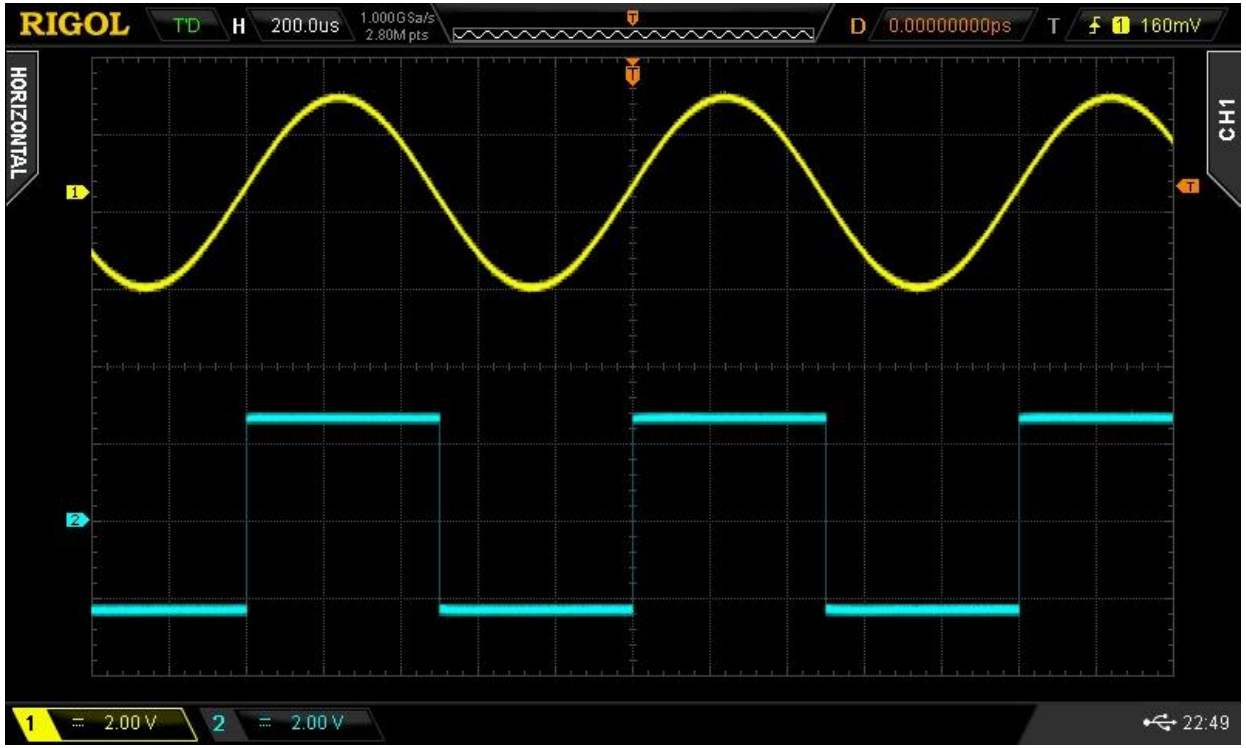
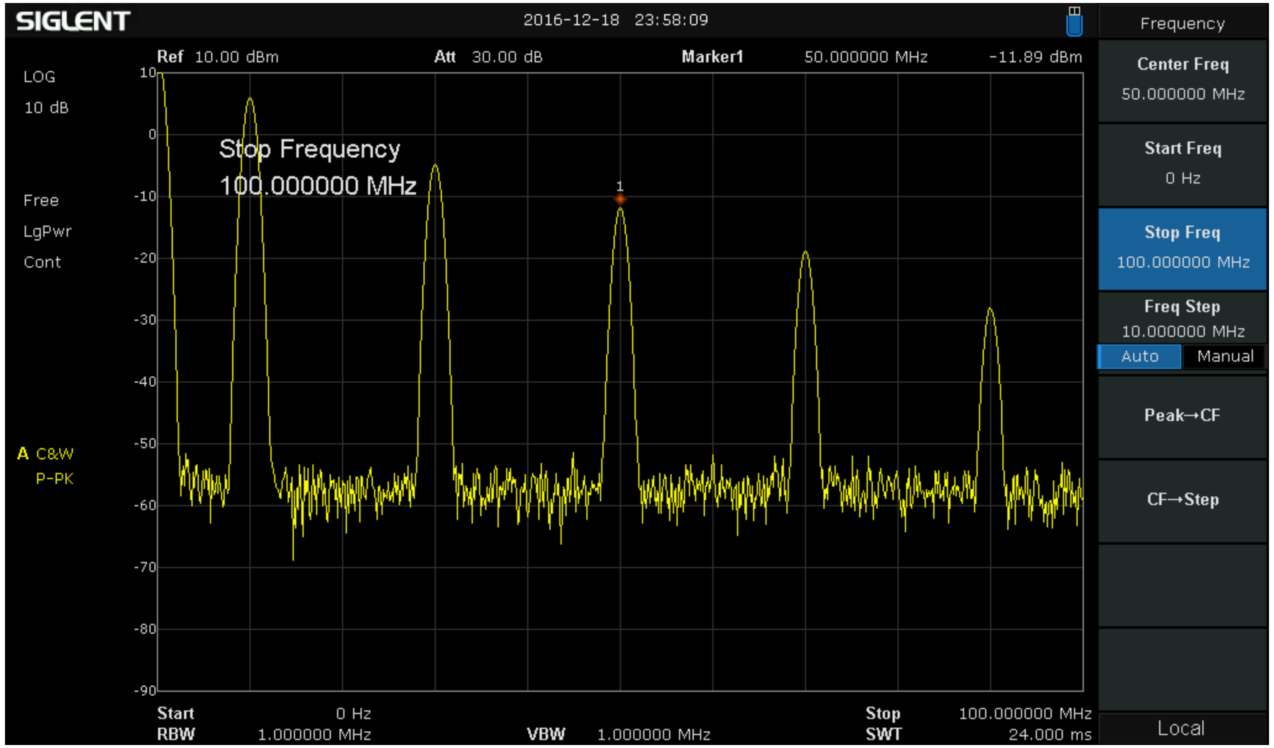
Università degli Studi di Padova

Spectrum analyzer

Lecture #11
Electronic measurements
Alessandro Pozzebon

Time domain vs Frequency domain





The spectrum analyzer

Applications

- **Signal source characterization**

- Determining signal composition in frequency
- Verifying the conformance to reference spectral behaviours

- Total Harmonic Distortion (THD)

Applications

- **Radiofrequency measurement**

- Characterization of signal modulation
- Test and verification of communication systems
- Spectrum monitoring and policing

Applications

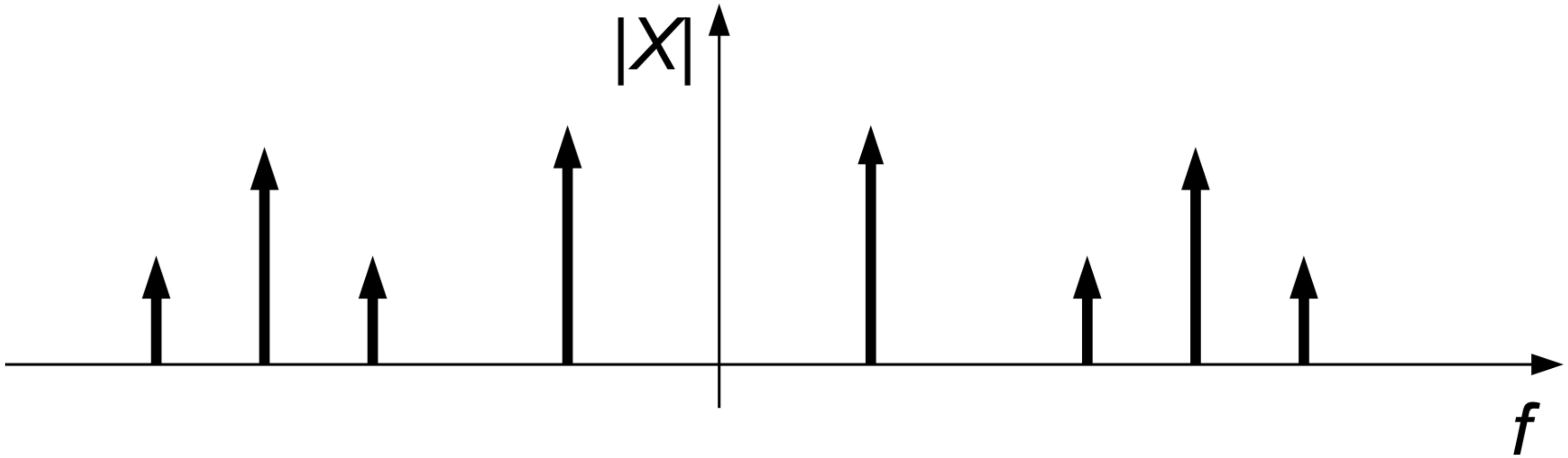
- **Electromagnetic compatibility testing**

- Disturbances **radiated** in the surrounding environment
- Disturbances **conducted** towards other devices through power supply lines

- **Electromagnetic compatibility (EMC)** tests
  - Check that emission intensities are below certain thresholds
  - EMC regulations

Discrete-spectrum signals

- **Signal composed of sinusoidal terms**



- If the frequencies of individual components are unrelated, the signal itself is not periodic
- $x(t)$ real function of time
- $X(f) \Rightarrow$ Hermitian symmetry: $X(-f) = X^*(f)$

Discrete-spectrum signals

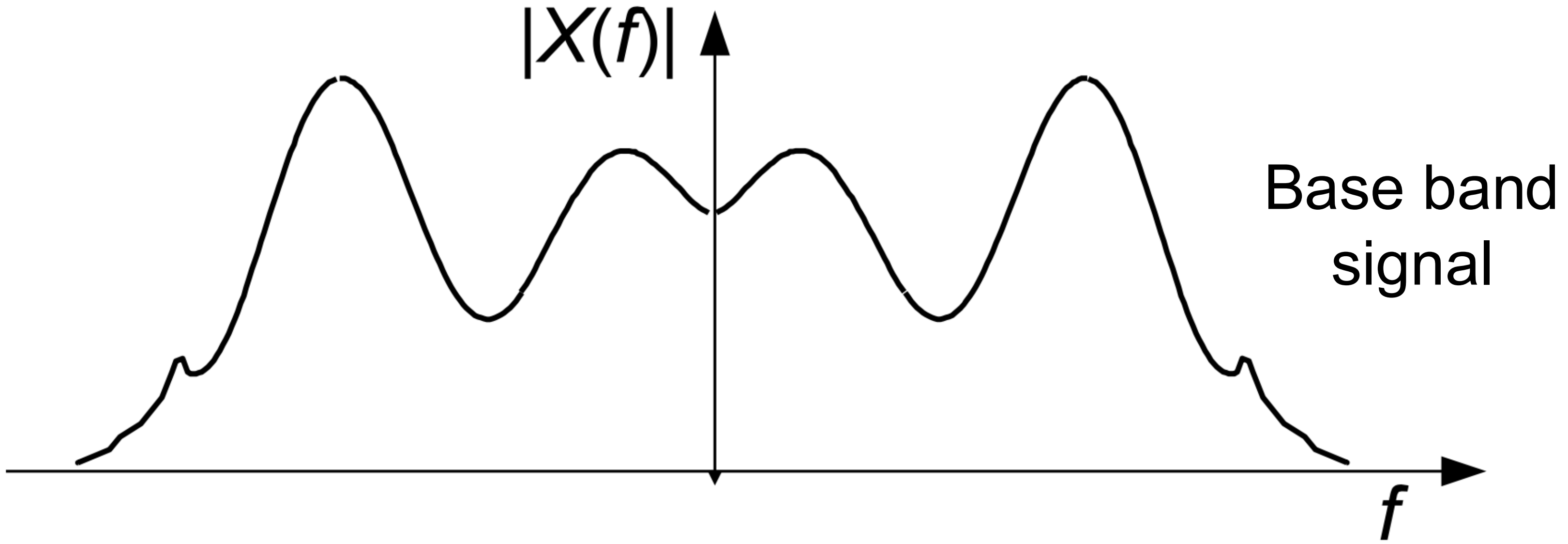
$$x(t) = |X(0)| + \sum_{k=1}^{+\infty} 2|X(f_k)| \cos(2\pi f_k t + \arg[X(f_k)])$$

- $f_1, \dots, f_k, \dots$ signal components frequencies
- $\arg[X(f_k)] = \arctan Im[X(f)]/Re[X(f)]$ phase characteristic

- The full information about the signal spectral composition is already contained in **half the function $X(f)$** $\Rightarrow$ Positive frequencies
- $|X(0)|$ DC component $\Rightarrow$ Not accounted in spectrum analyzers
- The full information is provided by $2 \cdot |X(f_1)|, \dots, 2 \cdot |X(f_k)|, \dots$

Continuous-spectrum signals

- **No localized components at some specific frequencies**
- **Frequency bands**



- $X(f) \cdot X^*(f) = |X(f)|^2 \Rightarrow$ Power Spectral density (PSD)
- Parseval theorem

$$\int_{-\infty}^{+\infty} x^2(t)dt = \int_{-\infty}^{+\infty} |X(f)|^2 df$$

Spectrum measurements

- **Horizontal axis** ⇒ Calibrated frequency scale
- **Vertical axis** ⇒ Amplitude (RMS value $[V_{RMS}]$) or Power $[W]$

- **Amplitude values**:

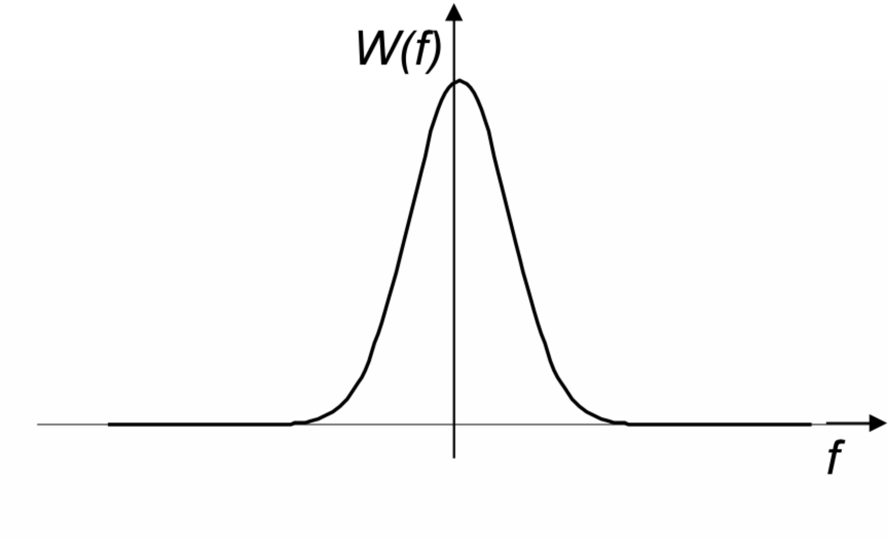
$$\frac{2\cdot|X(f_1)|}{\sqrt{2}}, \frac{2\cdot|X(f_2)|}{\sqrt{2}}, \dots, \frac{2\cdot|X(f_k)|}{\sqrt{2}}, \dots$$

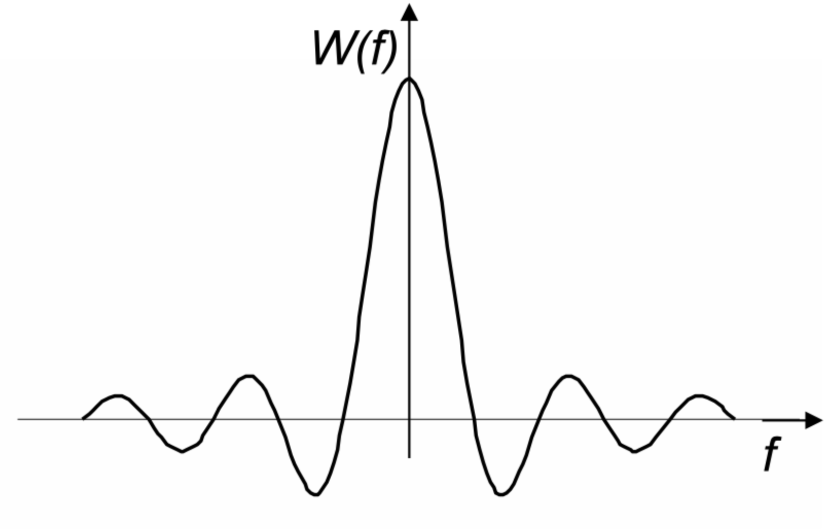
- **Power values** (referred to instrument input impedance $Z_i = R_i = 50\ \Omega$):

$$\frac{2\cdot|X(f_1)|^2}{R_i}, \frac{2\cdot|X(f_2)|^2}{R_i}, \dots, \frac{2\cdot|X(f_k)|^2}{R_i}, \dots$$

Spectrum measurements

- The spectrum analyzer output is **not an exact measurement** of the observed signal spectrum $X(f)$
- **Resolution function** $\mathrm{W}(f)$ ⇒ capability to discriminate individual discrete frequency components





- **Measured trace** $\mathrm{G}(f)$ ⇒ frequency-domain convolution of $X(f)$ and $\mathrm{W}(f)$

Spectrum measurements

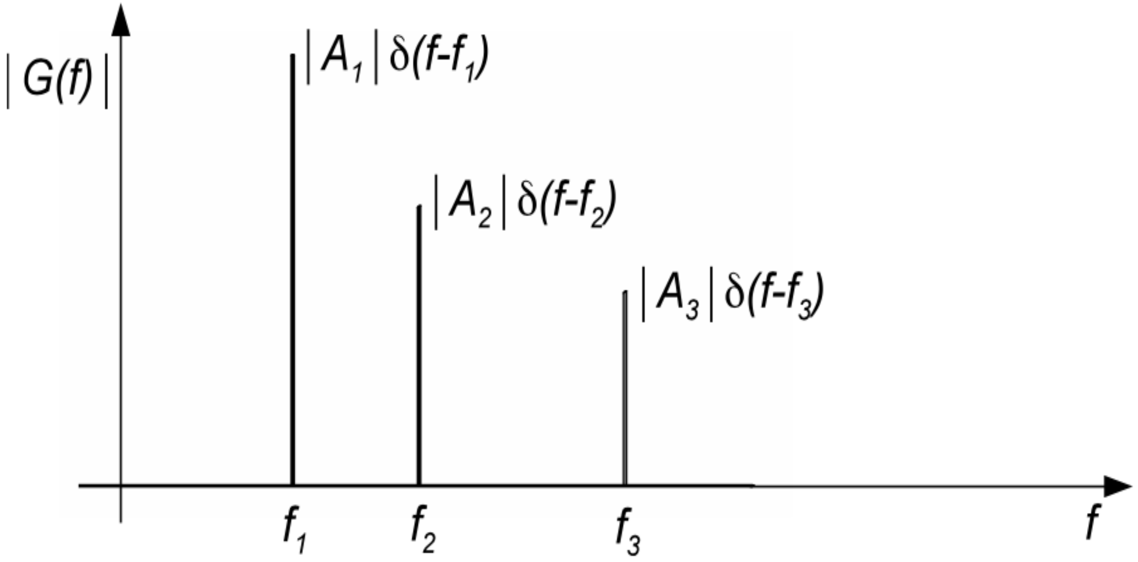
$$G(f) = \int_{-\infty}^{+\infty} X(\nu) \cdot W(f - \nu) d\nu$$

- Discrete spectrum:

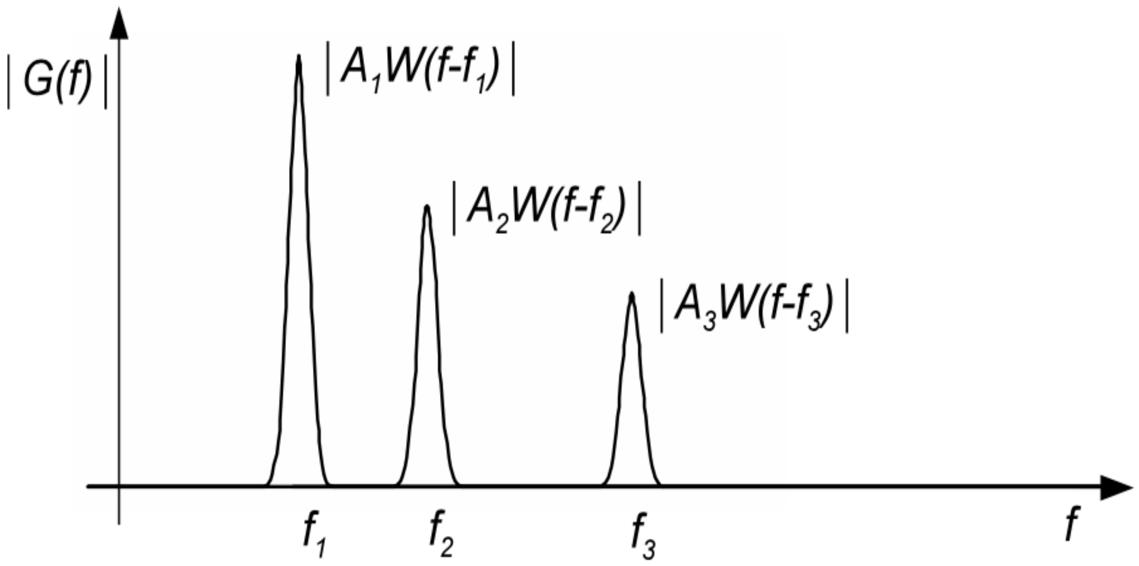
$$G(f) = \sum_{k=-\infty}^{+\infty} A_k \cdot W(f - f_k)$$

- A_k and f_k **amplitude and frequency** of the signal components
- The spectrum would remain unaltered only if $W(f) \cong \delta(f)$
- In practice, each signal component is associated to a peak whose shape is described by $W(f)$
- $W(f)$ should be a **narrow-band function**
- $G(f_k) = A_k \cdot W(0), \forall k$

Spectrum measurements



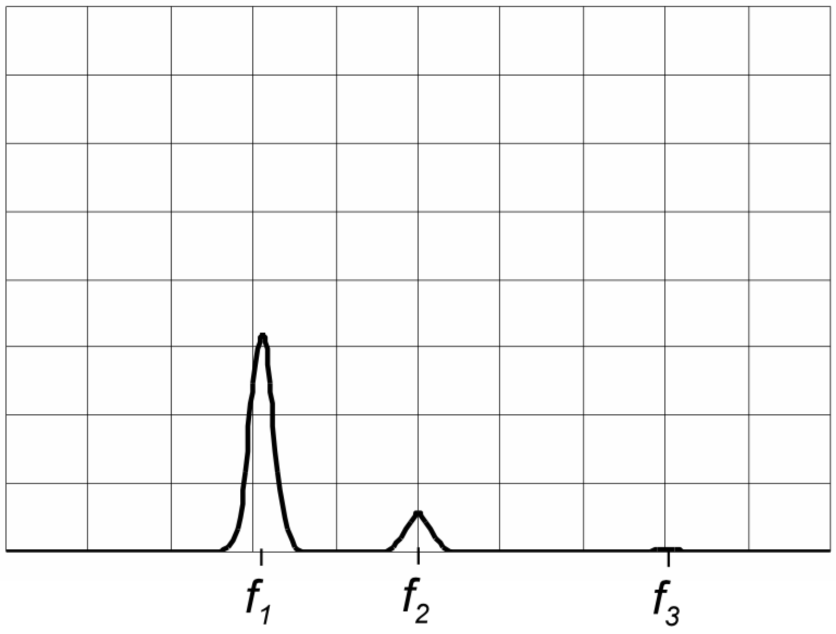
spectrum, from theory



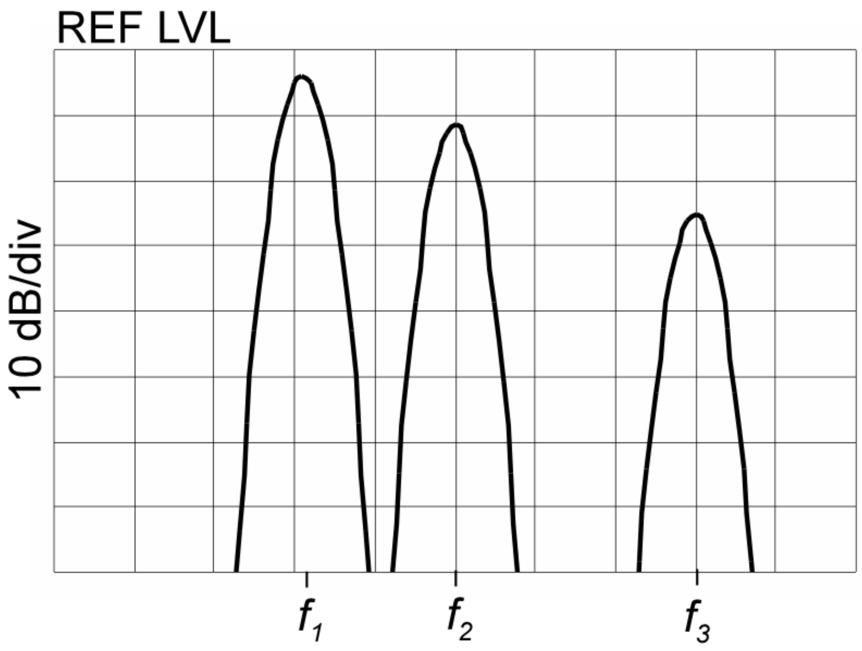
convolution with $W(f)$.

Logarithmic scale display

- **Measurements** ⇒ grid and cursors
- Simultaneous detection of **very small and large signal components**
- Typical values of 80 dB **amplitude dynamics**
- **Logarithmic** vertical scale



Linear scale



Logarithmic scale

Logarithmic scale display

- The displayed trace is always positive, being proportional either to $|X(f)|$, or to $|X(f)|^2$
- **Linear scale** ⇒ 0 at the bottom of the scale, upper bound determined by the vertical scale factor
- **Logarithmic scale** ⇒ $\log_x(0) = -\infty$. Reference level defined for the maximum value, corresponding to the top of the grid

- Units:
  - **Amplitude** measurements: dBV ⇒ $20\log_{10}\frac{V_X}{1[V_{RMS}]}$
  - **Power** measurements: dBm ⇒ $10\log_{10}\frac{P_X}{1[mW]}$

Spectrum analyzer specifications

Frequency specifications

- **Wide frequency range**: several decades with a given level of accuracy (e.g., from 10 kHz to 100 GHz, or from 0.1 Hz to 100 kHz)
  - Measurable frequency range vs measured frequency span
- **Good frequency resolution**: ability to distinguish the components of a signal even when their frequency separation is small

Spectrum analyzer specifications

Amplitude specifications

- **High amplitude dynamics**: accurate measurement of low-level components even when much larger ones are simultaneously present
  - Dynamics is specified as the **ratio, in dB**, of the largest to the smallest levels that can be measured on the instrument display
- **Good sensitivity**: low-level signal components should be accurately measured even when much larger ones are present
- **Uniformity**: the instrument behaviour should be **the same over the full range** of analyzed frequencies

Spectrum analyzer specifications

Frequency resolution

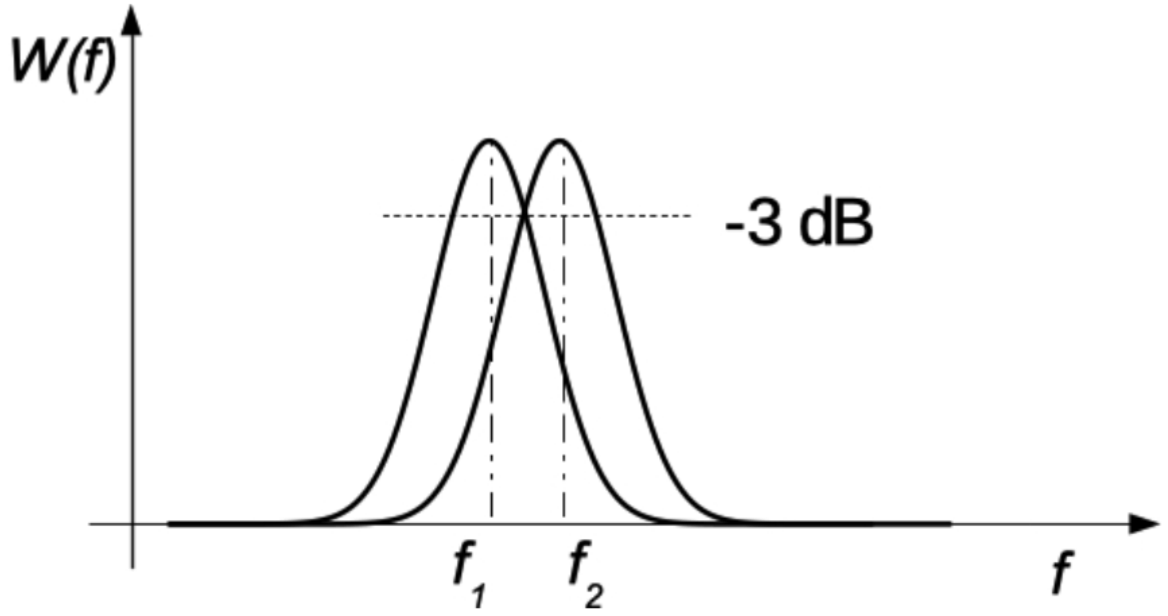
- Instrument resolution vs frequency resolution
- “*the minimum frequency separation at which two sinusoidal components having the same amplitude can be distinguished as two individual spectral components*” ⇒ **Equal amplitude**

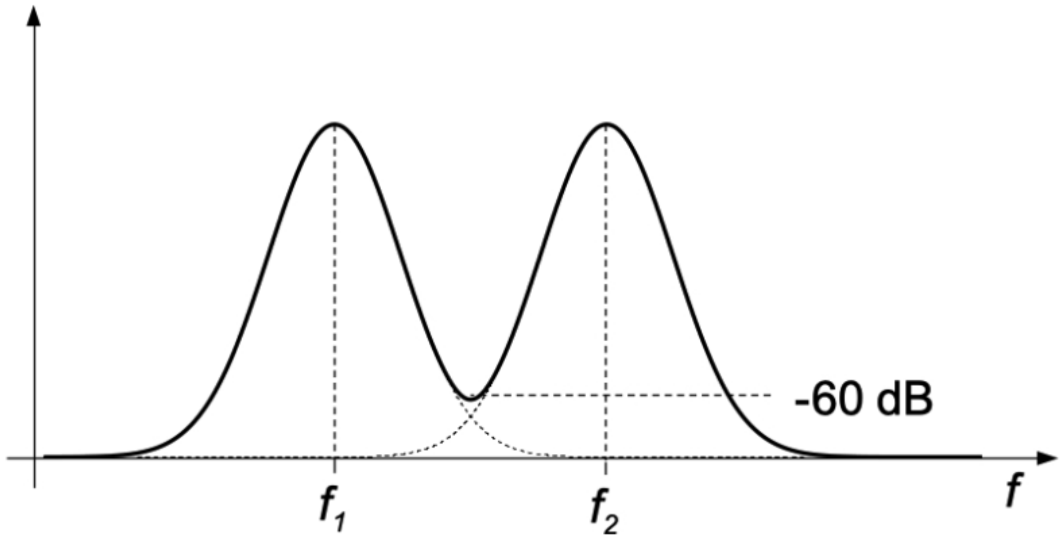
- **Resolution bandwidth** $B_R = 2 \cdot B_{-3dB}$

- Accurate measurement requires greater separation ⇒ spectral interference needs to be avoided

Spectrum analyzer specifications

- -60 dB bandwidth of the resolution function B_{-60dB}
- Distance at which interference caused by one component is equal to 0.1% of its amplitude
- **Selectivity**: $B_{-60dB}/B_{-3dB} \rightarrow$ Depends on the shape of the resolution function $W(f)$





Spectrum analyzer specifications

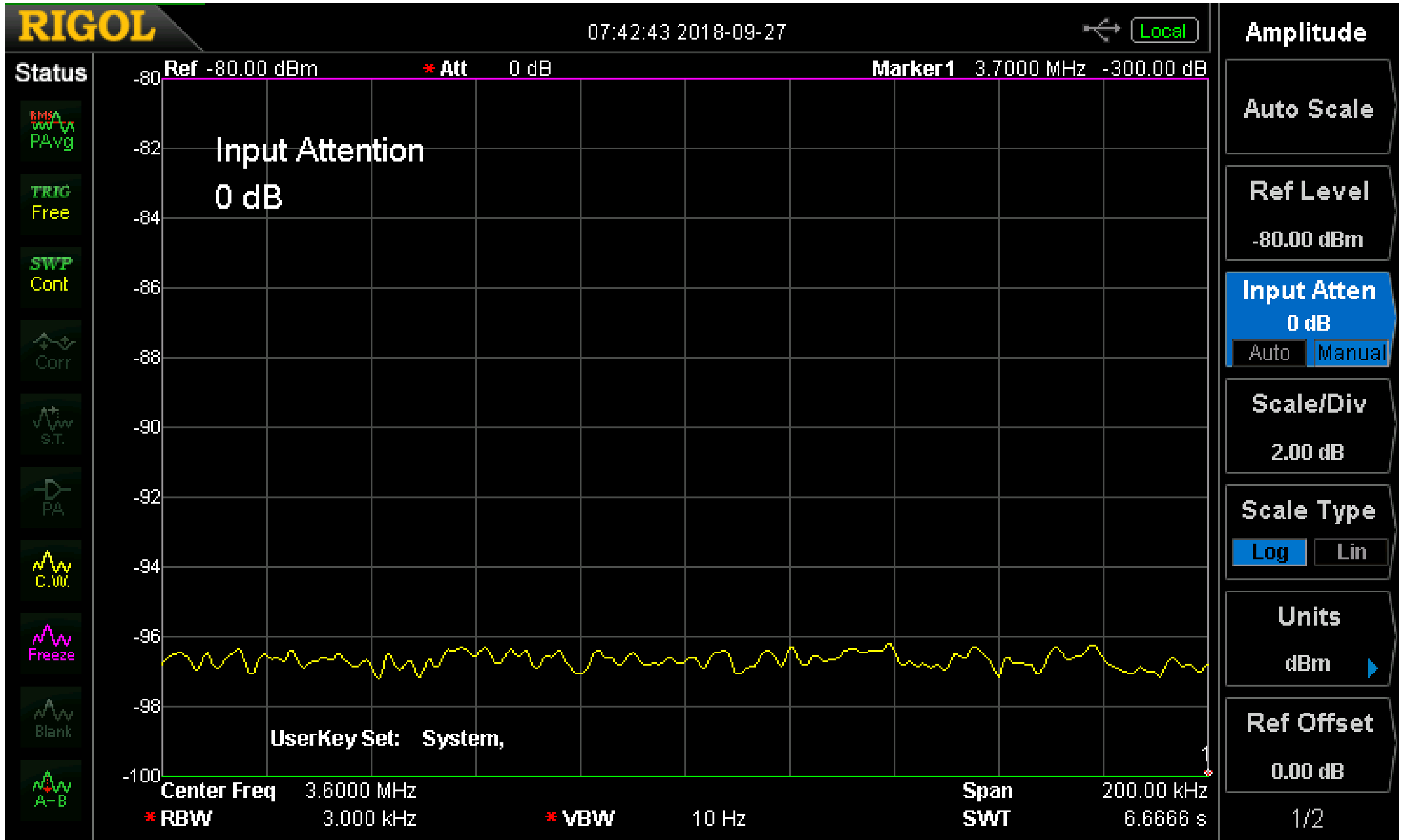
Linearity specifications

- Any distortion caused by non-linearity within a spectrum analyzer might introduce **new frequency components**
- Extremely good linearity is required with respect to the measured signal
- Spurious responses to be avoided

Spectrum analyzer specifications

Sensitivity

- The minimum power level at which a sinusoidal component can be distinguished from the instrument **noise floor**



Spectrum analyzer specifications

Sensitivity

- **Thermal noise power spectral density** $\Rightarrow S_{nn}(f) = kT$
  - Boltzmann constant $\mathrm{k} = 1.38 \times 10^{-23}\ \mathrm{J} \cdot \mathrm{K}^{-1}$
  - Absolute temperature in Kelvin T

- Reference temperature $T = 290\ \mathrm{K} \Rightarrow S_{nn}(f) = 4 \times 10^{-21}\ \mathrm{W/Hz} \Rightarrow -174\ \mathrm{dBm/Hz}$

- **Noise Figure (NF):** noise added by the instrument circuitry ⇒ between 10 and 20 dB

- $B_R = 1\ \mathrm{kHz}$, NF = 15 dB ⇒

$$-174\,\frac{\mathrm{dBm}}{\mathrm{Hz}} + NF + 10\log_{10} B_R = -174 + 15 + 30 = -129\ \mathrm{dBm}$$

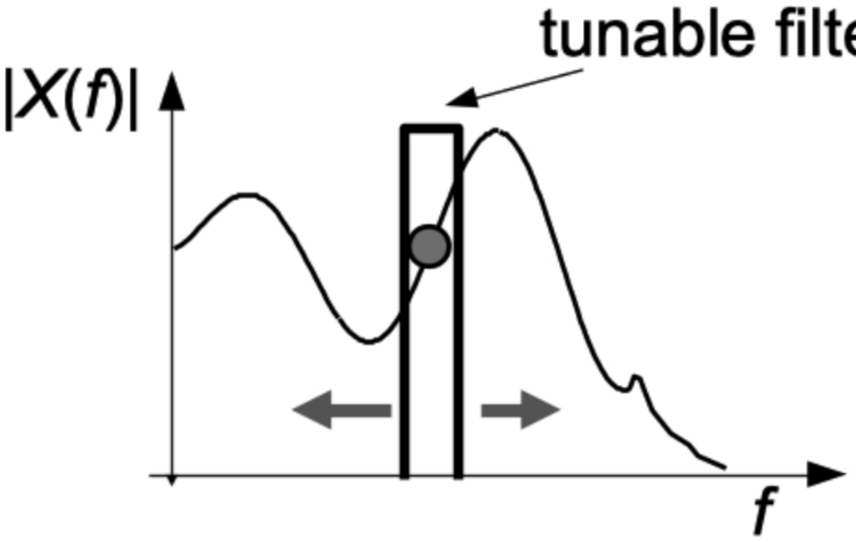
Spectrum analyzers

- Frequency composition ⇒ frequency selective narrow-band filters

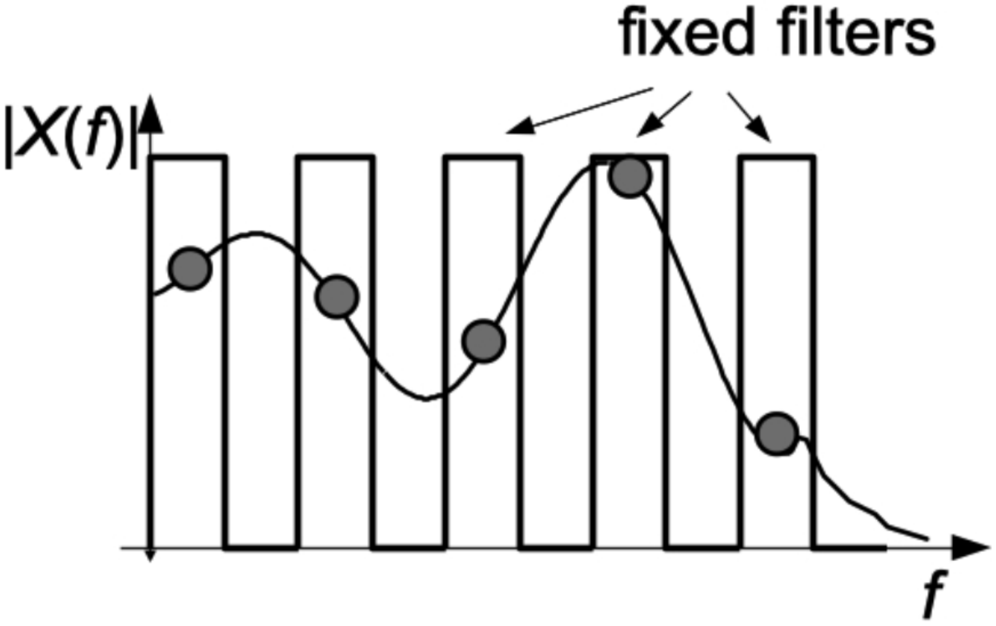
- **Scanning spectrum analyzers**: The measuring instrument automatically scans the frequency range of interest and sequentially measures signal component strengths at each frequency ⇒ equivalent to **tunable filter**
- **“real-time” spectrum analyzers**: The measuring instrument digitizes the signal within the frequency range of interest and determines the spectrum by algorithm computation of the Fourier transform ⇒ equivalent to the use of **parallel analogue filter banks**

Spectrum analyzers

- Frequency composition ⇒ frequency selective narrow-band filters



tunable filter



selective filter bank

Swept frequency spectrum analyzer

- Used in **radiofrequency** and microwave measurement
- Typical range from **few kHz to several GHz** (possible extension to few tens of Hz and 100-200 GHz)

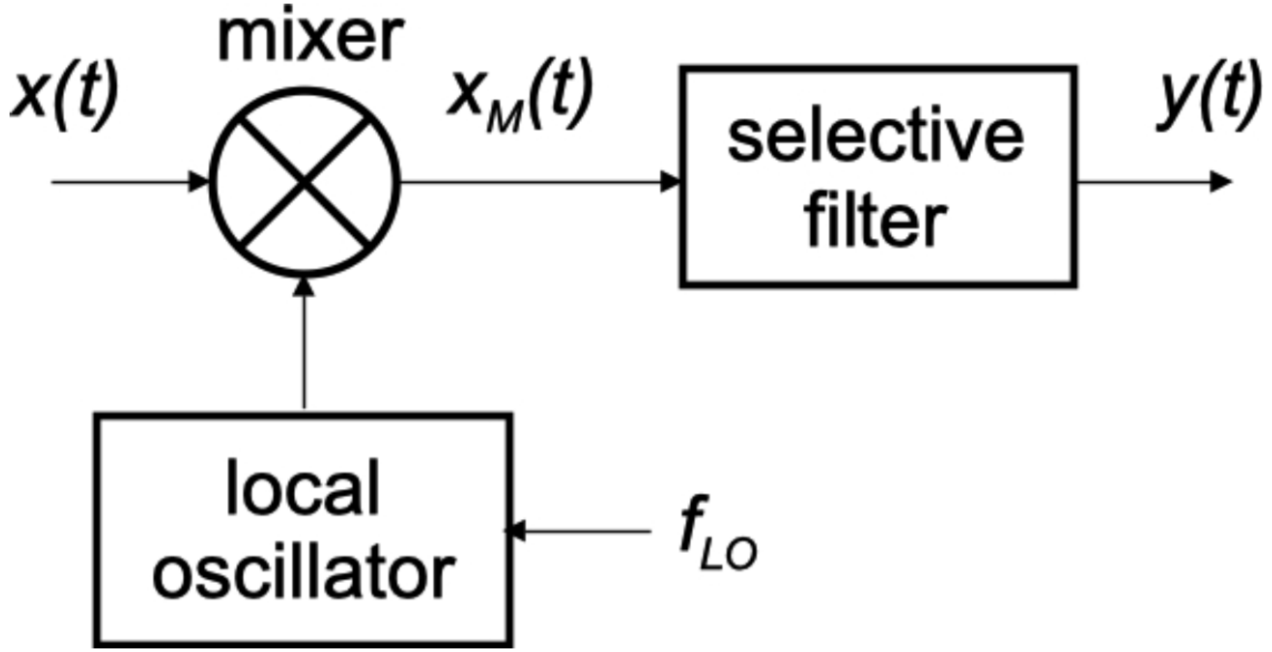
- **Wide input range (up to 6 decades)** ⇒ hard to use tunable selective filters

- **Superheterodyne** (Frequency transposition)
  - Selectivity in frequency
  - Wide frequency intervals

Swept frequency spectrum analyzer

Basic elements:

- Mixer
- Variable-frequency oscillator
- Selective filter



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