16 Frequency Response Analyser [View Menu]

The Cleverscope Frequency Analyser (FRA) is a tool set you can use to measure Power Supply performance (Gain/Phase response, Input and Output impedance and Power Supply Rejection Ratio) and the impedance and phase of Power input filters, feedback networks, transformers, PCB power planes, capacitors, resistors and inductors. It can be used for both narrow band swept frequency measurements, and wideband single shot spectral measurements. Values can be displayed in ohms, Farads, Henry's and degrees or radians.

Measuring the performance of switched mode power supplies using traditional methods is difficult because of the switching noise generated by the supply. The FRA uses narrow band frequency domain measurements to synchronously measure the signal generator stimulus and response without being affected by the switching noise. This makes possible the use of low amplitude stimulus signals which do not interfere with the normal working of the power supply - the supply can be measured loaded, and in use.

The FRA is equally useful for measuring the impedance and phase of components such as capacitors, inductors, PCB power planes, transformers, filters and resistors. The gain/phase function can be used to measure the response of networks such as filters, amplifiers, transformers, and mechanical systems.

The FRA is based on a standard CS320A/CS328A oscilloscope, with a CS701 isolated sig generator plugged in.. The CS701 has 300V Class II reinforced isolation, a capacitance of 16 pF to ground when mounted in the CS328A, and negligible series inductance. The CS701 has a frequency range of 0 - 65 MHz, and includes DC offset. For Power Supply work an isolation transformer is not required. The isolation transformer has a more limited frequency range, and introduces higher parasitic capacitance and inductance. The CS701 can be used for Gain/Phase, and low current PSRR measurements. It can be safely used on Mains power supplies up to 230 VAC.

To measure high current PSRR, or find the Input or Output Impedance and phase of live power supplies you will also need the CS1070 power amplifier. It has a 1A capability from -18 to +36V, with a frequency range of 0 - 52 MHz. It can be operated isolated, with care!

You can use the existing CS700A for FRA work, but it is not isolated and so cannot be used for PSU Gain/Phase, and has a more limited frequency range of 0 - 10 MHz.

The FRA is useful for measuring the performance of Power Factor Correction controllers (0.1- 2 Hz), switched mode PWM power controllers (10 - 500kHz), effects of line frequency and harmonics (50 - 10 kHz), PWM Switching Frequency analysis (100k - 2 MHz), EMC (300k - 100 MHz), and LC/Transformer and filter resonances on the power supply voltage rail.

This frequency range is also useful for characterizing anything from power supply bulk capacitors (0.1 - 1000 Hz), to small pF capacitors, nH inductors and ferrite beads at up to 65 MHz.

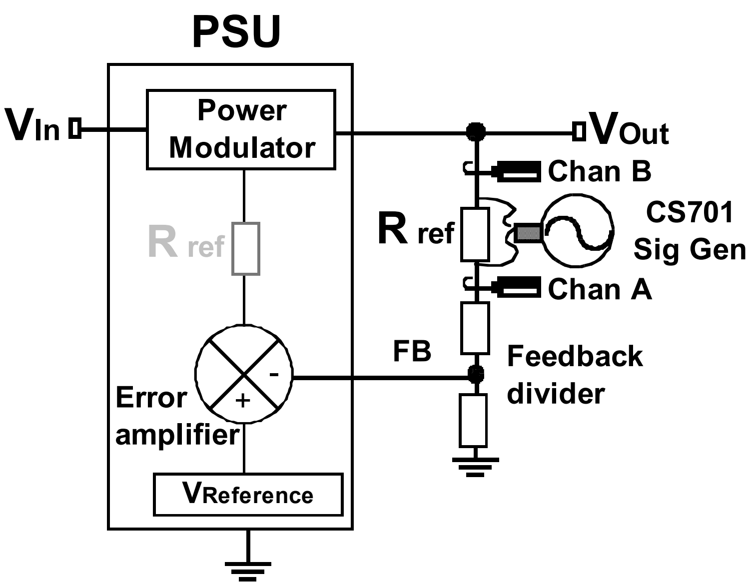
The +/- 24V DC offset capability of the input to the CS328A means you can measure the response down to DC in power supplies of up to +/-24V. For higher voltage power supplies use AC coupling (with a lower frequency limit of 5Hz (1x probe) or 0.5 Hz (10x probe), or use a CS1030 Differential Probe.

The FRA Control Panel makes it easy to set up everything in one place - you don't need to know how to use the rest of the Cleverscope system. On the panel are controls for you to measure Power Supply parameters such as Gain/Phase, Input and Output Inductance and PSRR, as well as the Capacitance, Inductance, Effective Series Resistance, Dissipation Factor and the Quality Factor of components. Using the FRA Control Panel you can fully evaluate a transformer's transfer response, the primary and secondary inductances, the leakage inductance and inter-winding capacitance, overall frequency behaviour. Using DC offset you can check saturation and DC sensitivity. You don't need to buy an expensive Network Analyser because the Cleverscope FRA does all this for you over a 0-65Mhz frequency range! The Scope Display is useful in being able to see the signal, and check that you are not over-driving a power supply under test.

16.1 Use of the FRA with Power Supplies

One of the most important uses of the FRA is for measuring the gain/phase response of a Power Supply. The response is used to establish stability and bandwidth.

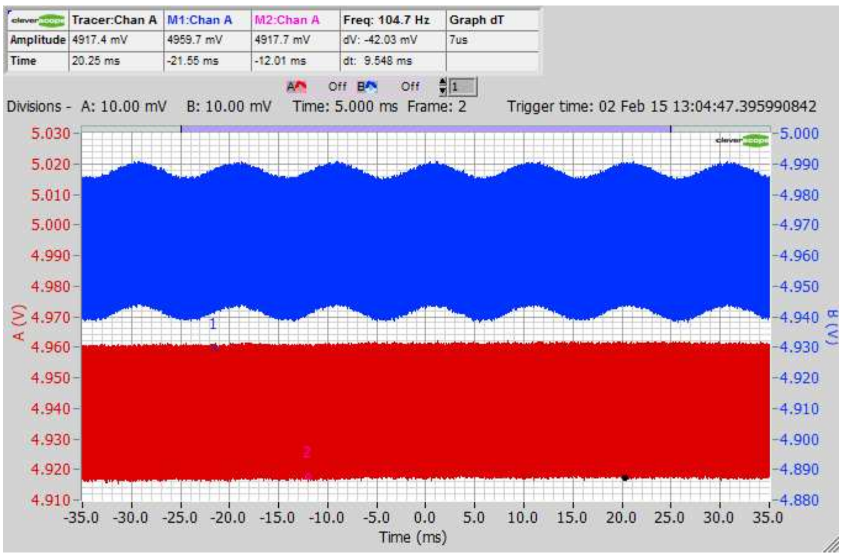
A generic power supply has this form:



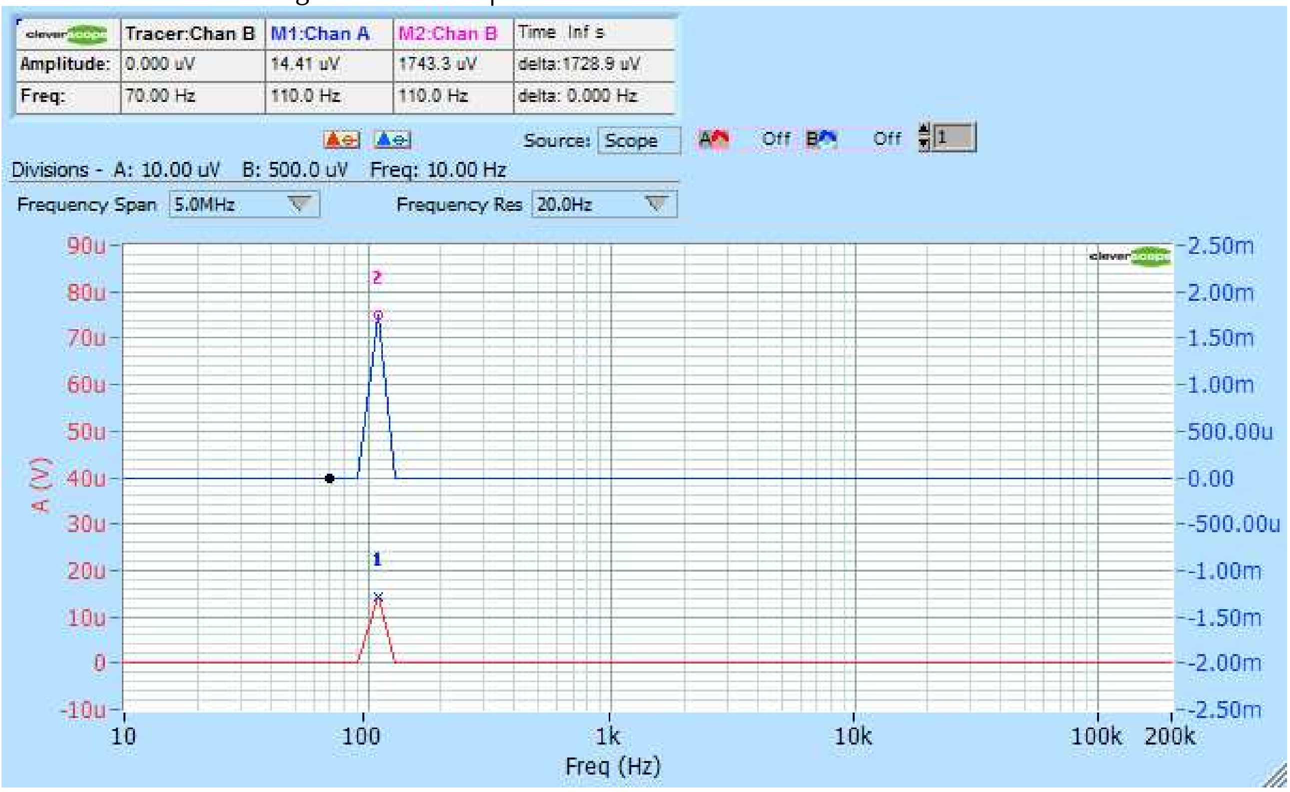
The FRA injects a signal into the feedback path that simulates perturbing V_{out}. This can be done either in the feedback chain, as shown, or after the error amplifier (as shown, greyed).

Key points are:

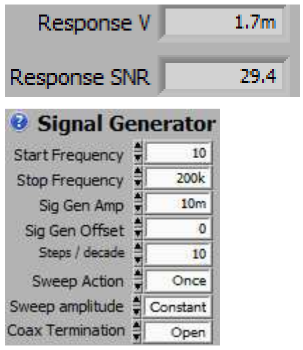
- An isolated, low capacitance to ground signal source is required. The isolated CS701 is suitable. It is superior to injection transformers as it has performance to DC, and has much lower ground capacitance and series inductance, which act as parasitic elements.
- The injection point is characterised by a low source impedance (and hence a virtual AC earth) looking into a high impedance destination. Vout is very low impedance, while the feedback input is high impedance. This also applies to the error amplifier, and so they are suitable injection points.
- A small value series resistor (20 - 50 Ohm) is used to inject a signal which adds to the feedback signal. The error amplifier sees this added signal and attempts to null it out.
- The Signal Generator injected signal appears as a **stimulus** signal to the input of the feedback chain. This stimulus is measured by Channel A.
- The **response** signal is measured by Channel B, and is the output of the Power Modulator.
- The signal frequency is swept over the desired frequency range, while Channels A and B measure the stimulus signals synchronous with this frequency. The measurement bandwidth is quite narrow (between 0.1 Hz and 1KHz maximum) which reduces the in-band switching noise to achieve a useful signal to noise ratio. This means the FRA can measure the response to the signal frequency **independent** of any other corrections the error amplifier is making. Using this method, we can measure the gain/phase response of the Power Supply Unit. To illustrate this here is a Switch mode power supply exhibiting 50 mV of p-p switch noise. Channel A is the stimulus and Channel B the response (and output of the power supply). In this example the Signal Generator was set to 10 mV p-p.



- This results in the following Narrow Band Spectrum:

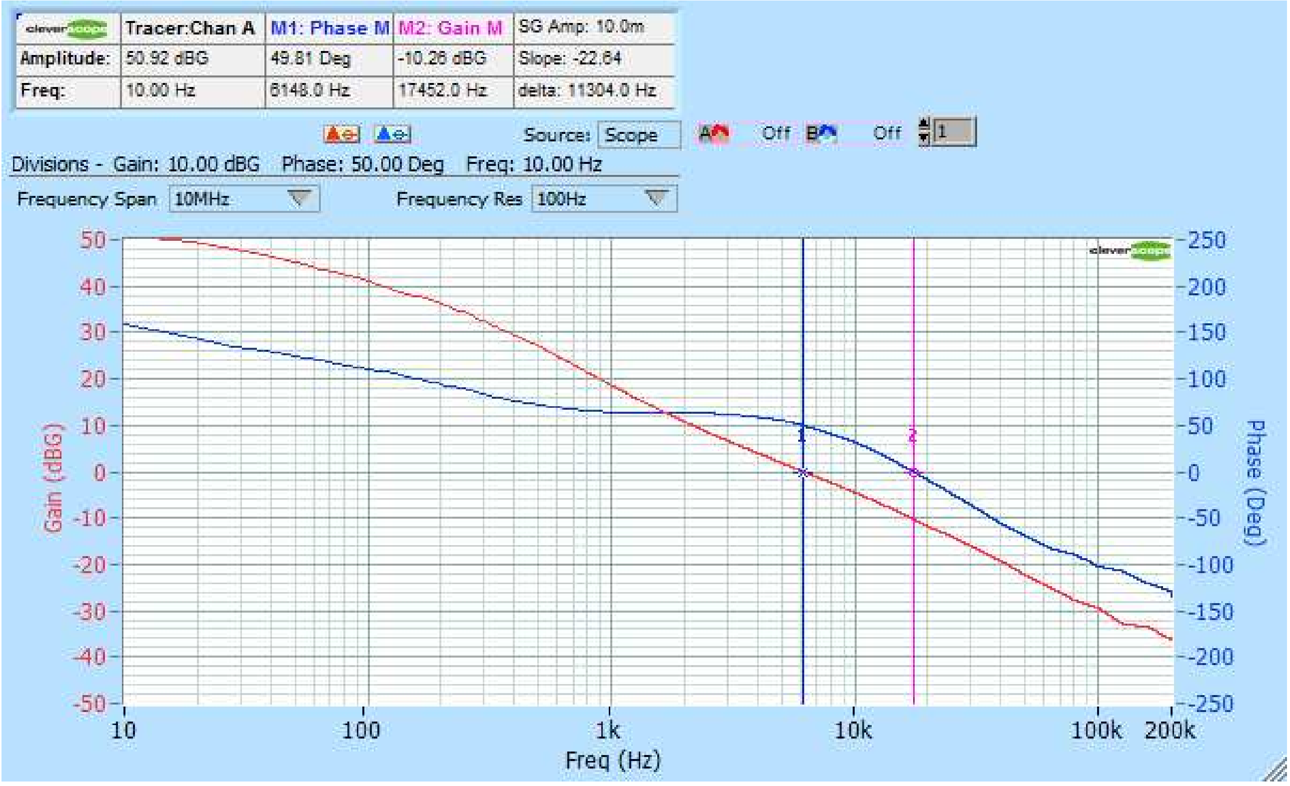


The stimulus (Chan A) has been reduced by the effects of the error amplifier to just 14.4 uV rms. The response, which is the output of the power supply, has an amplitude of 1743 uV rms. The gain of the loop is thus 1743/14.4 = 121 or 41.7 dB at 110 Hz. Both signals are much smaller in amplitude than the p-p switching noise, and so cannot be seen using a time-domain oscilloscope. Because the response amounts to only 1.7 mV rms, the power supply can be measured in operation without problems. The Information panel displays the Response Amplitude as 1.7 mV rms, and the Signal to Noise Ratio (SNR) as 29.4. The SNR is an important measure of signal quality. A value >3 means that you can trust the results you are seeing. If the SNR is too small, you should decrease bandwidth (20 Hz in this example), or increase the stimulus (10mV p-p in this example).



- Channels A and B are DC coupled so we can measure the response from DC up to the maximum signal generator frequency of 65 MHz. They include the ability to DC offset to maintain dynamic range. So you can for example measure a 100mV range centred on 24V DC.
- Channels A and B have high dynamic range. An ADC is used which has sufficiently low differential non-linearity to achieve 14 bits resolution. This is combined with dither to achieve more than 100 dB of dynamic range (10uV in 1V FSD) when taking into account the FFT narrow band process gain.
- The gain of the error amplifier serves to reduce the amplitude of the stimulus signal. An amplifier gain of 60 dB will reduce the stimulus signal 60 dB below the signal generator level. To counter-act this attenuation, the signal generator amplitude can be programmatically varied in the range 1 mV p-p to 6V p-p (and 40V p-p using the CS1070), a dynamic range of >70 dB. When using the 'Auto' or 'Table' method of sweep amplitude control, we can vary the amplitude of the signal generator with frequency to counter the error amplifier gain and maximize signal to noise ratio. This means we have a total dynamic range of about 170 dB available as a combination of signal resolution and signal generator amplitude.
- Error amplifiers have gain that is high at low frequencies, and reduces as the frequency increases. The goal of the power supply designer is to achieve a stable system with minimum ringing in response to a load step. This is best achieved by having a positive phase margin, ideally in the range 50 - 60 degree as the system gain goes through 0 dB (unity gain). As the phase margin reduces to 0 (and the phase lag through the system is 180 degrees), the power supply output becomes more oscillatory. At 0 deg margin, the power supply will oscillate continuously. Analysis of the circuit above shows that we can measure

Response/Stimulus as a complex division to yield gain and phase. Here is an example response:



- You can find the Gain and Phase margins by clicking on the FR 0dB button. This will automatically position the vertical markers, and place the gain and phase margins, and the frequency at wheich they occur in the Marker information area. In this example the Phase margin is 49.8 degrees at 6148 Hz where the gain becomes unity. The Gain Margin of -10.2 dB where the phase margin becomes 0 is a measure of how tolerant the design is to variation due to components, voltage, temperature and load.

  This power supply has high gain (>50 dB) below about 20 Hz. It is here that we need a large signal generator amplitude (the stimulus) to ensure a measureable response. The power supply output impedance is proportional to gain. At high gains, the effective output impedance is low, and perturbations in load current will not cause large changes in output voltage. As the frequency increases, gain reduces, and effective output impedance increases. At some point, typically for a gain of less than 20 dB, the effective output impedance becomes so high that the power supply does not source the load current without significant output voltage variation. At this frequency we need an alternative current source - such as output capacitors, to supply the load.

The gain/phase, or Bode plot, is useful to measure these factors:

- Stability of the power supply (50 - 60 deg Phase Margin is ideal).
- The susceptibility of the design to component, voltage or temperature change (Gain Margin). 10 dB is minimum, 20 dB is good.
- The frequency at which an alternate current source is required - 900 Hz in this case. This frequency allows us to calculate the size of the output capacitors (from $Z = 1/\omega C$), based on the desired output impedance. We calculate based on the ripple voltage we allow. $V_{ripple} = Z\ I_{load}$, at the frequency of interest. For some devices such as FPGA's which have a multitude of switching elements it is important to have low impedance over a very wide frequency range (0 - 30 MHz is typical), while for audio amplifiers a much reduced range of 0 - 20 kHz maybe all that is required. Choosing a higher bandwidth power supply unit will reduce the cost and size of the output capacitors needed to maintain a low output impedance.

16.2 Getting Started with the FRA

It can be a bit daunting to know where to start, so here are some suggestions. There are worked examples at the end of this chapter.

If you want to plot the spectral response to a stimulus signal sweeping in frequency then you are in the right place! If you just want to display the spectrum of a signal, then you do not need this panel. For displaying just a spectrum without swept frequency response you should turn off **Use Swept Narrow Band**, and close the FRA Control Panel. The Sig Gen Control Panel is easier to use in this situation.

We suggest you open the Spectrum Display, Scope Display, as well as FRA Control Panel using the View menu. Arrange them so you can see them all at the same time. Choose *View/Displays are docked* on the Cleverscope Control Panel, and then you can move or minimize the whole group around by moving/minimizing the Cleverscope Control Panel.

Close the Sig Gen Control panel, there is no need for it.

There is an individual help button on most panels that explain that panel in more detail.

If you want to save an FRA capture points only file, see the end of this description.

If you do want a swept response, for most situations you want these LEDs turned on:

- **Use Swept Narrow Band** - ON - the FRA builds up a picture of the response by sweeping the signal generator over a range of frequencies, and records and plots the response at only that frequency.
- **Interpolate plot** - ON - means all the sample points are joined up.
- **Auto Setup** - ON - gives you a first estimate of the amplitude range. If the signals on the Scope Display are being clipped, or are tiny, you can turn this off, and manually adjust the scope display.

Ok, now you will need to set the frequency range, and Sig Gen Amplitude. If you are using a passive system, a **Sig Gen Amp** of 2V is a good start. If you are working with a Power Supply Unit (PSU) then these are our suggestions:

- **PSU Gain/Phase** - set the **Sig Gen Amp** to 10 mV, and the **Sweep Amplitude** to *Auto*. Set the **Auto Amp Limit** to half the power supply voltage or 6V, whichever is lower.
- **PSU PSRR**, **Input Impedance or Output Impedance** - set the **Sig Gen Amp** to 1V, and **Sweep Amplitude** to *Constant*.

Now to start a sweep click **Start Sweep**. There is no need to click any other buttons such as the Acquire buttons, or Averaging, or work with the Sig Gen Control panel.

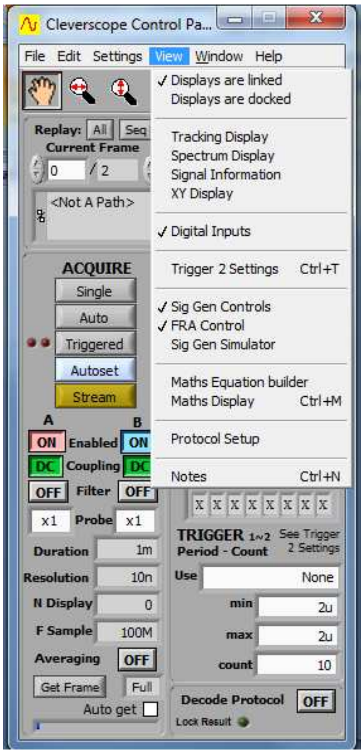
If you have Auto Setup turned on, then at completion of the sweep, the amplitude axis will be auto fitted. Once things are approximately right, you can turn Auto Setup off, and tweak things manually.

Saving FRA files

FRA sequences automatically get converted into very long linear arrays for display. However, if you are after just the data points, you can save them as a text file. After having done an FRA response, make sure the **Spectrum Display** was selected (the Control Panel shows DISPLAY: Spectrum), and then use **File/Save as Text**.. and only the swept data points will be saved to the text file. In addition you can use the **File/File Options/Save Options** to choose **'Save using Fast Save Button'** and the **Fast Save button** will appear top right of the Cleverscope Control Panel, and you can save just by clicking the button.

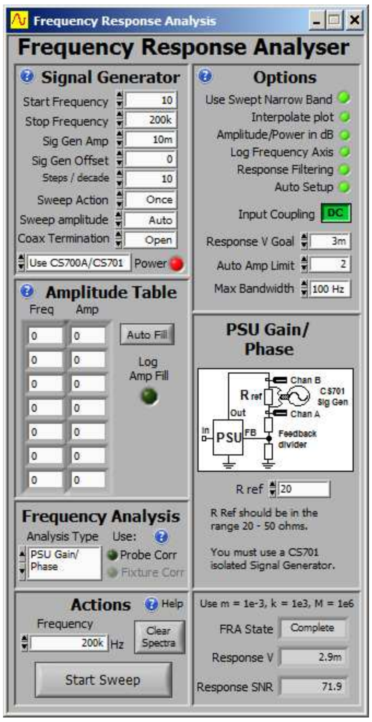
See http://www.cleverscope.com/videos/ for videos on how to do all this.

16.3 Frequency Response Analyser Control Window



The Cleverscope FRA Control Panel is accessed from the **View** menu.

Click on the View menu at the top of the Cleverscope Control Panel and select the "FRA Control" option.

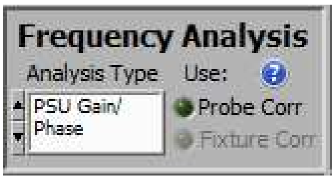


The Cleverscope Frequency Response Analyser Control Panel has 7 panels to make it straightforward to set up the required test conditions.

These are detailed below. The Frequency Analysis panel chooses the type of analysis to be done. The Actions panel is used to start a sweep. The Signal Generator panel defines the signal generator chracteristics. The Options panel sets overall capture and display options.

The connections panel shows you how to connect up the FRA, and includes analysis specific values.

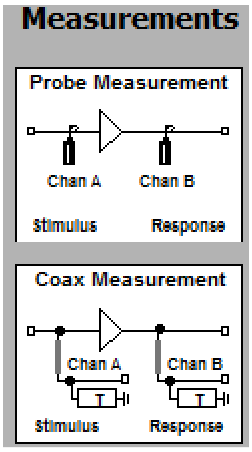
16.3.1 Frequency Analysis



To see help click on .

Frequency Analysis
Click on the Analysis type control to choose the analysis type. Each type displays versus frequency. A connection diagram is given in the right hand panel:

16.3.1.1 Measurements Group



Measurement Group
These types are used for making standard wideband, or swept frequency narrow band measurements (if **Use Swept Narrow Band** is on**)**.

- **RMS amplitude** - RMS amplitude (in dBV or Volts)
- **Power** - signal power (in dBm or Watts)
- **Power density**- signal power density (in dBm/Hz or Watts/Hz)

- **Gain/Phase** - Gain (in dB or G) on Channel A, and Phase (in degrees or rads) on Chan B. Gain/Phase is best done Narrow Band.

To display in dB turn on the **Amplitude/Power in dB** Led in the Options panel, for linear units turn the Led off.

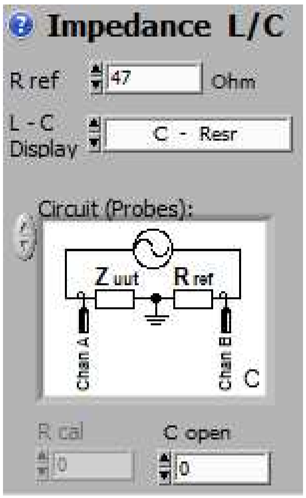
16.3.1.2 Impedance L/C Group

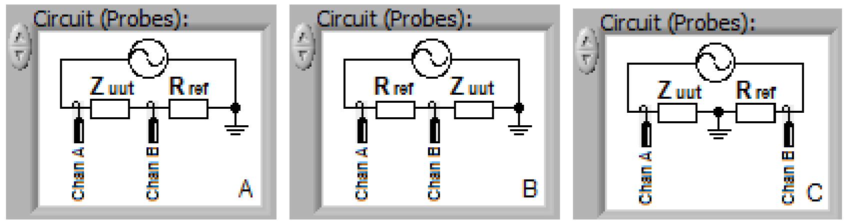
Using Probes:
(Coax Termination = Open)

Impedance L/C Group

- **Impedance/Phase** - lZl in ohms or dBOhm on Chan A, and Phase (in degrees or rads) on Chan B. Uses the Circuit as selected (A, B or C) for the measurement setup.
- **Capacitance/Inductance** -the values chosen by the L-C Display control, uses the Circuit as selected (A, B or C) for the measurement setup.

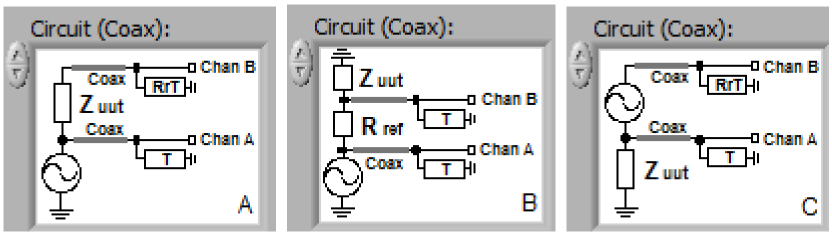
Use this panel to measure impedance, capacitance and inductance vs frequency. Three measurement setups are supported labelled A-C in the **Circuit** control. In addition you use this panel when doing Fixture Calibration. These are the setups:



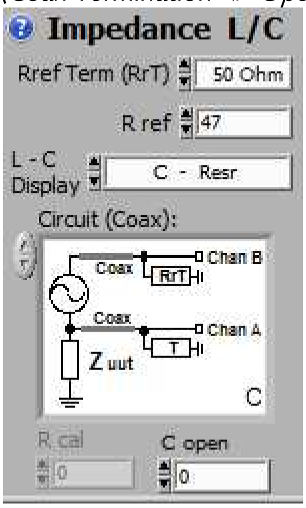


Controls are:

- **R ref** - which sets the reference resistor when using probes. A good starting value is 50 ohm - to match the sig gen impedance. For low esr, or large (>10uF) Capacitors use 10 ohms. Same for low value Inductors (<10 uH).
- **L -C Display**. Choose Inductance or Capacitance as appropriate. The Channel B axis can plot either Resr (the effective series resistance of the unknown impedance) or Dissipation Factor / Quality Factor. Use Fit after plotting to see the whole amplitude range. Position the tracer on the plot you wish to expand, and then use Ctrl Up/Down to zoom in/out on that tracer position. Use Tab to switch between channels.
- When using Coax, **Circuit** lists three coax connection circuits.



Using Coax
(Coax Termination <> Open)



- **Rref Term (RrT)** - sets the measurement termination resistor value for Circuits A and C if you are using coaxial cables. Coax is best when you are working above 10 MHz. Coax should be terminated for maximum accuracy. 50 ohms is a good value.
- **R ref** - which sets the reference resistor for Circuit B. A good starting value is 50 ohm - to match the sig gen impedance. For low esr, or large (>10uF) Capacitors use 10 ohms. Same for low value Inductors (<10 uH).
- **R Cal** is used as a calibration resistor and replaces **Zuut** when calibrating the jig. See the calibration section below.
- **C Open** is used to compensate for the jig open circuit capacitance. Typical values are 0.5 - 1pF.

Circuit and Measurement Jig Discussion

For low frequency applications (< 10 MHz) you can use the scope probes to directly connect to the device under test. For High Frequency (>10 MHz) we recommend using a 50 ohm terminated coaxial cable connected test system. See the 'Impedance Measurement with FRA' video on www.cleverscope.com/videos.

For high frequency applications, higher impedance, Circuit A yields the best performance. The 50 ohm termination on the BNC coaxial cable acts as the Reference resistor. Set R Ref to 50 ohms. For low impedance (such as ground and power planes) use Circuit C. For **best results** use Probe and Ficture Correction (see *Calibration* section).

The scope probes set to 1x give the best dynamic range, but because of the approx 70pF/1M ohm loading the impedance under test should equate to less than 1/10 of this - for example capacitances > 700 pF or impedance < 2k at 100 kHz or 200 ohm at 1 MHz. When using smaller capacitors, or higher impedances, use the 10x probe setting, which loads about 17 pF/10 M ohm on the unit under test. This reduces dynamic range by 20 dB. You can compensate to some extent by reducing the Max Bandwidth by a 1/10 (eg to 100 Hz). Make sure you do a Probe Calibration before starting out.

In both cases the Probe ground clip inductance ends up limiting the maximum usable frequency to about 10 MHz. After that you need to use a 50 ohm terminated coaxial cable test jig. When using SMT parts we recommend a 3 port BNC test fixture (see Impedance Measurement with FRA video on www.cleverscope.com/videos) which you can build yourself. Cleverscope also have a fixture available on our website.

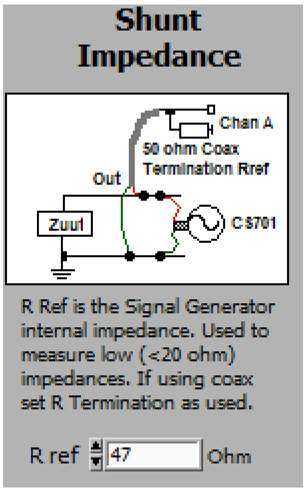
A signal generator level of 2-4V works well, dependant on component rating. For electrolytic capacitors apply a voltage bias by setting the Sig Gen offset to a positive value (eg 0.5V).

If the system is capturing signals, but the spectrum result is 0 for that frequency, the system has determined that the **signal to noise ratio** (SNR) is poor, and the measurement suspect, and therefore not displayed. Improve it by lowering the Bandwidth, or increasing the signal level.

Keep an eye on the Scope Display, and make sure the signal fills at least 10% of the amplitude range at maximum amplitude, but is not larger than the graph range (otherwise clipping and errors will result). When using Auto Sweep amplitude we suggest a Response V goal of 3-10mV for power supplies, and 300mV for everything else. However for linear units under test, a Constant amplitude will result in a faster response. You can use Auto Setup to get a reasonable approximation to the settings you need.

If you are having problems with noise in the plot, decrease the measurement bandwidth. A good starting point is 1kHz, but if too much noise, reduce BW to 100 Hz.

Use CS700A/CS701:

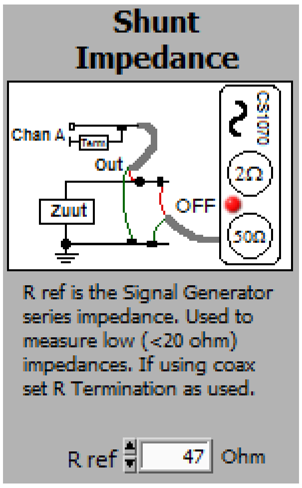


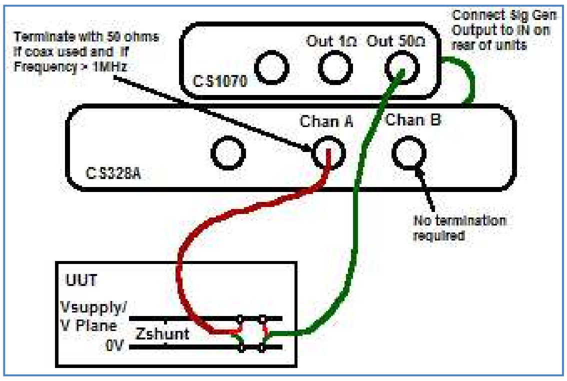
- **Shunt Impedance** - used to measure low impedance (1 mOhm to 20 Ohm) values. Does not require a reference resistor. Use the Circuit as shown - you must use a terminated coaxial cable connection to project a 50 ohm impedance to the board connection. Keep the coax pigtails as short as possible. The CS1070, if available, allows impedance and phase measurement with higher voltages and into powered up circuits with voltages as high as 30V. If using just the CS700A or CS701 a maximum circuit voltage of 3.3V applies. Impedance in Ohms or dBOhms. Good for PCB impedance measurement with powered or unpowered power planes.

For both the CS700A/701 and the CS1070 you must use the 50 ohm output to ensure best matching to the coax at high frequencies. The CS1070 1R output is not suitable due to mismatch.

Use CS1070 50R:

Use the CS1070 to boost the signal generator output voltage. The CS1070 can output a signal over a voltage range of +30 /-18V. To measure shunt impedance on a powered up Unit Under Test (UUT) make sure the CS1070 has power conected, and is disabled (red led on). The CS1070 power supply should be at least 2 volts higher than the UUT voltage. Connect up the system as below (with power turned off to the UUT).





Note that you need to make a 4 point measurement - the Channel A ground and signal lines should be connected close to, but not on the signal generator ground and signal lines. After connecting up the CS328A and CS1070 to the UUT as above, configure the FRA control panel as follows:

- Choose the Use CS1070 50 ohm signal generator option.
- Power Led selected to Red - the CS1070 will be turned on by the application.
- Analysis Type
- Set to Shunt Impedance. Shunt Impedance is used to meaure low impedances from 1 mOhm up to about 20 Ohms. Impedance is plotted.
- Auto Setup
- Set Options/Auto Setup On to ensure that the signal generator offset is correctly set.

Set Sig Gen Amp to give a good SNR, 1V is a suitable starting point. You can use a Sweep Amplitude of Auto, and a Response V Goal of >3mV. Make sure you set the Auto Amp Limit to less than the power supply voltage.

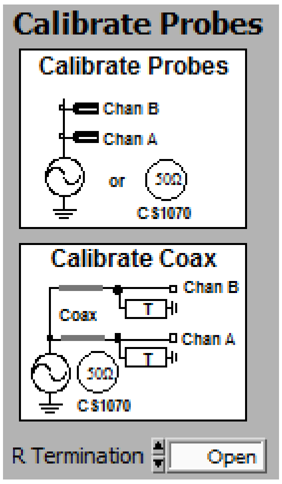
The application automatically turns the CS1070 power on and off (assuming you have the CS1070 link port connected to the CS3288A link port). If needed you can independently control the CS1070 power enable state by clicking on the Power LED 

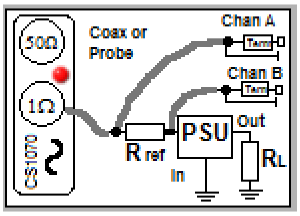
. Green is enabled. Red is disabled.

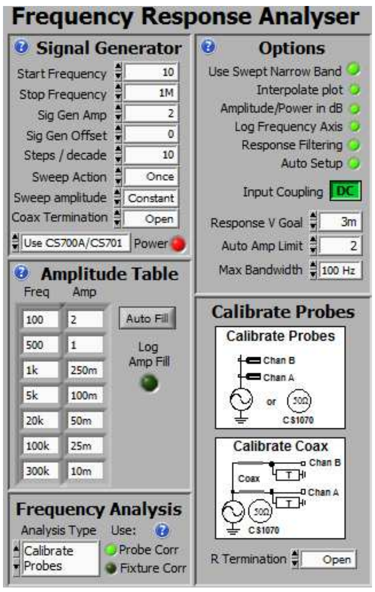
Notes:
If the UUT is powered, the CS1070 output is automatically set to be a sinking load, and the sine wave signal does not go above the UUT power rail. If the UUT is not powered, the CS1070 will output a signal centered on 0V.

The Signal Generator amplitude is specified in V p-p.

16.3.1.3 Calibration







Calibration

- Calibrate Probes
- Calibrate CS1070 1R
- Calibrate Fixture

You can improve the accuracy of the FRA system by calibrating the probes and the fixture and by compensating for the Open Circuit Capacitance of your test system. Calibration results are saved in your setup, and also in any .apc results files. You can save a setup as a .apc file, and when you load the file, you will use the calibration data captured earlier.

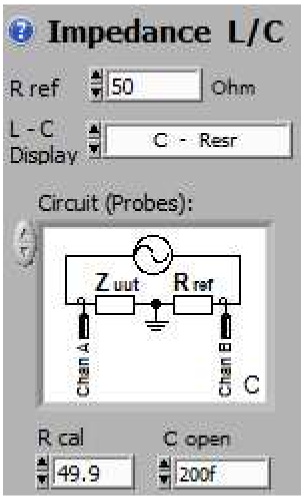
Probe Calibration (Short Circuit calibration) - also applies to CS1070 1R
To correct and calibrate Probe non-linearities connect the Sig Gen output to the Channel A and Channel B probe tips, all together. Have no additional impedance to ground (other than coaxial terminations). Connect all the ground clips together. See the Calibrate Probes diagram.

If you are using a SMT fixture with 50 ohm terminated coax cables use a 0 ohm resistor in the fixture to set Zuut = 0. If you are using a Shunt connected fixture, have nothing connected to the shunt connection. Calibration automatically takes account of the number of termination resistors. If you are calibrating the CS1070 1R, do not connect the PSU.

Select the **Analysis Type** to *Calibrate Probes*. Setup the Start and End Frequency to capture the frequency range you are likely to be using. You will get best results if you choose the same number of steps per decade (or more) as you intend to use. Interpolation is used as necessary. A Sig Gen Amp of 2V, and Scope Graph ranges of +/-1.5V will give good results. Click Start Sweep, and the Probes or Fixture will be calibrated. Probe Correction is applied when the Probe Corr LED control is on. The LED is dimmed when there are no recorded correction values in the .apc file.

A typical probe calibration setup is shown to the left.

Calibrating the Open Circuit Capacitance
This is best done after a Probe Calibration. Setup your test jig as it will be, but do not connect **Zuut**. Set the Analysis type to Capacitance/Inductance, and the L-C Display to C - Resr. Set C Open to 0. Start a sweep, click Fit on the Spectrum Display to show the Capacitance values. You will only be able to measure this above about 10 kHz. Note the value - it is the open circuit capacitance. Enter this value into the C Open field. A value of 1pF is entered as 1p. If you run the sweep again the Capacitance graph should show approximately 0 pF. Next do a fixture calibration for maximum accuracy.



The setup when using probes:

Fixture Calibration (known impedance calibration)
Any test arrangement you use, for example scope probes or an SMT test fixture will have additional parasitic resistance, capacitance and inductance in the fixture and cables. We would like to de-embed these parasitics.

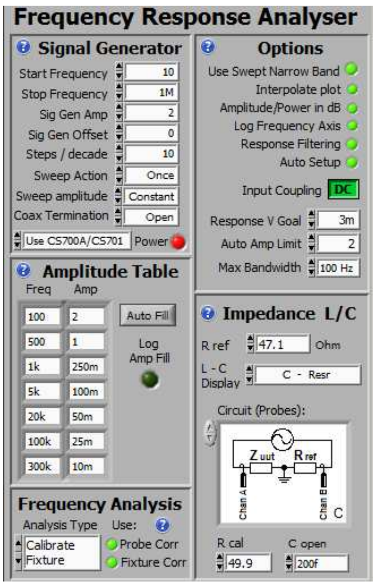
Use the Impedance Setup that you intend to use (Probe or coax, Circuit A, B or C).

R cal replaces Zuut. By knowing Rcal, we can estimate the additional parasitic elements, and compensate for them. Data is recorded in the .apc file, so do a file Save As.. and save the setup for later use.

Select the Analysis Type to **Calibrate Fixture**. Select the Circuit you intend to use. Type in the two known values **R ref** and **R cal**. R cal substitutes for **Zuut**. Ensure the value you use is accurate. You can only use Fixture Correction when the Circuit you used in calibration matches the circuit you are using to test with. R ref and R cal should have low parasitic L and C.

To do the Fixture Calibration:

1. You **must** do a Probe Calibration before doing the Fixture Calibration, and have **Probe Corr** on Probe Corr.
2. Find the Open Circuit Capacitance as explained above and enter it.
3. Set the Analysis Type to **Calibrate Fixture**.
4. Choose the correct measurement circuit. Set up R cal (Zuut) and R ref as shown in the diagram, enter the values. Set the frequency range to be same as used for Calibrate Probes. Use Narrow Band. Setup Scope display to capture signal (+/-1.5V should do it). Set up Sig Gen amplitude (2V should do it).

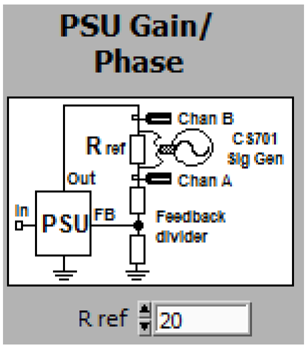


5. Click Start Sweep. The system will measure and display the R ref value including parasitics. Make sure the Probe Corr LED is ON.
6. Do Save As.. and save a file name which reminds you of the fixture and frequency range. This setup will save both the Probe and Fixture calibration values.
7. Now set the Analysis Type back to what you wish to measure, (the Fixture Corr LED will automatically have been turned on) and Start Sweep as normal.

You can turn Fixture Correction on or off with the **Fixture Corr** control LED.

A typical probe based fixture correction is shown to the left. We are using Circuit C. Zuut is replaced with 49.9 ohms (Rcal), R ref is measured with a precision multimeter as 47.1 ohm. The open circuit capacitance was found to be 200fF.

16.3.1.4 PSU Measurement Group



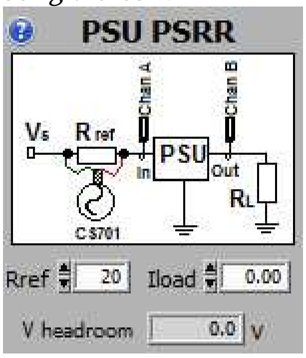
PSU Measurement Group

- **PSU Gain/Phase -** used to measure the Gain/Phase of power supplies, where the signal is injected across a resistor in the feedback path. Can only be used with the CS701 or an isolated CS1070.

  See the examples at the end of this section.

Rref is the value used to inject the signal across, which is in series with the feedback chain. Useful values are 20 - 50 ohms.

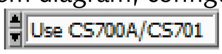
Using the CS701



- **PSU PSRR -** used to measure the Power Supply Rejection Ratio of power supplies. With a CS701 (NOT the CS700A) you inject across a resistor in series with the power supply. With a CS1070, current (<1A) is provided by the CS1070. The PSRR is the ratio of the input voltage perturbation to the output response. It is a positive number expressed in dB. Generally power supplies will have high PSRR at low frequencies dropping off as frequency increases. To measure the PSRR of PSU alone, make sure any input capacitors are the minimum required for stability.

Use the CS701 to measure the PSRR (Power Supply Rejection Ratio) of low current (< 500 mA) regulators. A separate Power Supply sources Vs for the test. The CS701 applies an AC voltage across a series resistor which is sourcing current to the **Unit Under Test (UUT)** from Vs. This requires isolation, and the CS700A **cannot** be used. Connect up the system as shown in the system diagram. **Rref** is the series resistor across which the AC signal is impressed. You need to make sure the separate power source supplying Vs has an output voltage> Vin (psu) + V headroom.

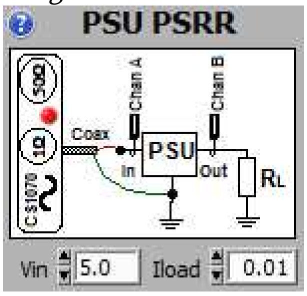
After connecting up the CS328A and CS701 to the UUT as shown in the system diagram, configure the FRA control panel as follows:

- 

  A CS701 is required. A CS700A cannot be used.

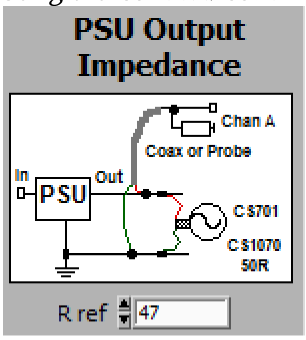
- **Rref**
  The series resistor across which the CS701 signal is applied. It is preferable to connect the BNC shield to the Vs side of Rref. Suitable values for Rref range from 5 ohms to 50 ohms. Make sure the voltage drop across Rref does not exceed 2V. For example with 50 ohms, you can source a maximum of 50 mA. With 5 ohms, you can source a maximum of 500 mA. The CS701 signal is applied via a 50 ohm series resistor, and so will be attenuated by Rref. With a 5 ohm Rref, maximum impressed voltage is 630 mV p-p. With a 50 ohm series resistor the maximum is 3.5 V p-p. The assumption is that the sourcing supply is low impedance to reflect this impressed voltage to the UUT.
- **Iload**
  Estimate the load current based on the output voltage and load resistance, or just measure it. The load value is used to estimate V headroom.
- **Sig Gen Amp**
  Set the AC signal voltage used to excite the UUT input supply. This should be set to the minimum needed to get a good Response SNR. You can also set Sweep Amplitude to Auto. A target stimulus of 3mV is suitable.

Using the CS1070:



- Use CS1070 1 ohm
  Select to use the CS1070.
- Power If needed you can independently control the CS1070 power enable state by clicking on this LED. Green is enabled. Red is disabled. The application automatically turns the power on and off as required.
- **Vin**
  Is the required input voltage.
- **Iload**
  Is the estimated total current load of the UUT. It must be under 1A.
- **Sig Gen Amp**
  Use a value that results in a useful SNR >5, but as small as you can manage. 0.5V is a good starting point. . You can also set Sweep Amplitude to Auto. A target stimulus of 3mV is suitable.

Using the CS700A/CS701:



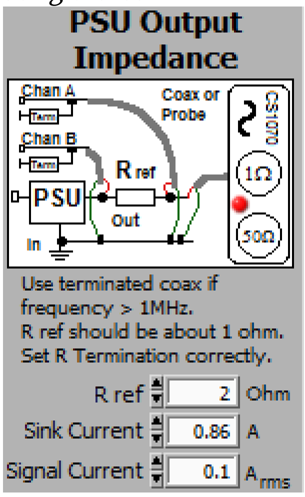
- **PSU Output Impedance -** used to measure the Output Impedance of passive or powered Power Supplies and power planes. Uses a Shunt Impedance measurement when using the CS701 or CS1070 50 ohm, and a sense resistor when using the CS1070 1 ohm. Using the CS1070 1 ohm allows higher current testing, and returns both impedance and phase.

Notes:
If the UUT is powered, the CS1070 output is automatically set to be a sinking load, and the sine wave signal does not go above the UUT power rail. If the UUT is not powered, the CS1070 will output a signal centered on 0V, unless a DC current is specified (+ve for below 0V, and -ve for above 0V, as it is a load current).

The CS701 output is not offset. You can manually offset it using the Sig Gen Offset value. The maximum voltage rail value should be <3.5V.

Rref is the Signal Generator series impedance, including any external resistors. If you are using coax, the maximum PSU Vout is 1.8V, or 3.5V when using an oscilloscope probe.

Using the CS1070:

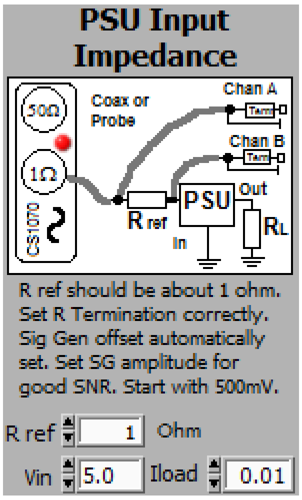


The CS1070 1R output allows the **Sink** and AC signal currents to be set directly. The CS1070 measures the rail voltage before applying current. Make sure the CS1070 input power supply voltage is at least the rail voltage + 3V.

Optimum power transfer, performance and minimum EMC result when the output impedance of the power supply is matched to the input impedance of the load. Simply adding capacitance to the output of the power supply may be counter-productive as it can lower the phase margin of the supply. The optimum goal is that the impedance of the power plane matches the impedance of the power supply, which matches the load impedance. Using the FRA, you can measure the plane impedance, and then use capacitors and/or inductors with appropriate ESR (or series resistors) to match the power supply to the plane, and to the load.

The output impedance does determine the voltage rail ripple generated by current demand at a particular frequency. It is Vr = Z Ir.

Using the CS1070:



- **PSU Input Impedance** - used to measure the Input Impedance of passive or powered Power Supplies. You must use the CS1070 1R output. A maximum of 1A is available. If you need more than 1A, we have an app note on how to do this.

The phase is displayed. A phase of around 0 means a resistive load, -90 deg is capacitive, +90 deg is inductive, and around -180 or +180 is a negative impedance. Switch mode supplies exhibit negative impedance at low frequencies because a positive change in input voltage results in a negative change in current. As R = +ΔV/-ΔI, the resistance is negative.

PSU's are often preceded by an input filter to meet conducted EMC requirements. A high Q filter has high impedance at the resonant frequency. The filter can resonate with the negative PSU input impedance.

In addition, if the output impedance of the filter is higher than the closed loop input impedance of the PSU, the total gain/phase response of the Filter/PSU will be affected. This may include reducing the gain at the filter resonant frequency, and modifying the phase, and therefore the transient response of the combination, including forcing instability.

If the filter uses ceramic capacitors with very low ESR, the filter Q will be high, increasing the possibility of oscillation. Electrolytic capacitors, with their higher ESR, may be a better solution for the filter (but not the input to the PSU, which demands low transient impedance). The ESR will damp the high Q, and maintain the filter impedance. Alternatively a parallel connected series R-C can be used to damp the filter at the resonant frequency. The R serves to absorb the resonant current, while the C ensures the loss is not at lower frequencies.

The FRA can be used to measure the output impedance of the filter (short the input to do this) and the input impedance of the PSU without the filter. You can make sure the filter Q is not high, and that the Filter output impedance is always lower than the PSU input impedance.

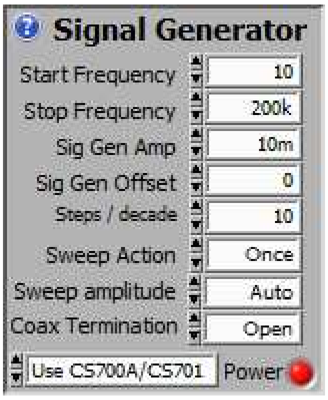
16.3.2 FRA Actions

FRA Actions

Once you have setup the FRA Control Panel, click **Start Sweep** to begin the capture process. If you have **Auto Sweep Amplitude**, or **Auto Setup** selected, the **Start Sweep** will initiate measurement of the current environment, before actually starting the sweep - you can see the current state in 

. You can clear the Spectrum Display by clicking **Clear Spectra**. The current frequency is displayed, and you can over-type this to change the Signal Generator frequency if you want.

16.3.3 Signal Generator Control



Use this panel to setup the FRA frequency range, amplitude, offset and sweep method. These controls work in parallel with the Signal Generator Control Panel.

Start Frequency the start of the sweep frequency range.

Stop Frequency the completion of the sweep frequency range.

If the ratio between Stop Frequency and Bandwidth is > 500 000, then the actual stop frequency will be reduced.

Sig Gen Amp the default Signal Generator output amplitude in V p-p.

See the **Sweep Amplitude Control** below on how this might be varied.

Sig Gen Offset the DC voltage by which the Signal Generator is Offset.

If using an electrolytic capacitor use a value of 0 - 1V. You can also use this to offset a power supply up to 3.6V for live power plane impedance testing.

Steps/Decade sets the number of frequency steps per decade. If Log Sweep is on, these are spread logarithmically, otherwise linearly.

Sweep Action sweeps once or repeatedly from the start frequency up to the stop frequency.

Sweep amplitude sets how the amplitude will vary with frequency.

If **Constant**, the Sig Gen Amplitude is set by Sig Gen Amp. If **Auto**, the system measures the gain of the Device Under Test at selected frequencies, , and then carries out the sweep, varying the amplitude dynamically to achieve the Response Voltage Goal. If the SNR is not sufficient the

Bandwidth is dynamically reduced to improve it.

The output amplitude is limited to a maximum of Auto Amp Limit. In some gain situations this may result in instability, so the limit should be reduced. The **Table** sweep amplitude method may be used when there is instability, or you want control of the Amplitude vs Frequency sweep.

Coax Termination

This control determines if you are using terminated coaxial cable to make connections to the UUT. Leave as **Open** if you are using Probes, or no termination. Set to **25, 50** or **75** ohm dependant on what you have connected. The FRA automatically compensates for the termination impedance when calculating the signal generator output amplitude with its 50 ohm series impedance.

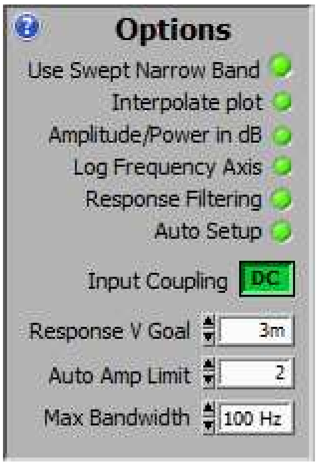
Use CS700A/CS701

This control determines if you are using a CS700A/CS701, or the CS1070 Amplifier with 50 ohm output, or the CS1070 with the 1 ohm output.

Power

Click to **Green** to enable the CS1070 output. Click to **Red** to disable the CS1070. When disabled the CS1070 can stay connected to the load which has a voltage applied to it, as long as the CS1070 power supply is greater than 3V higher than the load voltage. The CS1070 link input must be connected to the CS328A link output.

16.3.4 Options



Use this panel to setup how the Spectrum Display looks, and Amplitude options.

Click on the LEDs to change settings. Hover to see help for a control (if *Settings/Display Tools Tips* is on).

All panel controls work in parallel with the standard controls, which you can still continue to use.

Use Swept Narrow Band

Enables the FRA. Set this on, and the FRA to measures the signal coherent with the signal generator while excluding all other frequencies.

This option gives the best dynamic range. If not selected, all frequencies are displayed, and dynamic range reduces. PSU, Impedance and component value measurement require **Narrow Band**.

Interpolate plot

draws a line between each frequency/amplitude point and the next to improve the look of the graph. If you want to see just the measurement points, turn this option off.

Amplitude / Power in dB

selects dB or Volts amplitude axis.

After changing the value run the Sweep again to plot using the alternate units.

Log Frequency Axis

selects a Log or Linear Frequency axis.

Response Filtering

Turns on the Moving Averaged Filters that are used to improve SNR and dynamic range (for the 10 bit ADC).

With filters on, the amplitude is down 1 dB at the limit of the sweep range. To avoid this while plotting RMS or Power Graphs at the limit of the frequency range turn off this control. Usually you should turn this control on.

Auto Setup

Automatically measures the DC on any signals, estimates the AC signal amplitude and then sets up the graphs appropriately.

After completing the plot, the A and B channel 'Fit' commands are run to fit the Spectrum display. After the first Auto Setup, you can turn the control off, and make small adjustments yourself.
Note that Ctrl Up Arrow and Control Down Arrow zoom vertically on the tracer position, which can be handy to see detail.

Input Coupling

Sets DC or AC coupling for the two channels (you can still set channels individually using the Cleverscope Control Panel). If the signal being probed exceeds +/-24 V DC you will need to use AC coupling. The AC -3dB lower cutoff frequency is 5 Hz (1x) or 0.5Hz (10x).

Response V Goal

This is the response voltage goal. Ideally it should not alter the system performance but result in good Signal to Noise Ratio (SNR). For power supplies a response goal of 3- 10 mV is appropriate. For Passive devices such as filters, transfomers etc, use 500 mV. The Response V Goal is used by Sweep Amplitude = Auto to achieve the correct Stimulus. If the SNR is <3, the system will automatically reduce the Bandwidth. Alternatively you could increase the Response V Goal, provided it does not affect your system.

Auto Amplitude Limit

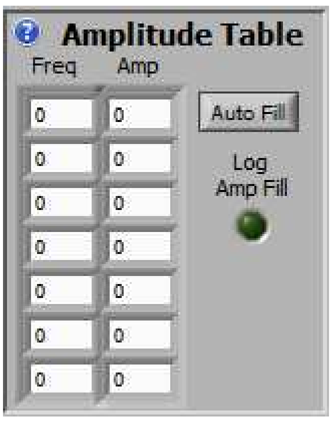
When using Auto or Table methods for determining the signal generator amplitude, an absolute limit of this value (in V p-p) will be applied.

Max Bandwidth

The Frequency Bin bandwidth is set automatically as the sweep proceeds.

You can limit the maximum bandwidth used to improve collection of low amplitude signals. Increasing the bandwidth reduces sample collection time, but also reduces the dynamic range. Reducing the bandwidth increases sample collection time and dynamic range, allowing you to measure smaller signals. Usual values are 1kHz or 100 Hz.

16.3.5 Amplitude Table



Use this panel to setup the table used to set the amplitude when the **Sweep Amplitude** control is set to **Table**.

The Table is used to generate an open loop varying frequency/amplitude plot to compensate for gain variations which are not easily handled by the Auto method of amplitude control.

Most amplifiers and power supplies have high gain at low frequencies, falling off as frequency increases. If the gain includes discontinuities, or the signal levels are very low, the table is a good approach.

Type values into the Frequencies or Amplitudes entries. The signal generator does linear interpolation between the first two frequencies that straddle the output frequency.

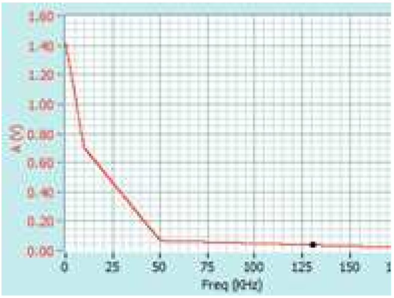
Freq (Frequencies) contains up to 7 frequencies with corresponding Amp (Amplitude) values.

Enter values in ascending order. Overtype as necessary. You don't have to fill in all entries. Just make sure that a pair of frequencies straddle the frequency range you will be using.

Auto Fill interpolates from the first pair in the table to the last pair.

Log Amp Fill determines how the amplitude values are interpolated - log or linear.

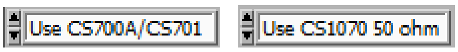
Many amplifiers have a 20 dB/decade reducing gain characteristic and using a log fill can compensate for this.



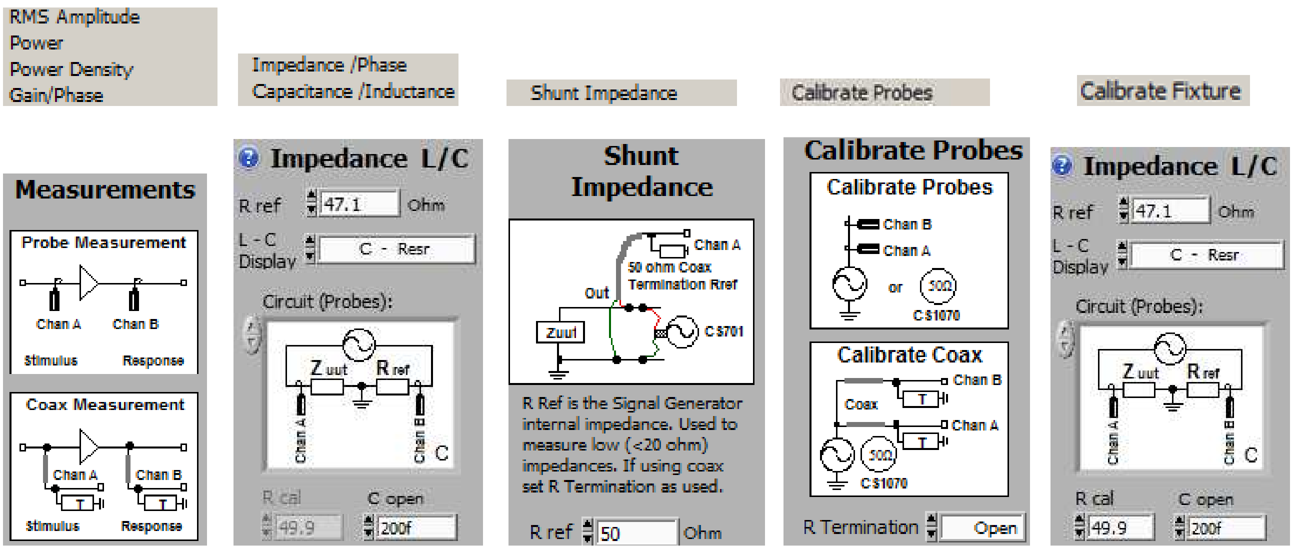
Here is an example plot using 4 values, sweeping from 0 to 200 kHz.

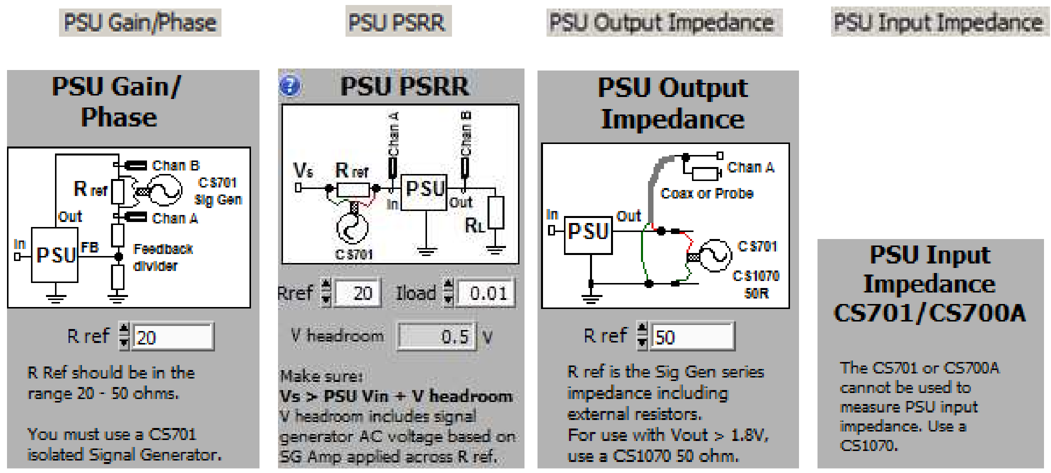
16.3.6 Measurements

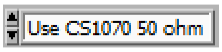
This panel has been covered under the Frequency Analysis panel discussion. For Completeness here are the panels.



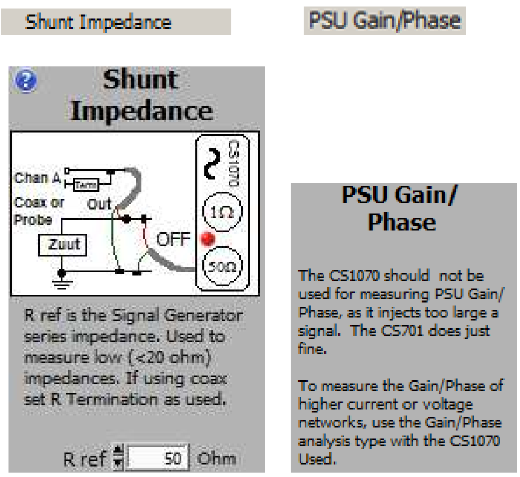
Should not be used for PSU Input Impedance



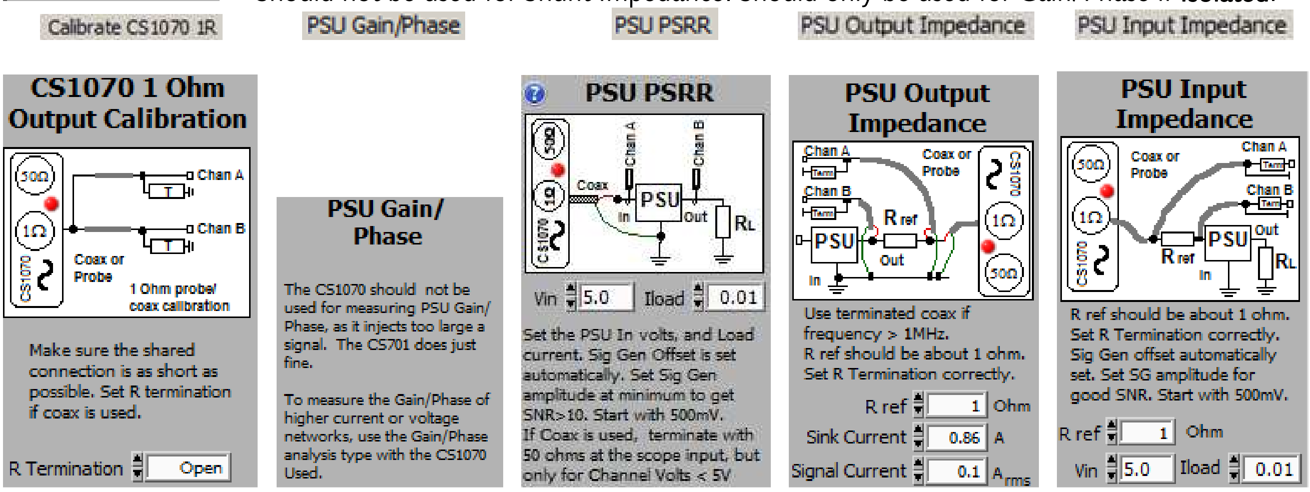




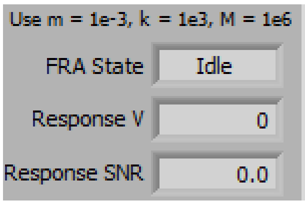
Should only be used for Gain/Phase if **Isolated**. Otherwise do **not** use.



Should not be used for Shunt Impedance. Should only be used for Gain/Phase if **Isolated**.



16.3.7 FRA Information



FRA Information

This panel details information about the FRA.

FRA State	The FRA State shows the current state - Idle, Calibrate, wait, Sweep or Complete when carrying out a FRA sweep.
Response V	Displays the measured Response Voltage
Response SNR	Displays the measured Response Signal To Noise Ratio. A value >3 is required, and >10 is good.

16.3.8 Gain and Phase Margin Display

To display the Gain and Phase margins for a power supply click the  button on the Spectrum Display. This will automatically position the vertical markers on the 0dB gain and 0 degrees phase points on your gain and phase curves. The gain and phase margins, with corresponding frequency are displayed in the marker information area.

16.3.9 -3dB Fo frequency value

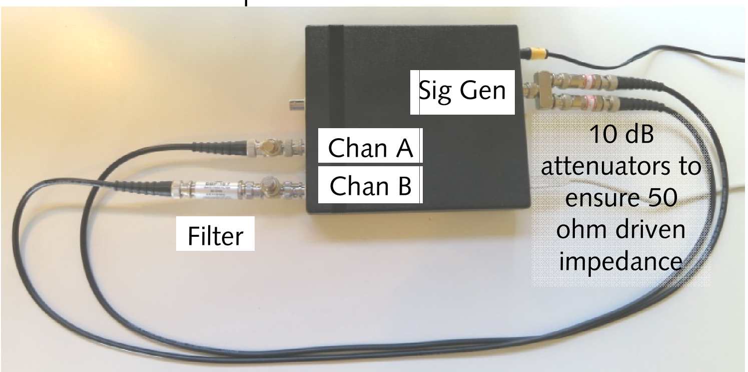
You can display and measure the -3dB frequency cutoff point on a frequency response plot by using the  button on the Spectrum Display. This will automatically position the vertical markers on the -3dB points for Channels A and B. The -3dB frequency values are saved into the marker information area.

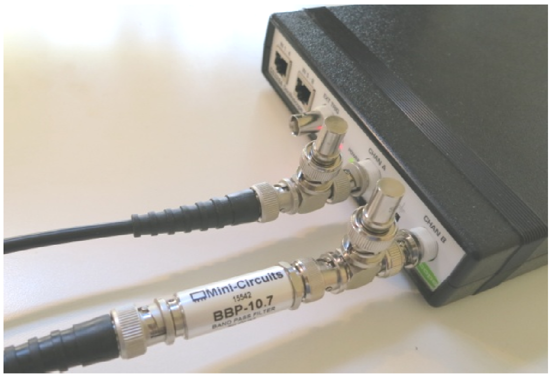
16.3.10 Example FRA Setups

These setups should help you in setting up the Cleverscope to make various FRA measurements.

16.3.11 Measuring the Gain/Phase of a Minicircuits 10.7 MHz Band Pass Filter

The Minicircuits filter is designed to be driven by a 50 ohm source with a 50 ohm load. To do this, we used a BNC splitter to drive two 10dB attenuators, with equal length coax then driving the filter terminated with 50 ohms. This is the setup:



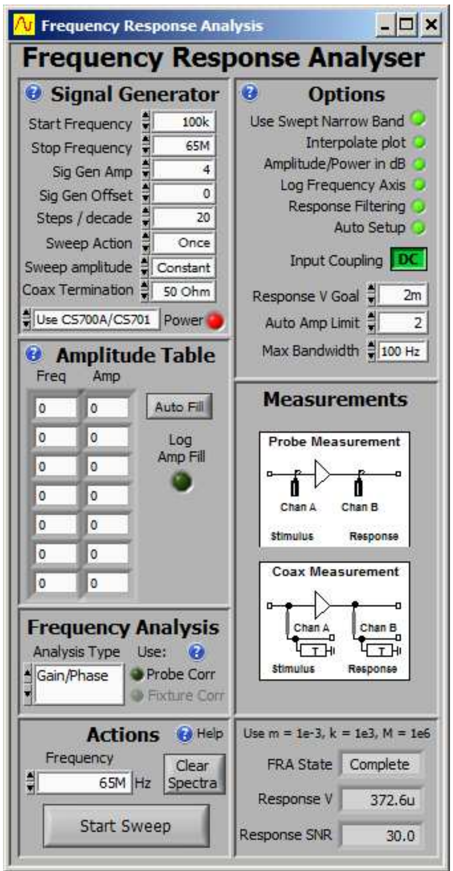


The filter is shown plugged into channel B, with 50 ohm terminators on the two channels.

Here is the response we measure, the markers show the band pass frequencies to be 9.07 - 12.23 MHz:

The Stop Band amplitude is -80 dB or so.

The FRA Control Panel setup:

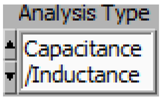


The Mini-Circuits insertion loss in the data sheet is shown to the right.

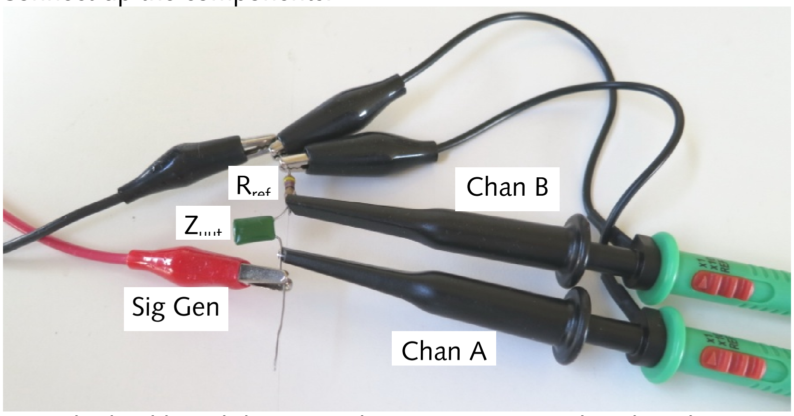
It is inverted with respect to the Gain/Phase. To plot insertion loss with the FRA, reverse the A and B channels.

16.3.12 Measuring a Capacitor, Inductor or Resistor

Steps:

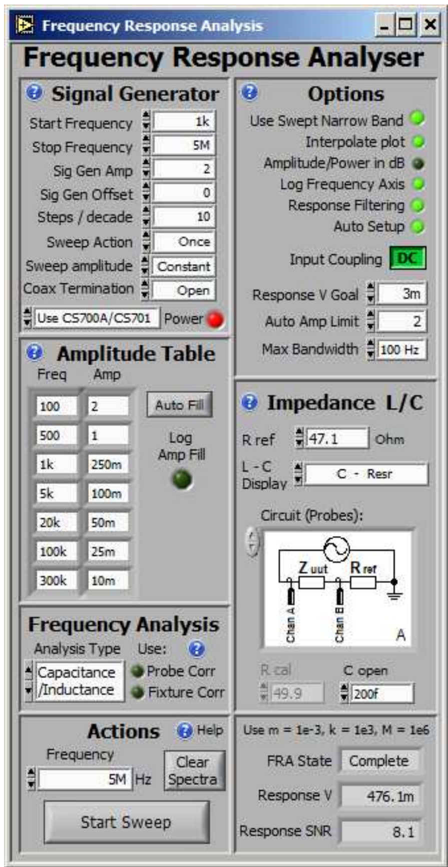
1. Choose 

2. We are measuring a 6.8 nF leaded mylar capacitor, using Circuit A, over a frequency range of 1kHz to 5 MHz. Setup the FRA control panel as shown.
3. Connect up the components:



Keep the lead length between the components and probes short to minimize lead inductance.

4. Click *Start Sweep*.



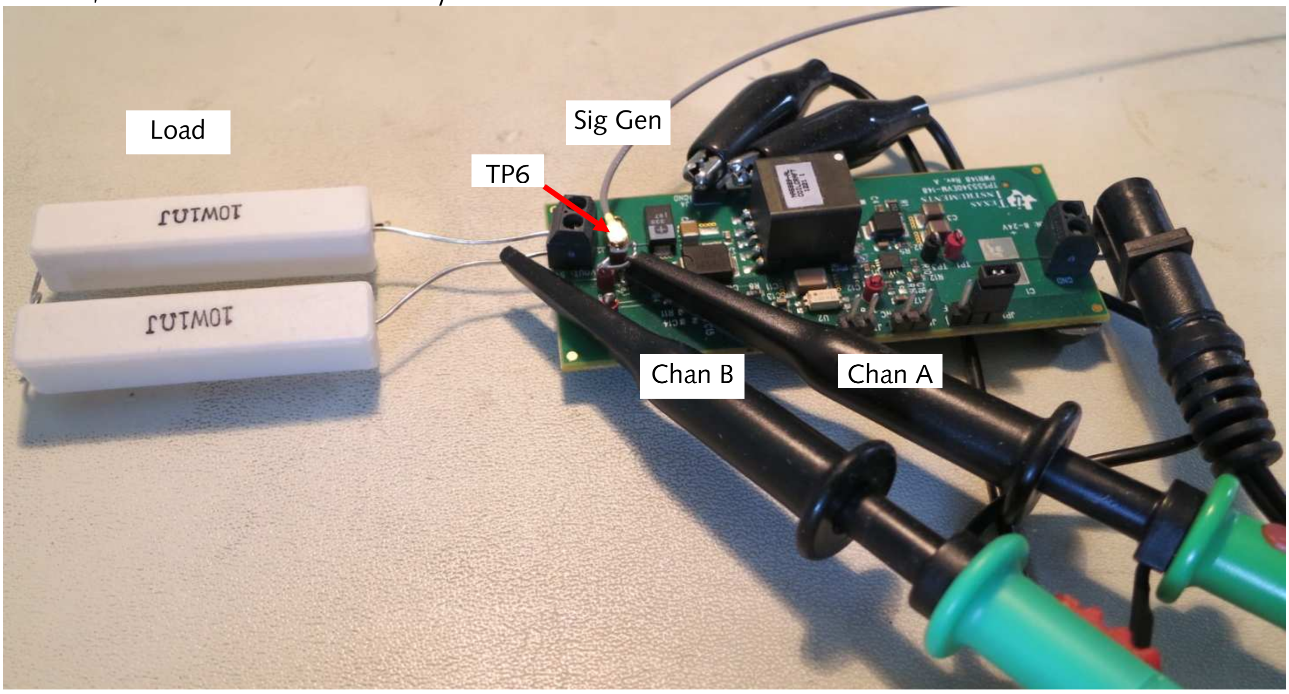
The Scope Display will be automatically setup, and the Spectrum display shows the plot below. You can adjust the view using the axis tools (hover over a control to see help), or use the Ctrl / Arrow keys to zoom in and out on the tracer. The tracer, in black, shows values at that point (3.4 nF at 6.37MHz - half capacitance). The markers (1/blue and 2/red) are placed by clicking '1' and '2'. Tab between channels. Here we see the 6.8nF capacitor is actually 6.5 nF (-4.4%), and falls off at about 1.5 MHz. ESR is 34m Ohms at the self resonant frequency.

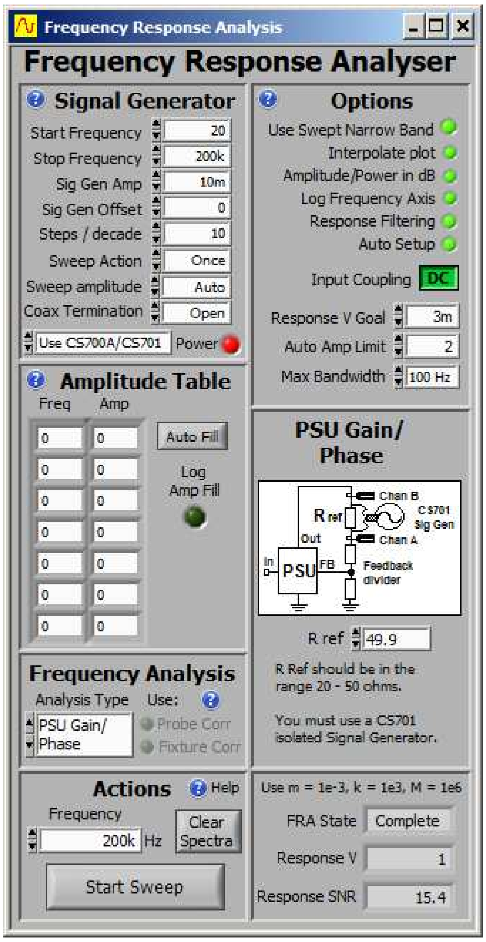
The self resonant frequency is about 2.5 MHz.

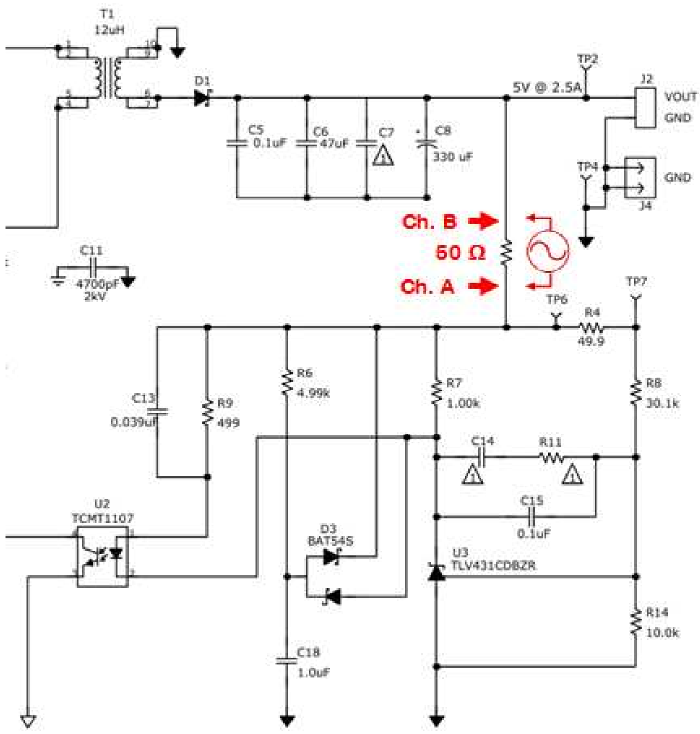
16.3.13 Measuring the Gain/Phase of a live switched mode power suppply

The CS701 Isolated Signal Generator is required for this. You cannot use the CS700A. If using the CS1070, make sure it is driven by a CS701, and is fully isolated.

Probes are used for connection. We soldered a UFL socket onto TP6 to inject the signal. Chan A measures the *stimulus*, and Chan B measures the *response*.

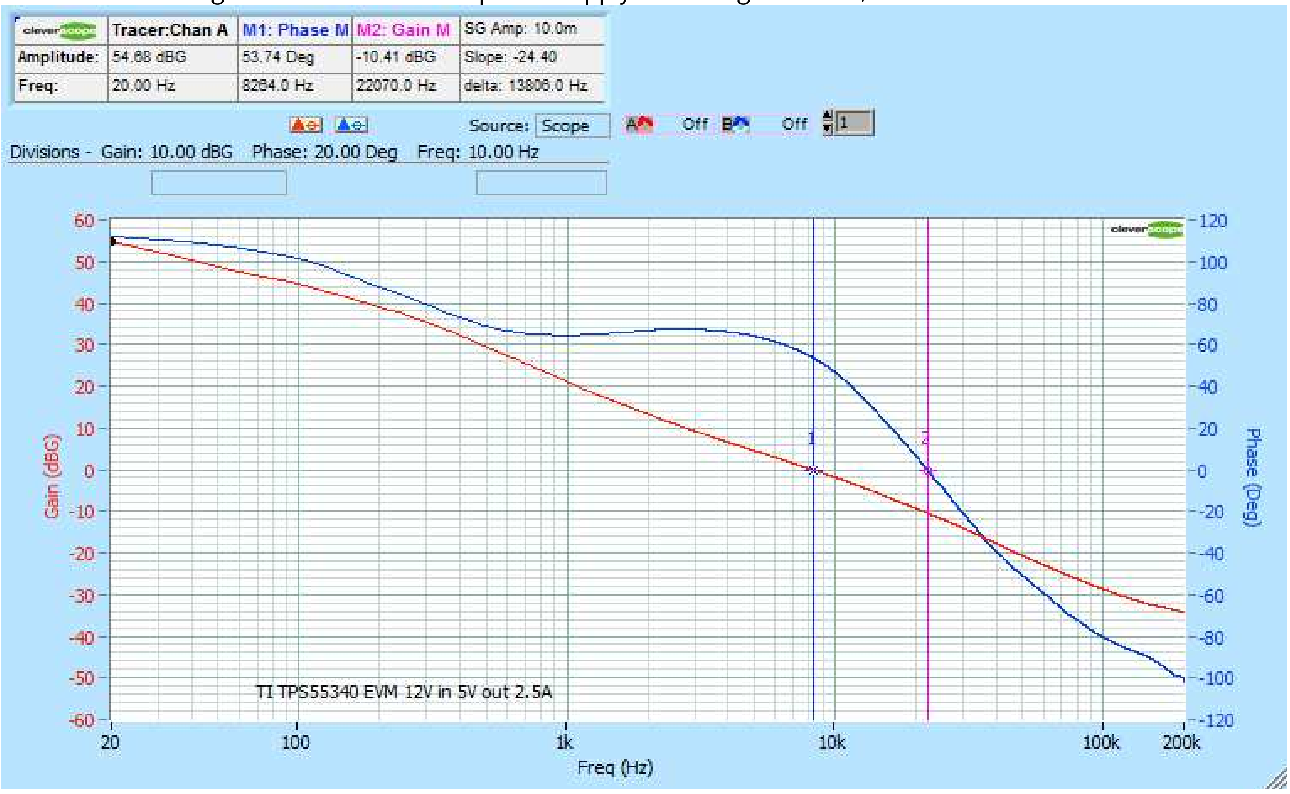






The TI EVM power supply voltage control loop part of the schematic is shown. We have inserted a 50 ohm resistor between the output and TP6, which is the start of the feedback attenuator chain. The FRA setup covers a range of 20Hz to 200 kHz, and is set for Auto Setup with auto amplitude.

Here is the resulting Gain/Phase for a live power supply delivering 2.5A out, at 5V:



Click the FR 0dB button on the Spectrum Display to show the Gain and Phase Margin Markers. Notice the Phase Margin is 53.7 degrees, which is in the optimum range, while the Gain Margin is -10 dB which is adequate in allowing for component and temperature variation whilst ensuring stability.

The gain at low frequencies is upward of 55 dB. The relatively small bandwidth of about 1 kHz (gain >20 dB) means output capacitors will be required if there is a current demand at higher frequencies.

