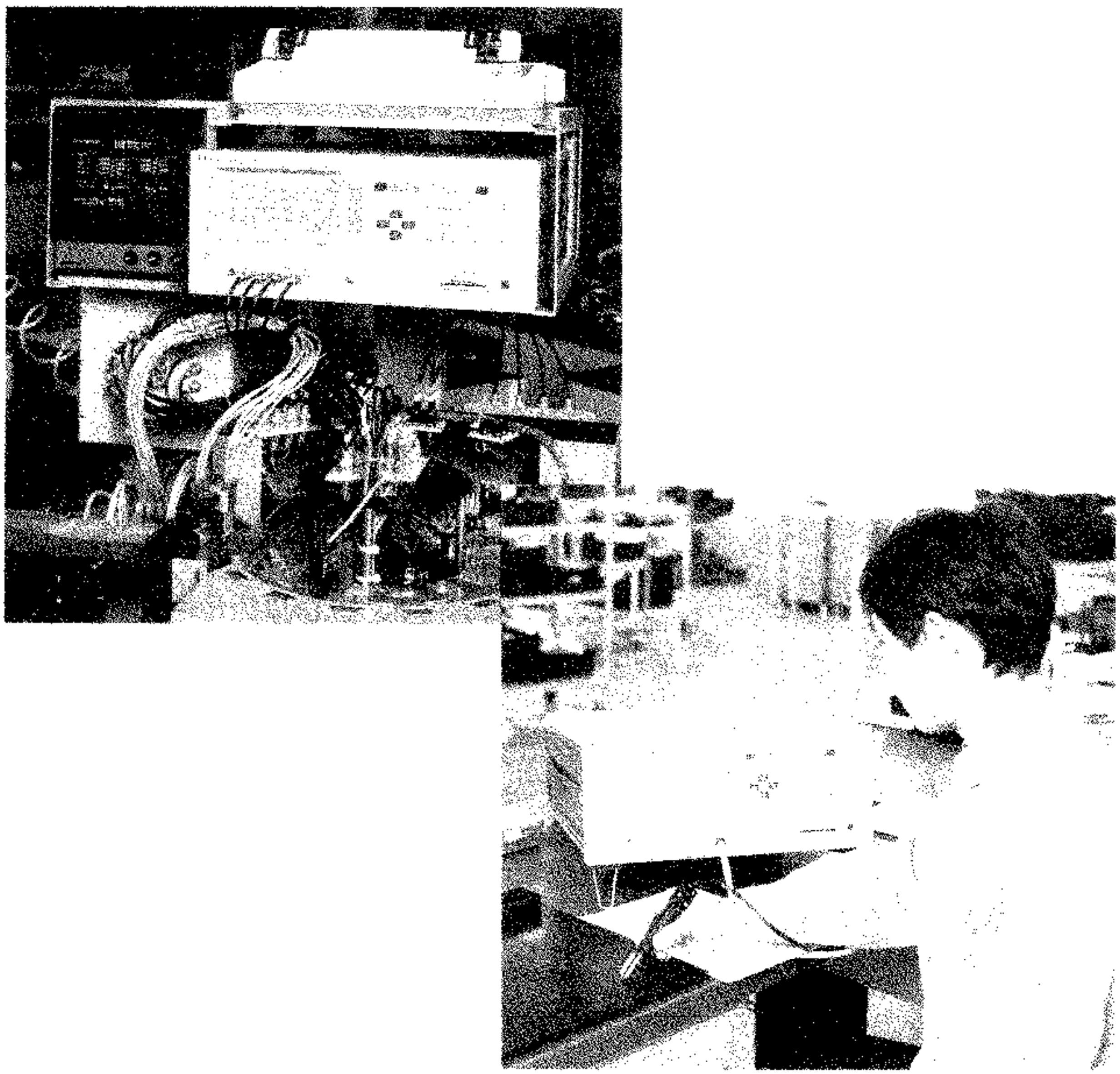
HEWLETT PACKARD

Effective Impedance Measurement Using OPEN/SHORT/LOAD Correction

Application Note 346-3



Introduction

Generally, impedance measurement instruments have a reference plane to define the measurement accuracy at the UNKNOWN terminals of its front panel. HP impedance measurement instruments have a cable length correction function which is applicable for defining the reference plane at the end of the HP test leads. In the actual measurement, a test fixture is connected to the reference plane. Test fixtures degrade the total measurement accuracy by their residual impedance. To improve this degradation, error correction should be applied. The OPEN/SHORT correction is the most popular correction technique used in recent impedance measurement instruments. But when complicated residuals exist (for example, when a scanner or a handler is used), or when using an extension cable whose length cannot be compensated with the cable length correction function, the OPEN/SHORT correction cannot minimize error sufficiently. To minimize these errors, the OPEN/SHORT/LOAD correction is very effective. This application note describes effective impedance measurements using the OPEN/SHORT/LOAD correction.

How OPEN/SHORT/LOAD correction differs from OPEN/SHORT correction

Here we compare the principle of the OPEN/SHORT/LOAD correction with the OPEN/SHORT correction.

1. OPEN/SHORT correction

In the OPEN/SHORT correction, the residuals of a test fixture can be modeled as an equivalent circuit shown in Figure 1.

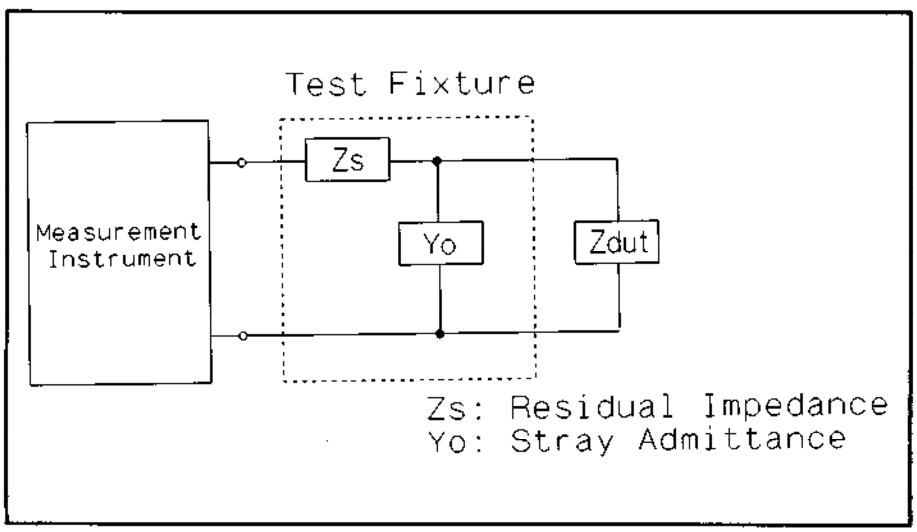


Figure 1. OPEN/SHORT Correction Model

Since Zs<<1/Yo, stray admittance Yo can be measured when the test terminals are open. Similarly residual impedance Zs can be measured when the test terminals are shorted. Using this correction data, Device-Under-Test(DUT) measurement data Zm can be compensated with the following equation. Then a true value, Zdut, can be derived from Zm by removing the residuals of a test fixture.

$$Zdut = \frac{Zm - Zs}{1 - (Zm - Zs)Yo}$$

where,

- Zdut: True value of DUT
- Zm: Measurement value of DUT
- Yo: Admittance of OPEN condition
- Zs: Impedance of SHORT condition

(Note that each parameter has real and imaginary components.)

As it has been shown, simple measurement errors can be mathematically compensated by using the OPEN/SHORT correction. However, this specific technique is usable only when performing measurements under the following test conditions:

- Using an HP test fixture
- Measurements at the front panel terminals
- Measurements using an HP test cable compensated for electrical length

There are numerous test conditions where complicated impedance parasitics cannot be modeled as the simple equivalent circuit in Figure 1. The OPEN/SHORT correction will not truly compensate for errors introduced in the following test situations:

- Scanner/multiplexer/matrix switches
- Component handlers
- Custom-made test fixture
- Non-standard length cable test leads
- External DC bias circuitry
- Balun transformer
- Additional filters and amplifiers

In addition, the OPEN/SHORT correction has the following severe limitations:

- Not able to correlate measurement values from different test instruments
- Not able to improve measurement repeatability

To solve these test limitations and issues, the OPEN/SHORT/LOAD correction is necessary.

2. OPEN/SHORT/LOAD correction

The OPEN/SHORT/LOAD correction requires the measurement data of a standard DUT with known values in addition to the OPEN/SHORT measurement data. The residuals of a test fixture can be defined as a four-terminal network expressed with A, B, C, D parameters as shown in Figure 2.

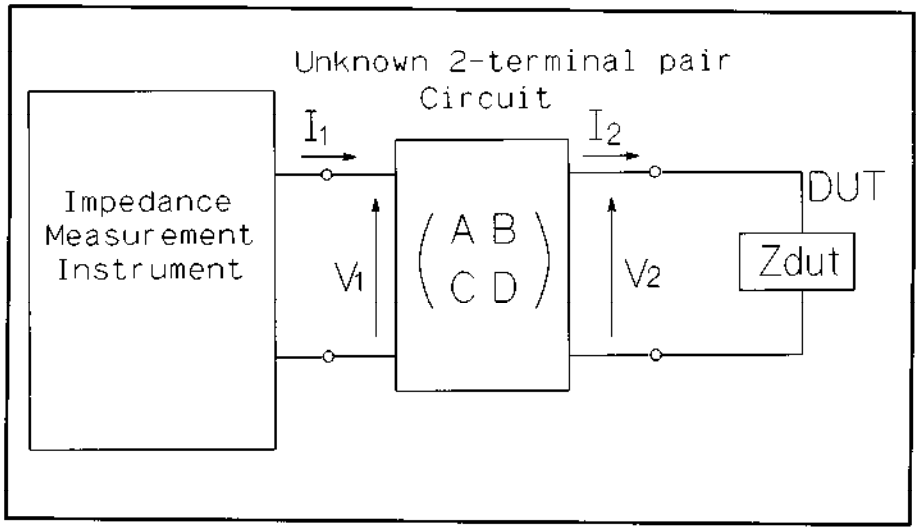


Figure 2. OPEN/SHORT/LOAD Correction Model

With the assumption that a DUT with an impedance of Z_2 is connected to the front panel terminals, the instrument would measure an impedance value of Z_1. The following relationship defines Z_1.

Given: $Z_1 = V_1/I_1$ and $Z_2 = V_2/I_2$

$$Z_1 = \frac{AV_2 + BI_2}{CV_2 + DI_2} = \frac{AZ_2 + B}{CZ_2 + D}$$

The parameters of A,B,C and D can be removed when using the following definitions:

Zo: Measured value when the instrument terminals are open.
Zs: Measured value when the terminals are shorted.
Zsm: Measured value of the standard DUT when connected to the test setup.
Zstd: True (or expected) value of the reference DUT.
Zxm: Measured value of DUT.
Zdut: Corrected value of DUT.

All of the analysis yields an equation that corrects for impedance parasitcs:

$$Zdut = \frac{Zstd(Zo - Zsm)(Zxm - Zs)}{(Zsm - Zs)(Zo - Zxm)}$$

(Note that each parameter has real and imaginary components.)

The OPEN/SHORT/LOAD correction function is built into the following HP LCR meters:

- HP 4263A
- HP 4278A
- HP 4279A
- HP 4284A
- HP 4285A

Otherwise, when using other LCR meters or analyzers, a computer can be programmed to make the OPEN/SHORT/LOAD corrections through HP-IB.

Consideration with OPEN/SHORT/LOAD correction

When performing OPEN/SHORT/LOAD correction, the following points should be considered.

1. OPEN correction

It is important to measure the stray admittance of a test fixture accurately in the OPEN correction. When getting the OPEN correction data, the distance between measurement teminals should be the same as the distance that is required for actually holding the DUT.

2. SHORT correction

It is important to measure the residual impedance of a test fixture accurately in the SHORT correction. When getting the SHORT correction data, the measurement terminals should be shorted or connected to a shorting device. When using the shorting device, the residual impedance must be much less than impedance value of DUT.

3. LOAD correction

In the LOAD correction, selection and measurement of the standard DUT should be considered carefully.

(1) Selection of standard DUT

When selecting the standard DUT, there is no restriction that inductor must be used for inductance measurement, or capacitor must be used for a capacitance measurement. Any device can be used if its impedance value is accurately known. It is important to use a stable DUT not susceptible to influences of environment such as temperature or magnetic fields. From this viewpoint, capacitors or resistors are better suited than inductors which are more susceptible to the environment.

Especially in the case of measuring low loss(low D, high Q low ESR) DUTs, it is necessary to use as low loss standard DUT as possible. Since it is difficult to get low loss inductor but easy to get capacitor, low loss capacitors are recommended for the standard DUT.

(2) Impedance value of standard DUT

When measuring a DUT's various impedance values, it is recommended to use a 100 Ω to 1 kΩ device as the standard DUT. It can be measured accurately by impedance measurement instruments and is not susceptible to contact resistance or residuals.

When measuring a DUT of one impedance value, it is recommended that the standard DUT have a impedance value close to that of the DUT. By using a standard DUT, we can reduce the non-linear errors near its impedance value. However, when the DUT's impedance value is very low or very high, it is recommended to use a standard DUT of 100 Ω or 1kΩ, whose value isn't close to the impedance of the DUT. When a low or high impedance standard DUT is used, the reference value (described later) of the standard DUT cannot be obtained accurately, and it may cause the abnormal measurement results, not the true value of the DUT.

(3) Referencing the standard DUT

To perform the OPEN/SHORT/LOAD correction, it is necessary to measure the standard DUT for a reference value (known value) beforehand. When measuring it, it is important to use a high accuracy instrument and to set its measurement conditions(such as integration time or averaging time) so that it can measure as accurately as possible. To minimize the measurement error, the standard DUT should be measured using a direct-connected test fixture after performing the OPEN/SHORT correction.

4. Measurement condition of impedance measurement instruments when performing the OPEN/SHORT/LOAD correction

Impedance measurement equipment with the OPEN/SHORT/LOAD correction function will automatically set the measurement condition (such as integration time or averaging time) so that it can perform error correction with highest accuracy.

If performing the OPEN/SHORT/LOAD correction for instruments not equipped with the OPEN/SHORT/LOAD correction function using an external controller, the measurement conditions should be set to measure correction data as accurately as possible.

Example of actual OPEN/SHORT/LOAD correction

Figure 3 shows the measurement example to extend the HP 4285A's measurement terminal using 16048E(4m cable). In this case, it is necessary to perform the OPEN/SHORT/LOAD correction since the HP 4285A cannot compensate the 4m extension cable with its cable length correction function. Figure 4 shows the comparison of measurement error between 100pF capacitor measurement with the OPEN/SHORT correction and that with the OPEN/SHORT/LOAD correction. A 47pF capacitor is used as a standard DUT. This measurement result shows the error cannot be minimized sufficiently with the OPEN/SHORT correction, but can be compensated with an OPEN/SHORT/LOAD correction as shown by the plot.

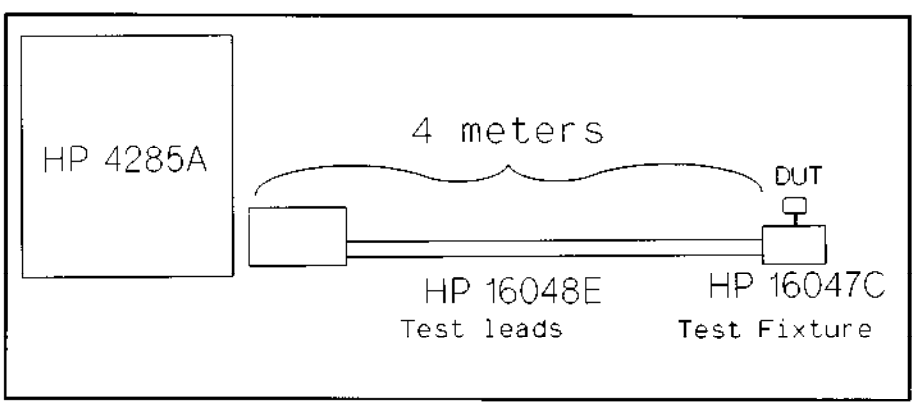


Figure 3. Cable Extension Using an HP 16048E (4m)

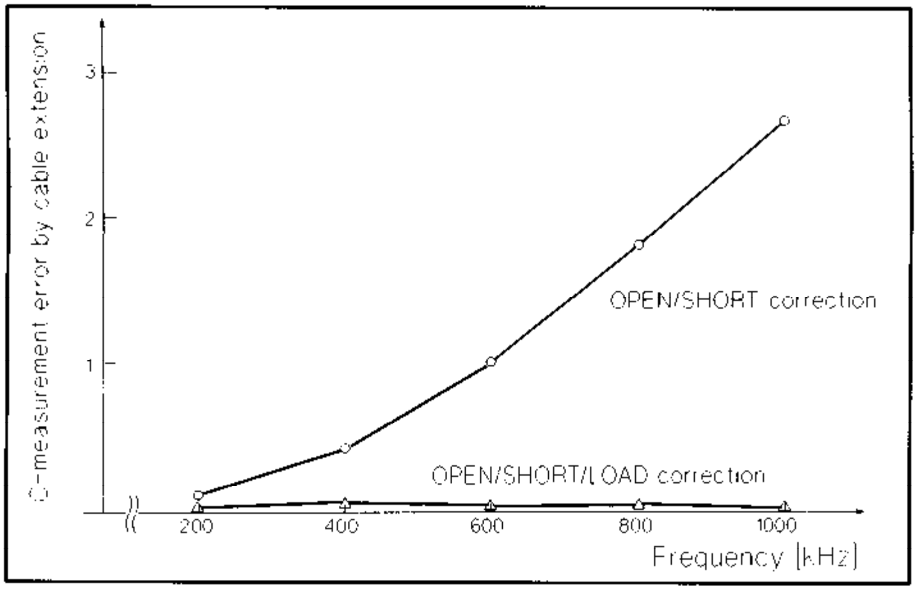


Figure 4. Comparison Between OPEN/SHORT Correction and OPEN/SHORT/LOAD Correction

OPEN/SHORT/LOAD correction with an external controller

The OPEN/SHORT/LOAD correction can be accomplished with simple key operation when using an impedance measurement instruments equipped with the OPEN/SHORT/LOAD correction function. When using instruments not equipped with the OPEN/SHORT/LOAD correction function, it is possible to perform the OPEN/SHORT/LOAD correction by executing the correction calculation with an external controller. But this method has the following trade-off problems as the comparison with the correction of a measurement instrument alone.

- Complicated operation
- Slow measurement speed due to data transfer time

Figure 5 shows an example program to execute the OPEN/SHORT/LOAD correction for capacitor measurement using the HP 4194A Impedance Analyzer. In this program, the measurement is performed at one frequency point with a manual trigger mode.

Line 130-190	Setting measurement condition.
Line 210-270	Measuring impedance of OPEN condition in G-B mode.
Line 300-330	Measuring impedance of SHORT condition in R-X mode.
Line 350-610	Measuring impedance of the standard DUT after inputting Cs-D or Cp-D value of valued standard DUT.
Line 660-690	Selecting DUT mode(Cs-D or Cp-D).
Line 710-1010	Executing correction calculation after measuring impedance of DUT, then displaying the result.

Conclusion

This application note shows the principle of the OPEN/SHORT/LOAD correction and some points to be considered in the execution. With the proper OPEN/SHORT/LOAD correction, measurement comes higher in accuracy.

"Reference" Impedance measurement handbook (5091−3000)

Figure 5. Sample Program for HP 4194A OPEN/SHORT/LOAD Correction

```
10   !   OPEN/SHORT/LOAD CORRECTION (4194A C-D MEAS)
20   !
30   CLEAR SCREEN
40   OPTION BASE 1
50   DIM Rcor(3),Xcor(3)          ! CORRECTION DATA:Zcor(*)=Rcor(*)+jXcor(*)
60   COMPLEX Zcor(10),Zstd,Zxm,Z  ! LOAD VALUE:Zstd=Rstd+jXstd
70                                ! DUT MEASUREMENT VALUE:Zxm=Rxm+jXxm
80                                ! CORRECTED RESULT:Z=R+jX
90   Freq=1.000E+6                                  ! f=1MHz
100  !
110  ASSIGN @Adrs TO 717
120  REMOTE @Adrs
130  !                                              << 4194A SET UP >>
140  OUTPUT @Adrs;"FNC1"                            ! IMPEDANCE MEAS MODE
150  OUTPUT @Adrs;"SWM3"                            ! MANUAL MEAS
160  OUTPUT @Adrs;"MANUAL=1M"                       ! f=1MHz
170  OUTPUT @Adrs;"TRGM2"                           ! EXT/MAN TRG MODE
180  OUTPUT @Adrs;"OPN0"                            ! OPEN OFFSET:OFF
190  OUTPUT @Adrs;"SHT0"                            ! SHORT OFFSET:OFF
200  !
210  !                                              << OPEN MEASUREMENT >>
220  OUTPUT @Adrs;"IMP9"                            ! SET 4194A TO G-B
230  PRINT "MEASURE OPEN (TYPE 'CONT')"
240  PAUSE
250  CALL Measure(G,B,@Adrs)                        ! OPEN MEASUREMENT
260  Rcor(2)=G/(G*G+B*B)                            !  -> Rcor(2),Xcor(2)
270  Xcor(2)=-B/(G*G+B*B)
280  !
290  !                                              << SHORT MEASUREMENT >>
300  OUTPUT @Adrs;"IMP2"                            ! SET 4194A TO R-X MODE
310  PRINT "MEASURE SHORT (TYPE 'CONT')"
320  PAUSE
330  CALL Measure(Rcor(3),Xcor(3),@Adrs)            ! SHORT MEASUREMENT
340  !                                                 -> Rcor(3),Xcor(3)
350  !                                              << LOAD MEASUREMENT >>
360  INPUT "MODE OF LOAD : 1.Cs-D   2.Cp-D ",Mode   ! SELECT Cs-D OR Cp-D
370  IF Mode=1 THEN
380    OUTPUT @Adrs;"IMP2"                          ! SET 4194A TO  R-X
390    INPUT "Cs OF LOAD=",Cstd                     ! INPUT LOAD VALUE
400    INPUT "D OF LOAD=",Dstd                      !
410    Xstd=-1/(2*PI*Freq*Cstd)                     ! Cs,D -> Rstd,Xstd
420    Rstd=Xstd*Dstd                               !
430    PRINT "MEASURE LOAD(TYPE 'CONT')"
440    PAUSE
450    CALL Measure(Rcor(1),Xcor(1),@Adrs)          ! LOAD MEASUREMENT
460  END IF                                         !  ->Rcor(1),Xcor(1)
470  !
480  IF Mode=2 THEN
490    OUTPUT @Adrs;"IMP9"                          ! SET 4194A TO G-B
500    INPUT "Cp OF LOAD=",Cstd                     ! INPUT LOAD VALUE
510    INPUT "D OF LOAD=",Dstd                      !
520    Bstd=2*PI*Freq*Cstd                          ! Cp,D -> Rstd,Xstd
530    Gstd=-Dstd*Bstd                              !
540    Rstd=Gstd/(Gstd*Gstd+Bstd*Bstd)              !
550    Xstd=-Bstd/(Gstd*Gstd+Bstd*Bstd)             !
560    PRINT "MEASURE LOAD(TYPE 'CONT')"
570    PAUSE
580    CALL Measure(G,B,@Adrs)                      ! LOAD MEASUREMENT
590    Rcor(1)=G/(G*G+B*B)                          !  -> Rcor(1),Xcor(1)
600    Xcor(1)=-B/(G*G+B*B)
610  END IF
620  !
630  MAT Zcor= CMPLX(Rcor,Xcor)                     ! Zcor(*)=Rcor(*)+jXcor(*)
640  Zstd=CMPLX(Rstd,Xstd)                          ! Zstd=Rstd+jXstd
650  !
660  !                                              << SELECT DUT MODE >>
670  INPUT "MODE OF DUT : 1.Cs-D  2.Cp-D",Dmode     !
680  IF Dmode=1 THEN OUTPUT @Adrs;"IMP2"            ! Cs-D -> SET 4194A TO R-X
690  IF Dmode=2 THEN OUTPUT @Adrs;"IMP9"            ! Cp-D -> SET 4194A TO G-B
700  PRINT "MEASURE DUT(TYPE CONT!)"
710  PAUSE
720  !                                              << DUT MEASUREMENT >>
730  P=1
740  WHILE P<>0                                     !
750    CALL Measure(Gxm,Bxm,@Adrs)
760    IF Dmode=1 THEN                              ! Cs-D
770      Rxm=Gxm                                    !
780      Xxm=Bxm                                    !
790    END IF
800    IF Dmode=2 THEN                              ! Cp-D
```

```
810         Rxm=Gxm/(Gxm*Gxm+Bxm*Bxm)                     !
820         Xxm=-Bxm/(Gxm*Gxm+Bxm*Bxm)                    !
830       END IF
840       Zxm=CMPLX(Rxm,Xxm)                              ! Zxm=Rxm+jXxm
850       Z=FNCalcurate(Zcor(*),Zstd,Zxm)                 ! CALCURATION
860       R=REAL(Z)                                       ! Z=R+jX
870       X=IMAG(Z)                                       !
880       IF Dmode=1 THEN                                 !
890         D=R/X                                         ! R,X -> Cs,D
900         Cs=-1/(2*PI*Freq*X)                           !
910         PRINT "Cs,D=",Cs,D                            !
920       END IF
930       IF Dmode=2 THEN                                 !
940         D=R/X                                         ! R,X -> Cp,D
950         B=-X/(R*R+X*X)                                !
960         Cp=B/(2*PI*Freq)                              !
970         PRINT "Cp,D=",Cp,D                            !
980       END IF
990       INPUT "CONTINUE?(N=0)",P
1000    END WHILE
1010    END
1020    !
1030    DEF FNCalcurate(COMPLEX A(*),COMPLEX B,COMPLEX C)  ! << CALCURATION >>
1040      COMPLEX D                                        !
1050      D=B*(C-A(3))*(A(1)-A(2))                         !
1060      D=D/((C-A(2))*(A(1)-A(3)))                       !
1070      RETURN D                                         !
1080    FNEND
1090    !
1100    SUB Measure(M,N,@Adrs)                            ! << MEASUREMENT >>
1110      S=SPOLL(@Adrs)                                  ! CLEAR STAT BYTE
1120      OUTPUT @Adrs;"RQS2"                             ! ENABLE BIT 2 OF STAT BYTE
1130      OUTPUT @Adrs;"TRIG"                             ! TRIGGER 4194A
1140      LOOP                                            ! WAIT UNTIL MEAS END
1150        EXIT IF BINAND(SPOLL(@Adrs),2)                !
1160      END LOOP                                        !
1170      !
1180      OUTPUT @Adrs;"MKRA?"                            ! MEAS DATA -> M,N
1190      ENTER @Adrs;M                                   !
1200      OUTPUT @Adrs;"MKRB?"                            !
1210      ENTER @Adrs;N                                   !
1220    SUBEND
```

Appendix. Correction Capability of HP Instruments

Model No.	Correction Capability	Cable Length Correction
HP 4284A	OPEN/SHORT/LOAD Correction Multi Channel Correction (Opt.301)	0m/1m 0m/1m/2m/4m (Opt.006)
HP 4285A	OPEN/SHORT/LOAD Correction Multi Channel Correction (Opt.301)	0m/1m/2m
HP 4278A	OPEN/SHORT/LOAD Correction Multi Channel Correction (Opt..301)	0m/1m/2m
HP 4279A	OPEN/SHORT/LOAD Correction Multi Channel Correction	0m/1m/2m
HP 4263A	OPEN/SHORT Correction OPEN/SHORT/LOAD Correction (via HP-IB)	0m/1m/2m
HP 4274/75A	OPEN/SHORT Correction	0m/1m
HP 4276/77A	OPEN/SHORT Correction	0m/1m
HP 4192A	OPEN/SHORT Correction	0m/1m
HP 4194A	OPEN/SHORT Correction	0m/1m
HP 4195A with HP 41951A	OPEN/SHORT Correction	

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Latin American Region Headquarters
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