ETH zürich

P&S: Our Daily Exposure to Electromagnetic Radiation

The Spectrum Analyzer

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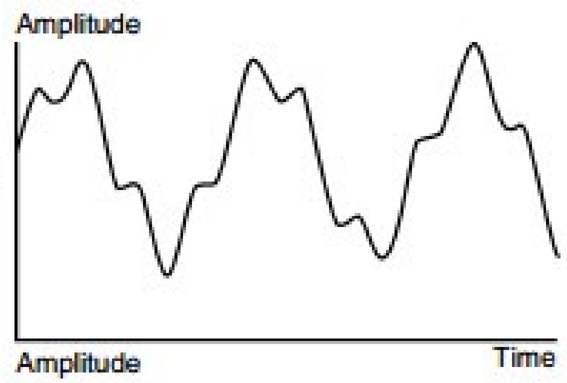
Today

- What is a spectrum analyzer and what is it good for?
- Working principle and implementation
- How to use a SA: Measurement settings:
  - Span, RBW, VBW, Sweep time, Attenuator…
- Limits of a conventional spectrum analyzer
- Practical measurement

Frequency Domain Measurements

- Radio electronics often deal with clocks, tones, and carriers…
- Periodic oscillatory waveforms can be interpreted as sum of sinusoids or cosines
- Spectrum Analysis = Separation of frequency components



Ref: http://machineryequipmentonline.com

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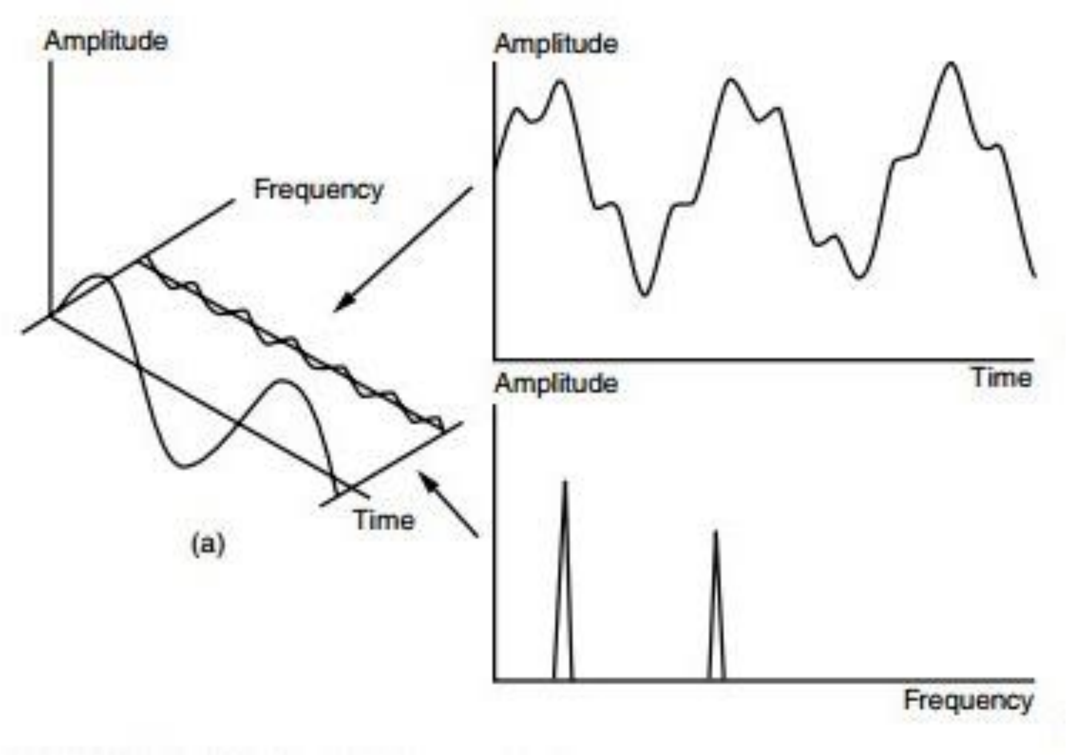

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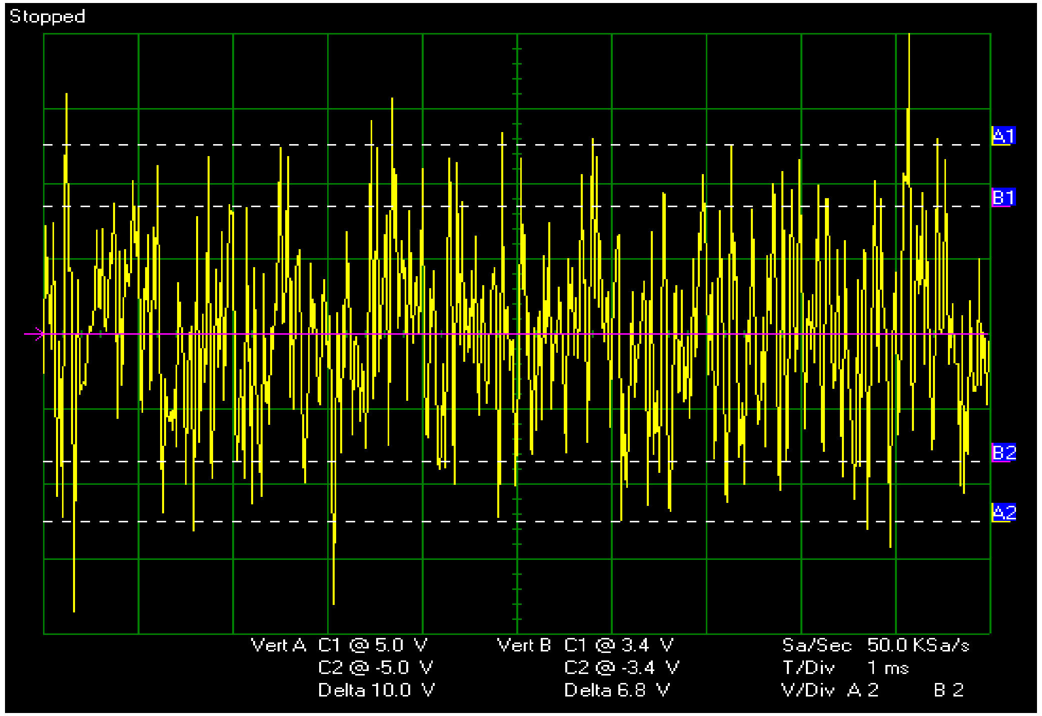
The RF spectrum analyzer

- Makes RF spectrum visible
- Overview of used frequency bands
- Enables frequency selective power measurements

Example:
Wideband RF measurement viewed in the **time domain**

Connecting a wideband antenna to an **oscilloscope** often looks like that:



The RF spectrum analyzer

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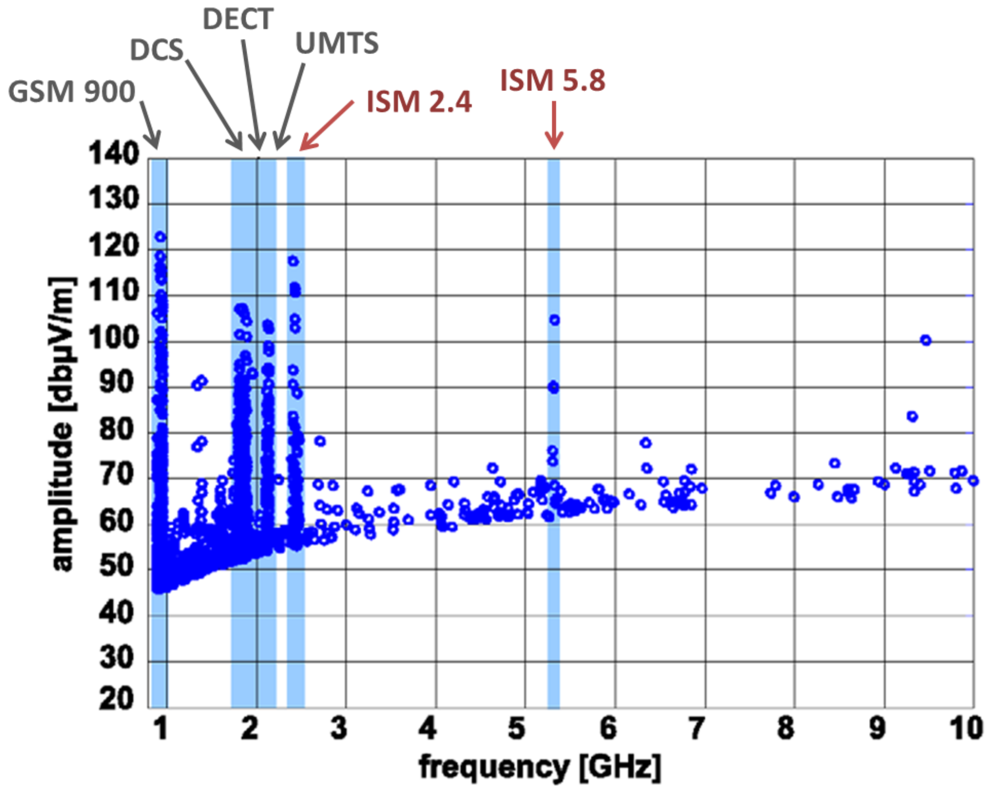
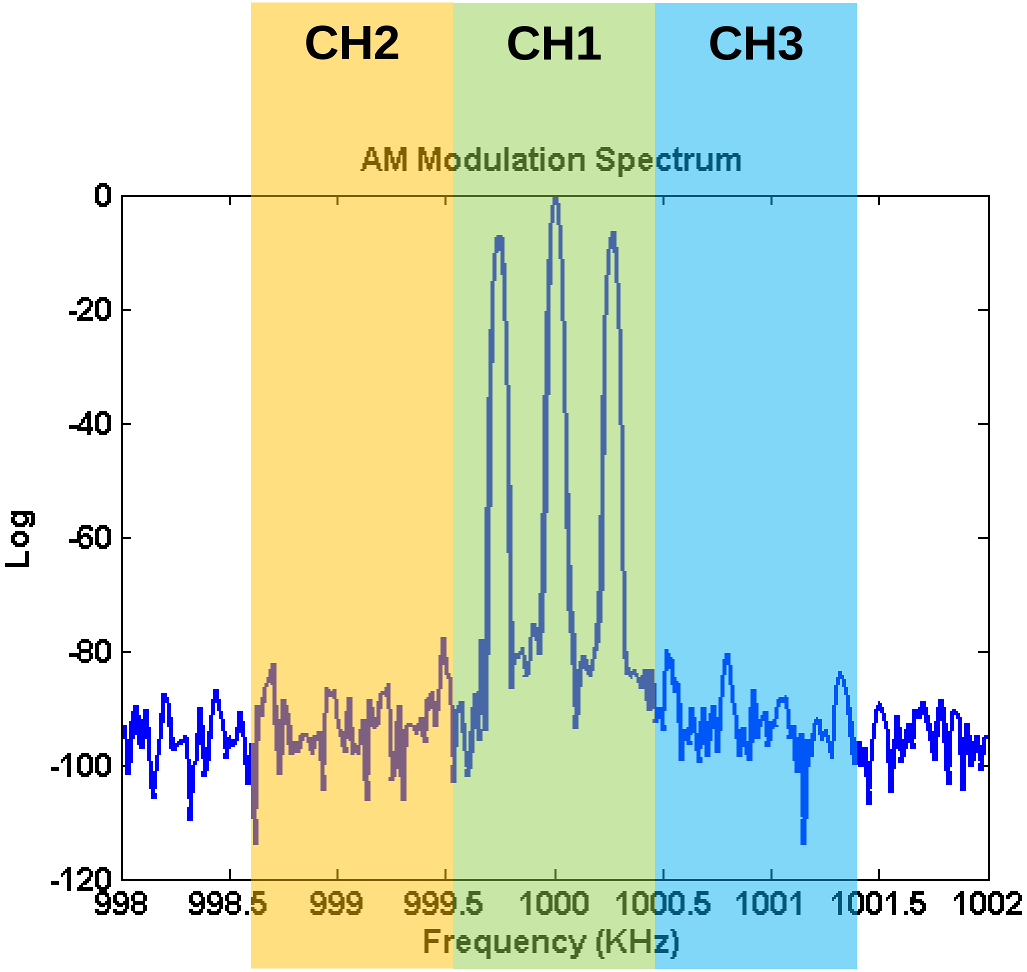
Example:
Wideband RF measurement viewed in the **frequency domain**

Connecting a wideband antenna to a **spectrum analyzer** reveals much more useful and detailed information:



The RF spectrum analyzer: Applications

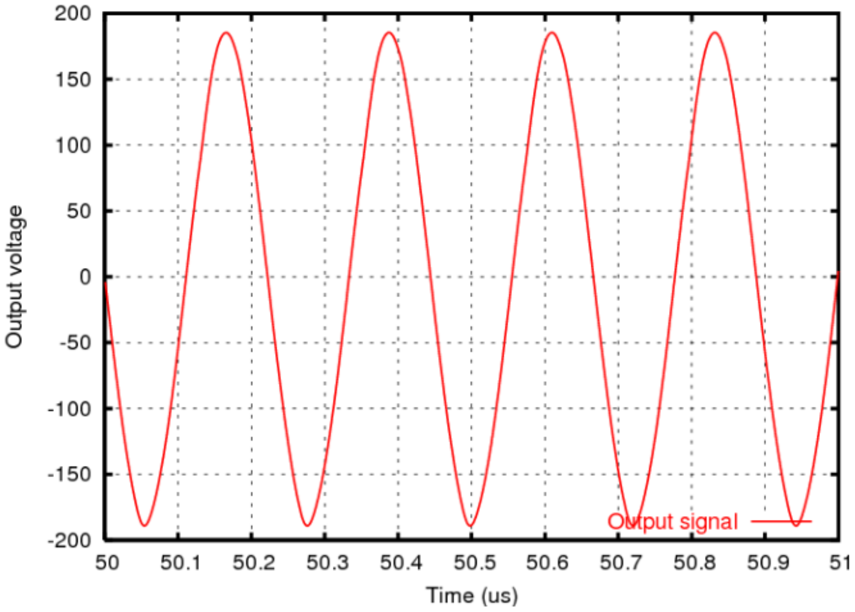
- Analysis of occupied bandwidth of modulated signals



The RF spectrum analyzer: Applications

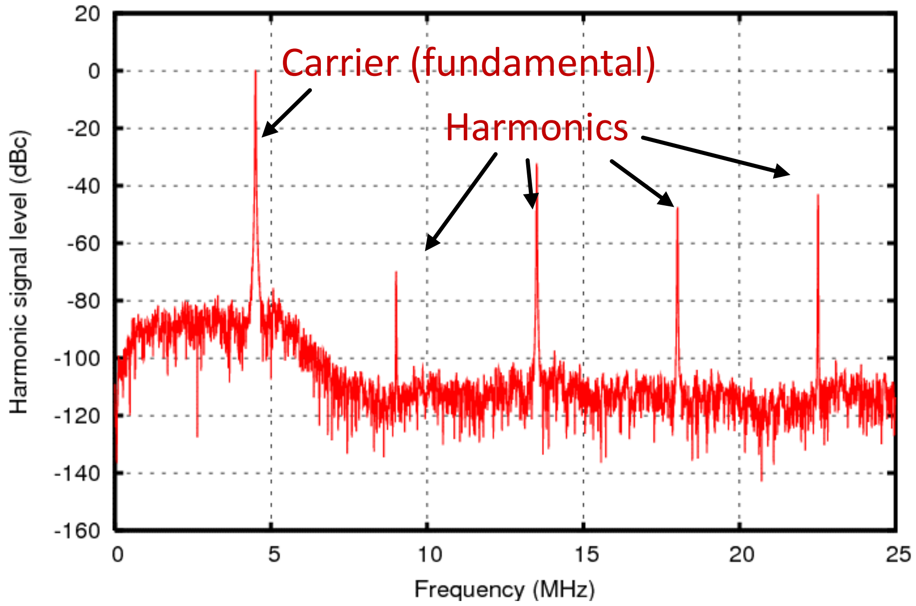
- Nonlinearities of signal sources and amplifiers:

Signal after (nonlinear) amplification:
Time domain view (e.g. oscilloscope)



dBc = dB relative to carrier (fundamental frequency)

Frequency domain (spectrum)



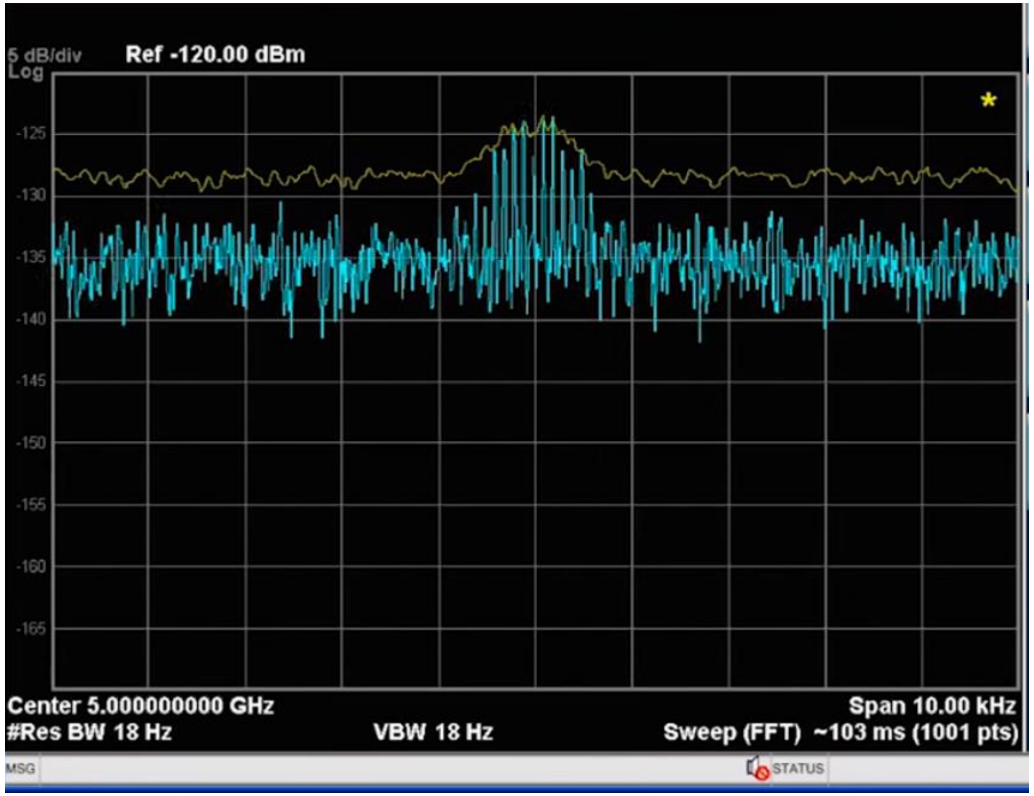
Harmonics at N x f0 can cause interference to other devices!

Harmonic content can be hardly seen in time domain but clearly visible in the spectrum (and using dB scale)

The RF spectrum analyzer: Applications

- Measuring very low power periodic signals
- Frequency selectivity and narrow measurement bandwidth enhances SNR

-135 dBm



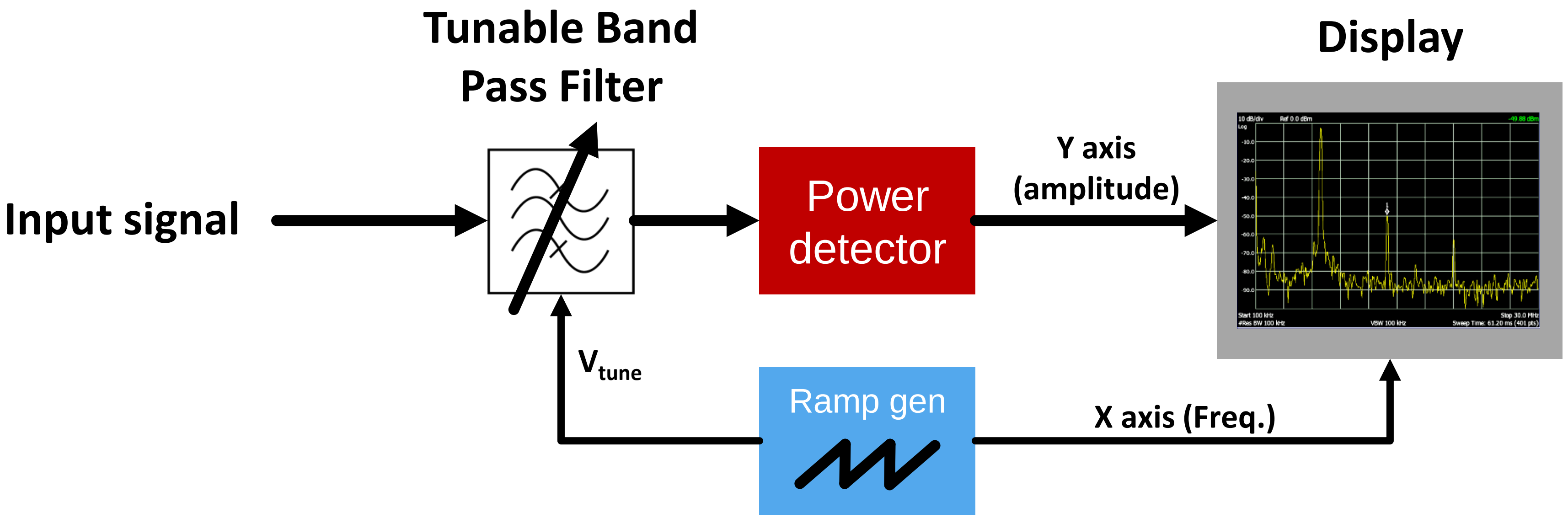
Theoretical measurement limit (noise floor) for a measurement at room temperature

Measurement BW	Noise power	RMS voltage (50Ω)
1 GHz	-83 dBm	28.3 µV
1 MHz	-104 dBm	0.9 µV
1 kHz	-144 dBm	28.3 nV
1 Hz	-174 dBm	0.9 nV

$$P = \mathrm{BW} \cdot T \cdot k_B$$

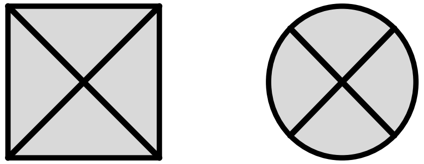
The spectrum analyzer: How does it work?

- Analyzes the input signal in the frequency domain
- Plots signal amplitude / power vs. frequency
- Basic implementation idea: **Sweeping tunable band pass filter**
- Problem: Wideband tunable BPF is extremely hard to implement



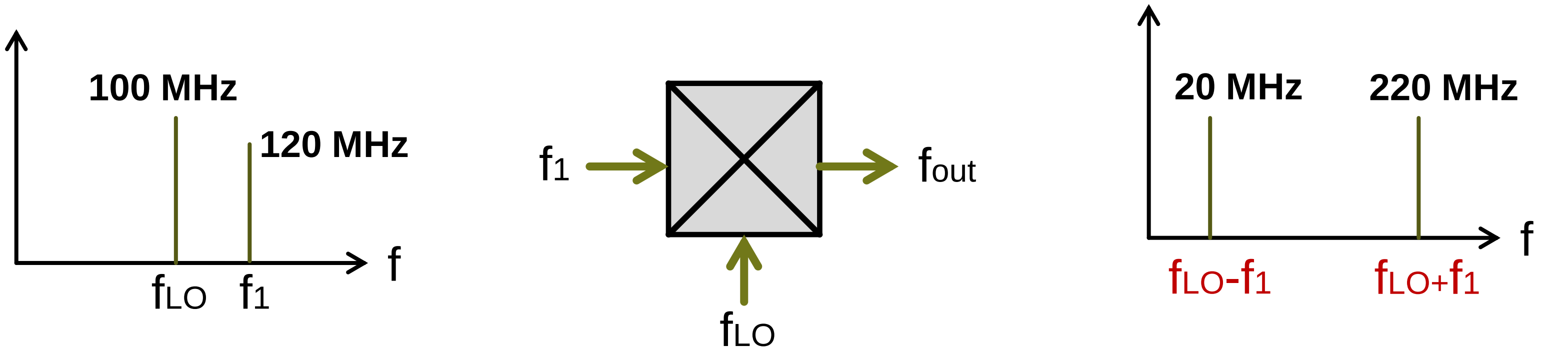
Frequency mixing

Mixer schematic symbol:



- (Ideal) Mixer: Multiplies two signals together
- Application: **Frequency conversion:**

$$A \cdot \cos(\omega_1 t) \cdot B \cdot \cos(\omega_{LO} t) = A \cdot B \cdot \left(\cos(\omega_1 t + \omega_{LO} t) + \cos(\omega_1 t - \omega_{LO} t)\right)$$



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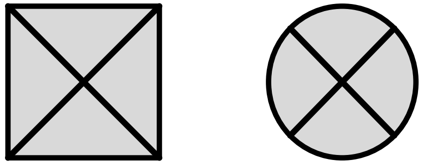
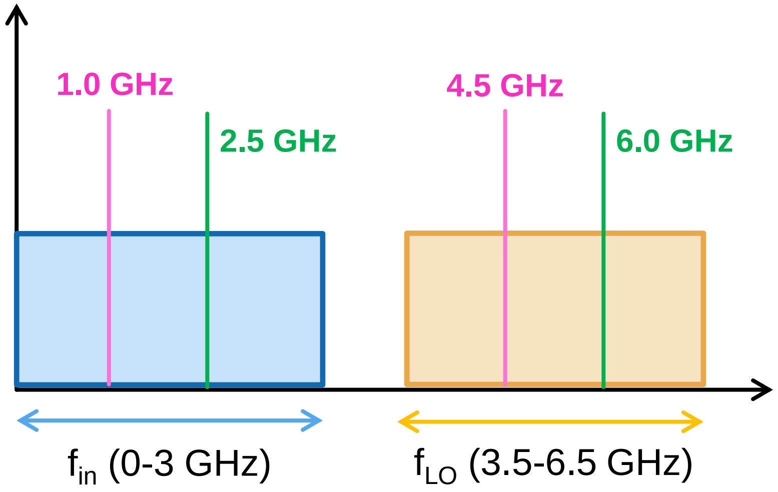
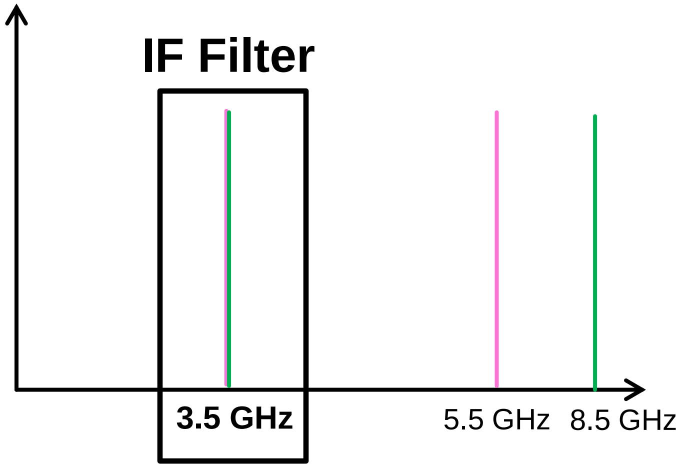


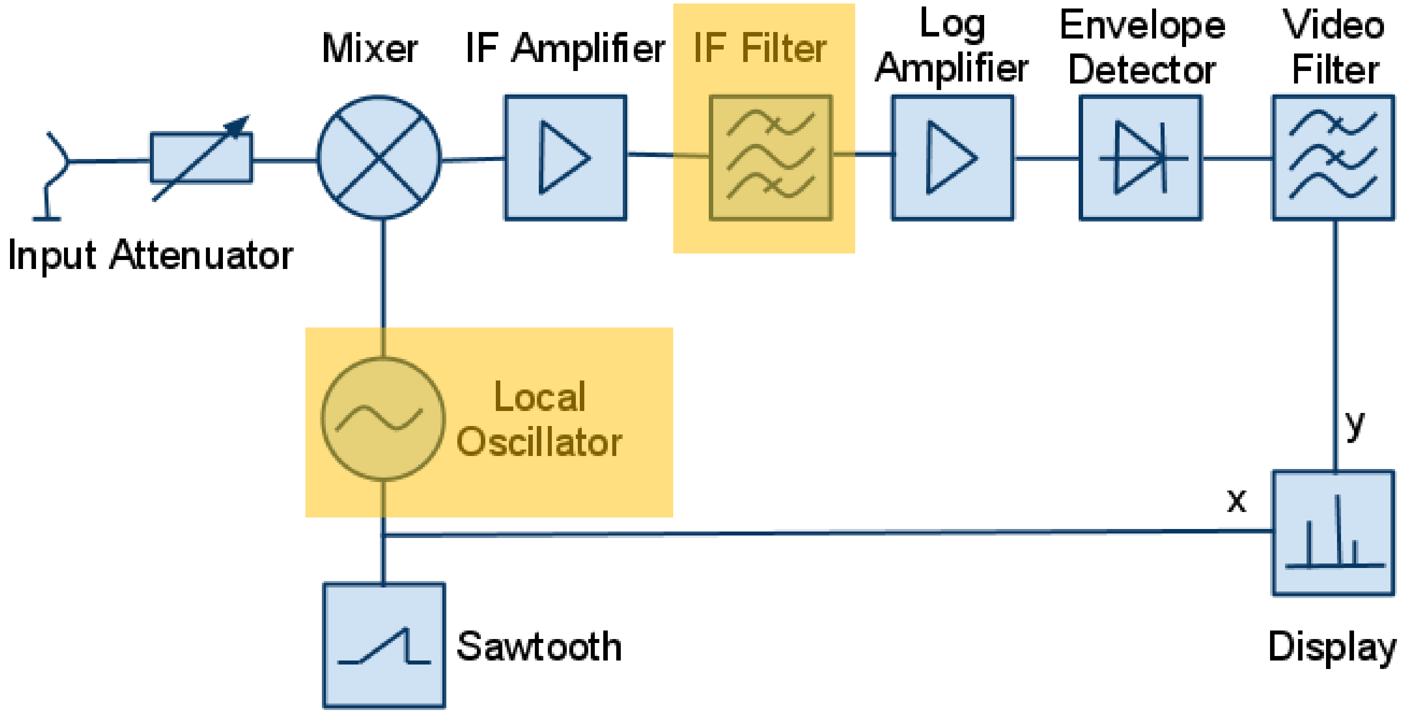
- Sweeping LO converts variable input frequency to fixed output frequency





Inside a spectrum analyzer

- Tunable band pass filter: Realized by tunable oscillator (LO) + band pass filter at fixed intermediate frequency (IF)



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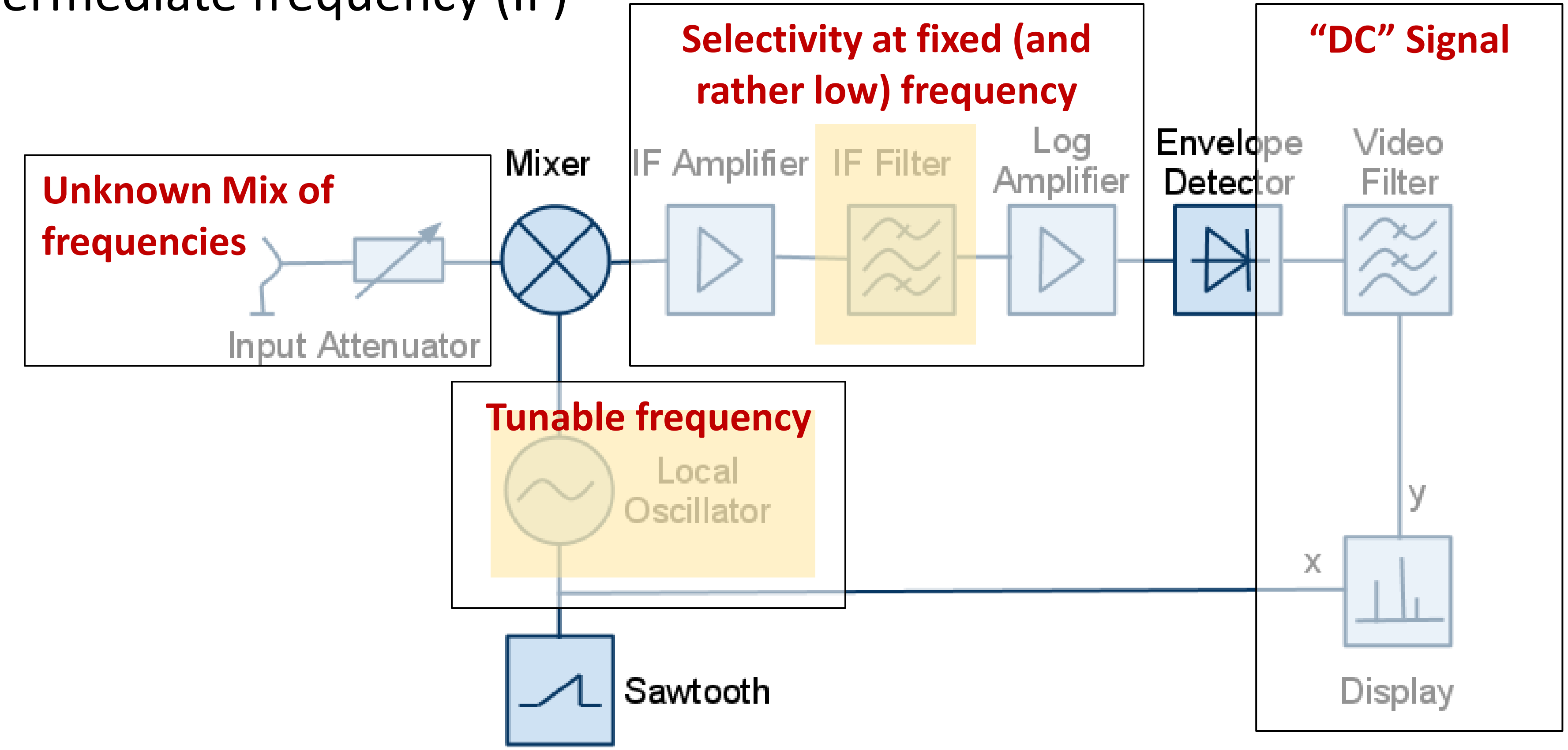
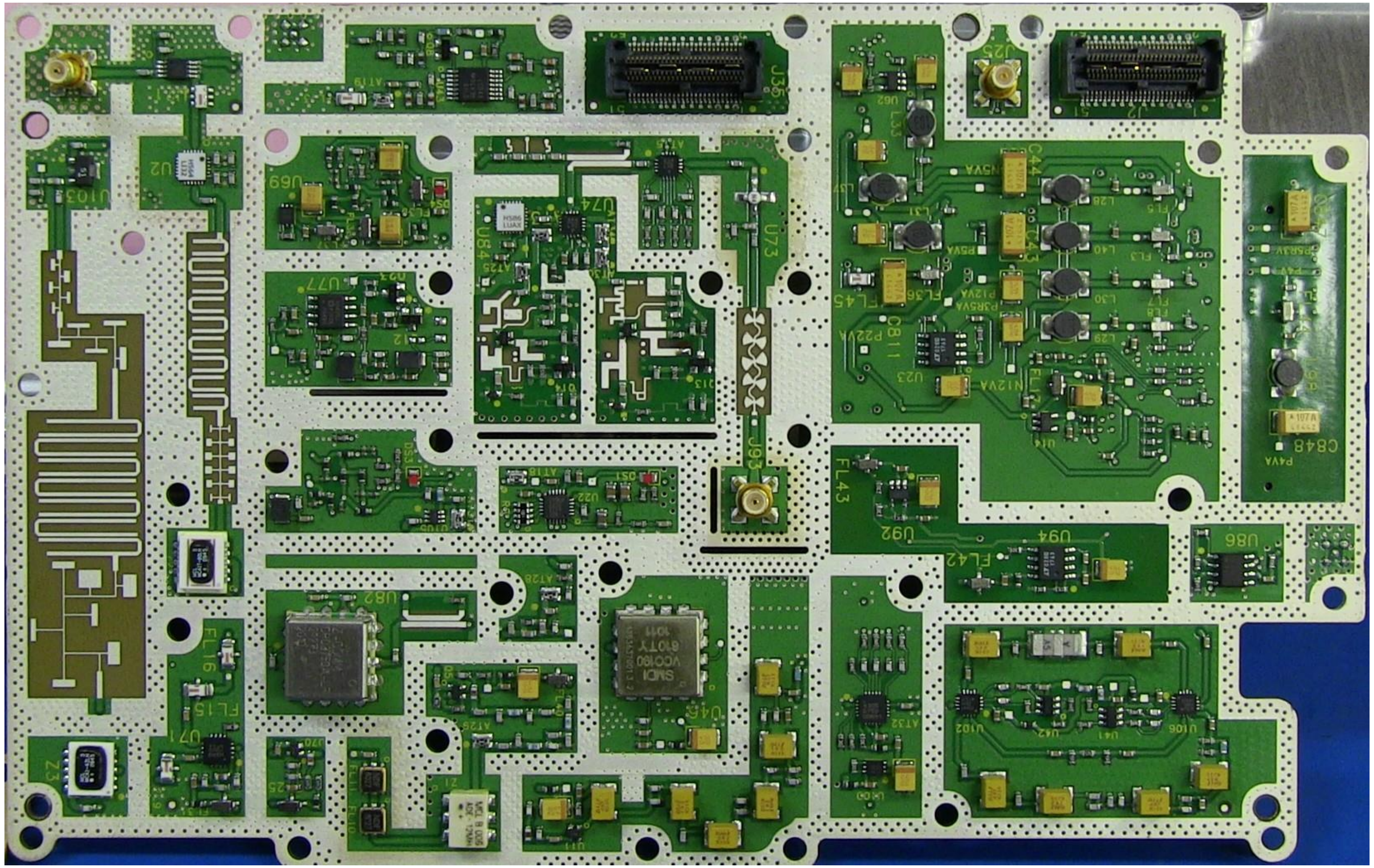


Inside a spectrum analyzer



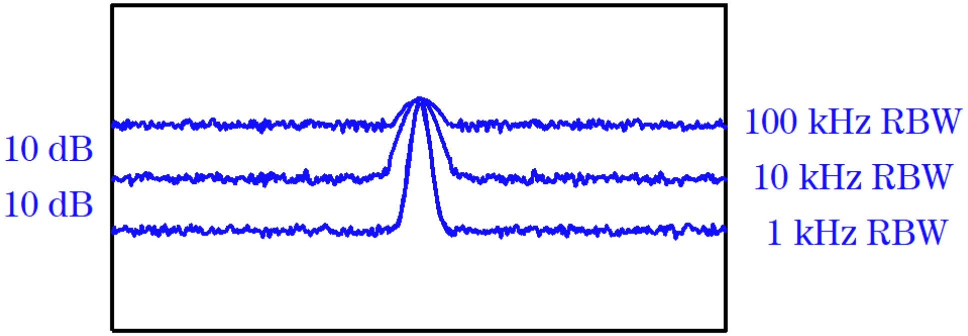
Agilent N9344C (9 kHz to 20 GHz handheld spectrum analyzer)

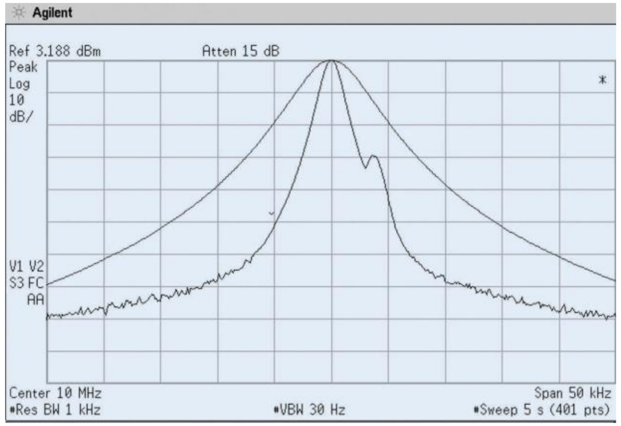
Spectrum analyzer

User settings

1. Resolution bandwidth

Defines the bandwidth of the tuned filter





Narrow RBW:

+ Higher spectral resolution
+ lower noise floor (less noise power / band)

– Long sweep times
– Modulated signals
– Signal bursts easy to miss:

2. Video bandwidth

Averaging/smoothing of the detected signal power on the display (video)

Large Video BW:

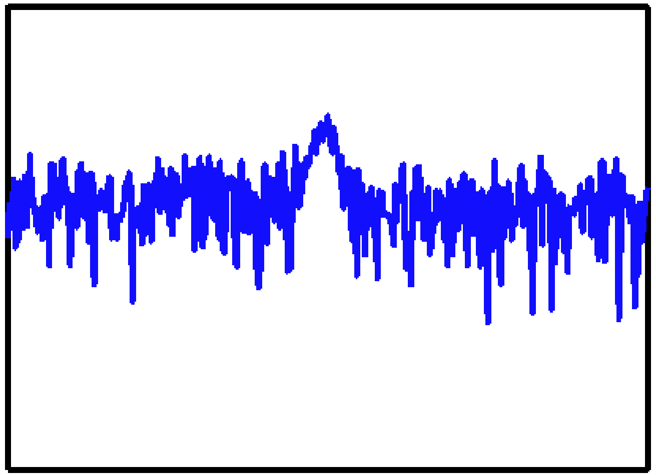
+ Fast sweep (only limited by RBW)

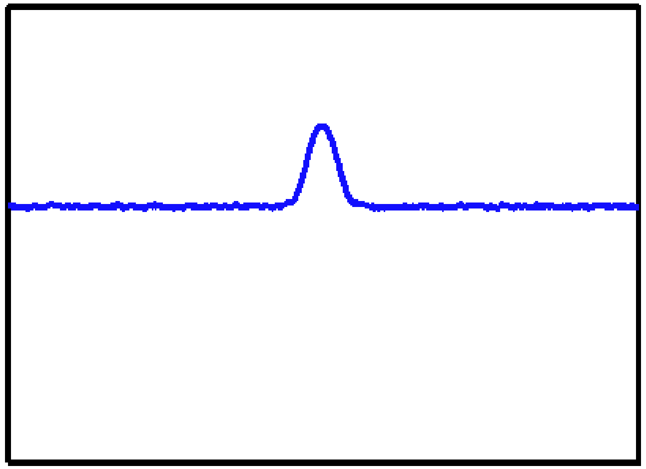
- Rough and bumpy noise floor

Narrow Video BW:

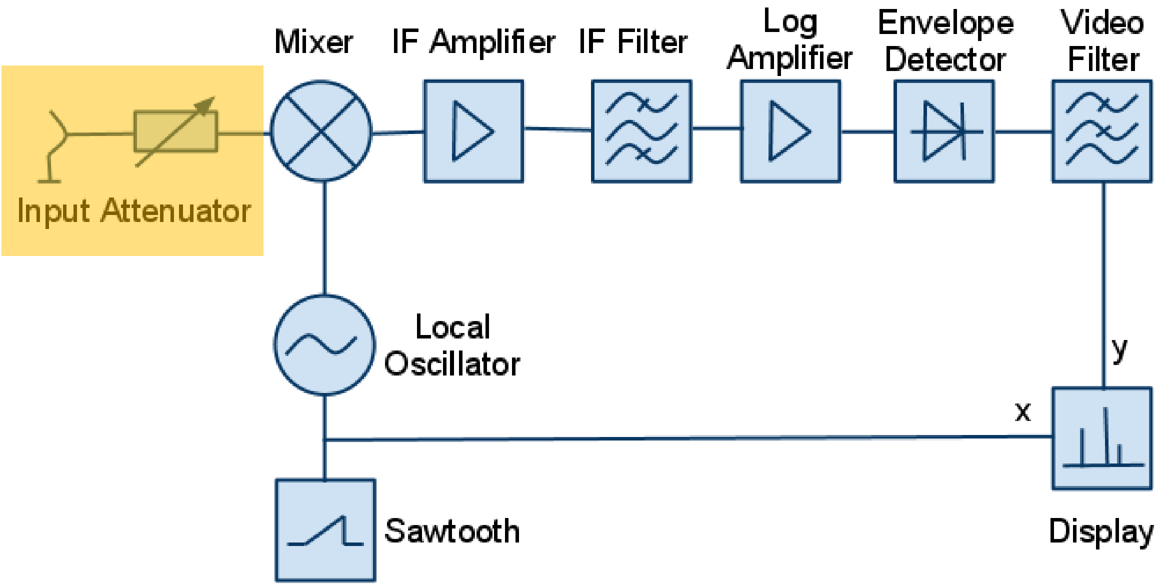
+ Signals close to noise floor easier to see

- Averaging takes time -> Slow sweep





3. Input Attenuator (reference level)



Input attenuation: **-** Necessary if input signal is too large (mixer saturation or damage!)
- Saturation => wrong signal amplitudes, spurious tones
- Sensitivity is reduced by attenuation factor
- Positive side effect: Attenuator masks mixer impedance mismatch

Measuring veeeeery weak signals

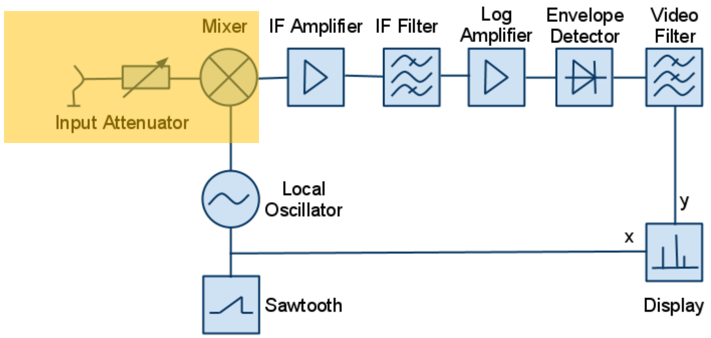
RF and microwave signals can be extremely weak and close to the thermal noise floor.

To make them visible we can:

- Set resolution bandwidth to minimum value
- Set video bandwidth to a low value or enable trace averaging -> smooth trace
- Set input attenuation to 0 dB

… is there anything else we can do?

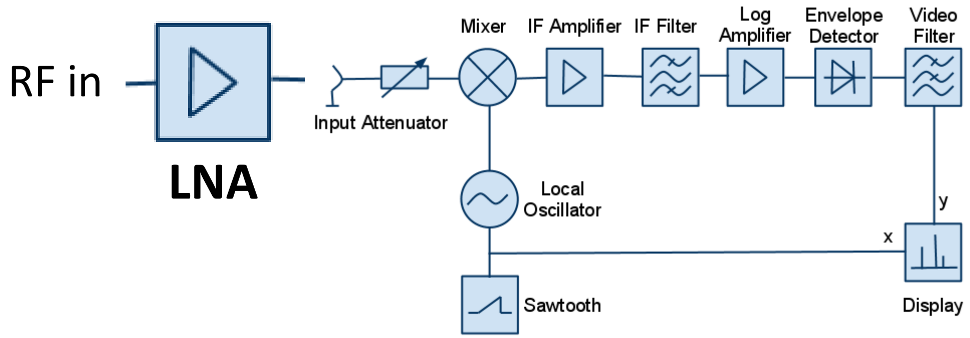
Measuring veeeeery weak signals



There are several components between the RF input connector and the first amplifier in the instrument:

- Connector and cables → **1-3 dB loss**
- Switches and attenuator (even at 0 dB setting) → **1-2 dB loss**
- Pre-filtering → **1-4 dB loss**
- Mixer conversion loss → **5-10 dB loss**

Measuring veeeeery weak signals



Solution: A **low noise amplifier (LNA)** allows to approach the theoretical SNR limits

- LNA compensates losses of SA input stage → **SNR improvement**
- Improvement of the overall noise figure
- However: Keep in mind that a LNA can be nonlinear, saturate, and create distortion! → **spurious signals**

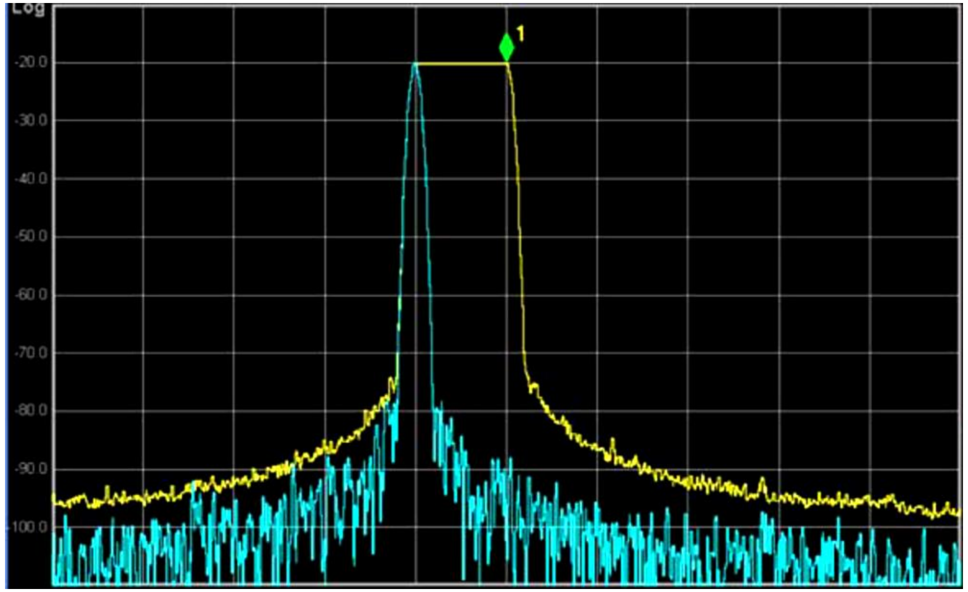
Measuring modulated / time-varying signals

- Due to the sweeping principle, the SA is only measuring a small portion of the spectrum at the time
- Spectrum analysis assumes **periodic signals** (like Fourier transform)
- However, real signals are not periodic at all:
  Bluetooth: **Frequency hopping**
  Wifi/mobile phones: **Packet bursts, frames, TDMA …**

Measuring modulated / time-varying signals

- **Use large resolution bandwidth:**
  Short sweep times, wider spectrum portion measured at once

- **Max hold:**
  Performs an indefinite number of sweeps and holds the maximum measured value at all frequencies (yellow)



Summary

	High	Low
Resolution bandwidth **RBW**	• Fast sweep time • Better transient detection	• Lower noise floor • Detection of closely spaced tones
Video bandwidth **VBW**	• Fast sweep time (only limited by RBW)	• Weak signals better visible • Smooth spectrum shape
Input attenuation **ATT**	• Avoids distortion products • Input mixer protection • Less impedance mismatch	• Better overall SNR • Improved sensitivity

SA Measurement: Heavily used frequency bands

Service	Frequency [MHz]	Modulations
FM Radio	87.5 – 108	FM
DAB Radio	174 – 230	ODFM
TV	470 – 790	AM/FM, OFDM
Mobile 700 MHz (4G & 5G)	703 – 788	OFDM
Mobile 800 MHz (4G & 5G)	832 – 915	OFDM
Mobile 900 MHz (2G - 5G)	880 – 960	GMSK, QPSK, OFDM, CDMA
Mobile 1800 MHz (2G - 5G)	1710 – 1880	GMSK, QPSK, OFDM, CDMA
DECT (cordless phones)	1880 – 1900	GFSK
Mobile 2100 MHz (3G - 5G)	1920 – 2170	QPSK, OFDM, CDMA
Wi-Fi, Bluetooth, microwave oven, remote controls…	2400 – 2485 (2.4 GHz ISM band)	various
Mobile 2600 MHz (4G & 5G)	2500 – 2690	OFDM
Mobile 3.5 GHz (5G)	3424 – 3800	OFDM
Wi-Fi 5GHz	5150 – 5875	OFDM