

Keysight Technologies

Wide Range DC Current

Biased Inductance Measurement

Application Note

Keysight E4980A Precision LCR Meter

Keysight 4284A Precision LCR Meter

Keysight 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.

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 Keysight E4980A or 4284A and Keysight 42841A

The Keysight Technologies, Inc. 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)	E4980A (with Option E4980A-002)
	4284A (with Option 4284A-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

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



Figure 1. 42842A bias current test fixture

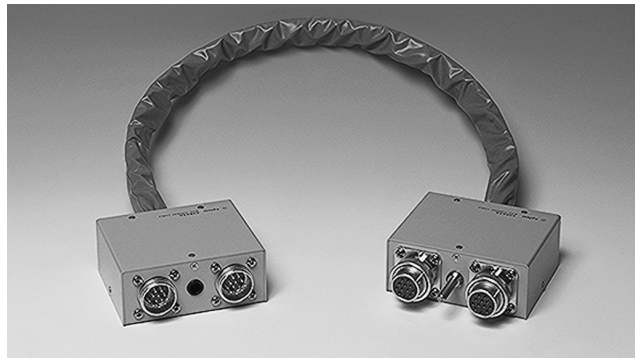


Figure 2. 42843A bias current cable



Figure 3. 16048A test leads

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.

$$DCR = \frac{V_{MON}}{I_{BIAS}} - 3 \times 10^{-3} [\Omega]$$

V_{MON} is the bias voltage measurement value (unit is V), I_{BIAS} is the bias current (unit is A) setup value and the $3 \times 10^{-3} [\Omega]$ 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.

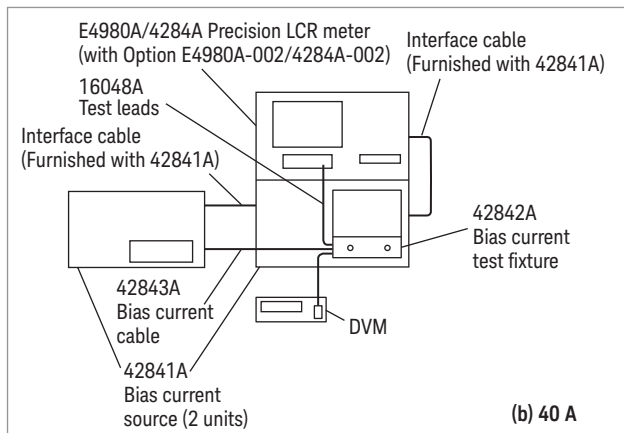
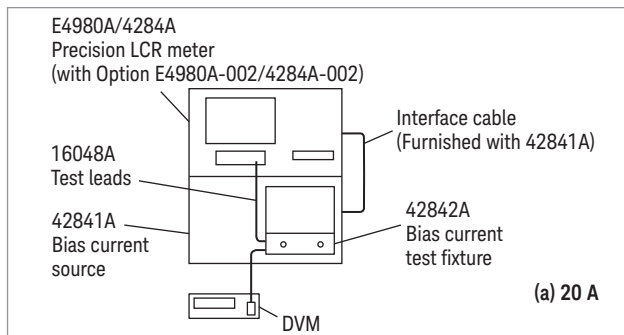


Figure 4. Measurement configuration

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

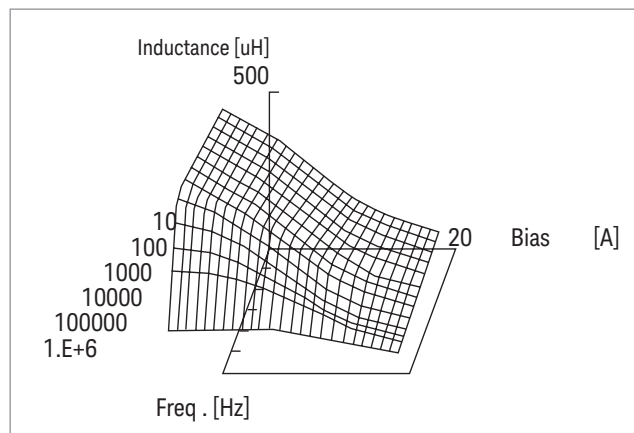


Figure 6. Frequency characteristics of L-IDC

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.

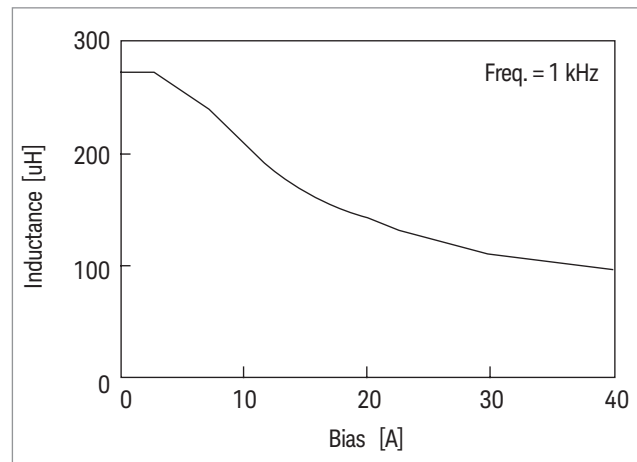


Figure 7. Measurement results up to 40 A

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

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

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

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

When $I_{BIAS} > 5$ A

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

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

Appendix B. 1. Keysight 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 0A
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. Keysight E4980A Sample program list *continued...*

```

1610 FOR Ifreq=1 TO Nfreq
1620   FOR Ibias=1 TO Nbias
1630     DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq)
1640     NEXT Ibias
1650     MOVE Xp(1,Ifreq+1),Yp(1,Ifreq+1)
1660   NEXT Ifreq
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)
1710       NEXT Ifreq
1720       MOVE Xp(Ibias+1,1),Yp(Ibias+1,1)
1730     NEXT Ibias
1740   STOP
1750 Trans_init!
1760   Xd=-.5
1770   Yd=1
1780   RETURN
1790
1800 Trans:
1810   Xxx=XYZ(1)
1820   XYZ(1)=XYZ(2)-Xxx*Xd
1830   XYZ(2)=XYZ(3)-Xxx*Yd
1840   RETURN
1850
1860 Axis:
1870   Axis$(1)="FREQ."
1880   Axis$(2)="BIAS"
1890   Axis$(3)="INDUCTANCE"
1900   MAT Axis=(0)
1910   FOR Iax=1 TO 3
1920     Axis(Iax,Iax)=1.2
1930   NEXT Iax
1940   MAT XYZ=(0)
1950   GOSUB Trans
1960   Xzero=XYZ(1)
1970   Yzero=XYZ(2)
1980   FOR Iax=1 TO 3
1990     MAT XYZ=Axis(Iax,*)
2000     GOSUB Trans
2010     MOVE Xzero,Yzero
2020     DRAW XYZ(1),XYZ(2)
2030     LABEL Axis$(Iax)
2040   NEXT Iax
2050   RETURN
2060
2070 DATA 17
2080 DATA 20,50,100,200,500,1E3,2E3,5E3,1E4,2E4,5E4,1E5,2E5,3E5,4E5,5E5,7E5
2090 END

```

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

```

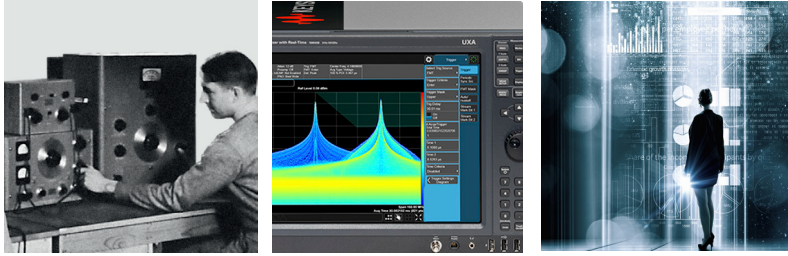
1600 MOVE Xp(1,1),Yp(1,1)           ! <<Draw graphic>
1610 FOR Ifreq=1 TO Nfreq          ! Top of freq. loop <-----+
1620   FOR Ibias=1 TO Nbias        ! Top of bias loop <-----+
1630     DRAW Xp(Ibias,Ifreq),Yp(Ibias,Ifreq) ! Draw graph
1640     NEXT Ibias                ! bottom of bias loop -----+
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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