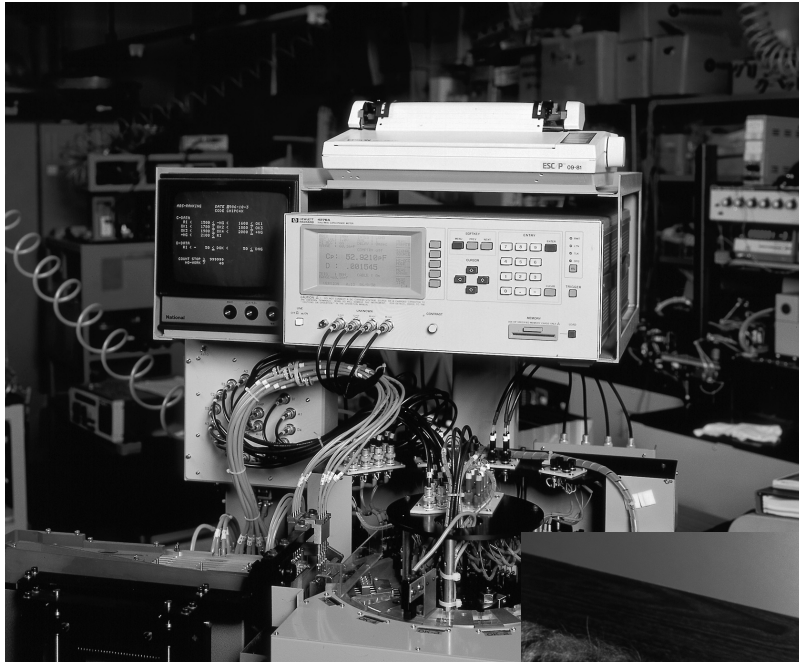

Effective Impedance Measurement Using OPEN/SHORT/LOAD Correction

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.

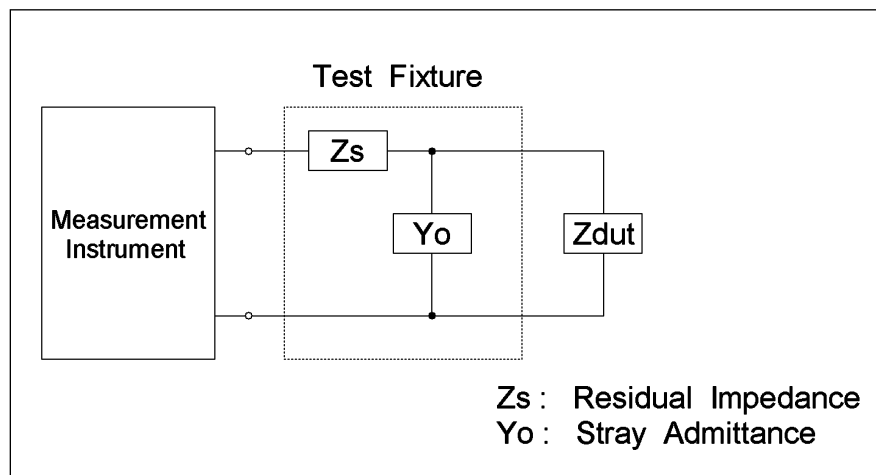


Figure 1. OPEN/SHORT Correction Model

Since $Z_s \ll 1/Y_o$, stray admittance Y_o can be measured when the test terminals are open. Similarly residual impedance Z_s can be measured when the test terminals are shorted. using this correction data, Device-Under-Test(DUT) measurement data Z_m can be compensated with the following equation. Then a true value, Z_{dut} , can be derived from Z_m by removing the residuals of a test fixture.

$$Z_{dut} = \frac{Z_m - Z_s}{1 - (Z_m - Z_s)Y_o}$$

where,

Z_{dut} : True value of DUT

Z_m : Measurement value of DUT

Y_o : Admittance of OPEN condition

Z_s : 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.

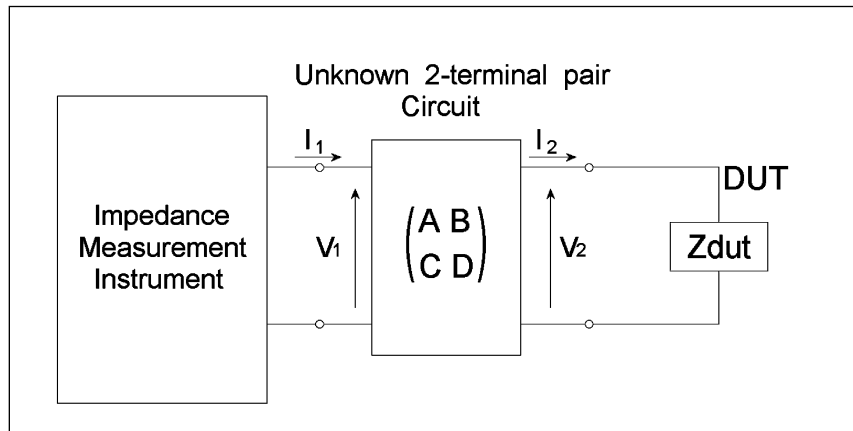


Figure 2. OPEN/SHORT/LOAD Correction Model

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 .

$$\text{Given: } Z_1 = V_1/I_1 \text{ and } Z_2 = V_2/I_2$$

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

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 parasites:

$$Z_{dut} = \frac{Z_{std}(Z_o - Z_{sm})(Z_{xm} - Z_s)}{(Z_{sm} - Z_s)(Z_o - Z_{xm})}$$

(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 100 Ω to 1k Ω 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 $1k\Omega$, 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

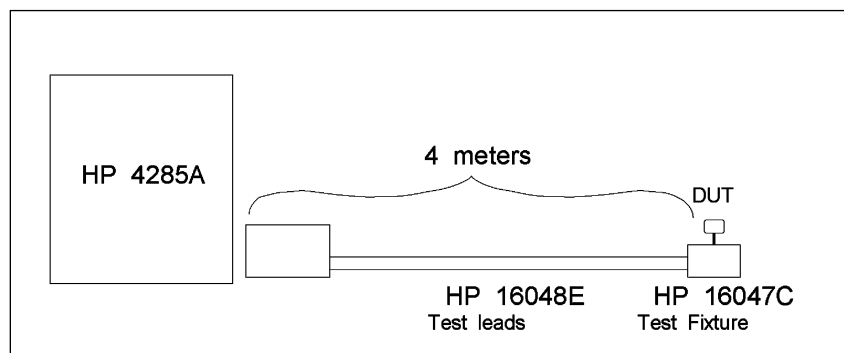


Figure 3. Cable Extension Using an HP 16048E (4m)

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.

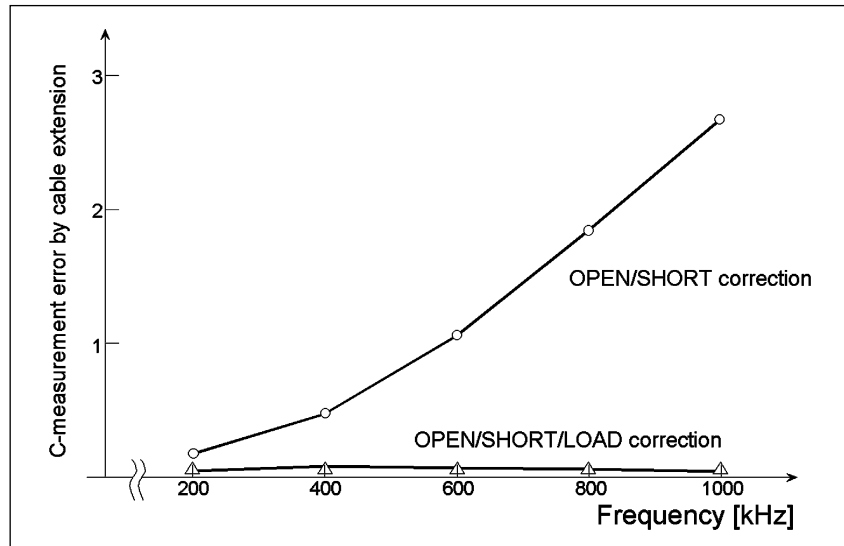


Figure 4. Comparison Between OPEN/SHORT Correction and OPEN/SHORT/LOAD Correction

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 !
140 OUTPUT @Adrs;"FNC1" << 4194A SET UP >>
150 OUTPUT @Adrs;"SWM3" ! IMPEDANCE MEAS MODE
160 OUTPUT @Adrs;"MANUAL=1M" ! MANUAL MEAS
170 OUTPUT @Adrs;"TRGM2" ! f=1MHz
180 OUTPUT @Adrs;"OPNO" ! EXT/MAN TRG MODE
190 OUTPUT @Adrs;"SHT0" ! OPEN OFFSET:OFF
200 ! ! SHORT OFFSET:OFF
210 !
220 OUTPUT @Adrs;"IMP9" << OPEN MEASUREMENT >>
230 PRINT "MEASURE OPEN (TYPE 'CONT')" ! SET 4194A TO G-B
240 PAUSE
250 CALL Measure(G,B,@Adrs) ! OPEN MEASUREMENT
260 Rcor(2)=G/(G*B+B*B) ! -> Rcor(2),Xcor(2)
270 Xcor(2)=-B/(G*B+B*B)
280 !
290 !
300 OUTPUT @Adrs;"IMP2" << SHORT MEASUREMENT >>
310 PRINT "MEASURE SHORT (TYPE 'CONT')" ! SET 4194A TO R-X MODE
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 !
530 Gstd=-Dstd*Bstd ! Cp,D -> Rstd,Xstd
540 Rstd=Gstd/(Gstd*Bstd+Bstd*Bstd) !
550 Xstd=-Bstd/(Gstd*Bstd+Bstd*Bstd) !
560 PRINT "MEASURE LOAD(TYPE 'CONT')" !
570 PAUSE
580 CALL Measure(G,B,@Adrs) ! LOAD MEASUREMENT
590 Rcor(1)=G/(G*B+B*B) ! -> Rcor(1),Xcor(1)
600 Xcor(1)=-B/(G*B+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 !
670 INPUT "MODE OF DUT : 1.Cs-D 2.Cp-D",Dmode << SELECT DUT MODE >>
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 !
730 P=1 << DUT MEASUREMENT >>
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/1m/2m
HP 4263B	OPEN/SHORT/LOAD Correction	0m/1m/2m/4m
HP 4274A(*) /HP 4275A(*)	OPEN/SHORT Correction	0m /1m
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/1m 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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