SARK-110

Vector Impedance Antenna Analyzer

Application Notes

6 April 2020

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1 ANTENNA MEASUREMENTS IN A RFID APPLICATION

1.1 INTRODUCTION

The SARK-110 antenna analyzer is a convenient tool for the measurement of antennas for HF RFID applications because features such as the graphical representations of the impedance, the determination of the sign of the reactance, and good accuracy characteristics. Besides, starting from firmware version v0.8.3.2 the analyzer implements a very convenient feature for this kind of applications, which is the automatic calculation of the equivalent circuit model of small loop antennas or coils.

The purpose of this application note is describing the step by step procedure of the use of the SARK-110 for this application using a practical example. This procedure will consist in the measurement of a 13.56 MHz RFID reader printed coil antenna, the determination of the equivalent circuit model and the matching to the reader output impedance, 50-ohm in this case.

The RFID antenna used in this application note is realized as a printed coil on a FR-4 board substrate. The series equivalent circuit is used to simulate the antenna in a RF simulation software and calculate the matching network. I have used the freely available RFSim99 simulator, but any other suitable simulation software can be used. After designing the matching network, the simulation results are verified with the measurement results.

1.2 ANTENNA

The design of the reader antenna is not in the scope of this application note. Manufacturers such as NXP, TI, or Microchip provide detailed antenna design guides included in application notes. In this example, the antenna is realized as a printed coil on a FR-4 board substrate, which also includes the placements for the matching network components. In order to facilitate the connection to the analyzer, it was soldered a board edge type SMA connector to the board.

In the first stage, this connector is connected directly to the coil for the measurement of the antenna characteristics and the determination of the equivalent circuit model. Once this process is completed, the components of the matching network are soldered to the board and the SMA connector connected to the input of the matching network.

Note: for the measurements, it is important that the antenna be at the final mounting position to consider all parasitic effects such as metal influence on quality factor, inductance and additional capacitance.

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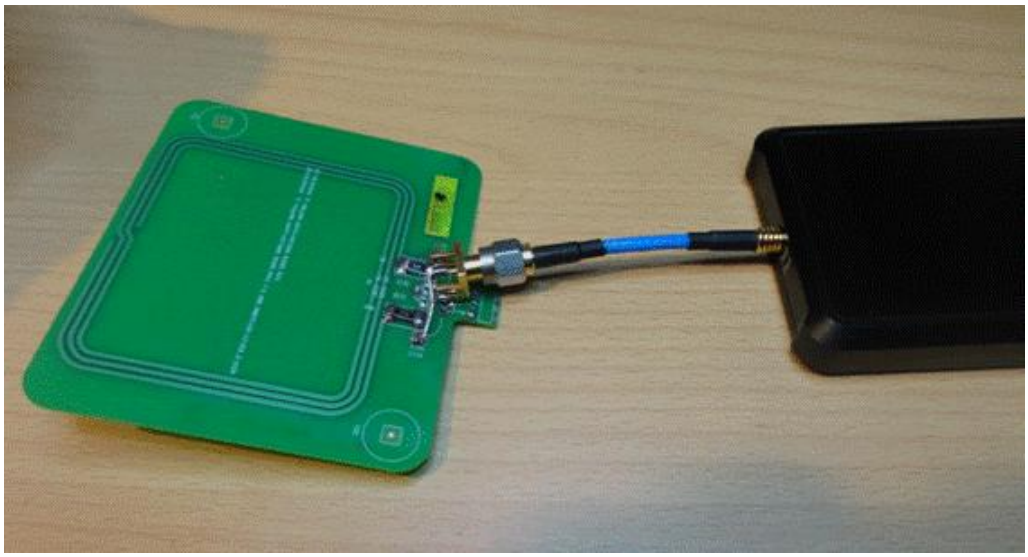

Figure 1, connection of the antenna coil to the analyzer

2 EQUIVALENT CIRCUIT MEASUREMENT

The antenna needs to be connected to the analyzer by using an appropriate test fixture that does not influence the antenna parameters. In this case it has been used a short (5cm) SMA to MCX adapter cable as illustrated in the Figure 1.

It is essential that the analyzer is calibrated before each measurement. The open, short and load calibration loads must be connected to the end of the test port extension cable, in this case to the SMA plug (see Figure 2). Please refer to the user's manual on how to carry out the steps for OSL calibration.

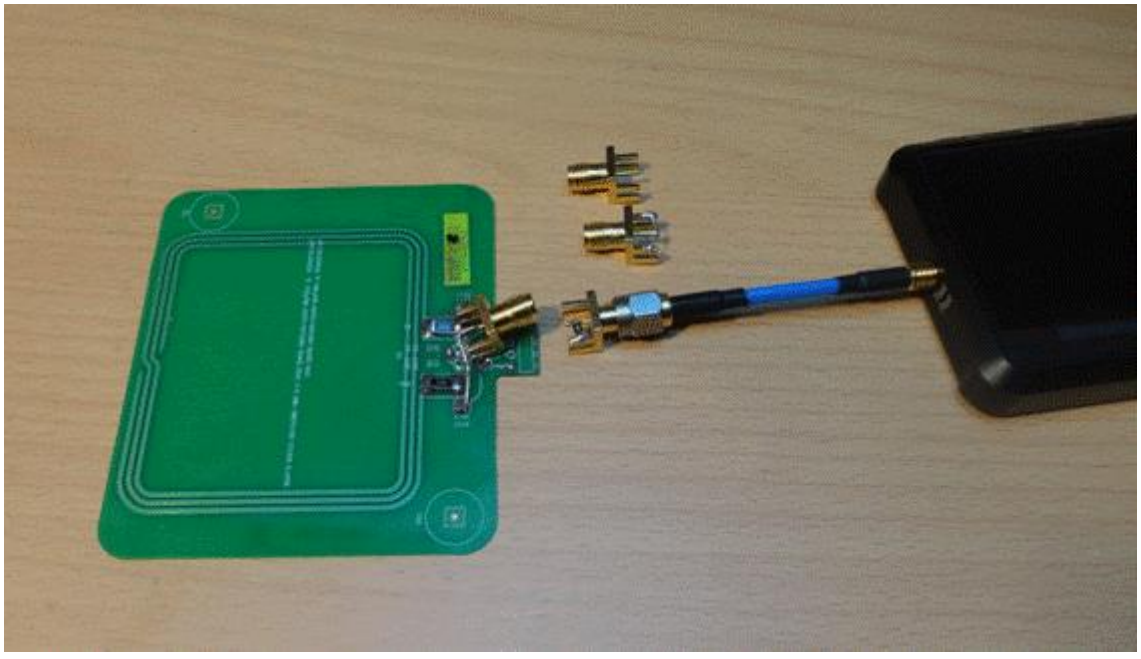

Figure 2, calibration loads connected to the end of the test port extension

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Once the calibration process is completed, the analyzer can be connected to the antenna via the test port extension cable. As a first verification step, we will visualize the graphs of the impedance characteristics of the antenna. We will start visualizing the reflection characteristics in the Smith Chart mode. In this case the analyzer centre frequency was set to a value of 36 MHz and the span to 71 MHz. The screen capture of the Smith chart is shown in the Figure 3. The marker is positioned around the self-resonance point of the antenna, which is around 52 MHz in this case.

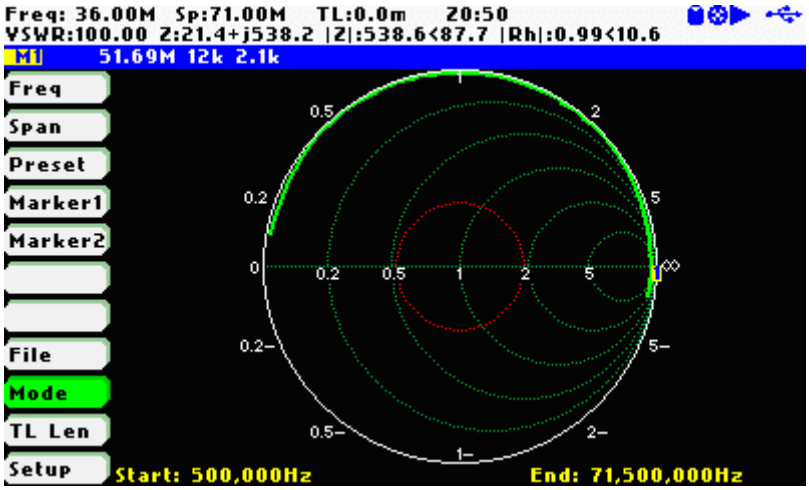

Figure 3, antenna impedance characteristics in the Smith chart

The Figure 4 shows the measurements results in the Scalar chart mode, that it is configured to show the modulus and the phase angle of the impedance. The marker is positioned at the resonance point as it was done in the Smith chart.

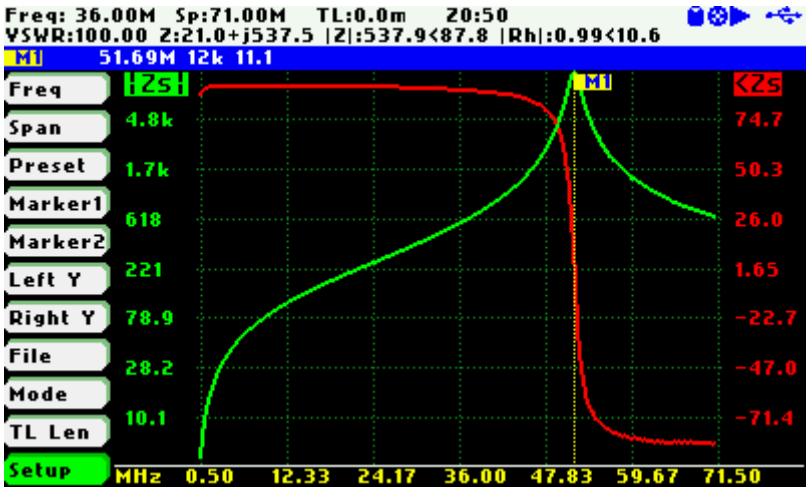

Figure 4, antenna impedance characteristics in the Scalar chart

The next step will be the determination of the equivalent circuit model of the antenna. This can be determined "manually" by doing impedance measurements at 1 MHz, at the operating frequency of the antenna (13.56 MHz), and at the self-resonance point of the antenna. These results are then taken as input for some calculations and the model can be derived. However, the SARK-110 does automatically all this process and provides the results of the equivalent circuit.

The procedure is the following:

Step 1. Perform OSL calibration (if not already done in a previous step): **«Setup»** *«Calibration»* «OSL Calibration»

Step 2. Connect the antenna to the analyzer

Step 3. Select Single Frequency mode: **«Mode»** *«Single Frequency»*

Step 4. Select **«CModel»** in the main menu (Figure 5)

Step 5. Select *«Loop Antenna / Coil»* in the submenu (Figure 6)

Step 6. Set the frequency according the desired operating frequency for this antenna (13.56 MHz) (Figure 7)

Step 7. After some seconds the results are shown on the screen (Figure 8). It is convenient saving the screen by selecting [●]

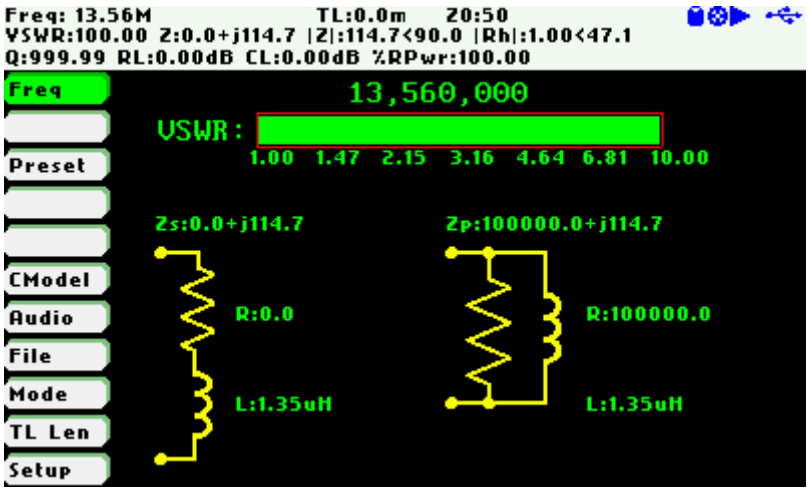

Figure 5, Single Frequency mode

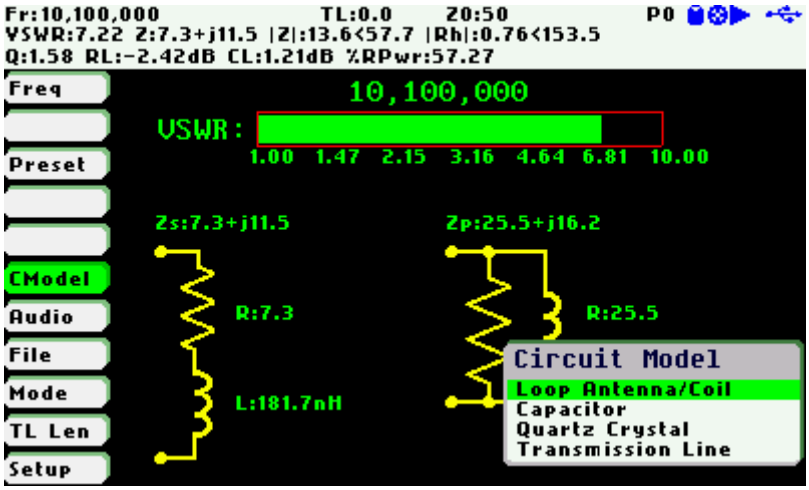

Figure 6, «CModel» menu options

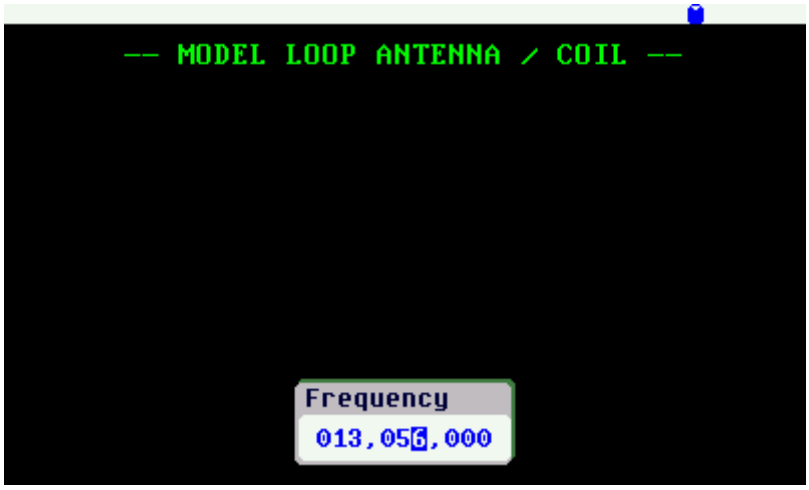

Figure 7, Setting operating frequency

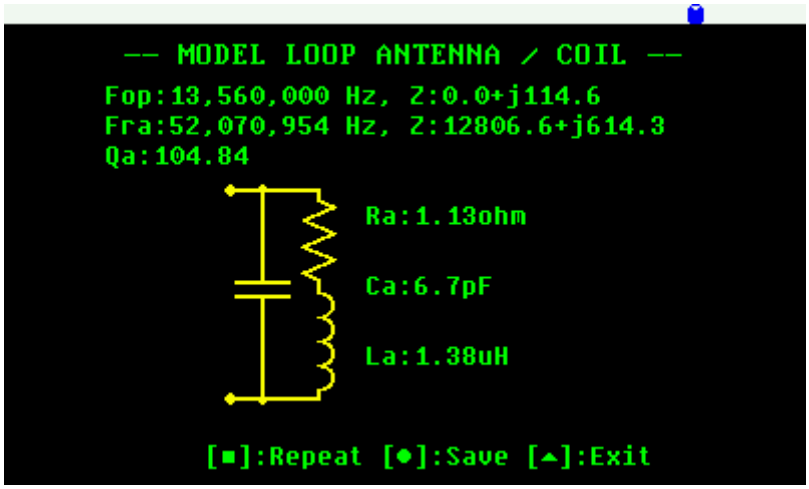

Figure 8, antenna equivalent circuit model screen

The contents of the measurement screen are described in the Figure 9:

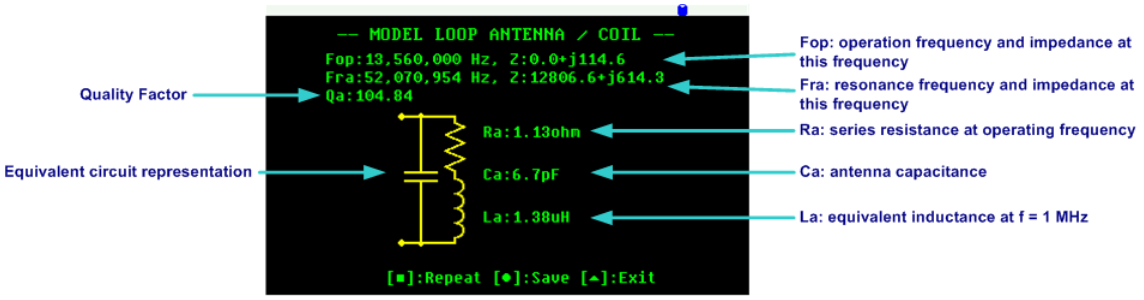

Figure 9, antenna equivalent circuit model screen explained

The internal procedure done by the analyzer is as follows: the analyzer measures the impedance at 1 MHz and at the desired operation frequency (13.56 MHz). Then it automatically scans for the antenna self-resonance frequency and measures the impedance at this point. The following parameters are extracted from these measurements:

Rs Equivalent resistance at F = 1 MHz

La Equivalent inductance at F = 1 MHz

Rp Equivalent resistance at the self-resonance frequency

Fra Self-resonance frequency of the antenna

After that, the antenna capacitance is calculated with the following equation:

$$Ca = \frac{1}{La \times (2 \times \pi \times Fra)^2}$$

The series equivalent resistance of the antenna (see Figure 10) at the operating frequency Fop = 13.56 MHz is calculated with the following equation:

$$Ra = Rs + \frac{(2 \times \pi \times Fop \times La)^2}{Rp}$$

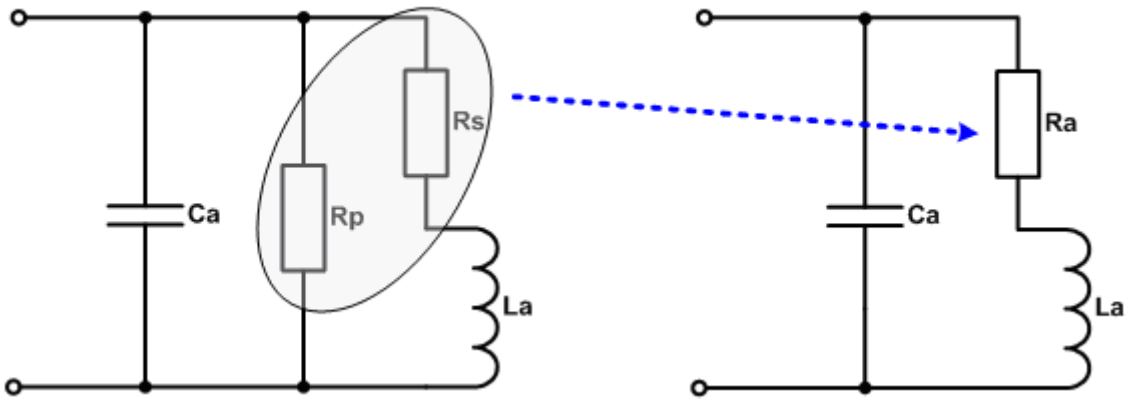

Figure 10, series equivalent resistance calculation

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Now we can start entering the model in the simulator software. Figure 11 shows the schematic in RFSim99 and Figure 12 the simulation results of the antenna equivalent circuit model.

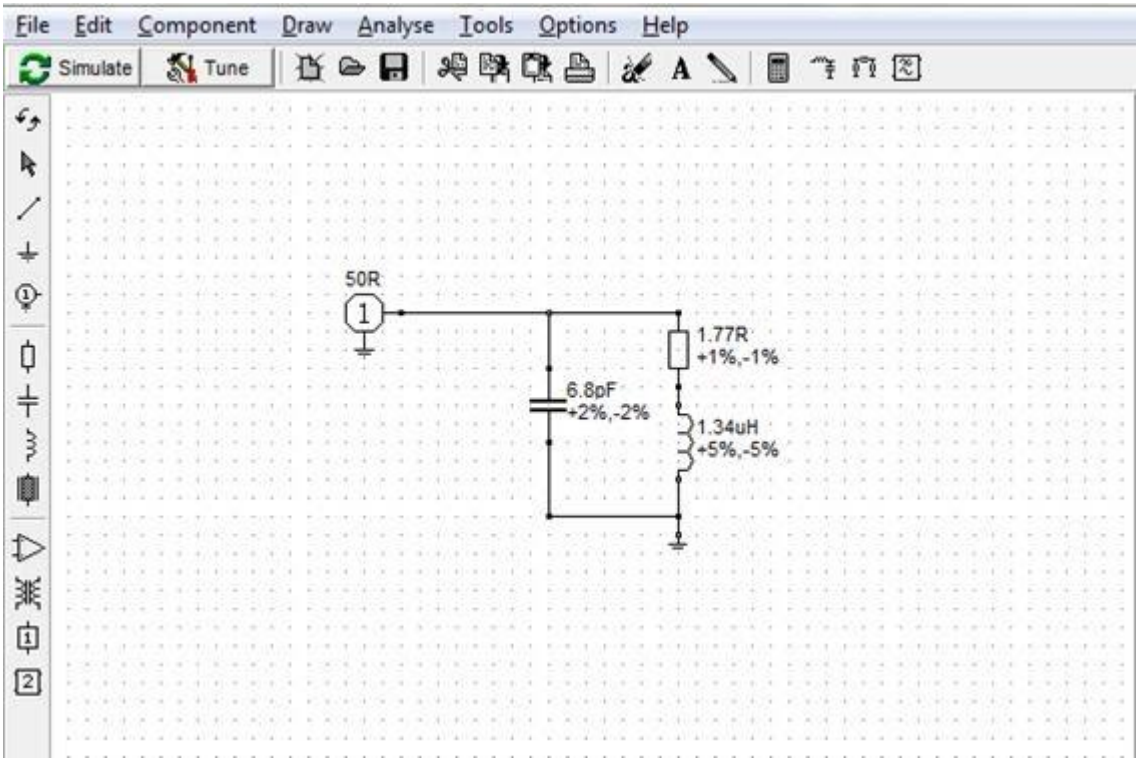

Figure 11, schematic of the antenna equivalent model in RFSim99

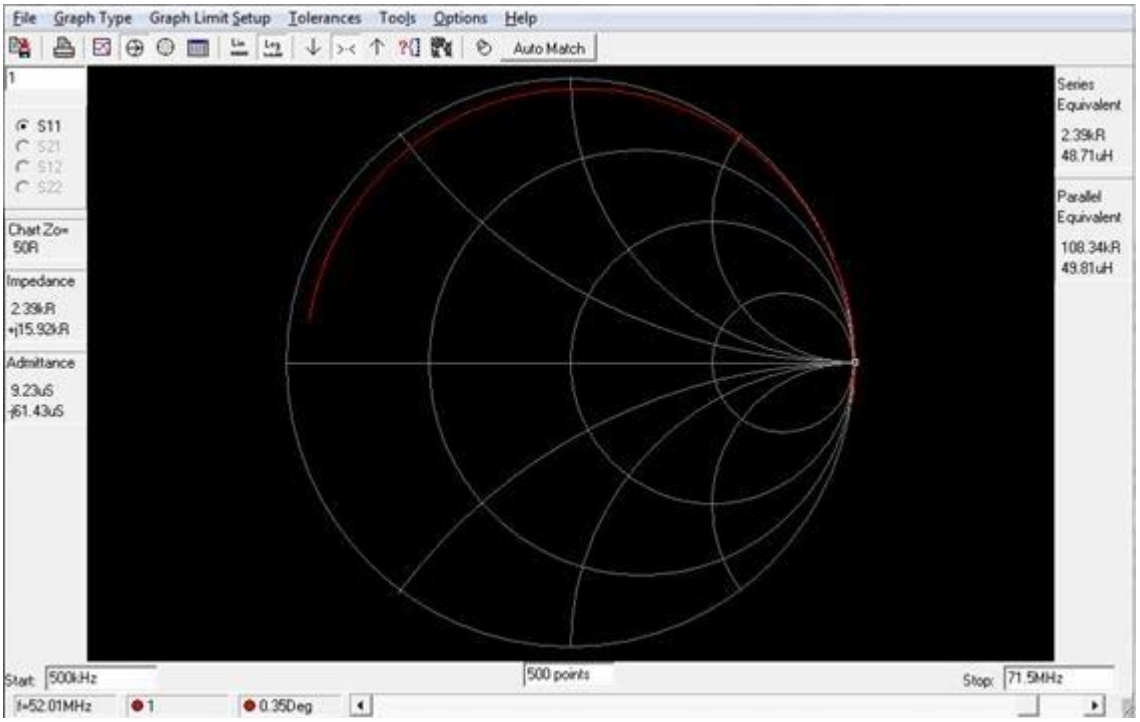

Figure 12, simulation results of the calculated antenna model in RFSim99

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2.1 CALCULATING THE MATCHING NETWORK

At this stage, the antenna circuit equivalent has been determined so it is available the necessary information for the design of the matching network for the adaptation to the output impedance of the RFID reader. In this example, the RFID reader output impedance is 50-ohm.

The Figure 13 illustrates the three-component matching network. The resistor RQ is a quality factor damping resistor required to reduce the Q factor of the circuit since normally is higher than the required. The two capacitors transform the complex impedance of the coil to the desired impedance of 50-ohm at the operating frequency.

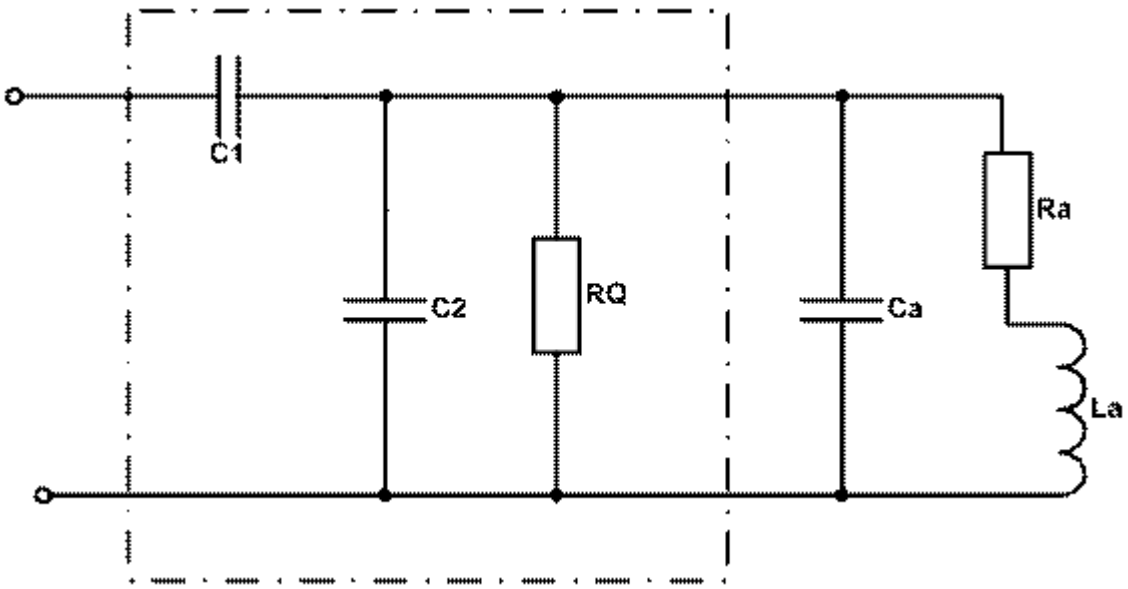

Figure 13, matching network

The matching procedure for this matching network is explained in the Figure 14 with a Smith chart. The complex impedance at the operating frequency of the antenna coil which must be matched is marked with “A” in the figure. The capacitor C2 transforms the impedance to the point B depending on its value. The resistor RQ defined by the operating bandwidth transforms the impedance to the point “C”. This point is located on the circle in the chart with the property Re (Z) = 1. From point “C” o “D” the serial capacitor C1 is used to reach the matching point.

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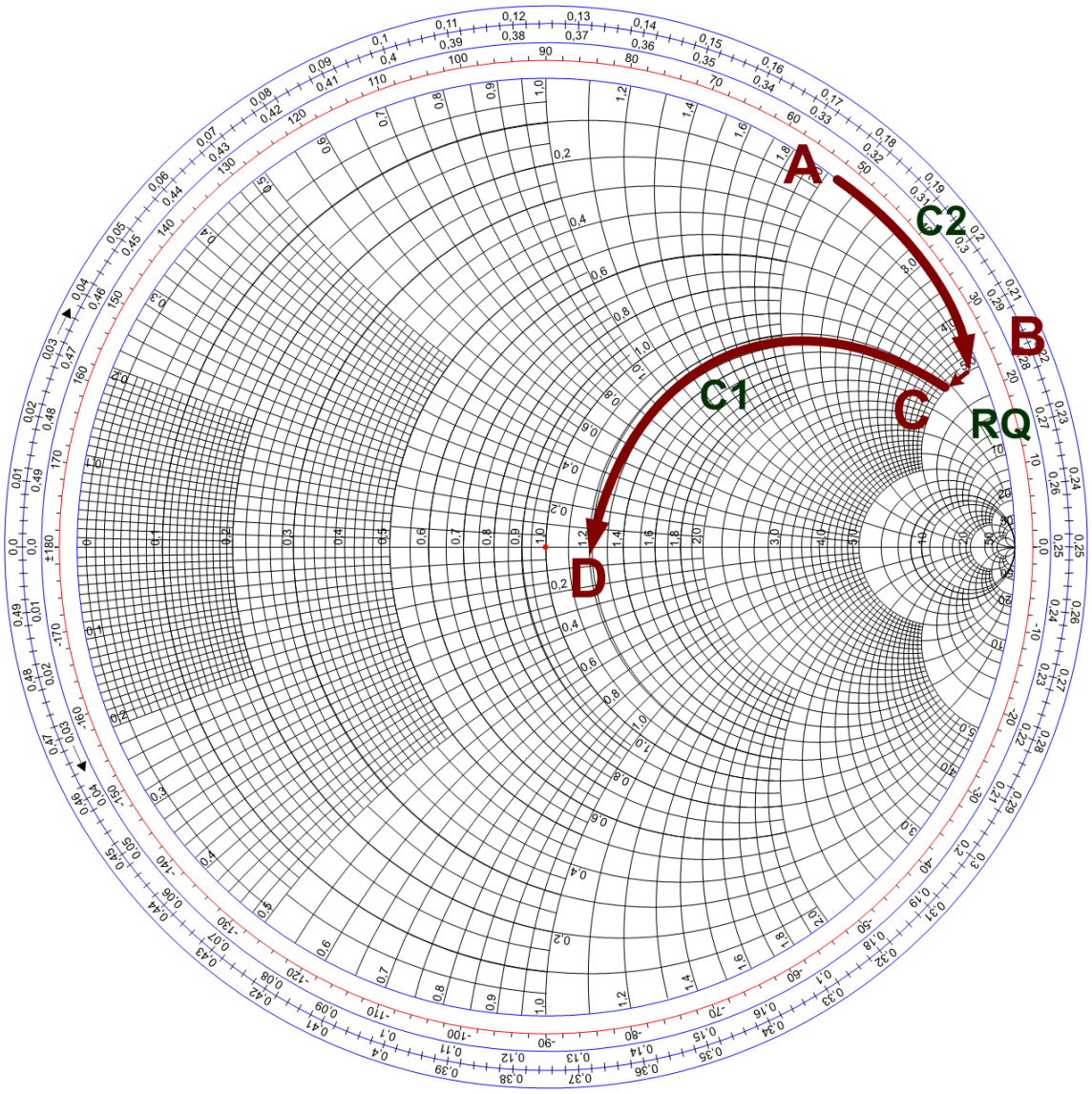

Figure 14, matching procedure

The bandwidth of the antenna can be defined by the Q factor. The relationship between the Q and bandwidth is defined by the following equation:

$$Q = \frac{Fop}{BW}$$

The value of the resistor RQ in the matching network can be calculated by the following equation:

$$Q = \frac{RQ}{XL}$$

$$RQ = Q \times XL$$

The XL value is the reactance of the antenna at the operating frequency, in this case the antenna has value XL=114.6; see Figure 15.

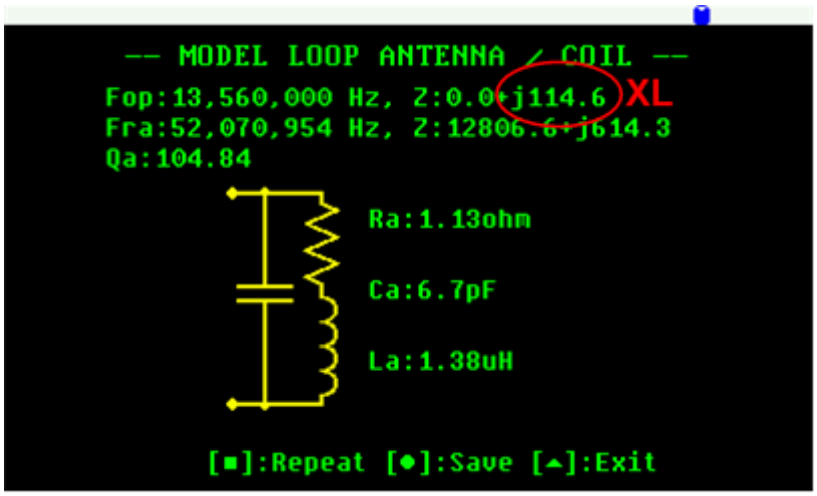

Figure 15, XL value in the equivalent circuit model screen

In this example, I selected a RQ value of 1.3K that calculates to a Q value of 11.4 and a bandwidth of about 1.2 MHz. Then following the matching procedure above, I obtained values of 47pF for C1 and 52pF for C2.

These values were introduced and the RFSim99 schematic and run the simulation to see the Smith chart (see Figure 15 and Figure 16). The marker is set at 13.57 MHz which is nearly the centre of the chart, corresponding to the perfect match.

The reason of not implementing a perfect match was due to the convenience of using standard capacitor values. It is usual in matching network implementations, implementing capacitors in parallel in order to get precise capacitances.

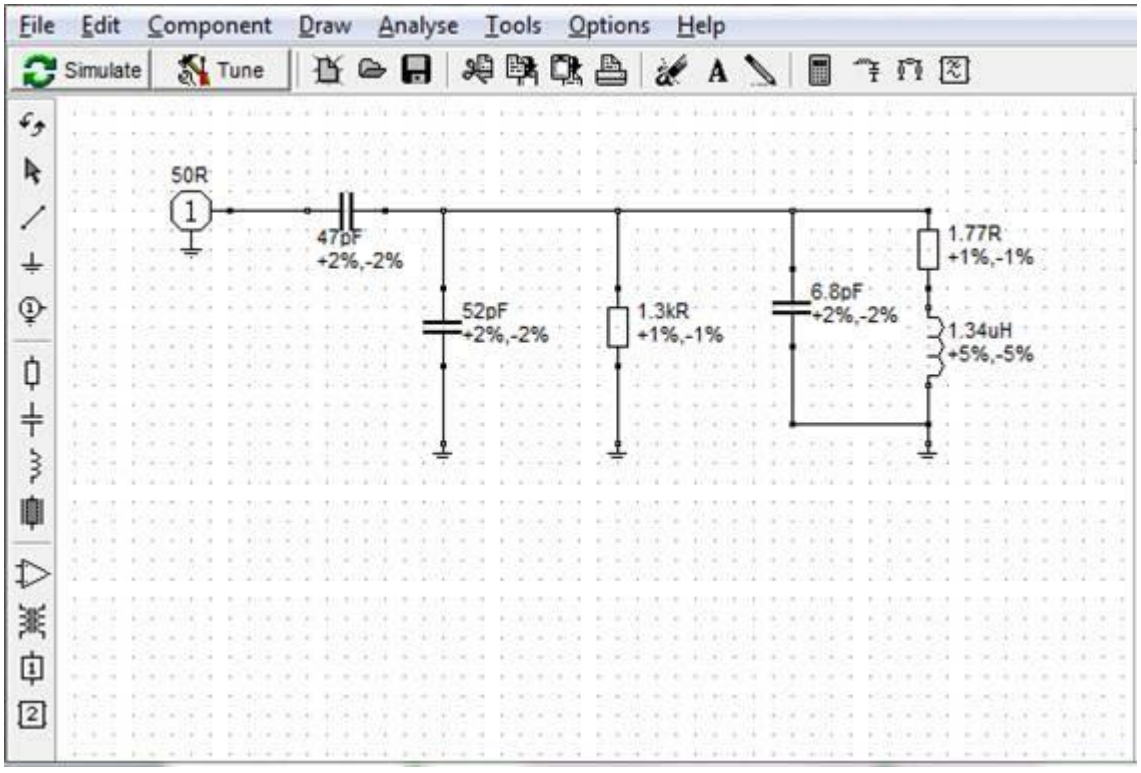

Figure 16, schematic of the antenna equivalent model and matching network in RFSim99

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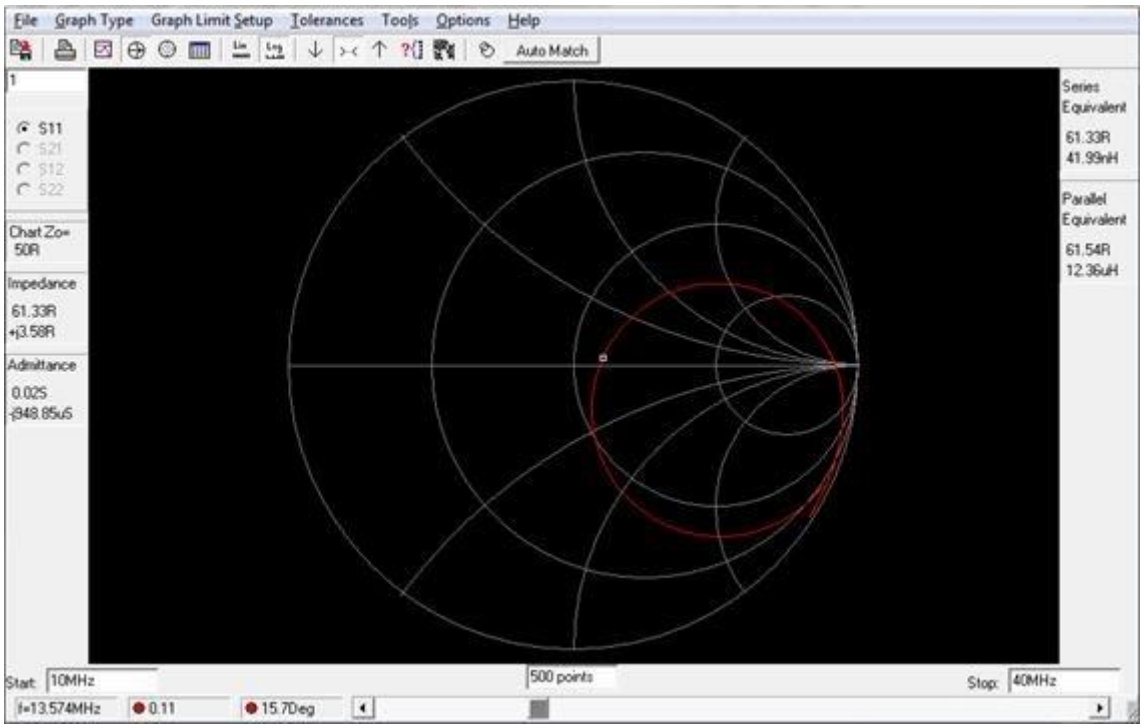

Figure 17, simulation results of the matched antenna model in RFSim99

Finally, the calculated components can be populated in the prototype antenna board in order to verify with the analyzer that the measurements are correct and match to the simulation results.

The Figure 18 and Figure 19 show the measurements of the antenna with the matching network, in both Smith and Scalar chart formats. The measurement results match quite accurately the results of the simulation.

In some cases, it will be needed some fine tuning of the components, following the matching procedure and then verifying the results with the analyzer.

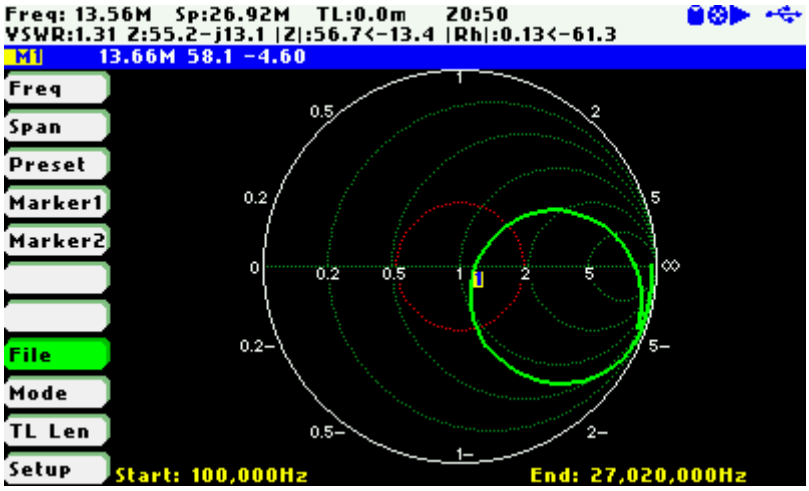

Figure 18, measurement of the matched antenna in a Smith chart

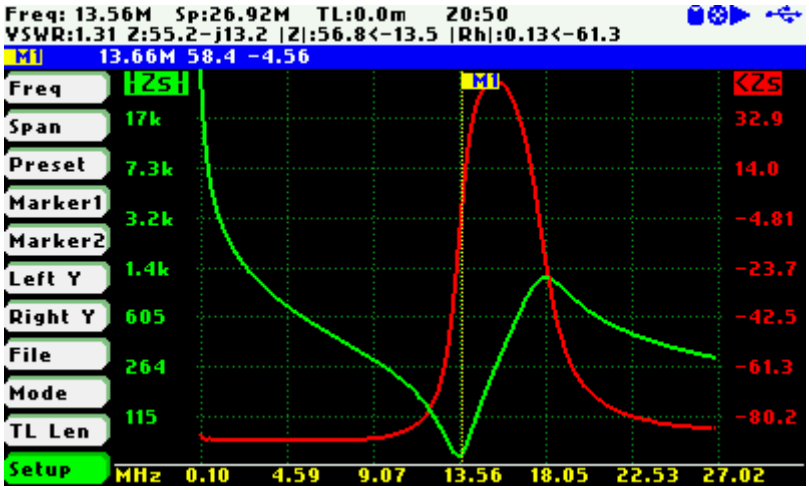

Figure 19, measurement of the matched antenna in a Scalar chart

2.2 CONCLUSION

The SARK-110 antenna analyzer allows the easy determination of the equivalent circuit model of an antenna coil for RFID applications. This facilitates the calculation process for the determination of the matching network component values and simulating the results using a RF simulation software such as RFSim99. The analyzer can then be used to verify the matched antenna characteristics very quickly.

3 CONTROL A SARK-110 REMOTELY USING A RASPBERRY PI

This application note explains how to setup remote access to a SARK-110 antenna analyzer connected to a Raspberry Pi from a computer running SARK Plots. This means that you can control the antenna analyzer from a computer that it is anywhere within the range of your home network such as a laptop connected via Wi-Fi. Besides, it is possible to configure it to have access from anywhere outside your home network.

The SARK-110 is connected to the Pi via the USB interface. The Pi runs a TCP server software and it is connected to the home network via Wi-Fi or Ethernet. The remote computer runs SARK Plots software (version v1.0.0.41 or higher) and it is connected to the home network as well.

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3.1 Raspberry Pi Setup

These setup instructions have been tested on a configuration with Raspberry Pi 3 Model B running Raspbian Stretch with Desktop operating system, so may need some changes for other operating system distributions or hardware model. For operating the Pi, you may need a keyboard and monitor or operate remotely using VNC for example. The Pi needs to be connected to the network via Wi-Fi or Ethernet interfaces.

The server source code and necessary files are available in GitHub in the following location: https://github.com/EA4FRB/sark110-srv-linux.

For getting the files and first setup you will need to do the following:

1. Open a terminal window and change to the directory you want to place the project, e.g. cd /home/pi/projects
2. Enter the command: git clone https://github.com/EA4FRB/sark110-srv-linux
3. Now you should have the server project located in: /home/pi/projects/sark110-srv-linux
4. First time, you will need to copy sark110.rules file to /etc/udev/rules.d. Enter command: sudo cp sark110.rules /etc/udev/rules.d

The executable sark110-srv.a is available, so you would not normally need to compile the project. Otherwise, please review the instructions available in the README.md file.

Now you can connect the SARK-110 to the Pi. For starting the server you will need typing: ./sark110-srv.a

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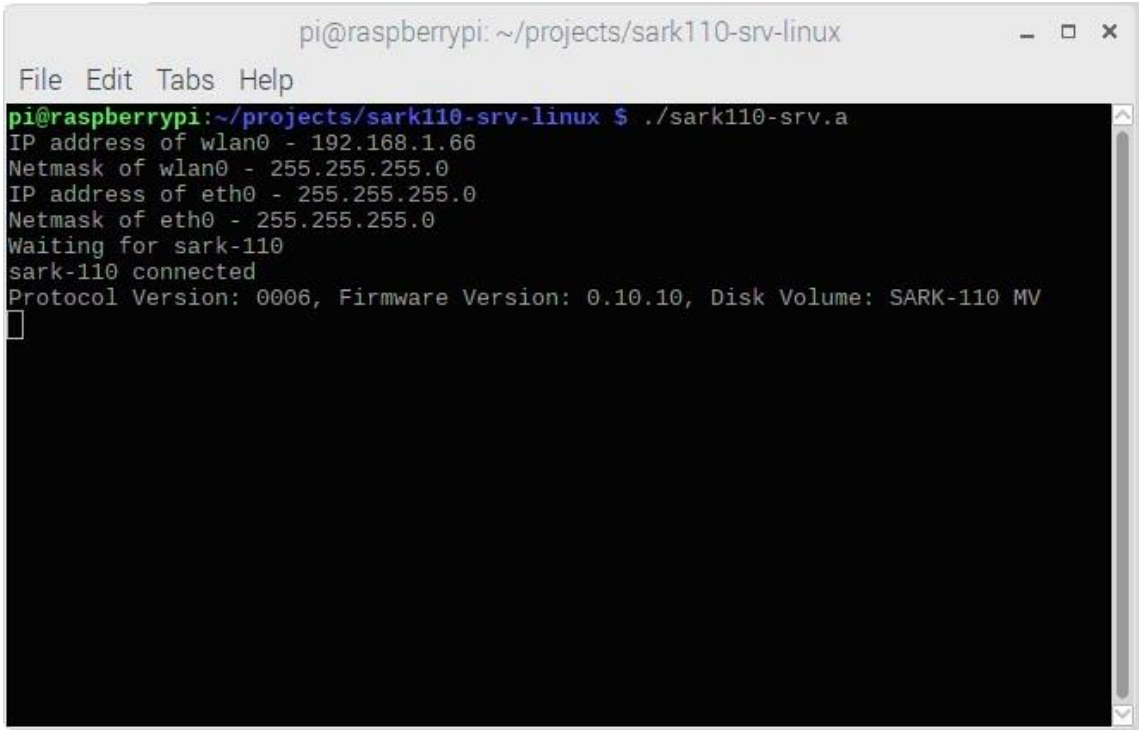
If everything is correct, you will see the following screen. Write down the IP address of the interface; in this case the IP address for the wlan0 interface is 192.168.1.66



Now you have the Pi ready for receiving commands from a computer in your local network running SARK Plots.

If you need to launch the server automatically on reboot, you can follow the following procedure:

1. Open a terminal window
2. Enter the command: crontab –e
3. Add at the end of the opened file: @reboot /home/pi/projects/sark110-srv-linux/sark110-srv.a
4. Save the file

3.2 SARK PLOTS SETUP

For setting SARK Plots to use the server you will need just to enter the IP address of the server. Select <Settings> <Parameters> and enter the IP address in the text box located on the bottom left side of the dialog box.

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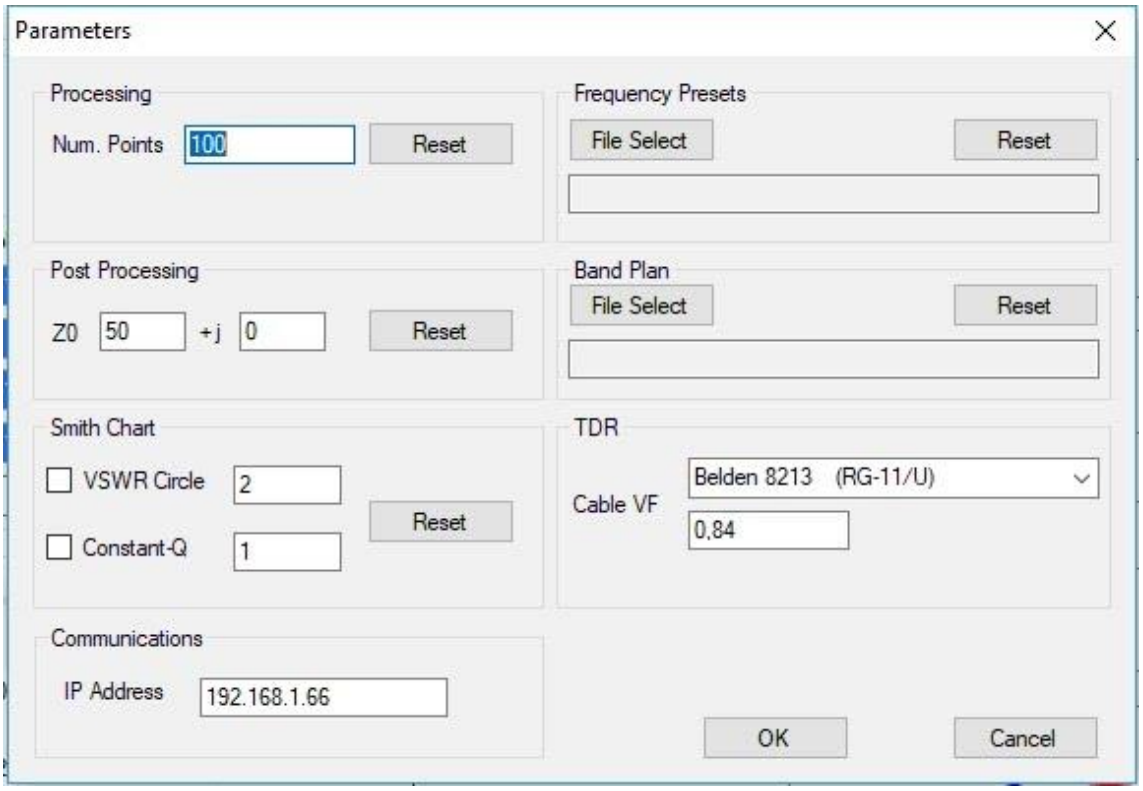
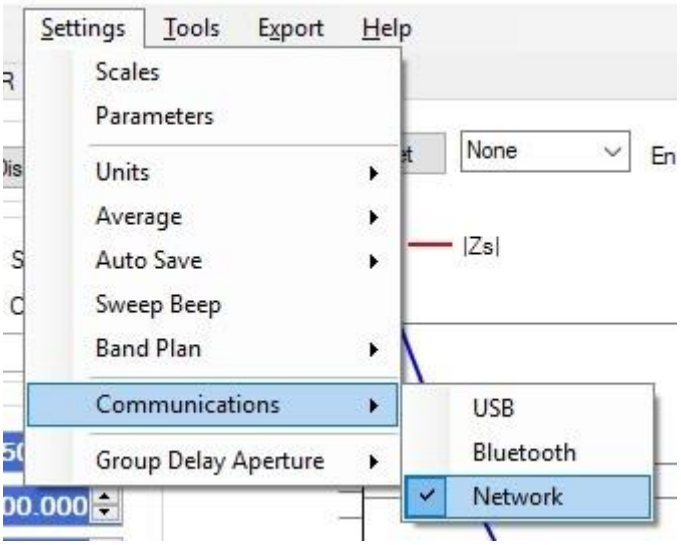


Then select <Settings> <Communications> <Network>:



Finally press the Connect and Run buttons to start plotting the measurements.

3.3 Remote Connection from Anywhere

The instructions above describe the setup for a remote connection within the range of your home network. It is also possible configuring the system for accessing from outside your home network using Port Forwarding. For using this feature, you will need to open ports in your router. The way to open ports depends on the router you are using, so you will need to refer to the manuals or documentation available in the Internet regarding Port Forwarding for configuring your router. Notice that the port used by this server is 8888.

For using the Port Forwarding with your Pi, you will need first to configure a static IP address. There are several ways for doing this, e.g. by entering in "Wireless & Wired Network Settings" by clicking on the network icon located on top right side of the desktop. Select Configure Interface wlan0, disable the checkbox "Automatically configure empty options" and enter the required addresses, e.g. IPv4 Address (e.g. 192.168.1.100), Router Address (usually 192.168.1.1 or 192.168.0.1) and DNS Servers address (usually same as router address). Enter these settings, reboot the Pi and run ifconfig to confirm if the settings are correctly applied.

Then configure your router for opening the port **8888** following the specific instructions. Finally, you will just need to know the public IP of your network and configure SARK Plots with this IP address for accessing to the SARK-110's Pi server.

4 Equivalent Circuit Determination of Quartz Crystals

This application note describes how to measure the equivalent circuit parameters of a quartz crystal with the SARK-110 Antenna Analyzer.

The process for the determination of the crystal parameters is laborious, so in order to simplify this process the SARK-110 provides the automatic determination of the crystal parameters feature. This feature is available in firmware versions v0.8.3.7 or higher.

The Figure 1 shows a screenshot of the measurement of the parameters of a crystal. The model provides the resonant frequencies –series and parallel, the quality factor, and the values of the crystal circuit model.

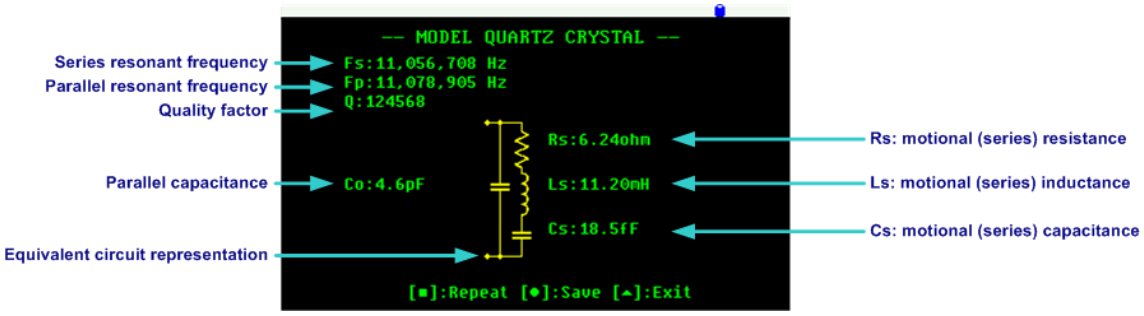


Figure 1, Quartz crystal equivalent circuit model screen

4.1 Equivalent Circuit Measurement

The crystal must be connected to the analyzer by using an appropriate test fixture. In this case it has been used a board edge type SMA connector, soldered to a socket for plug-in the crystal; see Figure 2. The test port adapter is a short SMA to MCX adapter cable.

It is essential that the analyzer is calibrated before each measurement. The open, short and load calibration loads must be connected to the end of the test port extension cable. In addition, it will be convenient performing frequency calibration for the best accuracy on resonance frequency measurements. Please refer to the user's manual on how to carry out the steps for calibration.

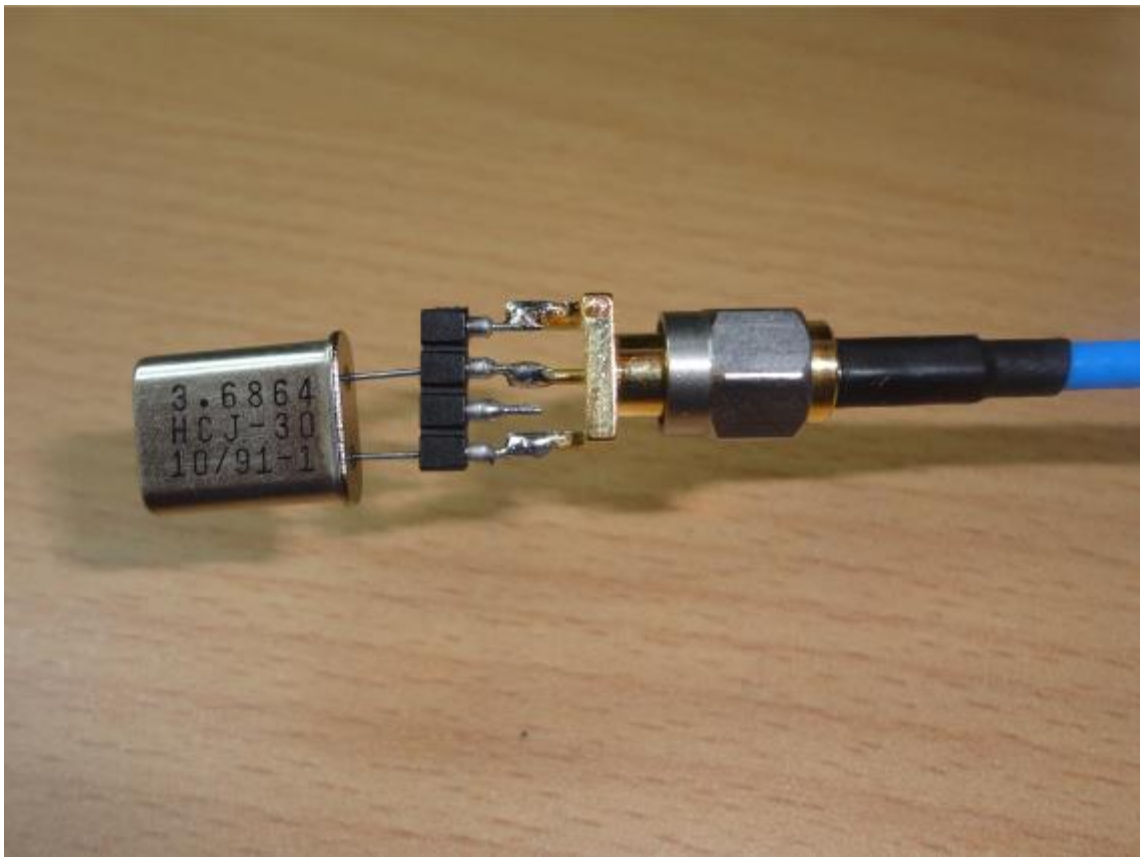


Figure 2, Crystal test fixture

The procedure for the determination of the circuit model is the following:

Step 1. Perform OSL calibration

Step 2. Connect the crystal

Step 3. Select Single Frequency mode: «Mode» «Single Frequency»

Step 4. Select «CModel» in the main menu

Step 5. Select «Quartz Crystal» in the submenu

Step 6. Set the frequency to a value close to the expected resonant frequency of the crystal

Step 7. After some seconds the results are shown on the screen (Figure 3). It is convenient saving the screen by selecting [●]

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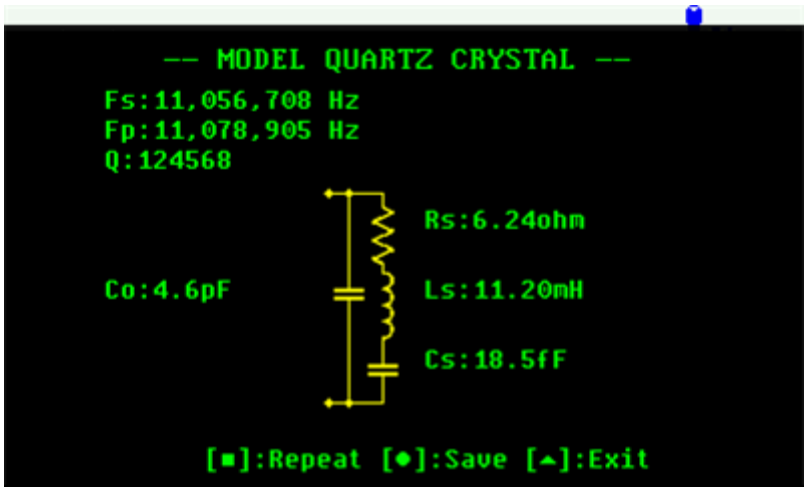

Figure 3, Equivalent circuit model of an 11 MHz crystal

The value of the series resonant frequency is transferred to the frequency in Single Frequency mode and to the centre frequency in the sweep modes, e.g. Scalar Chart or Smith Chart modes. This allows graphically examining the characteristics at the resonant frequency; see Figure 4, Figure 5 and Figure 6.

Note that it is important setting the automatic scale for the correct display of the impedance characteristics in the Scalar Chart mode.

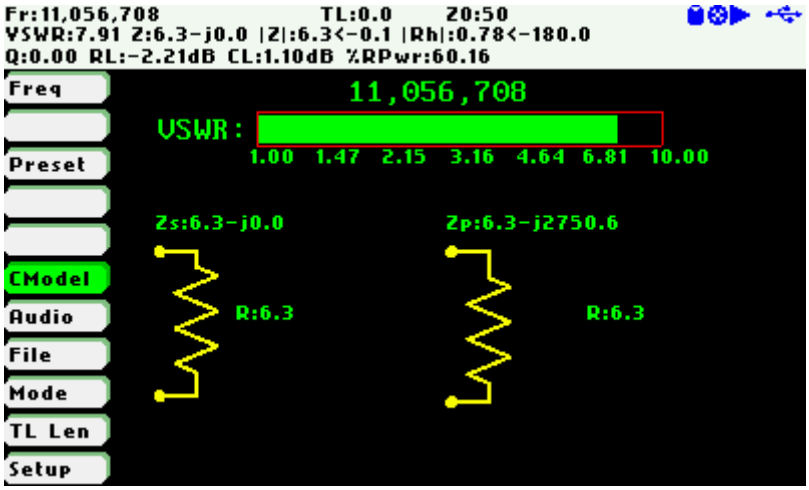

Figure 4, Crystal impedance values at resonant frequency in Single Frequency mode

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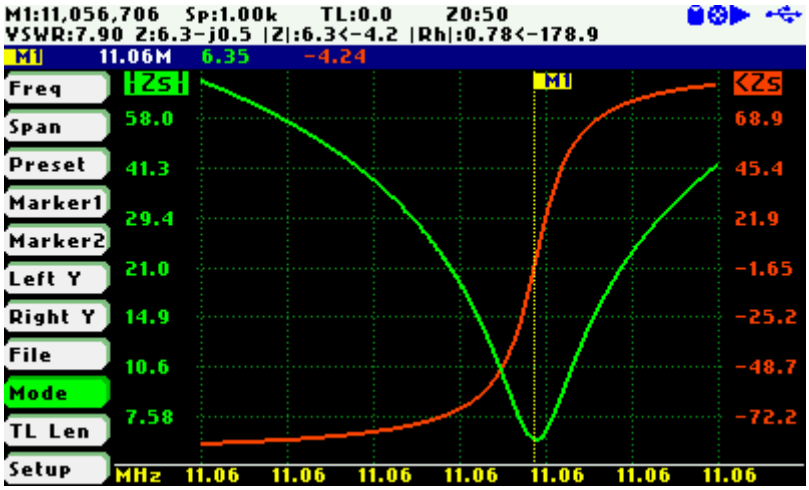

Figure 5, Crystal impedance characteristics at resonant frequency

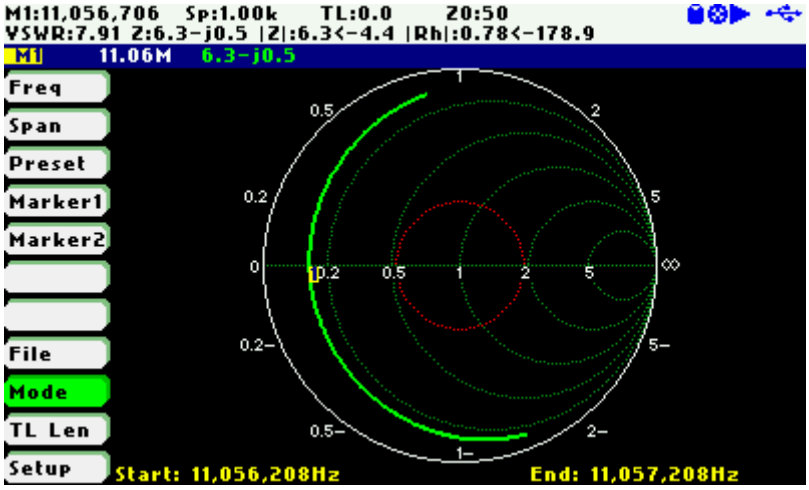

Figure 6, Crystal impedance characteristics at resonant frequency

The Figure 7 shows the series and parallel resonant frequencies in the Scalar Chart mode. For this crystal it was set a span of 40 kHz for the complete display of those resonant frequencies.

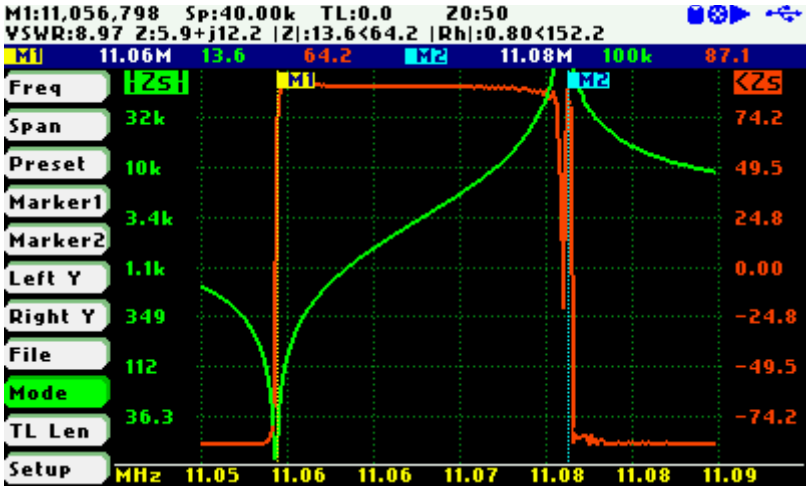

Figure 7, Series and parallel resonant frequencies

4.2 How it works

The process starts by automatically looking for the series and parallel resonant frequencies. The start scan frequency is taken from the frequency value in Single Frequency mode. The scan range is +1MHz up and -1MHz down from this value.

The resonant frequencies are identified in the singularities where the impedance changes from pure capacitive (phase value close to -90º) to pure inductive (phase value close to +90º). The resonant frequencies are then obtained from the frequency points where measured phase value is close to zero.

After determining the series and parallel resonant frequencies, it is measured the series resistance (Rs) at the series resonant frequency. Then it is measured the parallel capacitance (Co). This value is measured in a frequency that is 2.5 MHz below Fs or 2.5 MHz above Fp. With all these measurements, it will be derived the rest of parameters:

The value of series capacitance (Cs) is given by:

$$Cs = 2 \times Co \times \left(\frac{Fp}{Fs} - 1 \right)$$

The value of the series inductance (Ls) is given by:

$$Ls = \frac{1}{\left(4 \times \pi^2 \times Fs^2 \times Cs\right)}$$

Finally, the quality factor of the crystal (Q) is calculated by:

$$Q = \frac{1}{Rs} \times \sqrt{\frac{Ls}{Cs}}$$

5 Extending low frequency range limit down to 10 kHz

The SARK-110 lower frequency range is limited by the hardware and the software of the device to 100 kHz. This limit is not an issue for most use cases, but for some applications such as eddy current measurements it is required operation at even lower frequencies.

Note: these Hardware Modifications described below are already implemented in units sold starting September 2014

However, it is possible to overcome this limitation and prepare the unit for a low frequency range limit of 5 kHz by replacing six capacitors and downloading a variant of the firmware.

Warnings:

- Due to the small size of the components (0402 size), you will need excellent soldering skills and proper tools to perform this operation safely.

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- You will need a complete set of calibration loads

5.1 Hardware Modifications

The hardware modification consists in replacing the following capacitors: C62, C64, C67, C79, C81, and C84. The changed capacitors have a capacity of 220nF, dielectric X7R, and 0402 size. Following is the description of a capacitor available at DigiKey:

- DigiKey P/N: 1276-1176-1-ND
- Manufacturer P/N: CL05B224KO5NNNC
- Description: CAP CER 0.22UF 16V 10% X7R 0402

Note that it is convenient purchasing additional spares because they are very easy to lose during the assembly.

The location of the capacitors in the board is illustrated in the Figure 1.

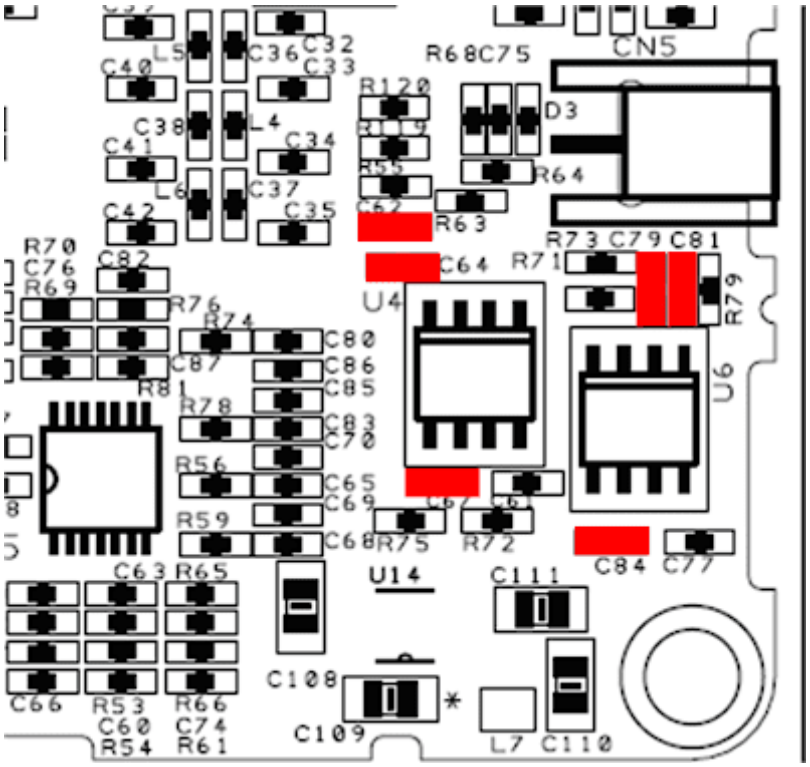

Figure 1, Changed capacitors

5.2 Updating the Firmware

There is a specific variant of the firmware supporting this lower frequency range. In order to differentiate from the standard firmware, the version identifier includes the suffix “b”, example “SARK110-VAA-APP0.8.5.3b.dfu.zip”.

After installing the new firmware, it is necessary performing the detector calibration first and then the OSL calibration.

5.3 Example Application

One of the possible applications for the extended lower frequency range is eddy current measurement. In this application note I will not enter in the theory and details of eddy current measurements, but just in a practical measurement example.

Following reference is an excellent source of information about eddy current testing: An introduction to eddy current testing from the NDE/NDT resource center

For this example, I built the probe coil shown in Figure 2. This is built of 0.35mm copper, and four layers of about 25 windings per layer. The radius of the coil is 7.4mm and height 9.6mm.

As measurement targets, I used a FR4 board (Figure 3) and aluminium board (Figure 4).

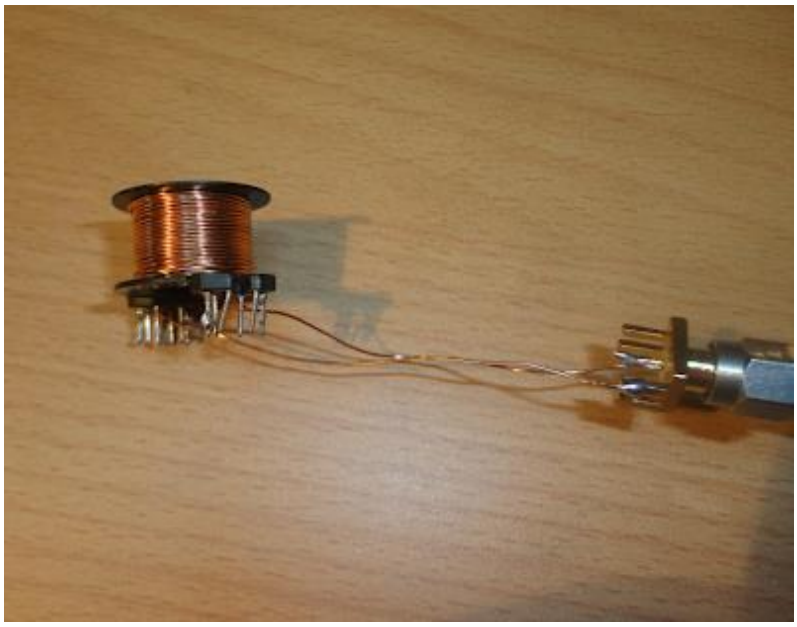

Figure 2, Coil

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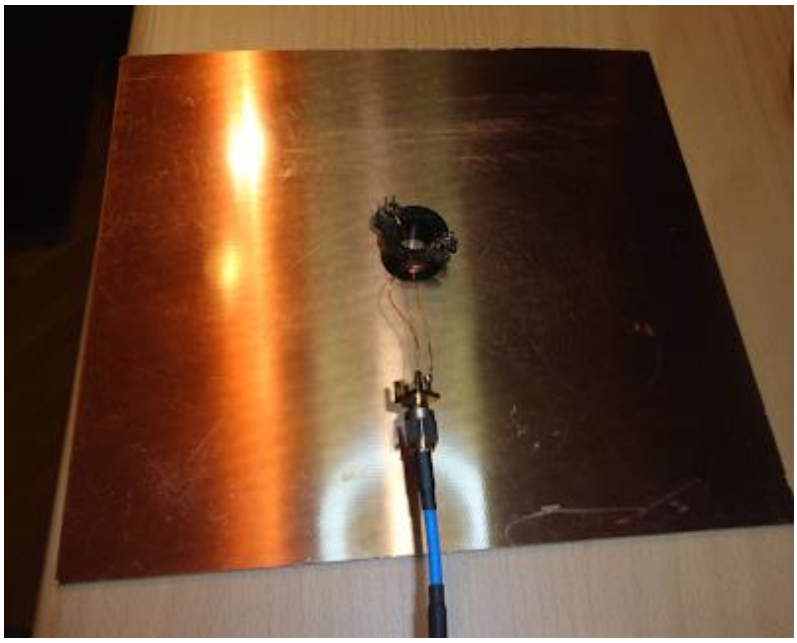

Figure 3, FR4 Board

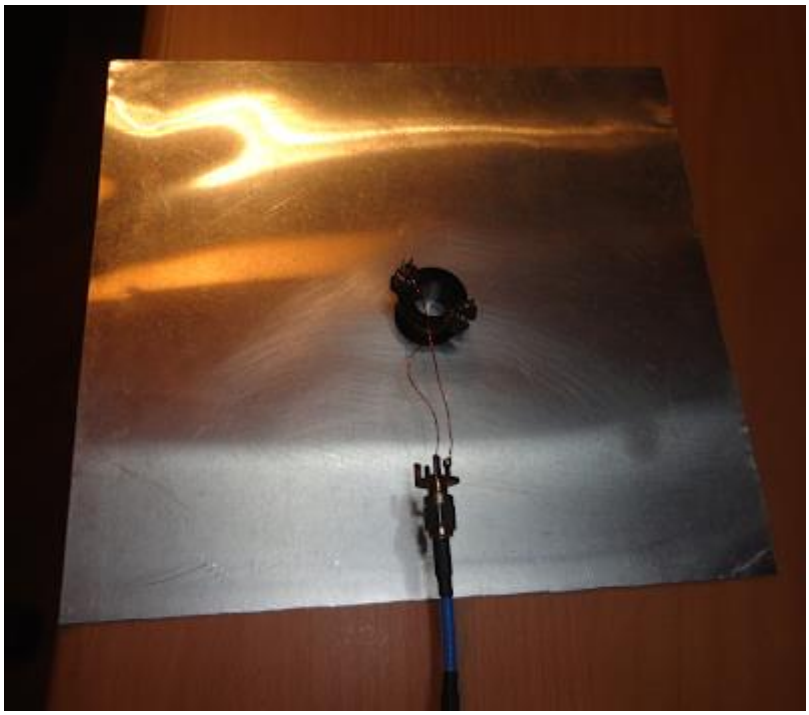

Figure 4, Aluminium plate

Before performing the measurements, it is necessary doing OSL calibration. For the measurements, select Scalar Chart mode and <Ls> for the left axis and <Zs> for the right axis. Then select the desired frequency range.

Following screenshots show the measurements in free space (Figure 5), FR4 board (Figure 6) and aluminium plate (Figure 7). You will easily observe the variations in the inductance of the probe coil due to the different conductivity of the measurement targets.

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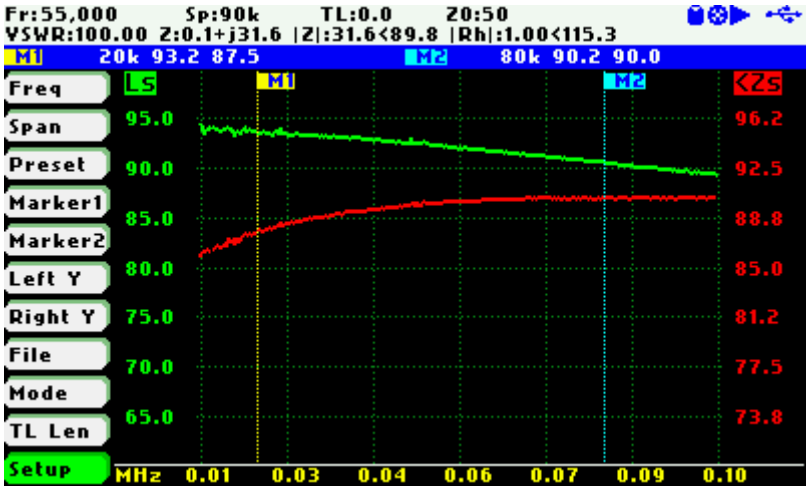

Figure 5, Measurements in free space

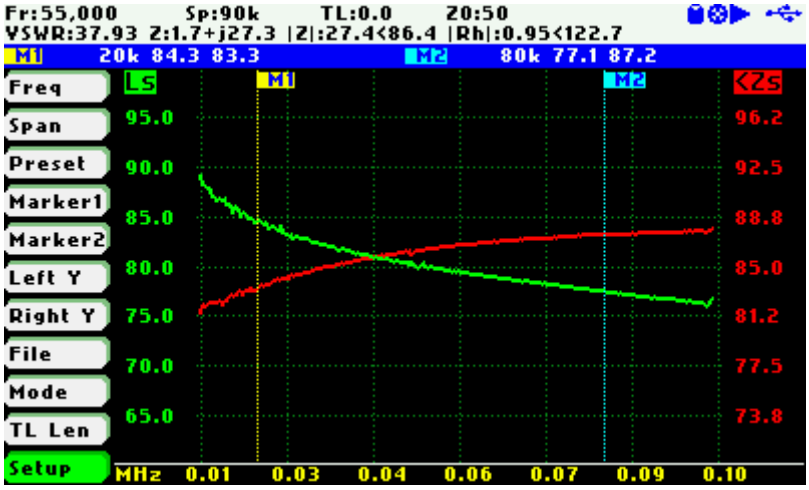

Figure 6, Measurements with FR4 board

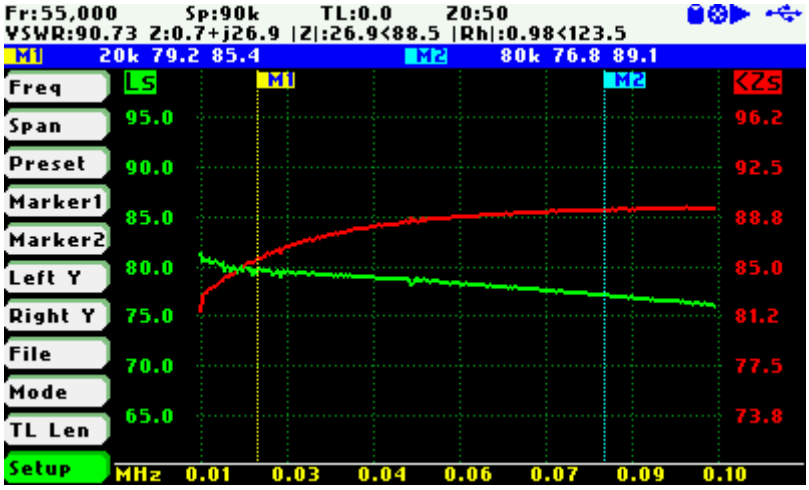

Figure 7, Measurements with aluminium plate

6 MEASURING CABLE INSERTION LOSS

The SARK-110 provides direct measurement of the insertion losses of a transmission line.

The insertion loss measurement setup for a typical transmission feed line is shown in Figure 1. Remove the antenna and connect a “short” at the end of the transmission line.

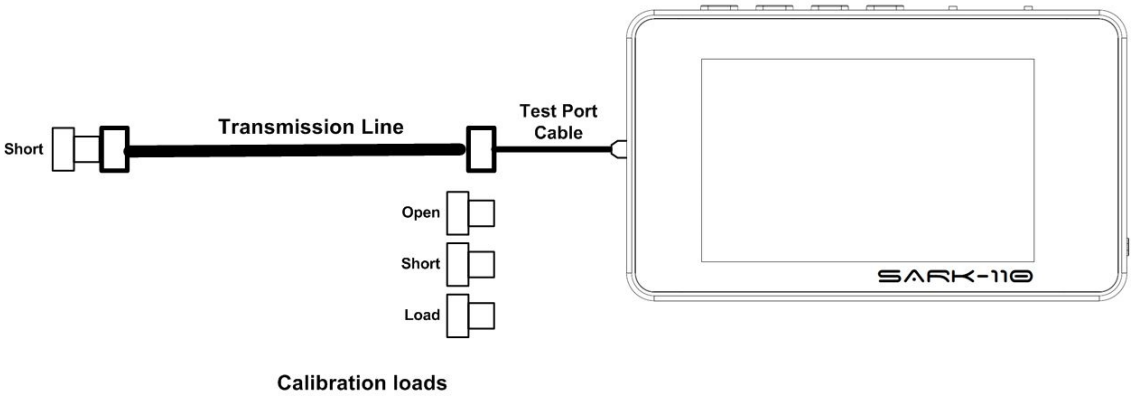

Figure 1, Insertion loss measurement setup

6.1 PROCEDURE

Step 1. Power on the SARK-110 and select Scalar Chart mode: **«Mode»** *«Scalar Chart»*

Step 2. Change the vertical left axis parameter to select CL (Cable Losses) parameter: **«LeftY»** *«CL»*

Step 3. Optionally change the vertical right axis parameter to select Disabled: **«RightY»** *«Disabled»*

Step 4. Set the center frequency **«Freq»** and span **«Span»**; or select a frequency preset **«Preset»**. As an example, select **«Preset»** *«Full HF»*

Step 5. Connect the test port extension adaptor or cable

Step 6. Perform OSL calibration at the end of the test port extension

Step 7. Disconnect the antenna and connect an enclosed “short” load at the end of the transmission line

Step 8. Connect the other end of the transmission line to the test port extension cable. A trace will be displayed on the screen if the SARK-110 is Run mode

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Step 9. Adjust the scale if necessary: **«Setup»** *«Scale»*

Step 10. Set Marker 1 to track the minimum value of CL: **«Marker1»** *«Tracking»*«Min»«CL»

Step 11. Set Marker 2 to track the maximum value of CL: **«Marker2»** *«Tracking»*«Max»«CL»

Step 12. Calculate the insertion loss by averaging M1 and M2 values as follows:

$$InsertionLoss = \frac{M1(dB) + M2(dB)}{2}$$

Step 13. Save the measurements and name the trace for historical documentation that can be used in the future to compare, check or verify changes in the transmission line performances: **«File»** *«Save Data File»*

In the example shown in the Figure 2, the analyzer was configured with the "Full HF" preset in order to sweep from 0.1 to 32 MHz. The measured loss minimum valley is at 842 kHz and has a value of 0.26 and the maximum peak is at 30.89 MHz and has a value of 2.89.

Therefore, the average insertion losses in this cable at this frequency range are:

$$InsertionLoss = \frac{0.26 + 2.89}{2} = 1.575$$

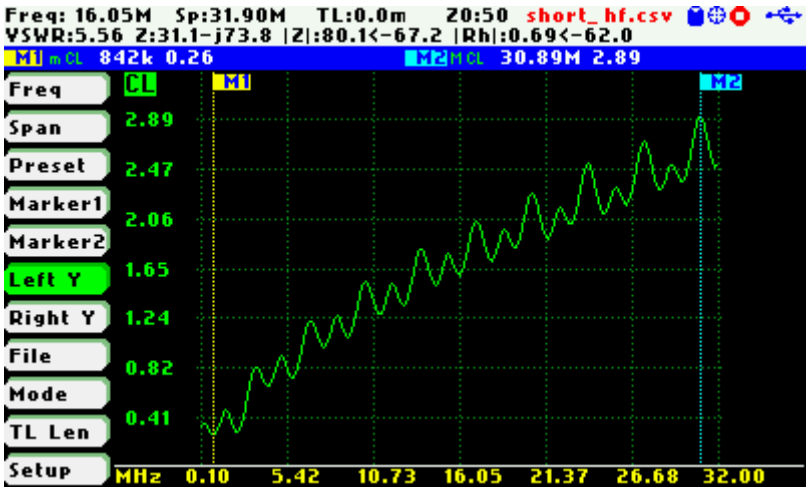

Figure 2, typical insertion loss display in SARK-110 screen

The Field Mode is also very convenient for this type of measurement since it automatically provides the maximum and minimum values; see the Figure 3.

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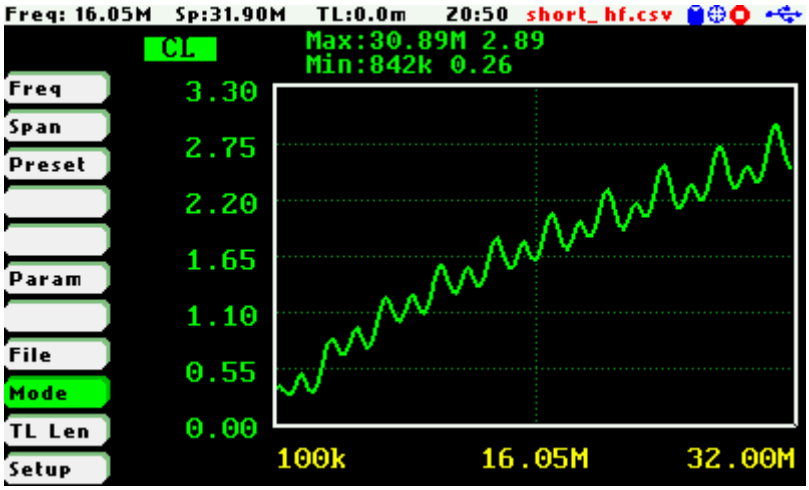


Figure 3, cable loss display in Field Mode

It is also possible measuring the cable insertion losses using the return loss parameter (RL). The procedure is the same as the described above but for calculating the insertion loss it is needed to apply the following formula:

$$InsertionLoss = \frac{M1(dB) + M2(dB)}{4}$$

The procedure in SARK Plots is similar. See in the Figure 4 a screenshot of the measurements of the same cable as shown in SARK Plots.

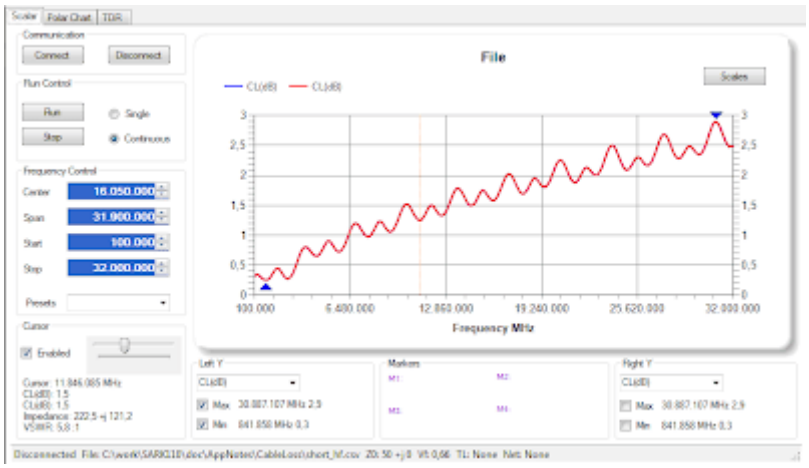


Figure 4, typical insertion loss display in SARK Plots

7 MEASURING TRANSMISSION LINE LENGTH

The SARK-110 supports several methodologies that allow easy measurement of the length of transmission lines. These are explained in this application note for the measurement of a section of approximately 3 meters of RG-58 cable as a practical example.

7.1 FDR METHOD (CABLE TEST MODE)

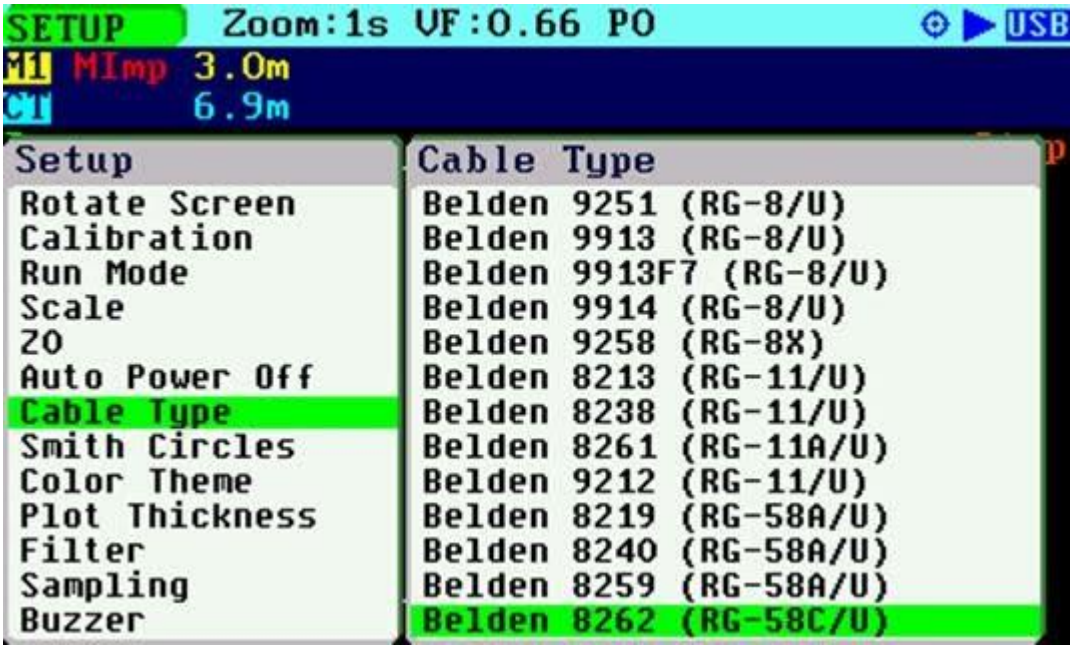
The Cable Test Mode uses the Frequency Domain Reflectometry (FDR) measurement technique for performance verification and failure analysis of transmission lines. One of its applications is to determine the length of a cable.

The measurement procedure is as follows:

1) Connect the section of cable to be tested to the analyzer and leave the other end unterminated.

2) Select Cable Test mode.

3) Select the cable type from the dropdown list from menu **«Setup»** *<Cable Type>*.



4) Set the more appropriate Zoom option according the expected cable length. For this short cable length, it will be selected **«ZOOM»** *<1st Sixteenth>*.

5) For the automatic determination of the cable length, set a marker to track the maximum value of impulse.

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6) Wait for the measurement to complete and the marker will automatically position itself at the peak of the impulse response. The distance reading will be the length of the cable; 3.0 meters in this case.

7) The distance value in the marker area has low resolution. Select «Marker 1» <Info> to get the distance with higher resolution; 2.982 meters in this case.

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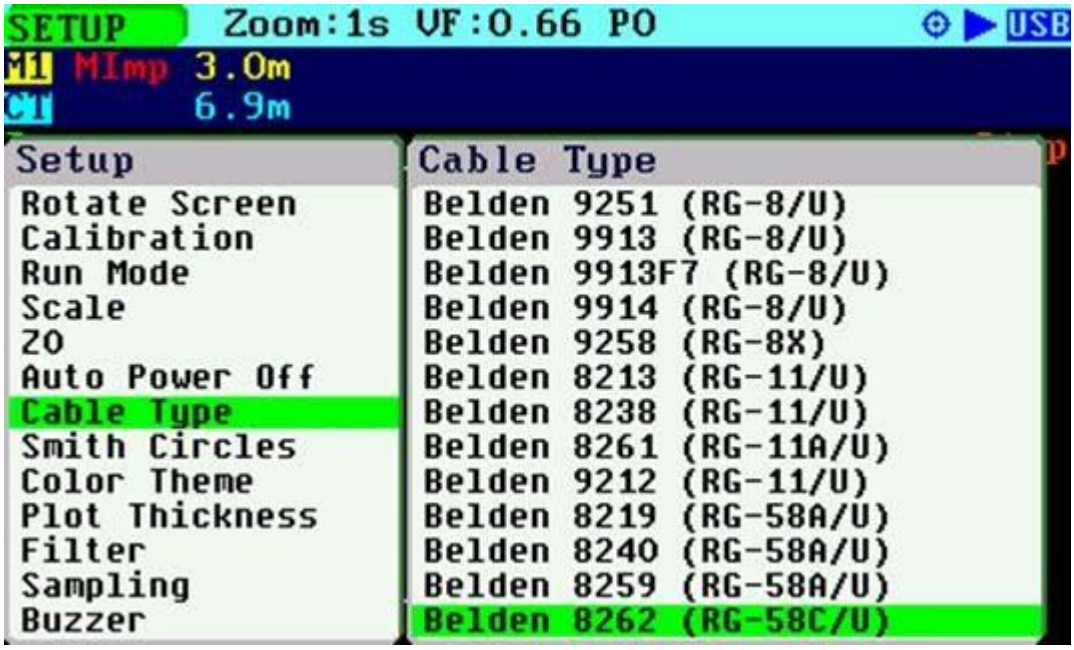
7.2 SMITH CHART "UNWRAP" METHOD

The Smith Chart "unwrap" method is described in section 4.1. of the User's Manual as a method to determine the length of a cable and cancel the effect of it using the Transmission Line Subtract feature.

The measurement procedure is as follows:

1) Connect the section of cable to be tested to the analyzer and leave the other end unterminated.

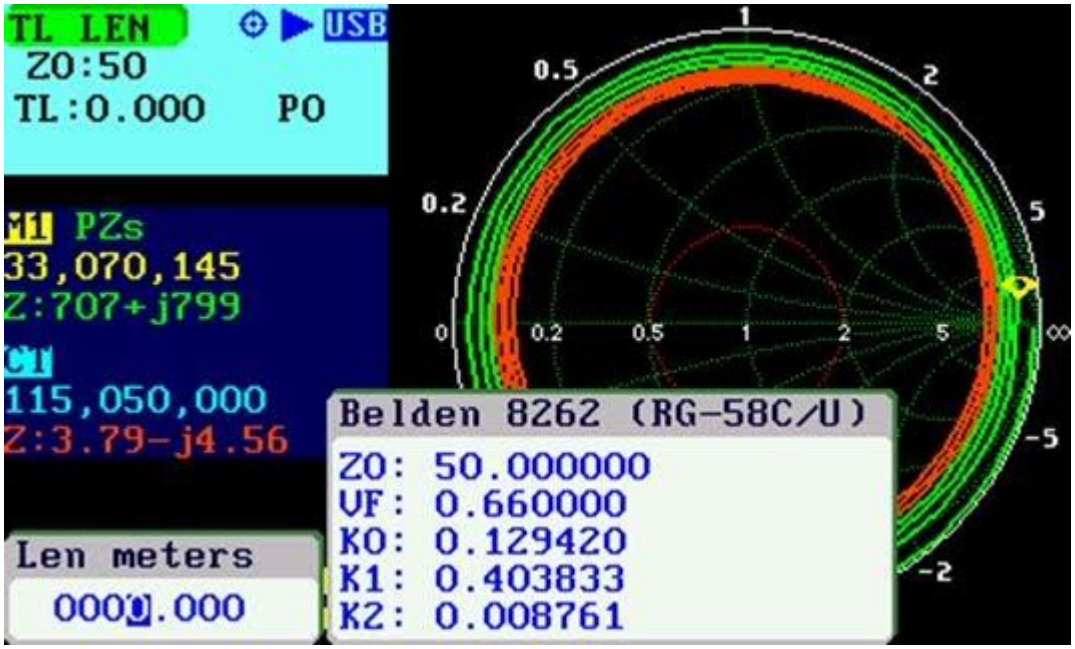
2) Select the cable type from the dropdown list from menu **«Setup»** <*Cable Type*>.



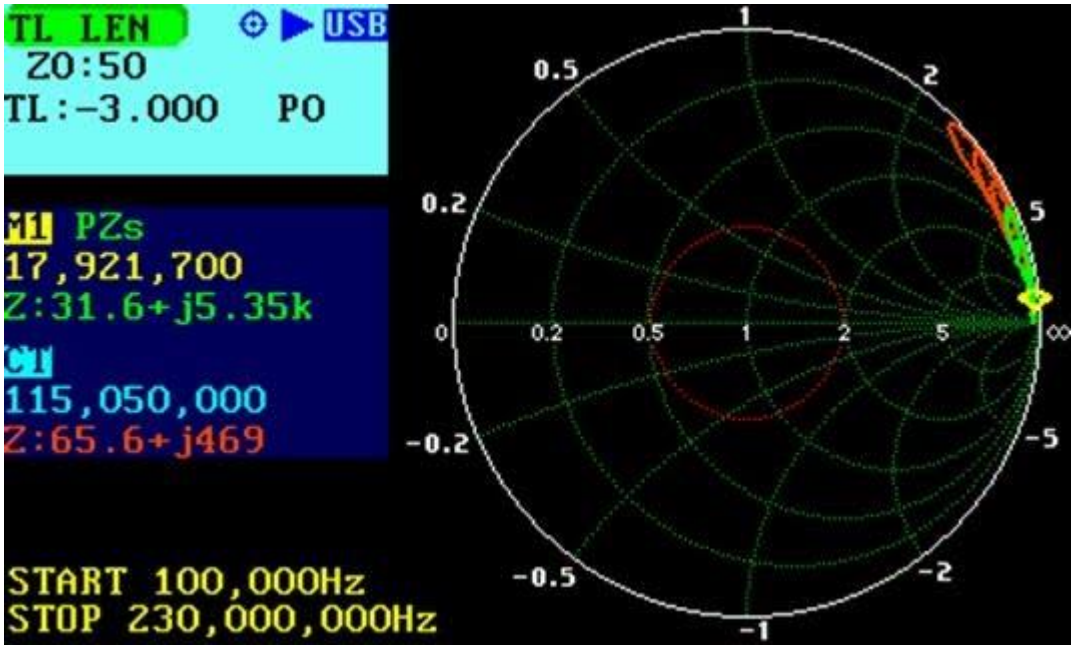
3) Select Smith Chart mode.

4) Select **«Preset»** *<Full Span>*.

5) Set the estimated cable length in menu **«TL Len»**, but as a negative value as we are subtracting the effect of a transmission line; in this case we will enter a value of 3 meters.



6) We observe in the screenshot below that the trace is in the inductive area of the chart, so we will need to adjust the length value to have the trace around the point of infinite impedance.



7) We set the TL value to -2.9 meters and the trace moved to the capacitive region of the chart. Then the length value must be between -2.9 and 3 meters.

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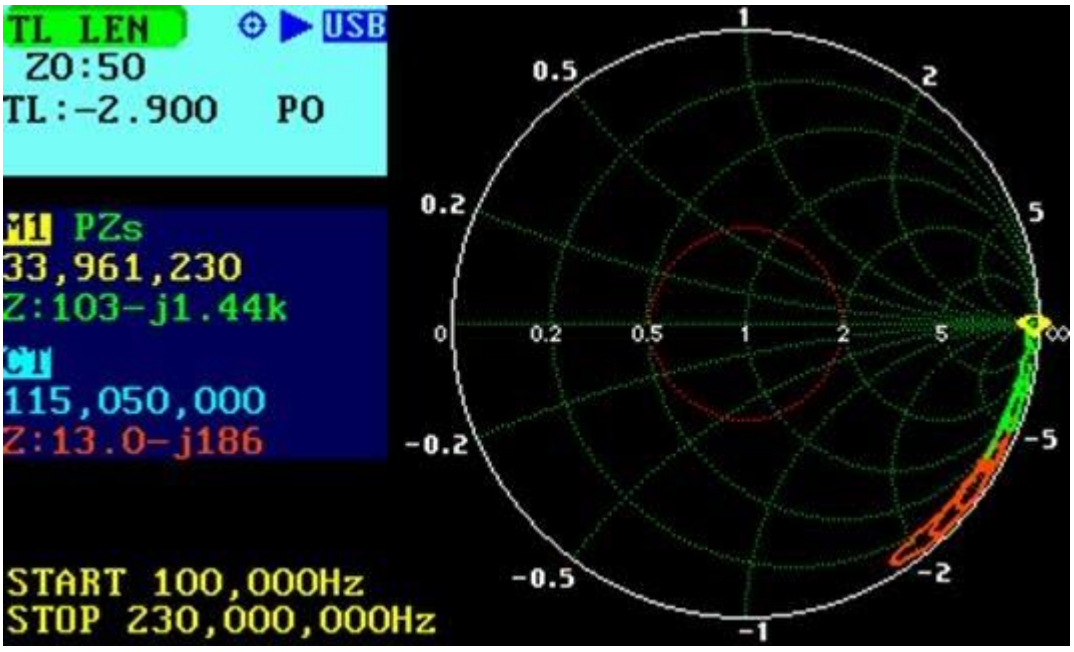
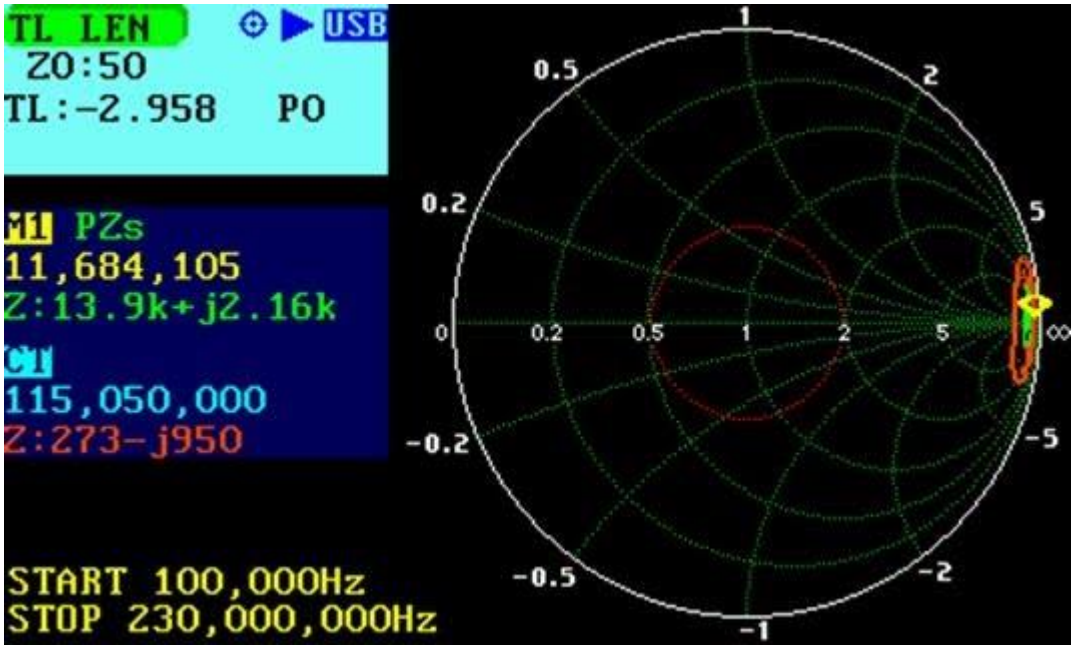


8) After checking several intermediate values, we found that the correct length of this coax is -2.958 meters.



9) Besides determining the length of the cable, it can be connected the antenna to the end of the coax cable and the effect of this cable will be discounted.

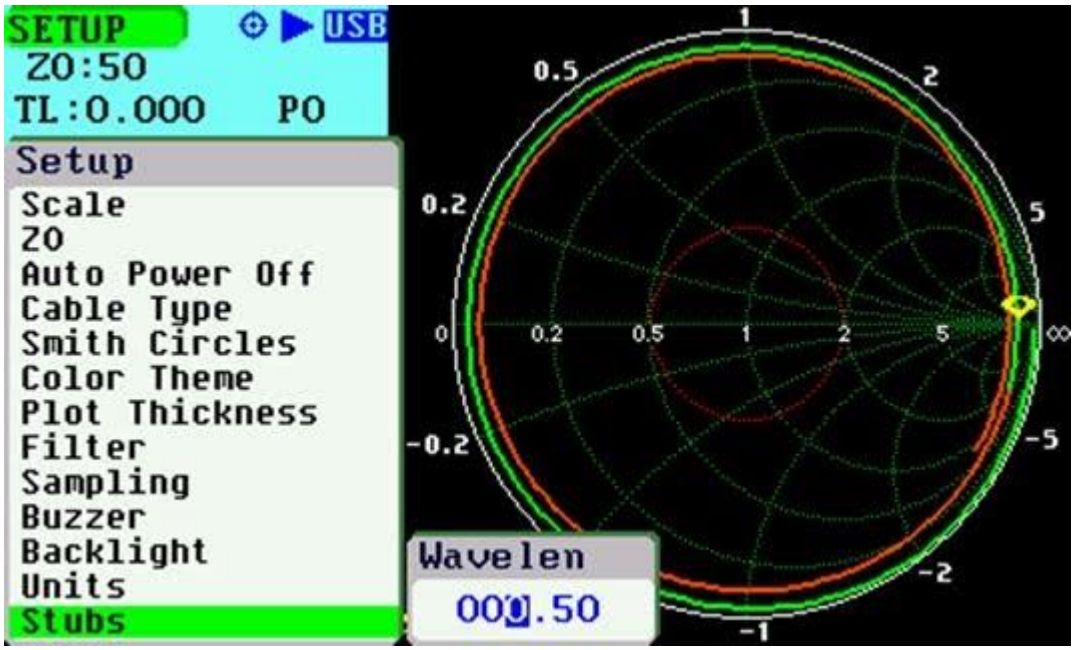
7.3 HALF-WAVE METHOD

This method is a variant of the Tuning Stubs method described in section 4.3. of the User's Manual. This is based on that the Markers Info feature provide information about the electrical length of the transmission line.

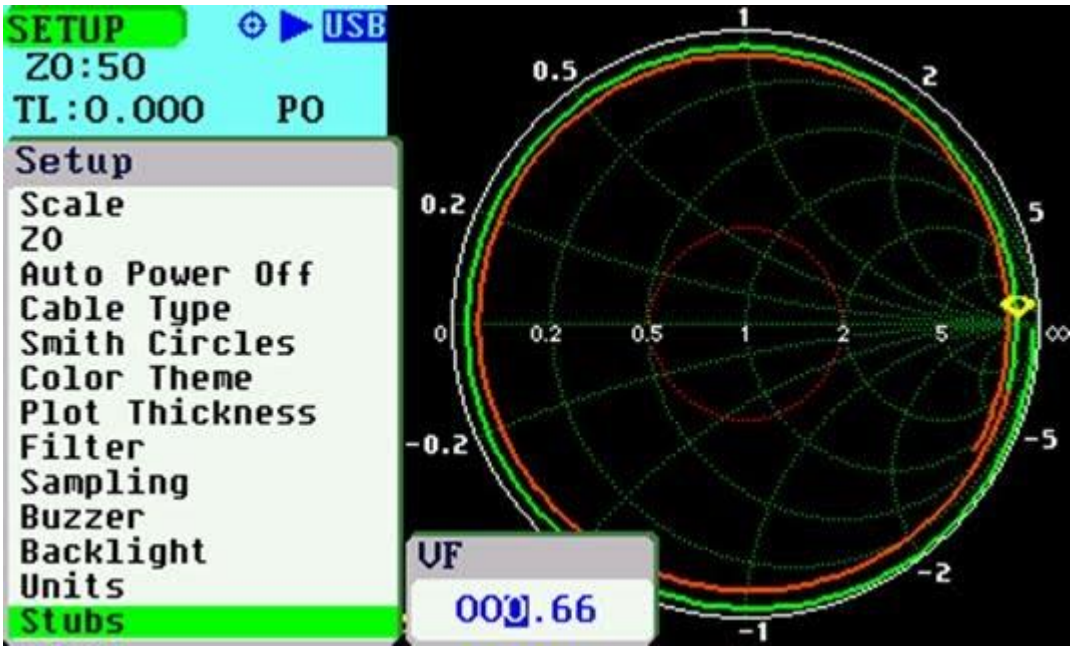
The measurement procedure is as follows:

1) Connect the section of cable to be tested to the analyzer and leave the other end unterminated.

2) Set the Stubs-Wavelen parameter to half wave: **«Setup»** <*Stubs*> to 000.50



3) In the same Stubs setting, enter the velocity factor of your cable:



4) Set the sweep range from the lowest frequency to a frequency where the trace shows at least one rotation on the Smith Chart.

5) Set a marker to detect the Peak Max of |Zs|:

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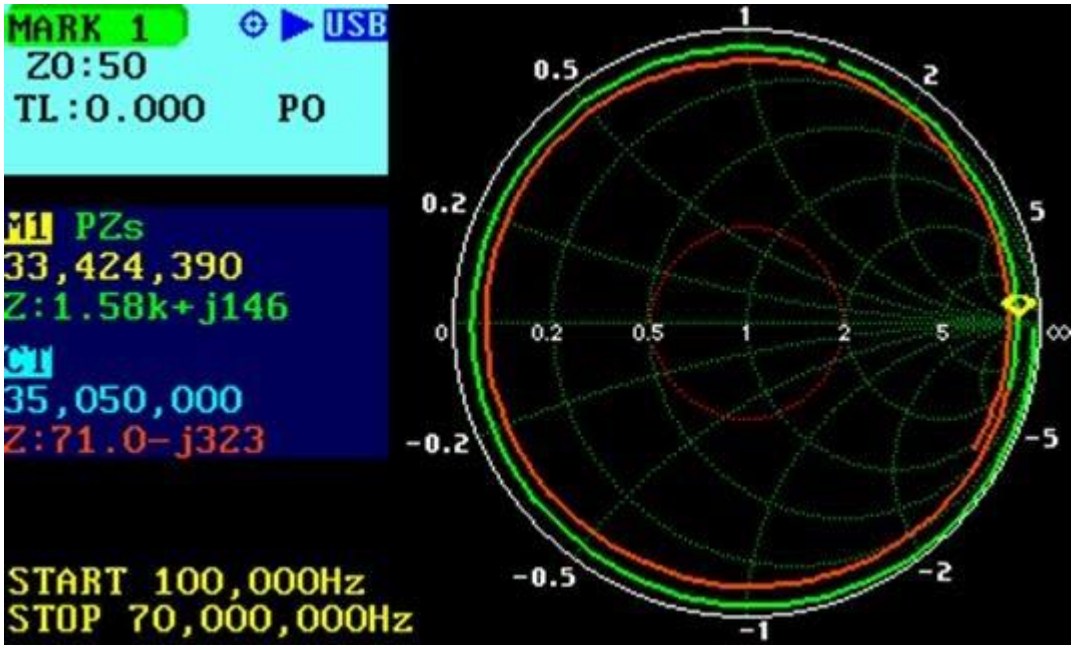
6) Move the marker to the second peak (the first peak is at the lowest frequency and the second is at the next half-wave point); in this case it is located at 33,424,390 Hz



7) Select «Marker 1» <Info>; the Len reading at the bottom will show the physical length of the cable; in this case 2.960 meters.

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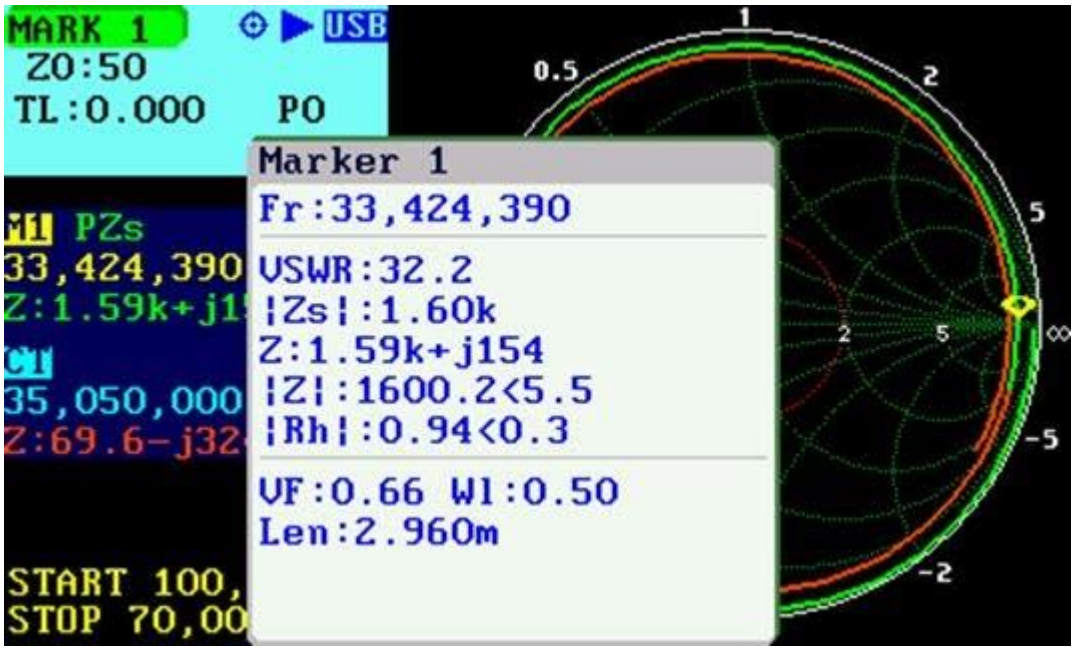
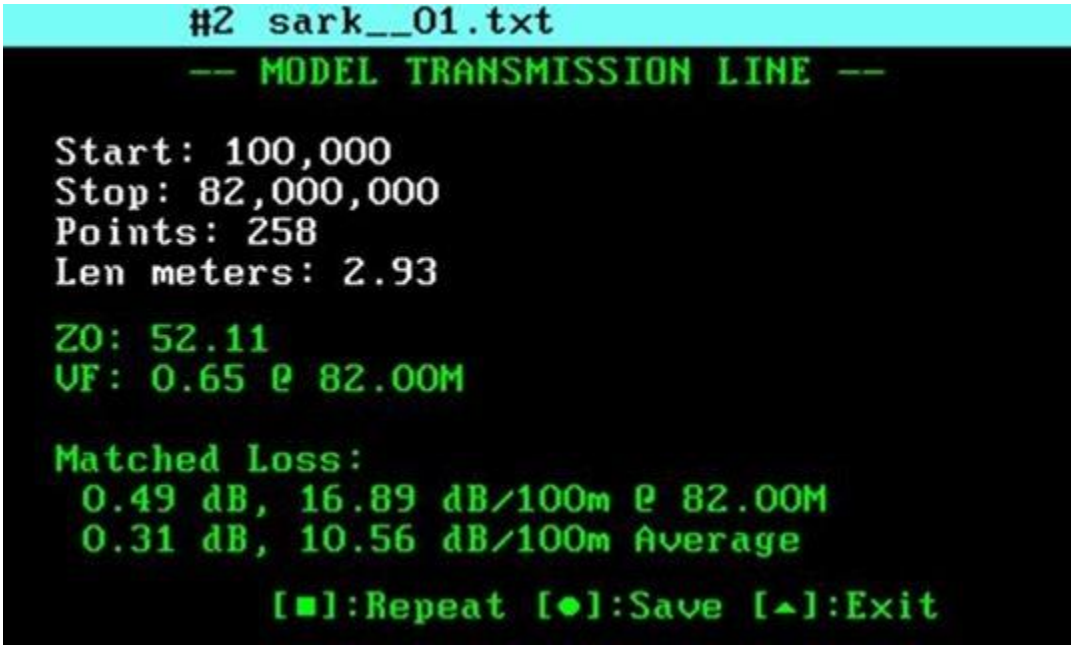


7.4 Transmission Line Model

If the characteristics of the transmission line are unknown, the analyzer provides a method to obtain them automatically. The procedure is described in section 4.2.4. of the User's Manual, so it will not be repeated here. The results for the used test cable are shown below as reference.



8 Measuring Traps

A trap is a parallel resonant circuit network that can perform either of two functions in an antenna system, depending on whether the traps are resonant at the operating frequency. The first function of a trap is where the trap is parallel resonant at the operating frequency. Because

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this parallel resonance, the trap behaves as an isolator so it can be used to isolate sections of the antenna.

The second function of a trap, obtained when the frequency of operation is not the resonant frequency of the trap, is one of electrical loading. If the operating frequency is below of trap resonance, the trap behaves as an inductor; if above, as a capacitor. Inductive loading will electrically lengthen the antenna, and capacitive loading will electrically shorten the antenna.

With the SARK-110 Antenna Analyser is very easy measuring the resonance frequency and the impedance characteristics of traps. This application note describes basic measurement procedures using as example a homebrew coaxial cable trap.

8.1 "GRID-DIP" METER METHOD

A simple way for the determination of the resonant frequency of a trap, or any tuned circuit is to connect a small section of wire forming a close loop, connected to the analyzer test port extension cable and put it near to or around the trap; see the Figure 1.

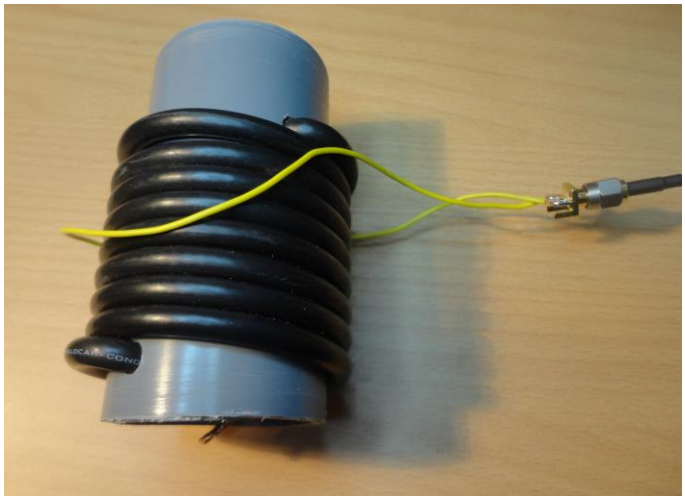

Figure 1

The measurement procedure will be aimed to determine the frequency point of highest impedance |Z|. This frequency will be the trap resonance frequency. The measurement can be done from the Scalar Chart mode with one of the traces selected to measure the modulus of the impedance |Z|. For this example, the peak maximum of |Z| was found at a frequency of 8.79 MHz, which is the measured resonant point of the trap.

A step by step procedure will be the following:

Step 1. Perform OSL calibration at the end of the test port extension

Step 2. Connect the wire loop to the test port extension and place close to the trap (Figure 1)

Step 3. Select Scalar chart mode: **«Mode»** *«Scalar Chart»*

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Step 4. Set automatic scale: **«Setup»** *«Scale»* «Auto»

Step 5. Set left axis to measure the impedance modulus: **«Left Y»** *«|Z|»*

Step 6. Set right axis to measure the impedance phase angle: **«Right Y»** *«<Z»*

Step 7. Set a wide frequency span to see where |Z| peaks: e.g. **«Preset»** *«Full HF»*

Step 8. Move the marker to the point where |Z| peaks (Figure 2)

Step 9. Change the frequency and span in order to have better visibility of the resonant point. Move the marker to the peak. (Figure 3)

Step 10. Optionally change to Smith chart mode: **«Mode»** *«Smith Chart».* The marker is just in the cross position with the horizontal axis since in the resonant point the phase is zero.

The advantage of this method is that there is no need of connecting physically the trap leads to the test port extension of the analyser, which has influence in the measured resonant frequency due to the inductance of the leads.

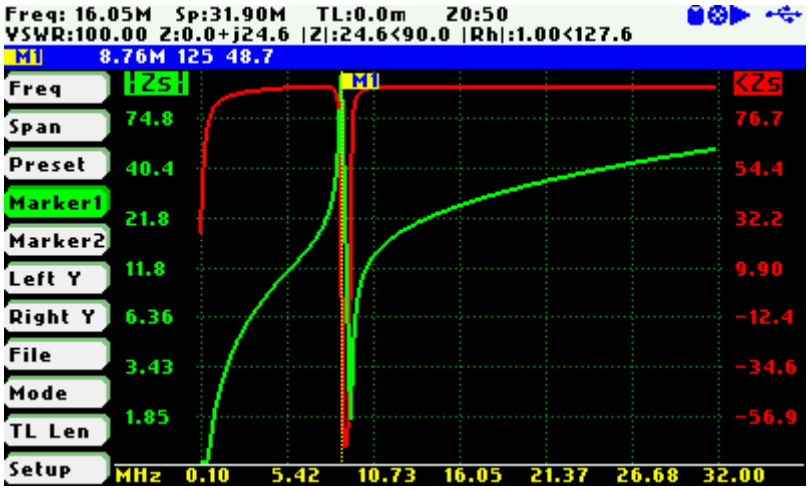

Figure 2

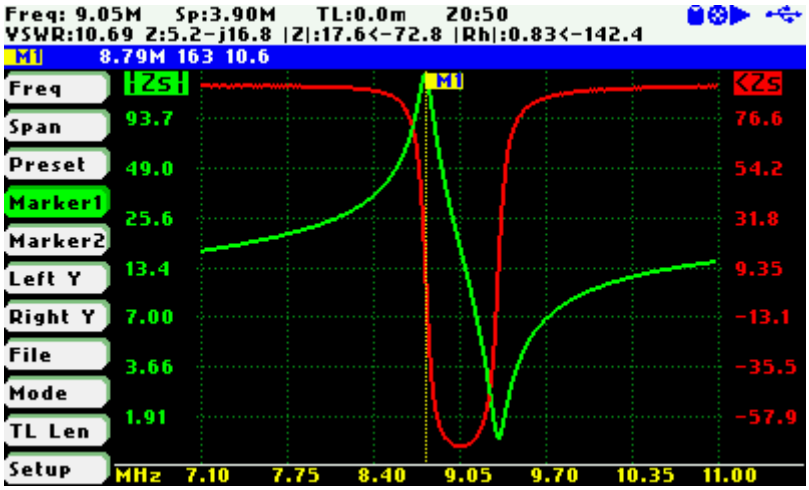

Figure 3

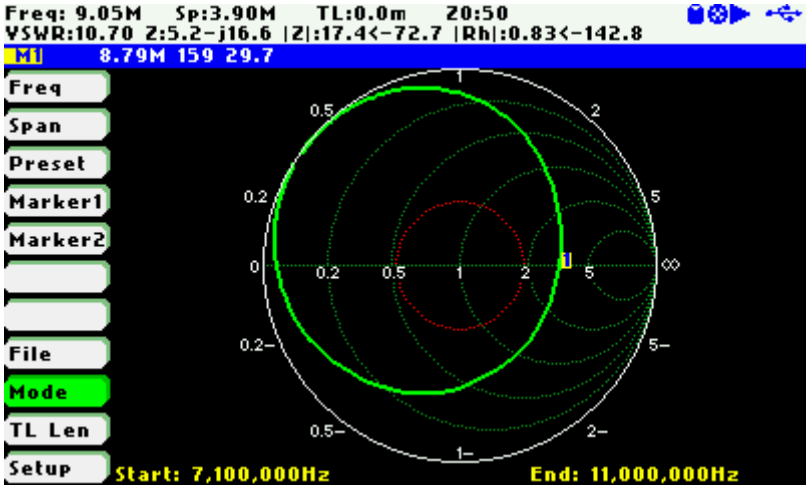

Figure 4

8.2 "DIRECT" METHOD

The trap resonance frequency and impedance characteristics can be measured by connecting the SARK-110 to the trap leads, as it is shown in the Figure 5.

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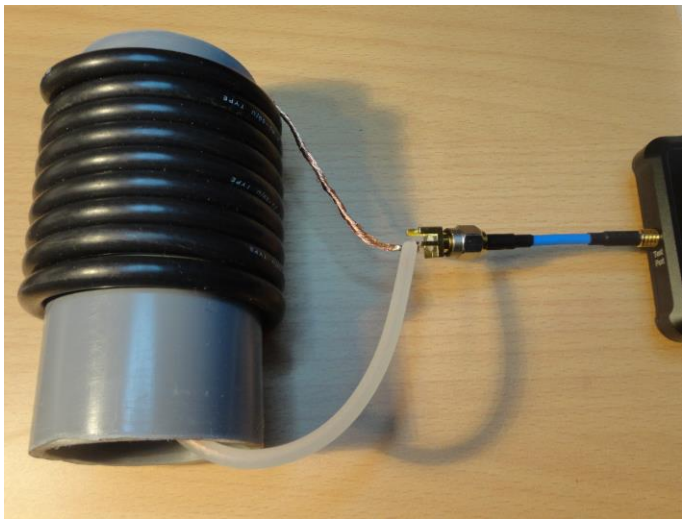

Figure 5

The measurement procedure is the same as for the “grip-dip” method so it will not be repeated here. The only difference is that the trap leads are connected to the test port extension.

The Figure 6 shows the Scalar chart with the Span set to cover up to 32 MHz (Full HF Preset). In this chart it can be observed that at the resonance frequency of 8.5 MHz the impedance modulus peaks and the phase changes from a positive value (pure inductive) to a negative value (pure capacitive). The Figure 7 shows the same measurement as seen in the Smith chart mode. The resonant point is at the crossing point of the horizontal axis. The Figure 8 shows again the Scalar chart but with a smaller Span.

Compared with the previous measurement method, there is a slight difference in the measured resonance frequency. This is due to the influence of the connection leads of the trap to the test port extension. However, with this method it can be obtained the complete impedance characteristics.

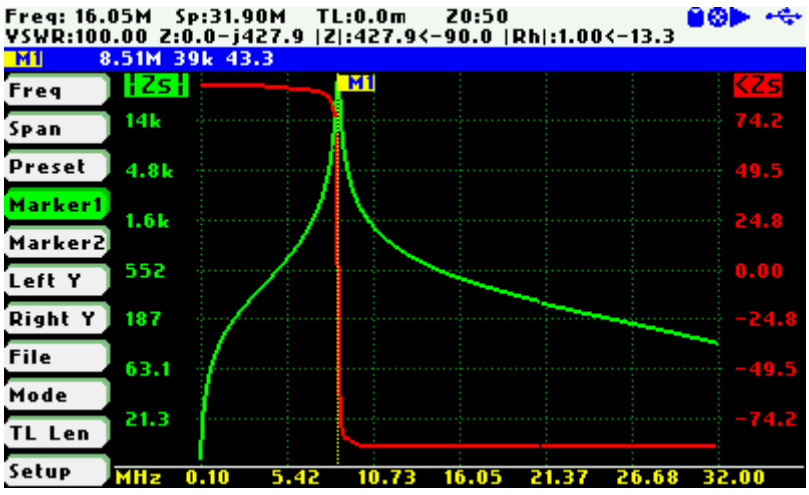

Figure 6

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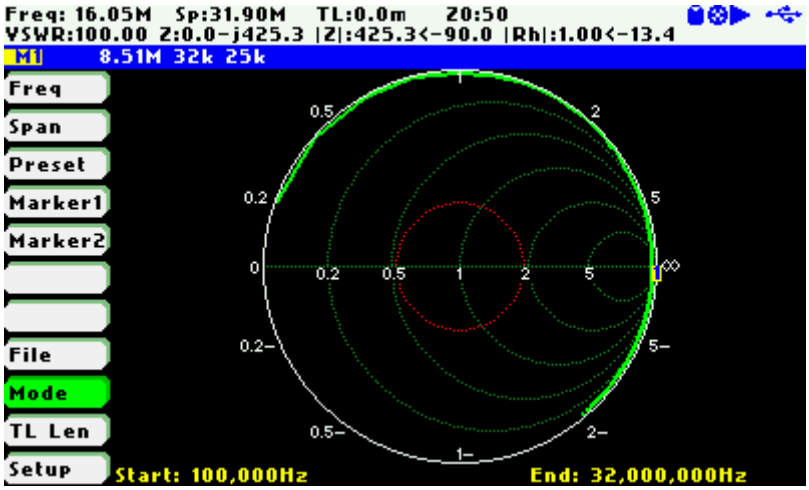

Figure 7

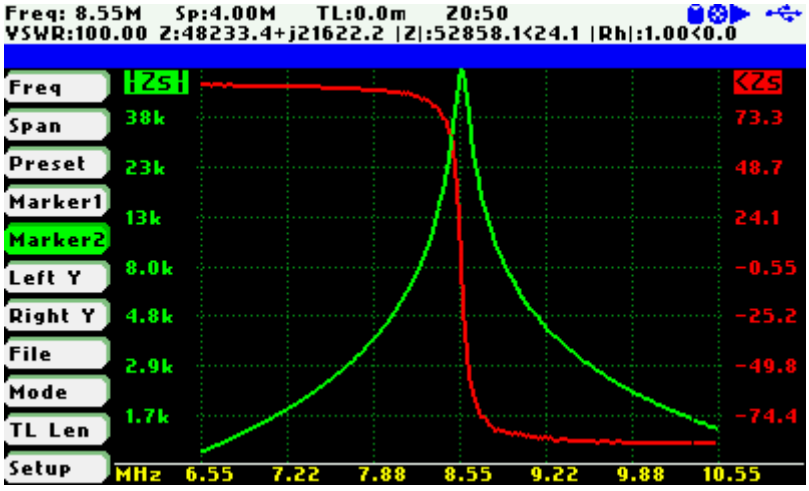

Figure 8

8.3 TUNED CIRCUITS

These measurement procedures can be used for both parallel and series tuned circuits. The Figure 9 shows an example of a tuned LC circuit. The Figure 10 shows the impedance plot when the circuit is arranged in a parallel tuned configuration. In this case the impedance is maximum at the resonant frequency. The Figure 11 shows the impedance plot for the series tuned configuration. In this configuration the impedance shows a peak minimum at the resonance frequency.

Figure 9

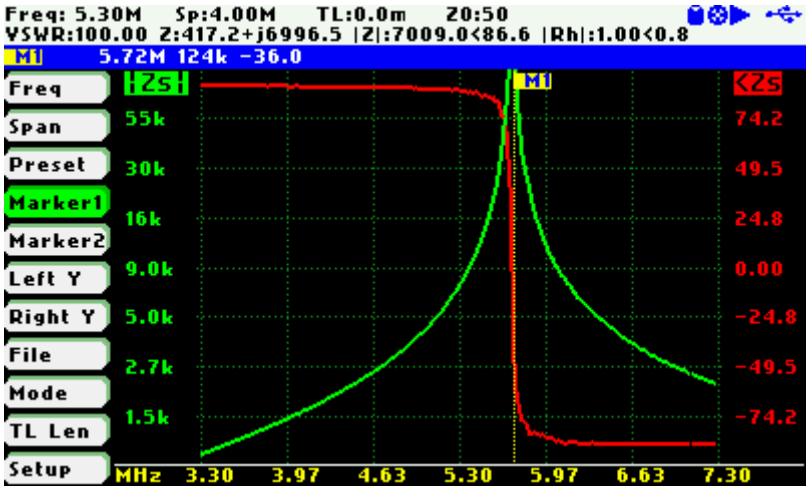

Figure 10

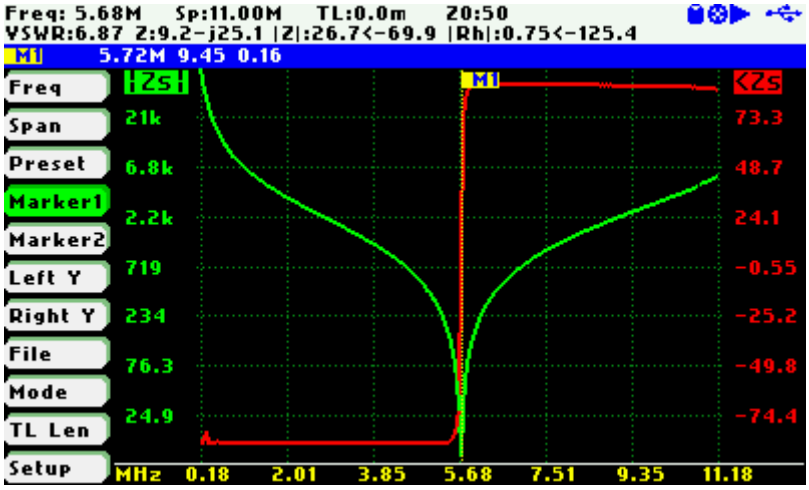

Figure 11

The values of the inductor of the capacitor forming the tuned circuit, can be independently measured using the Single Frequency mode. Figure 12 shows the measurement of the inductor value at 1 MHz and Figure 13 the measurement of a capacitor value at the same frequency.

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For a precise measurement it is important performing OSL calibration and that the leads to the component be the smaller as possible.

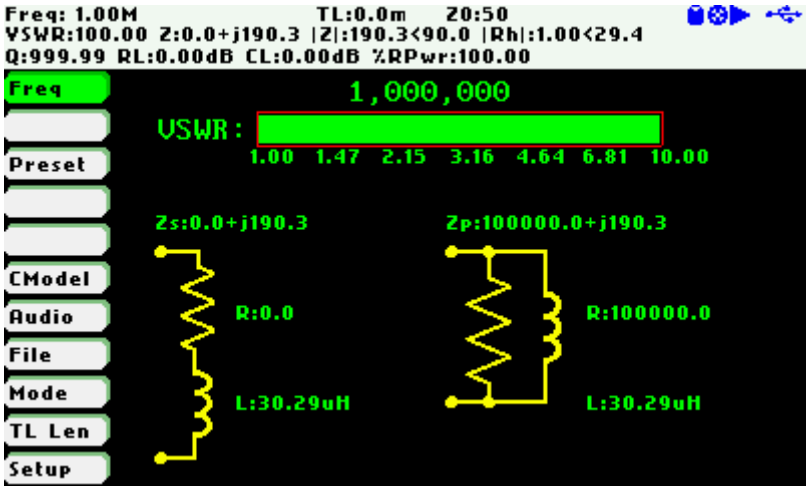


Figure 12

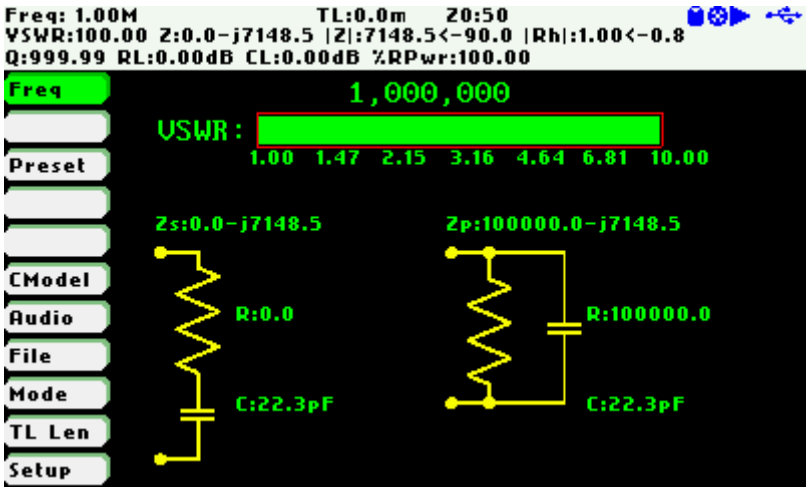


Figure 13

9 OBTAINING COAXIAL CABLE COEFFICIENTS

The SARK-110 allows user specifying custom coaxial cable settings, used for transmission line calculations. Coaxial cable datasheets normally provide attenuation values at some single frequencies, but not the attenuation constants. Therefore, the attenuation constants must be obtained by interpolation from the given frequency / attenuation pairs.

SARK Coax calculates automatically the cable attenuation coefficients based on the given frequency / attenuation pairs. In addition, the tool shows a graph of the attenuation or power loss.

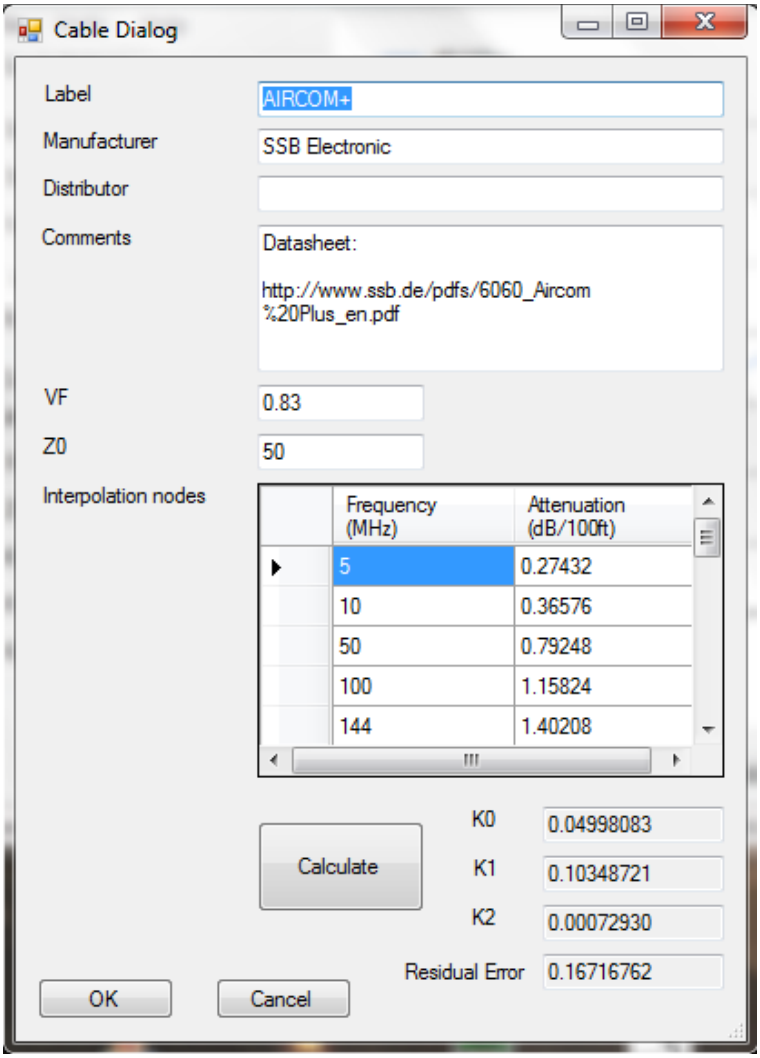
The calculated coefficients are compatible with the SARK-110 firmware, SARK Plots, and ZPlots, i.e. in dB/100ft. Notice that the naming of the coefficients and units are different from DL4MW - ATTCALC tool.

9.1 QUICK USAGE GUIDE

1. Select the right units (feet or meters): Menu <Units>

2. Create a new file <File><New> or open an existing file <File><Open>

3. If a new file is selected, it will open automatically the Cable Dialog box. Otherwise, select <File><Edit>



4. Enter the cable parameters.

5. Press the button "Calculate" and you will get the calculated coefficients

6. Select OK button. Then the cable attenuation characteristic is display in a graph. The type of graph can be selected in the <Param> combobox.

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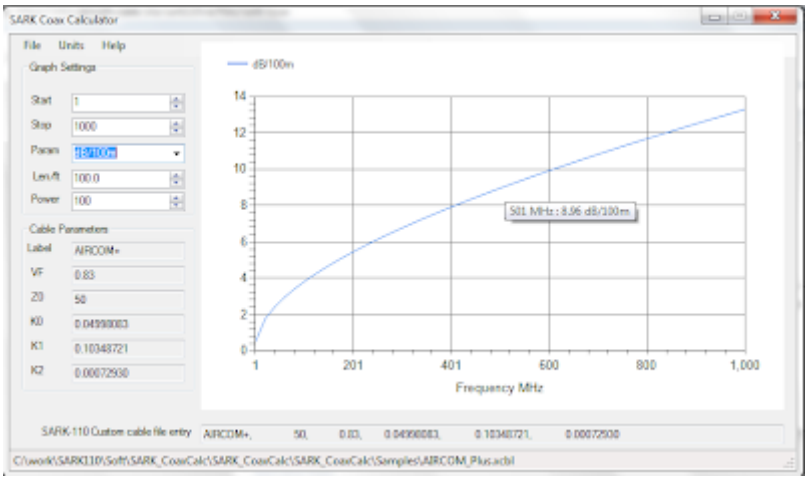

7. The edit box "SARK-110 Custom cable file entry" contents can be directly copied and pasted to an entry in the "custcab.txt" file, or the values used in SARK Plots or ZPlots

9.2 ACKNOWLEDGMENTS

- Siegfried Riesinger - DH3SR, who brings me the motivation to develop this tool
- SARK Coax tool was inspired on Ralf Schueler - DL4MW, ATTCALC tool (http://schueler.ws/?page_id=237&lang=en)
- This tool uses LMFIT-5.1 software: Copyright (c) 2004-2013 Joachim Wuttke, Forschungszentrum Juelich GmbH

10 STRUCTURAL RETURN LOSS MEASUREMENTS

The SARK-110 Antenna Analyzer firmware does not currently have a built-in function for the measurement of cable structural return loss (SRL). However, this measurement is possible with the help of the attached Microsoft Excel spreadsheet.

Structural return loss is defined as the return loss of the cable relative to its own impedance and summarizes the uniformity in cable construction. Cable manufacturing imperfections, defects and faults contribute to degrade cable performance. The extent of these imperfections is characterised by the SRL. Comprehensive definitions and measurement techniques are described in the References below.

For the measurement it is recommended to use the new Deep Sweep Save firmware function or the SARK Plots client software for capturing the data, since it allows to increase the number of measurement points. Structural return loss effects can be very narrow in frequency span, as they are caused by the cumulative effects of small reflections along the entire length of the cable.

Notice that the attached spreadsheet requires 1000-points but can easily adapted to an arbitrary number of frequency points.

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The measurement setup is described in the Figure 1. The far end of the cable must be terminated with the matched termination, e.g. 75-ohm for a cable with a characteristic impedance of 75-ohm.

Before starting the measurement, it is necessary to perform the OSL Calibration procedure with the calibration standards connected to the Adaptor.

For capturing the data using the Deep Sweep Save function, you will need first to set the frequency and span range either in the Scalar Chart, Field, or the Smith Chart modes. Then select <File><Deep Sweep><Save>. Then select the file name and the number of points, which by default is set to 1000. Wait for the completion of the measurement and once terminated to can connect the device to the PC and import the data into the spreadsheet.

This data can then be imported into the spreadsheet using the following procedure: open the spreadsheet, select the sheet "CSV", click in A1 cell and with right mouse button select <Update data>. Then the results are plotted in the sheets "Graph SRL" (Figure 2) and "Graph SLR-RL" (Figure 3), which plots both SRL and the Return Losses. The plots show also the maximum value of the SRL.

If using SARK Plots, change the number of points in <Settings><Parameters>; e.g. to 1000. Set the Run Control mode to Single, set the desired Start and Stop frequencies, and Run a sweep. Once the sweep is terminated, export the data using <File><Save File> and import the data into the spreadsheet using the procedure described above.

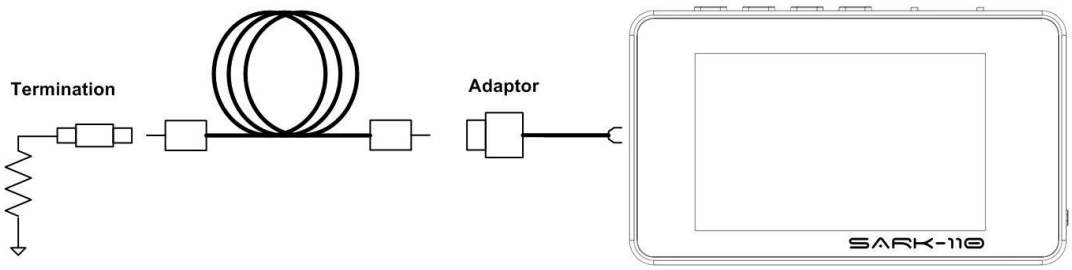

Figure 1

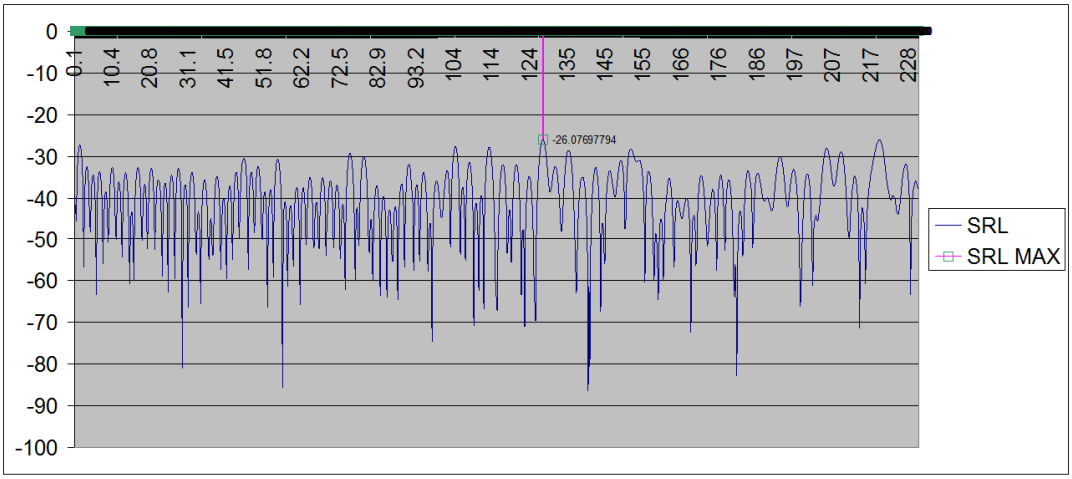

Figure 2

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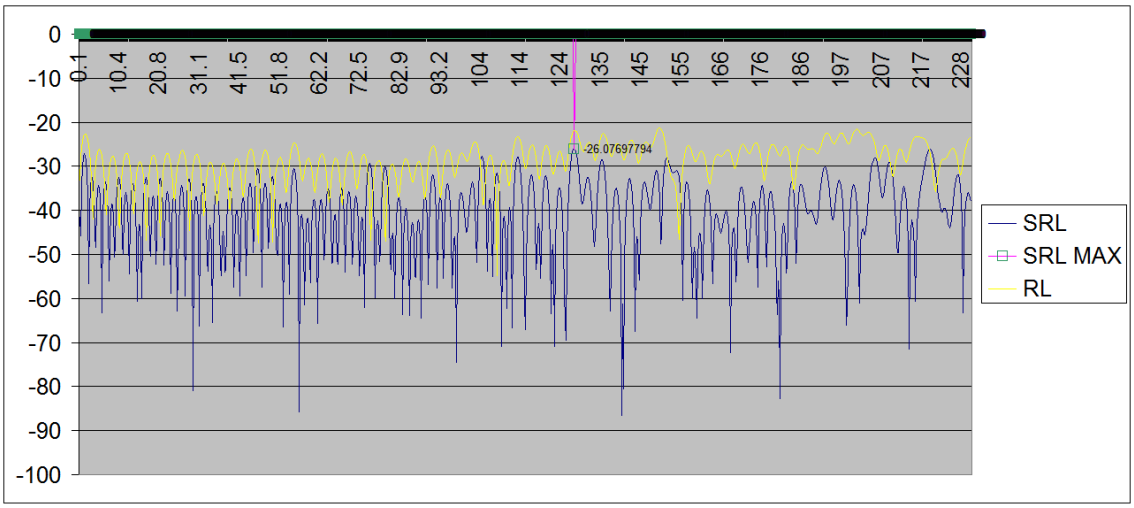

Figure 3

10.1 References

1. ANSI/SCTE 03 2008 -Test Method for Coaxial Cable Structural Return Loss; http://www.scte.org/documents/pdf/Standards/ANSI_SCTE%2003%202008.pdf

2. Cable Impedance and Structural Return Loss Measurement Methodologies; http://www.home.agilent.com/upload/cmc_upload/All/E206COMPTEST_METHOD.pdf?&cc=ES&lc=eng

11 SARK-110 Repair Instructions

The SARK-110 uses surface mount technology, but this does not prevent you from being able to fix it. This section provides a guidance for basic repair operations, including information to source the components.

If you decided to repair the device by your own, please observe the following basic precautions:

- Disconnect the power supply and the battery when repairing the unit
- Follow the basic electrostatic-discharge prevention precautions when manipulating the main board
- Protect the display area of the LCD module from scratches
- Ensure you have the right tools for working with surface mount devices

11.1 Battery Replacement

SARK-110 original battery model is PR-384160N; see datasheet at the end of this page. The basic specifications are the following:

- Chemistry: Li-ion Polymer
- Nominal Rated Voltage: 3.7V

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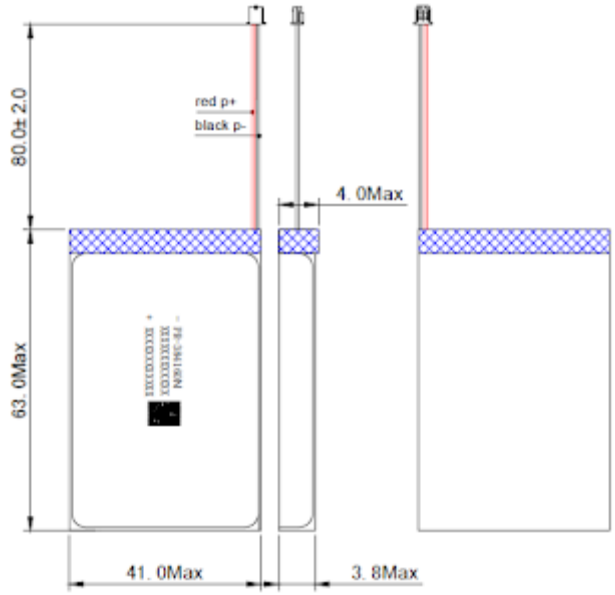
- Safe voltage range: 3 - 4.2V
- Nominal Capacity: 940mAh
- Dimensions: H=3.8mm W=41mm L=63mm
- Connector: Molex 51021-0200 (pitch 1.25mm)
- Operating Temperature: 0 ～45°C (Charging) / -10～60°C (Discharging)



There are some vendors of Li-Ion batteries offering similar batteries. These batteries are normally supplied without a connector, so it will require the original connector being cut off and re-joined to the new battery.

11.1.1 3.7V 1500mAh Li-Ion Polymer

This higher capacity battery is slightly thicker than the original one, but it fits inside the SARK-110 housing.

- Model: 504050
- size: H=5mm W=40mm L=50mm
- voltage: 3.7 V
- capacity: 1500mAh, 2C discharge

http://www.ebay.com/itm/3-7V-1500mAh-Li-Polymer-Lipo-ion-Battery-For-mobile-phone-GPS-DVD-TABLET-504050-/262496320924?hash=item3d1dfffd9c:g:4QYAAOSw-4BXbQ5H

http://www.ebay.com/itm/3-7V-1500mAh-Lipo-Polymer-li-ion-Battery-504050-for-cell-phone-Camera-GPS-PAD-PC-/111861099475

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http://www.ebay.com/itm/3-7V-1500mAh-504050-Li-Po-Battery-For-Mp3-Tablet-PC-bluetooth-camera-DVD-power-/171296937235

11.1.2 3.7V 1200mAh Li-Ion Polymer

This higher capacity battery offered by Adafruit is slightly thicker than the original one, but it fits inside the SARK-110 housing.

- Model: LP-503062
- size: H=5mm W=34mm L=62mm
- voltage: 3.7 V
- capacity: 1300mAh

Note that the provided connector is not compatible; also check shipping restrictions
https://www.adafruit.com/product/258

https://www.amazon.com/Battery-Packs-Lithium-Polymer-1200mAh/dp/B00J2QET64

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11.2 FORMATTING THE INTERNAL DRIVE

There may be situations in which the file system of the internal drive of the SARK-110 becomes corrupted. This could have been caused due to an unsafe eject, power interruption during file access or a race condition between the computer and the SARK-110 firmware.

A corrupted file system may cause unwanted effects such as reported incorrect free space values, the calibration is not preserved after cycling the device power or data files that cannot be stored or recalled.

To solve the issue first try to repair the drive using the Windows "Scan and repair drive" tool or equivalent tool if using another operating system. If this does not fix the issue, use the format tool in the computer or select the Reset Factory option in the Setup menu of the analyzer, and select the Format Disk option. Before formatting the drive, it is convenient making a copy of the existing files in the internal drive to the computer's drive. After formatting the drive, the saved files can be restored back to the SARK-110's internal drive.

11.3 INPUT STAGE

The test port input of the analyzer can be damaged by a discharge of static electricity or by the application of a DC voltage or a strong RF signal. Therefore, it is always suggested observing the following precautions when operating the device:

1. *Never connect the unit to an antenna during a lightning storm and windy dry days. Lightning strikes and static discharges can damage the unit and may kill the operator.*
2. *Static build-up on an antenna may cause damage to the unit when connected. As a precaution, before plugging the coax cable into the analyzer always discharge the antenna by momentarily shorting the centre and outer conductors of the connecting coax cable together and then touching the coax connector shell to the analyzer to equalize the charge. After operation, always disconnect the antenna.*
3. *Maximum safe RF input is 2V peak (+16 dBm). Exceeding this RF level may damage the unit. Note that powerful active transmitters nearby may induce a high RF voltage on the antenna.*
4. *Test port is DC coupled. Use an external series capacitor for measurement scenarios whereby a DC voltage is present.*

In case of damage, the good news is that the failure is usually restricted to a few components that are not difficult to replace.

11.3.1 Troubleshooting

The Calibrator Detector setup can be very useful for identifying the damaged components. From this setup, the correct operation of the Voltage and Current detectors used in the analyzer. can be verified. The section "Reference Voltage and Current Readings" below shows the typical readings of the Voltage and Current detectors for different loads.

For the troubleshooting, it will be also needed a multimeter and calibration loads (short, 50-ohm and open).

Please follow the procedure described below:

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1) In some cases, the problem can be a faulty external connector or cable adapter, so test the continuity of any connector adaptors and cables you may have between the load and test port.

2) Disconnect any load you might have connected to the test port.

3) Turn on the unit and select <SETUP><Calibration><Detector>. Please do not select Continue and observe the Voltage and Current bar graphs for the different load conditions.

Figure 1, Detector Calibration setup mode

4) For the no-load condition, the bar graphs should be as in the Figure 2. Voltage bar should be almost full and Current bar should be almost empty.

a. If both Voltage and Current bars are almost empty, this will likely be a severe problem: e.g. both mixers (U4: Voltage and U6:Current) and/or voltage bridge resistors damaged (R73 and R79), DDS faulty, etc.

b. If Current bar is filled more than 1/4, there could be a short circuit in the input stage, e.g. shorted D3 protection diode.

5) If previous step was correct, connect a short load and observe the bar graphs. Voltage bar should be full in half and Current bar almost full as illustrated in the Figure 3.

a. If the bar graphs show the same values as the no-load condition, the most likely fault is a damaged R64 (open or high resistance). R63 maybe be damaged as well. These resistances can be measured in place with a multimeter. It is possible that the mixer U4 (Voltage) is damaged as well.

6) If previous step was correct, connect a 50-ohm load and observe the bar graphs. Both Voltage and Current bar should be about full in half as illustrated in the Figure 4.

a. If the Voltage and Current bar graphs show significant different readings, it is likely that one of the mixers (U4: Current, U6: Voltage) is damaged; normally the one that displays a lower reading.

11.3.2 Reference Voltage and Current Readings

Screenshots below show the correct Voltage and Current readings in the Detector Calibration setup mode, for the different load conditions.

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Figure 2, Open load condition

Figure 3, Short load condition

Figure 4, 50-ohm load condition

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11.3.3 Repair

In most cases the repair will involve replacing the damaged resistors in the input stage, most likely R64; and the mixers (U4 and U6) maybe damaged as well. The resistors are very small (0402 size), so you should use a magnifier and thin tweezers for facilitating the rework operation.

In some severe cases, some components and tracks on the circuit board may have burned out, such as the example shown in the following image.

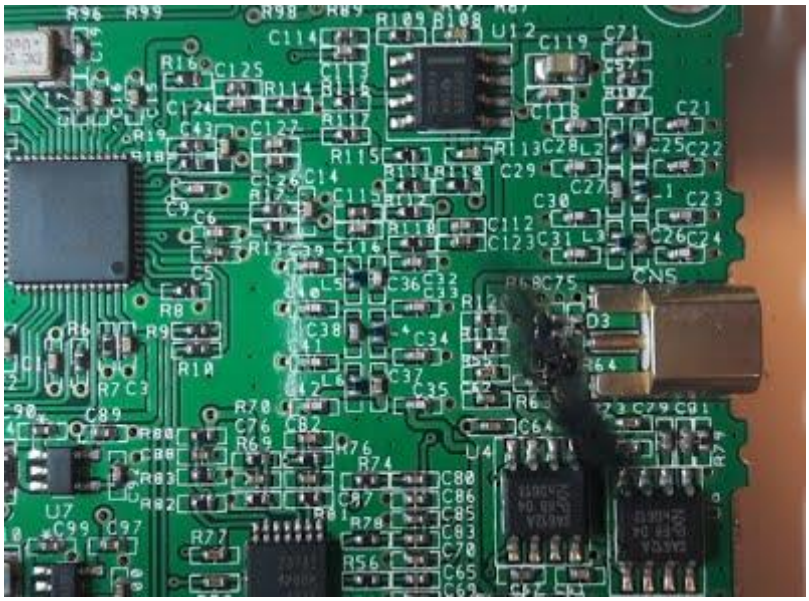

Figure 5

In these cases, the repair will be more difficult as you cannot use the original pads to solder the components, which means you can only fix it using hacks such as illustrated in the following image.

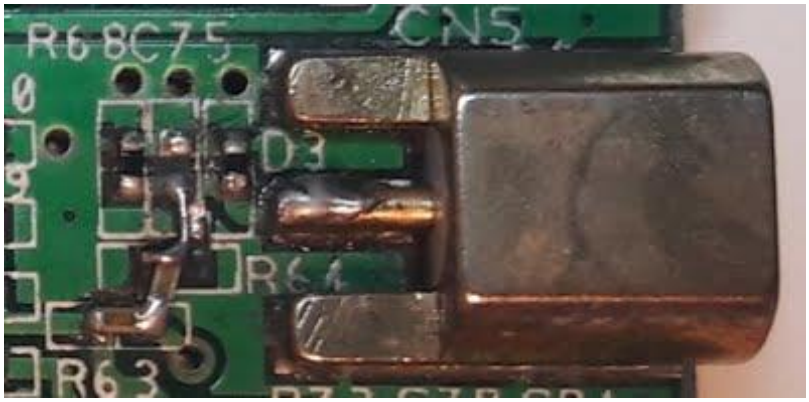

Figure 6

After repairing the unit, it will be necessary performing the Detector Calibration and then OSL calibration.

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11.3.4 Reference

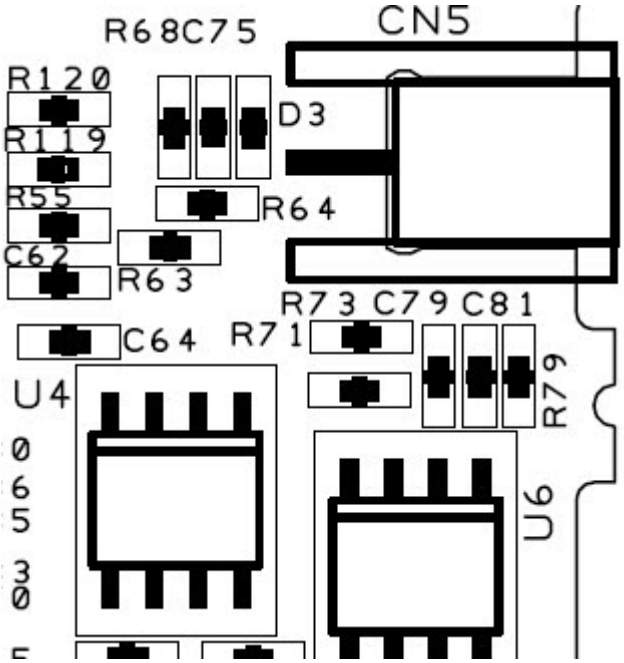

Figure 7, Input Stage Components Location

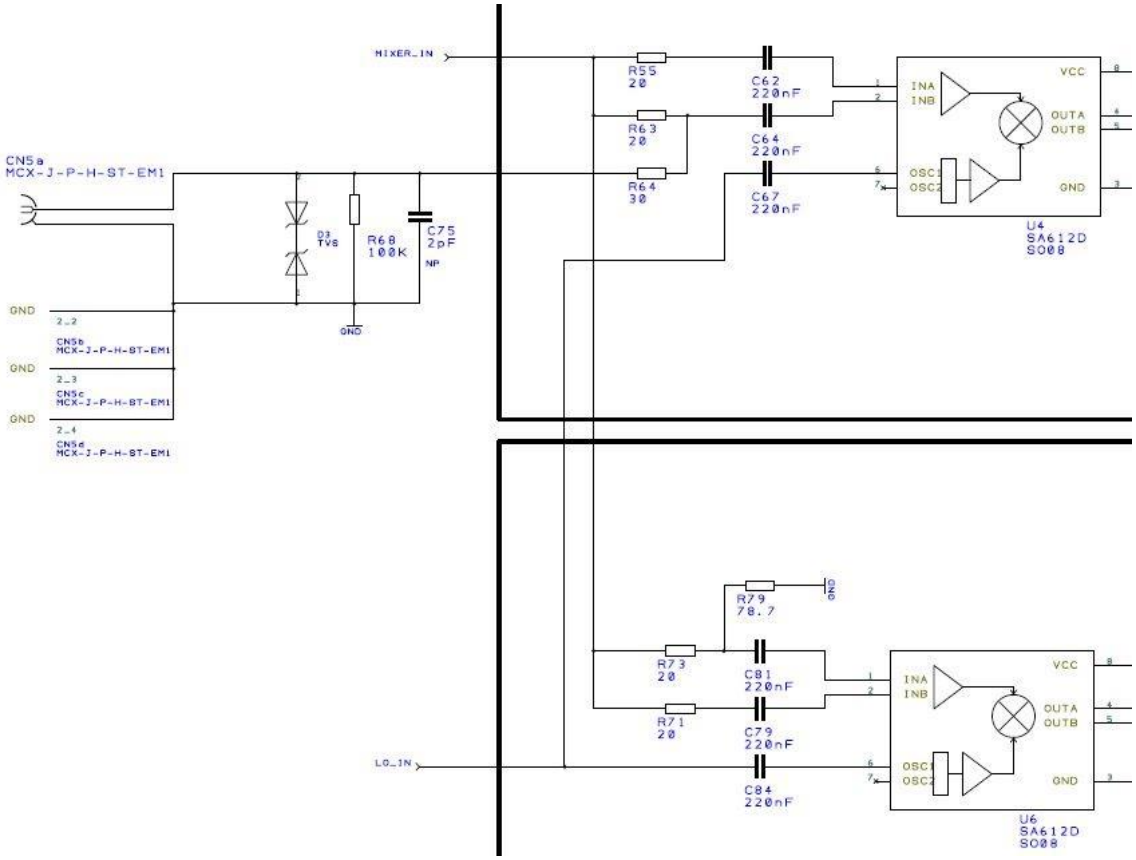

Figure 8, Input Stage Schematics

Digi-Key Part No.	Mfr Part No.	Reference	Description
RMCF0402FT100KCT-ND	RMCF0402FT100K	R68	RES 100K OHM 1/16W 1% 0402 SMD

RR05R30DCT-ND	RR0510R-300-D	R64	RES SMD 30 OHM 0.5% 1/16W 0402
ESD7551N2T5GOSCT-ND	ESD7551N2T5G	D3	TVS DIODE 13VC 2X2DFN
568-1204-5-ND	SA612AD/01,112	U6, U4	IC MIXER/OSC DOUBLE-BAL 8-SOIC
311-20UCT-ND	RT0402DRE0720RL	R63, R73	RES 20 OHM 1/16W .5% 0402 SMD
P78.7DCCT-ND	ERA-2AEB78R7X	R79	RES 78.7 OHM 1/16W .1% 0402 SMD

Table 1, Input Stage Bill of Materials

11.4 Navigator Switch Replacement

11.4.1 Repair Instructions

The navigator switches used in the SARK-110 are SMD components, which in case of failure they can be easily removed from the main board using a hot air gun. Take care to not overheat the surrounding components. It is a good measure using aluminium foil to protect the other components and ensure that the heat is directed only to the switch.

If the hot air gun is not available, a good solution will be to break the metal frame from the sides with a cutter pliers or a Dremel tool, being careful not to pull the pads off the board. Also, the contact leads will need to be cut to facilitate the desoldering. Then desolder the leads and pads with an iron and clean them with the iron and desoldering braid. Finally put the connector in place and carefully solder the metal frame support pads and contact pads using a thin-tipped iron.

11.4.2 Datasheet

Part Number: SLLB510100

See the datasheet at
http://www.alps.com/prod/info/E/HTML/MultiControl/Switch/SLLB5/SLLB510100.html

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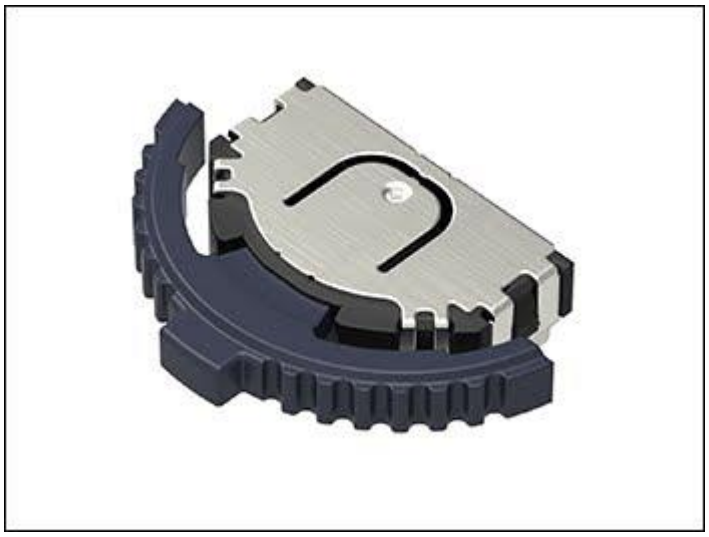

11.4.3 Sources

http://www2.mouser.com/ProductDetail/ALPS/SLLB510100/?qs=%2fha2pyFaduipMLJBaAma9EE1T6J0c7C5Swr3lyL2kPY%3d

https://www.aliexpress.com/item/Imported-multifunction-control-lever-pressing-type-switch-SLLB510100-100-000-genuine-life/32790239186.html?spm=2114.01010208.3.2.GNLx7C&ws_ab_test=searchweb0_0,searchweb201602_4_10152_10208_10065_10151_10068_10301_10136_10137_10303_10060_10155_10062_437_10154_10056_10055_10054_10059_303_5300014_100031_10099_10103_5320014_10102_10096_10109_10052_10053_10107_10050_10142_10051_10084_10083_10080_10082_10081_10110_519_10111_10176_10112_10113_10114_10182_10184_10078_10079_10073_10123_10189_142,searchweb201603_1,ppcSwitch_3&btsid=352b11f6-0dda-4627-860e-92d0b61b185a&algo_expid=d7f1031a-67b9-4fab-8e84-985ece84e438-0&algo_pvid=d7f1031a-67b9-4fab-8e84-985ece84e438

11.5 TACTILE SWITCHES REPLACEMENT

11.5.1 Repair Instructions

The tactile switches used in the SARK-110 are SMD components, which in case of failure they can be easily removed from the main board using a hot air gun. If this tool is not available, it will be convenient breaking the contact pads using a cutter or a Dremel tool, being careful not to pull the pads off the board. Then desolder the leads and pads with an iron and clean them with the iron and desoldering braid. Finally put the connector in place and carefully solder the four contact pads using a thin-tipped iron.

11.5.2 Datasheet

Part Number: CY-A03-02

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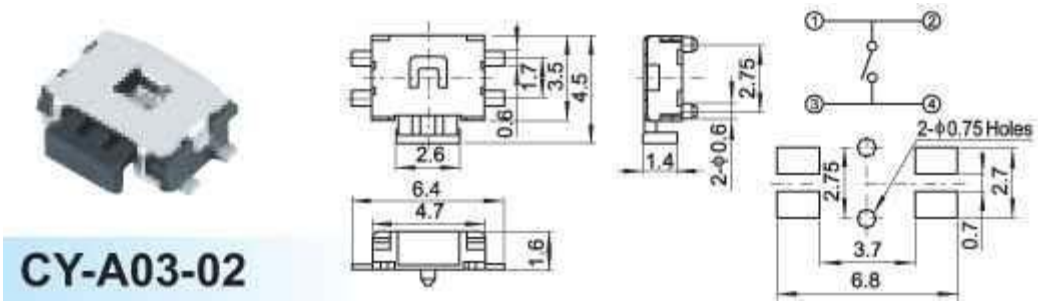

11.5.3 Sources

https://www.mouser.es/ProductDetail/Wurth-Elektronik/436331045822?qs=sGAEpiMZZMsgGjVA3toVBEzRptafNWBVKdmpStmLzOA%3D

https://es.aliexpress.com/item/100PCS-SMD-push-button-switch-microswitch-Tact-Switch-Side-button-free-shipping/32651135446.html?spm=a2g0s.9042311.0.0.vqnEkI

11.6 USB Socket Replacement

11.6.1 Repair Instructions

Under construction

11.6.2 Datasheet

There are multiple sources for the USB Mini-B socket. Sungtech's ST-USB-002A is one reference, see the attached datasheet.

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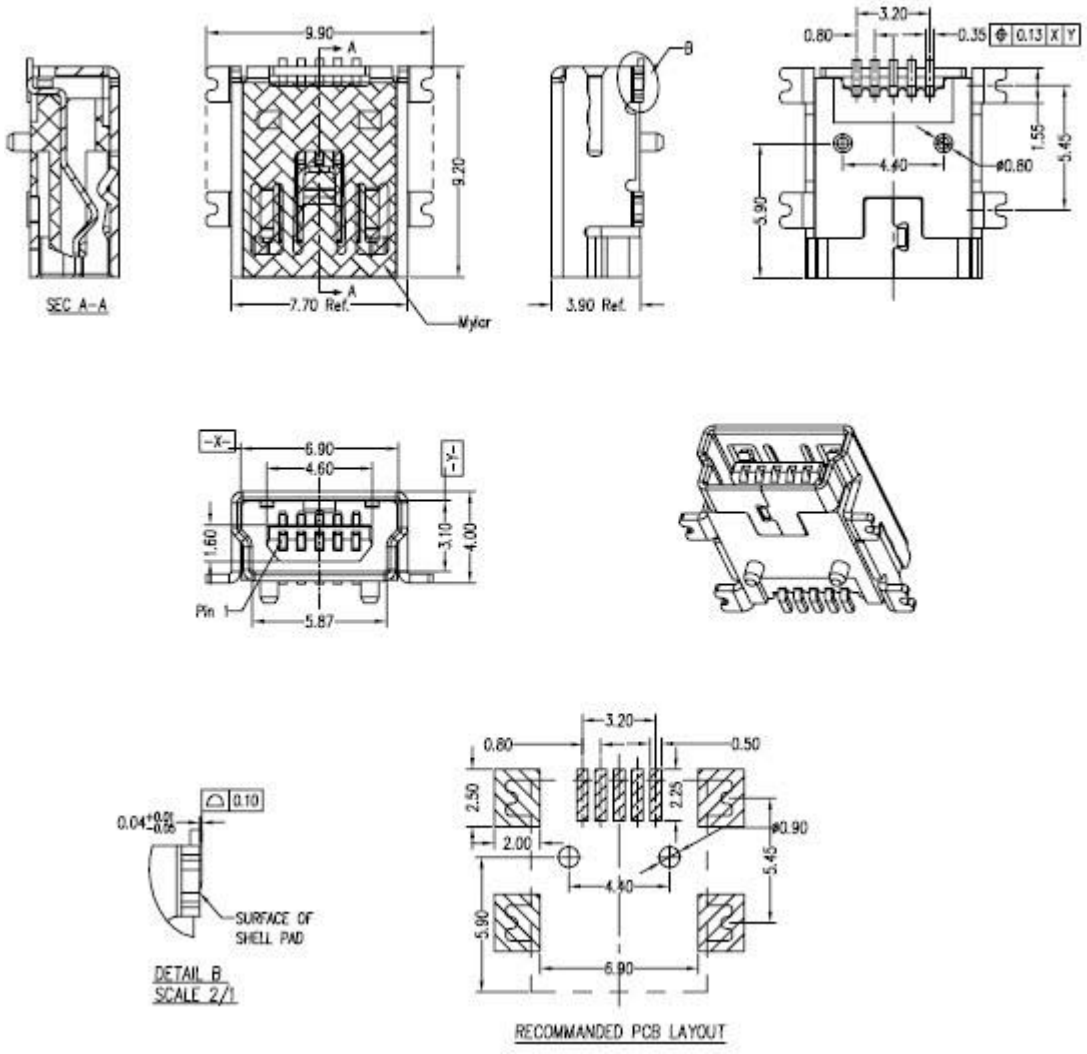

11.6.3 Sources

https://www.mouser.es/ProductDetail/CUI/UJ2-MBH-1-SMT-TR?qs=5mqXD9RfOg2uumvPfpWvPw%3d%3d

https://www.digikey.com/products/en/connectors-interconnects/usb-dvi-hdmi-connectors/312?k=usb+jack&k=&pkeyword=usb+jack&pv7=2&FV=ffe00138%2C70054b&quantity=0&ColumnSort=0&page=1&pageSize=25

12 CALIBRATION LOADS

12.1 CALIBRATION LOADS USING OFF-THE-SHELF TERMINATIONS

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Load	Description	DigiKey P/N	Mouser P/N	Manufacturer Name	Manufacturer P/N
Open	Connector SMA male plug solder PCB mount straight Note: center pin trimmed down to dielectric			*Multiple sources available*	
Short	CONN CAP CVR SHORT FOR SMA JACK	ACX2070-ND	523-132331 1	Amphenol Connex	132331
Load (50ohm)	CONN TERMINATOR PLUG SMA 50OHM	ACX1251-ND	523-132360 60	Amphenol Connex	132360

Note: for Open load it will be fine not connecting any load

Open Load

Short Load

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50-Ohm Load

12.2 COMPONENTS FOR BUILDING CALIBRATION LOADS

12.2.1 BNC Connectors

eBay:

- BNC male plug center solder PCB mount RF connector
- 10pcs BNC male plug center solder PCB mount RF connector

12.2.2 SMA Connectors

eBay:

- 2pcs connector SMA male plug solder PCB clip edge mount straight M
- 10pcs connector SMA male plug solder PCB clip edge mount straight M

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12.2.3 Resistors

12.2.3.1 50-ohm Load (2x 100-ohm in parallel) and 100-ohm Load

Specification:

- Composition: thin film
- Resistance: 100-ohm
- Tolerance: +-0.1%
- Temperature coefficient: +-25ppm/ºC
- Package: 0603

Examples:

DigiKey P/N	Manufacturer P/N	Description
P100DBCT-ND	ERA-3AEB101V	RES 100 OHM 1/10W .1% 0603 SMD
RG16P100BCT-ND	RG1608P-101-B-T5	RES 100 OHM 1/10W .1% 0603 SMD
P100YCT-ND	ERA-3YEB101V	RES 100 OHM 1/10W .1% 0603 SMD

12.2.3.2 200-ohm Load

Specification:

- Composition: thin film
- Resistance: 200-ohm
- Tolerance: +-0.1%
- Temperature coefficient: +-25ppm/ºC
- Package: 0603

Examples:

DigiKey P/N	Manufacturer P/N	Description

P200DBCT-ND	ERA-3AEB201V	RES 200 OHM 1/10W .1% 0603 SMD
RG16P200BCT-ND	RG1608P-201-B-T5	RES 200 OHM 1/10W .1% 0603 SMD

eBay: 200 OHM 0.1% 0603 25ppm Resistor RN731JTTD2000B25 KOA NEW Qty:100pcs

Note: could be used as well for the 50-ohm load (x4 in parallel) and the 100-ohm load (x2 in parallel)

12.2.4 Assembly examples

Notes:

- 50-ohm, 100-ohm and 200-ohm loads shown above were manufactured with 200-ohm resistors
- The centre pin of the connectors was trimmed down
- 100-ohm and 200-ohm loads are not required for calibration

12.2.5 Useful links about building calibration loads

http://blog.kotarak.net/2009/10/n2pk-vna-calibration-standards.html
http://blog.kotarak.net/2010/04/n2pk-vna-sma-calibration-standard.html
http://www.qsl.net/in3otd/electronics/VNA_calkit/calkit.html

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13 BATTERY MAINTENANCE AND SAFETY GUIDELINES

The internal Lithium-Ion rechargeable battery require routine maintenance and care in their use and handling. Read and follow the guidelines below to achieve the maximum battery life span and safely handle the battery.

1) Avoid extreme ambient temperatures

For a higher battery life span, the device should be operated in an ambient temperature range between 16° to 25° C (62° to 77° F). It's especially important to avoid exposing your device to ambient temperatures higher than 35° C (95° F), which can permanently damage battery capacity. That is, your battery won't power your device as long on a given charge. Charging the device in high ambient temperatures can damage it further. Also, never charge your device unattended or in any place where there is a risk of fire.

Even storing a battery in a hot environment can damage it irreversibly. When using your device in a very cold environment, you may notice a decrease in battery life, but this condition is temporary. Once the battery's temperature returns to its normal operating range, its performance will return to normal as well.

2) Store the device half charged when you store it long term

If you want to store your device long term, two key factors will affect the overall health of your battery: the environmental temperature and the percentage of charge on the battery when it's powered down for storage. Therefore, we recommend the following:

- Do not fully charge or fully discharge your device's battery — charge it to around 50%. If you store a device when its battery is fully discharged, the battery could fall into a deep discharge state, which renders it incapable of holding a charge -a deep discharged battery must not be recharged for safety reasons, so it should be replaced and disposed properly. Conversely, if you store it fully charged for an extended period, the battery may lose some capacity, leading to shorter battery life.
- Be sure to turn off the device to avoid additional battery use. To turn off the device completely, use the power switch and not the automatic power off function. The device uses some battery power during the automatic power-off state, so the battery can be completely discharged if the device is left in this state for a prolonged period.
- Place your device in a cool, moisture-free environment that's less than 32° C (90° F).
- If you plan to store your device for longer than six months, charge it to 50% every six months.

3) Replace the battery when necessary

The typical estimated life of a Lithium-Ion battery is about two to three years or 300 to 500 charge cycles, whichever occurs first. One charge cycle is a period of use from fully charged, to fully discharged, and fully recharged again. Use a two to three-year life expectancy for batteries that do not run through complete charge cycles.

Consider replacing the battery with a new one if you note that the battery run time drops below about 80% of the original run time. Also, deep discharged batteries must be replaced for safety reasons.

4) Properly dispose the battery

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Lithium-Ion batteries are subject to disposal and recycling regulations that vary by country and region. Always check and follow your applicable regulations before disposing of any battery. Many countries prohibit the disposal of waste electronic equipment in standard waste receptacles.

Place only discharged batteries in a battery collection container. If the connector is removed or the cable cut, use electrical tape or other approved covering over the battery connection points to prevent short circuits.

5) Properly handle the battery

Please note the below safety precautions when handling the device internal battery:

- Do not disassemble, crush, or puncture a battery.
- Do not short the external contacts on a battery.
- Do not dispose of a battery in fire or water.
- Do not expose a battery to temperatures above 60 °C (140 °F).
- Keep the battery away from children.
- Avoid exposing the battery to excessive shock or vibration.
- Do not use a damaged battery.
- If a battery pack has leaking fluids, do not touch any fluids. Dispose of a leaking battery pack (see the disposal and recycling considerations above).
- In case of eye contact with fluid, do not rub eyes. Immediately flush eyes thoroughly with water for at least 15 minutes, lifting upper and lower lids, until no evidence of the fluid remains. Seek medical attention.

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