REF LEVEL     FREQUENCY     FREQ SPAN/DIV

-20DBM     3.00GHZ     MAX

100     REF

-10

75     -20

-30

50     -40

-50

25     -60

-70

L I N %     ⟶+f     L O G dB

| 10DB/ VERTICAL DISPLAY | T | 10DB RF ATTENUATION | 3.0-7.1 FREQ RANGE | INT REFERENCE OSCILLATOR | 1MHZ RESOLUTION BANDWIDTH |
|---|---|---|---|---|---|

# Spectrum Analyzer Measurements

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# Contents

# 1   Introduction

Modern spectrum analyzers is a sophisticated instrument for making frequency-domain measurements of continuous wave (CW) and modulated signals. While there are many measurement options and analysis modes built into these instruments, basic usage skills are critical for making a valid measurement. Even with sophisticated algorithms the GIGO rule (garbage in — garbage out) still applies.

   In this laboratory exercise you will start from very simple basic signal measurements. Time permitting, you will transition to more elaborate measurement techniques. The goal is to familiarize you with the instrument we will be using in this class. For RF work, a spectrum analyzer is an indispensable tool in the laboratory and in the field, so you need to be fluent in its capabilities and controls.

# 2   Lab Equipment

In this lab you will use the following equipment

1. Agilent N9010A spectrum analyzer

2. Agilent N5181A signal generator

**WARNING: RF input connector of a spectrum analyzer is the most expensive part of the instrument. Behind that connector is an RF signal processing chain optimized for wide dynamic range and stability. As a result, that signal chain is easily damaged by excessive signal levels. Pay good attention to the warnings on the front panel. Start all measurements of unknown signals with maximum internal RF attenuation. If there is any risk of exceeding the maximum specified power level (typically $+30$ dBm), use external attenuation. Consider both average and peak power — this is especially relevant in accelerator settings where we often need to measure very short pulses. Finally, consider DC level of you signal. Spectrum analyzers do not tolerate DC!**

# 3 Exercises

## 3.1 Measuring a Known Signal

We will start from a very simple exercise, measuring a CW signal, known in advance.

1. Press `Preset` on N5181A signal generator. The display should show the maximum frequency (6 GHz) and the minimum output level.

2. Set frequency to 500 MHz by pressing `Freq`, `500`, `MHz`.

3. Set output level to 0 dBm by pressing `Amptd`, `0`, `dBm`. Do not connect the output of the signal generator to the spectrum analyzer yet.

4. Press `Mode Preset` on N9010A — this will give us a known starting point.

5. Press `AMPTD Y Scale`, `10`, `dBm` to set the reference level to 10 dBm.

6. Press `FREQ Channel`, `Center Freq`, `500`, `MHz` to set the center frequency to 500 MHz.

7. Set the span to 10 MHz by pressing `SPAN`, `10`, `MHz`.

At this point you should see the signal on the screen. To measure the amplitude of the signal, press `Peak Search`. This turns on a marker and places it on the highest amplitude signal. Both frequency and amplitude of the marker appear in the display block in the upper-right of the screen.

In order to measure the frequency more precisely, you can reduce the span in decade steps. Note that the analyzer will change the resolution bandwidth automatically as you reduce the span.

### 3.1.1 Questions

1. Record the measured signal frequency: _____

2. Is the measurement in agreement with the setting of the signal generator? If not, can you guess what is causing the error?

## 3.2  Measuring an Unknown Signal

In this exercise you will have to determine what is the amplitude and the frequency of the signal being generated by the synthesizer. Each group member needs to do this individually in turn. We will position the signal generator so that its display is not visible to the person working with the spectrum analyzer. For each group member the rest of the group will pick a frequency and a power level and set those on the N5181A, after disconnecting the RF cable between the generator and the analyzer. The person at the spectrum analyzer controls should locate the signal and determine its amplitude and frequency.

To find the unknown signal prepare the spectrum analyzer as follows:

- Set frequency span to maximum.

- Set RF attenuation to make sure spectrum analyzer is not damaged when you connect the RF cable.

How do you set the attenuation? In normal (factory preset) mode, the analyzer will adjust RF attenuation automatically, based on the setting of the reference (top of the screen maximum) level. Since we know that our signal source is N5181A generator with +13 dBm maximum output level, it is sufficient to set the reference level to a value above +13 dBm and to make sure that `Mech Atten` setting is in `Auto` mode (press `AMPTD Y Scale`, `Attenuation` to bring it up).

Inspect the spectrum to identify the signal. If you see nothing, that might mean that the signal is too small and is at the noise floor at current resolution bandwidth and radio frequency (RF) attenuation. Since you see no large signals, it is most likely safe[1] to reduce the reference level and the RF attenuation with it. Step down the reference level in 10 dB steps — you should see the noise floor drop by 10 dB each step, until you reach minimum attenuation setting.

If at this point the signal is still not visible, we need to reduce the displayed noise floor further, by lowering resolution bandwidth. Press `BW` to adjust resolution bandwidth. Use arrow keys to reduce the bandwidth in

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[1]In certain cases the signals can have large peak levels, but very low narrowband power — a beam position monitor (BPM) signal is a good example. In this case we are safe, since the generator is set up for a CW signal.

steps. You don't want to go too low here, since the lower is the resolution bandwidth, the longer is the sweep time.

If at this point you should see the signal. Zoom in on the center frequency to get faster sweeps at lower resolution bandwidth. If the signal is still not there, talk to one of the instructors or the teaching assistant.

### 3.2.1 Questions

1. Record measured signal frequency: _____

2. Record measured signal amplitude: _____

3. Check the settings on the signal generator and record the differences between your measurements and the settings:

   - Frequency error: _____
   - Amplitude error: _____

## 3.3 Signal Harmonics

While it would be nice to have an ideal signal generator with an output consisting of a single-frequency perfectly stable sine wave, in reality we have to deal with all sorts of imperfections. One of such imperfections is the output distortion. As discussed in the lecture today, periodic distortion of a sinewave signal produces harmonics of the signal frequency [2].

In this exercise we will study the harmonic content of N5181A signal generator operating at 500 MHz. Set output amplitude of the generator to 0 dBm and frequency to 500 MHz. Set spectrum analyzer to 0 dBm reference level and make sure the attenuation is in `Auto` mode. Set the frequency range to go from the fundamental to the fifth harmonic (make sure both of these frequencies are included, leave some margin on each side to clearly resolve the signal lines). Adjust resolution bandwidth to obtain a reasonable trade-off between sweep time and noise floor. Use peak search function to

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[2]You probably know already that the structure of the harmonics depends on the type of the distortion. Symmetric wave-shape distortion — for example, uniform positive and negative clipping — will produce only odd harmonics. Even harmonics show that there are differences between positive and negative parts of the waveform. More generally, nonlinear distortion function will produce only even harmonics if it is even (rectifier), odd - if odd (push-pull amplifier saturating), and a mix if it is asymmetric.

identify and record all visible peaks[3]:

Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____

Express the amplitude of the largest harmonic in dBc — dB relative to the carrier. Is it consistent with the signal generator specifications[4]?

Now let's zoom in on the fifth harmonic line at 2.5 GHz. Set mechanical attenuation to 0 dB. Now let's save the sweep data in trace 2. Press `Trace/Detector`, `Select Trace`, `Trace 2`, `Clear Write`. Wait for a few sweeps, so that the trace is valid and save it by pressing `Trace/Detector`, `View/Blank`, and selecting `View` (Update Off, Display On). Perform peak search and select `Marker Delta`. Now the delta marker shows the difference between stored trace 2 and active trace 1.

Set RF attenuation to 10 dB. What is the delta marker reading? If you see a shift of more than 1 dB, it indicates that the distortion you are seeing is, at least in part, created in the spectrum analyzer input chain.

Continue adjusting RF attenuation until the power level stops going down. Now you are seeing the true distortion level, as produced by the signal generator. Using this updated technique re-measure all harmonic lines, detectable above the noise floor:

Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____
Frequency: _____ Amplitude: _____

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[3]If some harmonics are not visible in the wide span mode, zoom close in ($\approx$100 kHz span)

[4]See the datasheet, available on class website, to determine what specifications apply here

# 4    Are You Done Early?

If you breezed through these exercises, you can find more ideas for interesting measurements in the "N9010A Spectrum Analyzer Mode Measurement Guide". Try working through sections 5: "Improving Frequency Resolution and Accuracy" and 11: "Demodulating AM Signals".

# 5    Further reading

Test and measurement equipment manufacturers have written many tutorials and applications notes on spectrum analyzers. After this class you should be able to follow their reasoning and suggestions at a fairly advanced level.

A good document to study is Agilent application note AN-150 ("Spectrum Analyzer Basics"). This 120-page document has plenty of useful information. A shorter AN-1286 ("8 Hints for Better Spectrum Analysis") is also useful.

# 6 Glossary

## Glossary

**beam position monitor (BPM)**

> An RF structure that couples to the beam in the accelerator. The output signal of such a structure allows measurement of the transverse or the longitudinal beam position. 4

**continuous wave (CW)**

> A signal of constant amplitude and frequency. 2, 4

**radio frequency (RF)**

> In the accelerator context, a constant frequency constant amplitude signal derived from or phase locked to the storage ring master oscillator. 4