Introduction to RF measurements and instrumentation

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Content

- RF power measurement
- Spectrum analyzers
- Vector network analyzers
RF power measurement

- Most popular methods to measure the RF power
  - **Diode envelope detection**: Most common, large dynamic range, suitable for constant signals
  - **Thermal**: Very accurate, limited dynamic range, ideal for complex modulated signals
  - **Electronic receivers**: Most complex, suitable for fast, pulsed signals
RF power measurement

- How to read specifications of a power sensor

Frequency range:
- Diode sensors ~10MHz
- Thermal sensors DC
- Pulsed sensors 50-100MHz

Power/dynamic range:
- Minimum and maximum power for your application.
- Values change typ. factor 1000+ between room temperature and superconducting state

External trigger and interface:
- Synchronized acquisition, USB interface, ethernet...
RF power measurement

• How to use a RF power meter

1. Set the frequency
2. Zero the offset
3. Connect sensor to the signal source
RF power measurement

Chose the desired measurement unit

If measuring through couplers/attenuators etc. set-up the offset for direct reading of the source power value, instead of measured power value.
RF power measurement

• Some comments:
  • The reading is noisier at the bottom of the dynamic range
  • The power sensor really burns when overloaded (very costly to repair)
  • Sensors have optimized dynamic range for type of measurements they do (very accurate, very fast, RMS…)
  • Sensors and instruments need certain time to measure a data point, be careful with automation
  • Decide what to buy based on how are you going to use the instrument: Table top, USB sensor, Ethernet sensor…
Spectrum analyzer

• Spectrum analyser is a device, which measures frequency content of a signal.
Spectrum analyser user interface

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Spectrum analyser user interface

X axis, frequency span: **Span**

Center frequency: **Center**

Start

Stop
Spectrum analyser user interface

Y axis, 1 square (/division)

Y axis, full scale 10 square
Set by: Amplitude/scale
Spectrum analyser user interface

Other important settings

- Ref Level: -10.00 dBm
- Att: 0 dB
- SWT: 19 ms
- RBW: 500 Hz
- VBW: 500 Hz
- Mode: Auto FFT

1Sa AvgLog
Spectrum analyser user interface
Spectrum analyzer user interface
Spectrum analyzer user interface

Screen + Soft keys

Frequency and amplitude

Markers and advanced

RF input
Spectrum analyser user interface
• IF detector bandwidth – resolution bandwidth

• Receiver signal bandwidth prior the power detector

• IF/resolution bandwidth defines the measurement noise floor AND how close two different signals can be in order to still distinguish them

Noise floor

Sweep time
Resolution bandwidth

Different signals
• IF detector bandwidth – resolution bandwidth

• Receiver signal bandwidth prior the power detector

• IF/resolution bandwidth defines the measurement noise floor AND how close two different signals can be in order to still distinguish them
Real time spectrum analyzer

Multiview Real-Time Spectrum

- Ref Level: -53.40 dBm
- RBW: 6.25 kHz
- Meas: High Resolution
- SWT: 30 ms
- Dwell Time: 30 ms

1 Real-Time Spectrum

CF 940.0 MHz
Span 20.0 MHz

2 Persistence Spectrum

CF 940.0 MHz
Span 20.0 MHz

2 Spectrogram

CF 940.0 MHz
Span 20.0 MHz
Signal demodulation by s.a.
Modern spectrum analysers
Vector network analyser

- Vector network analyser is a device, which excites a RF network and measures a response from its ports. All signals are measured as phasors.

If we know RFL and FWD we can calculate:
- VSWR
- S-parameters $S_{11}$, $S_{12}$
- Reflection coefficient $\Gamma$
- Impedance $R+jX$
- Admitance $Y+jB$
- Input matching

If we know TRN and FWD we can calculate:
- Gain, attenuation
- S-parameters $S_{21}$, $S_{22}$
- Transmission coefficient $T$
- Group delay
- Phase shift
Vector network analyser
Vector network analyser

- How does the VNA measure?
  - Send signal from port 1 and measure the response at port 1 and port 2
Vector network analyser

- How does the VNA measure?
  - Send signal from port 1 and measure response at port 1 and port 2

\[ S_{11} = \frac{A}{R} \]
Vector network analyser

- How does the VNA measure?
  - Send signal from port 1 and measure response at port 1 and port 2

\[ S_{21} = \frac{B^-}{A^+} \]
VNA user interface

Menu bar

X Axis, typ. Frequency
Start/stop
Center/span

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VNA user interface

Y axis, measured parameter
VNA user interface

Instrument status, calibration, reference etc.
VNA user interface

Calculation of a derived parameter using the measured trace
Setting up process…

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Few notes on IF bandwidth

- VNA uses a super-heterodyne receivers to measure the RF signals
- Same noise handling procedures as for the spectrum analyser apply
IF (detector) bandwidth

- Bandpass filter measurement, $f_c=1\text{GHz}$
IF (detector) bandwidth

- Bandpass filter measurement, $f_c=1\,\text{GHz}$
IF (detector) bandwidth

- Bandpass filter measurement, $f_c=1$GHz

IF bandwidth 1kHz
IF (detector) bandwidth

- Bandpass filter measurement, $fc=1\text{GHz}$
IF (detector) bandwidth

- Bandpass filter measurement, fc=1GHz

Noise floor for IFBW=100kHz

Noise floor for IFBW=10Hz
IF (detector) bandwidth

- Bandpass filter measurement, fc=1GHz

IF bandwidth 10Hz

Plus averaging
Measurement errors and calibration

- The instrument always shows some curves...

- ...but in 99% cases this is not what you want to measure
Measurement errors and calibration

• “Hello Daniel, this is Nikolai. We are trying to measure the 1.3GHz superconducting cavity but the instrument shows something strange…”
Measurement errors and calibration

- We work in the RF domain
- The instrument measures our DUT
- …but also everything around (cables, connectors, adapters, spurious reflections etc.)
- …and the instrument is sensitive to temporal alignment of the signals as well
- …finally the instrument also measures himself
Measurement errors and calibration

- All networks which connect DUT to the instrument introduce static systematic errors.

- We can measure them and mathematically de-embed them from the measurement.

- This process is called Calibration.
Measurement errors and calibration

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- We can measure them and mathematically de-embed them from the measurement
- This process is called **Calibration**
Measurement errors and calibration

- Directional coupler measurement without and with full calibration
Calibration process

- 3 standards: Open, Short, Load + Thru

E5070B / E5071B

Through connection

Open  Short  Load  Open  Short  Load

Load  Load
Thank you for your attention

After the break: hands on part