

VNA Operating Guide for the MSA

2/1/10

The MSA as VNA

Introduction

This Guide contains individual pages to describe the use of the MSA in Transmission Mode [functioning as either a Scalar Network Analyzer (SNA) or a Vector Network Analyzer (VNA)], or in Reflection Mode. The pages can be accessed by clicking on the blue headings below, or by using the Bookmarks tab. This Guide assumes familiarity with the operating procedures set forth in the Spectrum Analyzer Operating Guide for the MSA.

The first several pages include material that is relevant to a wide range of measurements:

- Fixtures.** Basic fixtures for interfacing the DUT to the MSA.
- Shunt Fixtures.** Specifics on shunt fixtures.
- Series Fixtures.** Specifics on series fixtures.
- Bridges.** General description of reflection bridges.
- Cal--Transmission.** Calibration procedures for Transmission Mode.
- Cal--Reflection.** Calibration procedures for Reflection Mode
- OSL Standards.** Construction and characterization of OSL cal standards.
- Basic Transmission.** Basic procedures for measurement in Transmission Mode.
- Basic Reflection.** Basic procedures for measurement in Reflection Mode.
- Plane Extension.** Eliminating unwanted signal delays from measurements.

The following pages cover what are called Functions, available under the Functions menu:

- Filter.** Analysis of filter transmission peaks.
- Crystal.** Determination of crystal parameters for use in creating filters.
- Component Meter.** Component measurements similar to an LCR meter.
- RLC--Transmission.** Modeling devices as RLC combinations, using Transmission Mode measurements.
- RLC--Reflection.** Modeling devices as RLC combinations, using Reflection Mode measurements.
- Coax.** Measuring characteristics of coax cable or other transmission lines.
- Generate S21--**Generating S21 data from S11 measurements for “two terminal DUTs”

The following pages contain additional measurement procedures:

- Coax Z0--**Determining characteristic impedance of transmission lines.
- Reference Lines--**Creating Reference Lines for display or math.

At the end is reference information:

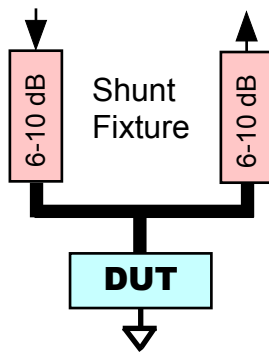
- Return Loss Reference.** Return Loss and related quantities.
- Smith Chart 1.** Basic description of the Smith Chart
- Smith Chart 2.** Circular graphs on the Smith Chart

Fixtures

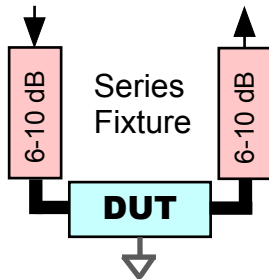
All Modes except Spectrum Analyzer

There are three basic types of fixtures for interfacing the MSA to the device under test (DUT) in SNA and VNA modes. Attenuators may be external or may be built into the fixture. Buffer amplifiers may be used in place of attenuators to maintain higher dynamic range.

The main purpose of the attenuators is to present the DUT with a precise impedance, which is referred to as the R_0 of the fixture. Home-made attenuators are far better for this purpose than commercial attenuators. R_0 may be a value other than 50 ohms if the attenuators are designed to transform the impedance.

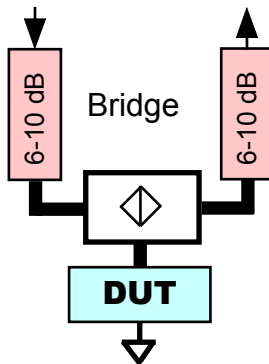


DUT is shunted to ground from the through-connection. For impedances from 0.1 ohm to 1 kohm.



DUT is in series with the signal path. For impedances from 3 ohms to 100 kohms. A Series Fixture with R_0 of 12.5 ohms is the standard for measuring crystals.

For transmission mode, the DUT may have a separate ground connection.



Normally for reflection mode only. But a good bridge can be used in SNA or VNA Transmission mode.

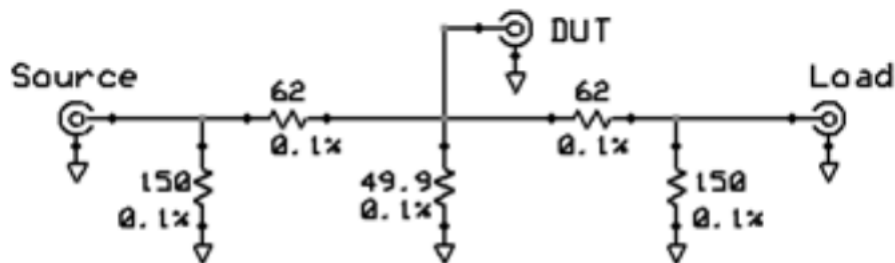
DUT is shunted to ground from the bridge connection. For impedances from 1 ohm to 1 kohm. The bridge has the best accuracy of any fixture for impedances close to 50 ohms.

Shunt Fixture Specifics

The shunt fixture can be constructed with two attenuators attached to a coax tee, with the DUT attached to the third arm. It is most important that the DUT see 50 ohms looking into each attenuator; this can be most reliably accomplished with homemade attenuators with precision resistors. A simple pi attenuator with values of 100-68-100 ohms makes a precision 9.6 dB attenuator; 120-49.9-120 makes a 7.7 dB attenuator. Both have excellent return loss in normal use as attenuators.

But the return loss and attenuation values are based on the assumption of a 50-ohm source and load. In the shunt fixture, the input attenuator sees a load consisting of the DUT in parallel with the output attenuator, so a zero-ohm DUT creates a zero-ohm load. This can make the return loss from the outside of a 7.7 dB attenuator as low as 15 dB.

We can obtain higher precision by building the attenuators on a fixture board, and using non-standard attenuator design. The following schematic shows a shunt fixture with modified 7.7 dB attenuators, and with the attenuator resistors nearest the DUT merged into one.



Approx. 15 dB insertion loss with 50 ohm DUT
Worst case 22 dB RL from outside, with zero DUT

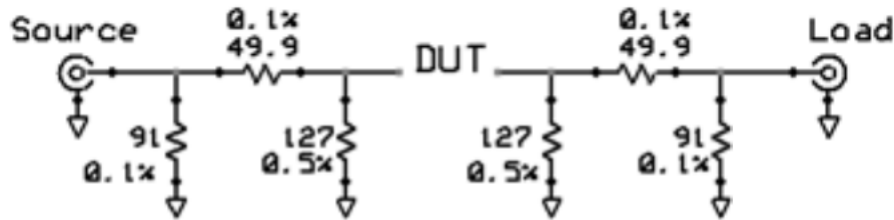
This design can significantly improve accuracy for low impedance DUTs if the source or load has return loss worse than about 25 dB, because it reduces reflections off the outside of the attenuators.

Note that for Reflection Mode measurements when OSL calibration is used (rather than the simpler Reference calibration), the issue described above is not important, as the calibration will compensate for the impedances seen by the DUT.

Series Fixture Specifics

The section discussing shunt fixtures describes resistor values for home-made attenuators, and discusses the fact that simply attaching standard attenuators to a fixture does not produce optimal results. For example, in the case of the series fixture, if the DUT has a large impedance, each attenuator sees a large load, rather than the 50 ohms that its design assumes. This causes the return loss at the outside of the attenuators to be very low, causing large reflections.

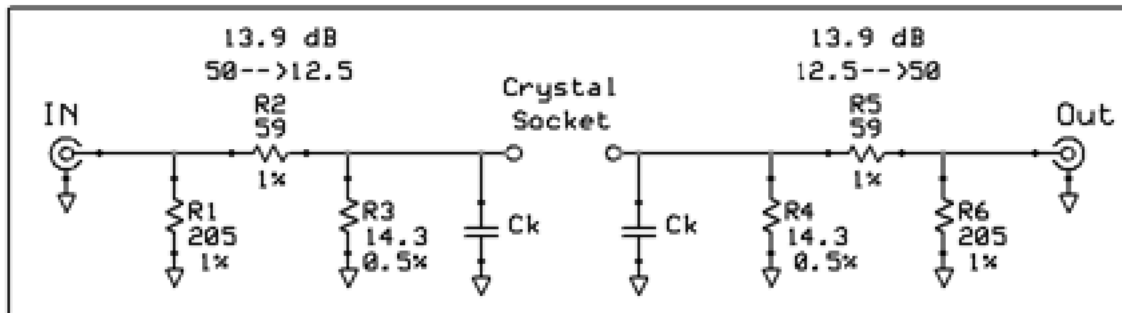
The design in the schematic below solves this problem and achieves a worst-case return loss of 20 dB (with an infinite DUT).



Approx. 20 dB insertion loss with 50 ohm DUT
Worst case 20 dB RL from outside, with large DUT

The “official” fixture for testing crystals is a series fixture with an R0 of 12.5 ohms; the schematic is shown below.

IEC 444 Pi-Network Resonator Fixture (Modified to use readily available resistors)



R0=12.5 ohms

The Ck components are for compensation, and aren't normally needed.

Note that the low values of R3 and R4 also make the return loss from the outside of the attenuators relatively insensitive to the DUT impedance, so this fixture also solves the problem discussed above, and could be used for purposes other than crystal testing.

Bridges

Bridges are normally used only in reflection mode. They are designed so that their output is proportional to the signal reflected by the DUT. The reflection coefficient is then that signal divided by the output level with an open DUT (since an open creates a 100% reflection). In dB, that division is done by subtraction.

Their quality can be judged by their directivity, which is the reflection coefficient (in dB) with a 50-ohm DUT (which should have zero reflection), and by whether the open and short reflections have equal magnitude but opposite phase. A bridge with good directivity and well matched open/short can be used with just Reference calibration. In fact, it can even be used in Transmission Mode, by doing a scan of the bridge with the Open attached, and comparing that level to a scan with the DUT attached. The difference is S_{11} .

The Active Bridge is constructed with two op amps, and has extremely high precision to 30 MHz and very good precision beyond 100 MHz, and thus is suitable for use with Reference calibration. Its active components allow it to measure reflections accurately with minimal signal loss.

Most passive bridges involve baluns with ferrite cores. The basic bridge design, with optional modest attenuators at the input and output, typically result in loss of 14-20 dB with passive bridges. That is, the maximum output (with an open or short DUT) is 14-20 dB below the input level.

The Parallel Line Bridge is a passive bridge good from 1 MHz to beyond 1 GHz. Its directivity is excellent over a broad range, but its open/short match is not ideal. It therefore can be used with Reference calibration for measuring return losses of 20 dB and higher, where directivity is the primary consideration. With OSL calibration, its performance is excellent.

The Balun-Plus-Beads Bridge is another passive bridge. It has a broader frequency range, from about 100 kHz (the practical lower limit for the MSA in VNA mode anyway) to 1 GHz. It is relatively simple to construct.

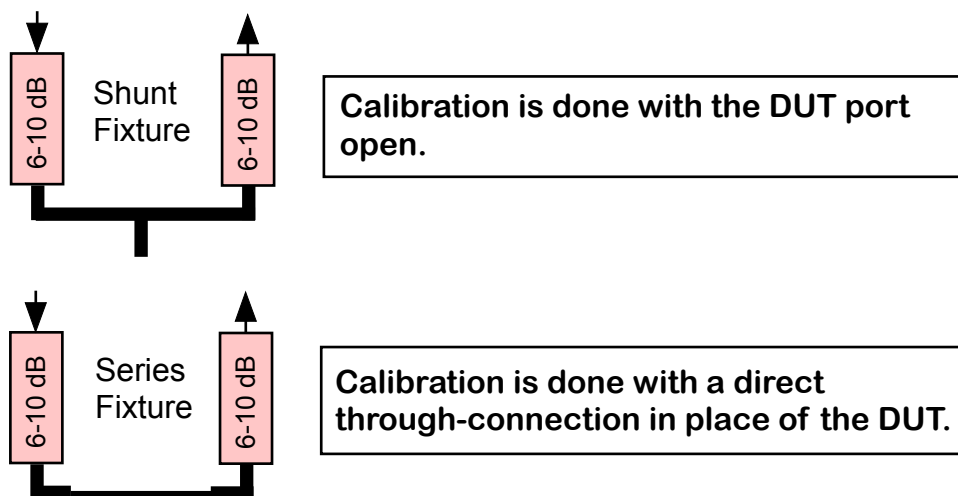
Passive bridges can also be made from transformers, splitters/combiners and directional couplers.

Transmission Mode Calibration

VNA or SNA Transmission Mode

Calibration is performed to establish the strength and phase of the signal transmitted in the absence of the DUT, to use as a reference when measuring the DUT transmission.

1. Set the frequency range and Final Filter Path as desired.
2. Open Operating Cal-->Perform Cal.
3. For the Series Fixture, attach a direct connection in place of the DUT. If you need to compensate for the length of the connection, enter the delay caused by the connection, in ns.
4. For the Shunt Fixture, have nothing attached as a DUT.
5. Click Perform Band Cal. The MSA will conduct one sweep to gather calibration Data. During the calibration sweep, a minimum Wait time of 110 ms is used, regardless of your Wait time setting. However, if your setting is greater than 110 ms, that longer time will be used.
6. If you want to save the Band Cal as a Base Cal file, click Save Base Cal.
7. Click Done. You may now attach a DUT and click Restart.



Reflection Mode Calibration

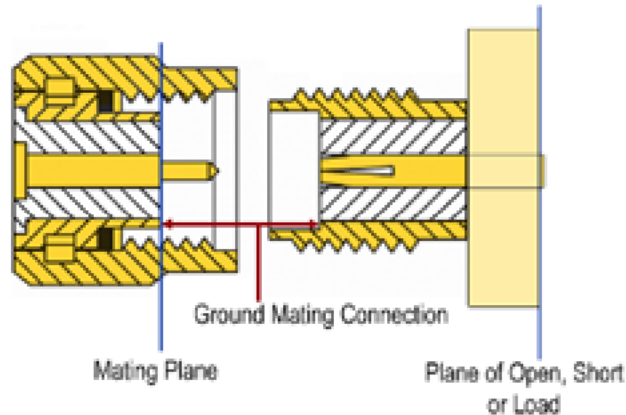
VNA Reflection Mode

Calibration is performed to establish the strength and phase of the signal reflected with one or more known “standards”. For Reference calibration, only one such standard is needed. For Full OSL, three are needed.

1. Set the frequency range and Final Filter Path as desired.
2. Open Operating Cal-->Perform Cal. Click Perform Band Cal to open the reflection mode calibration window.
3. Select whether you want to use Reference calibration (one standard; generally not used above 150 MHz) or Full OSL (three standards; highest accuracy.)
4. For Reference calibration, select the fixture type. If Shunt Fixture, you may enter the connector delay time. A delay of 0.115 ns is typical for an SMA connector.
5. Attach the appropriate calibration standard and click the button “Perform X”, where X is the name of the standard. For Full OSL, there will be a button for each of the three standards, and a sweep must be performed for each one. For Reference calibration, only one sweep is needed.
6. During the calibration sweeps, a minimum Wait time of 110 ms is used, regardless of your Wait time setting. However, if your setting is greater than 110 ms, that longer time will be used.
7. When finished, click Done. You will be back to the Perform Calibrations window. If you want to save the Band Cal internally as a Base Cal, click Save Base Cal.
8. Click Done. You may now attach a DUT and click Restart.

OSL Calibration Standards

We will consider here the construction of calibration standards to attach to a male SMA connector coming from the test fixture. The standards will be mounted on female connectors as shown below:



The legs are broken off the female connector (two can be left in place if desired). The Open is constructed by grinding the center pin flush on the back of the female connector. That pin is also ground almost flush for the Short and Load. The Short has a piece of brass sheet (with a hole poked in the center) soldered on the back; if the corners are notched with a Nibbler tool, the resulting cross shape sits nicely between the stubs of the broken-off legs, which hold it in place during soldering. The Load is made by soldering two 100-ohm 0805 resistors on the back in opposite directions; or four 200-ohm 0603 resistors can be used.

It is important to note where the test fixture ends and the DUT begins. If we are going to solder DUTs on the back of similar connectors, then the back plane of the female connector is where the DUT starts; everything left of that, including the front of the calibration standard connector, is part of the test fixture. In this case, the standards are properly described as an open, short and load without any connector delay--the connector is not part of the standard. The dividing point between the test fixture and the DUT is called the Calibration Plane or Reference Plane. (Some distinguish between these two terms; we use them interchangeably.)

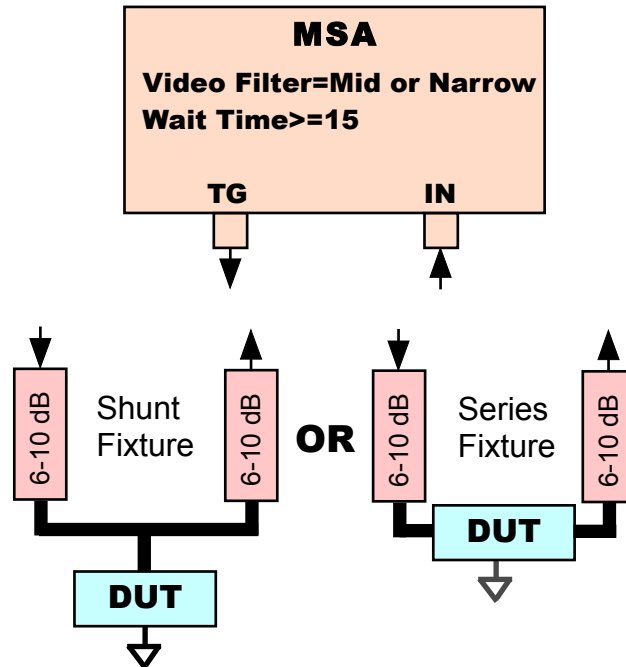
If the DUT already has its own connector, then the DUT will begin at the mating plane. In that case, our standards consist of the entire female connector, including what is on the backside. We must then describe the Open and Short standards as having some built-in delay, which we measure in ns. In addition, the Short will have some loss due to skin effect, which we describe as a parallel resistor||inductor. As long as the connector characteristic impedance is 50 ohms, the connector and Load resistors will still appear together as a perfect 50 ohms, so we do not need to specify a delay. It is permissible for the resistance to be a few tenths off of 50 ohms, as long as the true resistance is known.

When performing OSL calibration, the calibration window allows the characteristics of the standards to be entered, or the standards can be specified as pre-measured standards, which are still under development.

Basic Transmission Mode Measurements

VNA or SNA Transmission Mode

Measures the transmission coefficient of the DUT, determining the gain or loss caused by the DUT. The VNA measures phase and also determines the phase change caused by the DUT; the SNA does not.



Calibration

Preliminary measurements in Transmission Mode are sometimes made without calibration, to get a general idea where dramatic changes occur. But such measurements are generally preceded by reference calibration, to establish a signal level and phase against which to compare the DUT's transmission.

Settings:

Wait time should be ≥ 15 ms, but should be 50-150 ms for precision work, and should be at least 50 ms if video filter is Narrow.

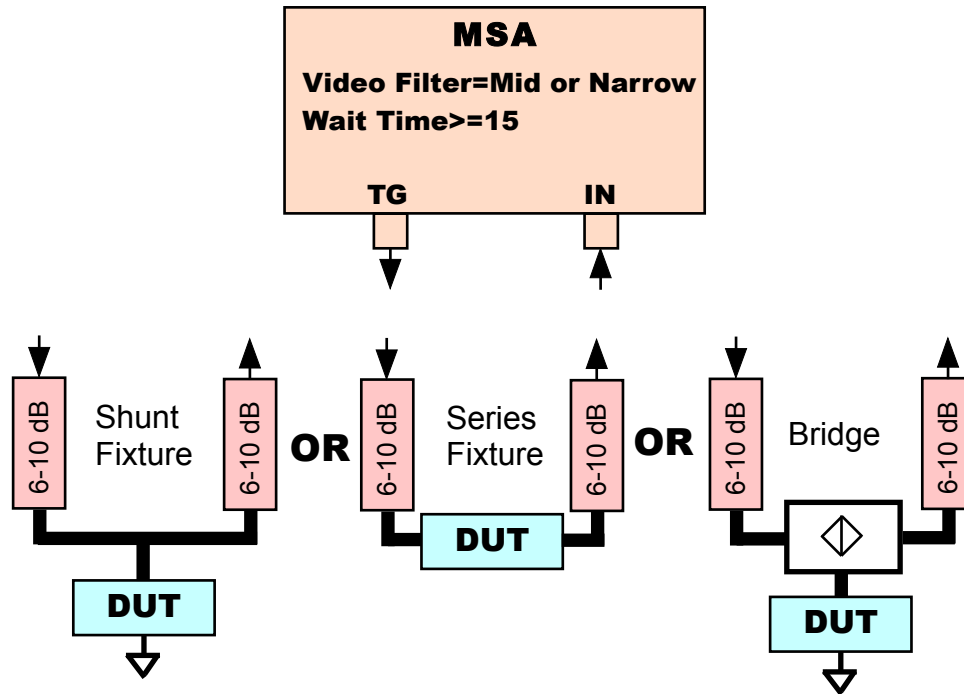
RBW is not critical but 2-10 kHz provides low noise.

Video filter should always be mid-range or narrow, primarily for phase accuracy. The Video filter must be set in hardware and software.

Basic Reflection Mode Measurements

VNA Reflection Mode

Measures the reflection coefficient of the DUT, from which impedance and other quantities can be calculated and graphed.



Calibration

Measurements in Reflection Mode are virtually meaningless unless preceded by calibration. Reference calibration can be used up to 150 MHz, depending on the quality of the fixture and the required accuracy. OSL calibration can be used with any fixture for any frequency range.

Settings:

Wait time should be ≥ 15 ms, but should be 50-150 ms for precision work, and should be at least 50 ms if video filter is Narrow.

RBW is not critical but 2-10 kHz provides low noise.

Video filter should always be mid-range or narrow, primarily for phase accuracy. The Video filter must be set in hardware and software.

Plane Extension

VNA Transmission or Reflection Mode

Eliminate the effect of a signal delay in Transmission or Reflection Mode measurements

Transmission Mode

The device being tested may include connectors or other causes of signal delay that we don't actually consider part of the DUT. Extra delay typically causes the phase graph to tilt downward to the right, as any given distance will cause more phase delay at higher frequencies, causing phase to become more negative (or less positive). Plane Extension can eliminate that tilt.

Reflection Mode

The device being tested may be connected to the test fixture with a connector, or PCB trace that we don't consider part of the DUT. Plane Extension can extend the Calibration Plane (which is essentially the dividing line between fixture and DUT) to a point closer to the true DUT. The unwanted signal delay causes a phase delay that increases at higher frequencies and shows up on the Smith chart as a clockwise rotation that increases with frequency. It also shows up on a regular graph of S11 as a downward tilt similar to that described for Transmission Mode.

Procedure

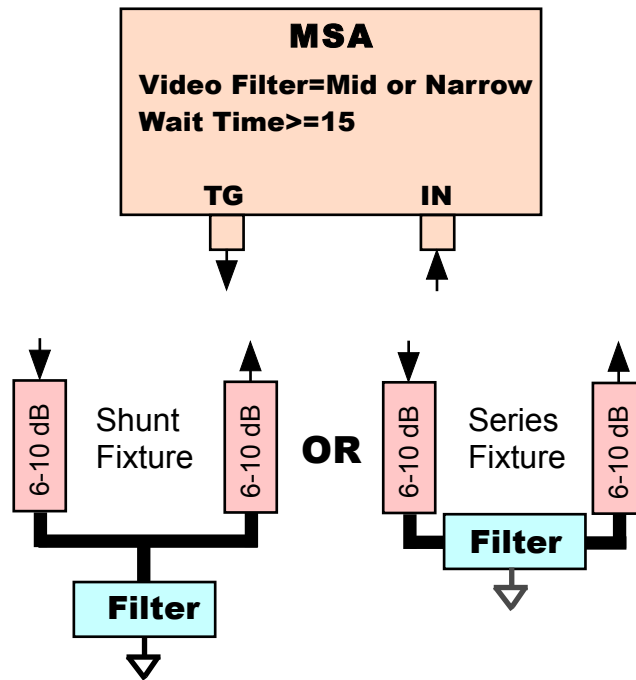
Plane Extension is accomplished by entering an adjustment factor in the Plane Extension box in the Sweep Parameters window. That factor is the delay, in nanoseconds, that needs to be eliminated. The effect of the extension can be viewed immediately by clicking the Recalc button underneath the box.

For example, in Reflection Mode if the DUT is soldered on a connectorized PCB, but we want to eliminate the effect of the connector and PCB trace leading to the DUT, we can create a short in the line leading to the DUT. That short will appear on the Smith chart as an arc caused by a point that rotates clockwise an increasing amount as frequency increases. By trying different Plane Extension values, and clicking Recalc, that rotation can be eliminated so the short appears as a single point at the far right side of the Smith chart. That effectively causes the Calibration Plane to be moved to the point of the short.

Filter Analysis Function

VNA or SNA Transmission Mode

Determines the peak of the filter response, as well as the -3 dB points or other points specified by the user. Displays peak frequency, bandwidth, Q, ripple and shape factor.

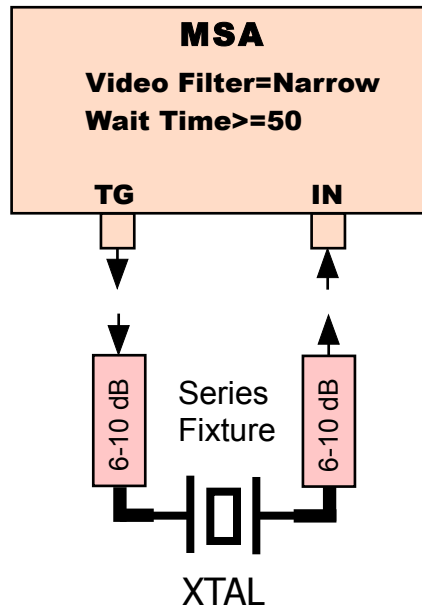


1. Perform a transmission (S21) scan showing the peak frequency, and the -3 dB points above and below that frequency, plus any other points you wish to identify.
2. Select Function-->Filter Analysis.
3. Indicate which dB points you wish to identify--for example, -3 dB and -20 dB.
4. Quit the function window. The desired points are marked and information is displayed in and next to the marker info area.
5. Continue the scan, and the markers and other information will be updated at the end of each scan.
6. When done, reopen Function-->Filter Analysis and turn it off. Use the Clear Markers button to get rid of existing markers.

Crystal Analysis Function

VNA or SNA Transmission Mode

Determines crystal series resonance (F_s), parallel resonance (F_p), motional parameters (R_m , C_m , and L_m) and parallel package capacitance (F_p).



1. Perform a line calibration with a short in a Series Fixture. A 12.5-ohm fixture is the standard for crystal analysis, but a 50-ohm fixture works well.

2. Insert the crystal and perform either:

--S21 dB scan of series resonance peak (F_s) and parallel resonance dip (F_p)

or

--S21 dB scan of series resonance peak, after separately doing a scan to determine for yourself the parallel resonance frequency.

3. Open Function-->Crystal Analysis, select the type of scan you performed, and if necessary enter the value of F_p in the text box. If the step size is too large to accurately determine F_s , click Zoom to F_s . You typically need a step size of 5-50 Hz/step, depending on your accuracy requirements.

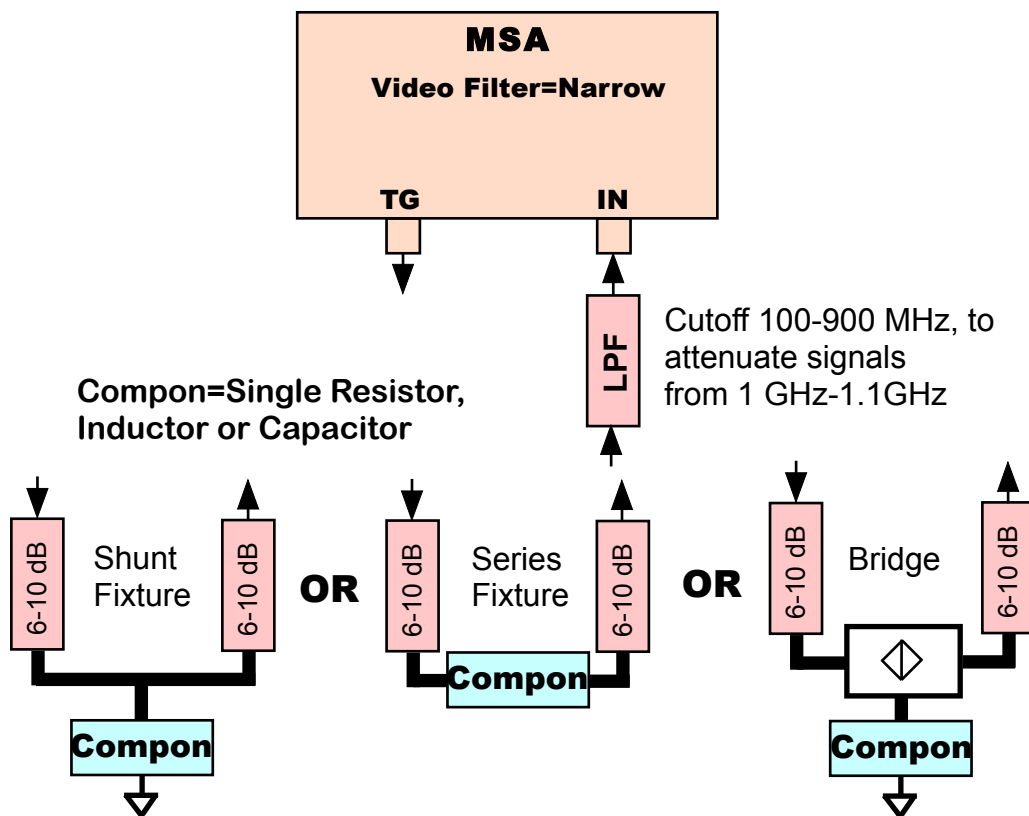
4. Click Analyze. The parameters of the crystal will be displayed.

5. You may create a list of crystals with their parameters by clicking Add To List. You must quit the function to do a scan for another crystal, but the list will continue until you close its window. Crystals in the list are numbered sequentially, but you may change the current number by clicking Set ID.

Component Meter Function

Reflection Mode or VNA/SNA Transmission Mode

Continuously measures and displays the values of resistors, inductors or capacitors. Measurements are made at relatively low frequencies to avoid self-resonance effects. More extensive capabilities are available in the RLC Analysis Functions.

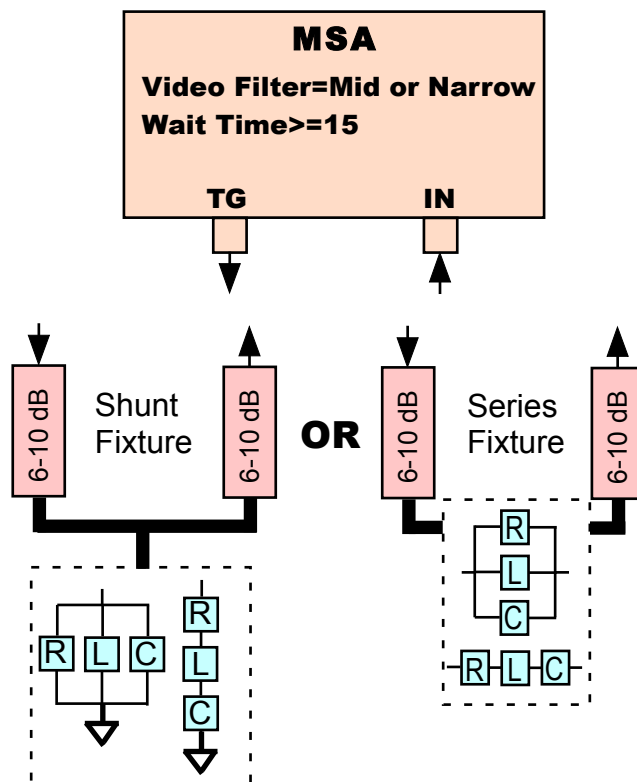


1. (Optional) Attach a low pass filter if you will be measuring larger components that the MSA will choose to measure at 100 kHz to 500 kHz. This will filter out high frequency TG signals that increasingly limit the dynamic range below 500 kHz.
2. Open Function-->Component Meter. There are no required pre-scans for this Function, which will establish its own settings and perform the necessary calibration and scans. (But you must set the video filter to Narrow.)
3. Select the fixture type being used, and enter its R0, which is the resistance seen by the DUT looking into each attenuator. For the Shunt Fixture, you may enter the connector delay, in ns; 0.115 ns is typical for an SMA connector. Attach the proper Open or Short connection and click Calibrate. In Reflection Mode, click Calibrate first, and enter the fixture information in the Reflection Calibration window if necessary. (It is not necessary for full OSL.)
4. Select the checkbox for the type of component to measure, attach it to the fixture and click Measure. The Measure button will change to Stop and the component value will be measured and displayed continuously until you click Stop. You may swap components while the measurement is in progress.
5. Once you click Stop, you may click +Freq or -Freq to obtain measurements at other frequencies.

RLC Analysis Function

VNA or SNA Transmission Mode

Models a circuit as combination of a resistor, inductor and capacitor, which may be actual components or parasitics. Calculates the values of those components and Q factors. More extensive RLC Analysis is available in Reflection Mode.

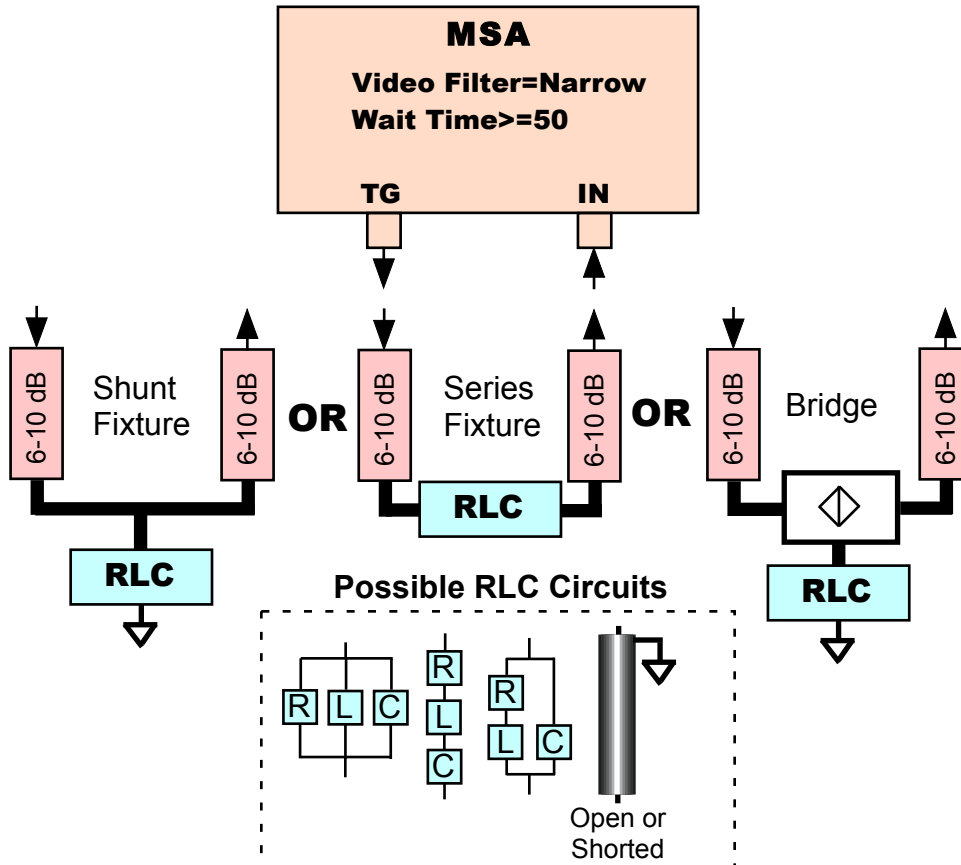


1. Perform a transmission (S21) scan showing the resonant frequency, and the -3 dB point above or below that frequency, or both -3 dB points. For a resonant peak, the -3dB points are 3 dB below the peak. For a resonant dip, they are at the absolute -3 dB level.
2. Select Function-->RLC Analysis.
3. Select the fixture type being used, and enter its R0, which is the resistance seen by the DUT looking into each attenuator. For the Shunt Fixture, you may enter the connector delay, in ns. 0.115 ns is typical for an SMA connector.
4. Select the Series or Parallel model to be used. For an explicit LC combination, enter whatever its configuration is; the parasitic R will be considered to have the same arrangement. For a single L or C component with parasitics, enter Series for capacitors and Parallel for inductors.
5. Click Analyze; the results will be displayed. You may then click +Freq or -Freq to change the frequency for which results are displayed.

RLC Analysis Function

VNA Reflection Mode

Models a circuit as a combination of a resistor, inductor and capacitor, which may be actual components or parasitics. Calculates the values of those components, and Q factors, and also creates graphs of those values which can be viewed after exiting the function.



1. Perform an S11 scan showing the frequency range of interest. Accuracy is best if the resonant frequency is included, but that is not required.

2. Open Function-->RLC Analysis. Select the Series, Parallel, or Lossy RLC model that best fits your circuit. Specify the number of points to be used in analyzing each frequency, typically 5-15.

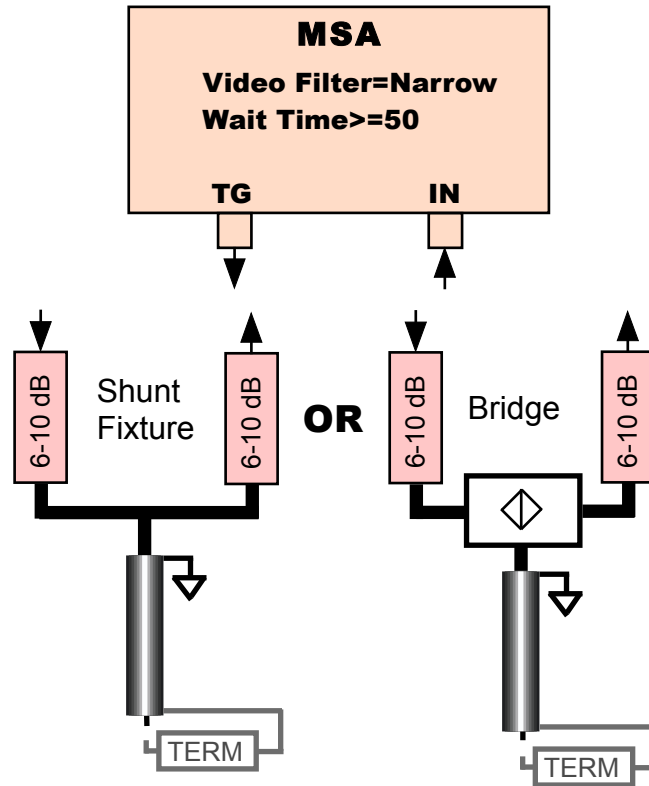
3. Click Analyze, which will display the R, L and C values, and the Q, all at a specified frequency. You may temporarily move to a different frequency by clicking +Freq or -Freq.

4. The graphs automatically change to LC--Series L and LC--Series C for the series model and LC--Parallel L and LC--Parallel C for the other models. When you quit the Function, you may also select to graph the Series Q or Parallel Q, as appropriate. These graphs will be available until Restart.

Coax Parameters Function

VNA Reflection Mode

Measures length or velocity factor, plus loss factor(A0, dB per hundred feet) and characteristic impedance (Z0).



1. Perform an S11 scan of an open coax stub, focused around the quarter-wavelength resonance (near +/-180 degrees S11 phase).
2. Open Function-->Coax Analysis.
3. Enter either the length or velocity factor of the coax stub.
4. Click Analyze. The resonant frequency, length, velocity factor and loss factor (A0, dB per hundred feet) are displayed, and the Analyze Z0 button appears.
5. To measure Z0, attach a terminating resistor to the stub, click Analyze Z0, and enter the value of the termination in the dialog that opens. When you click OK a scan will be performed and the results will be displayed. For best accuracy, the value of the terminating resistor should be in the ballpark of what you expect Z0 to be, but you may choose to use no termination at all, in which case you should enter 1 mega-ohm or larger as the termination value. (Z0 will be displayed as a complex number, but only the real part is generally used to identify coax cable.)

Generate S21

VNA Reflection Mode

For certain types of DUTs, which we call “two-terminal DUTS”, the transmission characteristics (S21) of the DUT can be calculated from the reflection characteristics (S11). Two-terminal DUTs include devices with exactly two connections, such as resistors, capacitors and inductors, or series or parallel combinations of those devices. They also include devices that have one connection plus a permanent or implicit ground, such as a wire antenna. Two-terminal DUTs are effectively nothing but an impedance, and we can hypothetically place that impedance in a series or shunt fixture, and calculate the S21 of the device in that fixture.

To generate S21 values,

1. After proper calibration, do an S11 scan of the DUT. Note that one terminal is always grounded in S11 scans.
2. Open Functions->Generate S21. A window will open allowing you to specify the type (Series or Shunt) of fixture, and the R0 of the fixture. After specifying those options, click Generate.
3. The window will close and the generated S21 values will be graphed. As for all Function graphs, these are temporary graphs created by the function, which are listed as graph options in the Y-axis windows until the next Restart.
4. If desired, you may re-open Generate S21 to modify the selected fixture or R0. It is not necessary for the original S11 values to actually be graphed for Generate S21 to work.

LC Example

If a reflection scan is performed with a parallel or series LC combination, the resulting S11 values can be used to generate S21 graphs that show how the LC combination would perform as a filter. The R0 used for the series fixture can be the actual source/load values of the filter’s intended environment. Or, by using a very high R0 value, such as 100 kOhms, the S21 graphs will effectively show the profile of the response of the LC combination with no load (though the absolute level of the entire response profile will be shifted downward). In the latter case, Q can be determined by dividing the center frequency by the -3 dB bandwidth, and that Q value is effectively the unloaded Q (Qu).

Coax Z0

There are several ways on the MSA to measure characteristic impedance (Z_0) of transmission Lines.

Method 1 (Manual Method)

Perform a reflection mode scan of an open stub, and look for the first valley of low impedance. Place a marker on the point of zero reactance. That will be the quarter-wavelength resonance. If your scan is very broad, narrow to a few MHz around the marker. Add a termination resistor to the end of the cable; anything in the range 50-100 ohms is fine. Scan again and note the series resistance at the resonance point. (If the marker at the resonance point is the selected marker, the resistance will be shown on the bottom of the Smith Chart.) You can then calculate the real part of the characteristic impedance by the formula

$$Z_0 = \text{Sqrt}(Z_t * Z_{in}), \text{ where } Z_t \text{ is the termination resistance, and } Z_{in} \text{ is the coax input resistance measured by the MSA.}$$

Method 2 (Coax Parameters Function)

See section on [Coax Parameters Function](#).

Method 3 (Infinite Length Method)

If you measured the impedance of an infinite length of coax, the result would be the characteristic impedance, no matter what the termination of the coax. If you have a significant length (more than 25 feet for modestly lossy cable, more than 100 feet for low loss cable), you can terminate it with a resistor approximating the characteristic impedance and measure at a high frequency (say, 200 MHz). The measured resistance will be very close to the characteristic impedance. (At high frequencies the imaginary part is likely to be small, so we ignore it here.) If the measured value is not flat over frequency, look at the Smith chart, where there will be a circle around the characteristic impedance. (You may need to maximize the Smith chart window to get a good view). If necessary, you can change the Graph Z_0 in the Sweep Parameters window to change the center of the Smith Chart to the value that appears to be circled.

Method 4 (Simulation Method)

You can simulate a coax cable of a known type by opening the Sweep Parameters window and selecting Data Type 5 (Simulated RLC/Coax). Specify a resistance equal to something close to the nominal Z_0 of the coax. Deselect the inductance and capacitance. Select the coax type, or select Custom and enter your own parameters. Enter a length of 50 k feet and a resistance of 50 ohms. Select the desired frequency range; in order for the actual Z_0 to differ much from the nominal Z_0 , the frequency must be below about 20 MHz. Close the window and click Restart. The graphed data will simulate the coax terminated by the specified resistance. The long length is effectively infinite, so the measured input impedance of the cable will in fact be the characteristic impedance, Z_0 . You can graph Series Resistance and Series Reactance to see the real and imaginary parts, or simply place a marker on the graph and look at the information displayed at the bottom of the Smith chart for that marker.

Reference Lines

Reference lines can be created in any mode. They may either be displayed on the graph, or combined with the graph data by addition or subtraction. They are accessed through the menu Options->Reference Lines. That menu item opens a window that allows you to specify the reference line type, which axes will have reference lines, and the color and width of the reference lines (if they are to be drawn). A reference line may be created for each axis, but if two are created they must both be of the same type. The reference line types are described below.

Fixed Value References

Fixed value references are created by selecting that type and entering the value for the appropriate axis. For example, if a value of -18 is specified, a horizontal line will be drawn at -18 on the selected axis, provided that the Graph Option "Data and Ref" is selected. That option means to graph both the data and the reference. Instead, you may perform subtraction or addition with the reference line, by selecting the appropriate Graph Option. For example, if you have a transmission mode graph with a peak value of -18 dB, and create a reference of -18, setting Graph Option to Data-Ref, the reference will be subtracted from the data so the peak will appear at 0 dB, and all other graph values will effectively be dBc relative to that peak.

Saved Data References

You may save the current data as a reference. This allows you to compare the current data to future scans, either visually or by subtracting one from the other. If you re-open the Reference Line window when you already have a data reference, and you keep that reference type, then when you close the window you will have the option to update to the current data, or to retain the old data. For example, if you just want to change the line color, you will want to retain the old data when closing the window. When data is saved, it is the underlying dBm value (SA mode) or dB/angle values (SNA/VNA modes) that is saved. But the saved data is converted to the current graph data before being used. For example, if a reflection mode graph shows capacitance, the saved S11 data is converted to capacitance before being graphed or added/subtracted.

RLC References

You can create a reference line from simulated RLC data, just as though the current scan contained that data. "RLC data" is a parallel or series RLC combination, that optionally can be treated as terminating a transmission line. This is useful if you want to compare graph data to some RLC combination, to see how well the DUT can be modeled by that combination.

Reference lines are temporary objects, in that they are created for short-term use. They are not saved when you save Preferences or Test Setups. If you change the frequency range settings, any Saved Data Reference will disappear, but Fixed Value or RLC References will survive.

RETURN LOSS REFERENCE

RETURN LOSS AND RELATED QUANTITIES

| Return Loss | Reflect Co. Mag. | SWR | % Power Reflected | R>50 ohms | R<50 ohms |
|-------------|------------------|-------|-------------------|-----------|-----------|
| 0 | 1.00 | INF | 100.0 | INF | 0.0 |
| 0.25 | 0.97 | 69.5 | 94.4 | 3475 | 0.7 |
| 0.5 | 0.94 | 34.8 | 89.1 | 1738 | 1.4 |
| 1 | 0.89 | 17.4 | 79.4 | 870 | 2.9 |
| 2 | 0.79 | 8.7 | 63.1 | 436 | 5.7 |
| 3 | 0.71 | 5.8 | 50.1 | 292 | 8.5 |
| 4 | 0.63 | 4.4 | 39.8 | 221 | 11.3 |
| 5 | 0.56 | 3.6 | 31.6 | 178 | 14.0 |
| 6 | 0.50 | 3.0 | 25.1 | 150 | 16.6 |
| 7 | 0.45 | 2.6 | 20.0 | 131 | 19.1 |
| 8 | 0.40 | 2.3 | 15.8 | 116 | 21.5 |
| 9 | 0.35 | 2.1 | 12.6 | 105 | 23.8 |
| 10 | 0.32 | 1.9 | 10.0 | 96.2 | 26.0 |
| 15 | 0.18 | 1.4 | 3.2 | 71.6 | 34.9 |
| 20 | 0.10 | 1.2 | 1.00 | 61.1 | 40.9 |
| 25 | 0.056 | 1.12 | 0.32 | 56.0 | 44.7 |
| 30 | 0.032 | 1.07 | 0.10 | 53.3 | 46.9 |
| 35 | 0.018 | 1.04 | 0.03 | 51.8 | 48.3 |
| 40 | 0.010 | 1.02 | 0.01 | 51.0 | 49.0 |
| 50 | 0.003 | 1.01 | 0.001 | 50.3 | 49.7 |
| 60 | 0.0010 | 1.002 | 0.0001 | 50.1 | 49.9 |
| 70 | 0.0003 | 1.001 | 0.00001 | 50.03 | 49.97 |

Return Loss is the negative of S11 magnitude, in dB. The reflection coefficient magnitude is the S11 magnitude expressed as a ratio from 0 to 1, representing the proportion of the signal voltage that is reflected. The square of that ratio gives the reflected power ratio, expressed above as a percentage.

Each value of Return Loss can be generated by two pure resistances, one greater than 50 ohms and one less than 50 ohms. Those resistances equal $50 \cdot \text{SWR}$ and $50/\text{SWR}$. That Return Loss can also be generated by any resistance in-between those two values combined with the necessary capacitance or inductance.

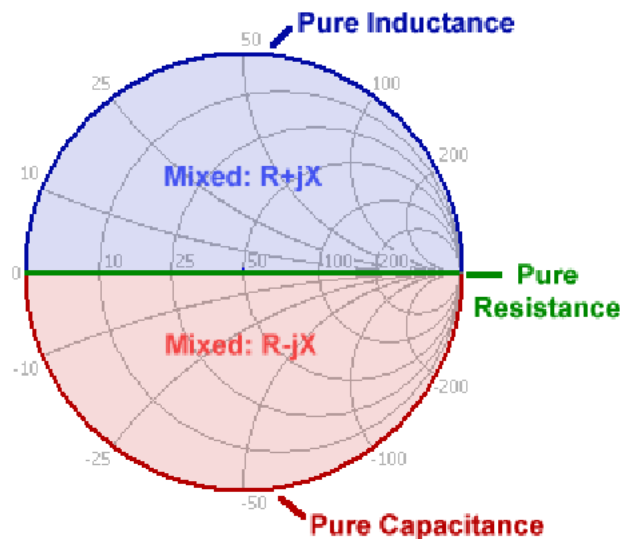
THE SMITH CHART-PART 1

The Smith Chart is used to graph reflection coefficients, and to relate them to impedances. The MSA automatically creates a Smith Chart in Reflection Mode. At the end of each sweep it draws the measured reflection coefficients on the Smith Chart.

Reflections coefficients are graphed by starting at the center of the chart (marked 50) and moving outward a distance equal to the reflection coefficient magnitude, in the direction indicated by the reflection coefficient angle. The chart is considered to have radius=1. Zero phase is toward the right of the chart, and positive angles are measured counter-clockwise from that zero line.

The impedance at any point on the chart can be read from the grid lines. The circles represent constant resistance (marked on the center line) and the arcs represent constant reactance (marked at the boundary). The impedance at a point is based on the resistance circle and reactance arc that cross at that point.

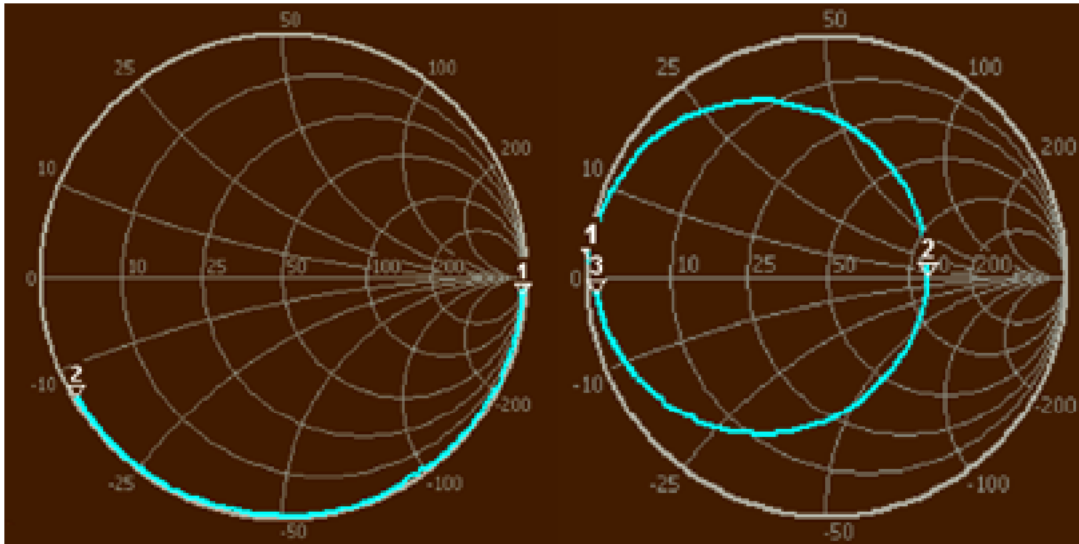
The chart can be divided into regions as shown below:



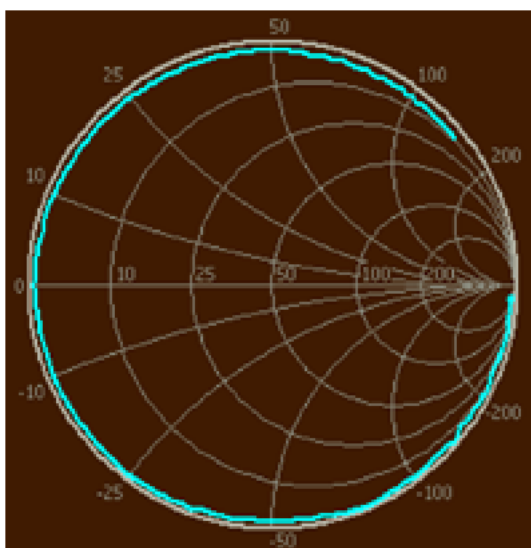
Thus, the nature of a device can be quickly judged based on where its reflection coefficient is graphed. Anything with a capacitive component is in the bottom half; inductive components are in the top half, and pure resistances are on the horizontal center line.

THE SMITH CHART-PART 2

The Smith Chart is particularly useful for viewing graphs that follow a circular path. All Smith Chart graphs proceed in a generally clockwise direction as the frequency increases, but the most interesting ones actually trace out partial or complete circles. Below are such graphs:



The left graph is a capacitor, and therefore lies entirely on the lower boundary, starting at high impedance at marker 1 and moving to marker 2 as the frequency increases. The right graph is a parallel coil and capacitor, which begins as an inductance at marker 1 and moves clockwise, falling away from the boundary due to inductor losses. At marker 2 it reaches resonance (because it is crossing the center line of pure resistances), after which it becomes capacitive and moves on to marker 3.



An unterminated coax cable starts in the capacitive zone near the boundary, and moves clockwise as the increasing phase delay at higher frequencies makes the phase more negative. It eventually crosses the center line of pure resistance, which is its quarter-wavelength resonance. The impedance at that point is nearly zero. It continues around the top of the chart. Here the graph stops shortly before it would have reached the half-wavelength resonance at the right side of the chart.