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

<table>
<thead>
<tr>
<th>INSTRUMENTS</th>
<th>MAX. BIAS CURRENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20 A</td>
</tr>
<tr>
<td>LCR meter</td>
<td>HP 4284A</td>
</tr>
<tr>
<td></td>
<td>(with Opt. 002)</td>
</tr>
<tr>
<td>Bias current source</td>
<td>HP 42841A</td>
</tr>
<tr>
<td>test fixture</td>
<td>HP 42842A</td>
</tr>
<tr>
<td>Bias current cable</td>
<td>Not required</td>
</tr>
<tr>
<td>Test leads</td>
<td>HP 16048A</td>
</tr>
</tbody>
</table>

*1 HP 42842B can be used for 20 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 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 \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.

**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 \( \mu \text{H} \) 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.

<table>
<thead>
<tr>
<th>MODE</th>
<th>SEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIAS [A]</td>
<td>Ls [H]</td>
</tr>
<tr>
<td>100.00m</td>
<td>544.933u</td>
</tr>
<tr>
<td>200.00m</td>
<td>545.282u</td>
</tr>
<tr>
<td>500.00m</td>
<td>544.529u</td>
</tr>
<tr>
<td>1.000</td>
<td>538.915u</td>
</tr>
<tr>
<td>2.000</td>
<td>522.914u</td>
</tr>
<tr>
<td>5.000</td>
<td>444.466u</td>
</tr>
<tr>
<td>10.000</td>
<td>330.656u</td>
</tr>
<tr>
<td>12.000</td>
<td>296.950u</td>
</tr>
<tr>
<td>15.000</td>
<td>258.190u</td>
</tr>
<tr>
<td>20.000</td>
<td>213.129u</td>
</tr>
</tbody>
</table>

Figure 5. Measurement Result using the List Sweep function

Figure 6. Frequency Characteristics of L-IDC
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 \text{ A}

\[ \pm \left\{ (1.2 + \frac{0.5}{\text{I}_{\text{BIAS}}} \right)^\% + \frac{5}{\text{I}_{\text{BIAS}}} \text{ m}\Omega \right\} \]

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

\[ \pm \left\{ 2.2\% + \frac{5}{\text{I}_{\text{BIAS}}} \text{ m}\Omega \right\} \]

When I_{BIAS} > 5 \text{ A}

\[ \pm \left\{ 3.2\% + \frac{5}{\text{I}_{\text{BIAS}}} \text{ m}\Omega \right\} \]

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

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.

Figure 7. Measurement Results up to 40 A
APPENDIX B. Sample Program List

1000 DIM Xp(100,20), Yp(100,20) ! Address of HP 4284A
1010 DIM Work$[100] ! Assign I/O path to store data
1020 DIM Bias(200), Freq(20), A(200, 20), B(200, 20) ! Min. bias value is 0A
1030 DIM Xyz(3), Axis$(3) [10] ! Max. bias value is 20A
1040 DIM Axis(3,3), Axis$(3) ! Step of bias sweep
1050 !
1060 Hp4284a=717 ! read number of frequency
1070 ASSIGN @Work TO "WORK" ! <<HP 4284A initialization>>
1080 Min_bias=0 ! Trigger mode is Bus trigger
1090 Max_bias=20 ! Meas function is Ls-Rs
1100 Step_bias=1 ! Display page is Meas. page
1110 READ Nfreq ! Initialize
1120 FOR Ifreq=1 TO Nfreq ! Bias ON
1130 READ Freq(Ifreq) ! <<Meas. routine>>
1140 NEXT Ifreq
1150 Nbias=(Max_bias-Min_bias)/Step_bias+1 ! Freq. sweep loop <--------+
1160 IF Nbias>200 THEN STOP ! I
1170 FOR Ibias=1 TO Nbias ! Top of bias. sweep loop <---- | !
1180 Bias(Ibias)=Min_bias+Step_bias*(Ibias-1) ! Triggering | !
1190 NEXT Ibias ! Enter Meas. data | !
1200 ! Bottom of bias loop <------- | !
1210 OUTPUT Hp4284a;"TRIG:SOUR BUS" ! Bottom of freq. loop <--------+
1220 OUTPUT Hp4284a;"FUNC:IMP LSRS" ! Store meas. condition
1230 OUTPUT Hp4284a;"INIT:CONT ON" ! Store meas. data
1240 OUTPUT Hp4284a;"DISP:PAGE MEAS" !
1250 OUTPUT Hp4284a;"INIT" !
1260 OUTPUT Hp4284a;"BIAS:STAT ON" !
1270 !
1280 FOR Ifreq=1 TO Nfreq !
1290 OUTPUT Hp4284a;"FREQ &VAL$(Freq(Ifreq)) !
1300 FOR Ibias=1 TO Nbias !
1310 OUTPUT Hp4284a;"BIAS:CURR &VAL$(Bias(Ibias)) !
1320 OUTPUT Hp4284a;"TRG" !
1330 ENTER Hp4284a;Work$ !
1340 A(Ibias,Ifreq)=VAL(Work$[1,12]) !
1350 NEXT Ibias !
1360 NEXT Ifreq !
1370 OUTPUT Hp4284a;"BIAS:STAT OFF" !
1380 OUTPUT @Work,Nfreq,Nbias !
1390 FOR Ifreq=1 TO Nfreq !
1400 FOR Ibias=1 TO Nbias !
1410 OUTPUT @Work;A(Ibias,Ifreq) !
1420 NEXT Ibias !
1430 NEXT Ifreq !
1440 !
1450 CLEAR SCREEN !
1460 GOSUB Trans_init !
1470 WINDOW -2, 2, -2, 2 ! Initialize Trans subroutine
1480 GOSUB Axis !
1490 Amax=MAX(A(*)) !
1500 FOR Ifreq=1 TO Nfreq !
1510 FOR Ibias=1 TO Nbias !
1520 Xyz(1)=LOG(Freq(Ifreq))/LOG(Freq(Nfreq)) !
1530 Xyz(2)=Bias(Ibias)/Bias(Nbias) ! Make graphic data of 3D
1540 Xyz(3)=A(Ibias,Ifreq)/Amax !
1550 GOSUB Trans !
1560 Xp(Ibias,Ifreq)=Xyz(1) !
1570 Yp(Ibias,Ifreq)=Xyz(2) !
1580 NEXT Ibias !
1590 NEXT Ifreq

APPENDIX B. Sample Program List
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 ! <<Make 3D graph data>>
1810 Trans:!! 
1820 Xxx=Xyz(1) ! 
1830 Xyz(1)=Xyz(2)-Xxx*Xd ! 
1840 Xyz(2)=Xyz(3)-Xxx*Yd ! 
1850 RETURN ! 
1860 ! <<Draw axes>>
1870 Axis:!! 
1880 Axis$(1)="FREQ."
1890 Axis$(2)="BIAS"
1900 Axis$(3)="INDUCTANCE"
1910 MAT Axis= (0) ! Init. axes data 
1920 FOR Iax=1 TO 3 ! 
1930 Axis(Iax,Iax)=1.2 ! 
1940 NEXT Iax ! 
1950 MAT Xyz= (0) ! Make 3D graph data of zero 
1960 GOSUB Trans ! 
1970 Xzero=Xyz(1) ! 
1980 Yzero=Xyz(2) ! 
1990 FOR Iax=1 TO 3 ! 
2000 MAT Xyz= Axis(Iax,*) ! 
2010 GOSUB Trans ! Make 3D graph data of axes 
2020 MOVE Xzero,Yzero ! 
2030 DRAW Xyz(1),Xyz(2) ! Draw axis 
2040 LABEL Axis$(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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