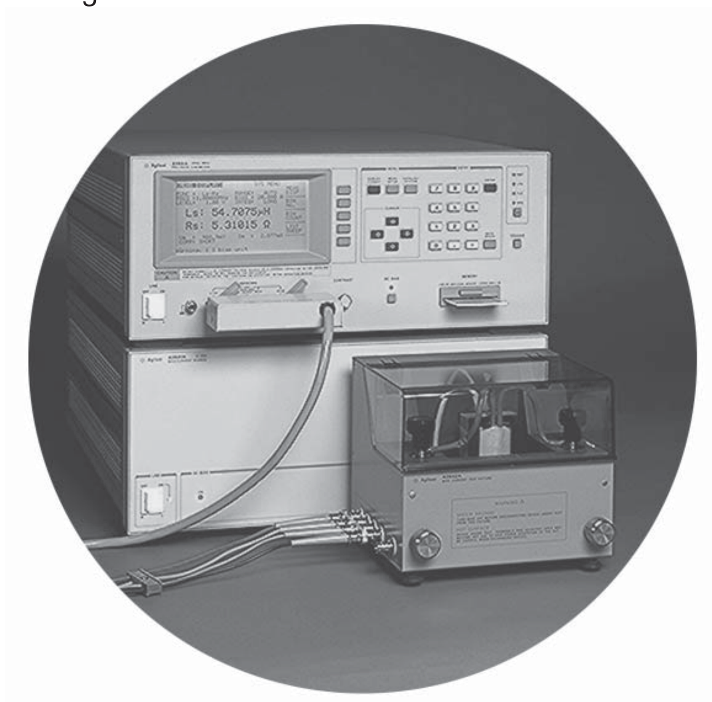
Agilent
Wide Range DC Current Biased Inductance Measurement

Application Note 369-8

Agilent E4980A Precision LCR Meter
Agilent 4284A Precision LCR Meter
Agilent 42841A Bias Current Source



Introduction

A large number of switching power supply inductors with extended high frequency characteristics have recently been developed. The reason for this is the increase in the switching frequency to reduce size of switching power supplies which are being built using electronic components which are more compact than are conventional components. However, if components which are not suitable for high frequency are used, the increase in the frequency lowers the efficiency of the switching power supply and creates electrical noise. Consequently, lower noise components and circuits for use at higher frequencies must be developed for future switching power supply designs.

Inductors are one of the easiest components to reduce in size by raising the frequency and will require the development of low-loss, low leakage cores. The development and production of such inductors requires DC current biased inductance measurements to evaluate the inductance characteristics under actual operating conditions.

This application note describes DC current biased inductance measurements that are more accurate and made over a wider frequency range than was previously possible.

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Problems concerning DC current biased inductance measurements

DC current biased inductance measurements involve the following problems.

- Measurement preparations and procedures are time-consuming
- An external bias circuit is required
  - Setting and confirming current values are troublesome
  - Automation of measurement procedures is difficult
  - Safety problems
- Frequency range is insufficient
- Not enough bias current can be generated
- Measurement accuracy is not guaranteed

Solutions offered by the Agilent E4980A or 4284A and Agilent 42841A

The E4980A or 4284A precision LCR meter (with Option E4980A-002/4284A-002 current bias interface) in combination with the 42841A bias current source ensures simple and safe DC current biased inductance measurements. The E4980A and 4284A allow for DC current biased inductance measurements with the following advantages.

- Wide 20 Hz to 2 MHz (E4980A), 1 MHz (4284A) frequency range measurements
- DC current biased inductance measurements up to 40 A using two the 42841As,
- Basic accuracy of 1%
- List sweep function for bias sweep measurements of up to 10 points
- The bias current is easily set using the 4284A's front panel keys or by using an external controller via GPIB.
- The 42842A/B bias current test fixtures which protect the operator and instrument are provided.
- Built-in memory function and removable memory (USB memory for E4980A, memory card for 4284A) for storing instrument setups

Measurement Preparation

Accessories required

When DC current biased inductance measurements are made using an E4980A or 4284A, the accessories required depend on the maximum bias current to be used. Table 1 is a list of what accessories are required. Figures 1, 2, and 3 show the external appearance of the 42842A bias current test fixture, the E4980A or 42843A bias current cable and the 16048A test leads.

Table 1. Measurement instruments

Instruments	Max. bias current 20 A	Max. bias current 40 A
LCR meters	E4980A (with Option E4980A-002) 4284A (with Option 4284A-002)	E4980A (with Option E4980A-002) 4284A (with Option 4284A-002)
Bias current source	42841A	Two 42841A units
Bias current test fixture	42842A	42842B[1]
Bias current cable	Not required	42843A
Test leads	16048A	16048A

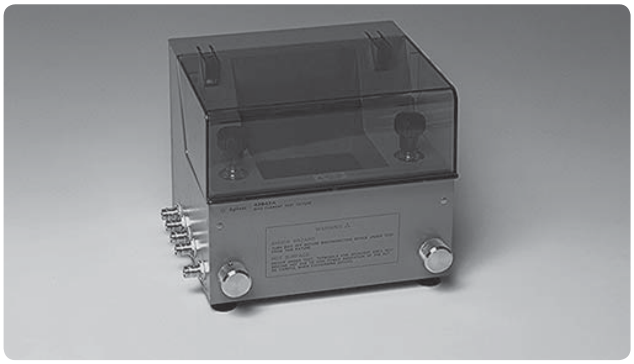

Figure 1. 42842A bias current test fixture

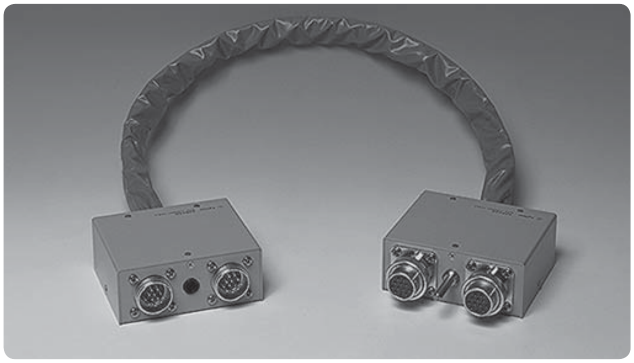

Figure 2. 42843A bias current cable

Figure 3. 16048A test leads

1. The 42842B can be used for both 20 A and 40 A DC current biased measurements.

Connections

The table shows which accessories are to be connected for maximum bias currents of 20 A and 40 A. The 42841A is connected to the E4980A or 4284A by plugging in the provided interface cable. The E4980A and 4284A use the 16048A test leads to connect to the 42842A/B. Two 42841A units have to be connected parallel when making bias current measurement up to 40 A. (See Figure 4)

The 42842A/B are equipped with a voltage monitor terminal for connecting a digital voltmeter (DVM) to monitor the bias voltage applied to the device under test directly. Only a DVM with an input impedance of 10 MΩ or more should be connected to the voltage monitor terminal, since the output monitor has 10 kΩ resistance. The DC resistance (DCR) of the device under test can be derived from this bias voltage measurement according to the following formula.

$$DCR = \frac{V_{MON}}{I_{BIAS}} - 3x10^{-3} \; [\Omega]$$

V_{MON} is the bias voltage measurement value (unit is V), I_{BIAS} is the bias current (unit is A) setup value and the 3×10^{-3} [Ω] in the formula is the residual DCR of the fixture. Refer to 'Appendix A' for information on the accuracy of DCR measurements using this method.

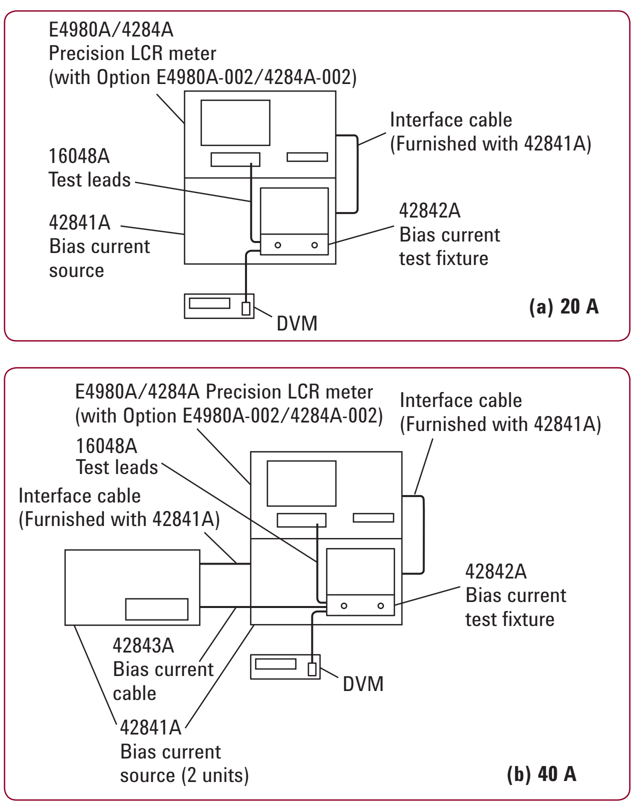

Figure 4. Measurement configuration

Measurement safety

Large DC current biased measurements have to be conducted with utmost care. The spike voltages caused by accidental removal of the device under test from the measurement terminals while a DC biased current is applied are particularly hazardous. If current exceeding the rating is run through a device under test (DUT), the heat generated may cause a fire or smoke. Following precautions should be taken when DC current biased measurements are being made.

- The bias current must be switched off before the DUT is disconnected.
- Make sure that the test leads between the DUT and the LCR meter are securely connected to prevent accidental disconnections.
- Check at all times that not too much current is put through the DUT to prevent abnormally high temperatures. (Check for heat or smoke.)
- The bias current must be turned off after a bias sweep operation is made with the list sweep function. (If the bias current is not turned off, the last bias current sweep value will continue to flow through the DUT.)

The 42842A is provided with the following safety features.

- Components are automatically discharged when the protective cover is opened, to ensure the safety of the operator while disconnecting a DUT.
- Transparent protective covers are used to facilitate monitoring the DUT during a measurement.
- Protective circuits are built in to prevent damage to the LCR meter from voltage spikes.
- The bias current is automatically cut off if the temperature in the fixture becomes abnormally high (i.e. 200 °C in the DUT and 70 °C at the measuring terminal.)

Compensation

Since the residual impedance caused by the 42841A is negligible, no compensation is required for normal inductance measurements. However, when measuring devices with an inductance lower than 10 μH use the E4980A or 4284A's short compensation function to reduce errors.

Measurement Results

The purpose of measuring the DC current biased inductance of inductors is to derive the current rating from the measured inductance versus DC current biased (L-IDC) characteristics. The current rating is defined as the value of the bias current when the inductance is decreased by 10% (or 30% to 50%).

The E4980A and 4284A can measure L-IDC characteristics and the measurements can be easily automated by using an GPIB interface and the bias sweep function (list sweep) are used. Actual measurement examples and the information required for such measurements are given in the following paragraphs.

L-IDC characteristics measured with the list sweep function

The list sweep function of the E4980A and 4284A can be used to sweep up to 201 bias (E4980A) or 10 bias (4284A) current points. Figure 5 shows the rough L-IDC characteristics and the rated current. The E4980A and 4284A automatically waits until the bias current has settled (settling time) at the specified current value before starting a measurement. Since the meter wait for the optimum moment to start ordinary measurements or list sweep measurements, the settling time need not be considered when the bias current is changed. Consequently, measurements are always made after the bias current has settled.

However, temporary discrepancies in the measured values result after bias current changes during measurement of the device that are slow to respond to changes in the bias current. This occurs when transient response of the device is longer than the settling time of E4980A or 4284A. A suitable delay time should be set with the E4980A or 4284A to compensate for this.

Always make sure to turn off the bias current to ensure that no current is flowing through the DUT after a bias sweep operation.

Measurements of L-IDC characteristics using an external controller

Since bias current values can be controlled by an external GPIB controller when the 42841A bias current source is used together with the E4980A or 4284A, it is possible to perform L-IDC measurements automatically. Furthermore, the wide measurement frequency range of E4980A or 4284A make it possible to check the L-IDC characteristics per frequency as shown in Figure 6.

The result shown in Figure 6 shows that there are differences in the L-IDC characteristics depending on the frequency used. The program (running on an HP 9000 series 300 computer) used to conduct these measurements is described in 'Appendix B'.

Measurements up to 40 A

DC current biased inductance measurements up to 40 A require the use of two 42841A units. Figure 7 shows the measured L-IDC characteristics when DC current bias up to 40 A is used.

<LIST SWEEP DISPLAY> SYS MENU

MODE : SEQ

BIAS [A]	Ls [H]	Rs [ ]	CMP
100 . 00m	544 . 933u	0 . 11931	
200 . 00m	545 .282u	0 . 11863	
500 . 00m	544 . 529u	0 . 11723	
1 . 000	538 . 915u	0 . 11503	
2 . 000	522 . 914u	0 . 11138	
5 . 000	444 . 466u	0 . 09126	
10 . 000	330 . 656u	0 . 06747	
12 . 000	296 . 950u	0 . 06206	
15 . 000	258 . 190u	0 . 05593	
20 . 000	213 . 129u	0 . 04150	

Figure 5. Measurement result using the list sweep function

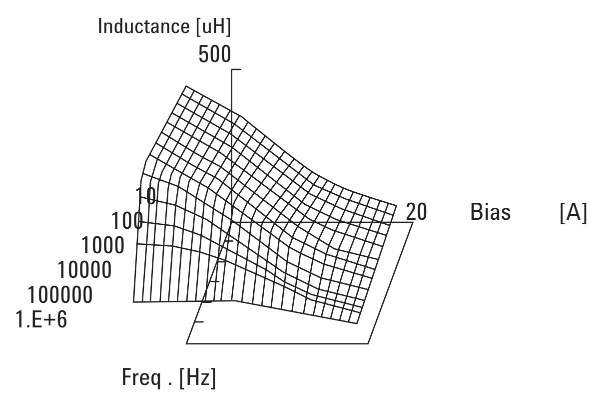

Figure 6. Frequency characteristics of L-IDC

Conclusion

The E4980A and 4284A equipped with the Option E4980A-002/4284A-002 and the 42841A bias current source will permit highly accurate and efficient DC current biased inductance measurements up to the 1 MHz frequency range. All of these combine to promote the development and production of high frequency switching power supply inductors.

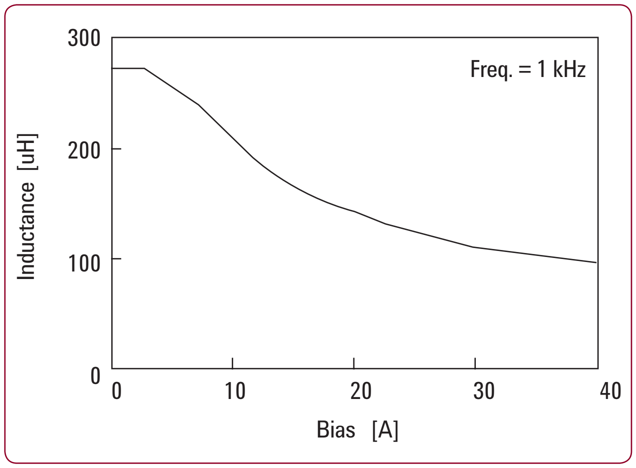

Figure 7. Measurement results up to 40 A

Appendix A. Accuracy of DCR Measurements (Typical Values)

Accuracy of DCR measurements are as follows.
Here I_{BIAS} is the bias current set value.

When $I_{BIAS} \leq 1$ A

$$\pm\{(1.2+\frac{0.5}{I_{BIAS}})\% + \frac{5}{I_{BIAS}}\ m\Omega\}$$

When $1\ A < I_{BIAS} \leq 5A$

$$\pm\{2.2\% + \frac{0.5}{I_{BIAS}}\ m\Omega\}$$

When $I_{BIAS} > 5$ A

$$\pm\{3.2\% + \frac{5}{I_{BIAS}}\ m\Omega\}$$

Note that the input impedance of the DVM must be more than 10 MΩ.

Appendix B. 1. Agilent E4980A Sample program list

```
1000    DIM Xp(100,20),Yp(100,20)                           !
1010    DIM Work$[100]                                      !
1020    DIM Bias(200),Freq(20),A(200,20),B(200,20)          !
1030    DIM Xyz(3)                                          !
1040    DIM Axis(3,3),Axis$(3)[10]                          !
1050                                                        !
1060    Lcr=717                                             ! Address of E4980A
1070    ASSIGN @Work TO "C:\work.txt"                       ! Assign I/O path to store data
1080    Min_bias=0                                          ! Min. bias value is OA
1090    Max_bias=20                                         ! Max. bias value is 20A
1100    Step_bias=1                                         ! Step of bias sweep
1110    READ Nfreq                                          ! read number of frequency
1120    FOR Ifreq=1 TO Nfreq                                !
1130        READ Freq(Ifreq)                                ! read meas. frequency
1140    NEXT Ifreq                                          !
1150    Nbias=(Max_bias-Min_bias)/Step_bias+1               ! calc. number of bias points
1160    IF Nbias>200 THEN STOP                              ! check number of bias points
1170    FOR Ibias=1 TO Nbias                                !
1180        Bias(Ibias)=Min_bias+Step_bias*(Ibias-1)        ! set bias value
1190    NEXT Ibias                                          !
1200                                                        ! << E4980A initialization>>
1210    OUTPUT Lcr;"TRIG:SOUR BUS"                          ! Trigger mode is Bus trigger
1220    OUTPUT Lcr;"FUNC:IMP LSRS"                          ! Meas function is Ls-Rs
1230    OUTPUT Lcr;"INIT:CONT ON"                           !
1240    OUTPUT Lcr;"DISP:PAGE MEAS"                         ! Display page is Meas. page
1250    OUTPUT Lcr;"INIT"                                   ! Initialize
1260    OUTPUT Lcr;"BIAS:STAT ON"                           ! Bias ON
1270                                                        ! <<Meas. routine>>
1280    FOR Ifreq=1 TO Nfreq                                ! Freq. sweep loop <-----------------------+
1290      OUTPUT Lcr;"FREQ "&VAL$(Freq(Ifreq))              !                                          |
1300      FOR Ibias=1 TO Nbias                              ! Top of bias. sweep loop <--------+       |
1310      OUTPUT Lcr;"BIAS:CURR "&VAL$(Bias(Ibias))         ! Set bias                         |       |
1320              OUTPUT Lcr;"*TRG"                         ! Triggering                       |       |
1330              ENTER Lcr;Work$                           ! Enter Meas. data                 |       |
1340              A(Ibias,Ifreq)=VAL(Work$[1,12])           !                                  |       |
1350          NEXT Ibias                                    ! Bottom of bias loop <------------+       |
1360    NEXT Ifreq                                          ! Bottom of freq. loop <-------------------+
1370    OUTPUT Lcr;"BIAS:STAT OFF"                          ! Bias OFF
1380    OUTPUT @Work;Nfreq,Nbias                            ! Store meas. condition
1390    FOR Ifreq=1 TO Nfreq                                !
1400        FOR Ibias=1 TO Nbias                            !
1410            OUTPUT @Work;A(Ibias,Ifreq)                 ! Store meas. data
1420        NEXT Ibias                                      !
1430    NEXT Ifreq                                          !
1440                                                        ! <<Graphic initialize>>
1450    CLEAR SCREEN                                        ! Clear screen
1460    GOSUB Trans_init                                    ! Initialize Trans subroutine
1470    WINDOW -2,2,-2,2                                    ! Set graphic window
1480    GOSUB Axis                                          ! Draw axes
1490    Amax=MAX(A(*))                                      ! Find max. value of meas. data
1500    FOR Ifreq=1 TO Nfreq                                ! <<Calc. graphic data>>
1510     FOR Ibias=1 TO Nbias                               !
1520      Xyz(1)=LOG(Freq(Ifreq))/LOG(Freq(Nfreq))          !
1530      Xyz(2)=Bias(Ibias)/Bias(Nbias)                    !
1540              Xyz(3)=A(Ibias,Ifreq)/Amax                !
1550              GOSUB Trans                               ! Make graphic data of 3D
1560              Xp(Ibias,Ifreq)=Xyz(1)                    !
1570              Yp(Ibias,Ifreq)=Xyz(2)                    !    !
1580          NEXT Ibias                                    !
1590    NEXT Ifreq                                          !
1600    MOVE Xp(1,1),Yp(1,1)                                ! <<Draw graphic>>
```

Appendix B. 1. Agilent E4980A Sample program list *continued...*

```
1610   FOR Ifreq=1 TO Nfreq                          ! Top of freq. loop <-----------+
1620       FOR Ibias=1 TO Nbias                      ! Top of bias loop <--------+   |
1630           DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq)  ! Draw graph                |   |
1640       NEXT Ibias                                ! bottom of bias loop ------+   |
1650       MOVE Xp(1,Ifreq+1),Yp(1,Ifreq+1)          !                               |
1660   NEXT Ifreq                                    ! bottom of freq. loop ---------+
1670   MOVE Xp(1,1),Yp(1,1)                          !
1680   FOR Ibias=1 TO Nbias                          !
1690       FOR Ifreq=1 TO Nfreq                      !
1700           DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq)  ! Draw grid
1710       NEXT Ifreq                                !
1720       MOVE Xp(Ibias+1,1),Yp(Ibias+1,1)          !
1730   NEXT Ibias                                    !
1740   STOP                                          !
1750  Trans_init:!                                   ! <<Init.routine for Trans>>
1760   Xd=.5                                         !
1770   Yd=1                                          !
1780   RETURN                                        !
1790                                                 !
1800  Trans:                                         ! <<Make 3D graph data>>
1810   Xxx=Xyz(1)                                    !
1820   Xyz(1)=Xyz(2)-Xxx*Xd                          !
1830   Xyz(2)=Xyz(3)-Xxx*Yd                          !
1840   RETURN                                        !
1850                                                 !
1860  Axis:                                          ! <<Draw axes>>
1870   Axis$(1)="FREQ."                              ! Label of Y axis
1880   Axis$(2)="BIAS"                               ! Label of X axis
1890   Axis$(3)="INDUCTANCE"                         ! Label of Z axis
1900   MAT Axis=(0)                                  ! Init. axes data
1910   FOR Iax=1 TO 3                                !
1920       Axis(Iax,Iax)=1.2                         !
1930   NEXT Iax                                      !
1940   MAT Xyz=(0)                                   !
1950   GOSUB Trans                                   ! Make 3D graph data of zero
1960   Xzero=Xyz(1)                                  !
1970   Yzero=Xyz(2)                                  !
1980   FOR Iax=1 TO 3                                !
1990       MAT Xyz=Axis(Iax,*)                       !
2000       GOSUB Trans                               ! Make 3D graph data of axes
2010       MOVE Xzero,Yzero                          !
2020       DRAW Xyz(1),Xyz(2)                        ! Draw axis
2030       LABEL Axis$(Iax)                          ! plot label
2040   NEXT Iax                                      !
2050   RETURN                                        !
2060                                                 ! <<Meas. freq. data>>
2070   DATA 17                                       ! Number of data
2080   DATA 20,50,100,200,500,1E3,2E3,5E3,1E4,2E4,5E4,1E5,2E5,3E5,4E5,5E5,7E5
2090   END
```

Appendix B. 2. Agilent 4284A Sample program list

```
1000    DIM Xp(100,20),Yp(100,20)                      !
1010    DIM Work$[100]                                 !
1020    DIM Bias(200),Freq(20),A(200,20),B(200,20)     !
1030    DIM Xyz(3)                                     !
1040    DIM Axis(3,3),Axis$(3)[10]                     !
1050                                                   !
1060    Agt4284a=717                                   ! Address of 4284A
1070    ASSIGN @Work TO "C:\work.txt"                  ! Assign I/O path to store data
1080    Min_bias=0                                     ! Min. bias value is OA
1090    Max_bias=20                                    ! Max. bias value is 20A
1100    Step_bias=1                                    ! Step of bias sweep
1110    READ Nfreq                                     ! read number of frequency
1120    FOR Ifreq=1 TO Nfreq                           !
1130        READ Freq(Ifreq)                           ! read meas. frequency
1140    NEXT Ifreq                                     !
1150    Nbias=(Max_bias-Min_bias)/Step_bias+1          ! calc. number of bias points
1160    IF Nbias>200 THEN STOP                         ! check number of bias points
1170    FOR Ibias=1 TO Nbias                           !
1180        Bias(Ibias)=Min_bias+Step_bias*(Ibias-1)   ! set bias value
1190    NEXT Ibias                                     !
1200                                                   ! << 4284A initialization>>
1210    OUTPUT Agt4284a;"TRIG:SOUR BUS"                ! Trigger mode is Bus trigger
1220    OUTPUT Agt4284a;"FUNC:IMP LSRS"                ! Meas function is Ls-Rs
1230    OUTPUT Agt4284a;"INIT:CONT ON"                 !
1240    OUTPUT Agt4284a;"DISP:PAGE MEAS"               ! Display page is Meas. page
1250    OUTPUT Agt4284a;"INIT"                         ! Initialize
1260    OUTPUT Agt4284a;"BIAS:STAT ON"                 ! Bias ON
1270                                                   ! <<Meas. routine>>
1280    FOR Ifreq=1 TO Nfreq                           ! Freq. sweep loop <-----------------------+
1290        OUTPUT Agt4284a;"FREQ "&VAL$(Freq(Ifreq))  !                                          |
1300        FOR Ibias=1 TO Nbias                       ! Top of bias. sweep loop <---------+      |
1310        OUTPUT Agt4284a;"BIAS:CURR "&VAL$(Bias(Ibias))  ! Set bias                     |      |
1320            OUTPUT Agt4284a;"*TRG"                 ! Triggering                        |      |
1330            ENTER Agt4284a;Work$                   ! Enter Meas. data                  |      |
1340            A(Ibias,Ifreq)=VAL(Work$[1,12])        !                                   |      |
1350        NEXT Ibias                                 ! Bottom of bias loop <-------------+      |
1360    NEXT Ifreq                                     ! Bottom of freq. loop <-------------------+
1370    OUTPUT Agt4284a;"BIAS:STAT OFF"                ! Bias OFF
1380    OUTPUT @Work;Nfreq,Nbias                       ! Store meas. condition
1390    FOR Ifreq=1 TO Nfreq                           !
1400        FOR Ibias=1 TO Nbias                       !
1410            OUTPUT @Work;A(Ibias,Ifreq)            ! Store meas. data
1420        NEXT Ibias                                 !
1430    NEXT Ifreq                                     !
1440                                                   ! <<Graphic initialize>>
1450    CLEAR SCREEN                                   ! Clear screen
1460    GOSUB Trans_init                               ! Initialize Trans subroutine
1470    WINDOW -2,2,-2,2                               ! Set graphic window
1480    GOSUB Axis                                     ! Draw axes
1490    Amax=MAX(A(*))                                 ! Find max. value of meas. data
1500    FOR Ifreq=1 TO Nfreq                           ! <<Calc. graphic data>>
1510        FOR Ibias=1 TO Nbias                             !
1520            Xyz(1)=LOG(Freq(Ifreq))/LOG(Freq(Nfreq))     !
1530            Xyz(2)=Bias(Ibias)/Bias(Nbias)               !
1540            Xyz(3)=A(Ibias,Ifreq)/Amax                   !
1550            GOSUB Trans                                  ! Make graphic data of 3D
1560            Xp(Ibias,Ifreq)=Xyz(1)                       !
1570            Yp(Ibias,Ifreq)=Xyz(2)                       !       !
1580        NEXT Ibias                                       !
1590    NEXT Ifreq                                           !
```

Appendix B. 2. Agilent 4284A Sample program list *continued...*

```
1600   MOVE Xp(1,1),Yp(1,1)                         ! <<Draw graphic>>
1610   FOR Ifreq=1 TO Nfreq                         ! Top of freq. loop <-----------+
1620       FOR Ibias=1 TO Nbias                     ! Top of bias loop <---------+  |
1630           DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq) ! Draw graph                 |  |
1640       NEXT Ibias                               ! bottom of bias loop ------+  |
1650       MOVE Xp(1,Ifreq+1),Yp(1,Ifreq+1)         !                               |
1660   NEXT Ifreq                                   ! bottom of freq. loop ---------+
1670   MOVE Xp(1,1),Yp(1,1)                         !
1680   FOR Ibias=1 TO Nbias                         !
1690       FOR Ifreq=1 TO Nfreq                     !
1700           DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq) ! Draw grid
1710       NEXT Ifreq                               !
1720       MOVE Xp(Ibias+1,1),Yp(Ibias+1,1)         !
1730   NEXT Ibias                                   !
1740   STOP                                         !
1750  Trans_init:                                   !
                                                    ! <<Init.routine for Trans>>
1760   Xd=.5                                        !
1770   Yd=1                                         !
1780   RETURN                                       !
1790                                                !
1800  Trans:                                        ! <<Make 3D graph data>>
1810   Xxx=Xyz(1)                                   !
1820   Xyz(1)=Xyz(2)-Xxx*Xd                         !
1830   Xyz(2)=Xyz(3)-Xxx*Yd                         !
1840   RETURN                                       !
1850                                                !
1860  Axis:                                         ! <<Draw axes>>
1870   Axis$(1)="FREQ."                             ! Label of Y axis
1880   Axis$(2)="BIAS"                              ! Label of X axis
1890   Axis$(3)="INDUCTANCE"                        ! Label of Z axis
1900   MAT Axis=(0)                                 ! Init. axes data
1910   FOR Iax=1 TO 3                               !
1920       Axis(Iax,Iax)=1.2                        !
1930   NEXT Iax                                     !
1940   MAT Xyz=(0)                                  !
1950   GOSUB Trans                                  ! Make 3D graph data of zero
1960   Xzero=Xyz(1)                                 !
1970   Yzero=Xyz(2)                                 !
1980   FOR Iax=1 TO 3                               !
1990       MAT Xyz=Axis(Iax,*)                      !
2000       GOSUB Trans                              ! Make 3D graph data of axes
2010       MOVE Xzero,Yzero                         !
2020       DRAW Xyz(1),Xyz(2)                       ! Draw axis
2030       LABEL Axis$(Iax)                         ! plot label
2040   NEXT Iax                                     !
2050   RETURN                                       !
2060                                                ! <<Meas. freq. data>>
2070   DATA 17                                      ! Number of data
2080   DATA 20,50,100,200,500,1E3,2E3,5E3,1E4,2E4,5E4,1E5,2E5,3E5,4E5,5E5,7E5
2090   END
```

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