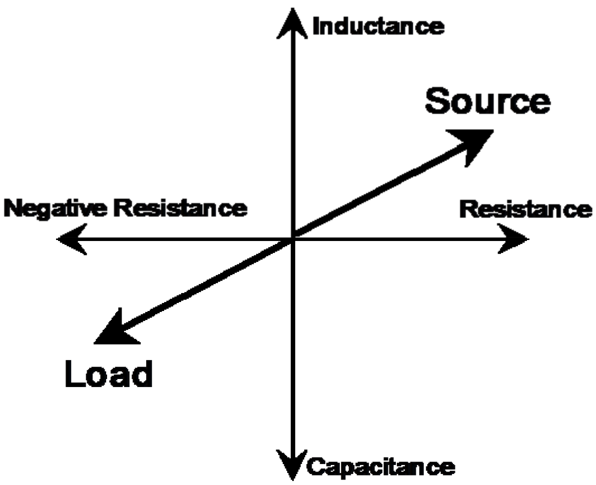
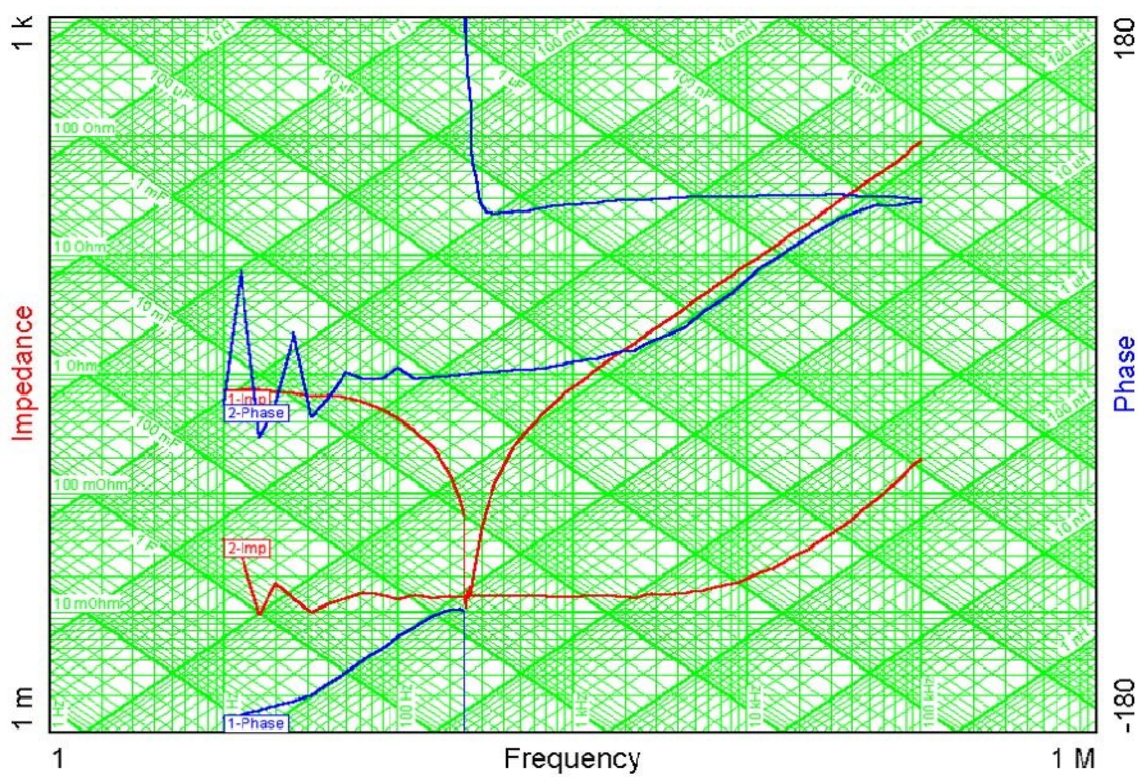
Measurement of the Input and Output Impedance of Power Supplies

Why are Source-Load impedance measurements important? Distributed power systems can oscillate, especially when driving one power supply with another power supply. Loads, especially switching power supplies, draw constant power over the input voltage range and therefore look like negative resistors at low frequencies. Connecting a negative resistor to a resonant circuit can reduce or eliminate the damping. Negative input impedance can cause an entire system to become unstable and oscillate.



- Source Z + Load Z = Zero
- Magnitude of source impedance = Magnitude of load impedance
- Phase of source impedance = Phase of load impedance +180°

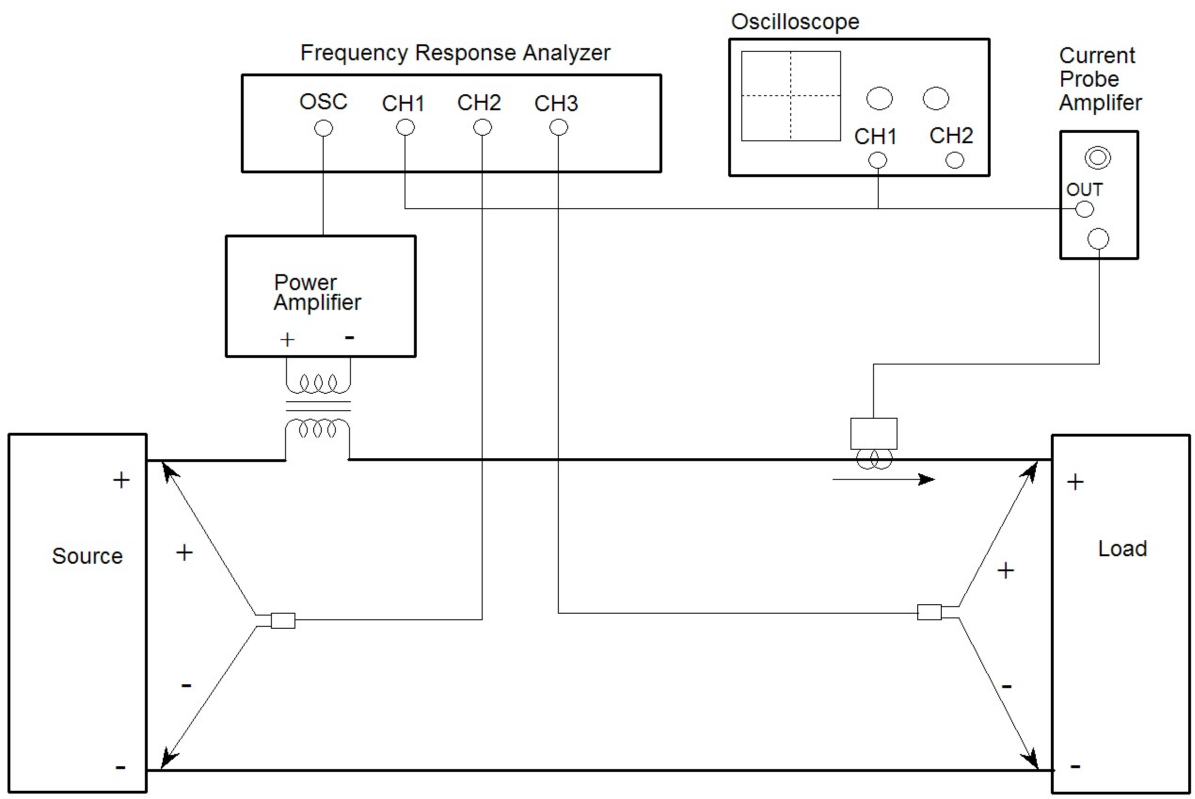
Criteria for Instability



Unstable Source and Load Combination Over Plotted

05/24/18

With the Input/Output Impedance Test Set option of the Venable Instruments System, you can measure input and output impedance of any power supply (or almost anything else for that matter). The Input/Output Impedance Test Set consists of a high-power 4-quadrant amplifier and power injection transformer. The injection transformer is capable of handling large amounts of DC current while still coupling an AC signal into the circuit. The standard power amplifier is rated 300 watts, and higher power ratings are available on special request. The injection transformer is rated 50 or 100 amps DC depending on model. Because the power amplifier is 4-quadrant, this system will also work for making measurements with an AC power source instead of DC. Since AC load current is transformed by the injection transformer and has to flow through the power amplifier, check with us here at Venable Instruments before making high power AC measurements to make sure the power amplifier is not overloaded and damaged. DC measurements are safe up to the rated current of the injection transformer.



Test setup for measuring input and output impedance.

- CH3 = Voltage across the load
- CH2 = Voltage across the source
- CH1 = Voltage across R_{sense} or Voltage output of Current Probe Amp
- Source output Z = $-CH2 \times R_{sense} / CH1$
- Load input Z = $CH3 \times R_{sense} / CH1$
- Scale factor = R_{sense} or Effective Resistance of the Current Probe

05/24/18

The test setup above shows a general purpose setup for measuring impedance. If the "Source" is truly a source and the "Load" is the Unit Under Test, this setup will measure input impedance of the Unit Under Test. As with component measurements, the impedance is voltage divided by current. In the test setup shown, source output impedance is CH2/CH1 and load input impedance is CH3/CH1 noting that there may also have to be a scale factor if the output of the current probe amplifier is not 1 volt per amp. If the "Load" is the Unit Under Test, CH3/CH1 is the input impedance of the Unit Under Test.

If the "Source" is the Unit Under Test and the "Load" is an actual or simulated load, this test setup will measure the output impedance of the Unit Under Test. CH2/CH1 is the output impedance of the Unit Under Test. If your system does not have a channel 3, then you must move CH2 to the source side of the injection transformer to measure the output impedance of the Unit Under Test.

Current probes are directional. If the arrow on the current probe is pointing toward the load, then the measured impedance of the load will be the correct polarity. The scale factor of the data set will be the effective resistance of the current probe, which is the rated volts per division of the current probe amplifier output (usually 0.01 volts per division) divided by the amps per division setting of the current probe amplifier. For measuring the output impedance of the source, if the arrow on the current probe is pointing toward the load (away from the source) then the scale factor will be the negative of the value calculated above for the load input impedance data set. It is important to pay attention to the direction of the current probe arrow, especially if you do not have a feel for the expected phase of the test result readings.

Impedance measurements are a lot trickier than they look. The hardest part is getting the current probe set up properly. The second hardest part is making sure the drive levels are correct and nothing is being under driven or overdriven. The third hardest part is getting the scale factor and polarity correct.

Let's start with the current probe. If you want good performance at low frequency, choose a DC current probe such at the Tektronix AM503S System. The current probe is not part of the Venable System or the Input/Output Impedance Test Set. It must be purchased separately if you do not already have one. Models are available in 20, 100, and 500 amp versions. Try to use one matched as closely as possible to the current you plan to measure. Trying to measure a few milliamps with a 100 or 500 amp current probe will not give very satisfactory results. The next thing to remember is that the Tektronix current probe amplifier is made to work into a 50 ohm load. That means you need to put a coaxial 50 ohm termination on each input of the FRA that is measuring current. The termination goes on the frequency response analyzer end of the BNC cable, not the current probe amplifier end. Make sure the termination is really 50 ohms by checking it with a good ohmmeter. You would be amazed how many 50 ohm terminations are "burned up" from connecting them to high-power sources. The accuracy of the impedance measurement is dependent on the accuracy of the 50 ohm termination. Failure to properly terminate the current probe is a common source of error in impedance measurements. Once you have chosen a current probe of the correct current rating and properly terminated it, the next area of concern is the range setting of the current probe amplifier. The Tektronix current probe amplifier has a dynamic range of about ±10 divisions. In other words, if you set the current probe amplifier to 1 amp per division, it will read accurately up to about ±10 amps. In general, the measurements we are making are on DC power lines. We are superimposing a small amount of AC voltage in series with the DC output voltage of the source in order to make a small AC deviation in the DC current being drawn or supplied. The current probe amplifier range should be set so the DC current represents a large portion of the dynamic range but does not exceed the dynamic range. For best accuracy, choose a range setting where the DC current being sensed represents between 3 and 8 divisions. For example, if the DC current is 3 amperes, the current probe amplifier setting can be 1 amp per division (3 divisions) or 0.5 amps per division (6 divisions). Either setting will work and give good sensitivity without saturating the current probe amplifier.

The next critical adjustment of a current probe amplifier is DC balance. The newer current probe amplifiers are self-balancing, but older ones need to be adjusted so they output 0 volts DC when there is no current flowing through the probe. A small amount of DC error will not cause a problem since the FRA rejects DC, but if there is a large balance error it can affect the dynamic range of the amplifier and cause it to saturate with less than 10 divisions of deflection. Current probes get “gaussed”, which means that they have some residual flux in the core of the transformer used to sense current. The DC balance adjustment corrects for this residual flux. Current probe amplifiers have a “Degauss” button, which drives the internal transformer with a large amplitude but exponentially decreasing AC excitation with the objective of minimizing the residual flux in the transformer. After you “degauss” the current probe, you will have to readjust the DC balance setting. The problem is that when you make another measurement, the DC current flowing through the probe “gausses” the transformer again and it immediately needs to be readjusted for DC balance. Our recommendation is to not degauss the probe because you will only make it difficult to adjust the DC balance again once you start taking measurements. One highly recommended step is to connect an oscilloscope in parallel with the FRA input (after the 50 ohm termination) so you can see the level of DC offset, the amount of deflection caused by the DC current, and the amount of AC deviation superimposed on the DC current.

The final detail of using a current probe is to calculate the effective resistance of the probe. If you used a resistor of value R to measure current, you would get R volts across the resistor for every amp through it. The current probe has an effective resistance, which is the number of volts out of the current probe amplifier for every amp through the current probe. The Tektronix AM503 series of current probe amplifiers have a fixed output of 0.01 volts for a unit of current equal to the range setting.

AM 503 Current Probe Amplifier

- Current Probe Output Voltage Scale = 10 mV/Div
- Current Probe Input Current Range = 1mA-50A/Div

The current probe amplifier output is 0.01 volts per division and the range setting is given in amps per division so the effective resistance of the current probe is 0.01 divided by the range setting. If the amplifier is set to 10 milliamps (0.01 amps) per division, then the effective resistance is 1 ohm. One common error in making impedance measurements is to leave the current probe amplifier set to 10 milliamps per division no matter what current is being measured. This simplifies the math, since there is no need to use the Scale Factor provision of the testing and plotting software. It also means that often the current probe will be operated far from its optimum range, sometimes even in the saturation region where the output is no longer linearly proportional to the input. Failure to choose the proper range is another common source of error in impedance measurements. That about covers the common mistakes people make in the use of current probes.

Calculating Scale Factor or Effective Resistance

- AM503 Scale Factor = Voltage Scale/Current Range
- Example

10 mV/Div/50mA/Div = 0.2Ω

Scale Factor or Effective Resistance = 0.2Ω

Now let's go to the subject of drive levels. There are two variables in setting the drive level. One is the level of the Oscillator Output of the FRA; the other is the gain setting of the power amplifier. Since the amplifier output is the product of these two gain settings, there is an infinite number of gain setting possibilities for any given output level. The simplest way to set the level is to use one of the gain variables to set the injection transformer output level to the desired level at an intermediate frequency such as 1 kHz and then leave the gain settings alone during the sweep. An effective way to do this adjustment is to set the FRA Oscillator Output to a reasonable level like 1 volt and then use a voltmeter or oscilloscope to monitor the output of the injection transformer and adjust the gain knob on the power amplifier for the desired output value. This can be done before power is applied; in fact it can be done before the injection transformer is even connected into the circuit. For example, let's say you are testing the impedance of some piece of the International Space Station. The Space Station power bus is 120 VDC and program officials have decided that a 2% variation in the power bus will not damage the equipment. That means that the 120 VDC bus can vary by ±2.4 volts and still be in the safe region. You can set the analyzer AC Volts Out to 1 volt peak. You can then monitor the output of the injection transformer and set the gain control of the power amplifier for ±2 volts peak voltage at 1 kHz. This will give a small margin of safety (from 2 volts to 2.4 volts). The amplitude of the oscillator output is very flat with frequency. The gain of the power amplifier is also flat with frequency except where the output falls off, below 10 Hz and above 100 kHz. This means that by setting the amplitude in mid-range (1 kHz), the output amplitude will not exceed this value at any time during the sweep.

When you plot the test results, the variable called Scale Factor on the Data Set Properties window is the resistance used to measure the current or the effective resistance of the current probe. The polarity will be correct if the current probe arrow is pointing toward the Unit Under Test. If the current probe arrow is pointing away from the Unit Under Test, the Scale Factor will have to be entered as a negative value.

The graph below is actual test data of the input impedance of one of the Orbital Replacement Units of the International Space Station.