This application note will describe the process of analysing the impedance of a capacitor when subjected to high DC bias voltages. This particular application required impedance analysis of a 1µF capacitor, upon which a 0~48V DC bias voltage would also be applied. A typical application for this test is the analysis of SMPS filter capacitors.

**Set Up:**

1. PSM1700 Frequency Response Analyzer (PSM3750 recommended for voltages exceeding 48Vrms)
2. LPA400B Power Amplifier
3. HF01A Current Shunt
4. Load (1µF capacitor in series with a 1kΩ current limiting resistor)

**Schematic:**

![Schematic Diagram](image)

**Fig. 1**
Note: The Oscilloscope in the picture above is used for the purposes of a visual representation of both the DC offset and the AC injected ripple frequency during the tests. An oscilloscope is not required for this test as the DC and AC components of the injected waveform can be verified more accurately with the PSM1700 "RMS Voltmeter" mode.

**LPA400B Settings:**
- Bandwidth = LOW
- Coupling = AC+DC
- Gain = x50

A resistor of 1kΩ is fitted in series with the 1uF capacitor, this is installed to limit the inrush current in the circuit when the LPA400B is turned on, preventing inadvertent tripping of the amplifier protection circuit.

**Test Configuration**

Output and CH1 screens will change as the test sequences are progressed, Ch2 - which is used to measure the current through the circuit will stay constant, settings for the external shunt are shown below.

```
Fig. 2

```

```
Fig. 3

```

```
<table>
<thead>
<tr>
<th>INPUT 2</th>
<th>external shunt</th>
</tr>
</thead>
<tbody>
<tr>
<td>input 2</td>
<td>10mΩ</td>
</tr>
<tr>
<td>minimum range</td>
<td>full autorange</td>
</tr>
<tr>
<td>autoranging</td>
<td>0Ω</td>
</tr>
<tr>
<td>coupling</td>
<td>-1.0000</td>
</tr>
<tr>
<td>scale factor</td>
<td>1.0000</td>
</tr>
<tr>
<td>external shunt</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

```
A shunt value of 1Ω is set, as per the HF01A shunt datasheet.

**Test 1:**
- AC signal set to 50mV x 50 gain = 2.5V
- DC offset set to 0V
- Ripple frequency set to 1 kHz

It is important to remember that it is the ripple frequency that is used to analyze the capacitance of the test device. This is performed via a DFT (Discrete Fourier Analysis) technique, which extracts the magnitudes and phases of the voltage and current at the injected ripple frequency, from which the impedance is calculated.

**PSM1700 Output and CH1 display settings**
Note: All LCR screenshots taken will illustrate the corresponding results at each Frequency and DC offset point, with the coupling set on CH1 to ac+dc and ac only.

<table>
<thead>
<tr>
<th>OUTPUT OPTIONS</th>
<th>INPUT 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplitude</td>
<td>50.000mV/pk</td>
</tr>
<tr>
<td>ceiling</td>
<td>10.000mV/pk</td>
</tr>
<tr>
<td>frequency</td>
<td>1.000kHz</td>
</tr>
<tr>
<td>offset</td>
<td>+90°, -90°</td>
</tr>
<tr>
<td>waveform</td>
<td>sine wave</td>
</tr>
<tr>
<td>amplitude step</td>
<td>1.1000 times</td>
</tr>
<tr>
<td>frequency step</td>
<td>2.3000 times</td>
</tr>
<tr>
<td>output</td>
<td>on</td>
</tr>
</tbody>
</table>

Oscilloscope image showing the AC ripple frequency, no DC offset.

Fig. 4

Fig. 5
NOTE: You will notice from Fig. 7 above that the magnitude of the AC signal across the load measures 300.52mV and therefore the PSM1700 instrument which is set to full autorange for CH1 has selected the 1V range for both AC and AC+DC coupling configurations. Once an offset is applied, it is good practice to AC couple the measurement inputs (after verification of the DC signal level) as this will allow the instrument to range upon the AC signal only, instead of the DC signal. Thus facilitating high accuracy through lower range errors, as well as more stable results.

Test 2:

AC signal set to 50mV x 50 gain = 2.5V
DC offset set to 0V
Ripple Frequency set to 10 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 10 kHz
Again note that the PSM1700 has auto ranged on CH1 to the 100mV range as the measured voltage across the load is now 30.3mV

**Test 3:**

AC signal set to 50mV x 50 gain = 2.5V  
DC offset set to 0V  
Ripple frequency set to 100 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 100 kHz

![LCR Meter Measurement](image)

**Test 4:**

AC signal set to 50mV x 50 gain = 2.5V  
DC offset set to 10V  
Ripple frequency set to 1 kHz

Output adjusted for a DC offset of 200 mV x50 gain = 10V

![Output Options](image)
RMS Mode display

<table>
<thead>
<tr>
<th></th>
<th>CH1 1V</th>
<th>CH2 10mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms</td>
<td>10.005V</td>
<td>-1.5914mA</td>
</tr>
<tr>
<td>dc</td>
<td>10.00V</td>
<td>45.469μA</td>
</tr>
<tr>
<td>ac</td>
<td>316.45mV</td>
<td>1.600mA</td>
</tr>
<tr>
<td>dBm</td>
<td>-2776dBm</td>
<td>2345dBm</td>
</tr>
<tr>
<td>peak</td>
<td>10.43V</td>
<td>2225mA</td>
</tr>
<tr>
<td>cf</td>
<td>104</td>
<td>-1.91</td>
</tr>
<tr>
<td>surge</td>
<td>13.43V</td>
<td>2718mA</td>
</tr>
</tbody>
</table>

The PSM1700 RMS display measures a 10V dc offset along with the ac ripple voltage.

Oscilloscope display showing ripple frequency on top the DC signal, 1 kHz AC and 10V DC offset.

Fig. 14

Fig. 15
LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 1 kHz.

**Test 5:**

AC signal set to 50mV x 50 gain = 2.5V
DC offset set to 10V
Ripple frequency set to 10 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 10 kHz.

**Fig. 16**
Coupling = ac+dc

**Fig. 17**
Coupling = ac only

**Fig. 18**
Coupling = ac+dc

**Fig. 19**
Coupling = ac only
**Test 6**

AC signal set to 50mV x 50 gain = 2.5V  
DC offset set to 10V  
Ripple frequency set to 100 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 100 kHz

<table>
<thead>
<tr>
<th>LCR METER</th>
<th>LCR METER</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnitude</td>
<td>magnitude</td>
</tr>
<tr>
<td>2.0588mV</td>
<td>1.8157mV</td>
</tr>
<tr>
<td>capacitance</td>
<td>capacitance</td>
</tr>
<tr>
<td>795.6nF</td>
<td>888.2nF</td>
</tr>
<tr>
<td>resistance</td>
<td>resistance</td>
</tr>
<tr>
<td>-286.2mΩ</td>
<td>6.420mΩ</td>
</tr>
<tr>
<td>tan δ</td>
<td>tan δ</td>
</tr>
<tr>
<td>0.14307</td>
<td>0.00358</td>
</tr>
<tr>
<td>phase</td>
<td>phase</td>
</tr>
<tr>
<td>-0.0142°</td>
<td>-0.0010°</td>
</tr>
<tr>
<td>frequency</td>
<td>frequency</td>
</tr>
<tr>
<td>100.000kHz</td>
<td>100.000kHz</td>
</tr>
</tbody>
</table>

Fig. 20  
Coupling = ac+dc

Fig. 21  
Coupling = ac only

This test illustrates the issue when AC+DC coupling, it is noticeable that the capacitance value is not the same in both modes. It is advisable to only use AC coupling for impedance measurements with high voltage DC bias.

**Test 7:**

AC signal set to 50mV x 50 gain = 2.5V  
DC offset set to 48V  
Ripple frequency set to 1 kHz

Output adjusted to achieve a DC offset of 960 mV x 50 gain = 48V

**OUTPUT OPTIONS**

- amplitude
- ceiling
- frequency
- offset
- waveform
- amplitude step
- frequency step
- output

Fig. 22
RMS Mode

Screenshots below are taken with CH1 coupling set to ac+dc and ac only. Note how the PSM1700, set to autorange in CH1 ranges to suit the appropriate input signal.

<table>
<thead>
<tr>
<th>CH1 30mV</th>
<th>CH2 10mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms</td>
<td>47.677V</td>
</tr>
<tr>
<td>dc</td>
<td>0.673V</td>
</tr>
<tr>
<td>di/dn</td>
<td>-2.368dBm</td>
</tr>
<tr>
<td>peak</td>
<td>-8.07V</td>
</tr>
<tr>
<td>cf</td>
<td>1.03</td>
</tr>
<tr>
<td>surge</td>
<td>-8.11V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CH1 30mV</th>
<th>CH2 10mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>rms</td>
<td>300.12mV</td>
</tr>
<tr>
<td>dc</td>
<td>0.000mV</td>
</tr>
<tr>
<td>di/dn</td>
<td>-0.036dBm</td>
</tr>
<tr>
<td>peak</td>
<td>-4.156mV</td>
</tr>
<tr>
<td>cf</td>
<td>1.45</td>
</tr>
<tr>
<td>surge</td>
<td>-4.157mV</td>
</tr>
</tbody>
</table>

Fig. 23
Coupling set to ac+dc

Fig. 24
Coupling set to ac only

Oscilloscope display showing ripple frequency at 1 kHz and dc offset to be 48V

Fig. 25
LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 1 kHz

\[
\begin{array}{c|c|c}
\text{LCR METER} & \text{CH1 10mV} & \text{CH2 3mV} \\
\hline
\text{magnitude} & 30.11mV & -1.682mV \\
\hline
\text{capacitance} & 883.5nF & \text{parallel} \\
\hline
\text{resistance} & 286.9m\Omega & 1291k\Omega \\
\hline
\text{tan } \delta & 0.00159 & \text{phase} \\
\hline
\text{frequency} & 1.00000kHz & \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{LCR METER} & \text{CH1 10mV} & \text{CH2 16mV} \\
\hline
\text{magnitude} & 299.62mV & -1.6843mV \\
\hline
\text{capacitance} & 894.7nF & \text{parallel} \\
\hline
\text{resistance} & 69.60m\Omega & 5427k\Omega \\
\hline
\text{tan } \delta & 0.00039 & \text{phase} \\
\hline
\text{frequency} & 1.00000kHz & \\
\end{array}
\]

Note: When AC+DC coupling is selected, channel 1 ranges to the 100V range due to the 48V DC offset present. It is recommended that AC coupling is selected, so that the CH1 input will range to the AC ripple frequency component.

**Test 8:**

AC signal set to 50mV x 50 gain = 2.5V
DC offset set to 48V
Ripple frequency set to 10 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 10 kHz

\[
\begin{array}{c|c|c}
\text{LCR METER} & \text{CH1 10mV} & \text{CH2 16mV} \\
\hline
\text{magnitude} & 30.95mV & -1.7023mV \\
\hline
\text{capacitance} & 875.1nF & \text{parallel} \\
\hline
\text{resistance} & 193.8m\Omega & 1.704k\Omega \\
\hline
\text{tan } \delta & 0.01065 & \text{phase} \\
\hline
\text{frequency} & 10.0000kHz & \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{LCR METER} & \text{CH1 10mV} & \text{CH2 16mV} \\
\hline
\text{magnitude} & 30.27mV & -1.7002mV \\
\hline
\text{capacitance} & 893.8nF & \text{parallel} \\
\hline
\text{resistance} & -14.93m\Omega & -21.24k\Omega \\
\hline
\text{tan } \delta & 0.00084 & \text{phase} \\
\hline
\text{frequency} & -690.048\text{Hz} & \\
\end{array}
\]

Fig. 26
Coupling = ac+dc

Fig. 27
Coupling = ac only

Fig. 27
Coupling = ac+dc

Fig. 27
Coupling = ac only
Test 9:

AC signal set to 50mV x 50 gain = 2.5V
DC offset set to 48V
Ripple frequency set to 100 kHz

LCR Meter displays the capacitance measurement in both coupling modes with the frequency set to 100 kHz

<table>
<thead>
<tr>
<th></th>
<th>LCR METER</th>
<th></th>
<th>LCR METER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CH1 10mV</td>
<td>CH2 10mV</td>
<td>CH1 10mV</td>
</tr>
<tr>
<td>magnitude</td>
<td>4.566mV</td>
<td>-1.018mV</td>
<td>1.017mV</td>
</tr>
<tr>
<td></td>
<td>CH1 10mV</td>
<td>CH2 10mV</td>
<td>CH1 10mV</td>
</tr>
<tr>
<td></td>
<td>4.566mV</td>
<td>-1.018mV</td>
<td>1.017mV</td>
</tr>
<tr>
<td>capacitance</td>
<td>383.3nF</td>
<td>383.3nF</td>
<td>888.6nF</td>
</tr>
<tr>
<td></td>
<td>series</td>
<td>parallel</td>
<td>series</td>
</tr>
<tr>
<td>resistance</td>
<td>000.0mΩ</td>
<td>200.0mΩ</td>
<td>5.417mΩ</td>
</tr>
<tr>
<td>tan δ</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00302</td>
</tr>
<tr>
<td>phase</td>
<td>-090.000°</td>
<td>-090.000°</td>
<td>-099.927°</td>
</tr>
<tr>
<td>frequency</td>
<td>100.000kHz</td>
<td>100.000kHz</td>
<td>100.000kHz</td>
</tr>
</tbody>
</table>

Fig. 28  Coupling = ac+dc  
Fig. 29  Coupling = ac only

Test Results:

High DC Bias Voltage / Capacitor Tests

Notes: PSM1700 AC amplitude = 50.00mVpk
LPA400B set to x 50, AC Output Signal of 2.5Vpk

<table>
<thead>
<tr>
<th>DC offset</th>
<th>Frequency</th>
<th>Capacitance measurements with coupling set to ac+dc</th>
<th>Capacitance measurements with coupling set to ac only</th>
</tr>
</thead>
<tbody>
<tr>
<td>0V</td>
<td>1kHz</td>
<td>892.8nF</td>
<td>894.4nF</td>
</tr>
<tr>
<td>0V</td>
<td>10kHz</td>
<td>892.3nF</td>
<td>894.3nF</td>
</tr>
<tr>
<td>0V</td>
<td>100kHz</td>
<td>893.5nF</td>
<td>888.0nF</td>
</tr>
<tr>
<td>10V</td>
<td>1kHz</td>
<td>893.7nF</td>
<td>894.3nF</td>
</tr>
<tr>
<td>10V</td>
<td>10kHz</td>
<td>894.0nF</td>
<td>894.3nF</td>
</tr>
<tr>
<td>10V</td>
<td>100kHz</td>
<td>795.6nF</td>
<td>888.2nF</td>
</tr>
<tr>
<td>48V</td>
<td>1kHz</td>
<td>883.5nF</td>
<td>894.7nF</td>
</tr>
<tr>
<td>48V</td>
<td>10kHz</td>
<td>875.1nF</td>
<td>893.8nF</td>
</tr>
<tr>
<td>48V</td>
<td>100kHz</td>
<td>383.3nF</td>
<td>888.6nF</td>
</tr>
</tbody>
</table>
Summary

This application note has described the use of the N4L PSM1700 and the LPA400 Laboratory Power Amplifier for impedance analysis of Capacitors with high Voltage DC bias. As highlighted in the results, it is recommended that engineers make use of AC coupling as this will offer more stable results when measurements are taken in the presence of high DC bias, facilitated by more suitable range selection of the input channel.

The PSM3750 is an ideal option for impedance measurements above 50Vrms, the PSM3750 will directly measure up to 500Vpk.

The capacitor used for these tests provided stable results throughout both the frequency range and the DC bias voltage range tested.