Wide Range DC Current Biased Inductance Measurement

Application Note 369-8

with
HP 4284A Precision LCR Meter /
HP 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 HP 4284A and HP 42841A

The HP4284A Precision LCR Meter (with Option 002 Current Bias Interface) in combination with the HP 42841A Bias Current Source ensures simple and safe DC current biased inductance measurements. The HP4284A allows for DC current biased inductance measurements with the following advantages.

- Wide 20 Hz to 1 MHz frequency range measurements
- DC current biased inductance measurements up to 40 A using two the HP 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 HP 4284A's front panel keys or by using an external controller via HP-IB.
- The HP 42842A/B Bias Current Test Fixtures which protect the operator and instrument are provided.
- Built-in memory function and a removable memory card for storing instrument setups

MEASUREMENT PREPARATION

Accessories Required

When DC current biased inductance measurements are made using an HP 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 HP 42842A Bias Current Test Fixture, the HP 42843A Bias Current Cable and the HP 16048A Test Leads.

Table 1. Measurement Instruments

INSTRUMENTS	MAX. BIAS CURRENT 20 A	40 A
LCR meter	HP 4284A (with Opt. 002)	HP 4284A (with Opt. 002)
Bias current source	HP 42841A	Two HP 42841A units
Bias current test fixture	HP 42842A	HP 42842B*1)
Bias current cable	Not required	HP 42843A
Test leads	HP 16048A	HP 16048A

*1) **HP 42842B can be used for 20 A DC current biased measurements**

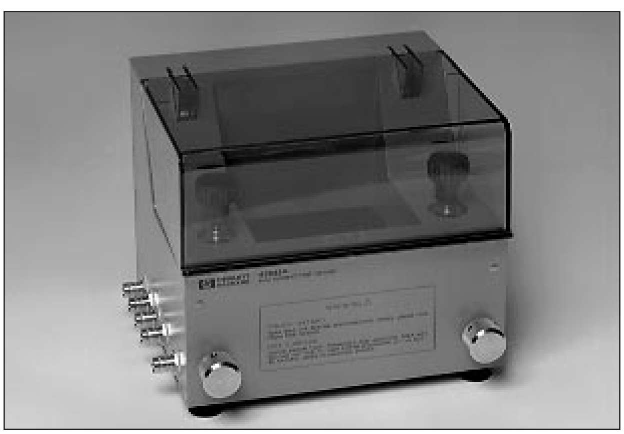


Figure 1. HP 42842A Bias Current Test Fixture

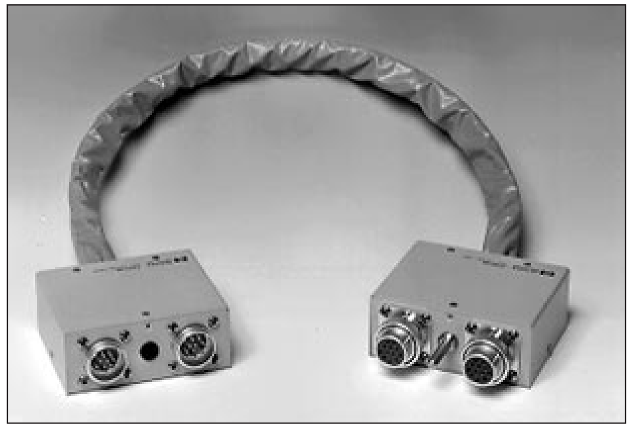


Figure 2. HP 42843A Bias Current Cable

Figure 3. HP 16048A Test leads

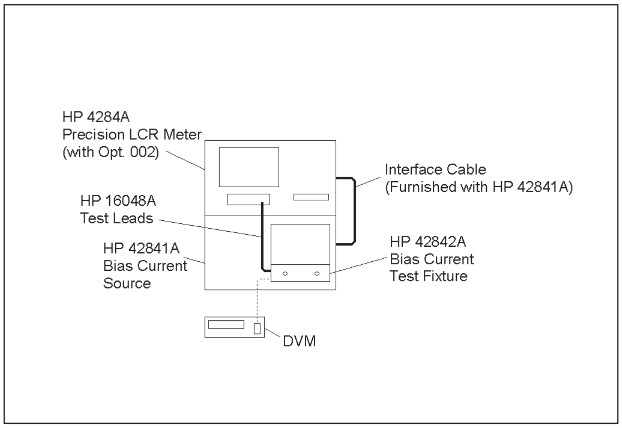
Connections

The table shows which accessories are to be connected for maximum bias currents of 20 A and 40 A. The HP 42841A is connected to the HP 4284A by plugging in the provided Interface cable. The HP 4284A uses the HP 16048A Test Leads for connection to the HP 42842A/B. Two HP 42841A units have to be connected parallel when making bias current measurement up to 40 A.

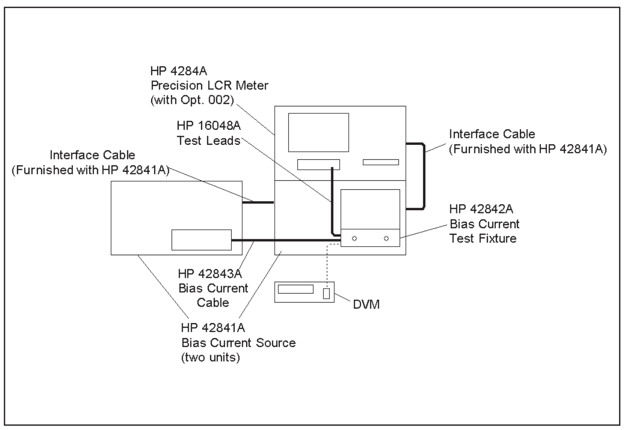
The HP 42842A/B are equipped with a voltage monitor terminal for connecting a digital voltmeter (DVM) to monitor the bias voltage applied to the device under test directly. Only a DVM with an input impedance of 10 MΩ or more should be connected to the voltage monitor terminal, since the output monitor 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.

$$DCR = \frac{V_{MON}}{I_{BIAS}} - 3\times10^{-3}\ [\Omega]$$

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.



(a) 20 A



(a) 40 A

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, 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 device under test is disconnected.
- Make sure that the test leads between the device under test and the LCR meter are securely connected to prevent accidental disconnection.
- Check at all times that not too much current is put through a device under test 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 HP 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 device under test.
- Transparent protective covers are used to facilitate monitoring the device under test 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 device under test and 70°C at the measuring terminal.)

Compensation

Since the residual impedance caused by the HP 42841A is negligible, no compensation is required for normal inductance measurements. However, when measuring devices with an inductance lower than 10 µH use the HP 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 HP 4284A can measure L-IDC characteristics and the measurements can be easily automated by using an HP-IB 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 HP 4284A can be used to sweep up to 10 bias current points. Figure 5 shows the rough L-IDC characteristics and the rated current. The HP 4284A automatically waits until the bias current has settled (settling time) at the specified current value before starting a measurement. Since the meter waits 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 HP 4284A. A suitable delay time should be set with the HP 4284A to compensate for this.

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

Measurements of L-IDC Characteristics Using an External Controller

Since bias current values can be controlled by an external HP-IB controller when the HP 42841A Bias Current Source is used together with the HP 4284A, it is possible to perform L-IDC measurements automatically. Furthermore, the wide measurement frequency range of HP 4284A makes 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 HP 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 . 09162	
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

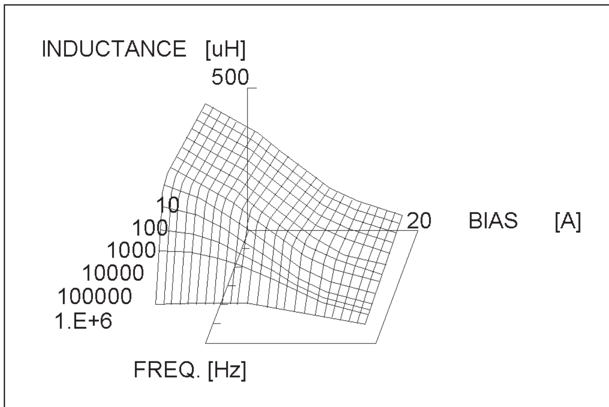


Figure 6. Frequency Characteristics of L-IDC

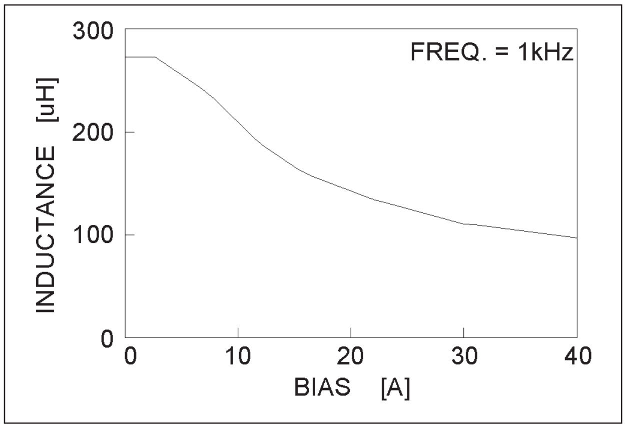


Figure 7. Measurement Results up to 40 A

CONCLUSION

The HP 4284A equipped with the Option 002 and the HP 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.

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

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

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

$$\pm \left\{ 2.2\% + \frac{5}{I_{BIAS}}\ \mathrm{m\Omega} \right\}$$

When $I_{BIAS} > 5$ A

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

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

```
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   Hp4284a=717                                   !  Address of HP 4284A
1070   ASSIGN @Work TO "WORK"                        !  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                                                 !  <<HP 4284A initialization>>
1210   OUTPUT Hp4284a;"TRIG:SOUR BUS"                !  Trigger mode is Bus trigger
1220   OUTPUT Hp4284a;"FUNC:IMP LSRS"                !  Meas function is Ls-Rs
1230   OUTPUT Hp4284a;"INIT:CONT ON"                 !
1240   OUTPUT Hp4284a;"DISP:PAGE MEAS"               !  Display page is Meas. page
1250   OUTPUT Hp4284a;"INIT"                         !  Initialize
1260   OUTPUT Hp4284a;"BIAS:STAT ON"                 !  Bias ON
1270                                                 !  <<Meas. routine>>
1280   FOR Ifreq=1 TO Nfreq                          !  Freq. sweep loop  <------------+
1290     OUTPUT Hp4284a;"FREQ "&VAL$(Freq(Ifreq))    !                                 |
1300     FOR Ibias=1 TO Nbias                        !  Top of bias. sweep loop <---+  |
1310       OUTPUT Hp4284a;"BIAS:CURR "&VAL$(Bias(Ibias))    ! Set bias              |  |
1320       OUTPUT Hp4284a;"*TRG"                     !  Triggering                  |  |
1330       ENTER Hp4284a;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 Hp4284a;"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>>
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                                              !
1760 Trans_init:!                                 !  <<Init. routine for Trans>>
1770  Xd=.5                                       !
1780  Yd=1                                        !
1790  RETURN                                      !
1800                                              !
1810 Trans:                                       !  <<Make 3D graph data>>
1820  Xxx=Xyz(1)                                  !
1830  Xyz(1)=Xyz(2)-Xxx*Xd                        !
1840  Xyz(2)=Xyz(3)-Xxx*Yd                        !
1850  RETURN                                      !
1860                                              !
1870 Axis:                                        !  <<Draw axes>>
1880  Axis$(1)="FREQ."                            !  Label of Y axis
1890  Axis$(2)="BIAS"                             !  Label of X axis
1900  Axis$(3)="INDUCTANCE"                       !  Label of Z axis
1910  MAT Axis= (0)                               !  Init. axes data
1920  FOR Iax=1 TO 3                              !
1930    Axis(Iax,Iax)=1.2                         !
1940  NEXT Iax                                    !
1950  MAT Xyz= (0)                                !
1960  GOSUB Trans                                 !  Make 3D graph data of zero
1970  Xzero=Xyz(1)                                !
1980  Yzero=Xyz(2)                                !
1990  FOR Iax=1 TO 3                              !
2000    MAT Xyz= Axis(Iax,*)                      !
2010    GOSUB Trans                               !  Make 3D graph data of axes
2020    MOVE Xzero,Yzero                          !
2030    DRAW Xyz(1),Xyz(2)                        !  Draw axis
2040    LABEL Axis$(Iax)                          !  Plot label
2050  NEXT Iax                                    !
2060  RETURN                                      !
2070                                              !  <<Meas. freq. data>>
2080  DATA 17                                     !  Number of data
2090  DATA 20,50,100,200,500,1E3,2E3,5E3,1E4,2E4,5E4,1E5,2E5,3E5,4E5,5E5,7E5
2100  END                                         !
```

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Latin American Region Headquarters
5200 Blue Lagoon Drive
9th Floor
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U.S.A.
Tel: (305) 267-4245
(305) 267-4220
Fax: (305) 267-4288

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Blackburn, Victoria 3130
Australia
Tel: 1 800 629 485 (Australia)
0800 738 378 (New Zealand)
Fax: (61 3) 9210 5489

Asia Pacific:
Hewlett-Packard Asia Pacific Ltd.
17-21/F Shell Tower, Times Square,
1 Matheson Street, Causeway Bay,
Hong Kong
Tel: (852) 2599 7777
Fax: (852) 2506 9285

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