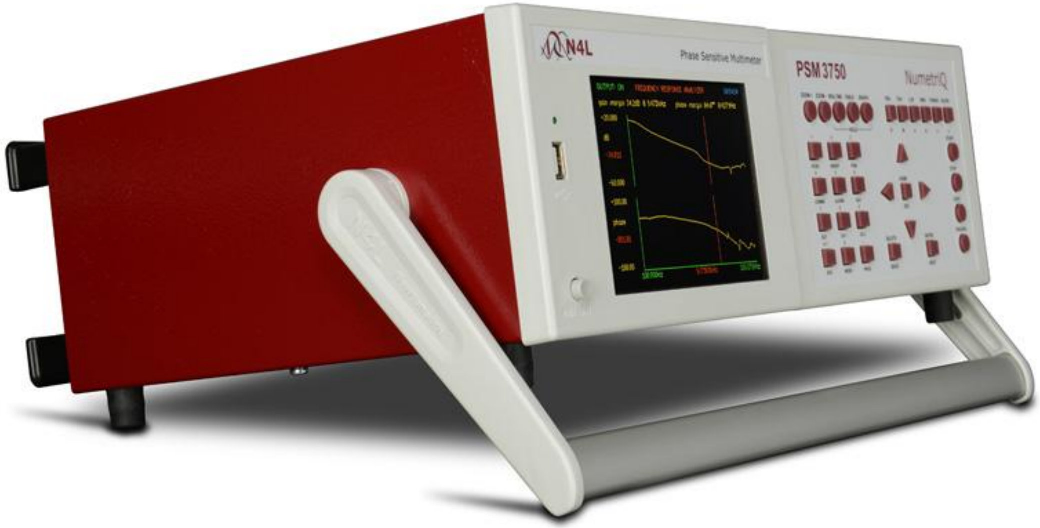
N4L Frequency Response Analysers – more than just loop analysis



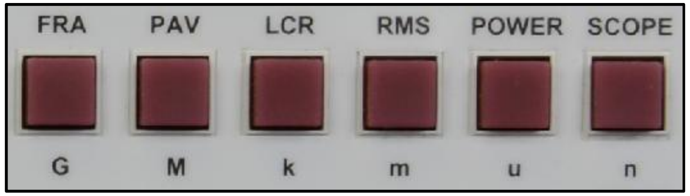
A true “multipurpose tool” - often under utilised and under valued.

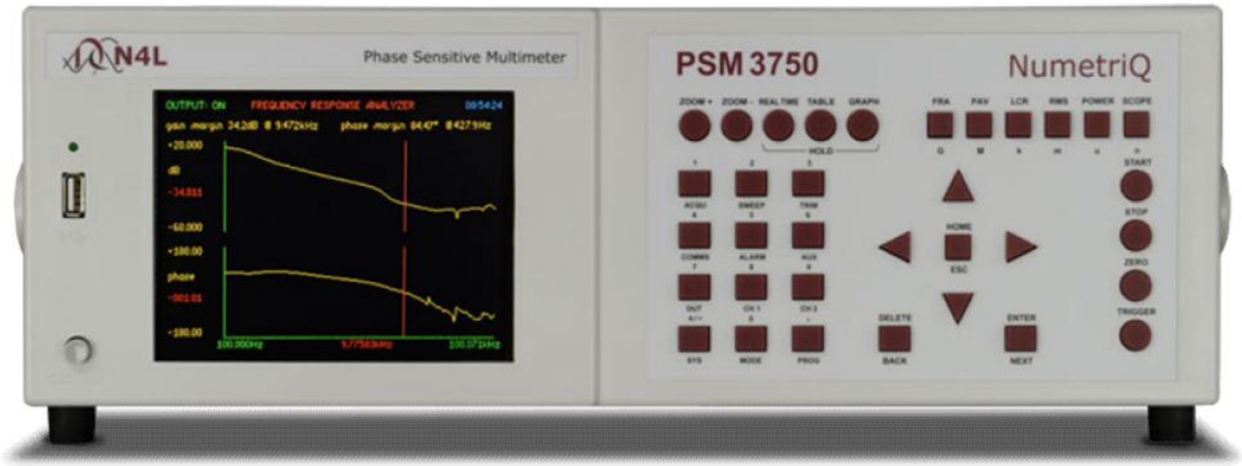
N4L Newtons4th Ltd

N4L PSM Series – Not just an FRA

The PSM series of instruments offer more than just accurate frequency response (gain/phase) measurement.

This presentation will explore the various modes within the PSM range of analysers and how you can exploit them during research and development work

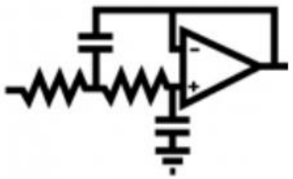




Applications

Control Loop Stability Analysis

Transistor Performance Analysis

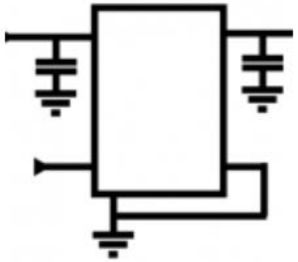


Filter Design

Audio Amplifier Design

OptoCoupler Evaluation

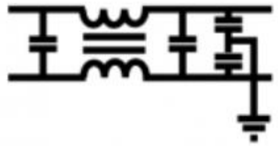
Coax Cable Frequency Response



LDO Regulator Evaluation

Signal Transformer Performance Evaluation

Cross Talk Testing

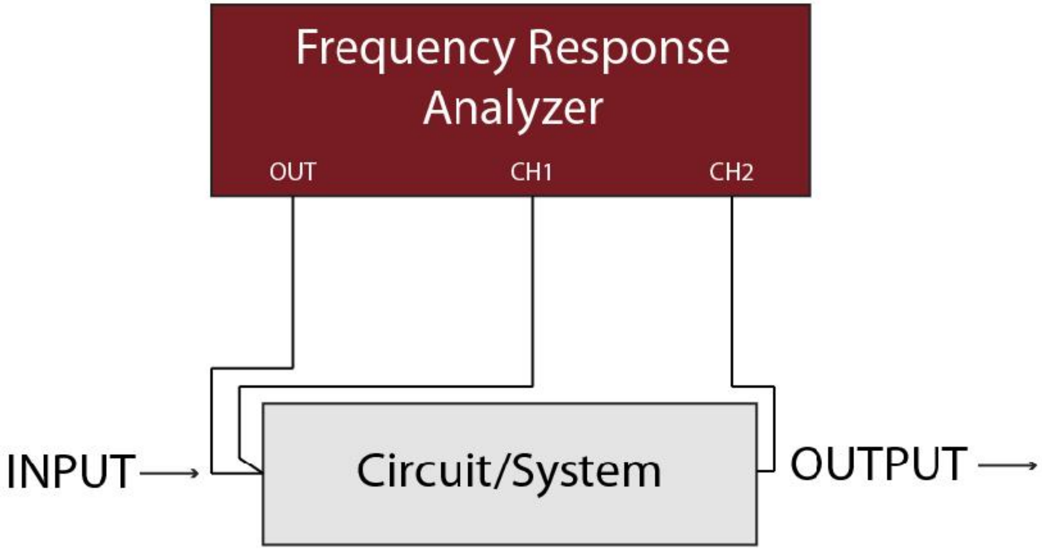


RFI/EMC Filter Design

FRA Background

What is a “Frequency Response Analyser”?

- Consists of a signal generator – to inject various test frequencies into test circuit
- Plus at least two Voltage measurement channels



- Injected test frequency is usually swept across a range of frequencies in order to determine the “frequency response of the circuit/system under test.

FRA Background

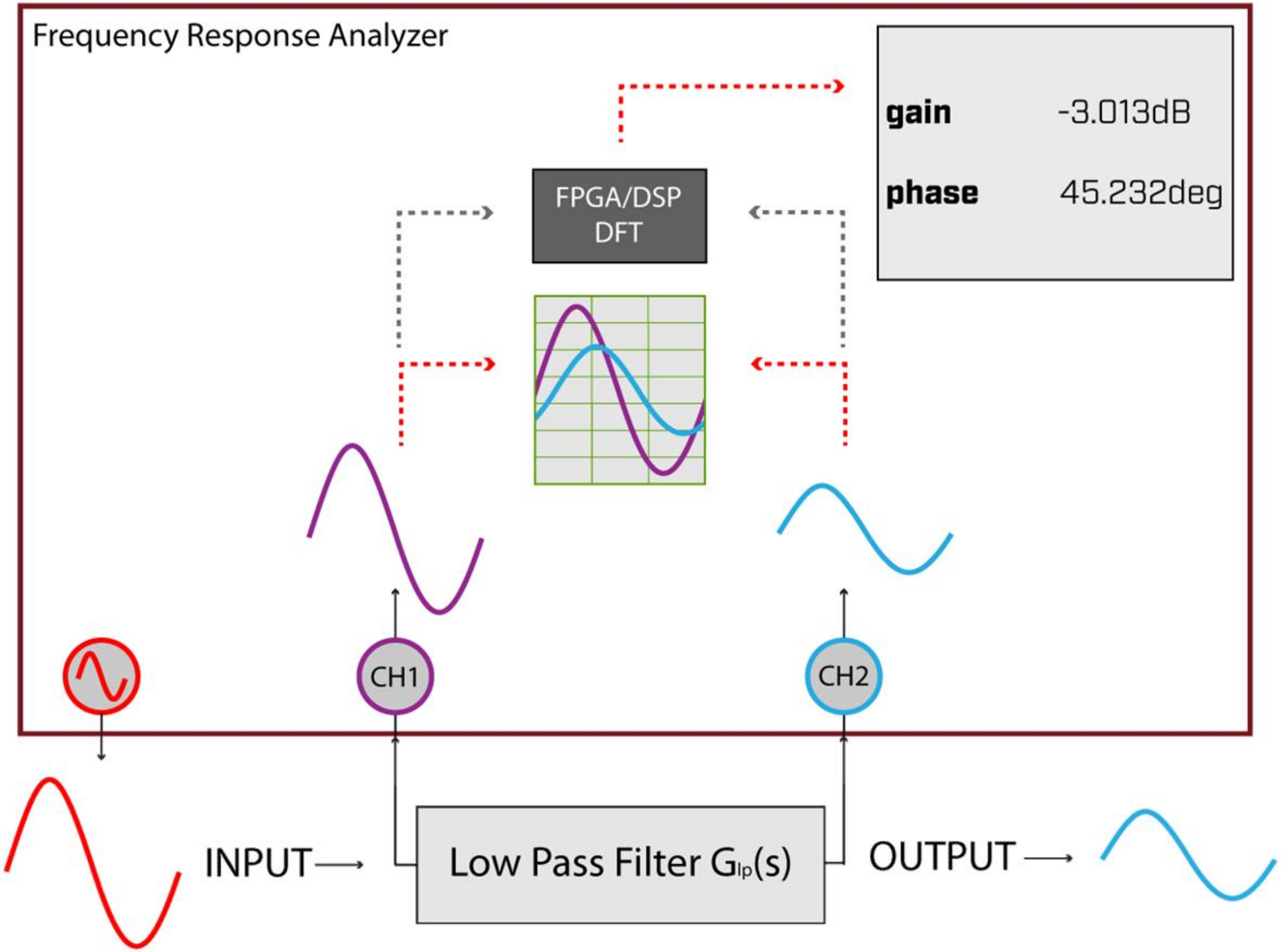
- Most common measured parameters are "Gain" (dB) and Phase (degrees)

$$\text{Gain (dB)} = 20\log_{10}(\text{Vout}/\text{Vin})$$

The gain measurement is simply a dB scaled ratio of the system output signal magnitude and system input signal.

- Typically CH1 measures an injected signal into a circuit/system
- CH2 measure the response/output signal from the system
- CH1 and CH2 measured voltage are compared, both for magnitude ratio (converter to dB) and phase shift between CH1 signal and CH2 signal

FRA Background – Simplified FRA block diagram



Signal Processing and the Discrete Fourier Transform

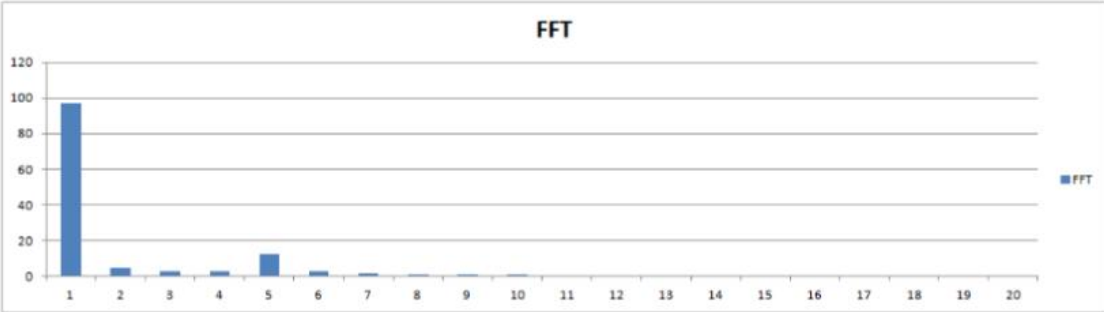
- FPGA/DFT block on previous page is where the “magic happens”
- This block analyses the signals on CH1 and CH2, separates the signal of interest from the wideband noise
- Signal of interest is nearly always the injected frequency from the generator
- Performs a DFT on the acquired data.

- High quality frequency response analysers utilise discrete Fourier transforms to determine gain and phase for the following reasons;

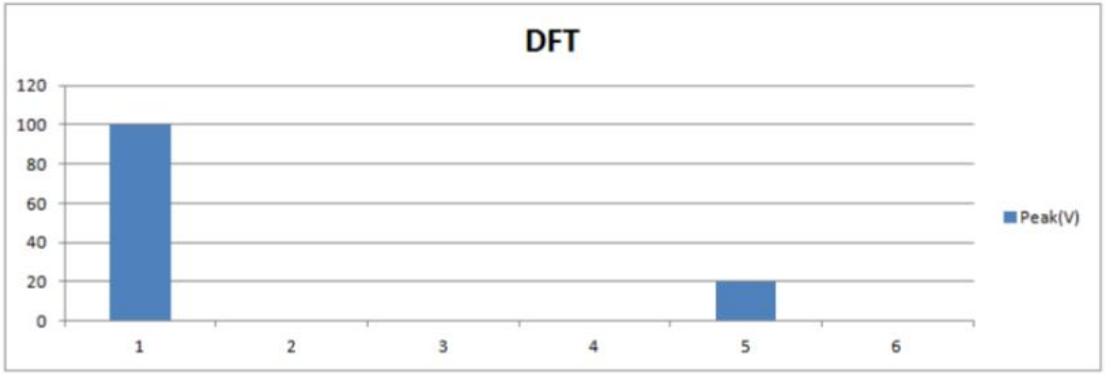
    - FRA needs selective measurement, separating the injected frequency from the wideband noise
    - The DFT is very accurate for gain/phase determination
    - FFT suffers from leakage, poor accuracy

N4L FRA's utilise the Discrete Fourier Transform

Example Signal – H1 = 100V, Injected signal H5 = 20V (Simulating extraction of small signals in presence of wideband noise)



- FFT exhibits leakage, if trying to extract the 20V signal - errors can be significant, sample number limited to 2^n samples.

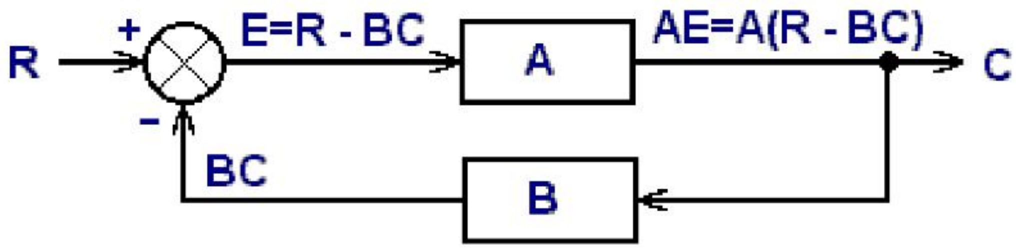


- DFT is able to extract small signals in presence of wideband noise very accurately, utilising any number of samples.

FRA Mode - Feedback Loop Analysis

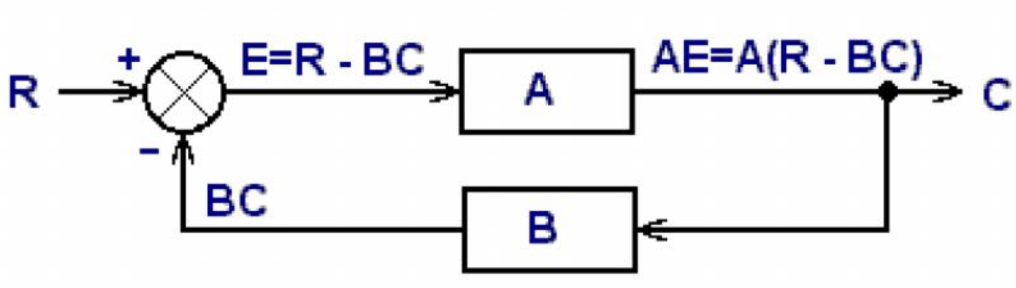
Engineers most familiar with frequency response analysers tend to be control engineers/power supply designers who utilise FRA's in order to determine loop stability.

- Control engineers/Power Supply designers need to determine if their circuits/systems are stable.
- A frequency response analyser provides an ideal tool in order to determine whether or not the system is stable
- While engineers "design-in" stability, the only way of truly knowing if the system is stable is to perform some kind of transfer function analysis.
- Frequency response analysis, whereby a range of frequencies are injected into the feedback loop of the system under test is the most common technique for determination of stability



Feedback Loop Analysis

Generic Control system

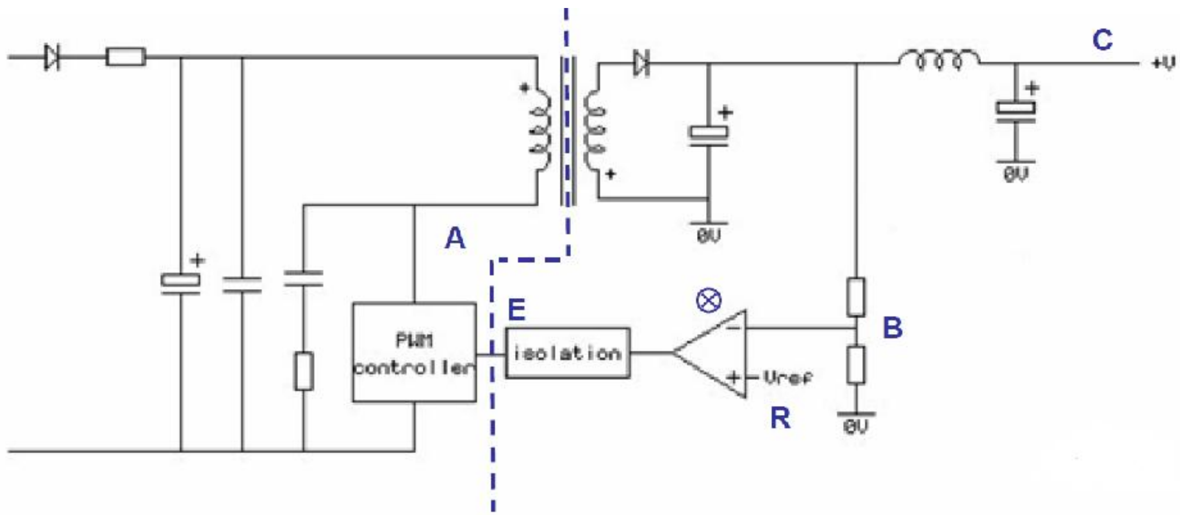


R = Reference
A = Amplifier or Gain Stage
C = Controlled Variable
B = Feedback stage
⊗ = Summing Junction or Comparator
E = Error Signal

$$\frac{(\ )}{(\ )} = \frac{(\ )}{(\ )\ (\ )} = \frac{(\ )}{(\ )}$$

where T(s) is the loop gain

Typical Isolated
SMPS DC Power Supply



Feedback Loop Analysis

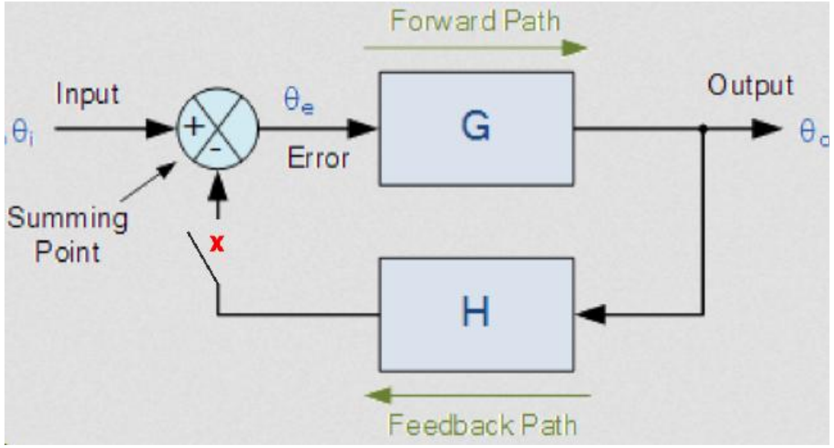
Typical Closed Loop Feedback System Design Process

- It is the task of the frequency response analyser to determine the loop gain of the control system

1. A stable control system is designed in Spice/Matlab etc
2. The control system may have some desired transient/steady state behaviour, this determines the poles/zeros of the system
3. System is assembled as a prototype
4. Real life system tested in closed loop using FRA, data compared to simulated results
5. Gain/Phase data is checked against stability margins

Feedback Loop Analysis

Before “closing the loop”, it is sometimes wise to test the open loop response first, potentially preventing dangerous conditions.



In open loop conditions, the open loop response is sometimes called the “return ratio”, G(s)H(s)

Feedback Loop Analysis – Choosing an Injection point

- Feedback loop analysis is generally performed with the loop "closed"
- Using a technique known as the "Voltage injection method"
- The measured result should be close to the open loop gain, for reasons of assessing the stability via gain/phase margins.

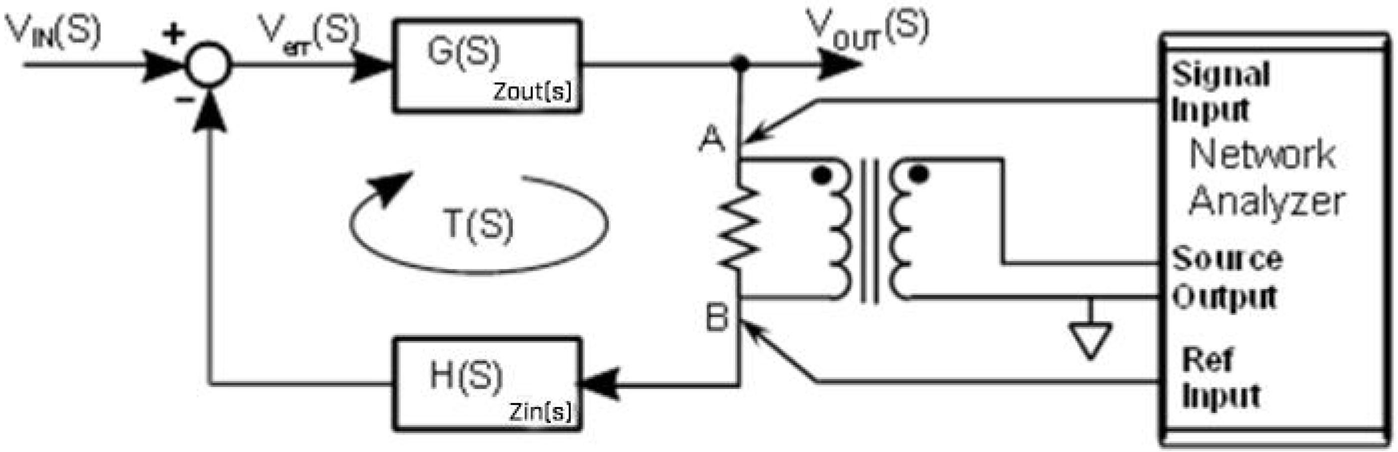
Choosing an Injection Point

Although we are trying to determine closed loop stability, gain/phase margins are based upon the open loop gain T(s) of the system.

We need to find a suitable injection point so that the measured transfer function approximates to the open loop gain T(s).

Where to inject?

Feedback Loop Analysis – Choosing an Injection point



In order for the measured gain/phase plot to represent the open loop gain T(s) the following conditions must be met:

1. The impedance looking into the loop (into H(s)) must be much greater than the impedance looking back around the loop (into G(s))

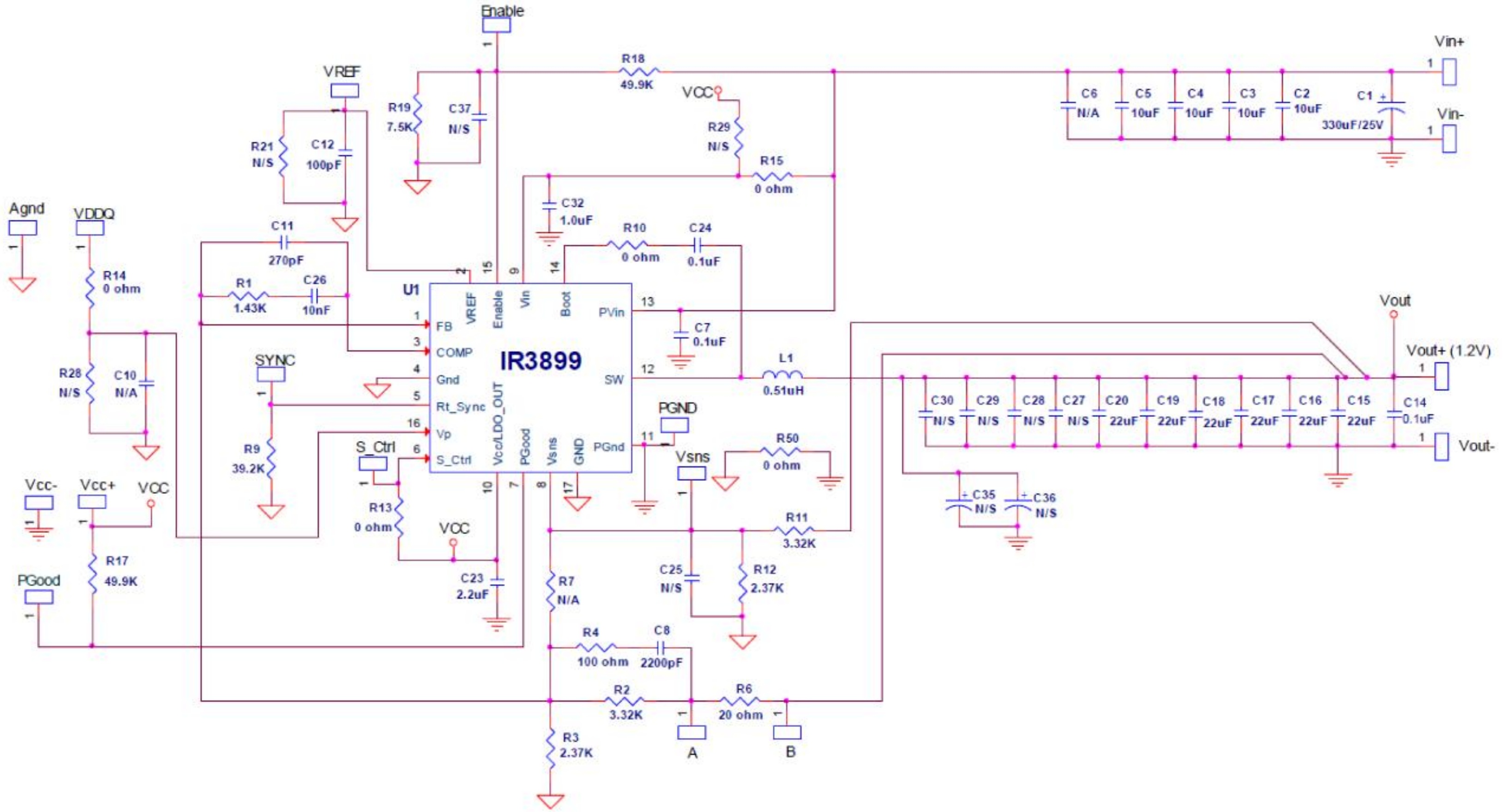
$$|.\quad(\;)| \gg |.\quad(\;)|$$

2. The measured loop gain must be significantly greater than the ratio-metric relationship in gain between Zout(s) and Zin(s)

$$(\;) \gg \frac{|.\quad(\;)|}{|.\quad(\;)|}$$

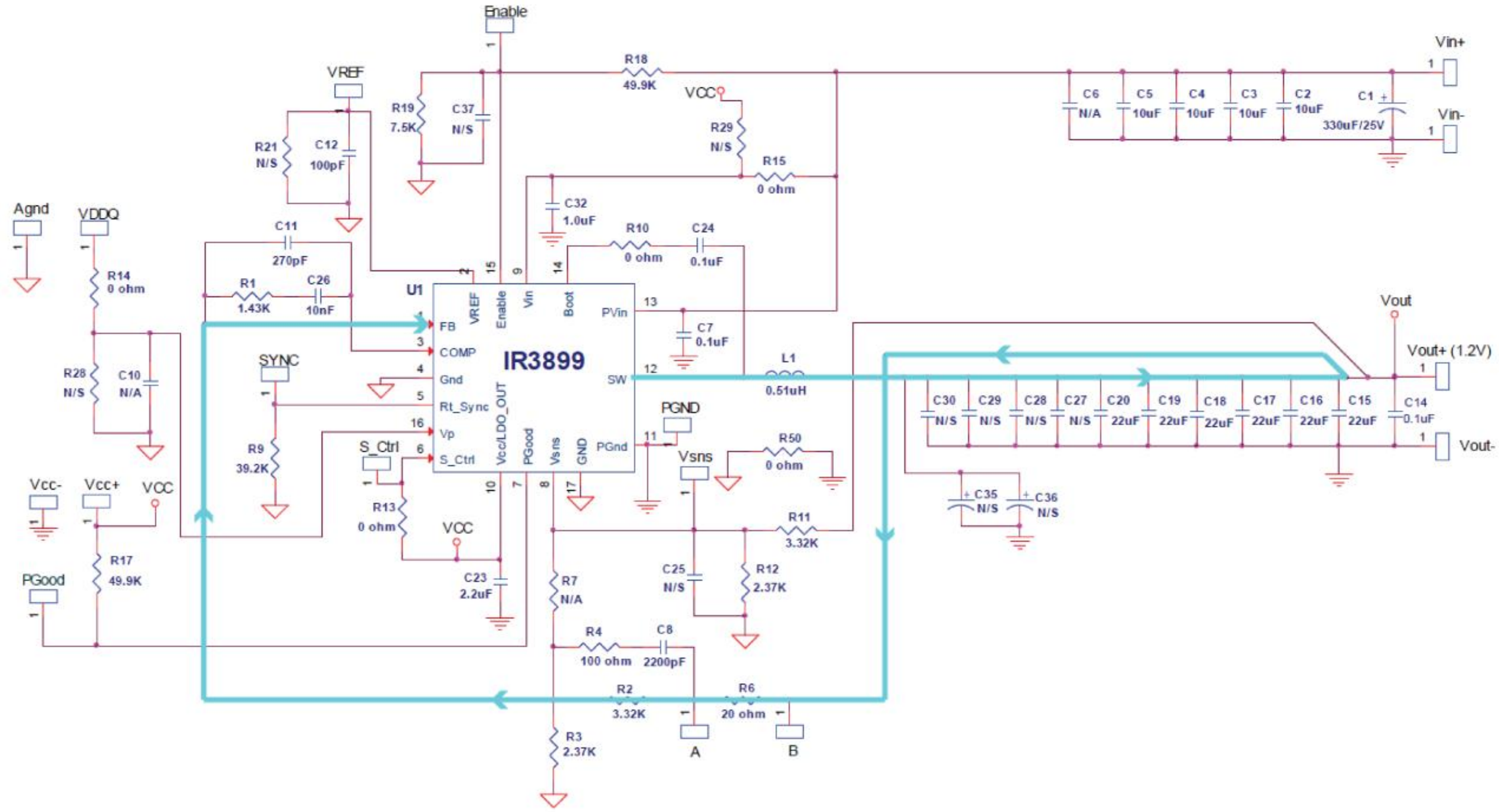
Feedback Loop Analysis – Example Measurement

International Rectifier Buck converter



International IOR Rectifier

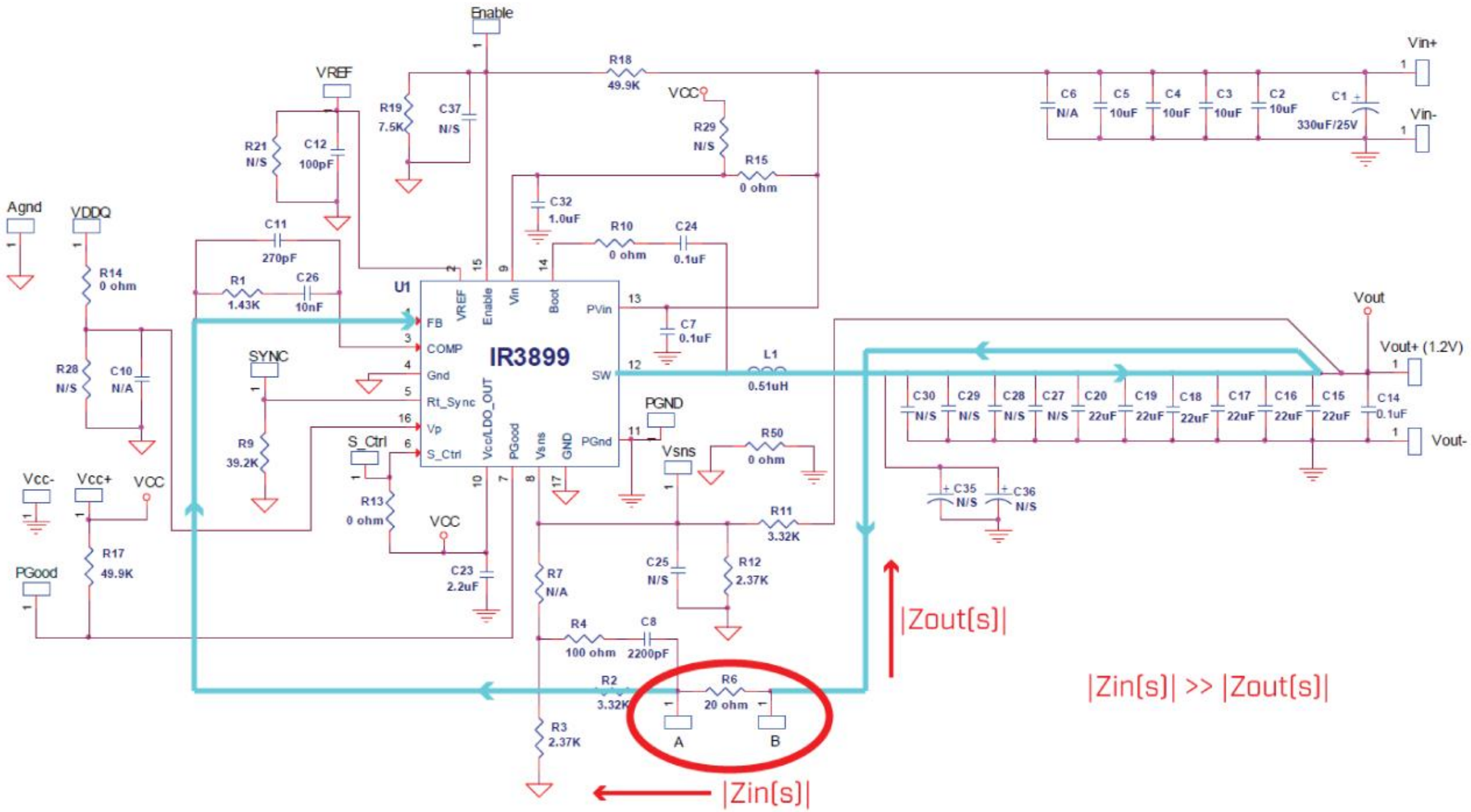
IR3899 Feedback Loop



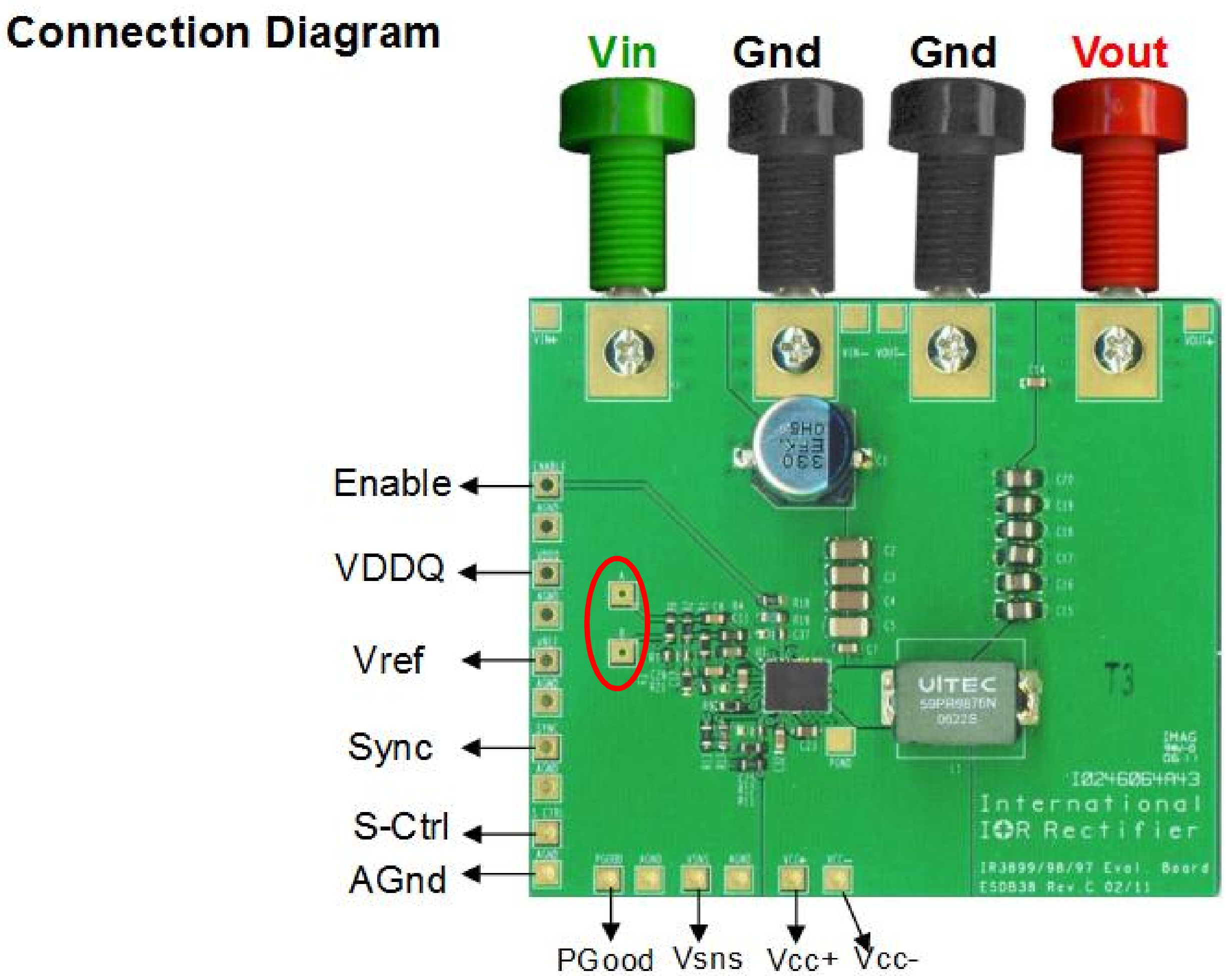
Feedback Loop Analysis – Example Measurement

Injection Point

International IOR Rectifier



International IOR Rectifier



Feedback Loop Analysis – Example Measurement

- Sweeps performed at various loads
- This is important as the smoothing inductor in particular will exhibit varying inductances when DC bias current is applied which will affect the loop gain
- It is advisable to test loop gain over complete range of load currents in order to ensure stability under all conditions

Pink/Red sweep settings: Speed Medium, Cycles 1

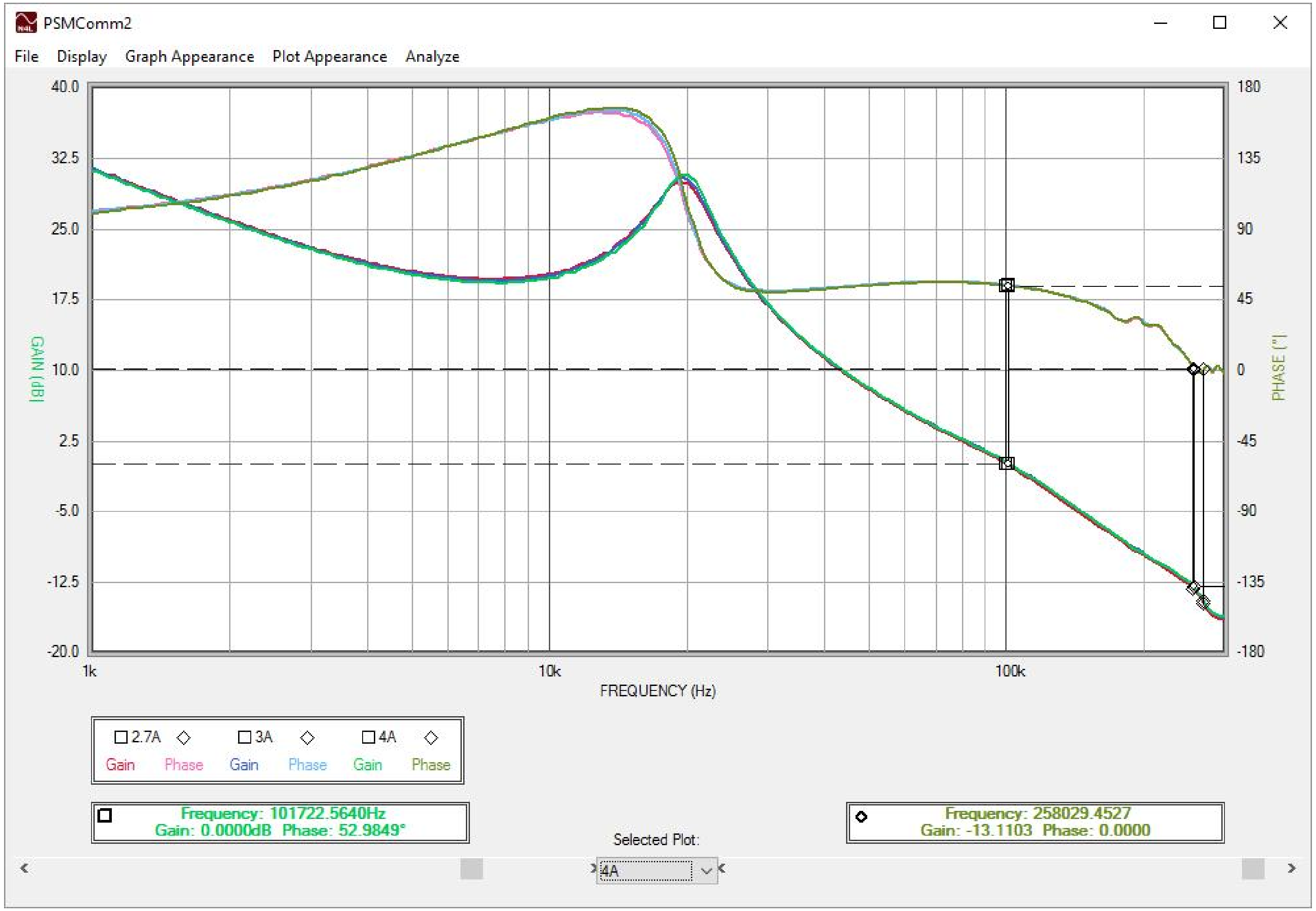
Light blue/Blue Sweep settings: Speed slow, Cycles 4, for removal of noise

Note: Initial sweep (pink/red) was performed with standard settings, if you have concerns with **noise**, use slower speeds and multiple cycles.

In this case, it is not necessary to remove noise, but noise removal has been performed for clarity

Feedback Loop Analysis – Example Measurement

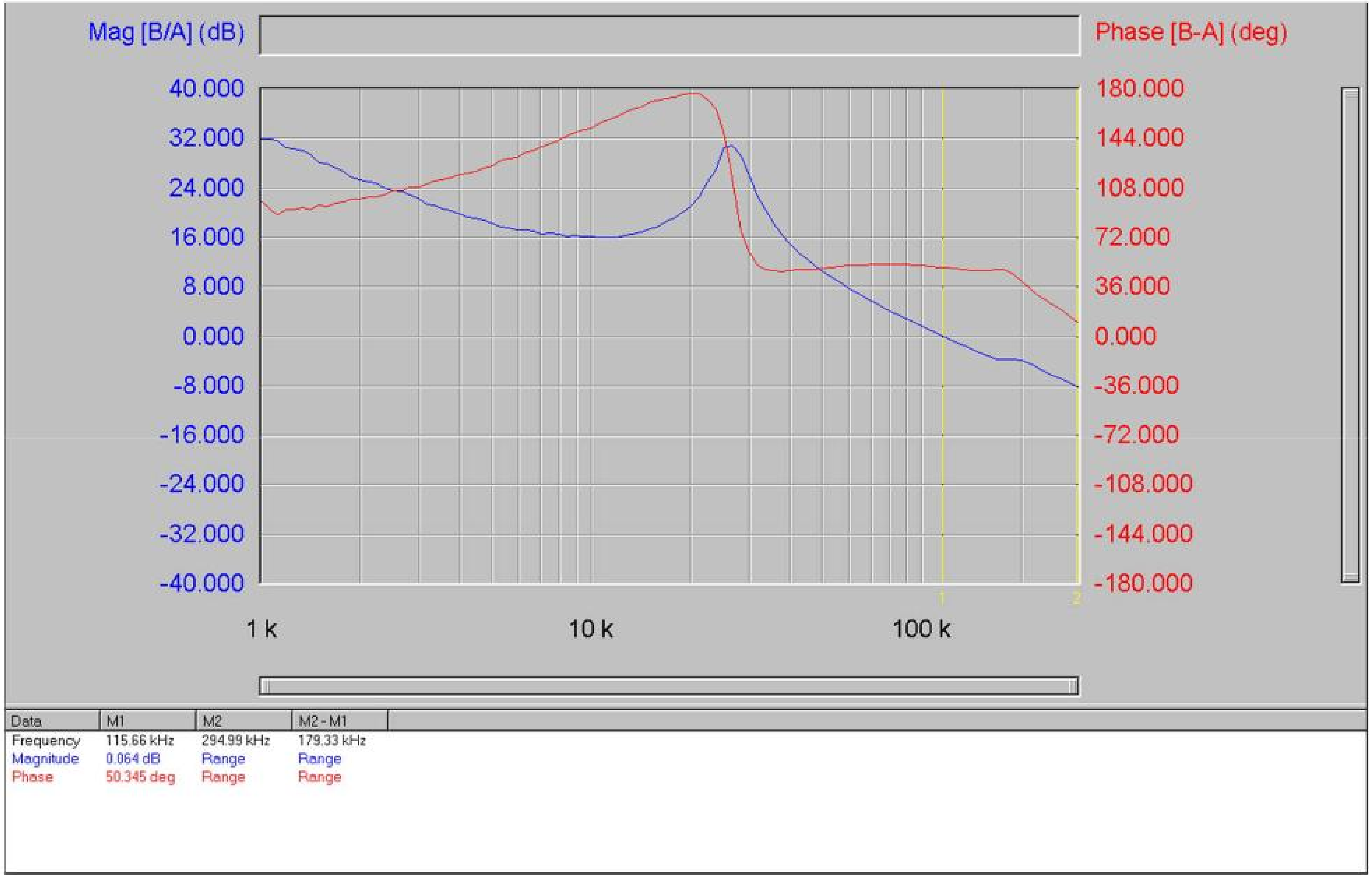
- Loop analysis performed at 2.7A, 3A and 4A



Feedback Loop Analysis – Example Measurement

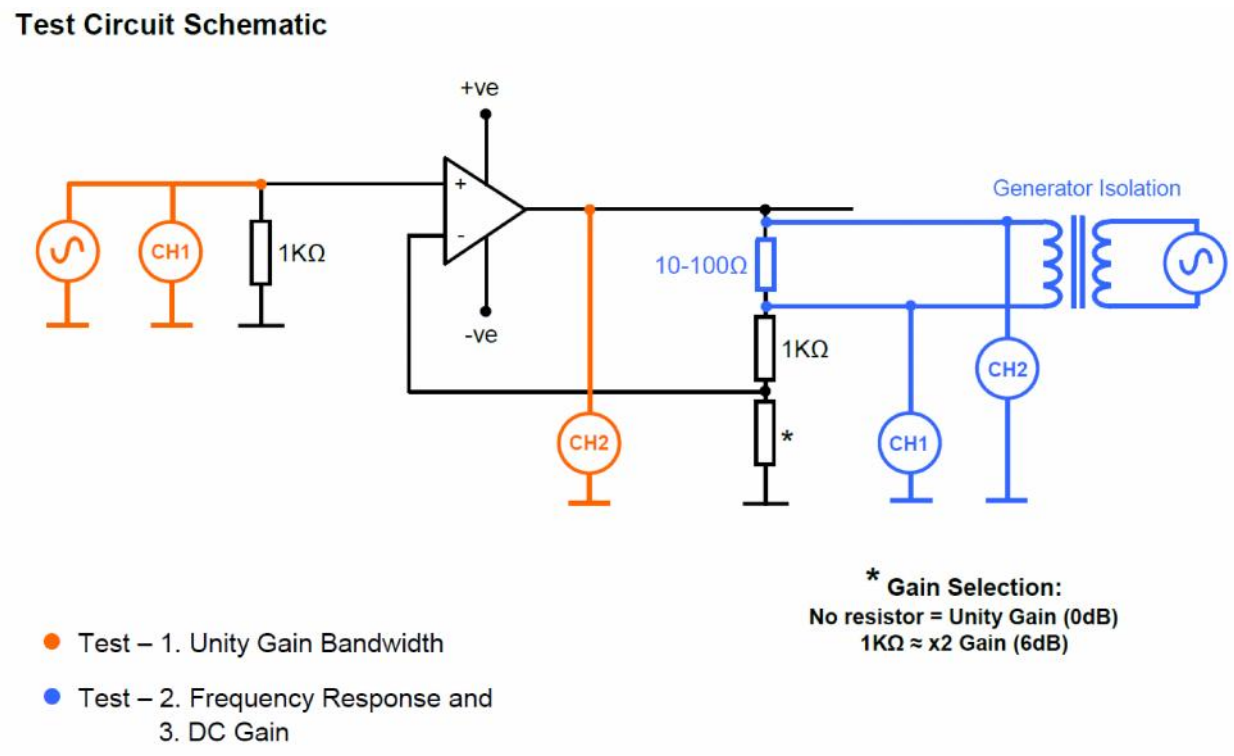
- Manufacturer states phase margin of 58deg
- Measurements obtained show 53deg

Manufacturer spec

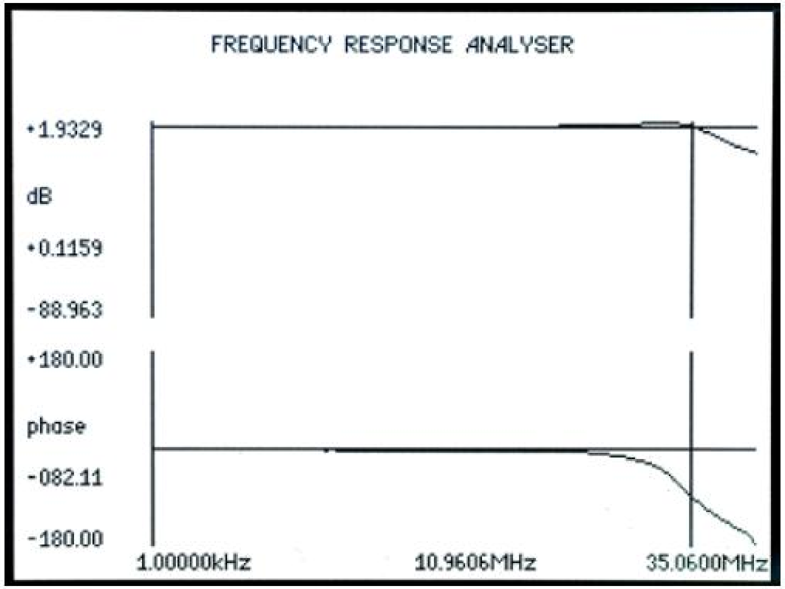


FRA Mode - Op Amp Analysis

- N4A Frequency Response Analysers are able to determine Op Amp performance
    - DC Gain
    - Bandwidth
    - Frequency Response



Unity Gain Bandwidth



Spec for NE5532 – Unity Gain to 10MHz

Test connections:	Generator	point E
	Channel 1	point E
	Channel 2	point A

Test conditions: Gain selection resistor - open

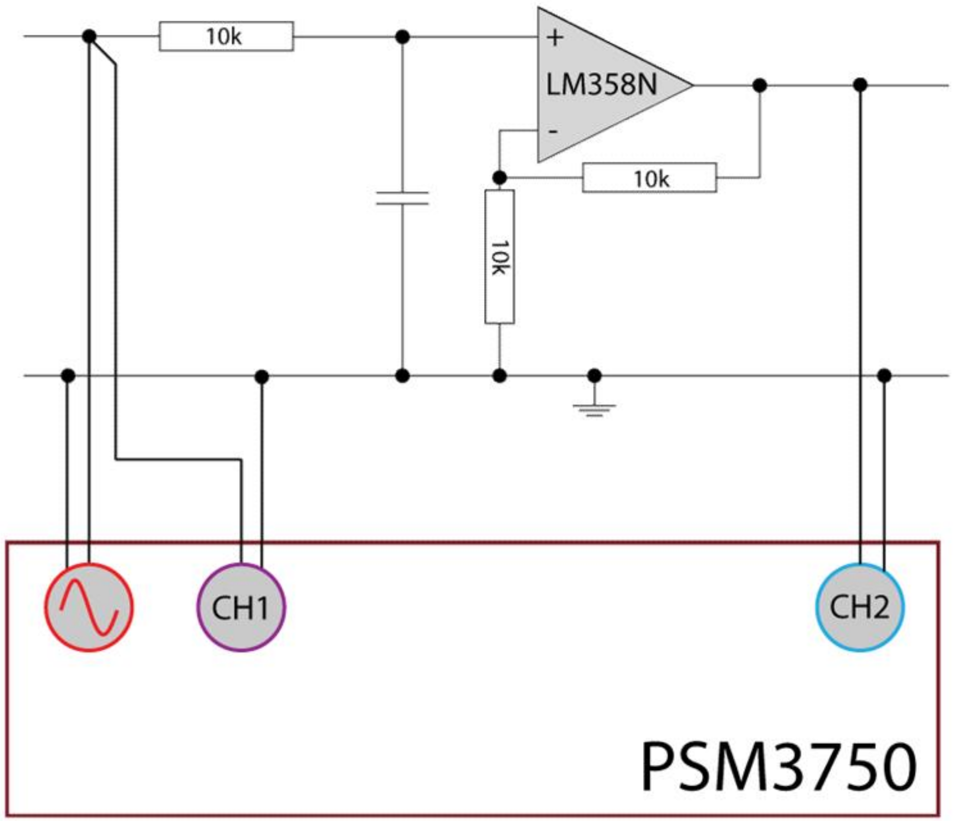
Signal	50mV
Speed	medium or slow
Coupling	ac
Bandwidth	auto

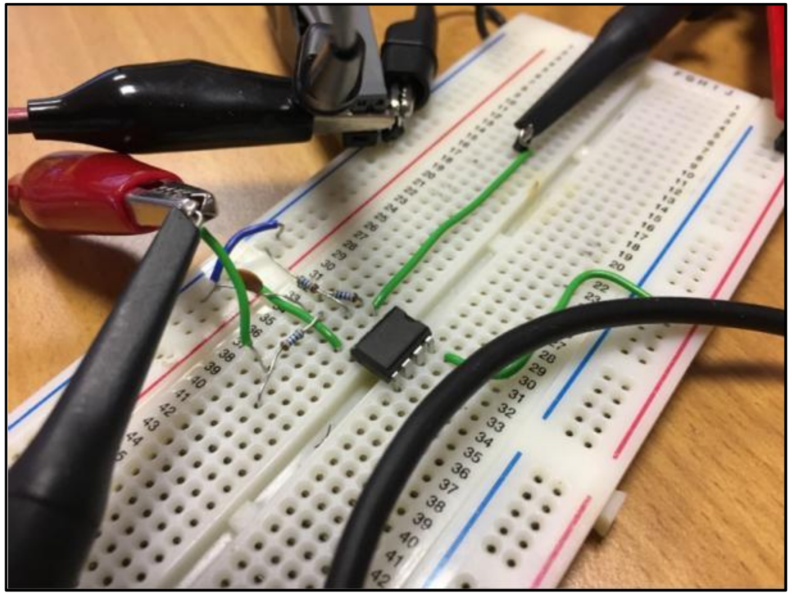
Sweep 1kHz to 35MHz
Oscilloscope probes x10
(x10 probe setting reduces the effect of probe capacitance)

Result: Unity gain maintained up to 10.96Mz

FRA Mode – Active Low Pass Filter Design

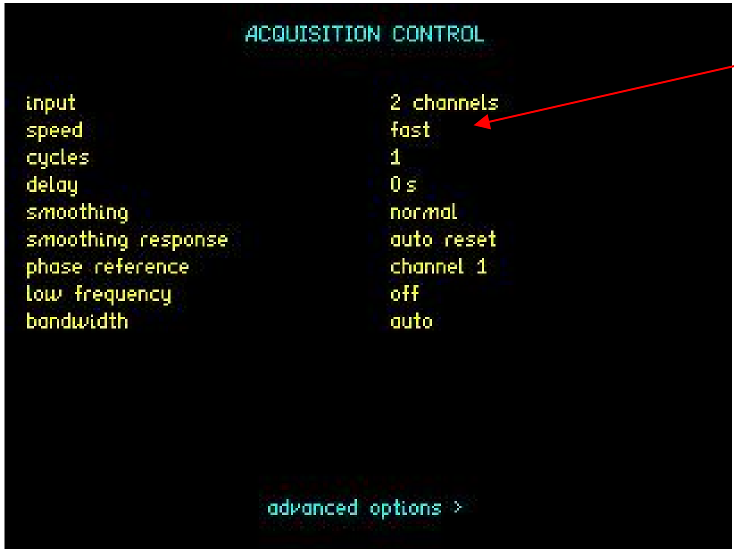
A simple use for FRA mode is for the design of filters, in this example an active filter based around the Texas Instrument LM1458 was analysed for both gain and phase characteristics. The filter was designed to have a DC gain of 2 and a cut off frequency of 15.9kHz



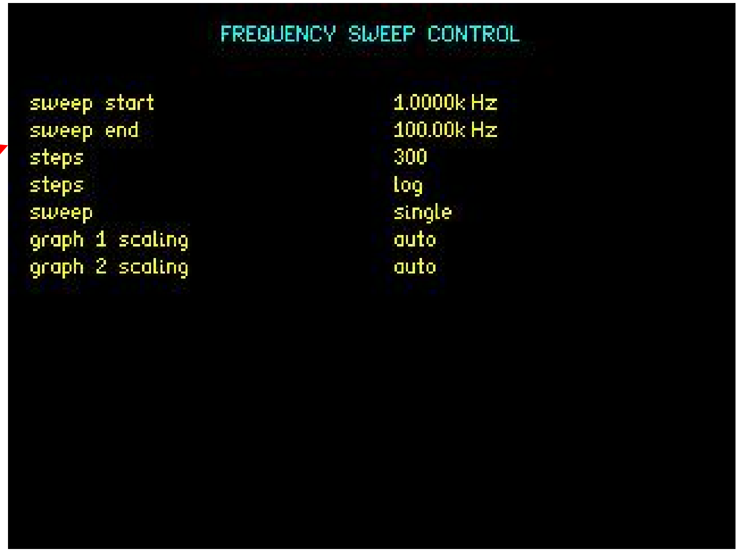


FRA Mode – Active Low Pass Filter Design

- DC gain +6dB
- -3dB Cut-off frequency : 15.92kHz
- Single order roll off : 20dB/decade

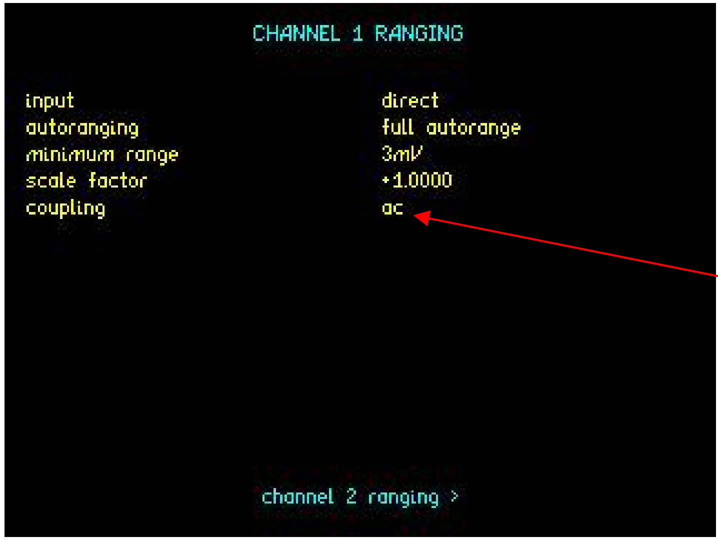


Speed set to fast

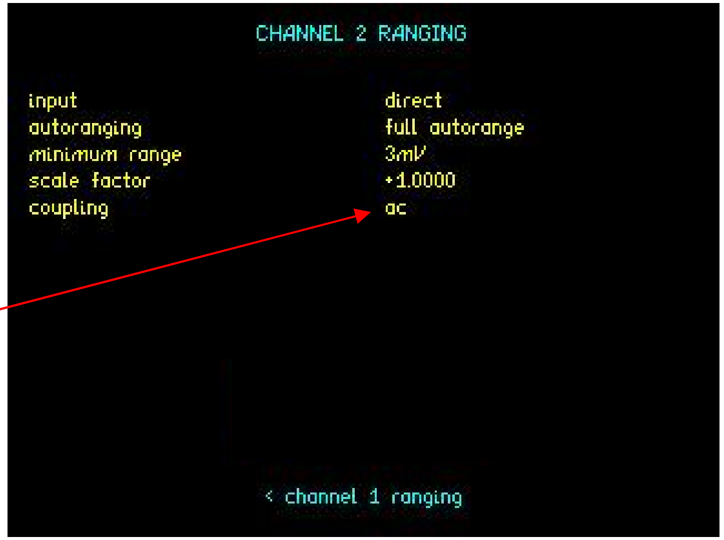


1kHz ~ 100kHz
300 steps

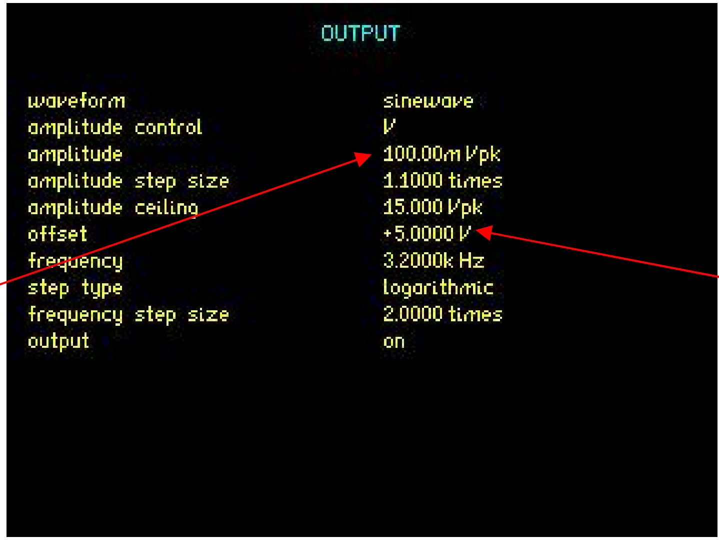
FRA Mode – Active Low Pass Filter Design



AC coupling allows PSM to range on AC signal only – improving accuracy

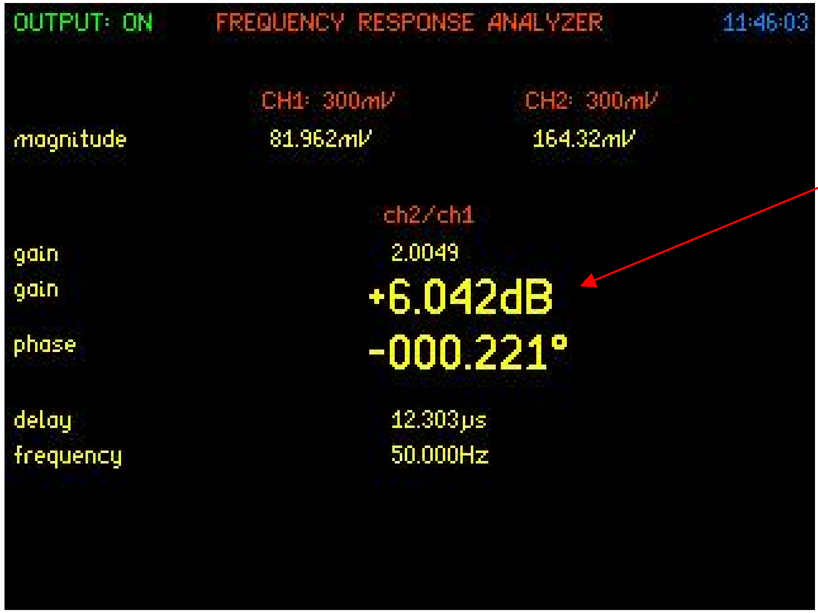


100mV, 500mV and 1V injected in 3 separate sweeps



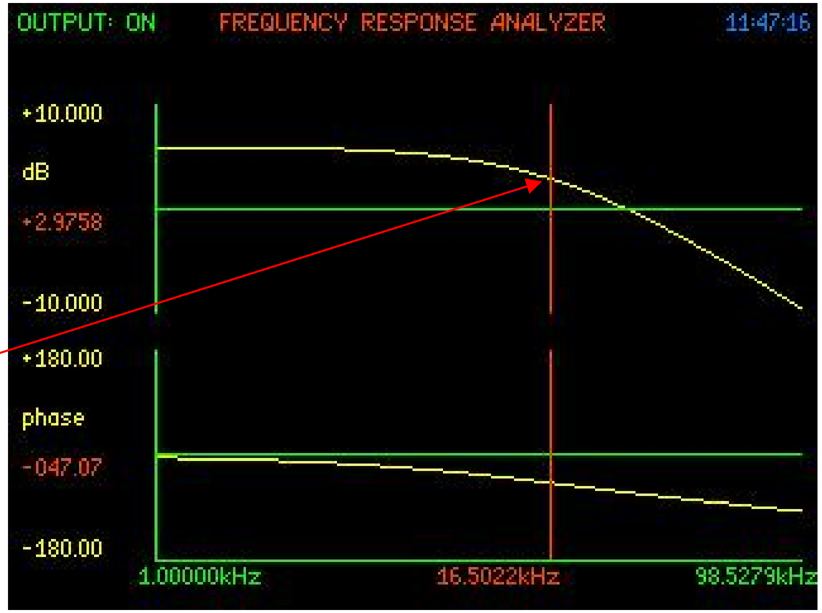
5V DC offset to account for single supply to LM358N (0~15V rails)

FRA Mode – Active Low Pass Filter Design



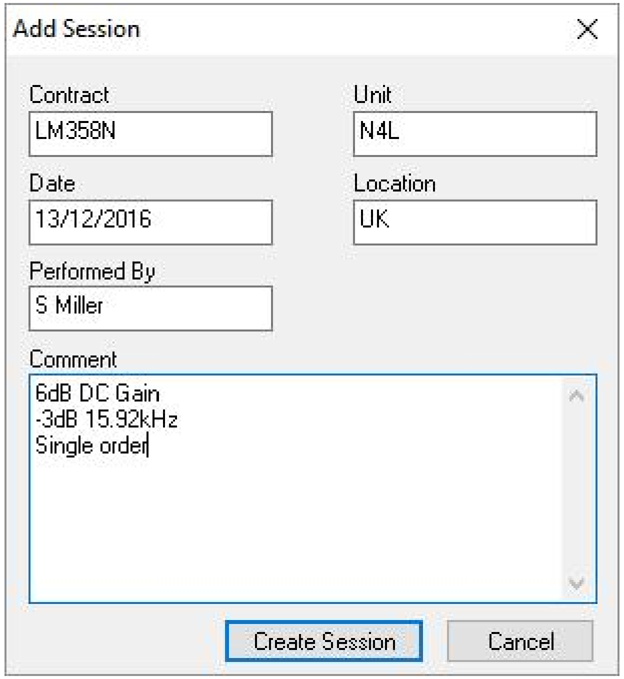
At low frequencies, +6dB gain as expected

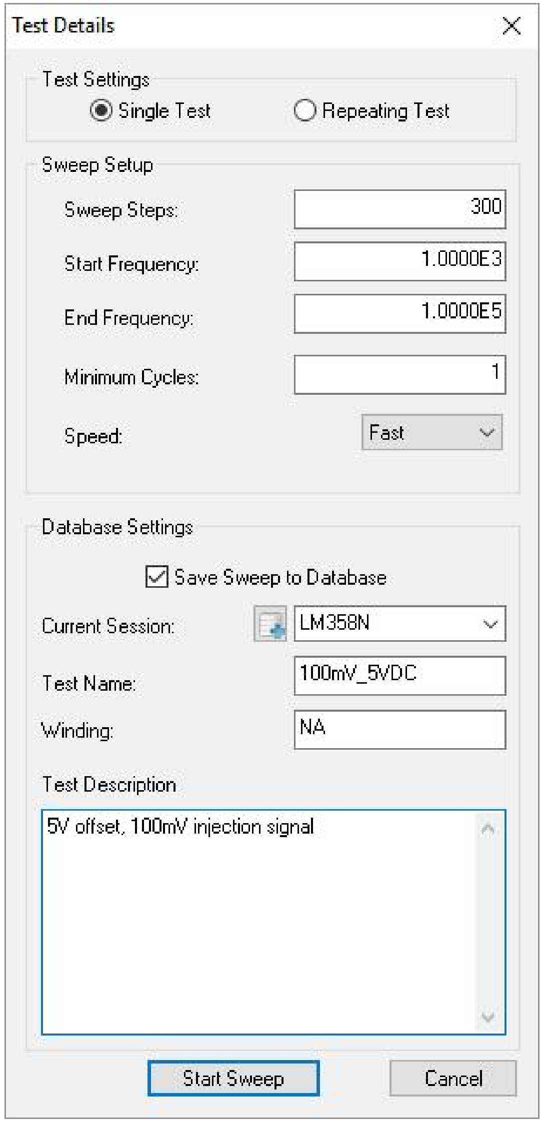
Notice phase shift of 0.22deg @ 50Hz



-3dB @ 16kHz approx.

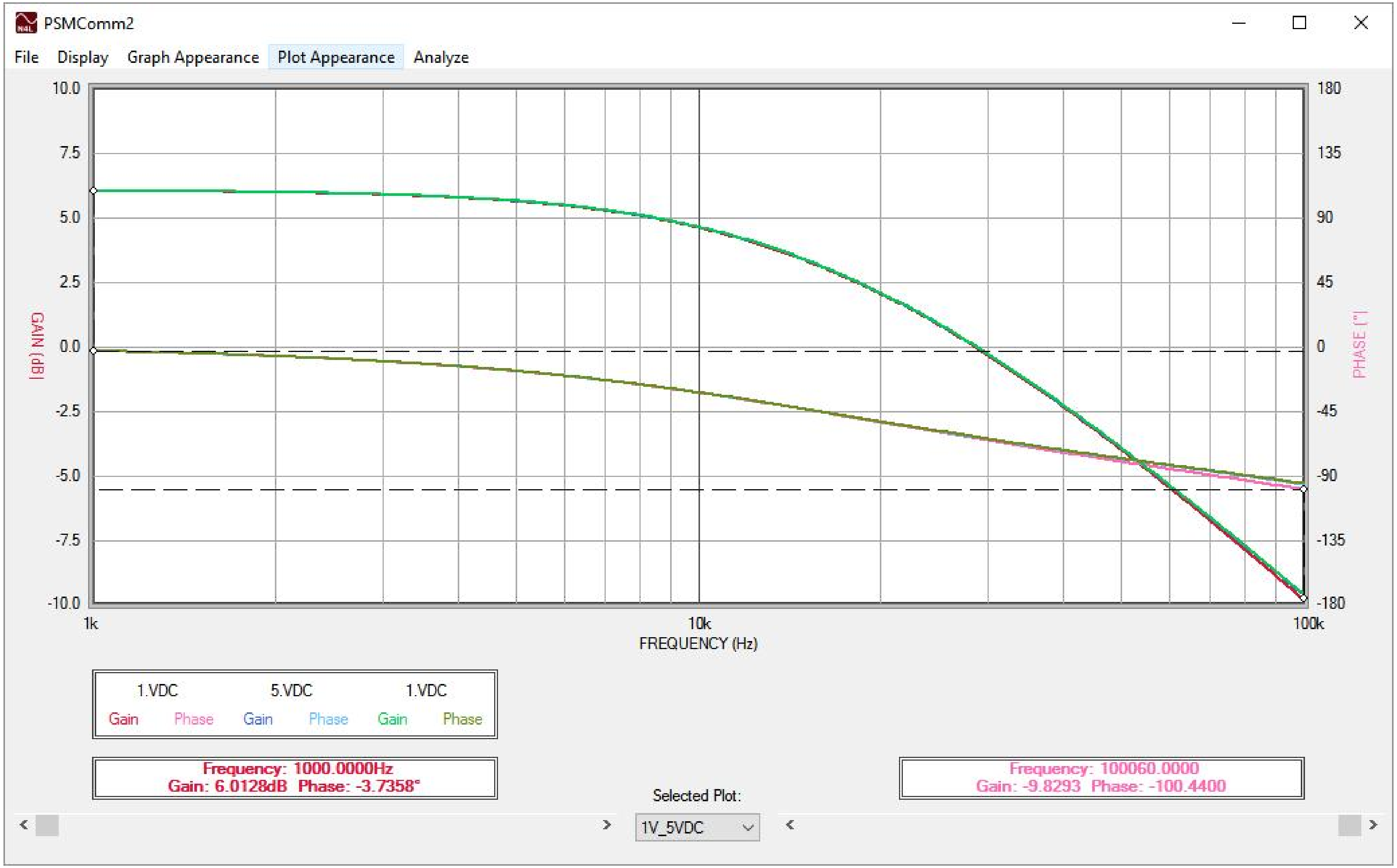
FRA Mode – Active Low Pass Filter Design





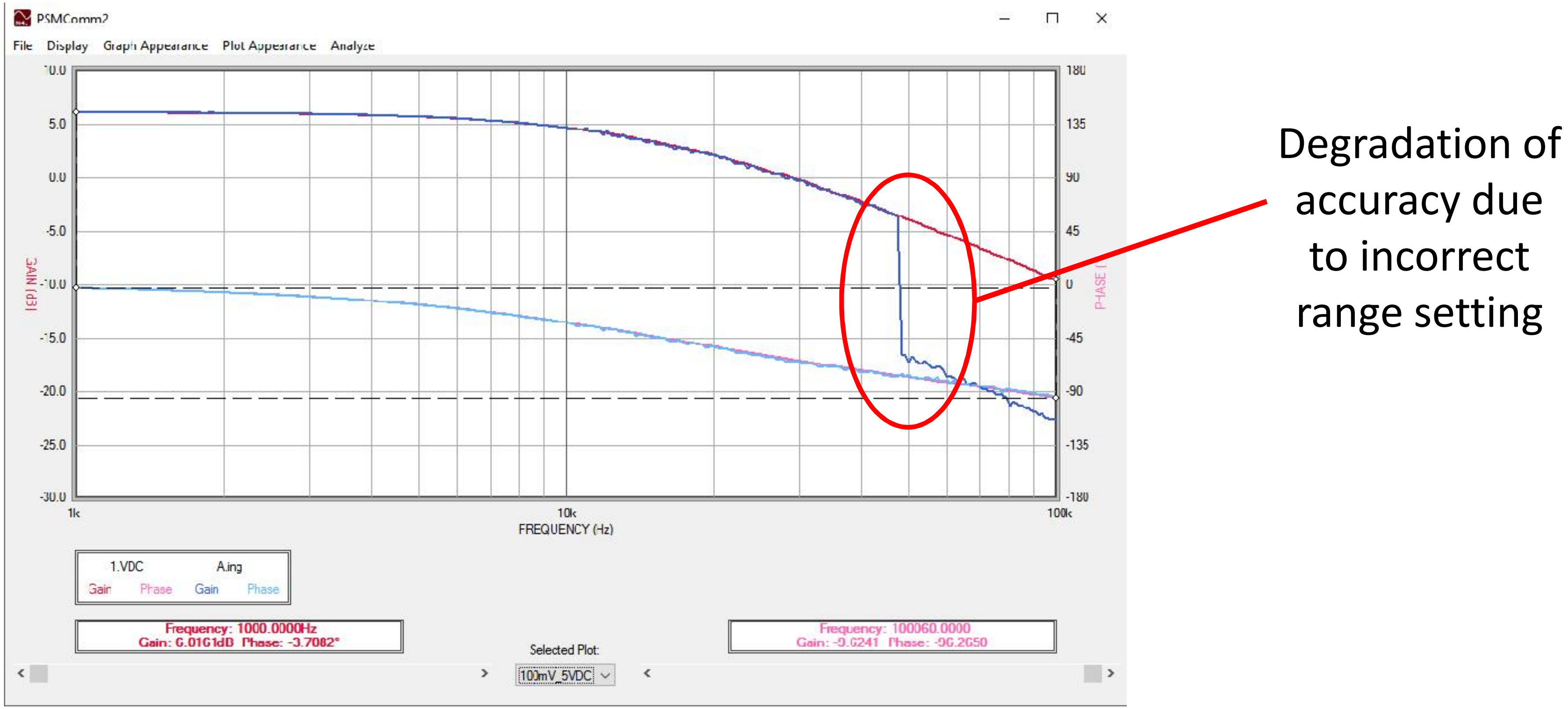
- Create new test session within PSMComm2
- Enter details for 100mV test
- Commence sweep

FRA Mode – Active Low Pass Filter Design



FRA Mode Ranging – Common mistakes

- It is unlikely there is a requirement to measure the DC offset in FRA mode
- Set coupling to AC
- PSM will range onto the AC component only
- Improving accuracy and signal sensitivity

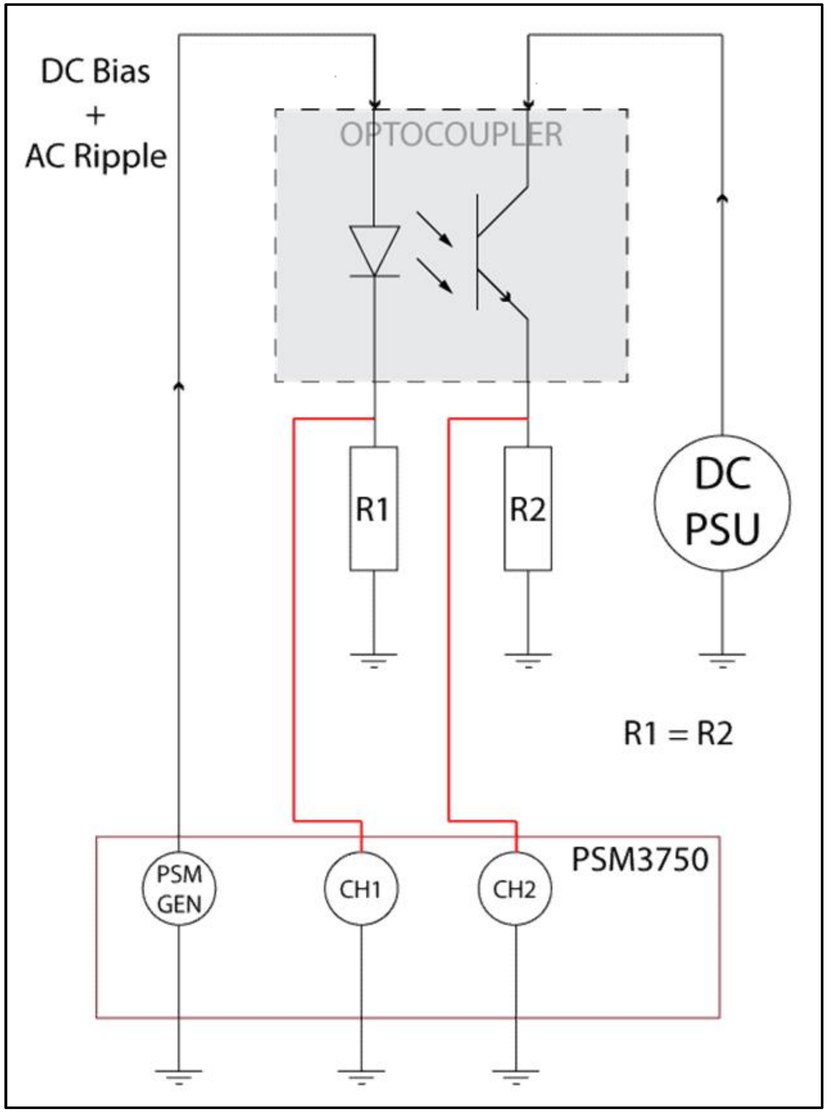


FRA Mode – Optocoupler Evaluation

- The PSM FRA mode can be used to evaluate Optocoupler performance
- Optocouplers within feedback loops affect the loop response due to frequency roll off and delays
- FRA can provide evaluation of CTR (Current Transformer Ratio)

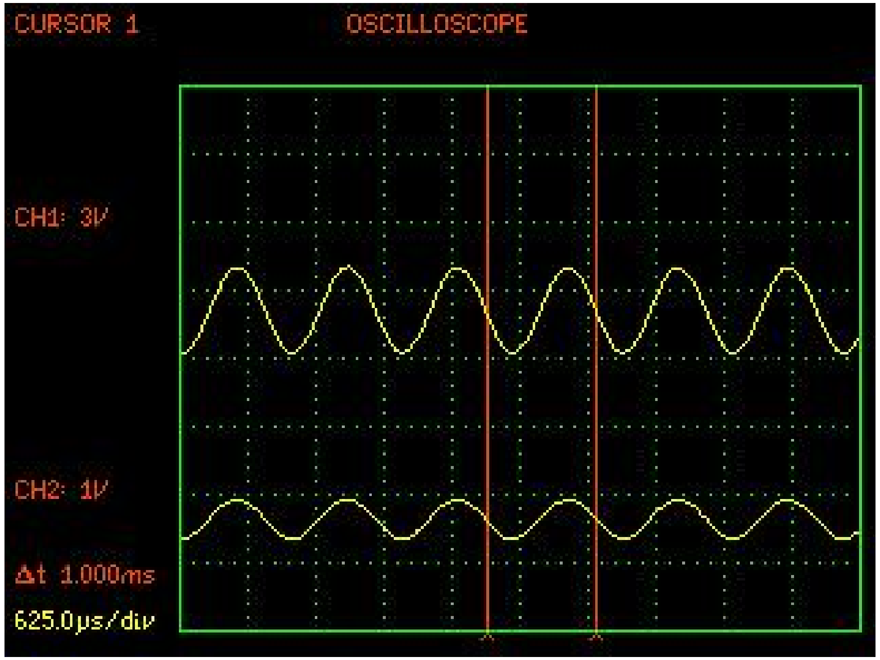
$$(\%) = 100 * — \qquad \text{If R1} = \text{R2}\,,$$

$$\text{CTR}(\%) = 100 * \frac{\text{V}}{\text{V}}$$



Scope Mode – Sanity checks

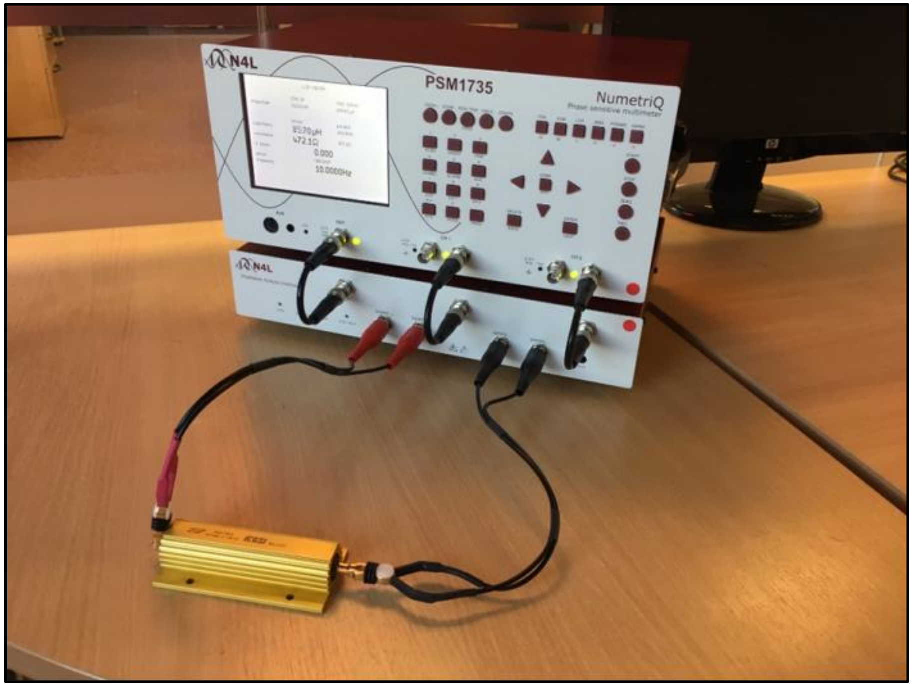
- FRA instruments do not traditionally feature an oscilloscope
- The PSM3750 includes a 3 channel oscilloscope
- Handy reference for "sanity checks" to verify presence of AC, DC and waveform composition.



LCR Mode – A High Accuracy Wideband Impedance Analyzer

- It is easy to forget that the PSM range can be coupled with an IAI/IAI2 Impedance analysis module
- Converting the PSM into a high performance Impedance Analyser
- Measure Inductance, Capacitance, Resistance, Tan delta, Q, conductance, impedance ….. Etc ….. Etc

The wide ranging applications and vast breadth of measurements the PSM+IAI combination offers should to be covered in a dedicated presentation…..



Thank you for listening