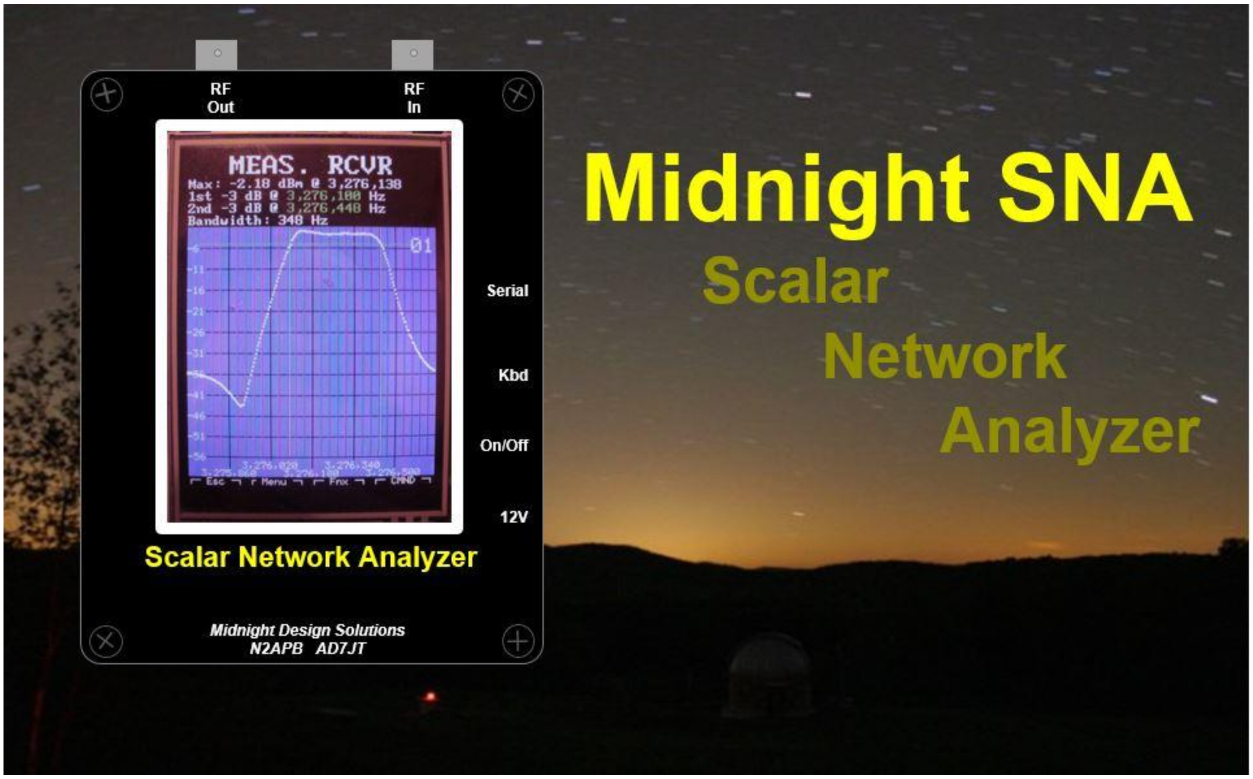

Tutorial 7 - LC Measurements

for Firmware Version 4.30

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2016-02-29

This tutorial takes you through the steps to configure and use your MSNA to measure unknown capacitance and inductance values. It includes a discussion of the theory behind the LC Meter (LCM) and a description of one possible implementation of the required LC Meter fixture (LCMF).

CONTENTS

1. APPLIES TO

All Midnight SNA units running V4.30 firmware or later.

2. PREREQUESITES

Before attempting LC measurements, the following MSNA calibrations should be performed:

1. Set the RF Power Meter slope-intercept points and DDS-60 (RF Out) power level per the ***MSNA Tutorial M1 - Power Level Calibrations for Firmware Version 4.00*** (and laer).
2. Set the reference clock frequency per the **REFERENCE CLOCK FREQUENCY** section of the ***MSNA Quick Reference for Firmware Version 4.30*** (and later).
3. Load the calibration buffer per the **CALIBRATION** section of the ***MSNA Quick Reference for Firmware Version 4.30*** (and later).

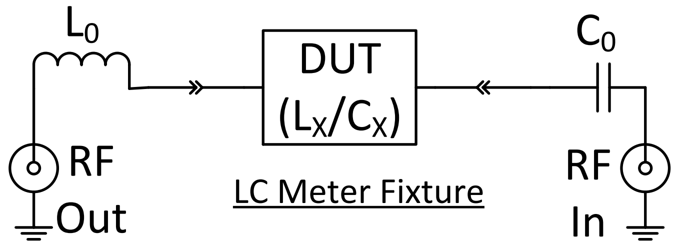
3. ADDITIONAL REQUIREMENTS

In addition to the MSNA, the following will be needed to complete this tutorial:

1. A simple LC Meter fixture consisting of a standard capacitor (C_0) and a standard inductor (L_0) that can be attached to the MSNA's **RF Out** and **RF In** BNC connectors with connect-ors/terminals to attach the device to be measured ("device under test" or "DUT").
2. Adapters or cables to attach the LC Meter fixture to the MSNA.

4. HOW IT'S DONE

The LCM measures the resonant frequency of an LC circuit consisting of an inductor (L_0) in series with a precision capacitor (C_0) without and with an unknown inductor (L_X) or capacitor (C_X) in the circuit. The readings are then used to determine the type of device (inductor or capacitor) and to calculate its value in micro Henrys or pico Farads.



A series- resonant LC circuit is a type of band-pass filter for which the MSNA is well suited to analyze. A band-pass filter has minimum insertion loss (maximum power transfer) at resonance. The resonant frequency is determined by doing a frequency sweep across a range of frequencies known to include the resonance point. The resonant frequency ($\boldsymbol{f}$) for a series LC circuit is given by the following equation:

$$\boldsymbol{f} = \frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\pi}\sqrt{\boldsymbol{LC}}}$$

Before measuring a DUT, the values of $\boldsymbol{L_0}$ and C_0 must be known. Since it is much easier (and less costly) to obtain precision capacitors than precision inductors, we assume $\boldsymbol{C_0}$ is of a known value and the value of $\boldsymbol{L_0}$ is not known to adequate preci-sion. The value of $\boldsymbol{L_0}$ can be determined by determining the resonant frequency of the circuit with the DUT shorted out.

$$\boldsymbol{f_0} = \frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\pi}\sqrt{\boldsymbol{L_0 C_0}}}$$

Since C_0 is known, once $\boldsymbol{f_0}$ is determined, we can solve for $\boldsymbol{L_0}$.

$$\boldsymbol{L_0} = \frac{\mathbf{1}}{\mathbf{4}\boldsymbol{\pi}^{\mathbf{2}}\boldsymbol{f}_{\mathbf{0}}^{\mathbf{2}}\boldsymbol{C_0}}$$

When the DUT is added to the circuit, it will either increase the inductance or reduce the capacitance of the circuit depending on the DUT type. From the first equation we can see that increasing the inductance will lower the resonant frequency and reducing the capacitance will raise the resonant frequency. The type of DUT can be determined by comparing the resonant frequency ($\boldsymbol{f_X}$) with the DUT in the circuit to the resonant frequency with the DUT shorted out ($\boldsymbol{f_0}$).

$$\boldsymbol{f_X < f_0 : DUT\ is\ an\ Inductor\ (L_X)}$$

$$\boldsymbol{f_0 < f_x : DUT\ is\ a\ Capacitor\ (C_X)}$$

Once the device type is known, the appropriate equation(s) can be selected to calculate the value of the DUT ($\boldsymbol{L_X}$ or $\boldsymbol{C_X}$).

When an inductor is in the circuit

$$\boldsymbol{f_X = \frac{1}{2\pi\sqrt{(L_0 + L_X)C_0}}}$$

$$\boldsymbol{L_X = \frac{1}{4\pi^2 f_X^2 C_0} - L_0}$$

When a capacitor is in the circuit it gets a little more complicated

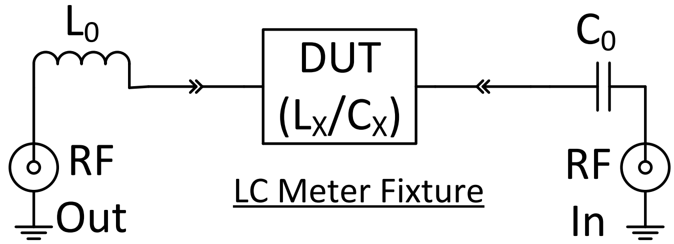
$$\boldsymbol{f_X = \frac{1}{2\pi\sqrt{L_0 C}}}$$

$$\boldsymbol{C = \frac{1}{4\pi^2 f_X^2 L_0} = \frac{C_X C_0}{C_X + C_0}}$$

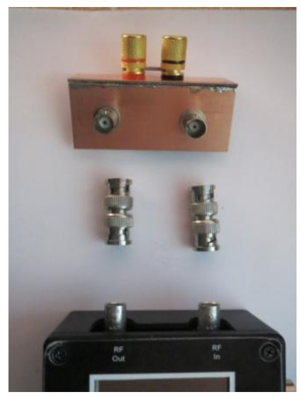
$$\boldsymbol{C_X = \frac{C C_0}{C_0 - C}}$$

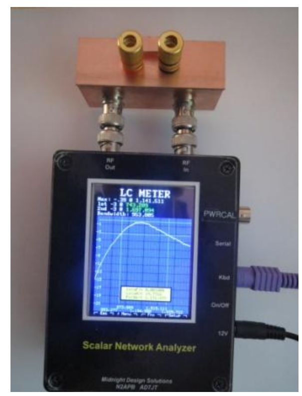
Don't worry about the math, the MSNA firmware does it all.

5. LC METER FIXTURE (LCMF)

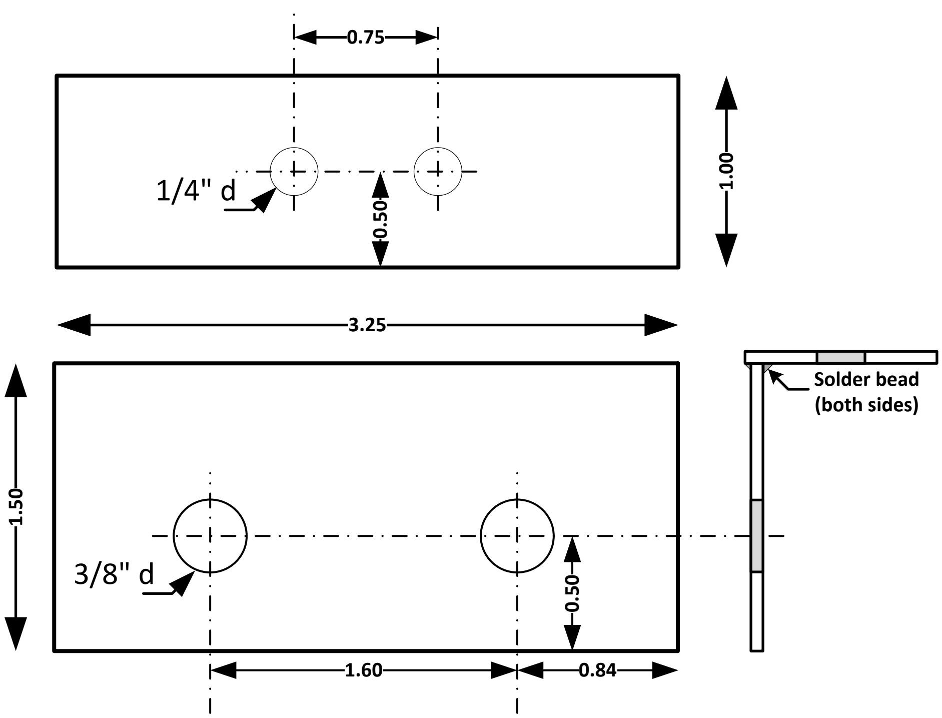


I built my LCMF on a small chassis made from two pieces of copper-clad PCB stock.





C_0 is a 0.001 uF, 1% silver mica capacitor. L_0 is a 25 uH, 10% axial lead inductor.



6. LC METER FIXTURE CALIBRATION

Calibrating the LCMF consists of finding the resonant frequency (f_0) of the fixture with the DUT shorted and computing the value of L_0. These values are saved in EEPROM.

1. Attach the LCMF to the MSNA **RF Out** and **RF In** connectors with the DUT terminals shorted.
2. Enter the value of C_0 using **Setup** > **C** [Scroll Lock > C] in pico Farads.
3. Prepare a macro data form with a frequency range from 100 KHz to 20 MHz and 601 rows specified on page one. On page two of the form specify op modes **L** and **R**.

4. Start the macro and tap the screen [SPACE] to start a frequency scan.
5. From the context menu, select **Auto Scale BW x 2** [2] to expand the plot around the resonant frequency.

6. Tap **Calibrate LC Mtr** [CTRL-L] to trap and save L_0 and f_0.

7. MEASURE UNKNOWN INDUCTOR

The LC Meter fixture is now calibrated and the MSNA is prepared to measure device parameters. Follow the following steps to measure an unknown inductor.

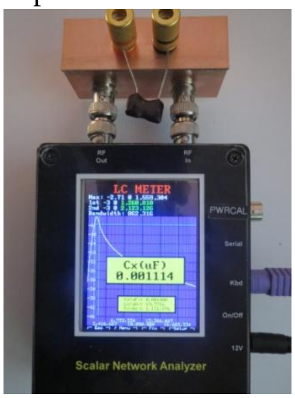
1. With the macro used in the previous section running, replace the DUT short with the unknown inductor.
2. Tap **Restore Original Scale** [0] on the context menu to widen the scope of the plot and start a frequency scan..
3. Tap **Auto Scale BW x 2** [2] to expand the plot around the new resonant frequency.

4. Read the inductance L_X from the yellow window. The inductor used here was marked 100 uH, tolerance unknown.

8. MEASURE UNKNOWN CAPACITOR

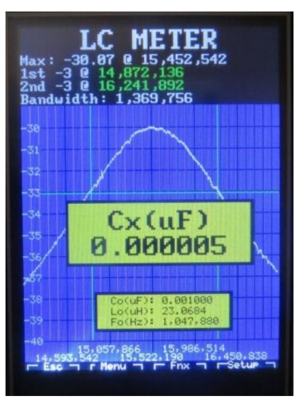
The steps to measure an unknown capacitor are essentially the same as those to measure an unknown capacitor.

1. With the macro used in the previous section running, replace the DUT short with the unknown capacitor.
2. Tap **Restore Original Scale** [0] on the context menu to widen the scope of the plot and start a frequency scan..
3. Tap **Auto Scale BW x 2** [2] to expand the plot around the resonant frequency.

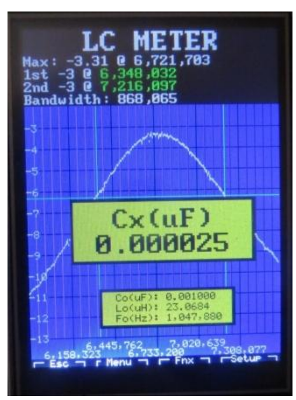


4. Read the capacitance C_X from the yellow window. The capacitor used here was marked .001 uF, tolerance unknown.

When measuring small values of capacitance, it may be advisable to take the LC Meter fixture's parasitic capacitance into account. This capacitance can be measured by leaving the DUT terminals open. The test fixture shown here indicates an open-terminal C_X of 5 pF. This capacitance is in parallel with the DUT so it can be subtracted from small value capacitance measurements.



Open Terminals



22 pF Capacitor