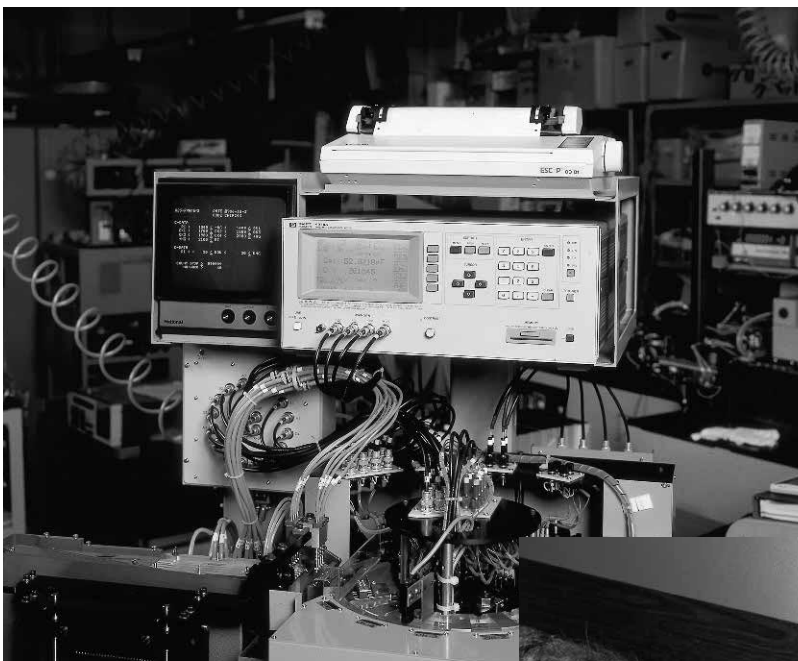
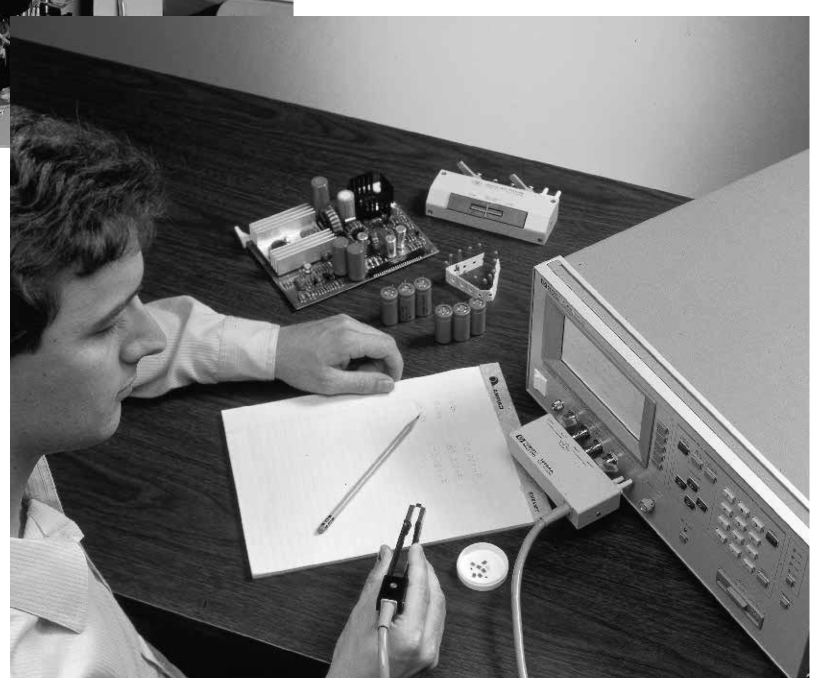
Effective Impedance Measurement Using OPEN/SHORT/LOAD Correction

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.

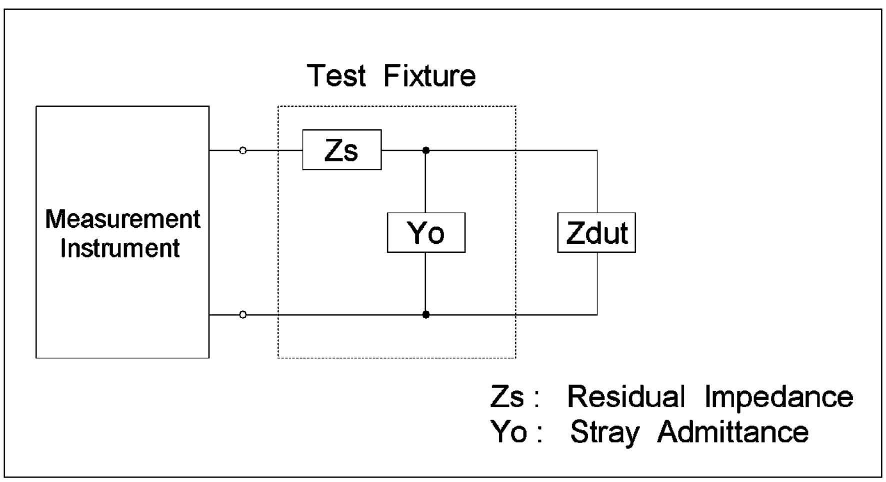


Figure 1. OPEN/SHORT Correction Model

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 parasitic 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.

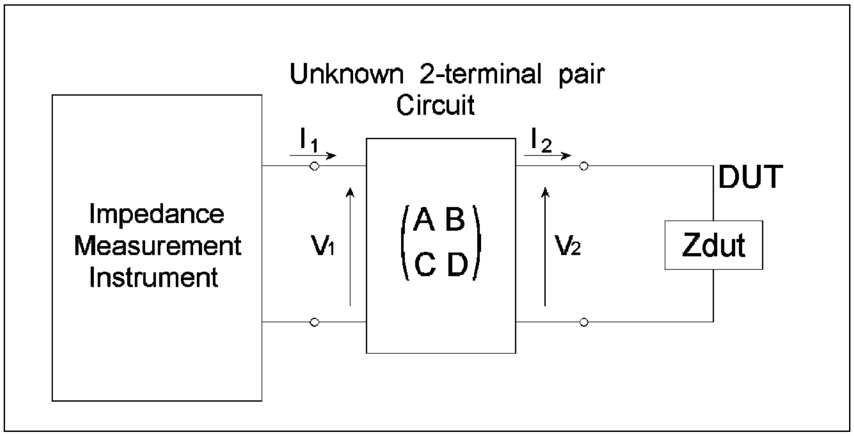


Figure 2. OPEN/SHORT/LOAD Correction Model

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/analyzers:

- HP 4263B
- HP 4278A
- HP 4279A
- HP 4284A
- HP 4285A
- HP 4286A
- HP 4291B
- HP 4395A with opt. 010 and HP 43961A
- HP 4396B with opt. 010 and HP 43961A

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 terminals 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 sited 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 100Ω to 1kΩ 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 100Ω 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

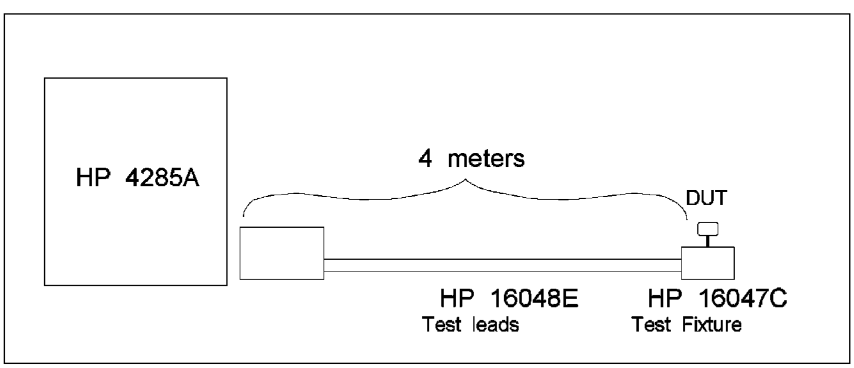


Figure 3. Cable Extension Using an HP 16048E (4m)

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.

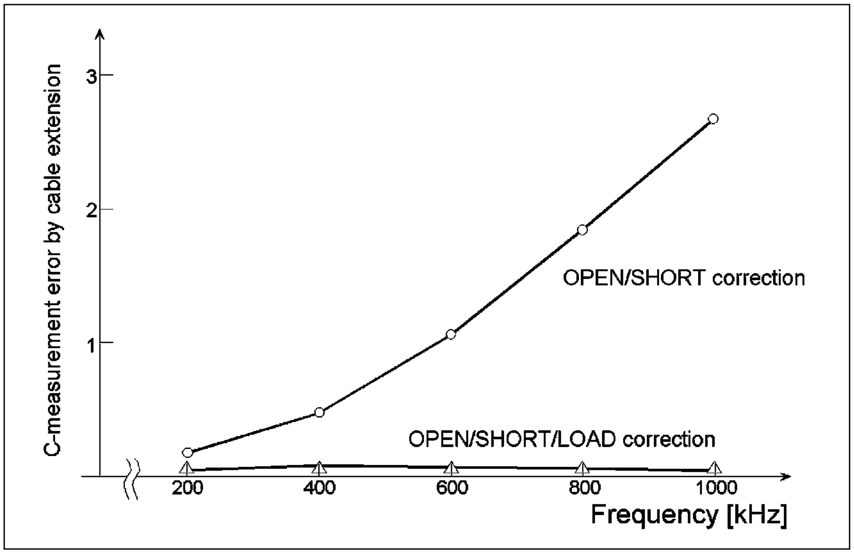


Figure 4. Comparison Between OPEN/SHORT Correction and OPEN/SHORT/LOAD Correction

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 tradeoff 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 4192A	OPEN/SHORT Correction	0m/1m
HP 4194A	OPEN/SHORT Correction	0m/1m
HP 4195A(*) with HP 41951A	OPEN/SHORT Correction	none (Electrical Length Correction)
HP 4263A(*)	OPEN/SHORT Correction OPEN/SHORT/LOAD Correction (via HP-IB)	0m/lm/2m
HP 4263B	OPEN/SHORT/LOAD Correction	0m/1m/2m/4m
HP 4274A(*) /HP 4275A(*)	OPEN/SHORT Correction	0m /lm
HP 4276A(*) /HP 4277A(*)	OPEN/SHORT Correction	0m/1m
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 4284A	OPEN/SHORT/LOAD Correction Multi Channel Correction (Opt.301)	0m/lm 0m/1m/2m/4m (Opt.006)
HP 4285A	OPEN/SHORT/LOAD Correction Multi Channel Correction (Opt.301)	0m/1m/2m
HP 4286A	OPEN/SHORT/LOAD Correction	none (Electrical Length Correction)
HP 4291A(*)	OPEN/SHORT/LOAD Correction	none (Electrical Length Correction)
HP 4291B	OPEN/SHORT/LOAD Correction	none (Electrical Length Correction)
HP 4395A with Opt.010,43961A	OPEN/SHORT/LOAD Correction	none (Electrical Length Correction)
HP 4396B with Opt.010,43961A	OPEN/SHORT/LOAD Correction	none (Electrical Length Correction)

(*) Obsolete

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