.

Note: *Internal dc bias voltage applied to sample is automatically set to 0 volts when the instrument is turned on (initial settings).*

Caution: When RCL 1 or RCL 2 function is activated, a memorized bias voltage setting for previous measurement is restored. To avoid a harmful voltage from being inadvertently applied to sample, monitor the voltage setting value by pressing [Blue] key and "PARAMETER SPOT FREQ/BIAS" key before setting the DC BIAS switch!

Note: *To monitor actual dc bias voltage applied to sample, connect a DVM at rear panel DC BIAS EXT INPUT/INT MONITOR connector.*

USE OF STATIONARY (FIXED) VOLTAGE BIAS

To apply a stationary (fixed) bias voltage to sample, set the desired bias voltage in accord with the following procedure:

Note: Test frequency can be swept while using the internal dc bias set to desired (spot) voltage.

1. Press [Blue] key and PARAMETER SPOT FREQ/BIAS key to activate bias voltage setting function.

2. Set the desired bias voltage number with DATA input keys. Press ENTER key.

   (Example) Bias Voltage = 15.05V

   Key strokes: [blue] [SPOT FREQ/BIAS o] [1] [5] [.] [0] [5] [MHz cm V]

   A spot bias voltage of 15.05 will be displayed on Test Parameter Data Display.

   Note: The internal dc bias voltage is applied to the sample just after the bias voltage value is set by the front panel control keys (requires no trigger signal).

DC BIAS SETTLING TIME

It takes a maximum 100ms for dc bias voltage to reach more than 90% of the voltage setting value when a 1μF capacitor sample is measured.

3. To change the bias voltage, repeat steps 1 and 2 to enter new voltage value.

   Note: If dc bias is not needed, set front panel DC BIAS switch to OFF.

Figure 3-14. Fixed Bias Voltage Measurement.

BIAS VOLTAGE SWEEP

The desired internal bias voltage range can be digitally swept in step voltage intervals set by bias parameter input data. The operating procedures for setting the sweep voltage parameter data and the control of sweep mode operation are similar to those for a swept frequency measurement (described in Figure 3-9). The appropriate procedures for using bias voltage sweep functions are outlined below:

Note: Bias voltage cannot be swept while a swept frequency measurement is in process.

START, STOP, STEP VOLTAGES

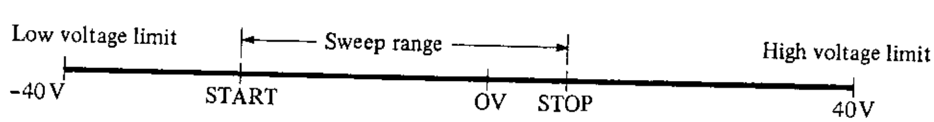
1. Press (Blue) key and PARAMETER START FREQ/BIAS key. Enter the low (bottom) voltage number of the desired sweep bias voltage range with DATA input keys. Press ENTER key. The start voltage setting is displayed in Test Parameter Data Display.

   Note: When logarithmic sweep function is used, a positive voltage number (above 0.01) must be entered as the start voltage.

   Similarly, enter Stop, Step and Spot voltage numbers in accord with the key stroke tabulation below:

Parameter	Key strokes		
	Function key	DATA key input	Enter
Start	[blue] [o] (START FREQ/BIAS)	Enters low voltage number of sweep voltage range.	[MHz V cm]
Stop	[blue] [o] (STOP FREQ/BIAS)	Enters high voltage number of sweep voltage range.	[MHz V cm]
*Step	[blue] [o] (STEP FREQ/BIAS)	Step interval voltage number.	[MHz V cm]
Spot	[blue] [o] (SPOT FREQ/BIAS)	Desired voltage number between Start and Stop voltages.	[MHz V cm]

Note: If the start voltage is a negative number, the start voltage should be lower than stop voltage as illustrated below:



**Note: Step voltage number need not be entered when logarithmic sweep function is used.*

Figure 3-15. Swept Bias Voltage Measurement (Sheet 1 of 3).

– LOGARITHMIC SWEEP –

Press [Blue] key and LOG SWEEP key (DATA input decimal point key). Indicator lamp above the key lights.

Note: Logarithmic sweep bias voltage measurements are taken at a total of 51 voltage points which are automatically selected at logarithmically regular voltage intervals in the start and stop setting voltage range. (STEP VOLTAGE function is deactivated).

MANUAL or AUTOMATIC SWEEP

2. Bias voltage can be swept manually or automatically using the following procedure:

– (MANUAL SWEEP) –

a. Press SWEEP FREQ/BIAS STEP [⇧] or [⇩] key to initiate measurement. Pressing and holding the STEP [⇧] or [⇩] key advances the sweep bias voltage measurement in a higher or lower voltage direction (from the programmed spot bias voltage), respectively. If the spot voltage is outside the programmed sweep range, E-04 annunciation is displayed. The bias voltage can also be shifted in step voltage intervals each time the key is pushed. A reverse direction sweep is also feasible.

Note: When FAST key is pressed simultaneously with the STEP [⇧] or [⇩] key, the step voltage interval is expanded to ten times its programmed value in linear sweep mode or to one-fifth the voltage points in logarithmic sweep mode.

– (AUTO SWEEP) –

a. Press [Blue] key, then press SWEEP FREQ/BIAS [⇧] or [⇩] key to initiate an automatic sweep bias voltage measurement. AUTO sweep indicator lamp above the [⇧] key lights simultaneously and stays lit while the auto sweep mode function is being set. Pressing [⇧] key starts a single sweep bias voltage measurement from the programmed start voltage. The voltage sweep ends at the stop voltage point. Pressing [⇩] key advances voltage sweep in the reverse direction (from the stop voltage towards start voltage).

Note: RANGE HOLD function is automatically set.

SWEEP PAUSE

If needed to temporarily stop a sweep bias voltage measurement at a desired voltage step point, press [Blue] key, then press PAUSE key. To restart the measurement, press [Blue] key and again press [⇧] or [⇩] key. The bias voltage is successively swept.

Figure 3-15. Swept Bias Voltage Measuremet (Sheet 2 of 3).

Note: Sweep parameter value and sweep mode settings (linear, logarithmic, auto or manual) can be changed when the PAUSE function is set. AUTO sweep indicator lamp stays lit until SWEEP ABORT key is pressed or until the bias voltage reaches start or stop voltage point.

While automatic sweep is advancing, panel control keys except SWEEP FREQ/BIAS and SWEEP ABORT keys are deactivated.

SWEEP ABORT

Auto-sweep bias voltage measurement of operation is automatically released when a single sweep measurement ends. To release the bias voltage sweep mode of operation before the measurement is complete, press [Blue] key, then press SWEEP ABORT key.

Note: Spot bias voltage is automatically set to the voltage point where a sweep bias voltage measurement function is released.

Figure 3-15. Swept Bias Voltage Measurement (Sheet 3 of 3).

RECORDING SWEPT FREQUENCY/BIAS MEASUREMENTS

Measured value of swept frequency (or bias voltage) measurements can be recorded in graphic format with an X-Y recorder (analog recorder output option) or with a plotting instrument interfaced with an HP-IB controller. To proportion the analog recorder output for display output and to prevent the instrument from changing range during recording, the RANGE HOLD function is set. This fixes the decimal point position during an auto-sweep measurement.

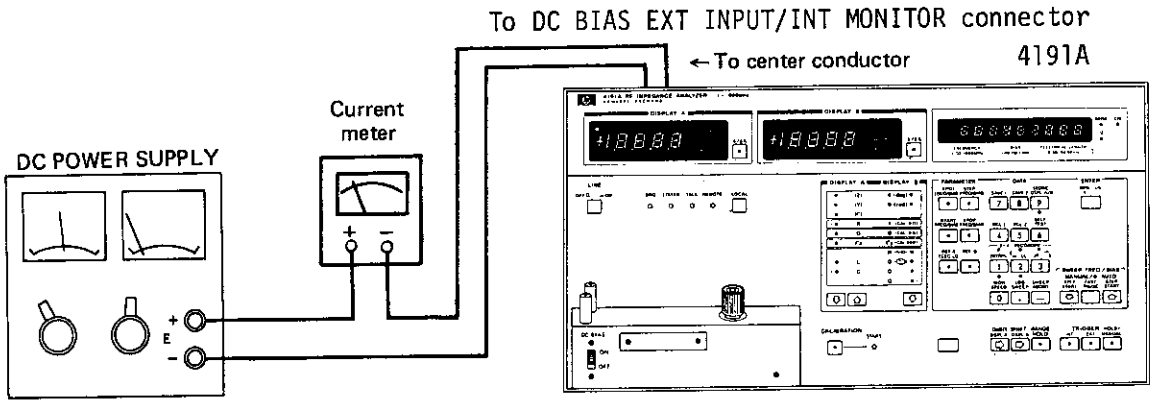
On the other hand, display output (and recorder output) may overflow the selected range when measuring a sample whose values vary greatly (such as varactor diodes, resonators, etc.). In such cases, the RANGE HOLD function may be manually released. Auto-ranged measurement output data can be processed by an HP-IB computing controller into an appropriate format for plotting with a graphic recorder.

To release the RANGE HOLD function in auto-sweep measurement, perform the following:

1) Press [Blue] key and SWEEP FREQ/BIAS PAUSE key to temporarily stop sweep operation just after the auto-sweep measurement is initiated (AUTO sweep indicator lamp lights).
2) If test frequency or bias voltage has advanced a few step intervals, reset it to the sweep start point by pressing SWEEP FREQ/BIAS [⇧] or [⇩] key.
3) Press RANGE HOLD key to release the function (key indicator lamp is extinguished).
4) Press [Blue] key and [⇧] or [⇩] key to restart the sweep measurement.

EXTERNAL DC BIAS OPERATION (≤ 40V)

To make measurements of capacitance, inductance or resistance samples using external dc bias voltages up to ± 40V, connect an external dc bias supply as shown in diagram.



PROCEDURE

Caution: Initially set DC BIAS switch on the 4191A test fixture installation deck to its OFF position.

1. Set 4191A rear panel DC BIAS INT EXT switch to EXT position.
2. Connect an external dc bias supply to rear panel DC BIAS EXT INPUT/INT MONITOR connector as illustrated.

   Caution: External dc bias supply output voltage should be set at zero volts.

3. Depress LINE button to turn instrument on.
4. In accordance with instructions in "Initial Mode Settings" (Figure 3-5), prepare to take measurements with the 4191A.
5. Set 4191A controls in accord with Basic Operating Procedure (Figure 3-7) steps 3 through 7.
6. Connect sample to test fixture.

   Caution: Do not connect a charged capacitor as DUT or internal circuitry may be damaged.

7. Set DC BIAS switch on 4191A test fixture installation deck to its ON position.
8. Set dc bias supply for the desired output voltage (below ± 40V).

   Caution: Never apply an external dc bias over ± 40V.

9. Read 4191A display output.

Figure 3-16. External DC Bias Circuits (Sheet 1 of 2).

BIAS VOLTAGE SETTLING TIME

The bias voltage settling time required for a dc voltage across a capacitor sample to reach more than 90% of the applied bias voltage, is less than 1ms for a 1μF capacitor.

DC BIAS VOLTAGE MONITOR

When it is desired to monitor actual dc voltage across the conductive sample being measured, read bias current flowing through the sample on a current meter connected between dc bias supply and the rear panel DC BIAS input connector. The effective bias voltage can be calculated by the following equation:

$$Eb = Eo - 0.39 \cdot Im \text{ (V)}$$

where, Eb is dc voltage across the sample.
Eo is dc bias supply output voltage.
Im is current meter reading in mA.

Inaccuracy of the calculated current value is ± 0.04 · Im (disregarding current meter accuracy).

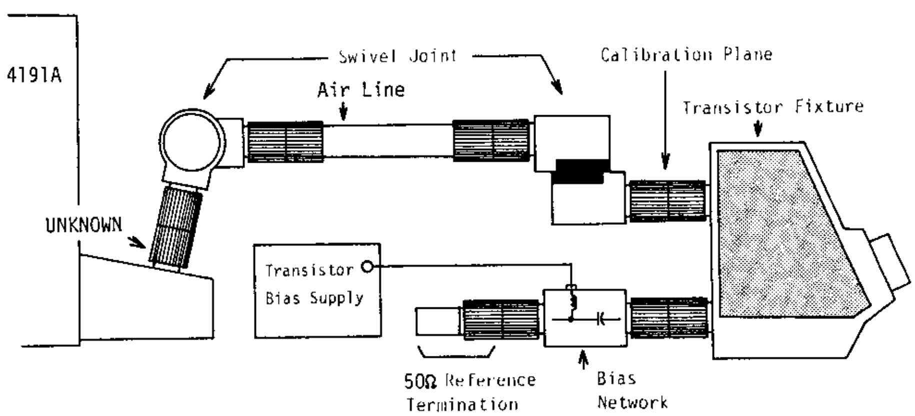
Note: Maximum bias current which can flow through sample is 100mA (when bias input voltage is 40V).

Figure 3-16. External DC Bias Circuits (Sheet 2 of 2).

RF TRANSISTOR MEASUREMENTS

The use of accessory transistor fixtures with the 4191A will facilitate the input/output impedance measurements of bipolar and field effect transistors and will enhance measurement accuracy and resolution at frequencies up to 1000 MHz. HP models 11600B, 11602B and 11608A Transistor Fixtures are especially matched to the 4191A and are useful in making measurement of transistors packaged in TO-5, TO-12, TO-18, TO-71 type or micro strip-line structures. The 4191A can measure transistor characteristic parameters corresponding to S (Scattering) parameter elements S_{11} and S_{22} with the fixture. To cause the desired operating current to flow the sample transistor, an external auxiliary bias supply can be used in combination with the internal bias supply.

Note: S parameter elements S_{12} and S_{21} can not be measured (these parameters are enabled by another instrument capable of measuring transmission coefficients).



Recommended test fixtures

Accessories	Model	Characteristics
Transistor Fixture	11600B	For TO-18 and TO-72 transistors
	11602B	For TO- 5 and TO-12 transistors
	11608A	For strip line transistors
Bias Network	85426A	0.1 to 500MHz, 70V max, 750mA max.
	11589A OPTION 001	100 to 3000MHz, 100V max, 500mA max.
Air Line Extension	11566A	APC-7 connector, 10 cm
Coaxial Swivel Joint	11588A	APC-7 connector
Transistor Bias Supply	8717B	100V max, 1A max.

Figure 3-17. RF Transistor Measurements (Sheet 1 of 2).

PROCEDURE

1. Connect two 11588A Coaxial Swivel Joints and 11566A Air Line Extension as shown in figure.
2. Depress LINE button to turn instrument on.
3. Perform auto-calibration with 0Ω, 0S and 50Ω reference terminations. Connect the termination at the tip of the 11588A swivel joint.
4. Attach 11600B (or 11602B or 11608A) Transistor Fixture, 85426A Bias Network and 50Ω termination as shown in figure.
5. Appropriately set transistor fixture snap-on dial to select the desired transistor socket.
6. Connect short-circuit termination (an accessory of the transistor fixture) to the 11600B transistor socket.
7. Enter a trial electrical length number in the 4191A and repeatedly try with other numbers so that phase angle display output in $|Z|-\theta$ measurement approaches zero (a minimum value).
8. Remove the short-circuit termination and connect sample transistor to the appropriate socket for the fixture.
9. Set internal bias and external bias voltage output to the desired voltage (current) value.

   Note: Set 4191A rear panel DC BIAS INT/EXT switch to INT position and front panel DC BIAS switch to ON.

10. Read impedance values of the sample in $|Z|-\theta$ or R-X measurement mode.

Note

For detailed operating procedures and associated information on the recommended transistor fixtures, refer to operating and service manual for each individual transistor fixture.

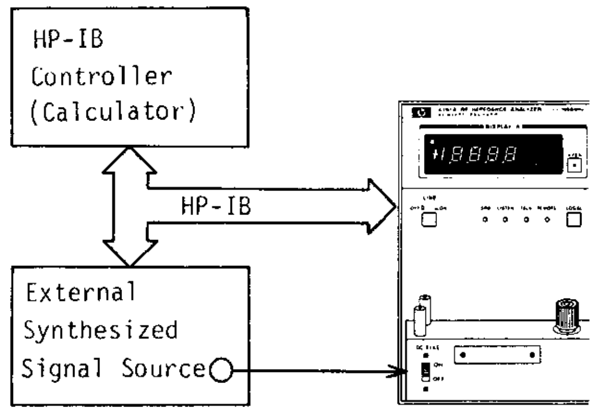
Figur 3-17. RF Transistor Measurements (Sheet 1 of 2).

USING EXTERNAL SIGNAL SOURCE

GENERAL

The requirements for analysis of sharp, complex perturbations such as those inherent in electromechanical absorption and resonance of materials, may sometimes necessitate higher measurement frequency resolution. The use of an external, high resolution frequency synthesizer enables the 4191A to respond to these special requirements. The improved measurement accuracy and resolution of the 4191A permits the detection of small, adjacent peaks and drops in change of sample values making the most of the effects of an increase in the test frequency resolution. The equipment setup and operating procedure for making such measurement are outlined below:

Note: Using an external singal source requires a simple modification by a technical person to the internal circuitry of the instrument. For the details, refer to Application Note 302-2.



PROCEDURE

1) Connect the 4191A and the desired synthesizer signal source to an HP-IB computing controller to achieve remote control and data transfer through the HP-IB interface cables as illustrated above.

2) Set 4191A measurement function to $\Gamma x - \Gamma y$ mode.

3) Program the following equations to calculate calibration data values:

$$e_{00} = \Gamma_{50}, \quad e_{11} = \frac{\Gamma_\infty + \Gamma_0}{\Gamma_\infty - \Gamma_0},$$

$$e_{01} = (\Gamma_{50} - \Gamma_0)(1 + e_{11})$$

where, Γ_{50} is measured Γ value for 50Ω reference termination.
Γ_∞ is measured Γ value for 0S reference termination.
Γ_0 is measured Γ value for 0Ω reference termination.

4) Remotely control the frequency of both the 4191A and the signal source simultaneously with the HP-IB controller. Measure Γ_{50}, Γ_∞ and Γ_0 values using reference terminations at the desired test frequency points and store the measured values in the memory of the HP-IB controller.

5) Calculate e_{00}, e_{11} and e_{01} values for each test frequency point from the memorized Γ_{50}, Γ_∞ and Γ_0 values. Store the calibration data in the controller.

6) Attach appropriate test fixture to 4191A UNKNOWN connector.

7) Connect sample to test fixture. Take measurements at the calibration frequencies and memorize the measured sample values.

Note: Measurement can only be taken at the calibration frequency points.

8) Correct the measured values using the memorized calibration data and the following equation:

$$\Gamma_{true} = \frac{\Gamma m - e_{00}}{e_{11}(\Gamma m - e_{00}) + e_{01}}$$

where, Γ_{true} is correct Γ value of sample.
Γ_m is measured Γ value of sample.

9) Convert the corrected Γ values to the desired parameter values by using equations given in Measurement Parameter Relationships (Page 3-20).

Table 3-x. Annunciation Display Meanings (Sheet 1 of 2).

Annunciation figure	Display section	Indicated Condition	What to Do	Display format
CAL	A or B	Error in auto-calibration operation. 1. Measurement is attempted before calibration is complete. 2. Test frequency was set at a frequency point outside the calibration frequency range.	Perform calibration for the selected frequency point. Otherwise, select another test frequency for which the calibration is complete.	C
E-01	p	Error in test parameter data input. Test frequency, electrical length or bias voltage setting number exceeds the selectable range limit.	Enter the test parameter data again using an appropriate number.	A
E-02	p	Error in bias voltage parameter data input. A negative voltage number was entered as test parameter input data for a swept bias voltage measurement in logarithmic sweep mode.	Enter the bias voltage setting data again using a positive number (not zero).	A
E-03	p	Error in sweep frequency/bias parameter data input. A stop frequency (voltage) number lower than start frequency (voltage) setting was entered. (This error message is displayed just after the sweep measurement is initiated).	Enter the start or stop frequency (voltage) data again so that the frequency settings follow the regular high and low frequency (voltage) relationship.	A
E-04	p	Error in spot frequency (bias voltage) data input. Spot frequency (voltage) setting is outside the preset sweep range.	Enter the spot frequency (voltage) data again using an appropriate number.	A
E-05	p	Error in deviation measurement control operation. 1. STORE DSPL A/B function was actuated while an error message was displayed. 2. STORE DSPL A/B function was actuated without releasing Δ or Δ% measurement function.	Restore the instrument to normal measuring conditions. Then actuate the STORE DSPL A/B function again.	A
E-06	A or B	Error in deviation measurement control operation. Δ or Δ% function was actuated without previously storing reference value for the selected measurement parameter.	Perform operating procedure necessary for entering reference value, then actuate the Δ or Δ% function again.	C
	p	REF A or REF B function was actuated despite that the reference data has not been entered (for the selected measurement parameter).	Press another PARAMETER key to release the input demand. Otherwise, enter an appropriate reference number.	C

Table 3-6. Annunciation Display Meanings (Sheet 2 of 2).

Annunciation figure	Display section	Indicated Condition	What to Do	Display format
E-07	p	Error in initial operation. A panel control key is pushed even though the instrument is not ready to take measurements (warm-up time is not yet fulfilled).	Do not push any control keys again. Error message display will disappear just after warm-up is complete.	C
E-08	p	Error in X-Y recorder control operation. An X-Y recorder control function was actuated despite that X-Y recorder output option (Opt. 004) is not installed.	The X-Y recorder control function should not be actuated again.	A
E-09	p	Error in continuous memory function. 1. Memory data to be continuously preserved has been lost. 2. Stand-by battery for continuous memory operation is exhausted.	The instrument requires servicing.	B
E-11 E-12	p	Abnormality in the instrument. (An instrument failure).	The instrument requires servicing.	C
E-NN	B	NN: Numbers above 20. Refer to Paragraph 3-5 SELF TEST.		C
-OF-	A or B	Measured value to be displayed exceeds the upper range limit.	Select another measurement parameter at which the sample can be measured.	C
	p	Error in reference value input data. Reference value input number for REF A or REF B exceeds the maximum display value on the selected range.	Enter the reference value input data again using an appropriate number.	

Abbreviation Notes

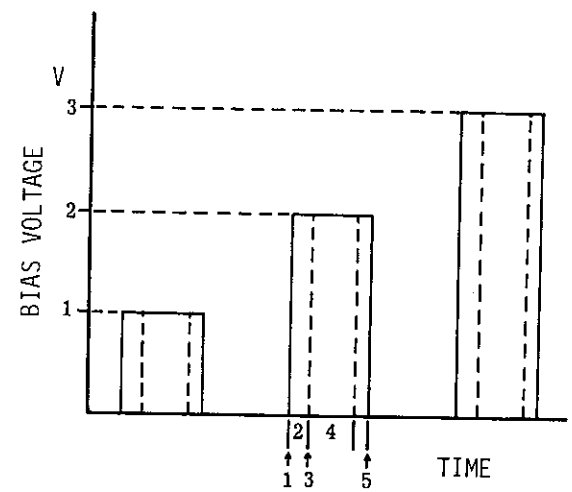
Display section	A	DISPLAY A
	B	DISPLAY B
	p	Test Parameter Data Display
Display format	A	Duration of Display is about 2 seconds. The inappropriate control input demand is automatically released.
	B	Duration of Display is about 2 seconds. The panel controls are automatically set to the normal initial control setting status.
	C	Continuously displayed until the erroneous setup is removed.

3-49. EXTERNAL TRIGGERING.

3-50. For making a synchronized measurement with an auxiliary instrument, for taking a measurement using a particular occurrence as the start, or for generating measurement data at a preset time in a data logging system, an external trigger will facilitate properly timed measurements with the 4191A. To accept external trigger signals, the front panel EXT TRIGGER key must be pressed. Connect the external triggering device to the rear panel EXT TRIGGER connector with a BNC cable. Triggering requires a TTL level signal that changes from low (0V) to high (+ 5 V) level. The trigger pulse width must be greater than 10μs. Shorting and opening (alternately) the center conductor of the EXT TRIGGER connector to ground (chassis) also effectively triggers a measurement.

Note: The center conductor of the EXT TRIGGER connector is normally at high level (no input).

Figure 3-18 shows an example of external triggering as used with programmed bias magnitudes.



(1) DC bias voltage applied.
(2) Time required for dc bias voltage to settle (100ms max.).
(3) Trigger point.
(4) Time required to measure sample.
(5) DC bias voltage removed.

Figure 3-18. Pulse Bias Measurements with External Triggering for Programmed Bias Magnitudes.

Trigger rate

Maximum external trigger input rates for normal and high speed measurement modes are listed in the table below:

Measurement Mode	Max. Trigger rate
Normal	810ms
High Speed	260ms

In normal measurement mode of operation, five measurements are automatically taken (to perform and display an average of the measurements) each time the instrument is triggered. If the trigger input rate is too fast, measurement data is not provided because subsequent trigger signals always initialize the measurement sequence of the instrument before measurement ends.

Cleaning APC-7 Connectors

APC-7 connector contact surfaces of the UNKNOWN terminal, terminations and test fixtures must be kept free of spots, dust, oil and adhesives which invite poor connector contact.

To maintain clean contact surfaces, it is recommended that the operator perform periodic cleaning as necessary.

Use lint-free cloth and, if a cleaning fluid is needed, use isopropyl alcohol.

Caution:
Do not use aromatic or chlorinated hydrocarbons, esters, ethers, terpenes, higher alcohols, ketones, or ether-alcohols such as benzene, toluene, turpentine, dioxane, gasoline, cellulose acetate, or carbon tetrachloride.
Keep exposure of the connector parts to both the cleaning fluid and its vapors as brief as possible.

3-51. OPTIONS.

3-52. Options are standard modifications to the instrument that implement user's special requirements for minor functional changes. Operating instructions for the 4191A options (except for rack mount and handle installation kit options) and associated information are described in the following paragraphs.

3-53. OPTION 002 HIGH RESOLUTION TEST FREQUENCY.

3-54. The 4191A Option 002 provides an internal frequency synthesizer test signal resolution selectable at 100Hz (to 500MHz) and at 200Hz (to 1000MHz) instead of the standard frequency resolution. The selectable frequencies for the spot, start, stop and step frequency settings are shown in Table 3-1. To provide test frequency readouts up to 1000MHz in conjunction with the improved resolution, the Test Parameter Data Display is extended to 7 digits (maximum display 1000.0000MHz). Other control functions and operating performance, except for the test frequency resolution, are identical to the standard unit.

The high resolution frequency setting capability as well as the excellent frequency stability (residual FM noise is below 30Hz rms at 500MHz) facilitate, in particular, analysis of devices whose characteristic values vary sharply with changes in frequency, such as crystal resonators and high selectivity band-pass/rejection filters. In addition, the programmable test frequency sweep capability and HP-IB compatibility permits automating such measurements which usually entail taking measurement data at numerous test frequency points.

3-55. OPTION 004 ANALOG RECORDER OUTPUT

3-56. The 4191A Option 004 is equipped with three analog RECORDER OUTPUT (BNC) connectors on the rear panel. These connectors output accurate voltages for recording measured sample values in terms of test frequency or internal dc bias voltage in swept frequency or swept bias voltage measurements. The recorder output voltages are provided in the following manner:

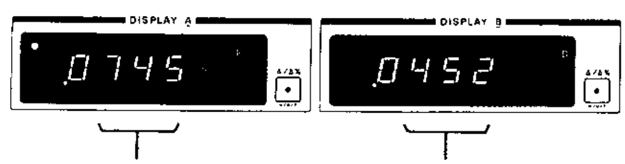
FREQ/BIAS connector: Output voltage is proportional to the test frequency or internal dc bias voltage setting and is given by the following equation:

$$E_0 = \frac{f_{spot} - f_{start}}{f_{stop} - f_{start}} \text{ or } \frac{V_{spot} - V_{start}}{V_{stop} - V_{start}} \text{ (V)}$$

The voltage value of E_0 is within the range of 0V and 1V. When LOG SWEEP function is set, the output voltage is proportional to logarithm of test frequency or of dc bias voltage.

DISPLAY A connector: Output voltage is proportional to the three lesser significant digit numbers of DISPLAY A display outputs (see illustration). 1mV per 1 count, ± 999 mV at full count display (± 999 counts).

DISPLAY B connector: Output voltage is proportional to DISPLAY B display output in the same manner as that for DISPLAY A connector output.



Outputs 745mV at DISPLAY A connector

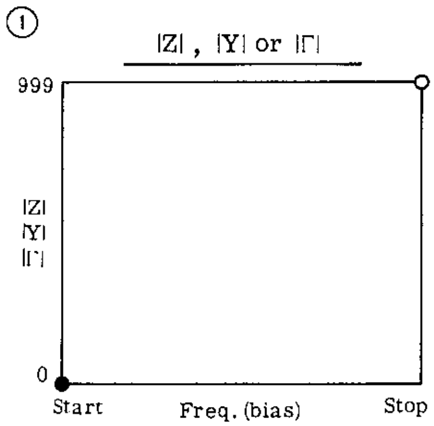
Outputs 452mV at DISPLAY B connector

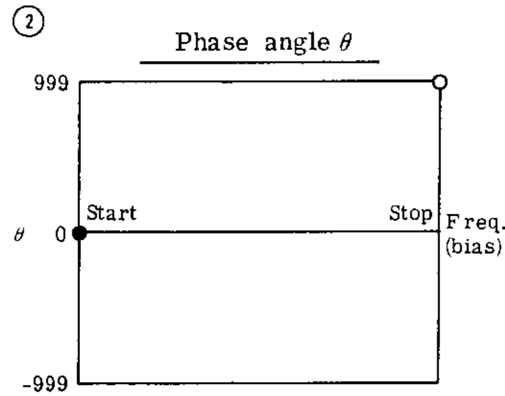
Notes:

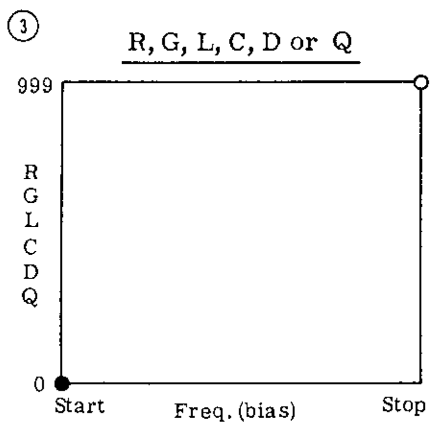
1. *When displayed number exceeds ±1000 counts, the recorder output voltage is -1V or +1V.*
2. *The recorder voltages are outputted only when the RANGE HOLD function is set automatically or manually.*

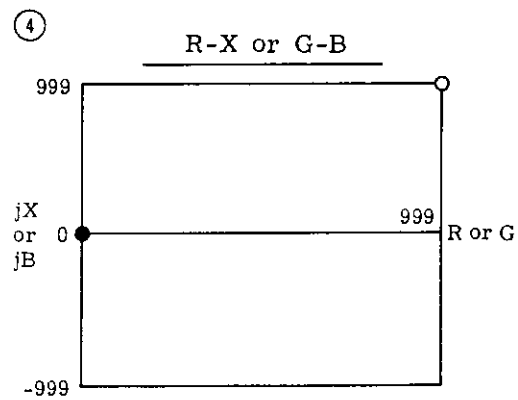
Chart Paper Coordinates

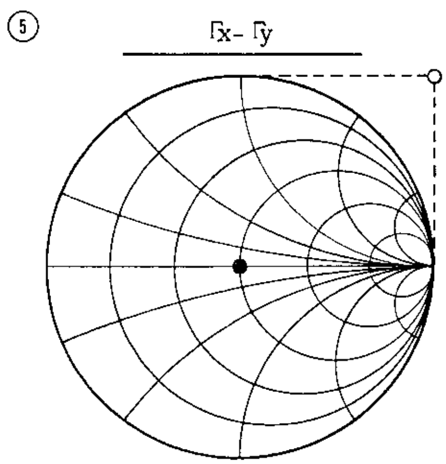
Use chart paper coordinates appropriate for the measurement parameter from among illustrations below:











Black spot (•) LL
White spot (o) .... UR

Scales indicate in counts (999 signifies 999, 99.9, 9.99, 0.999 or 0.0999).

Recording on Orthogonal X-Y Coordinates

Measurement parameter: |Z|, |Y|, |Γ|, R, G, L, C, D, Q
θ, R-X, G-B

1) Connect X-Y recorder X input and Y input terminals, respectively, to the appropriate RECORDER OUTPUTS on 4191A rear panel. Use shielded cables with BNC connectors. See table 3-7 for cabling method.

2) Place recording paper on X-Y recorder platen and set paper hold down function to on. Lift recorder pen up and hold it until recording starts.

3) Press [Blue] key and ↓← LL key (DATA input "2" key on the 4191A front panel). The indicator lamp above the ↓← LL key will light.

4) Adjust X-Y recorder zero adjustment controls (independently for X and Y channels) so that the recorder pen is positioned just above the chart paper coordinates denoted by black spot (•) in the illustration.

5) Press [Blue] key and UR→↑ key (DATA input "3" key) on the 4191A front panel. The indicator lamp above the UR→↑ key will light.

6) Adjust X-Y recorder sensitivity adjustment controls (for X and Y channels) so that the recorder pen is positioned just above the chart paper coordinates denoted by white spot (○) in the illustration.

7) Again press blue key and UR→↑ key to release the zero adjustment function.

8) Perform a trial sweep measurement for sample to verify the minimum and maximum display readouts.

Table 3-7. X-Y Recorder Cabling Method.

Recording parameters		X-Y recorder input connections		
X	Y	FREQ/BIAS	DSPL B	DSPL A
Freq or bias	|Z|, |Y| or |Γ|	X	—	Y
Freq or bias	θ	X	Y	—
Freq or bias	R,G,L or C	X	—	Y
Freq or bias	D or Q	X	Y	—
R or Q	X or B	—	Y	X
Γx	Γy	—	Y	X

9) Change number of display digits to properly set the recording value range by pressing DIGIT SHIFT DSPL A or DSPL B key.

10) Set the 4191A frequency or bias voltage at the sweep start point and set X-Y recorder pen down.

Note: If smooth recorder tracing to variations in measured sample values is desired, press blue key and INTRPL key.

11) Start sweep measurement.

Recording on Smith Chart

Measurement parameter: Γx−Γy

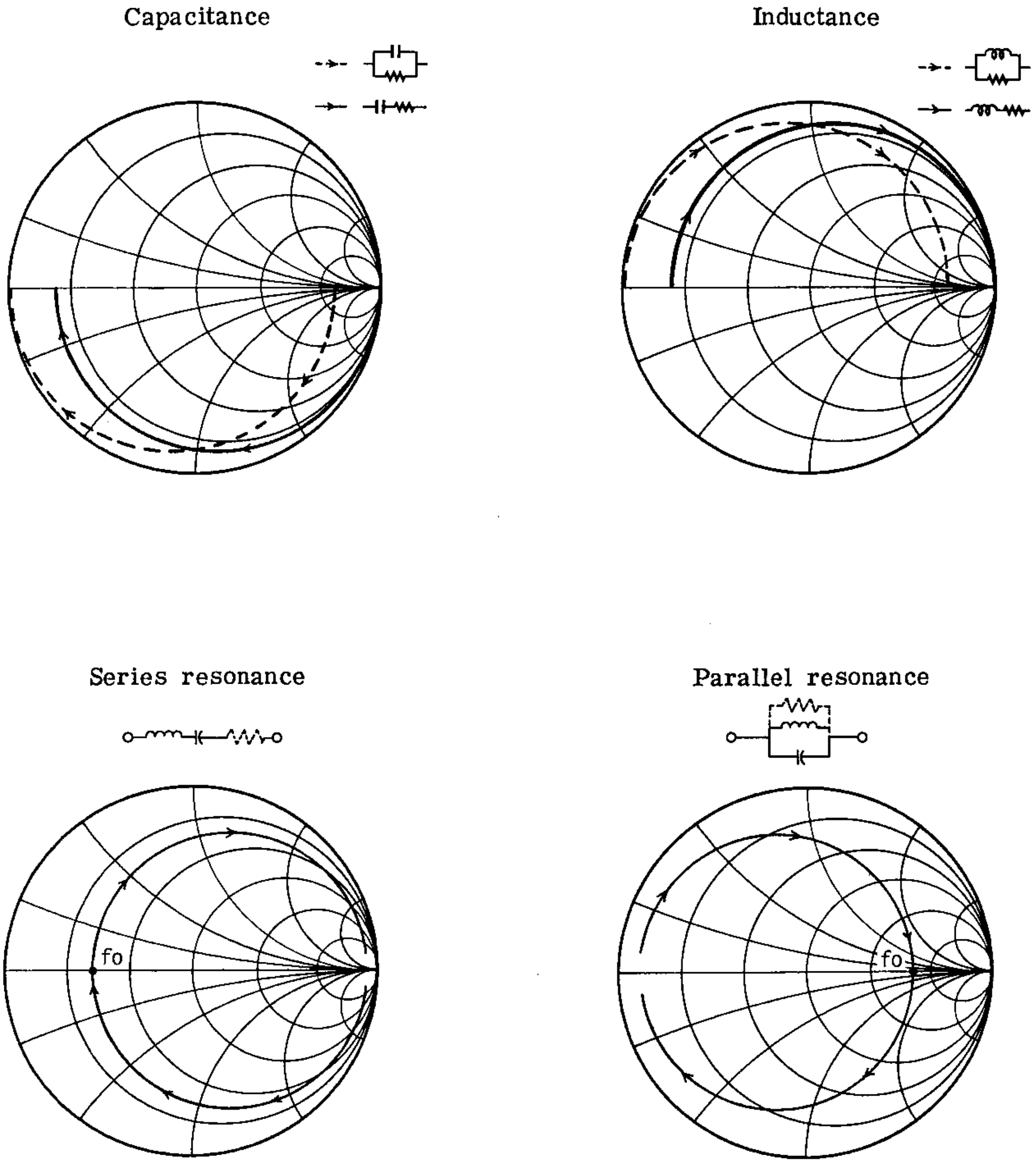
Reflection coefficient locus in sweep frequency measurement offers graphic data quite useful in various applications when it is recorded on a Smith Chart. As the reflection coefficient values are represented in the form of orthogonal X-Y coordinates on the Smith Chart plane, its locus can be recorded by using the same procedure as that for other parameter values (described above). For X-Y recorder sensitivity and zero scale adjustments, find the locations of the two spots illustrated in figure (5); the black spot denotes the coordinates (Γx, Γy) = (0, 0) and the white spot is identical to the virtual coordinates (Γx, Γy) = (1, 1).

Note: *To find the location of the white spot for sensitivity adjustment, construct two tangential lines of* |Γ| = 1 *circle at points* (Γx, Γy) = (1, 0) *and* (Γx, Γy) = (0, 1), *respectively, (as illustrated in figure* (5)*).*

3-57. Use of Strip Chart Recorder.

3-58. The analog recorder output also provides the convenience of monitoring drift or vibrations in sample values with time. To automate such time consuming tests, a strip chart recorder can perform the recording of measurement data without continuous monitoring by the operator. A single channel strip chart recorder permits recording either DISPLAY A or DISPLAY B measurement data outputs. A two channel recorder can simultaneously graph both data outputs on the chart paper.

Recorder sensitivity should be set so that the maximum displacement of the writing pen is within the chart paper span and, in addition, so that the change in measured values is readable on the chart.



As frequency increases, the reflection coefficient (impedance) plot moves in the direction of the arrow.

Figure 3-19. Smith Chart Illustrations of the Loci of Various Impedance Elements.

3-59. HP-IB INTERFACE

3-60. The Model 4191A can be remotely controlled by means of the HP-IB which is a carefully defined instrumentation interfacing method that simplifies the integration of instruments and a calculator, or computer into a system.

Note: HP-IB is Hewlett-Packard's implementation of IEEE Std. 488-1975 Standard Digital Interface for Programmable Instrumentation.

Note: The 4191A may exhibit the following phenomena:

Phenomenon -1.

(1) The first byte of measurement data is lost when read after Serial Polling.

(2) The first several bytes of measurement data is lost when read after Serial Polling. The number of bytes lost is proportional to the number of Serial Pollings performed.

Phenomenon -2. Output measurement data from the 4191A may include two or more spaces in the first part of each data string, though each data string should have only one space. Refer to paragraph 3-75 on page 3-77 for data output format.

Phenomenon -3. After Serial Polling, the status byte, which should be cleared, is not cleared from the register in the HP-IB Interface Adapter (Micro Port), A20U66.

Described below are software solutions for the above phenomena.

For Phenomenon -1 - (2):

"Serial Polling (read status)" and "read one byte of measurement data" should not be executed sequentially.

For Phenomenon -2:

(1) Read measurement data with free format.

(2) Measurement data is read with the procedure: hold trigger--execute (trigger)--read data. However, the first measurement data of sequential measurement data is invalid.

3-61. CONNECTION TO HP-IB

3-62. The 4191A may be connected into an HP-IB bus configuration with or without a controller (e.g. with or without an HP calculator). In an HP-IB system without a controller, the 4191A can function as a Talk Only unit (refer to paragraph 3-67).

3-63. HP-IB STATUS INDICATORS

3-64. The HP-IB Status Indicators are four LED lamps on the front panel. These lamps show the status of the 4191A in an HP-IB system as follows:

SRQ: SRQ signal on HP-IB line from 4191A (refer to paragraph 3-77).
LISTEN: The 4191A is set to be listener.
TALK: The 4191A is set to be talker.
REMOTE: The 4191A is remotely controlled.

Note: When the 4191A is controlled via the HP-IB, LISTEN lamp may not be lit by the "remote" command (REMOTE or rem).

3-65. LOCAL SWITCH

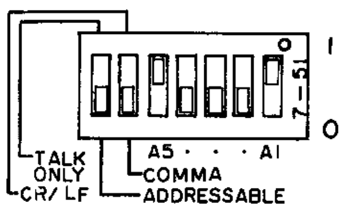
3-66. The LOCAL switch disables remote control from HP-IB control and enables setting measurement conditions at front panel controls (pushbutton switches). REMOTE HP-IB status indicator lamp turns off when LOCAL switch is depressed. This function can not be used when the 4191A is set to local lockout status by controller.

3-67. HP-IB CONTROL SWITCH

3-68. The HP-IB Control Switch on rear panel controls seven digits and three capabilities as follows:

(1) Bit 1 ~ 5: The HP-IB address is established by these five digits of the control switch.
(2) Bit 6 (delimiter form bit): This bit determines delimiter forms of output data which are:
0: Format A (comma)
1: Format B (carriage return, line feed).
(3) Bit 7 (talk only bit): This bit determines instrument capabilities which are:
0: Addressable
1: Talk Only

Note: The 4191A is set at the factory as given in Figure 3-20.



bit 1~5: 17
bit 6: Format A (comma)
bit 7: Addressable

Figure 3-20. HP-IB Control Switch.

3-69. HP-IB INTERFACE CAPABILITY OF 4191A

3-70. The interface of a device connected to the HP-IB is specified by the interface functions built into the device. The 4191A has eight HP-IB interface functions as given in Table 3-8.

Table 3-8. HP-IB Interface Capabilities.

Code	Interface Function* (HP-IB Capabilities)
SH1**	Source Handshake.
AH1	Acceptor Handshake.
T5	Talker (basic talker, serial poll, talk only mode, unaddress to talk if addressed to listen).
L4	Listener (basic listener, unaddress to listen if addressed to talk).
SR1	Service Request.
RL1	Remote-Local (with local lockout).
DC1	Device Clear.
DT1	Device Trigger.

* Interface functions provide the means for a device to receive, process and transmit messages over the bus.

** The suffix number of the interface code indicates the limitation of the function capability as defined in Appendix C of IEEE Std. 488-1975.

3-71. REMOTE PROGRAM CODE

3-72. Remote program codes for the 4191A are listed in Table 3-9.

Table 3-9. Remote Program Code (Sheet 1 of 3).

	Control	Program Code	Description
Display A Function	|Z|	A1	Combinations of A and B are listed in the table below:
	|Y|	A2	
	|Γ|	A3	
	R	A4	
	G	A5	
	Γx	A6	
	L	A7	
	C	A8	
Display B Function	θ (deg)	B1, B3, B4	
	θ (rad)	B2	
	R	B1	
	G	B2	"AUTO RANGE" mode is automatically set when these program codes are transmitted.
	D	B3	
	Q	B4	

A \ B	1	2	3	4
1	|Z|-θ (deg)	|Z|-θ (rad)	|Z|-θ (deg)	
2	|Y|-θ (deg)	|Y|-θ (rad)	|Y|-θ (deg)	
3	|Γ|-θ (deg)	|Γ|-θ (rad)	|Γ|-θ (deg)	
4	R – X			
5	G – B			
6	Γx – Γy			
7	L – R	L – G	L – D	L – Q
8	C – R	C – G	C – D	C – Q

Table 3-9. Remote Program Code (Sheet 2 of 3).

	Control	Program Code	Description
Deviation Measurement of Display A	OFF Δ Δ%	AN AD AP	Deviation measurement can not be done if reference data is not stored.
Deviation Measurement of Display B	OFF Δ Δ%	BN BD BP	"RANGE HOLD" mode is automatically set when AD, AP, BD or BP is assigned.
Displayed Value Input	STORE DISPLAY A/B	TD	
Key Status Memory	SAVE 1 SAVE 2	V1 V2	
Recall Saved Key Status	RCL 1 RCL 2	L1 L2	
Display A Multiplier	$\times 10^{3}$ (k) $\times 10^{0}$ $\times 10^{-3}$ (m) $\times 10^{-6}$ (μ) $\times 10^{-9}$ (n) $\times 10^{-12}$ (p)	P1 P2 P3 P4 P5 P6	
Display B Multiplier	$\times 10^{3}$ (k) $\times 10^{0}$ $\times 10^{-3}$ (m) $\times 10^{-6}$ (μ) $\times 10^{-9}$ (n)	Q1 Q2 Q3 Q4 Q5	
Display A Digit Shift	0 1 2 3 4	M0 M1 M2 M3 M4	
Display B Digit Shift	0 1 2 3 4	L0 L1 L2 L3 L4	
Manual Sweep	STEP ⇧ STEP ⇩	SU SD	
Auto Sweep	START ⇧ START ⇩ PAUSE ABORT	WU WD PS AB	
High Speed	OFF ON	H0 H1	
Log Sweep	OFF ON	G0 G1	
Calibration	OFF ON START	C0 C1 CS	

Table 3-9. Remote Program Code (Sheet 3 of 3).

	Control	Program Code	Description
Trigger Mode	INT EXT HOLD/ MANUAL	T1 T2 T3	
Range Hold	OFF ON	R0 R1	
Execute		EX	
Data Ready	OFF ON	D0 D1	
Self Test	OFF ON	S0 S1	
Recorder Control	OFF LL UR	XY LL UR	
Interpolation	OFF ON	I0 I1	

3-73. PARAMETER SETTING

3-74. A 4191A can be set to twelve parameters (refer to Table 3-10) by remote programming as follows:

XX±NNNN.NNNNEN
(1) (2) (3)

(1) Program code for parameter setting (refer to Table 3-10).

(2) Setting value (numeric or space).

(3) Parameter terminator.

Table 3-10. Program Code for Parameter Setting.

Parameter	Program Code	Setting Value
SPOT FREQUENCY (MHz)	FR	1.0 ~ 1000.0 (1.0000 ~ 1000.0000)
STEP FREQUENCY (MHz)	SF	0.1 ~ 999.0 (0.0001 ~ 999.0000)
START FREQUENCY (MHz)	TF	1.0 ~ 1000.0 (1.0000 ~ 1000.0000)
STOP FREQUENCY (MHz)	PF	1.0 ~ 1000.0 (1.0000 ~ 1000.0000)
SPOT BIAS (V)	BI	−40.00 ~ +40.00
STEP BIAS (V)	SB	0.01 ~ 40.00
START BIAS (V)	TB	−40.00 ~ +40.00
STOP BIAS (V)	PB	−40.00 ~ +40.00
DISPLAY A REFERENCE	RA	−199.99 ~ +199.99
DISPLAY B REFERENCE	RB	−199.99 ~ +199.99
ELECTRICAL LENGTH (cm)	EL	0.00 ~ 99.99
OPEN CAPACITANCE (pF)	OC	−1.000 ~ +1.000

3-75. DATA OUTPUT

3-76. Data outputted by the 4140A includes data statuses, measured parameters, deviation measured modes and measured values for displays A and B. Moreover, swept parameter and swept frequency or bias value are outputted by the 4191A in auto sweep or calibration mode. These data are outputted in format as shown in Figure 3-21.

① **SPOT MEASUREMENT**

The data is outputted in the following format when measurement frequency and bias voltage are fixed.

```
␣ X X X ± N N N . N N E ± N N , X X X ± N N N . N N E ± N N (CR)(LF)
(1)(2)(3)(4)        (5)         (6)(7)(8)(9)      (10)          (11)
```

② **AUTO SWEEP MEASUREMENT AND CALIBRATION**

The data is outputted in the following format when measurement frequency or bias voltage is swept automaically or when the 4191A is set to calibration mode.

```
␣ X ± N N N N . N N N N , X X X ± N N N . N N E ± N N , X X X ± N N N . N N E ± N N (CR)(LF)
(1)(12)       (13)      (6)(2)(3)(4)     (5)       (6)(7)(8)(9)      (10)          (11)
```

(1) Space
(2) Data status of display A
(3) Function of display A or calibration condition
(4) Deviation measurement mode of display A
(5) Value of display A (decimal point position is coincident with display)
(6) Comma (data delimiter)
(7) Data status of display B
(8) Function of display B or calibration condition
(9) Deviation measurment mode of display B
(10) Value of display B (decimal point position is coincident with display)
(11) Data terminator
(12) Swept parameter
(13) Measurement frequency or bias voltage (decimal point position is coincident with display)

Notes: 1. *Data delimiter is set at the factory to", (comma)" (see Figure 3-20). In this case, data outputted by the 4191A is a continuous string. To break the data into two or three groups (to limit line length) for outputting to certain peripherals such as to an HP Model 5150A Thermal Printer, the delimiter form bit (HP-IB control switch Bit 6) on the rear panel is set to "CR/LF" (see Figure 3-20).*

2. *Data status, function, deviation measurement mode and swept parameter are expressed by a letter of the alphabet as given in Table 3-11.*

Figure 3-21. Data Output Format for the 4191A.

Table 3-11. Data Output Codes.

	Information	Code
Data Status	Normal	N
	Overflow	O
	Deviation Measurement impossible	D
	Needs Calibration	U
Display A Function	|Z|	Z
	|Y|	Y
	|Γ|	M
	R	R
	G	G
	Γx	X
	L	L
	C	C
Display B Function	θ (deg)	D
	θ (rad)	R
	X	X
	B	B
	Γy	Y
	R	R
	G	G
	D	D
	Q	Q
Calibration Condition	0Ω	S
	0S	O
	50Ω	T
Deviation Measurement	Normal Measurement	N
	Deviation Measurement	D
	Deviation Measurement in Percent	P
Swept Parameter	Frequency	F
	Bias Voltage	V

3-77. SERVICE REQUEST STATUS BYTE

3-78. The 4191A sends RQS (request service) signal whenever one of bits 1 thru 4 or 6 is set. Figure 3-22 shows the Status Byte make up of the 4191A.

3-79. PROGRAMMING GUIDE FOR 4191A.

3-80. Sample Programs for HP Model 9825A/9835A Desktop Computers are provided in Figures 3-23 and 3-24. These programs are listed in Table 3-12.

Notes:

1. *Specific information for HP-IB programming with the 9825A or 9835A are provided in the 9825A or 9835A programming manuals.*
2. *The equipment required for these sample programs include:*
   4191A RF Impedance Analyzer
   98034A HP-IB Interface Card
   9825A Desktop Computer with 98210A String-Advanced Programming ROM
   98213A General I/O + Extended I/O ROM.
   or
   9835A Desktop Computer with 98332A General I/O ROM

Table 3-12. Sample Program using 9825A/9835A

Sample Program	Figure	Description
1	3-23	Remote control and data output in spot measurement.
2	3-24	Remote control and data output in auto sweep measurement.

Bit	8	7	6	5	4	3	2	1
Information	0	0/1	0/1	0/1	0/1	0/1	0/1	0/1

Signal bit 7 (RQS signal) establishes whether or not service request exists.
Signal bits 1 thru 4 and 6 identifies character of the service request states.

Service request states of the 4191A:

(1) Bit 1: ① If Data Ready is set to ON, this state is set when measurement data is provided.
② If Self Test is set to ON, this state is set when Self Test is completed.

(2) Bit 2: ① When the 4191A receives an erroneous remote program code, this state is set.
② If Bit 6 is set, this state is set when Vector Ratio Detector is defective.

(3) Bit 3: ① When the 4191A receives an illegal front panel control setting program, this state is set.
② If Bit 6 is set, this state is set when phase locked loop is defective.

(4) Bit 4: ① When the 4191A receives trigger signal before last measurement is completed, this state is set.
② When the 4191A provides measurement data before last measurement data is outputted, this state is set.
③ If Self Test is set to ON, this state is set when Self Test is faulty.

(5) Bit 6: ① If Vector Ratio Detector is defective, this state is set. Bit 2 is also set.
② If Phase Locked Loop is defective, this state is set. Bit 3 is also set.

Signal bit 5 is independent of bit 7 (RQS signal). When auto sweep or calibration is being performed, this bit is set.

Figure 3-22. Status Byte for the 4191A.

Sample Program 1

Description:

This program is a remote control and data output program in spot measurment.
The program has three capabilities which are:

(1) Control of the 4191A via HP-IB.
(2) Trigger of the 4191A via HP-IB.
(3) Data output from the 4191A in spot measurement via HP-IB.

9825A Program

```
0: flt4
1: wrt717,"A1B1T3"
      (1)(2)  (3)
2: wrt717,"FR10EN"
            (4) (5)
3: wrt717,"EX"
        (6)
4: red717,A,B
5: dspA,B
6: prtA,B
7: end
```

9835A Program

```
10: FLOAT4
20: OUTPUT717;"A1B1T3"
          (1)(2)  (3)
30: OUTPUT717;"FR10EN"
                (4) (5)
40: OUTPUT717;"EX"
            (6)
50: ENTER717;A,B
60: DISPA,B
70: PRINTA,B
80: END
```

(1) Select code of 98034A.
(2) Address code of 4191A.
(3) Program codes of the 4191A (refer to Table 3-9).
(4) Program codes for parameter setting of the 4191A (refer to Table 3-10).
(5) Parameter terminator of the 4191A (refer to paragraph 3-73).
(6) This line means the same as following program:
    9825A: trg717
    9835A: TRIGGER717

By using string variables, complete output information from the 4191A is stored by the following programs:

9825A Program:

```
0: dimA$[50]
1: wrt717,"A1B1T3"
2: wrt717,"FR10EN"
3: wrt717,"EX"
4: red717,A$
5: dspA$
6: prtA$
7: end
```

9835A Program:

```
10: DIMA$[50]
20: OUTPUT717;"A1B1T3"
30: OUTPUT717;"FR10EN"
40: OUTPUT717;"EX"
50: ENTER717;A$
60: DISPA$
70: PRINTA$
80: END
```

Figure 3-23. Sample Program 1 using 9825A/9835A.

Sample Program 2

Description:
This program is a remote control and data output program in auto sweep measurement.

The program has three capabilities which are:

(1) Control of auto sweep measurement of the 4191A via HP-IB.
(2) Auto sweep of the 4191A via HP-IB.
(3) Data output from the 4191A via HP-IB.

9825A Program:

```
 0: dimA$[100,50]
           (1)
 1: wrt717,"A1B1T3"
 2: wrt717,"SF1ENTF1ENPF100EN"
 3: wrt717,"WU"
 4: 0→I
 5: I+1→I
 6: red717;A$[I]
 7: dspA$[I]
 8: prtA$[I]
 9: rds(717)→A
       (2)
10: if bit (4, A); gto5
         (3)
11: end
```

9835A Program:

```
 10: DIMA$(100)[50]
            (1)
 20: OUTPUT717;"A1B1T3"
 30: OUTPUT717;"SF1ENTF1ENPF100EN"
 40: OUTPUT717;"WU"
 50: I=0
 60: I=I+1
 70: ENTER717;A$(I)
 80: DISP A$(I)
 90: PRINT A$(I)
100: STATUS717;A
          (2)
110: IF BIT(A,4)THEN60
          (3)
120: END
```

(1) Establishes a dimensional array parameter that is greater than number of measurement points.
(2) Inputs 4191A SRQ Status Byte to variable A.
(3) When auto sweep being performed, bit 4 of variable A (bit 5 of SRQ Status Byte) is set to "1".

Figure 3-24. Sample Program 2 using 9825A/9835A.

SMITH CHART APPLICATIONS

The Smith Chart is a convenient artifice for facilitating rf vector impedance calculations which are sometimes needed to correct measured values for change of electrical length or other test parameters. This paragraph offers a brief outline of the Smith Chart for the users who are not familiar with its use:

Figure A shows the Smith Chart plane of impedance coordinates. On the Smith Chart plane, the coordinate scales signify the following impedance component quantities:

The circles tangent at point ⓐ are the scales for which resistance values are constant. The arcs which cross at point ⓐ along with intersecting the circles at right angles are the scales for which reactance values are constant.

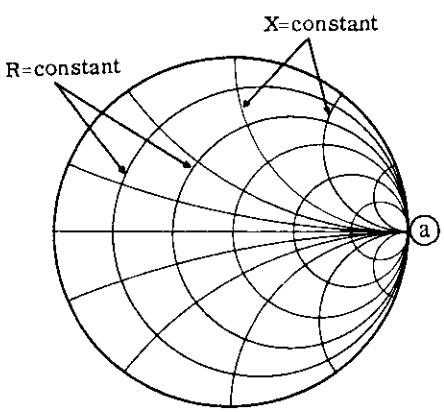


Figure A. Smith Chart.

These resistance and reactance scale values are the normalized values which are calculated by sample impedance (Zx = Rx + jXx) divided by the characteristic impedance (Zo = 50Ω) of the measuring circuit, that is:

$$\text{Normalized impedance } Rr + jXr = \frac{Zx}{Zo} = \frac{Rx}{50} + \frac{jXx}{50}$$

A sample impedance value is represented on the Smith Chart as a point coordinated with the scales corresponding to its normalized impedance (see figure B). The base impedance Zo (characteristic impedance) is located at the center of the Smith Chart plane. The radius vector $\overrightarrow{Zo \cdot Zr}$ represents the reflection coefficient value $|\Gamma| \angle\theta$ of the sample (in this case, the electrical length of the transmission line is not being taken into consideration). The phase angle scales for the reflection coefficient vector are provided along the outer circumference of the Smith Chart. The phase angle of the reflection coefficient can be read from the phase angle scale as indicated by an extension of the vector $\overrightarrow{Zo \cdot Zr}$. The absolute value of the reflection coefficient $|\Gamma|$ is constant at any point on the circle of the radius Zo Zr.

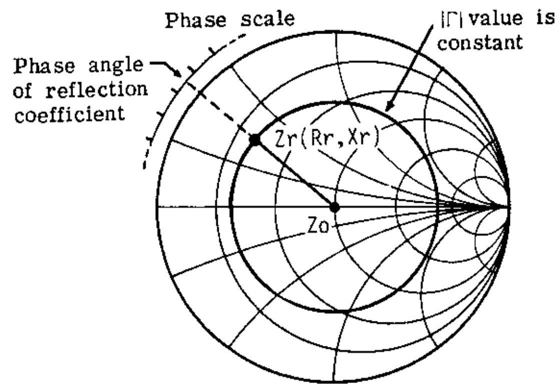


Figure B. Smith Chart.

When a parallel transmission line (coaxial line) of line length ℓ is terminated by the sample, the impedance value of the sample measured at the other end of the line is derived as follows:

First, the difference in phase angle of the reflection coefficient value Γ produced by the lead length ℓ is calculated using the following equation:

$$\theta = \frac{4\pi\ell}{\lambda} \quad (\lambda\text{: wave length of test signal})$$

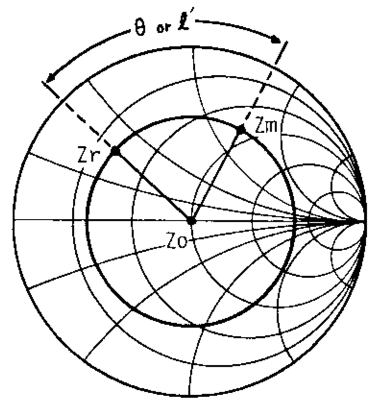


Figure C. Smith Chart.

Next, radius vector $Zo \cdot Zx$ is rotated clockwise (towards the generator) by the calculated phase angle θ. The measured impedance value (normalized impedance) coincides with the scale reading at point Zm. See Figure C.

Generally, a Smith Chart has wavelength scales for reading the phase difference in the ratio dimension of the line length to the wavelength. That is:

$$\ell' = \frac{2\ell}{\lambda}$$

The rotational angle may be measured as ℓ' on the wavelength scales instead of θ.

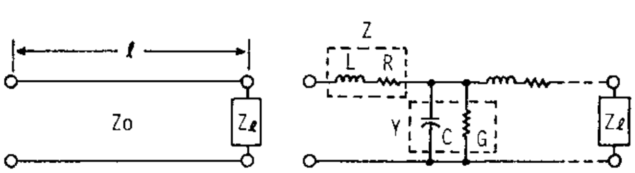
On the contrary, if a measured impedance value is Zm, the true impedance value of sample is found as Zr by rotating the radius vector $\overrightarrow{Zo \cdot Zm}$ counter-clockwise.

Notes:

1. *The above discussion assumes that the test signal propagation loss in the line is negligibly low. Actually, the propagation losses may be neglected when the measuring circuit length is short.*
2. *When the transmission line has a certain level of propagation loss, the radius vector of the measured reflection coefficient shortens by $1/e^{-2\alpha\ell}$ (α = attenuation coefficient of the line).*

TRANSMISSION LINE CHARACTERISTICS

When the test port is specially extended to gain access to the device tested, the extended measuring circuit should maintain the equality of the measuring circuit characteristic impedance. A discontinuity in characteristic impedance of measuring circuit, if not properly compensated, will cause differences between the measured values and true sample values. When a sample needs be measured together with the unknown cable connected to the sample or when the extension line used produces an impedance mismatch with the test port, how can the sample values be measured? In such cases, the actual sample values can be calculated from measured values if the charcteristics of the extra transmission line is ascertained. To discuss this problem, let's look at the characteristics of a transmission line.



L: distributed inductance per unit length.
R: distributed resistance per unit length.
C: stray capacitance per unit length.
G: stray conductance per unit length.

1) The above figure shows a lumped constant equivalent circuit model of a parallel or a coaxial transmission line. The characteristic impedance (Zo) of this line is represented by the following equation:

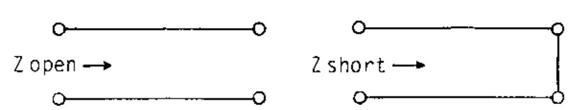
$$Zo = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where, R, L, G and C are the equivalent circuit elements of the distributed constants. Propagation constant (γ) of this line is given as:

$$\gamma = \sqrt{ZY} = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta$$

where, attenuation constant α and phase constant β represent the attenuation of the signal amplitude and the phase shift, respectively, per unit line length.

When the Zo and γ values of the transmission line are unknown, these constant values can be experimentally derived by measuring impedance as the line is terminated at open-circuit and short-circuit conditions:



$$Z_0 = \sqrt{Z_{open} \cdot Z_{short}}$$

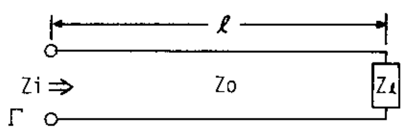
$$\gamma = \frac{1}{\ell} \tanh^{-1} \sqrt{\frac{Z_{short}}{Z_{open}}}$$

$$= \frac{1}{2\ell} \log \frac{Z_{open} + \sqrt{Z_{short} \cdot Z_{open}}}{Z_{open} - \sqrt{Z_{short} \cdot Z_{open}}}$$

$$Z = Z_0 \gamma$$

$$Y = \gamma / Z_0$$

2) When an impednace element Z_ℓ is connected to the tip of the line, the measured impedance value at the other end of the line is given by the following equation:



$$Z_i = Z_0 \frac{Z_\ell + Z_0 \tanh \gamma\ell}{Z_\ell \tanh \gamma\ell + Z_0}$$

Measured reflection coefficient is:

$$\Gamma = \Gamma_0 e^{-2\gamma\ell} \doteq \frac{Z_\ell - Z_0}{Z_\ell + Z_0} e^{-2\gamma\ell}$$

The sample impedance value is therefore calculated as:

$$Z_\ell = Z_0 \frac{Z_0 \tanh \gamma\ell - Z_i}{Z_i \tanh \gamma\ell - Z_0}$$

$$\text{or} \quad Z_\ell = Z_0 \frac{1 + \Gamma e^{-2\gamma\ell}}{1 - \Gamma e^{-2\gamma\ell}}$$

3) If the transmission line is ideal, — that is, it has no loss (R = 0, G = 0), the equations which represent the values for Z_0, γ, Z_i and Z_ℓ are simplified as follows:

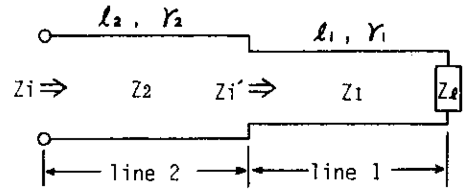
$$Z_0 = \sqrt{\frac{L}{C}}, \quad \gamma = j\omega\sqrt{LC} \quad (\alpha = 0,\ \beta = \omega\sqrt{LC})$$

$$Z_i = Z_0 \frac{Z_\ell + jZ_0 \tan \beta\ell}{Z_0 + jZ_\ell \tan \beta\ell}$$

$$Z_\ell = Z_0 \frac{Z_i - jZ_0 \tan \beta\ell}{Z_0 - jZ_i \tan \beta\ell}$$

$$\text{or} \quad Z_\ell = Z_0 \frac{1 + \Gamma e^{-2j\beta\ell}}{1 - \Gamma e^{-2j\beta\ell}}$$

4) With a cascade connection of different transmission lines as illustrated below, the impedance value of the sample can be calculated by using the given equations as follows:



$$Z_\ell = Z_1 \frac{Z_1 \tanh \gamma_1\ell_1 - Z_i'}{Z_i' \tanh \gamma_1\ell_1 - Z_1}$$

$$Z_i' = Z_2 \frac{Z_2 \tanh \gamma_2\ell_2 - Z_i}{Z_i \tanh \gamma_2\ell_2 - Z_2}$$

where, Z_i' is impedance value measured at the input of line 1 (Z_1, ℓ_1, γ_1).
Z_i is impedance value measured at the input of line 2 (Z_2, ℓ_2, γ_2).

As the above equations have the identical form of the equation terms, a programmed calculation can facilitate the procedure by repetitive use of the same basic equation.

Table 4-1. Recommended Test Equipment.

Equipment	Critical Specifications	Recommended Model	Use
Frequency Counter	Frequency: 1 GHz Sensitivity: −35dBm Accuracy : $\leq 1 \times 10^{-7}$	HP 5340A	P A
Attenuator	10dB to 1 GHz, 50Ω	HP 8491A	P A
Cable	N type connector cable	HP 11500B	P A
Cable	BNC to dual alligator clip cable		A
Terminal Converter	N type female to APC-7	HP 11524A	P A
Terminal Converter	SMC female to N type female	-hp- 1250 – 1153	A
RF Power Meter	Frequency: 1 GHz Sensitivity: −20 to 0dBm f.s. Accuracy : ±0.5dB	HP 436A	P A
Power Sensor	1μW min. to 1 GHz, 50Ω	HP 8482A	P A
Digital Multimeter	DC Voltage Range: 1mV to 100V Resistance Range : 100Ω f.s. min Voltage Accuracy : 0.01%	HP 3455A	P A T
Test Leads	Dual banana to alligator clip leads	HP 11002A	A T
Test cable	BNC to dual banana plug cable	HP 11001A	P
Terminal Convertor	APC-7 to BNC female		P
Spectrum Analyzer	Frequency Range: 1MHz to 1 GHz Resolution : 100 Hz Dynamic Range : > −90dB	HP 141T w/8554B w/8552B	P A
Oscilloscope	Bandwidth : 100MHz Sensitivity : 5mV min.	HP 1740A	A T
Probe	10MΩ, 10 : 1	HP 10006D	A T
DC Power Supply	Output Voltage: 0V to 20V Resolution : 0.01V	HP 6224B	A T
Thermometer	Temperature Range: 15°C to 30°C Accuracy : ±0.5°C	HP 2802A	A
Probe	Thermister Sensor	HP 18641A	A
Reference Terminations	0Ω 50Ω 0S (∞Ω) Coaxial Capacitor (318pF at 10MHz)	HP 16342A (Calibration Equipment Kit)	P A
Reference Air Line	20cm long (HP 11567A calibrated)		

Table 4-1. Recommended Test Equipment (cont'd).

Equipment	Critical Specifications	Recommended Model	Use
Calculator		HP 9825A w/98210A w/98216A	P
Interface Cable		HP 98034A	P
Logic Test Box	(Special electronic tool for troubleshooting digital control board using a signature analyzer)	HP 16341A	T
Signature Analyzer		HP 5004A	T
Extender Board	10 pin dual in-line 10 pin single in-line	-hp-04191-66560 -hp-04191-66561	A T
Printer	HP-IB capability	HP 2671A	P

P: Performance Test, A: Adjustment, T: Troubleshooting

SECTION IV
PERFORMANCE TESTS

4-1. INTRODUCTION

4-2. This section describes the tests and procedures used to verify the instrument specifications listed in Table 1-1. All tests can be performed without access to the interior of the instrument. A simpler, automatic operational test is presented in Section III under Self Test (papragraph 3-5). The performance tests described here can also be used when performing incoming inspection of the instrument and when verifying that the instrument meets specified performance after troubleshooting and/or adjustment. If the performance tests indicate that the instrument is operating outside specified limits, check that the controls on the instruments used in the test and the test set-up itself are correct and then proceed with adjustments and/or troubleshooting.

Note: To ensure proper test results and instrument operation, Hewlett-Packard suggests a 40 minute warm-up and stabilization period before performing any of the performance tests.

4-3. EQUIPMENT REQUIRED

4-4. Equipment required to perform all of the performance tests is listed in Table 4-1. Any equipment that satisfies or exceeds the critical specifications listed in the table may be used as a substitute for the recommend models. Accuracy checks described in this section use the HP Model 16342A Calibration Equipment Kit. The characteristics of the equipment in this kit satisfy the performance requirements for the accuracy checks and are especially suited for use as the 4191A's accuracy test standards.

Notes:

1. *Included in the 16342A is the 4191A Test Program Tape. This tape contains programs that, when used with the HP Model 9825A Desktop Computer, automatically perform the performance tests described here. For more information on the test programs, refer to the 4191A Test Program Tape User's Guide.*

2. *Components used as standards should be calibrated by an instrument whose accuracy is traceable to NBS or an equivalent standards group; or calibrated directly by an authorized calibration organization such as NBS. The calibration cycle should be in accordance with stability specifications of each component.*

4-5. TEST RECORD

4-6. Performance test results can be recorded on the Test Record at the completion of the test. The Test Record lists all the tested specifications and their acceptable limits. Test results recorded at incoming inspection can be used for comparison in periodic maintenance, troubleshooting, and after repairs or adjustments.

4-7. CALIBRATION CYCLE

4-8. This instrument requires periodic verification of performance. Depending on the conditions under which the instrument is used, e.g., environmental conditions or frequency of use, the instrument should be checked, with the performance tests described here, at least once a year. To keep instrument down-time to a minimum and to insure optimum operation, preventive maintenance should be performed at least twice a year.

ACCURACY TEST CONSIDERATIONS

GENERAL

Measurement accuracy of the 4191A is specified for the reflection coefficient which is the direct measurement parameter of the measuring circuit used. The accuracy of the other available measurement parameters are, if low order errors related to the significant digits in the parameter conversion calculations are disregarded, equivalent to the accuracy of the reflection coefficient parameter. The auto-calibration function of the 4191A implements error correction calculations for all measured reflection coefficients using calibration data obtained from measurements of three reference terminations, and reduces the errors to the level of inaccuracies inherent in those reference terminations. Consequently, if auto-calibration is performed in accordance with the programmed routine, errors inherent in the measurement circuit will have little or no effect on the resultant accuracy.

Theoretical background of the auto-calibration

The reflection coefficient vectors for the reference terminations are located on the axis corresponding to $\Gamma y = 0$ on the Smith Chart shown in Figure A. These vectors are:

$$0\Omega: \quad \Gamma x = -1, \ \Gamma y = 0 \quad (\Gamma = 1 \angle \pi)$$
$$0S: \quad \Gamma x = 1, \ \Gamma y = 0 \quad (\Gamma = 1 \angle 0)$$
$$50\Omega: \quad \Gamma x = 0, \ \Gamma y = 0 \quad (\Gamma = 0)$$

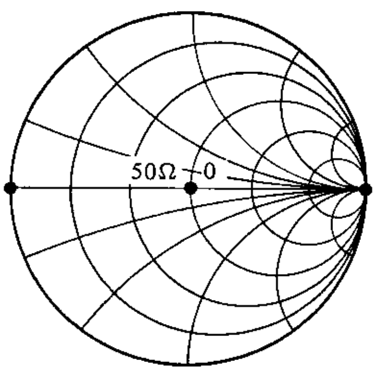


Figure A. Reference Termination Vectors.

During acquisition of calibration data, the reflection coefficients for these references are measured to verify the particular characteristics of the measurement circuit causing measurement errors. The measured Γ values provide the individual values of three dominant error factors, which are represented by the following equations:

$$\left.\begin{aligned} e_{00} &= \Gamma_{50} \\ e_{11} &= \frac{\Gamma_\infty + \Gamma_0}{\Gamma_\infty - \Gamma_0} \\ e_{01} &= (\Gamma_{50} - \Gamma_0)(1 + e_{11}) \end{aligned}\right\} \cdots\cdots (4\text{-}1)$$

where; e_{00} is the reflection crosstalk (directivity) error of the directional bridge measuring circuit.

e_{01} is the linear tracking error (full scale error).

e_{11} is the (unwanted) reflection port mismatch error.

Γ_0, Γ_∞ and Γ_{50} are measured Γ values for 0Ω, 0S and 50Ω reference terminations, respectively.

ACCURACY TEST CONSIDERATIONS

All the measured DUT values are corrected for the effects of these errors using the following calculation:

$$\Gamma_{true} = \frac{\Gamma_m - e_{00}}{e_{11}\,(\Gamma_m - e_{00}) + e_{01}} \quad \ldots\ldots \text{(4-2)}$$

where; Γ_{true} is the actual Γ value of the DUT.
Γ_m is the measured Γ value of the DUT.

Since e_{00}, e_{01} and e_{11} can be determined by making trial measurements of the desired three reflection coefficient points on Smith Chart, the three reference terminations used in auto-calibration are sufficient for obtaining the complete calibration data required for the correction calculations. Because the Γy values of the reference terminations are essentially zero, these terminations do not seem to offer the necessary reference vector(s) for taking correction data regarding Γy component vectors of the measured DUT's. Then, how does the auto-calibration make corrections on all the measured values as stated above? The answer is that, these dominant error factors are constant values irrespective of the reflection coefficient phase of the measured DUT. The errors related to the Γy components also deviate the measured values for the reference terminations from their nominal values and are included in the calibration data. Thus, error correction can be achieved on all measured vectors without additional reference.

The discussion that follows is related to the conditions that must be satisfied when performing an optimum calibration to maximize measurement accuracy. Figure B is a block diagram of the 4191A measurement section. A reflected vector signal from the DUT, which is represented by the directional bridge circuit, is phase-detected to separate its orthogonal phase (Γx and Γy) component from the signal. Inherent errors in the directional bridge, possible gain error and phase shift in the frequency converter and amplifier stages are included in the calibration data as equivalent factors. The auto-calibration minimizes these comprehensive errors in the measurement results. However, only the phase detection error is left uncorrected because it causes inaccuracy of the calibration data to occur. Accordingly, the phase detector must be operating at optimum detection accuracy. As the same phase detector circuit acts for both Γx and Γy vector components, the errors with respect to detection efficiency are equal for both and are eliminated from the measured values as a portion of the linear tracking error (e_{01}) by the auto-calibration function. Thus, the phase accuracy of the 0° and 90° detection phase signals eventually dominates the measurement accuracy.

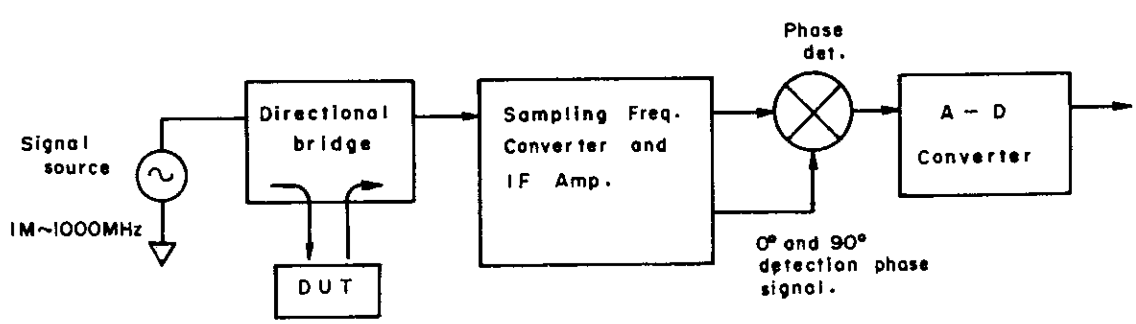


Figure B. 4191A Measurement Section.

ACCURACY TEST CONSIDERATIONS

Using a coaxial capacitor connected to the UNKNOWN connector, the detection phase signals are adjusted to be exactly 90 degrees out of the phase with each other. This special capacitive termination is included in the 16342A Calibration Equipment Kit. At the 10MHz test frequency, the 318 pF coaxial capacitor has a reflection coefficient equal to $\Gamma = 0 - j1$ (i.e. $Z = -j50\Omega$). Because of its structure and characteristics, the coaxial capacitor makes it easy to test the detection phase accuracy.

When performing auto-calibration over the entire frequency range, the measured vectors for the reference terminations will exhibit certain loci on the Smith Chart plane, as shown in Figure C. Deviations in magnitude of the measured vectors from the reference points represent basic errors, including various effects equivalent to internal losses in the measuring circuit (such as propagation losses, amplification and attenuation errors). On the other hand, those related to phase angle are electrical length (compensation) errors. If a measured reflection coefficient differs more than a certain extent from the reference termination value, calibration error increases. The individual vector loci should be within the ranges indicated by the shaded areas in Figure C.

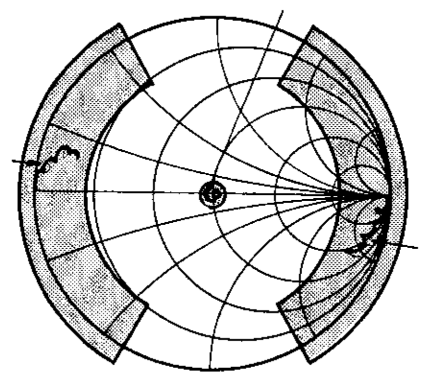


Figure C. Reflection Coefficient Loci of Calibration Data.

For further confirmation of the accuracy, the precision reference air line, included in the 16342A, permits tests that compare various reflection coefficient vectors with measured values. Instead of using several standard devices of ordinary design which cover only a narrow frequency range, a rotative vector developed by the air line provides a more practical means of testing over the entire 4191A measurement frequency range. When making a measurement with the reference air line connected to the UNKNOWN connector, the phase angle of the measured reflection coefficient is determined by the frequency and the electrical length of the air line. By sweeping the measurement frequency, the measured vector can turn around nearly 360 degrees on Smith Chart plane. For comparison, the inherent reflection coefficients of the air line at a total of 51 frequency points (identical to the 4191A calibration frequencies) are theoretically calculated from characteristic values. The requisite characteristic data for the calculation and the performance requirements of the reference air line are:

1) VSWR value (lower than 1.002).
2) Mechanical dimensions (accuracy higher than 0.2%).
3) Plating conditions on the surface (gold over silver plating).

ACCURACY TEST CONSIDERATIONS

The electrical length value is calculated from the mechanical dimensions and the propagation loss is determined by the quality of the plating. The theoretical calibration data of the air line is given in the test program cartridge tape furnished with the 16342A (HP-IB automatic test procedure). There is a close interrelation between the test with the coaxial capacitor and that with the air line. That is, an abnormality detected in either of the tests affects the result of the other test.

Accuracy test methods

Through the discussion for the basic theory of the auto-calibration, it is recognized that the measurement accuracy of the 4191A is assured by three different tests as listed below:

1) The test for verification of normal auto-calibration function, described in Para 4-15. Auto-calibration test.
2) The test for calibration data range, described in Para 4-17. Error correction function test.
3) The test for verification of phase detection accuracy, described in Para 4-19. Accuracy test.

REFERENCE TERMINATION ACCURACY

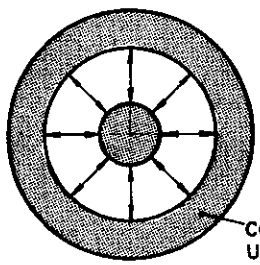
The accuracy of the 0Ω, 0S and 50Ω termination impedances of the three reference terminations determines the accuracy of the auto-calibration, and the measurement accuracy obtainable by using those terminations. To ensure the specified measurement accuracy of the 4191A, accurate termination impedances are achieved by precise design of the reference terminations using theoretical analysis for the actual termination impedances.

The theoretical background for the reliability of the reference terminations is outlined in the following paragraph.

0Ω Reference Termination:

The 0Ω Reference Termination (Part No. 04191-85300) has a gold plated, plane contact which short-circuits the test port to an accurate 0Ω impedance when connected to the UNKNOWN terminal of the 4191A. As the measurement signal current flows between the center and outer conductor of the terminal through the gold plated surface and across the contact plane of the 0Ω termination, the additive resistance to the 0Ω is extremely low. Moreover, the structure of the termination yields radial vectors of the measurement current flowing from the center towards the outer conductor (or the reverse direction), thus, there must be an opposite vector relating to an arbitrary current vector in the radial direction. Because the induced magnetic fluxes of the opposing current vectors cancel each other out, the sum of the integrated magnetic fluxes comes to nearly zero, and consequently, the residual inductance is also minimum. Accordingly, the 0Ω reference termination has 0Ω with a very low residual impedance (less than 2mΩ) at frequencies up to 1GHz. This residual impedance does not affect the values above the least significant digit of the measurement display output in the practical measurement ranges.

ACCURACY TEST CONSIDERATIONS



Radial vectors of the measurement signal current on the 0Ω termination surface.

50Ω Reference Termination:

The 50Ω Reference Termination (Part No. 04191-85301) has a non-reactive impedance of 50Ω with an accuracy of ±250mΩ over the entire measurement frequency range of the 4191A and is traceable to the National Bureau of Standards (NBS). The termination impedance of 50Ω is guaranteed to meet the specified accuracy $*|\Gamma| \leq 0.0025$ when shipped with the 4191A instrument from the factory. The accuracy of the 50Ω termination should be checked when performing the biannual calibration of the 4191A.

**Note: The accuracy of the 50Ω termination is specified for the reflection coefficient. This accuracy corresponds to 50 ± 0.25 Ω in impedance representation (not specified).*

0S Reference Termination:

When the 0S termination (Part No. 04191-85302) is connected to the UNKNOWN terminal, the stray conductance and the stray capacitance around the terminal are extremely low, thus the 0S termination realizes a termination admittance fairly close to 0S. As the considerable factor of the stray admittance, the fringe capacitance present between the center and outer conductors of the UNKNOWN terminal slightly turns the reflection coefficient vector from that of the true 0S. This fringe capacitance is theoretically calculated to be between 0.081 pF and 0.083 pF from the dimensions of the termination structure, and the most reliable value is 0.082 pF. To compensate the calibration data, obtained from the 0S Reference Termination, for the effect of the fringe capacitance, the value of 0.082 pF is continuously stored in the 4191A and is used in the calculation of the calibration data. When the actual fringe capacitance differs from the stored value, the error on the measured reflection coefficient phase angle is represented by the following equation:

$$\theta = 2 \tan^{-1} \frac{\pi \cdot f \cdot \Delta C_f}{10000}$$

where, θ is the phase angle.
f is the measurement frequency in MHz.
ΔC_f is the error of fringe capacitance in pF.

The ±0.001 pF error of the stored 0.082 pF causes a negligible error, less than 0.0006, in reflection coefficient measurements, even at 1GHz.

4-9. MEASUREMENT SIGNAL FREQUENCY ACCURACY TEST

4-10. This test verifies that measurement signal frequencies of the 4191A meet the specified frequency accuracy.

Frequency accuracy:
3 ppm at 23°C

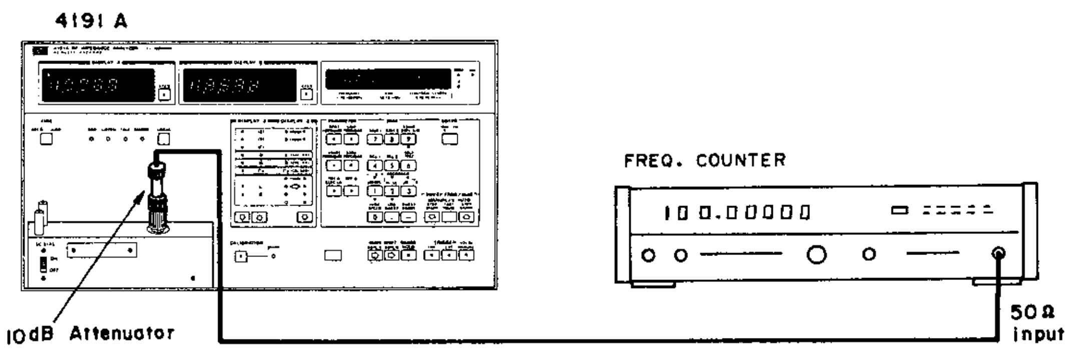


Figure 4-1. Measurement Frequency Accuracy Test Setup.

EQUIPMENT:

Frequency Counter	HP 5340A
10dB Attenuator	HP 8491A
Test Cable	N type connector cable
Terminal Converter	N type female to APC-7 connector (HP 11524A)

PROCEDURE:

1. Connect the 10dB attenuator and the connection cable between the frequency counter input and the 4191A UNKNOWN connector as illustrated in Figure 4-1.
2. Set 4191A SPOT frequency to 100MHz.
3. Set frequency counter display resolution to 10Hz.
4. Frequency counter display readout should be between 99.99970MHz and 100.00030MHz.
5. Set 4191A SPOT frequency in accordance with Table 4-2. Frequency counter readouts should satisfy the test limits listed in Table 4-2 at all test frequency settings.

Note: For units with option 002 (high resolution test frequency), also check at the frequencies listed in Table 4-3.

PERFORMANCE TESTS

Table 4-2. Frequency Accuracy Test Limits.

SPOT Freq.	Test limits	SPOT Freq.	Test limits
1.0MHz	± 20Hz	405.0MHz	±1200Hz
32.0	± 80Hz	405.1	±1200Hz
32.1	± 80Hz	450.0	±1340Hz
33.0	± 90Hz	450.1	±1340Hz
62.5	± 170Hz	500.0	±1490Hz
62.6	± 170Hz	500.2	±1490Hz
125.0	± 360Hz	528.0	±1570Hz
125.1	± 360Hz	528.2	±1570Hz
250.0	± 740Hz	556.0	±1650Hz
250.1	± 740Hz	556.2	±1650Hz
264.0	± 780Hz	588.0	±1750Hz
264.1	± 780Hz	588.2	±1750Hz
278.0	± 820Hz	630.0	±1880Hz
278.1	± 820Hz	630.2	±1880Hz
294.0	± 870Hz	680.0	±2030Hz
294.1	± 870Hz	680.2	±2030Hz
315.0	± 930Hz	744.0	±2220Hz
315.1	± 930Hz	744.2	±2220Hz
340.0	±1010Hz	810.0	±2420Hz
340.1	±1010Hz	810.2	±2420Hz
372.0	±1100Hz	900.0	±2690Hz
372.1	±1100Hz	900.2	±2690Hz
		1000.0	±2990Hz

Table 4-3. Additional Tests for Option 002.

SPOT Freq.	Test limits	SPOT Freq.	Test limits
10.0111MHz	± 20Hz	360.0666MHz	±1070Hz
100.0111	±290Hz	400.0777	±1190Hz
251.0000	±740Hz	440.0123	±1310Hz
270.0111	±800Hz	500.0000	±1490Hz
300.0999	±890Hz	800.0222	±2390Hz
330.0333	±980Hz		

4-11. MEASUREMENT SIGNAL LEVEL TEST

4-12. This test verifies that the measurement signal level at the 4191A UNKNOWN connector meets the specified value range at all measurement frequency settings.

Signal Level: -20 ± 3 dBm

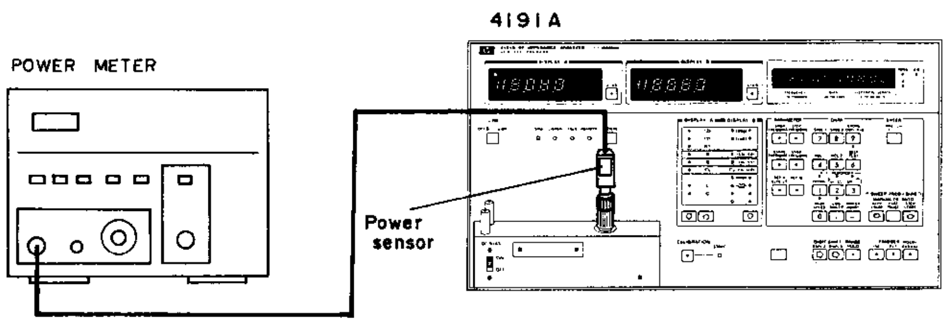


Figure 4-2. Measurement Signal Level Test Setup.

EQUIPMENT:

Power Meter .... HP 436A
Power Sensor .... HP 8482A

PROCEDURE:

1. Connect the power sensor between the 4191A UNKNOWN connector and RF power meter input as illustrated in Figure 4-2.
2. Set power meter controls to measure a power level of approximately -20dBm at 100MHz.
3. Set 4191A SPOT frequency to frequencies from 1MHz to 1000MHz in 50MHz increments (1, 50, 100, ...900, 950 and 1000MHz). Verify that the power meter display readout is within -20 ±3dBm at each SPOT frequency setting.

Notes: 1. Adjust power meter CAL FACTOR dial control for the calibration factor value plotted on the power sensor.
2. To set the SPOT frequency easier, set the STEP frequency to 50MHz and use the manual frequency sweep function.

4-13. MEASUREMENT SIGNAL PURITY TEST

4-14. This test verifies that the harmonics and any spurious signals included in the measurement signal are lower than the level given in the supplemental performance characteristics of the 4191A.

Supplemental performance characteristic data:

Harmonics : <-30dB below fundamental

Spurious Level: <-30dB below fundamental

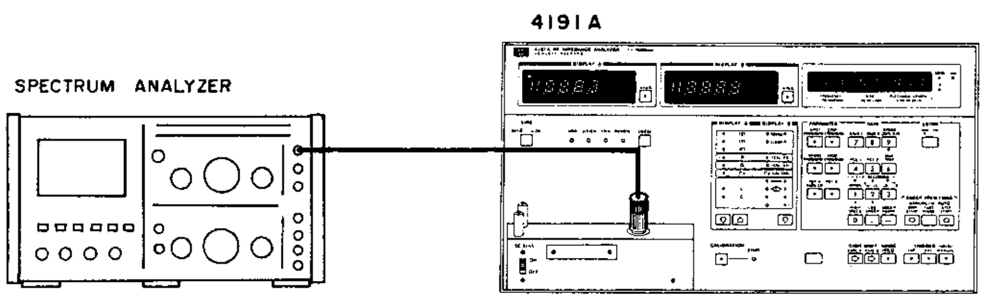


Figure 4-3. Measurement Signal Purity Test Setup.

EQUIPMENT:

Spectrum Analyzer	HP 141T w/ 8554B w/ 8552B
Test Cable	N type connector cable
Terminal Converter	N type female to APC-7 connector (HP 11524A)

PROCEDURE:

1. Connect an N type connector cable to the 4191A UNKNOWN connector and to the spectrum analyzer input as illustrated in Figure 4-3 (Use an APC-7 to N type terminal converter).

2. Set the spectrum analyzer controls as follows:

Center frequency	500MHz
Bandwidth	300kHz
Scan width	100MHz
Input attenuation	0dB
Scan time	10 msec
Log ref level	0dBm
Display scale	10dB LOG
Scan trigger	AUTO

3. Set 4191A controls as follows:
   - START frequency 1MHz
   - STOP frequency 1000MHz
   - STEP frequency 5MHz
4. Start auto frequency sweep from 1MHz (press [blue] key and SWEEP FREQ/BIAS [⇧] key).
5. The second and the third harmonic signal levels should be less than −30dB from the fundamental (at each sweep frequency point) on the spectrum analyzer CRT.

   Notes: 1. Check for low order (1/2 and 3/2) harmonic signals at frequency points above 500MHz (instead of the second and the third harmonics).
   2. Verify that the magnitude of the fundamental is greater than −23dBm at all frequencies.
6. Restart auto frequency sweep. Spurious signals should be less than −30dB from the fundamental on the CRT.

4-15. AUTO CALIBRATION TEST

4-16. This test verifies that the electrical length compensator is appropriately adjusted to optimize measurement accuracy.

EQUIPMENT:

Printer .... HP 2671A

Reference Terminations

0Ω	HP 16342A Calibration Equipment Kit
0S	
50Ω	

Note: The accessory reference terminations (0Ω: 04191-85300, 0S: 04191-85302, 50Ω: 04191-85301) supplied with the instrument may be used instead of the 16342A.

PROCEDURE:

1. Connect the 0Ω reference termination to the 4191A's UNKNOWN connector. And, connect an HP-IB cable between the Printer and the HP-IB connector on the rear panel. Set the TALKER bit of the ADDRESS switch to on.
2. Set 4191A controls as follows :

   START FREQ 1MHz
   STOP FREQ 1000MHz
3. Press the CALIBRATION key (key indicator lamp lights).
4. Press the CALIBRATION-START button.
5. Monitor calibration data (measured Γ_x and Γ_y values) printed out for individual calibration frequencies. The print outputs should be within the test limits given in Figure 4-4.
6. Perform auto-calibration again using the 0S and 50Ω reference terminations. Verify that the print outputs are within the test limits for the respective termination (in Figure 4-4).

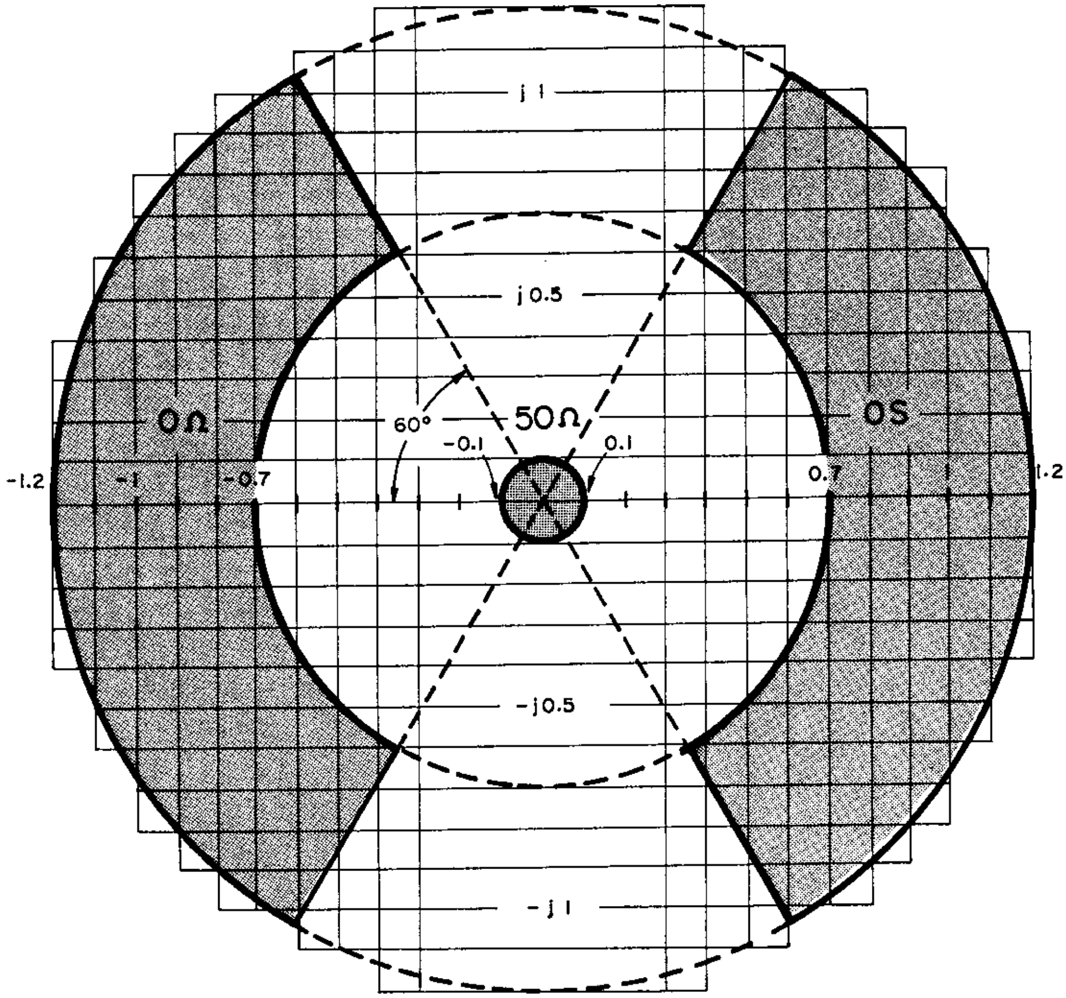


Figure 4-4. Calibration Data Test Limits.

Note: Calibration Data Test Limits graphically shown in Figure 4-4 are given below in equation form.

0Ω: Γx is negative and $|\Gamma y/\Gamma x| \leq \sqrt{3}$ and $0.7 \leq \sqrt{\Gamma x^2 + \Gamma y^2} \leq 1.2$

0Ω: Γx is positive and $|\Gamma y/\Gamma x| \leq \sqrt{3}$ and $0.7 \leq \sqrt{\Gamma x^2 + \Gamma y^2} \leq 1.2$

50Ω: $\sqrt{\Gamma x^2 + \Gamma y^2} \leq 0.1$

4-17. ERROR CORRECTION FUNCTION TEST

4-18. This test confirms the functions of the auto-calibration test including calibration data acquisition, memory and correction calculations for unartificial measurement data.

Note: It is recommended that the auto-calibration test described in Para. 4-16 be performed before this test.

EQUIPMENT:

0Ω reference termination: (Use the same termination that was used in Auto-Calibration).

PROCEDURE:

1. Connect the 0Ω reference termination to the 4191A UNKNOWN connector.
2. Set 4191A controls as follows:
   DISPLAY A and B parameters .... Γx - Γy
   START FREQ 1MHz
   STOP FREQ 1000MHz
   STEP FREQ *20MHz

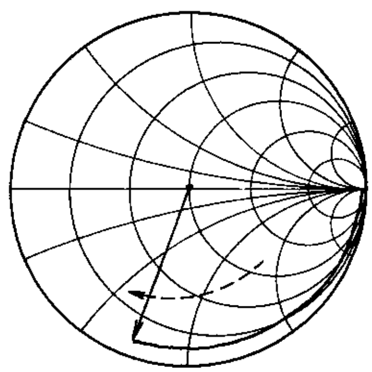
   **Note: For units with option 002, set the STEP frequency to 19.98MHz.*
3. Start the auto frequency sweep measurement from the programmed START frequency (1MHz). Monitor the measurement display values on DISPLAY A and DISPLAY B.
4. The display outputs should be within the test limits given below:
   DISPLAY A (Γx values) : -1.0000 ±10 counts.
   DISPLAY B (Γy values) : 0.0000 ±10 counts.

   Note: If this test fails, recalibrate the instrument and re-run this test.

4-19. ACCURACY TEST

4-20. This test measures a precision air line at various frequencies and compares the measured values with the calibrated values of the air line to verify that the 4191A meets its specified accuracy.

Note: This test also confirms the measurement accuracy of the reflection coefficient vectors which are out of phase with the reference termination vectors (in auto-calibration). Accuracy equivalent to that of the reference termination vectors is established for any phase vector if an accurate vector phase detection is achieved. This can be assured by measuring a precision air line that causes the measured reflection coefficient vector to turn 360 degrees as the measurement frequency increases.



The reflection coefficient vector of the air line develops its locus along the circumference of the Smith Chart as the measurement frequency increases, and allows testing accuracy for all the vectors.

EQUIPMENT:

Reference Air Line	....	HP 16342A
Terminations: 0S	....	Calibration
0Ω	....	Equipment Kit.

PROCEDURE:

Note: The test program tape included in the 16342A Calibration Equipment Kit automatically performs the data acquisition, comparison, printouts and plotting involved in the accuracy test procedure. For details on the use of the test program, refer to the Test Program User's Guide included in the Kit. This paragraph provides an outline of the test procedure.

1. If the memorized calibration data is not useable in the 1MHz to 1000MHz frequency range, perform auto-calibration for the full frequency range.
2. Connect the calibrated air line (20cm long) to 4191A UNKNOWN connector.
   Caution: Do not touch the precision contact surface of the air line.
3. Connect the 0S reference termination to the tip of the air line.

4. Set 4191A DISPLAY A and DISPLAY B parameters as follows:
   DISPLAY A .... |Γ|
   DISPLAY B .... θ (rad)

5. Measure the open ended air line at frequencies identical to the auto-calibration frequencies. Note DISPLAY A and DISPLAY B readouts (|Γ| - θ values).

6. Connect the 0Ω reference termination in place of the 0S termination.

7. Measure the short ended air line at the auto-calibration frequencies. Note DISPLAY A and DISPLAY B readouts.

8. Compare the measurement data obtained in steps 5 and 7 with the calibration data of the air line. The difference between measured values and the calibrated values should be within the test limits given in Table 4-5.

Table 4-5. Accuracy Test Limits.

Parameter	Test limits
|Γ|	C.V. ± (70 + 0.05f) counts
θ (rad)	C.V. ± (70 + 0.05f) counts

C.V. = Calibrated value of the air line
f = Test frequency in MHz

Note: The difference between the reflection coefficients measured at adjacent calibration frequencies should not be more than ±20counts.

4-21. DC BIAS VOLTAGE ACCURACY TEST

4-22. This test verifies that the internal dc bias voltages of the 4191A meet the specified voltage accuracy.

Bias voltage accuracy: ± (0.1% of setting + 10mV)

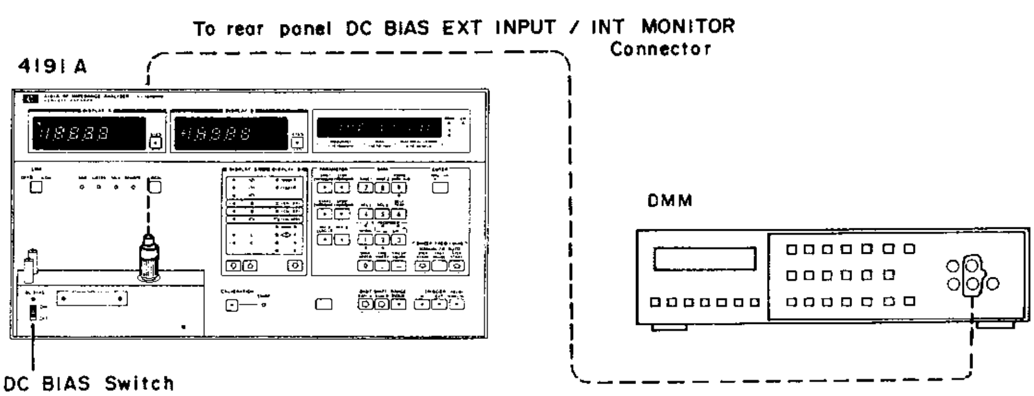


Figure 4-5. Internal Bias Voltage Accuracy Test Setup.

EQUIPMENT:

Digital Multimeter .... HP 3455A
Test Cable .... BNC to dual banana plug cable
Terminal Converter .... BNC to APC-7 connector

PROCEDURE:

1. Connect the BNC to dual banana plug cable to the DC BIAS EXT INPUT/INT MONITOR connector on the 4191A rear panel and to DMM input. See Figure 4-5.
2. Set the DC BIAS INT EXT switch on the rear panel to the INT position.
3. Set the DC BIAS switch on the UNKNOWN terminal deck to the ON position. Connect nothing to the UNKNOWN connector.
4. Set 4191A SPOT BIAS voltage in accordance with Table 4-6. DMM display readouts should be within the test limits given in the table.

Table 4-6. DC Bias Voltage Accuracy Test Limits

Voltage setting	Test limits	Voltage setting	Test limits
0.01V	0.00V min ~ 0.02V max	- 0.01V	0.00V min ~ - 0.02V max
0.03V	0.02V ~ 0.04V	- 0.03V	- 0.02V ~ - 0.04V
0.07V	0.06V ~ 0.08V	- 0.07V	- 0.06V ~ - 0.08V
0.15V	0.14V ~ 0.16V	- 0.15V	- 0.14V ~ - 0.16V
0.31V	0.30V ~ 0.32V	- 0.31V	- 0.30V ~ - 0.32V
0.63V	0.62V ~ 0.64V	- 0.63V	- 0.62V ~ - 0.64V
1.27V	1.26V ~ 1.28V	- 1.27V	- 1.26V ~ - 1.28V
2.55V	2.538V ~ 2.562V	- 2.55V	-2.538V ~ - 2.562V
5.11V	5.095V ~ 5.125V	- 5.11V	-5.095 V ~ - 5.125V
10.23V	10.21V ~ 10.25V	-10.23V	-10.21V ~ -10.25V
20.47V	20.44V ~ 20.50V	-20.47V	-20.44V ~ -20.50V
40.00V	39.95V ~ 40.05V	-40.00V	-39.95V ~ -40.05V

Confirmation check

This check verifies that correct dc bias voltage is applied to the UNKNOWN terminal.

1. Using an APC-7 to BNC terminal converter, connect the DMM input cable to the UNKNOWN connector.
2. Set SPOT BIAS votage in accordance with the table below and verify that the DMM display readouts meet the test limits given in the table.

Voltage setting	Test limits
40.00V	39.95V min ~ 40.05V max
-40.00V	-39.95V min ~ -40.05V max
0.00V	-0.01V ~ 0.01V

4-23. BATTERY MEMORY BACK-UP FUNCTION TEST

4-24. This test verifies that the front panel control settings, memorized by the SAVE function, can be continuously preserved by the internal stand-by battery if instrument power is lost.

EQUIPMENT:

No test equipment is required.

PROCEDURE:

1. Set 4191A controls as follows:
   DISPLAY A/B parameters .... Γx - Γy
   SPOT FREQ 100MHz
   STEP FREQ 20MHz
   HIGH SPEED .... on
2. Press [blue] key and STORE DSPL A/B key (to enter the displayed numbers as reference values).
3. Press DISPLAY A Δ/Δ% and DISPLAY B Δ/Δ% keys.
4. Press blue key and SAVE 1 key (to memorize these control settings).
5. Turn the instrument off, wait a few second and turn it back on. Repeat this procedure 5 times.
6. Press any key. An E-07 error message will occur. Press another key to cause the instrument to skip the programmed 10 minutes initial warm-up time. The 4191A will go into its automatic initial control settings.
7. Press [blue] key and RCL 1 key. Verify that the control settings memorized in step 4 are restored as the actual control settings.

4-25. ANALOG RECORDER OUTPUT TEST (OPT. 004)

4-26. This test verifies that the analog recorder output voltages, available with option 004, are proportional to the measurement display values with a specified voltage accuracy.

Output voltage accuracy: ± (0.5% + 2mV)

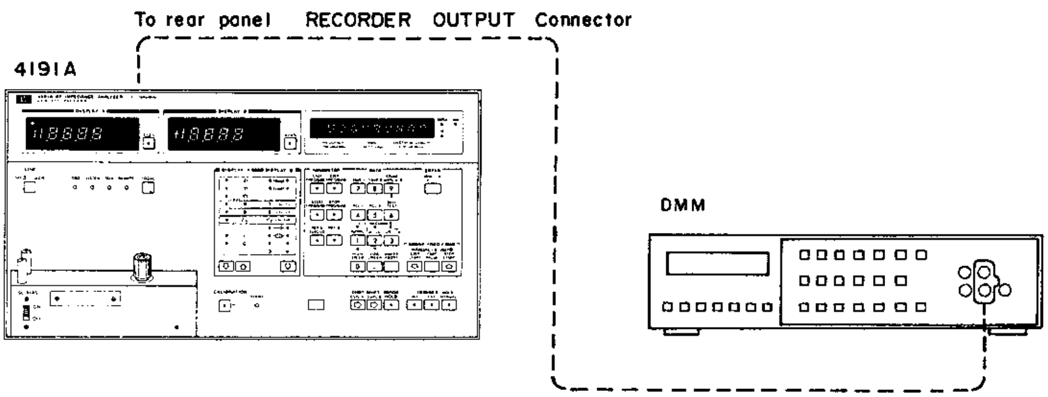


Figure 4-6. Recorder Output Voltage Accuracy Test Setup.

EQUIPMENT:

Digital Multimeter .... HP 3455A
Test Cable .... BNC to dual banana plug cable

PROCEDURE:

1. Press [blue] key and ↓←LL key on the 4191A front panel.
2. Connect the BNC to dual banana plug cable between RECORDER OUTPUTS DISPLAY A connector on the rear panel and DMM input. See Figure 4-6.
3. DMM readout should be within 0V ± 2mV dc.
4. Connect DMM input cable to RECORDER OUTPUTS DISPLAY B and FREQ/BIAS connector. DMM readout should satisfy the test limits given in Table 4-7.
5. Press [blue] key and UR→↑ key.
6. Measure dc voltages at RECORDER OUTPUTS connectors as in steps 2, 3 and 4. DMM readout should satisfy the test limits given in Table 4-7.

7. Set 4191A controls as follows:
   DISPLAY A/B function .... Γx - Γy
   TRIGGER .... HOLD/MANUAL
   RANGE HOLD .... on
   START FREQ 1.0MHz
   STOP FREQ 1000.0MHz
   SPOT FREQ 99.9MHz
8. Read DISPLAY A output as X and DISPLAY B output as Y.
9. Calculate X-0.0100 as $0.x_1 x_2 x_3 x_4$ and Y-0.0100 as $0.y_1 y_2 y_3 y_4$ value.
10. Enter the calculated numbers as the reference input numbers for REF A and REF B functions:

    Keystrokes : [REF A / ELEC LG: 0] [.] [x_1] [x_2] [x_3] [x_4] [MHz cm V]

    [REF B: 0] [.] [y_1] [y_2] [y_3] [y_4] [MHz cm V]
11. Press DISPLAY A Δ/Δ% and DISPLAY B Δ/Δ% keys. DISPLAY A and DISPLAY B readouts will change to .0100.
12. Measure the dc voltage at RECORDER OUTPUTS connectors. DMM display outputs should satisfy the test limits given in Table 4-7.
13. Press DISPLAY A Δ/Δ% and DISPLAY B Δ/Δ% keys to release these functions. Calculate X + 0.0100 and Y + 0.0100. Enter the calculated numbers as the reference input numbers using the procedures described in steps 8, 9 and 10.
14. Press DISPLAY A Δ/Δ% and DISPLAY B Δ/Δ% keys. DISPLAY A and DISPLAY B readouts will change to −.0100.
15. Measure the dc voltage at the DISPLAY A and DISPLAY B connectors. DMM readouts should be within −100mV ± 2mV for both connector outputs.

Table 4-7. Analog Recorder Output Test Limits.

Control setting	Output voltage test limits		
	DISPLAY A	DISPLAY B	FREQ/BIAS
↓← LL	0 ± 2mV	0 ± 2mV	0 ± 2mV
UR →↑	1000mV ± 7mV	1000mV ± 7mV	1000mV ± 7mV
DISPLAY A : 100 counts DISPLAY B : 100 counts SPOT FREQ : 99.9MHz	100mV ± 2mV	100mV ± 2mV	100mV ± 2mV

4-27. HP-IB INTERFACE TEST

4-28. This test verifies that the 4191A can be remotely controlled and can transfer measurement data to/from an external device via the HP-IB. The following HP-IB handshake functions for intercommunication with an HP-IB controller (desktop computer) are tested.

1) Talk only/Addressable modes.
2) Listener.
3) Talker.
4) Remote/Local capability.
5) Interface clear.
6) Device clear.
7) Device trigger.
8) EOI (End Or Identify).
9) Service request.

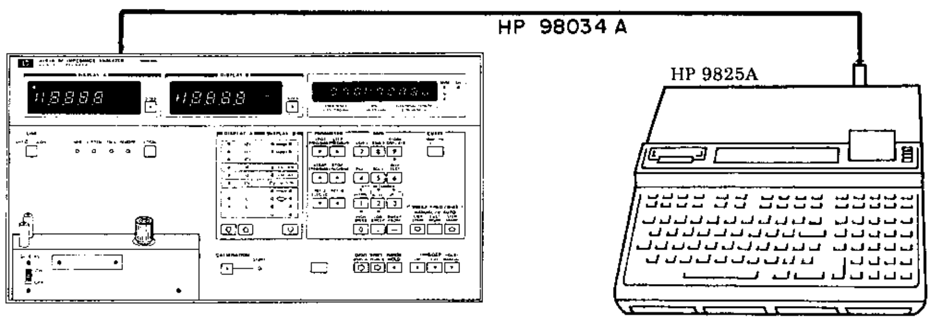


Figure 4-7. HP-IB Interface Test Setup.

EQUIPMENT:

Desktop Computer .... HP 9825A
w/98210A
w/98216A

Interface Cable .... HP 98034A

PROCEDURE:

1. Connect HP 98034A HP-IB Interface to the HP 9825A Desktop Computer, equipped with I/O ROM's 98210A/98216A, and to the HP-IB connector on the rear panel of the 4191A.
2. Load the test program listed in Figure 4-8 into the 9825A and run the program.
3. Set 4191A controls and follow the instructions displayed on the 9825A SLD in accordance with Table 4-8 and proceed with the programmed test routines.
4. Verify that "HP-IB TEST COMPLETED" is displayed on the 9825A SLD at test end.

Note: The data output and remote control functions are not tested for all the available functions in the above test procedure.

5. Try the sample programs given in Figures 3-23 and 3-24 of Section III. Compare the output data with the specified data format and measured DUT values.

```
0: "***** 4191A HP-IB CHECK PROGRAM ***** ":
1: dim A$[50],B$[50],D$[32],E$[32]
2: spc ;prt "#10..HPIB TEST..";spc
3: 0}U}V}E;cmpU}U
4: "4191A HP-IB CHECK PROGRAM"}E$;gsb "SLOWDSP"
5: "DIO LINE CHECK"}E$;gsb "SLOWDSP"
6: dsp "SET MEAS,Z,DEG,INT";stp
7: dsp "SET  ADDRESS SW TO TALK ONLY";stp
8: 0}E
9: time 2000;on err "ERR"
10: 0}E
11: rds(7,J,J,R)}J
12: if bit(7,R);gsb "EOIF3"
13: if E;stp ;gto 5
14: dsp "DIO LINE CHECK"
15: for I=1 to 50
16: gsb "GETDIO"
17: next I
18: gsb "TRNS"
19: if D$[1,15]="H X X X X X X X";gto "PASS"
20: gsb "PRTDIO"
21: stp ;gto 3
22: "PASS":dsp "      *** PASS ***";wait 500;gto "L3"
23:
24: "GETDIO":rdb(700)}R
25: band(R,U)}U;ior(R,V)}V;ret
26: "ERR":prt E$,"HANDSHAKE ERROR"
27: prt " ";prt " ";stp ;end
28: "PRTDIO":
29: prt "** DIO LINES **"
30: prt "8-7-6-5-4-3-2-1"
31: prt D$[1,15]
32: prt " ";prt " ";ret
33: "TRNS":
34: eor(U,V)}U
35: "X X X X X X X X"}D$[1,15]
36: for I=0 to 7
37: 15-2*I}K


38: if bit(I,U)=1;gto 41
39: "H"}D$[K,K]
40: if bit(I,R);"L"}D$[K,K]
41: next I
42: ret
43: end
44: "L3":
45: 0}U}V;cmpU}U
46: cli 7
47: lcl 7
48: rem 7
49: dsp "SET ADDRESS SW to ADDRESSABLE";stp
50:
51: 17}Y;700+Y}Y
52: "LISTENER CHECK"}E$;gsb "SLOWDSP"
53: dsp " LISTEN,REMOTE,C,D,INT on ?";wrt Y,"C0T1A8B3"
54: stp
55: 0}E;rds(7,K,L,M)}N;if bit(7,M)=1;gsb "EOIF3"
56: if E=1;gto 52
57: "TALKER CHECK"}E$;gsb "SLOWDSP"
58: dsp "TALK on & REMOTE off ?";lcl 7;red Y,A,B;stp
59: "IFC LINE CHECK"}E$;gsb "SLOWDSP";cli 7
```

Figure 4-8. HP-IB Interface Test Program (sheet 1 of 2).

```
60: dsp "TALK off ?";stp
61: "DEVICE CLEAR CHECK (AUTO)"→E$;0→E;gsb "SLOWDSP"
62: clr Y
63:
64: "TENT":wrt Y,"T1"
65:
66: red Y,A$;gsb "DELSP"
67: if A$[2,2]="Z" and A$[17,17]="D";dsp "      *** PASS ***";wait 300;gto 70
68: prt "DEVICE CLEAR"
69: prt "FAIL:",A$;stp ;gto 61
70: "TRIGGER CHECK (AUTO)"→E$;gsb "SLOWDSP"
71: wrt Y,"A8B3T3";trg Y
72: red Y,A$
73: gsb "DELSP"
74: if A$[2,2]="C" and A$[17,17]="D";dsp "     *** PASS ***";wait 300;gto "L1"
75: prt "TRIGGER CHECK";prt "FAIL:",A$
76: "L1":
77: "EOI CHECK (AUTO)"→E$;gsb "SLOWDSP"
78: 0→E
79: wrt Y,"T1"
80: if rdb(Y)#13;jmp 0
81: if bit(0,rds(7,M,M,M)→P)=1;gsb "EOIF1"
82: if E=1;stp ;gto 77
83: if rdb(Y)#10;jmp 0
84: if bit(0,rds(7,M,M,M)→Q)=0;gsb "EOIF2"
85: if E=1;stp ;gto 77
86: dsp "          *** PASS ***";wait 300
87: "L2":
88: "SRQ LINE CHECK (AUTO)"→E$;gsb "SLOWDSP"
89: 0→E
90:
91: clr Y
92: gsb "GETBUS"
93: if bit(5,R)=1;gsb "SRQF1"
94: if E=1;stp ;gto 88
95: wrt Y,"illegal code"
96: gsb "GETBUS"
97: if bit(5,R)=0;gsb "SRQF2"
98: if E=1;stp ;gto 88
99: dsp "     *** PASS ***";wait 300
100: prt " .....PASS.....";spc
101: dsp "* 4191A HP-IB TEST COMPLETED *";beep;stp
102: gto 3
103: "EOIF1":prt "FAIL:EOI LOW FOR [CR]";1→E;ret
104: "EOIF2":prt "FAIL:EOI HIGH FOR [LF]";1→E;ret
105: "EOIF3":prt "FAIL:EOI LINE LOW";1→E;ret
106: "SRQF1":prt "FAIL:SRQ LINE LOW";1→E;ret
107: "SRQF2":prt "FAIL:SRQ LINE HIGH";1→E;ret
108: "SLOWDSP":""→D$;len(E$)→W;for W=1 to len(E$);E$[W,W]→D$[W,W];dsp D$
109: wait 30;next W;wait 600;ret
110: "GETBUS":rds(7,P,Q,R)→S
111: band(R,U)→U;ior(R,V)→V;ret
112: "DELSP":
113: if A$[1,1]=" ";for U=1 to 32;A$[U+1,U+1]→A$[U,U];next U;jmp 0
114: ret
115: "TRNS":
116: eor(U,V)→U
117: "X X X X X X X X"→D$[1,15]
118: for I=0 to 7
119: 15-2*I→K
120: if bit(I,U)=1;gto 101
121: "0"→D$[K,K]



122: if bit(I,R);"1"→D$[K,K]
123: next I
124: prt D$[1,15];ret
125: "#10":end
*776
```

Figure 4-8. HP-IB Interface Test Program (sheet 2 of 2).

Table 4-8. HP-IB Interface Test Procedure.

Step	Controller instruction (display)	Required operation
1	4191A HP-IB CHECK PROGRAM	(See note)
2	DIO LINE CHECK	
3	SET MEAS, [Z], DEG, INT	Set the 4191A controls as follows: DISPLAY A . . . . |Z| DISPLAY B . . . . ∠θ (deg) Trigger . . . . INT Press (CONTINUE).
4	SET ADDRESS SW TO TALK ONLY	Set HP-IB address switch on the 4191A rear panel to TALK ONLY mode.  TALK ONLY (Set this switch to up position) Verify that the TALK lamp on the front panel is lit. Press (CONTINUE).
5	*** PASS ***	
6	SET ADDRESS SW TO ADDRESSABLE	Reset HP-IB address switch on the 4191A rear panel to ADDRESSABLE mode (set the switch to down position). *Note: TALK lamp may be extinguished.* Press (CONTINUE).
7	LISTENER CHECK	
8	LISTEN, REMOTE; C, D, INT on?	Verify that the following indicator lamps on the 4191A front panel are lit. 1) LISTEN 2) REMOTE 3) DISPLAY A parameter "C" 4) DISPLAY B parameter "D" 5) INT TRIGGER *Note: SRQ lamp may light.* Press (CONTINUE). If any of these lamps are not lit, troubleshoot the instrument.
9	TALKER CHECK	
10	TALK on & REMOTE off?	Verify that the REMOTE lamp is extinguished and that the TALK lamp is lit. Press (CONTINUE). If otherwise, troubleshoot the instrument.
11	IFC LINE CHECK	

Table 4-8. HP-IB Interface Test Procedure (continued)

Step	Controller instruction (display)	Required operation
12	TALK off?	Verify that the TALK lamp is extinguished. Press (CONTINUE). If otherwise, troubleshoot the instrument.
13	DEVICE CLEAR CHECK (AUTO)	*Note: The remaining tests are performed automatically. No manual operation is required for the subsequent tests.*
14	*** PASS ***	
15	TRIGGER CHECK (AUTO)	
16	*** PASS ***	
17	EOI CHECK (AUTO)	
18	*** PASS ***	
19	SRQ LINE CHECK (AUTO)	
20	*** PASS ***	
21	*4191A HP-IB TEST COMPLETED*	*Note: The 9825A will simultaneously print out the message: "#10 HP-IB . . . . . PASS".*

Note: Messages in steps 1, 2, 7, 9, 11, 13, 15, 17 and 19 appear on the 9825A SLD from right to left.

PERFORMANCE TEST RECORD

Hewlett-Packard
Model 4191A
RF Impedance Analyzer
Serial No. ____________

Tested by ____________
Date ____________

Paragraph Number	Test	Minimum	Results Actual	Maximum
4-10	MEASUREMENT SIGNAL FREQUENCY ACCURACY TEST			
	Frequency setting:			
	1.0MHz	0.99998MHz	______	1.00002MHz
	32.1MHz	32.09992MHz	______	32.10008MHz
	33.0MHz	32.99991MHz	______	33.00009MHz
	62.5MHz	62.49983MHz	______	62.50017MHz
	62.6MHz	62.59983MHz	______	62.60017MHz
	125.0MHz	124.99964MHz	______	125.00036MHz
	125.1MHz	125.09964MHz	______	125.10036MHz
	250.0MHz	249.99926MHz	______	250.00074MHz
	250.1MHz	250.09926MHz	______	250.10074MHz
	264.0MHz	263.99922MHz	______	264.00078MHz
	264.1MHz	263.09922MHz	______	264.10078MHz
	278.0MHz	277.99918MHz	______	278.00082MHz
	278.1MHz	278.09918MHz	______	278.10082MHz
	294.0MHz	293.09913MHz	______	294.00087MHz
	294.1MHz	294.09913MHz	______	294.10087MHz
	315.0MHz	314.99907MHz	______	315.00093MHz
	315.1MHz	315.09907MHz	______	315.10093MHz
	340.0MHz	339.99899MHz	______	340.00101MHz
	340.1MHz	340.09899MHz	______	340.10101MHz
	372.0MHz	371.99890MHz	______	372.00110MHz
	372.1MHz	372.09890MHz	______	372.10110MHz
	405.0MHz	404.99880MHz	______	405.00120MHz
	405.1MHz	405.09880MHz	______	405.10120MHz
	450.0MHz	449.99866MHz	______	450.00134MHz
	450.1MHz	450.09866MHz	______	450.10134MHz
	500.0MHz	499.99851MHz	______	500.00149MHz
	500.2MHz	500.19851MHz	______	500.20149MHz
	528.0MHz	527.99843MHz	______	528.00157MHz
	528.2MHz	528.19843MHz	______	528.20157MHz
	556.0MHz	555.99835MHz	______	556.00165MHz
	556.2MHz	556.19835MHz	______	556.20165MHz
	588.0MHz	587.99825MHz	______	588.00175MHz
	588.2MHz	588.19825MHz	______	588.20175MHz

Paragraph Number	Test	Minimum	Results Actual	Maximum
	630.0MHz	629.99812MHz	______	630.00188MHz
	630.2MHz	630.19812MHz	______	630.20188MHz
	680.0MHz	679.99797MHz	______	680.00203MHz
	680.2MHz	680.19797MHz	______	680.20203MHz
	744.0MHz	743.99788MHz	______	744.00222MHz
	744.2MHz	744.19788MHz	______	744.20222MHz
	810.0MHz	809.99758MHz	______	810.00242MHz
	810.2MHz	810.19758MHz	______	810.20242MHz
	900.0MHz	899.99731MHz	______	900.00269MHz
	900.2MHz	900.19731MHz	______	900.20269MHz
	1000.0MHz	999.99701MHz	______	1000.00299MHz
	Frequency setting for Option 002:			
	10.0111MHz	10.01108MHz		10.01112MHz
	100.0111MHz	100.01081MHz		100.01139MHz
	251.0000MHz	250.99926MHz		251.00074MHz
	270.0111MHz	270.01030MHz		270.01190MHz
	300.0999MHz	300.09901MHz		300.10079MHz
	330.0333MHz	330.03232MHz		330.03428MHz
	360.0666MHz	360.06553MHz		360.06767MHz
	400.0777MHz	400.07651MHz		400.07889MHz
	440.0123MHz	440.01099MHz		440.01361MHz
	500.0000MHz	499.99851MHz		500.00149MHz
	800.0222MHz	800.01981MHz		800.02459MHz

Paragraph Number	Test	Minimum	Results Actual	Maximum
4-12	MEASUREMENT SIGNAL LEVEL TEST			
	Frequency setting:			
	1.0MHz	−17.0dBm	______	−23.0dBm
	50.0MHz	↓	______	↓
	100.0MHz		______	
	150.0MHz		______	
	200.0MHz		______	
	250.0MHz		______	
	300.0MHz		______	
	350.0MHz		______	
	400.0MHz		______	
	450.0MHz		______	
	500.0MHz		______	
	550.0MHz		______	
	600.0MHz		______	
	650.0MHz		______	
	700.0MHz		______	
	750.0MHz		______	
	800.0MHz		______	
	850.0MHz		______	
	900.0MHz		______	
	950.0MHz		______	
	1000.0MHz		______	
4-14	MEASUREMENT SIGNAL PURITY TEST			
	Maximum harmonic level (below fundamental) and test frequency		______ dB ______ MHz	
	Maximum spurious signal level (below fundamental) and test frequency		______ dB ______ MHz	
4-16	AUTO CALIBRATION TEST			
	Test result (Pass/Fail)			
	0Ω		______	
	0S		______	
	50Ω		______	
4-18	ERROR CORRECTION FUNCTION TEST			
	Test result (Pass/Fail)		______	

Paragraph Number	Test	Minimum	Results Actual	Maximum
4-20	ACCURACY TEST			
	Test result (Pass/Fail)		______	
	Note: To make a complete record of the test results, use the test program cartridge type that is part of the 16342A Calibration Equipment Kit and keep the plotted chart.			
4-22	DC BIAS VOLTAGE ACCURACY TEST			
	Voltage setting			
	0.01V	0.00V	______	0.02V
	0.03V	0.02V	______	0.04V
	0.07V	0.06V	______	0.08V
	0.15V	0.14V	______	0.16V
	0.31V	0.30V	______	0.32V
	0.63V	0.62V	______	0.64V
	1.27V	1.26V	______	1.28V
	2.55V	2.538V	______	2.562V
	5.11V	5.095V	______	5.125V
	10.23V	10.21V	______	10.25V
	20.47V	20.44V	______	20.50V
	40.00V	39.95V	______	40.05V
	–0.01V	0.00V	______	–0.02V
	–0.03V	–0.02V	______	–0.04V
	–0.07V	–0.06V	______	–0.08V
	–0.15V	–0.14V	______	–0.16V
	–0.31V	–0.30V	______	–0.32V
	–0.63V	–0.62V	______	–0.64V
	–1.27V	–1.26V	______	–1.28V
	–2.55V	–2.538V	______	–2.562V
	–5.11V	–5.095V	______	–5.125V
	–10.23V	–10.21V	______	–10.25V
	–20.47V	–20.44V	______	–20.50V
	–40.00V	–39.95V	______	–40.05V
4-24	BATTERY MEMORY BACK-UP FUNCTION TEST			
	Test result (Pass/Fail)		______	

Paragraph Number	Test	Minimum	Results Actual	Maximum
4-26	ANALOG RECORDER OUTPUT TEST			
	Control setting : ↓← LL			
	DISPLAY A output	−0.2mV	________	0.2mV
	DISPLAY B output	−0.2mV	________	0.2mV
	FREQ/BIAS output	−0.2mV	________	0.2mV
	Control setting : UR →↑			
	DISPLAY A output	993mV	________	1007mV
	DISPLAY B output	993mV	________	1007mV
	FREQ/BIAS output	993mV	________	1007mV
	Control setting : DISPLAY A: 100 counts; DISPLAY B: 100 counts; SPOT FREQ: 99.9MHz			
	DISPLAY A output	98mV	________	102mV
	DISPLAY B output	98mV	________	102mV
	FREQ/BIAS output	98mV	________	102mV
	Control setting: DISPLAY A: −100 counts; DISPLAY B: −100 counts			
	DISPLAY A output	−98mV		−100mV
	DISPLAY B output	−98mV		−100mV
4-28	HP-IB INTERFACE TEST			
	Test result (Pass/Fail)		________	

SECTION V
ADJUSTMENT

5-1. INTRODUCTION

5-2. This section describes the adjustments and checks required to return the 4191A to the specifications listed in Table 1-1 after repairs have been made. These adjustments and checks can also be performed along with periodic maintenance to keep the instrument in optimum operating condition. The recommended adjustment cycle for the 4191A is twice a year. All adjustable components referred to in the adjustment procedures are listed in Table 5-1. If proper performance cannot be achieved after adjustment, refer to the troubleshooting procedures descibed in Section VIII.

Note: *To ensure proper results and instrument operation, Hewlett-Packard suggests a 40 minute warm-up and stabilization period before performing any of the adjustments described here.*

5-3. SAFETY REQUIREMENTS

5-4. Although the 4191A was designed in accordance with international safety standards, this manual contains information, cautions, and warnings which must be followed to ensure operator safety and to keep the instrument in a safe and serviceable condition. Adjustments described in this section should be performed by qualified service personnel only.

WARNING

ANY INTERRUPTION OF THE PROTECTIVE (GROUNDED) CONDUCTOR (INSIDE OR OUTSIDE THE INSTRUMENT) OR DISCONNECTION OF THE PROTECTIVE EARTH TERMINAL IS LIKELY TO MAKE THE INSTRUMENT DANGEROUS. INTENTIONAL INTERRUPTION, FOR ANY REASON, IS PROHIBITED.

5-5. The removel or opening of covers for removal or adjustment of parts, other than those which are accessible by hand, will expose live parts.

5-6. Capacitors in the instrument may still be charged even if the instrument has been disconnected from the power source (AC line) for an extended period of time.

WARNING

ADJUSTMENTS DESCRIBED IN THIS SECTION ARE PERFORMED WITH POWER SUPPLIED AND PROTECTIVE COVERS REMOVED. ENERGY EXISTING AT MANY POINTS MAY, IF CONTACTED, RESULT IN SERIOUS PERSONAL INJURY.

5-7. EQUIPMENT REQUIRED

5-8. All the equipment required to perform the adjustments described in this section are listed in Table 4-1 on page 4-A. Each piece of equipment listed in Table 4-1 should be calibrated to satisfy its own specifications, as well as those of the required characteristics. If the recommended model is not available, any instrument that equals or surpasses the specifications of the recommended model may be used instead.

5-9. FACTORY SELECTED COMPONENTS

5-10. Factory selected components are identifiable by an asterisk (*) adjacent to the reference designator on the schematic diagrams in Section VIII (only nominal values are given). Table 5-2 lists the reference designators of all factory selected components. Also listed in Table 5-2 are the nominal value range of each component and a brief description of how each component affects instrument performance.

Adjustable components, with reference designators, are listed in Table 5-1. This table also lists the name of the adjustment and its purpose.

5-11. ADJUSTMENT RELATIONSHIPS

5-12. The adjustment procedures described in this section, beginning with paragraph 5-17, are interactive and therefore should be performed in the sequence given. Ignoring or changing the order of the procedures may make it impossible to obtain optimum instrument performance. Table 5-3 lists the necessary adjustment procedures to follow after the instrument has been repaired.

5-13. ADJUSTMENT LOCATIONS

5-14. To help locate the appropriate adjustment points, the locations of the components to be adjusted are illustrated throughout the adjustment procedures. The locations of factory selected components, connectors, and other components related to the adjustments are shown in the individual board assembly-component illustrations (fold out service sheets) in Section VIII.

Table 5-1. Adjustable Components (sheet 1 of 2).

Reference Designator	Name of Control	Adjustment Purpose
A1C18 (Para 5-19)	FREQ ADJ	To properly set the oscillator frequency variable range.
A1R16 (Para 5-19)	BIAS ADJ	To set the oscillator amplification gain to ensure stable oscillation over the entire frequency control range.
.A4R1 R2 R3 R4 (Para 5-23)		To set the tuning control voltages for the voltage tunable filter on the A6 board
A10R18 (Para 5-27)	BIAS	To set the reverse bias voltage for the sampler diodes.
A10R19 (Para 5-29)	FB	To properly set the compensation magnitude for variations in sampling efficiency and to equalize the sampler output level at all test frequencies.
A11R18 (Para 5-27)	BIAS	To set the reverse bias voltage for the sampler diodes.
A11R19 (Para 5-29)	FB	To properly set the compensation magnitude for variations in sampling efficiency and to equalize the sampler output level at all test frequencies.
A12R1 (Para 5-31)	SH RANGE ADJ	To set the sampling frequency search control range.
A12R2 (Para 5-31)	CENT ADJ	To set the center frequency of the sampling frequency search control range.
A13C1 (Para 5-33)	FREQ ADJ	To properly set the sampling frequency variable range.
A16R1 (Para 5-25)		To adjust the amplitude of the ALC test signal to the appropriate level.
A17C12 (Para 5-37)		To adjust the detection phase of the phase detector.
A17R6 (Para 5-35)		To eliminate residual dc offset voltage from the phase detector circuit.
A18C3 C36 (Para 5-21)	100MHz ADJ	To adjust the clock frequency to exactly 100MHz and to maximize accuracy of the test signal frequency.
A21C58 (Para 5-39)		To set the microprocessor clock generator frequency.
A23R8 (Para 5-17)		To set ±12V power supply voltage.
A23R41 (Para 5-17)		To set +5V (3A) power supply voltage.
A23R42 (Para 5-17)		To set +5V (2A) power supply voltage.
A25R1 (Para 5-43)		To properly set the operating temperature of the directional bridge circuit.

Table 5-1. Adjustable Components (sheet 2 of 2).

Reference Designator	Name of Control	Adjustment Purpose
A30C1 (Para 5-45)	FREQ ADJ	To properly set the oscillator frequency variable range. (Opt. 002 only)
A33C18 (Para 5-47)	FREQ ADJ	To properly set the oscillator frequency variable range. (Opt. 002 only)
A33R16 (Para 5-47)	BIAS ADJ	To set the oscillator amplification gain to ensure stable oscillation over the entire frequency control range. (Opt. 002 only)
A40R1 R3 (Para 5-41)	-0 +0	To set the zero bias voltage to exactly zero volts.
A40R2 (Para 5-41)	-FS	To set the maximum negative bias output voltage to exactly -40V and to maximize bias voltage accuracy.
A40R4 (Para 5-41)	+FS	To set the maximum positive bias output voltage to exactly +40V and to maximize bias voltage accuracy.
A41R1 R2 R4 R5 R7 (Para 5-49)	+A0 -A0 +B0 -B0 C0	To eliminate any residual dc offset voltages from the analog recorder output amplifiers. (Opt. 004 only)
A41R3 R6 R8 (Para 5-49)	A. F. S B. F. S C. F. S	To adjust analog output voltage at full scale display counts to maximize output voltage accuracy. (Opt. 004 only)

Table 5-2. Factory Selected Components.

Component	Nominal Value Range	Affect on Performance
A6C4	▶ BLANK PN 0160-3872, C: FXD 2.2pF PN 0160-3873, C: FXD 4.7pF	Changes frequency characteristics of A6 Power Amplifier.

Component marked (▶) in table is usually used.

5-15. INITIAL OPERATING PROCEDURE

5-16. Before proceeding with the adjustments described starting in paragraph 5-17, perform the following three preliminary steps. This procedure provides access to the various adjustment points and facilitates a thoroughgoing adjustment.

[BASIC OPERATING CHECK]

Check that the instrument's line voltage selector switches, located on the rear panel, are set to the positions appropriate for the local line voltage. This should be performed before proceeding with any of the adjustments.
After the recommended 40 minute warm-up period, the instrument should pass the SELF TEST (no error message should appear), and the initial control settings listed in Figure 3-5 should be automatically set in preparation for measurements. If the instrument displays an error message or does not have the correct initial control settings, refer to the troubleshooting procedures given in Section VIII.

[TOP/BOTTOM COVER REMOVAL]

a. Remove the two plastic instrument feet located at the upper corners of the rear panel.

b. Fully loosen the top cover retaining screw located at the rear of the top cover.

c. Slide the top cover towards the rear and lift off. The top shield case, housing the A21 microprocessor digital control board, will be visible.

By first setting the instrument on its side, the same procedure can be used to remove the bottom cover.

[OPENING THE TOP SHIELD CASE]

The top shield case is hinged at the rear and opens much like the hood of an automobile. It is secured by a retaining screw, located at the center of the case, and by two fasteners, located at the front corners.

a. Fully loosen the retaining screw located at the center of top shield case.

b. Loosen the two fasteners located at the front of the case.

c. Raise the top shield case from the front and continue until it comes to rest on the rear frame. The top shieldplates of the various circuit board assemblies, housed in their own shielded cases, will be visible. Test points and adjustable components are accessible through the holes in the shield plates.

WARNING

AS A SAFETY PRECAUTION AGAINST POSSIBLE ELECTRICAL SHOCK HAZARDS AND RESULTANT INJURY, USE INSULATED TOOLS FOR ALL ADJUSTMENTS.

Caution:
Allowing the top shield case to slam down, when opening or closing, could damage the sensitive microprocessor mounted on the A21 board inside the case.

d. Remove the A21 board access-cover, located on the underside of the top shield case, by loosening the four retaining screws.

Table 5-3. Adjustment Requirements.

Assembly repaired or replaced	Required adjustment(s)
A1 04191-66501 (VTO)	Para. 5-19.
A2 04191-66502 A3 04191-66503	None
A4 04191-66504 (Programmable Switch Control Driver)	Para. 5-23
A5 04191-66505 A6 04191-66506 A7 04191-66507 A9 04191-66509	None.
A10 04191-66510 A11 04191-66510	Para. 5-27, 5-29.
A12 04191-66512 (PLL Sampling Controller)	Para. 5-31.
A13 04191-66513 (PLL Sampling Frequency VTO)	Para. 5-33.
A15 04191-66515	None
A16 04191-66516 (IF Ampl./Process Amplifier)	Para. 5-25.
A17 04191-66517 (Phase Detector/ A-D Converter)	Para. 5-35, 5-37.
A18 04191-66518 (100MHz Clock Generator/Doubler)	Para. 5-21.
A21 04191-66520 (Microprocessor Digital Control)	Para. 5-39.
A22 04191-66522	None
A23 04191-66523 (Power Supply)	Para. 5-17.
A25 04191-66525 (Heater Controller)	Para. 5-43.
A30 04191-66530 (VTO: 100–110MHz)	Para. 5-45.

Assembly repaired or replaced	Required adjustment(s)
A31 04191-66531 A32 04191-66532	None.
A33 04191-66533 (VTO: 250–500MHz)	Para. 5-47.
A40 04191-66540 (DC Bias Supply)	Para. 5-41.
A41 04191-66541 (Analog Recorder Output)	Para. 5-49.

5-17. DC POWER SUPPLY VOLTAGE ADJUSTMENTS

5-18. This adjustment sets the output voltages of the internal dc power supply to their levels to ensure that the instrument is functioning under the proper operating voltage levels.

Note: Before proceeding with the dc power supply voltage adjustment, first measure the voltage levels of TP1 through 7 on the mother board. If the measured voltages are within the limits listed in the table below, the dc power supply does not require adjustment. These test points are accessible from the top of the instrument after the top shield case has been raised. They are located on the right side of the mother board, about 4 cm from the instrument frame.

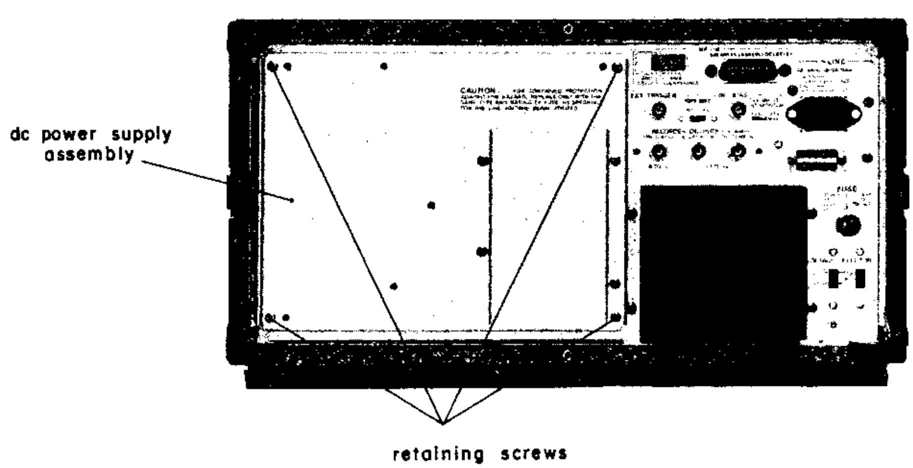
TP	Lower Limit	Upper Limit
7	5V	5.35V
6	12V	12.2V
5	-11.9V	-12.25V
4	45V	48V
3	-45V	-48V
2	30V	40V
1	-30V	-40V

EQUIPMENT:

Digital Voltmeter (DMM) .... HP 3455A
Voltmeter input cable .... Dual banana to dual alligator clip cable.

PROCEDURE:

1. Remove the four screws that secure the dc power supply assembly plate, located on the rear panel, as shown in the figure below.



The A23 dc power supply board is mounted on the reverse side of the plate.

WARNING

REMOVING THE DC POWER SUPPLY ASSEMBLY EXPOSES THE BLADES OF THE INSTRUMENT FAN. SERIOUS INJURY MAY RESULT IF FINGERS, HANDS, OR ADJUSTMENT TOOLS COME IN CONTACT WITH THE MOVING BLADES. OBSERVE EXTREME CAUTION.

2. Lower the dc power supply assembly until all components and test points are accessible. If necessary, remove the cable clamp located on the inside of the rear panel, above the instrument fan, to facilitate access to the A23 board.

   Caution: Do not force the cables connected between the A23 board and mainframe.

3. Connect the positive input of the dc voltmeter to TP8 (+12V) on the A23 board and the negative input to the instrument chassis.
4. Set the voltmeter to a range appropriate for measuring +12V.
5. Adjust potentiometer A23R8 until the display on the voltmeter is between 11.4V and 12.2V.
6. Connect the positive input of the voltmeter to the other test points listed in Table 5-4 and adjust the indicated potentiometer until the display on the voltmeter is within the limits listed in the table.

Table 5-4. DC Power Supply Voltage Adjustments.

Test Point	Potentiometer	Voltage Limits
A23 TP8	A23 R8	11.4 to 12.2V
TP3	R42	4.9 to 5.25V
TP5	R41	4.9 to 5.25V

7. Return the cable clamp and dc power supply assembly to their original positions.

5-19. TEST FREQUENCY SYNTHESIZER VTO ADJUSTMENT

5-20. This adjustment sets the controllable frequency range of the A1VTO to ensure generation of test frequency signals free of signal dead zone and parasitic oscillation at all test frequency settings.

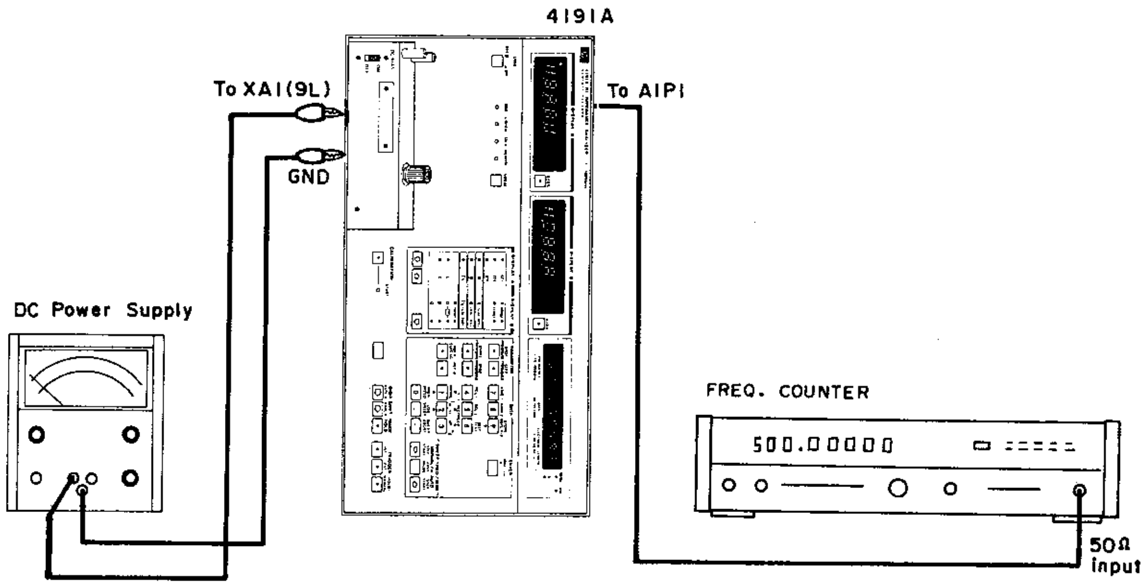


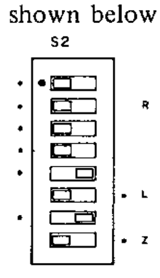
Figure 5-1. Test Frequency Synthesizer VTO Adjustment Setup.

EQUIPMENT:

Frequency Counter	HP 5340A
Spectrum Analyzer	HP141T/8554B/8552B
Connection Cable	N type connector cable
Terminal Converter:	
N type female to SMC female	-hp- 1250–1153
DC Power Supply	HP 6224B
Power Supply Output Cable	Dual banana to dual alligator clip cable

PROCEDURE:

1. Stand the 4191A on its right side.
2. Set switch S2 on the A21 board as shown below:



3. Disconnect the SMC connector (P1) from the A3 board top plate.
4. Remove the A3 board.

Caution: Set the dc power supply to zero (0) volts before performing step 5.

5. Connect the dual banana to alligator clip cable between XA1 pin 9L (board connector) of the 4191A and the positive output of the dc power supply, as shown in Figure 5-1.

6. Disconnect the SMC connector from A1P1.

7. Connect the frequency counter input to A1P1.

8. Set the 4191A SPOT frequency to 500.0MHz.

9. Set the dc power supply output voltage to +20V±0.1V.

10. Adjust trimmer capacitor A1C18 until the display on the frequency counter reads 502.0MHz ±0.1MHz.

11. Disconnect the SMC connector from A1P2. Connect the spectrum analyzer input to A1P2. Set the controls of the spectrum analyzer as follows:

    Input attenuation .... 10 dB
    Scan Width 100MHz/div
    Center Frequency 500MHz
    Bandwidth 300kHz

12. Vary the dc power supply output voltage from 0V to +20V and observe the spectrum analyzer CRT. Verify that there are no parasitic oscillation signals at any VTO frequency. If there are parasitic oscillation signals present, adjust potentiometer A1R16 until they have been eliminated.

13. Re-perform step 12 at each SPOT frequency listed in Table 5-5.

Table 5-5. VTO Spurious Signal Test

SPOT freq. setting	VTO frequency variable range		Frequency Band
	Minimum	Maximum	
500MHz	≤440MHz	≥502MHz	500 ~ 450MHz
450	≤400	≥452	450 ~ 405
400	≤365	≥407	405 ~ 372
350	≤335	≥374	372 ~ 340
320	≤310	≥342	340 ~ 315
300	≤290	≥316	315 ~ 294
280	≤275	≥295	294 ~ 278
270	≤260	≥279	278 ~ 264
260	≤245	≥264.5	264 ~ 250

14. Disconnect the frequency counter, spectrum analyzer and dc power supply from the 4191A.

15. Reconnect the SMC connectors to A1P1 and A1P2.

16. Replace the A3 board to its normal position and reconnect the SMC connector.

17. Reset switch A21S2 to its normal position.

ADJUSTMENTS

5-21. TEST SIGNAL FREQUENCY ADJUSTMENT

5-22. This adjustment sets the frequency of the clock frequency generator on the A18 board to a precise 100MHz to maximize test signal frequency accuracy.

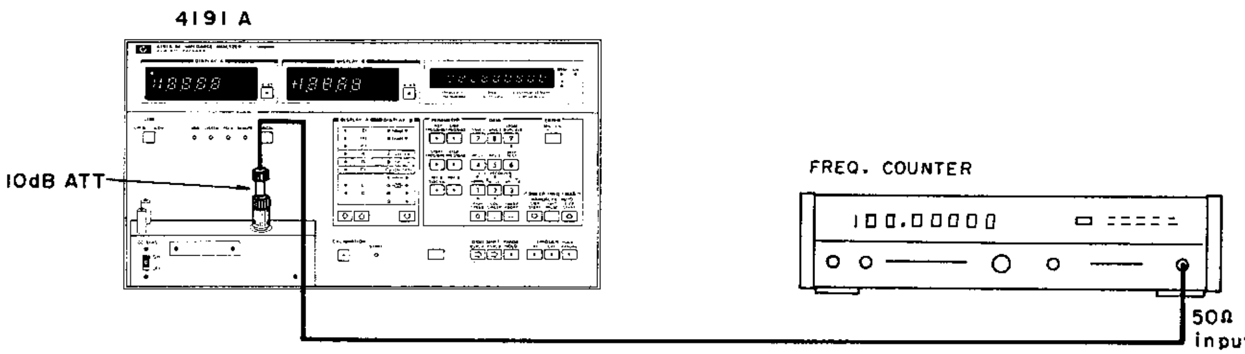


Figure 5-2. Test Signal Frequency Adjustment Setup.

EQUIPMENT:

Frequency Counter	HP 5340A
10dB Attenuator	HP 8491A
Connection Cable	N-type connector cable
Terminal Converter	N-type female to APC-7, HP 11524A

PROCEDURE:

1. Disconnect the SMC connector cable from A13P1 (E-12 will appear on the 4191A display).
2. Connect the 10dB attenuator and connection cable between the frequency counter input and the 4191A UNKNOWN connector as shown in Figure 5-2.
3. Remove the A18 board and re-install with an extender board.
4. Set the 4191A SPOT frequency to 100.0MHz.
5. Set the frequency counter to a frequency range appropriate for measuring 100MHz (10Hz resolution).
6. Set trimmer capacitor A18C3 to its mechanical center position.
7. Adjust trimmer capacitor A18C36 until the display on the frequency counter is 100.00000MHz ±20 counts.
8. Remove the extender board and return the A18 board to its normal position.
9. Adjust trimmer capacitor A18C3 until the display on the frequency counter is 100.00000MHz ±1 count.

   Note: Confirmation check procedure should be performed after this adjustment.
10. Reconnect the SMC connector cable to A13P1 (E-12 will disappear from the 4191A display).

Confirmation Check

Set the 4191A SPOT frequency in accordance with Table 5-6. Frequency counter readouts should meet the test limits at all test frequency settings.

Table 5-6. Frequency Accuracy Checks.

Test freq.	Test limits	Test freq.	Test limits
1.0MHz	± 11Hz	405.0MHz	± 415Hz
32.0	± 42Hz	405.1	± 415Hz
32.1	± 42Hz	450.0	± 460Hz
33.0	± 43Hz	450.1	± 460Hz
62.5	± 72Hz	500.0	± 510Hz
62.6	± 72Hz	500.2	± 510Hz
125.0	±135Hz	528.0	± 538Hz
125.1	±135Hz	528.2	± 538Hz
250.0	±260Hz	556.0	± 566Hz
250.1	±260Hz	556.2	± 566Hz
264.0	±274Hz	588.0	± 598Hz
264.1	±274Hz	588.2	± 598Hz
278.0	±288Hz	630.0	± 640Hz
278.1	±288Hz	630.2	± 640Hz
294.0	±304Hz	680.0	± 690Hz
294.1	±304Hz	680.2	± 690Hz
315.0	±325Hz	744.0	± 754Hz
315.1	±325Hz	744.2	± 754Hz
340.0	±350Hz	810.0	± 820Hz
340.1	±350Hz	810.2	± 820Hz
372.0	±382Hz	900.0	± 910Hz
372.1	±382Hz	900.2	± 910Hz
		1000.0	±1010Hz

5-23. VOLTAGE TUNABLE FILTER TUNING VOLTAGE ADJUSTMENT

5-24. This adjustment sets the tuning control output voltages for the voltage tunable filter (on the A6 board) to establish the appropriate frequency pass bands.

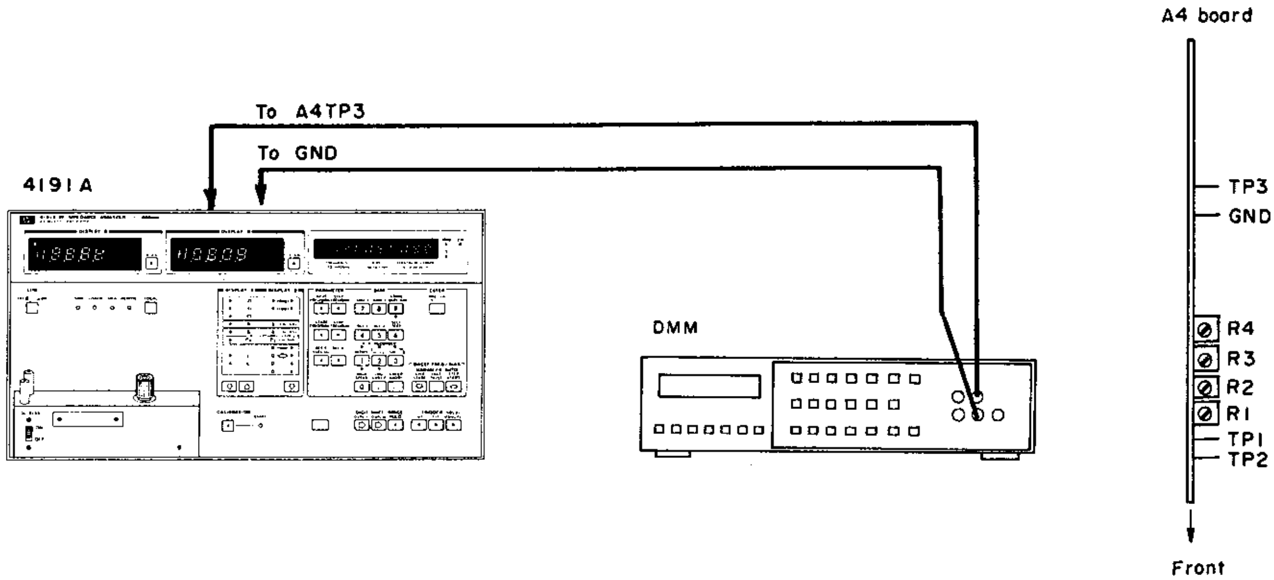


Figure 5-3. Voltage Tunable Filter Tuning Voltage Adjustment Setup.

EQUIPMENT:

Digital Voltmeter .... HP 3455A
Voltmeter input leads .... Dual banana to dual alligator clip leads

PROCEDURE:

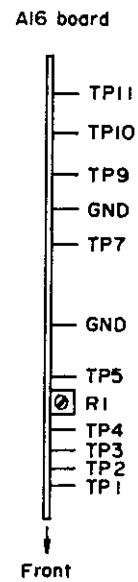
1. Connect the DC voltmeter input leads to TP3 and GND pin on the A4 board as shown in Figure 5-3.
2. Set the 4191A SPOT frequency to 520MHz.
3. Adjust potentiometer A4R4 until the voltmeter display reads -2.8V ±0.1V.
4. Set the 4191A SPOT frequency in accordance with Table 5-7. Adjust potentiometers R3, R2, and R1 until the voltmeter readouts are within the voltage limits given in the table.

Table 5-7. Tuning Voltage Adjustments.

Frequency setting	Potentiometer	Voltage limits
520MHz	A4 R4	-2.8 ± 0.1V
730MHz	R3	-7.4 ± 0.1V
800MHz	R2	-8.6 ± 0.1V
900MHz	R1	-11.0 ± 0.1V

5-25. TEST SIGNAL LEVEL ADJUSTMENT

5-26. This adjustment sets the test frequency signal level to meet specified value range.



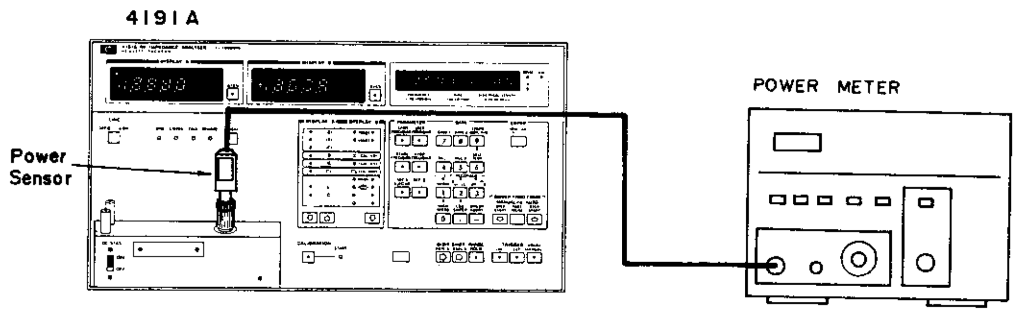


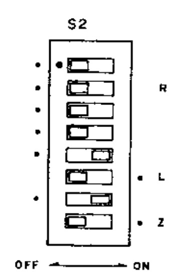
Figure 5-4. Test Signal Level Adjustment Setup.

EQUIPMENT:

Power Meter . . . . HP 436A
Power Sensor . . . . HP 8482A

PROCEDURE:

1. Set switch S2 on the A21 board as shown below:



2. Disconnect the SMC connector cable from A15P2.
3. Set the 4191A SPOT frequency to 100.0 MHz.
4. Connect the power sensor between the 4191A UNKNOWN connecctor and RF power meter input as shown in Figure 5-4.
5. Adjust potentiometer A16R1 for a -20.50dB ±0.05dBm reading on the power meter.

   Note: Confirmation check procedure should be performed after this adjustment.

6. Reconnect the SMC connector cable to A15P2.
7. Reset switch A21S2 to its normal position.

Confirmation Check

Set 4191A test signal frequency at various settings from 1MHz to 1000MHz in 5MHz steps. Power meter display should be -20dBm ±2dBm at all the test frequency settings. If the unit under adjustment fails this confirmation check, re-perform the Voltage Tunable Filter Tuning Voltage Adjustment (Para. 5-23) using a tolerance of ±1V (instead of ±0.1V).

5-27. SAMPLING DIODE BIAS VOLTAGE ADJUSTMENT

5-28. This adjustment sets the applied bias voltages of the A10 and A11 Sampler circuits to an appropriate value to prevent the transient ringing of the sampling pulse signal (see illustration) from activating the sampler.

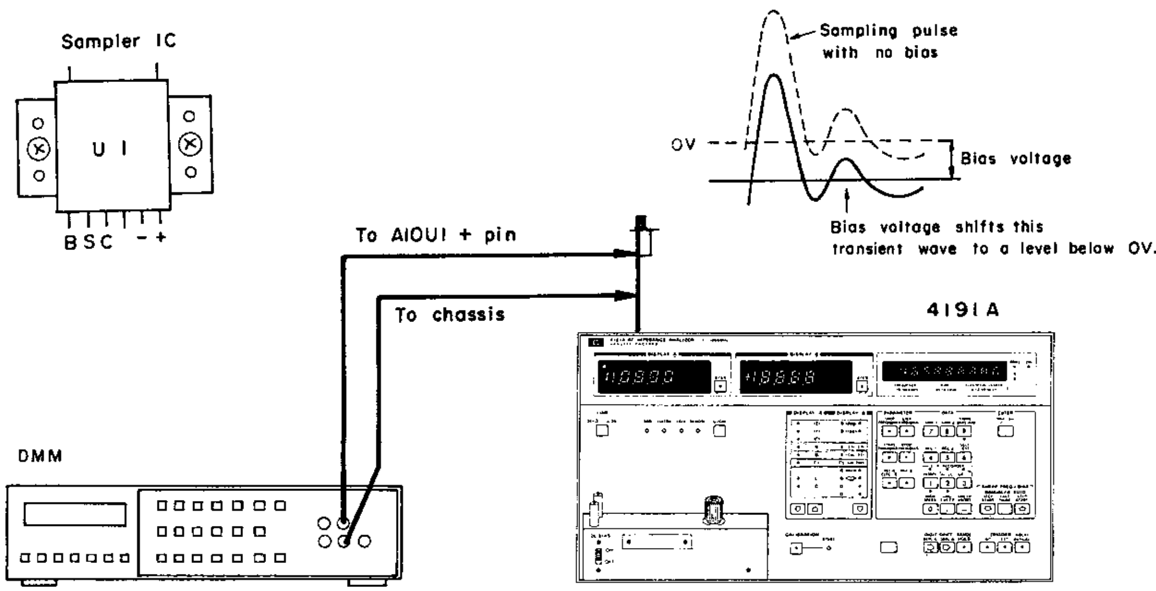


Figure 5-5. Sampler Diode Bias Voltage Adjustment Setup.

EQUIPMENT:

Digital Voltmeter (DMM) .... HP 3455A
Voltmeter input cable .... Dual banana to dual alligator clip cable

PROCEDURE:

1. Disconnect the SMC connector cables from A10P1 and P2.
2. Remove the A10 board from its shield box and re-install with an extender board.
3. Connect the dc voltmeter (DMM) input cable to test point "+" on the A10 board and instrument chassis as shown in Figure 5-5.
4. Adjust potentiometer A10R18 (labeled bias) until the voltmeter display reads 1.2V ±0.01V.

   Note: Verify that dc voltage at "–" test point on the A10 board is -1.2 V ±0.01 V. If this check fails, readjust A10R18.

5. Connect the dc voltmeter (DMM) input cable to A11 board test point "+" and instrument chassis, and adjust potentiometer A11R18 using the procedure described in steps 1 through 4.
6. Re-install the A10 and A11 boards to their normal positions.
7. Reconnect the SMC connector cables to their normal positions.

5-29. SAMPLING EFFICIENCY COMPENSATION ADJUSTMENT

5-30. This adjustment sets the compensation for decreases in sampling efficiency at lower frequency region of the sampling frequency control range. Because a maximum change in the sampling frequency (and efficiency) occurs when the measurement frequency shifts between 11.1MHz and 11.2MHz, this adjustment is performed using these specific measurement frequency settings.

EQUIPMWNT:

No equipment is required for this adjustment.

PROCEDURE:

1. Stand the 4191A on its right side.
2. Remove the bottom cover from the instrument.
3. Set 4191A controls as follows:

   SPOT FREQ .... 11.1 MHz
   STEP FREQ .... .1 MHz
   DISPLAY A/B function .... Γx – Γy

4. Make a note of the readouts on DISPLAY A and DISPLAY B.
5. Press the SWEEP FREQ/BIAS STEP [⇧] key to set the test frequency to 11.2MHz.
6. Adjust potentiometer A11R19 so that both DISPLAY A and DISPLAY B readouts approximate the values noted in step 4. Potentiometer A11R19 is accessible through the adjustment hole (labeled FB) on the instrument motherboard.
7. Press the SWEEP FREQ/BIAS STEP [⇩] key to reset the test frequency to 11.1MHz. Repeat A11R19 adjustment (steps 3, 4, 5 and 6) until the difference in display readouts is less than ±10 counts.
8. If adjustment of A11R19 can not satisfy the test limits, adjust potentiometer A10R19 using the same procedure as that for A11R19 adjustment (steps 3, 4, 5, 6 and 7). Potentiometer A10R19 is accessible through the adjustment hole (labeled FB) on the instrument motherboard.

Note: If the difference in display readouts can not be decreased to less than ±50 counts, troubleshoot A10 and A11 boards. If it does not exceed ±50 counts, proceed to the next adjustment procedure.

5-31. SAMPLING FREQUENCY SEARCH CONTROL ADJUSTMENT

5-32. This adjustment sets the output voltage variable range of the A12 PLL Sampling Controller to establish a sampling frequency control span sufficient for converting any measurement frequency signal to a 100kHz IF signal in the Sampler.

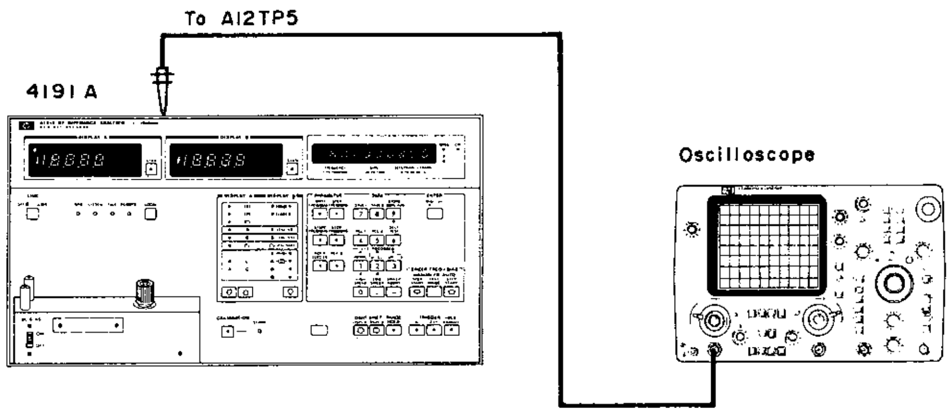


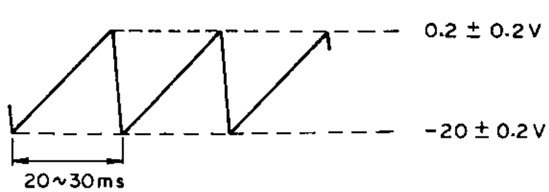
Figure 5-6. Sampling Frequency Search Control Adjustment Setup.

EQUIPMENT:

Oscilloscope .... HP 1740A
Oscilloscope probe .... HP 10006D (10MΩ, 10:1)

PROCEDURE:

1. Disconnect the SMC connector (P1) from the A13 board top plate.
2. Connect oscilloscope input probe (10:1) to test point A12TP5.
3. Set the oscilloscope controls as follows:
   Vertical sentitivity 5V/div
   Sweep time 10ms/div
4. Adjust potentiometers A12R1 (SH RANGE ADJ) and R2 (CENT ADJ) so that the amplitude of the sawtooth waveform on the CRT is greater than 20Vp-p. See waveform illustration below:



5. Reconnect the SMC connector to A13P1.

5-33. SAMPLING FREQUENCY VTO ADJUSTMENT

5-34. This adjustment sets the maximum oscillation frequency of the A13 Sampling Frequency VTO to cover the required sampling frequency variable range (in conjunction with the Sampling Frequency Search Control Adjustment).

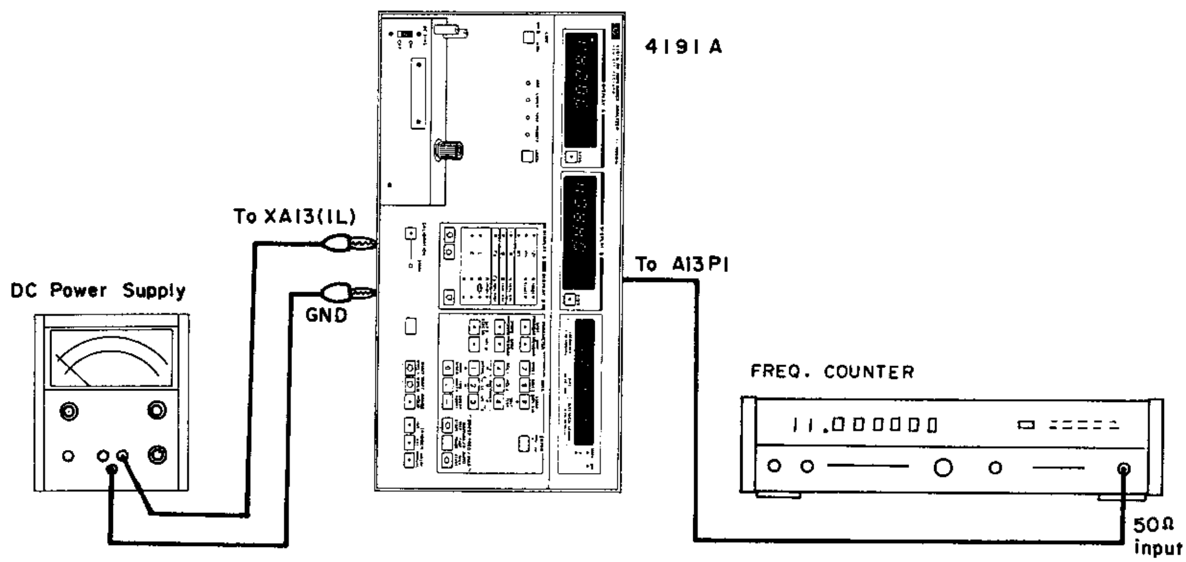


Figure 5-7. Sampling Frequency VTO Adjustment Setup.

EQUIPMENT:

Frequency Counter	HP 5340A
Connection Cable	N type connector cable
Terminal Converter:	
N type female to SMC female	-hp- 1250–1153
DC Power Supply	HP 6224B
Power Supply Output Cable	Dual banana to dual alligator clip cable

PROCEDURE:

1. Set 4191A test signal frequency to 11.0 MHz.
2. Remove the A12 board.
3. Stand the 4191A on its right side.
4. Remove the bottom cover from the instrument.
5. Connect the dual banana to alligator clip cable between 4191A XA13 pin 1L (board connector) and dc power supply output as shown in Figure 5-7.

   Caution: Set dc power supply output voltage to zero before connecting output cable.

6. Disconnect the SMC connector cable from A13P1.

7. Connect the frequency counter input cable to A13P1.

8. Set the dc power supply output voltage to -18.9V ±0.1 V (voltage at XA13 pin 1L is negative.).

9. Adjust trimmer capacitor A13C1 until the frequency counter display is within 11.30 and 11.33 MHz.

   Note: Use a non-metallic tool for this adjustment.

10. Disconnect the power supply output cable and the frequency counter input cable.

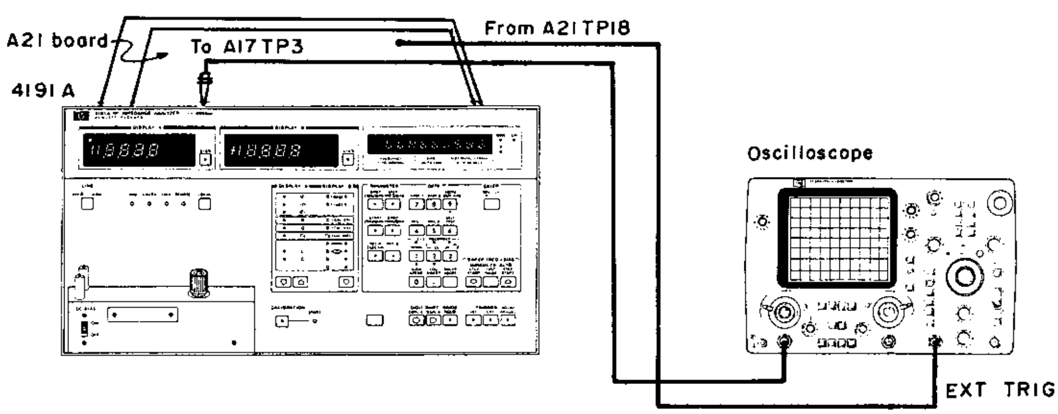
11. Re-install the A12 board to its normal position.

12. Reconnect the SMC connector cable to A13P1.

5-35. A-D CONVERTER OFFSET ADJUSTMENT

5-36. This adjustment eliminates any residual dc offset voltage from the phase detector output to minimize its affect on the accuracy.

Note: *The residual dc offset voltage does not significantly affect the accuracy because of the automatic offset compensation period achieved at initiation of the measurement sequence. This adjustment further increases the accuracy of the offset compensation.*



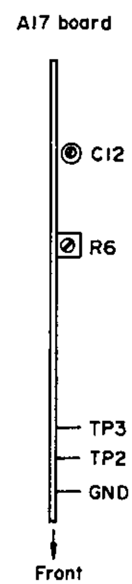


Figure 5-8. A-D Converter Offset Adjustment Setup.

EQUIPMENT:

Oscilloscope .... HP 1740A
Oscilloscope probe .... HP 10006D (10MΩ, 10:1)

PROCEDURE:

1. Connect oscilloscope input probe to A17TP3. Trigger the oscilloscope externally from A21TP18 (labeled RKEY).

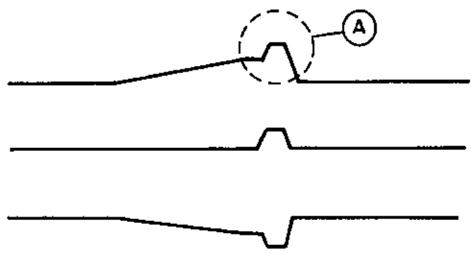
2. Observe integrator output waveform for phase I period (see illustration below).

Phase I Offset Control Cycle Period

3. Set oscilloscope TIME/DIV to 10 ms. Magnify waveform for phase I period on CRT.

4. Ajust potentiometer A17R6 so that the amplitude of the charge waveform (positive going ramp) is minimum.

   Note: *The small charge waveform Ⓐ (see illustration) shown for the integrator output waveform should appear in the positive domain. If the primary charge waveform is a negative going ramp, the small charge waveform will appear in the negative domain.*



5-37. PHASE DETECTOR REFERENCE PHASE ADJUSTMENT

5-38. This adjustment sets the 90° detection phase signal input of the phase detector to an accurate 90 degrees in phase referenced to the 0° detection phase signal and maximizes measurement accuracy.

EQUIPMENT:

Reference Terminations:

0Ω	HP 16342A Calibration Equipment Kit
0S	HP 16342A Calibration Equipment Kit
50Ω	HP 16342A Calibration Equipment Kit
Capacitance termination (318 pF)	HP 16342A Calibration Equipment Kit

PROCEDURE:

1. Perform auto-calibration using the 0Ω, 0S, and 50Ω reference terminations at 10MHz (only).

   Note: *Use the terminations provided in the Calibration Equipment Kit (kit number: Model 16342A).*

2. Release the CALIBRATION function (by re-pressing the CALIBRATION key).

3. Connect the reference coaxial capacitor (318 pF at 10MHz) of the Calibration Equipment Kit to the UNKNOWN connector.

   Note: *The reference capacitor is calibrated in reference to the same 50Ω termination supplied in the kit.*

4. Set 4191A controls as follows:

DISPLAY A function	$\|\Gamma\|$
DISPLAY B function	θ (deg)
SPOT FREQ	10.0MHz
DC BIAS switch	OFF

5. Adjust trimmer capacitor A17C12 until DISPLAY B readout (phase angle) is the reference value of the reference capacitor (approximately 90°) within ±2 counts (±0.02°).

   Note: *Verify that DISPLAY A readout is within 0.9960 and 1.0000. If otherwise, check the reference capacitor and troubleshoot the instrument.*

5-39. MICROPROCESSOR CLOCK FREQUENCY ADJUSTMENT

5-40. This adjustment properly sets the frequency of the microprocessor operating clock as well as the execution times for various functions (frequency sweep, auto calibration, etc.) to their nominal values.

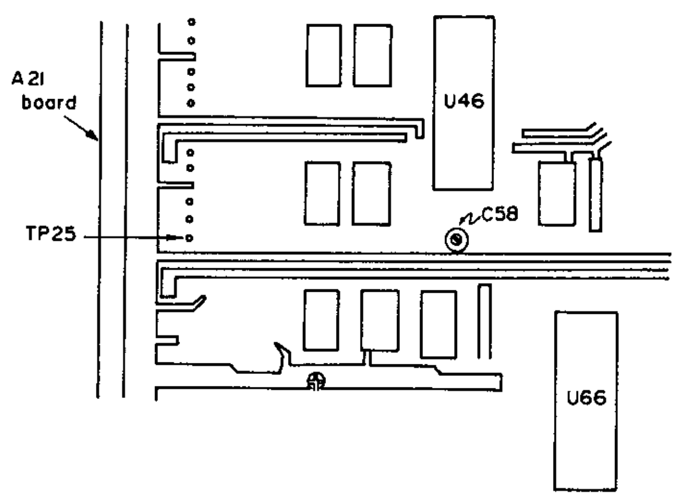
EQUIPMENT:

Frequency Counter .... HP 5340A
Connection Cable .... BNC to dual alligator clip cable

PROCEDURE:

1. Connect frequency counter input cable to A21TP25 and TP7 (GND). Use BNC to dual alligator clip cable. The A21 board is inside the top shield case.
2. Adjust trimmer capacitor A21C58 until the frequency counter display reads 975 kHz ±20 kHz.

   Note: Use a non-metallic tool for this adjustment.



5-41. DC BIAS VOLTAGE ADJUSTMENT

5-42. This adjustment eliminates any residual dc offset voltages from the A40 internal dc bias voltage supply circuit and sets the maximum bias output voltage to the specified value to optimize bias voltage accuracy.

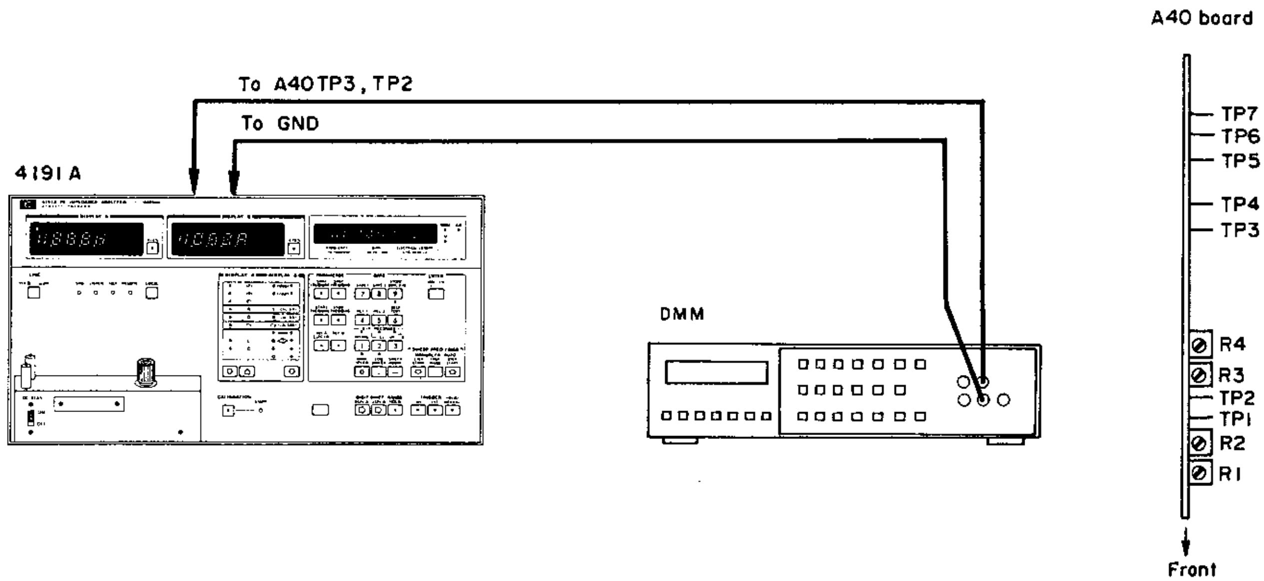


Figure 5-9. DC Bias Voltage Adjustment Setup.

EQUIPMENT:

Digital Voltmeter (DMM) .... HP 3455A
Voltmeter input cable .... Dual banana to dual alligator clip cable

PROCEDURE:

1. Set the 4191A internal dc bias voltage to 0V.
2. Connect the dc voltmeter (DMM) input to A40TP3.
3. Adjust potentiometer A40R3 (ZERO ADJ) for a 0V ±1mV readout on the dc voltmeter display.
4. Connect the dc voltmeter input to A40TP2.
5. Adjust potentiometer A40R1 (ZERO ADJ) for a 0V±1mV readout on the dc voltmeter display.
6. Set the 4191A internal dc bias voltage to 40V.
7. Adjust potentiometer A40R2 (–FS ADJ) for a –40V±1mV readout on the dc voltmeter display.
8. Connect the dc voltmeter input to A40TP3.
9. Adjust potentiometer A40R4 (+FS ADJ) for a 40V±1mV readout on the dc voltmeter display.

5-43. RF DIRECTIONAL BRIDGE TEMPERATURE ADJUSTMENT

5-44. This adjustment sets the stabilization control temperature of the A25 Heater Controller which regulates the operating temperature of the A9 RF Directional Bridge circuit assembly.

Note: This adjustment should be performed only when the A25 Heater Controller board has been repaired or when the posister heater or thermister temperature sensor has been replaced.

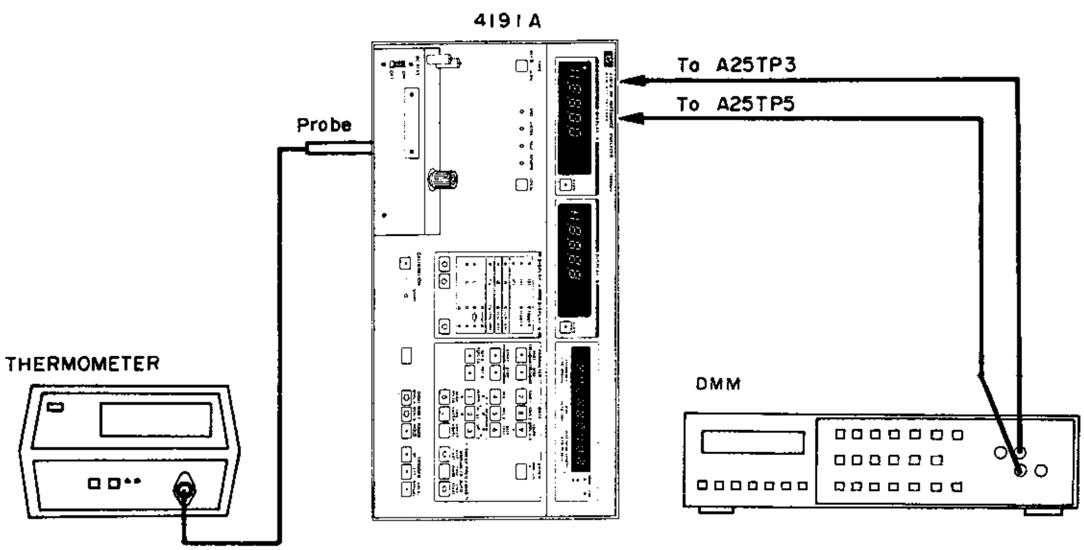


Figure 5-10. RF Directional Bridge Temperature Adjustment Setup.

EQUIPMENT:

Digital Multimeter	HP 3455A
Test lead	Dual banana to dual alligator clip lead
Thermometer	HP 2802A
Thermometer probe	HP 18641A

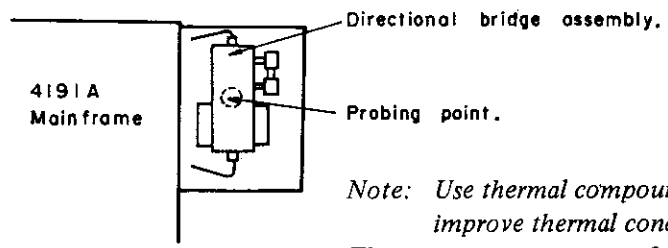
PROCEDURE:

Caution: **Be sure to turn instrument off before proceeding with the adjustment setups. Disconnect power cable plug from instrument socket.**

1. Stand the 4191A on its right side.
2. Remove the bottom cover from the UNKNOWN terminal deck.
3. Remove the A25 board and disconnect the cables from A25J1 and J2.

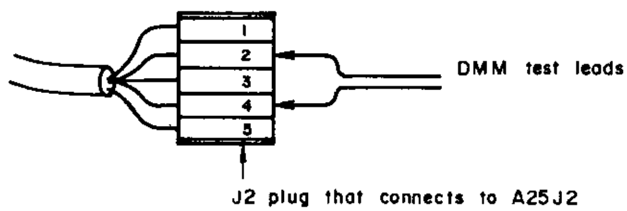
   Note: Allow at least 30 minutes for the temperature of the directional bridge assembly to stabilize.

4. Hold the thermometer probe to the center of the directional bridge assembly (see illustration).



Note: Use thermal compound to improve thermal conductivity.
Thermometer accuracy: ±0.5°C

5. Make a note of the thermometer readout as Tm with 0.1°C least significant digit resolution.
6. Connect the DMM test leads to pins 2 and 4 of J2 plug. Measure the resistance at an accuracy higher than ±10Ω and make a note of the DMM readout as Rm.



7. Calculate the center value of the optimum setting range of the temperature adjustment potentiometer A25R1 using the following equation:

$$Ra = Rm \cdot \exp\left\{-0.044 \times (30 - Tm)\right\} \times 1.237 \ (\Omega)$$

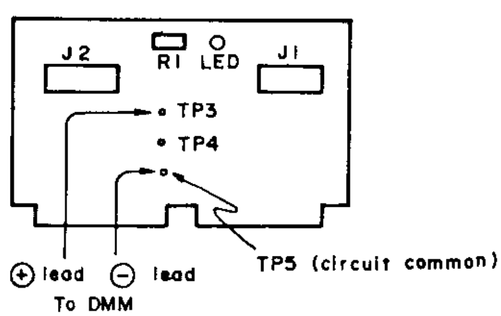
8. Connect the DMM positive input lead to A25TP3 and the negative input lead to circuit common.
9. Adjust potentiometer A25R1 for the calculated Ra value, ±50Ω on the DMM display.
10. Reconnect cable plugs J1 and J2 to their normal positions on the A25 board.
11. Turn instrument power on.

WARNING

Electrical shock hazard!
AC power line voltage is exposed. Do not touch A25 PC board patterns.

12. Verify that the LED indicator lamp on the A25 board begins flashing.

Note: The indicator lamp will not light when the ambient temperature is greater than 28°C (the Heater Controller stops functioning).



5-45. OPT 002 TEST FREQUENCY SYNTHESIZER LOCAL VTO ADJUSTMENT

5-46. This adjustment sets the maximum oscillation frequency of the A30 Test Frequency Synthesizer VTO so that the VTO covers the required frequency controllable range.

Note: A board frequency range on the VTO ensures coverage of the required frequency variable range by properly setting the maximum frequency.

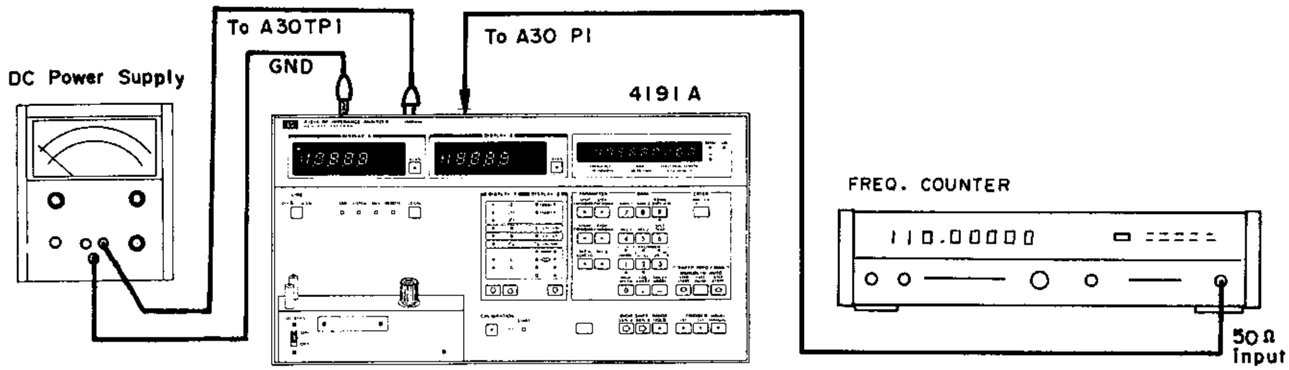


Figure 5-11. Opt. 002 Test Frequency Synthesizer VTO Adjustment Setup.

EQUIPMENT:

Frequency Counter .... HP 5340A
Connection Cable .... N type connector cable
Terminal Converter:
  N type female to SMC female .... -hp- 1250–1153
DC Power Supply .... HP 6224B
Power Supply output cable .... Dual banana to dual alligator clip cable

PROCEDURE:

1. Remove boards A3 and A31.
2. Connect the dual banana to dual alligator clip cable between A30TP1 and the dc power supply output as shown in Figure 5-11.

   Caution: Set dc power supply output voltage to zero before connecting output cable.
3. Disconnect the SMC connector cable from A30P1.
4. Connect the frequency counter input cable to A30P1.
5. Set the dc power supply output voltage to within 10.0 and 10.1V.

   Caution: Do not apply a negative dc voltage.
6. Adjust trimmer capacitor A30C1 until the frequency counter display readout is within 111.5 and 112.0MHz.

   Note: Use a non-metallic tool for this adjustment.
7. Reinstall A3 and A31 boards in their normal positions.
8. Reconnect the SMC connector cable to A30P1.

5-47. OPT 002 TEST FREQUENCY SYNTHESIZER FINAL VTO ADJUSTMENT

5-48. This adjustment sets the controllable frequency range of the A33 VTO to ensure generation of test frequency signals free of signal dead zones and parasitic oscillation at any test frequency setting.

EQUIPMENT AND PROCEDURE:

The A33 VTO board is identical to the A1 board of the basic instrument and has a different part number because of the option 002 circuit.

Adjustment can therefore be performed using the same equipment and procedure as for the A1 board adjustment. Follow the Test Frequency Synthesizer Adjustment in Paragraph 5-19 and, to make the procedure applicable to the A33 board, change portions of the adjustment procedure as follows:

1) Change the board number A1 in all the steps to read A33.
2) At steps 3 and 4, disconnect the SMC connectors (P1, P2 and P3) from the A32 board top plate and remove the A32 board.
3) At step 5, connect the alligator clip cable to XA33 pin 9L (instead of XA1 pin 9L).

5-49. OPT 004 ANALOG RECORDER OUTPUT ADJUSTMENT

5-50. This adjustment eliminates any residual dc offset voltages from the analog recorder outputs and sets the maximum output voltages to the specified values to maximize output voltage accuracy.

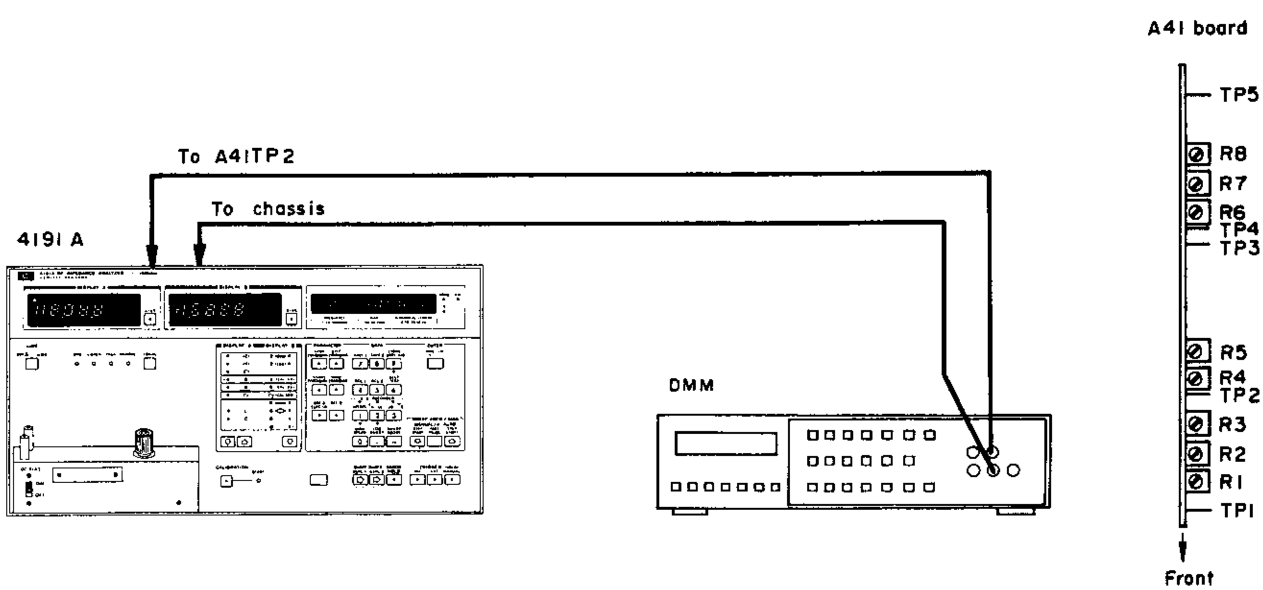


Figure 5-12. Opt. 004 Analog Recorder Output Adjustment Setup.

EQUIPMENT:

DC Voltmeter (DMM) .... HP 3455A
Voltmeter input cable .... Dual banana to dual alligator clip cable

PROCEDURE:

1. Press the **blue** key and ↓← LL key on the 4191A front panel.
2. Connect the dual banana plug to alligator clip cable to the DMM input and A41TP2 (connect negative lead to instrument chassis).
3. Connect a short clip lead to A41TP1 and to the chassis (ground TP1).
4. Adjust potentiometer A41R2 (-Aθ) for a 0±0.5 mV dc readout on the DMM display.
5. Connect the DMM input posititve lead to A41TP4.
6. Disconnect the short clip lead from TP1 and connect it to TP3 (ground TP3).
7. Adjust potentiometer A41R5 (-Bθ) for a 0±0.5 mV dc readout on the DMM display.
8. Remove the short clip lead.
9. Connect the DMM input positive lead to TP5, TP1 and TP3. Adjust potentiometers R7, R1, and R4 until the DMM display readout meets the test limits given in Table 5-8.

Table 5-8. Output Offset Zero Adjustments.

DMM input connection point	Adjustment potentiometer	Test limits	Adjustment condition
TP2	R2 (-Aθ)	0 ± 0.5mV	Ground TP1
TP4	R5 (-Bθ)	0 ± 0.5mV	Ground TP3
TP5	R7 (Cθ)	0 ± 0.5mV	–
TP1	R1 (+Aθ)	0 ± 0.5mV	–
TP3	R4 (+Bθ)	0 ± 0.5mV	–

10. Press the **blue** key and UR $\vec{\uparrow}$ key.
11. Connect the DMM input positive lead in accordance with Table 5-9 and adjust potentiometers R6, R3 and R8 for the test limits given in the table.

Table 5-9. Full Scale Output Adjustments.

DMM input connection point	Adjustment potentiometer	Test limits
TP3	R6 (B. F. S)	1000mV ± 0.5mV
TP1	R3 (A. F. S)	1000mV ± 0.5mV
TP5	R8 (C. F. S)	1000mV ± 0.5mV