Electronics course part 2:

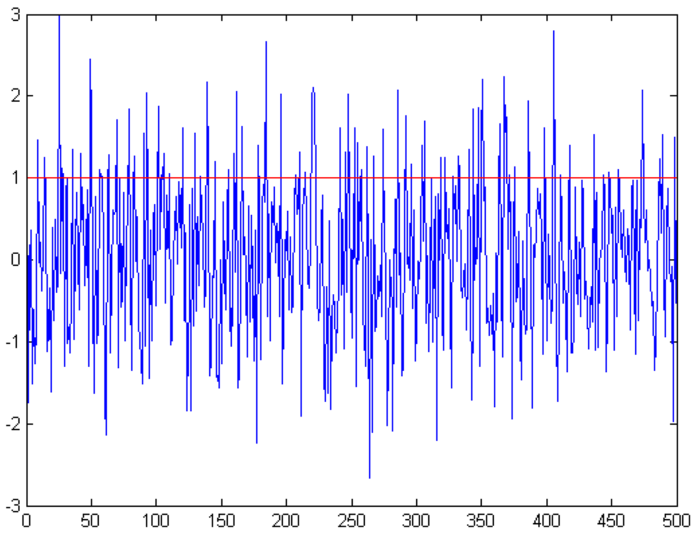
ETHZ / LPC / Alexander Däpp / 2018

- **Electronic noise**
- **Electromagnetic interference**
- **Spectral analysis**

Noise

- Random fluctuations amplitude
- Ideal „white noise“ gaussian amplitude distribution
- Broad spectrum
- Noise averaging

$$SNR \propto \sqrt{N}$$



Thermal Noise
(Johnson–Nyquist noise)

- Random motion of charge carriers
- Approx. white noise

$$V_N = \sqrt{4 k_B T R \Delta f} \qquad I_N = \sqrt{\frac{4 k_B T \Delta f}{R}}$$

- Physical limit of design

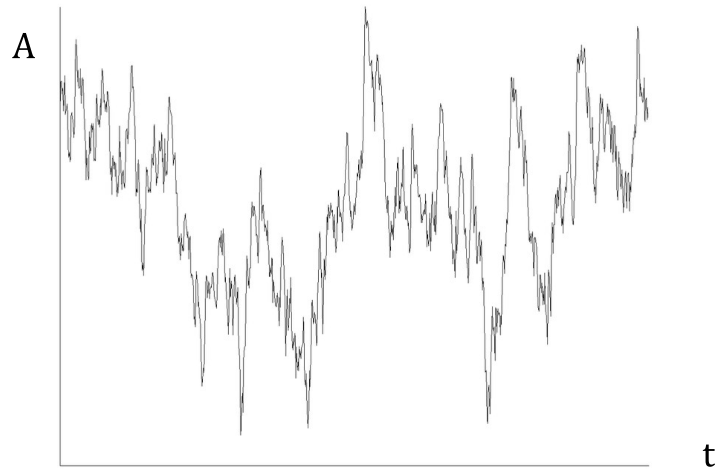
Shot Noise

- Charge carriers crossing a potential barrier
- Photomultiplier, transistor, diode
- Not temperature dependent

$$I_N = \sqrt{2 \cdot I_0 \cdot q \cdot \Delta f}$$

Low-Frequency Noise

- pink noise, flicker noise
- Frequency dependent: Power density 1/f
- DC current in discontinuous medium (contact noise)
- Especially in downscaled components
- MOSFET more than BJT
- Chopper-OpAmp reduced 1/f Noise



Example Datasheet OpAmp

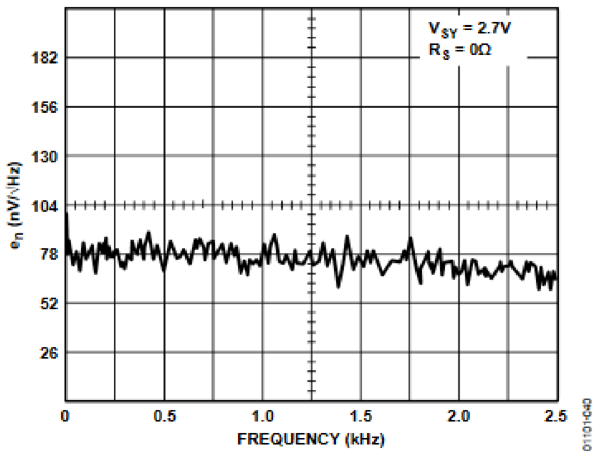


Figure 40. Voltage Noise Density at 2.7 V from 0 Hz to 2.5 kHz

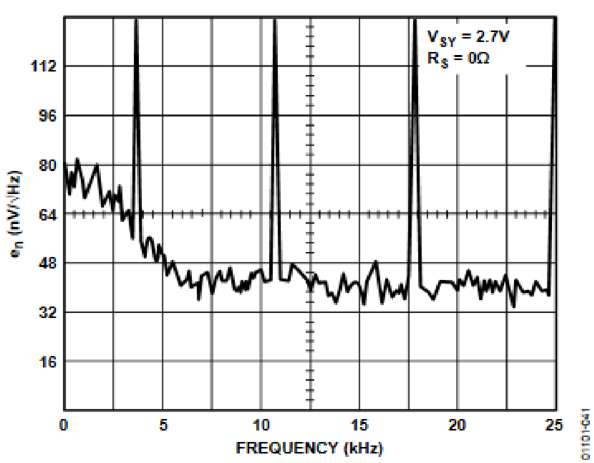


Figure 41. Voltage Noise Density at 2.7 V from 0 Hz to 25 kHz

NOISE					
	Input Voltage Noise, f = 0.1 Hz to 10 Hz		90	90	nVp-p
			15	15	nVrms
e_n	Input Voltage Noise Density	f = 10 Hz	3.5	3.5	nV/√Hz
		f = 100 Hz	3	3	nV/√Hz
		f = 1 kHz	3	3	nV/√Hz
i_n	Current Noise Density	f = 1 kHz	0.4	0.4	pA/√Hz

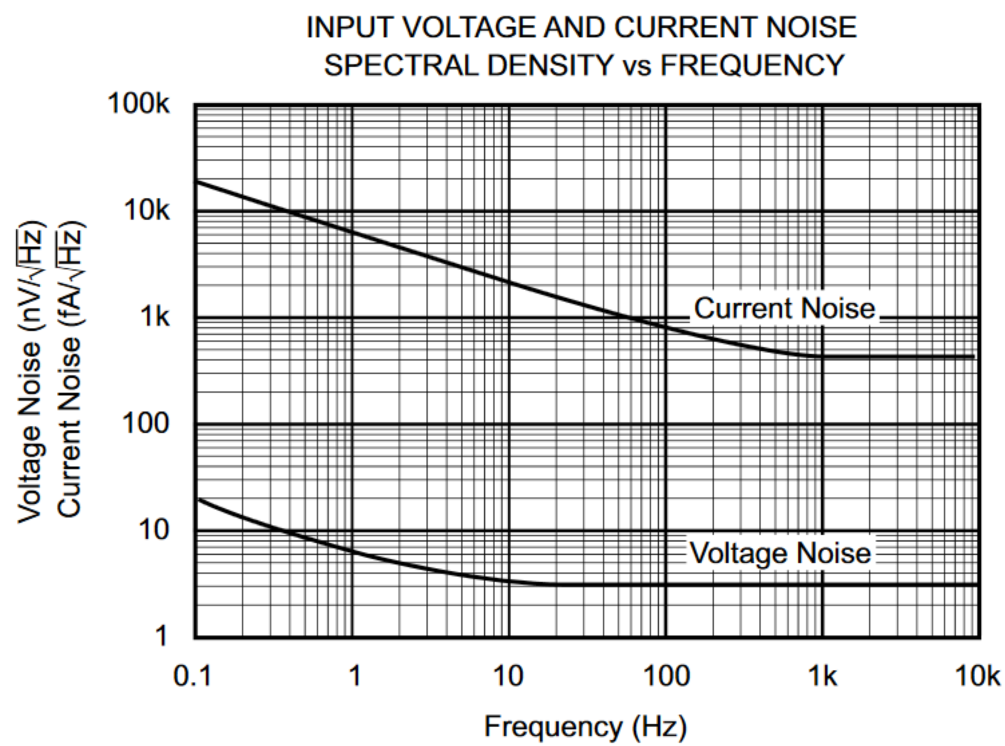


Figure 4. Input Voltage and Current Noise Spectral Density vs Frequency

Unit dB, dBm

Decibel is al logarithmic Unit

$$dB = 10 \cdot \log \frac{P_2}{P_1}$$

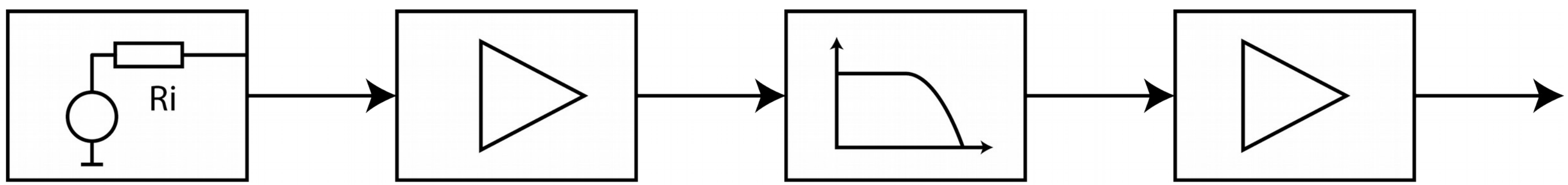
	P
3dB	~2
10dB	10

	U
6dB	~2
20dB	10

Can be referenced to 1mW

$$0\,dBm = 1\,mW$$

Noise in Signal Chain



Signal:	P_S	0.1µW		20µW		10µW		5mW
Gain:	P_2 / P_1		200		0.5		500	
Noise:	P_N	0.004pW		2pW		**0.1pW***		50pW
S/N:	P_S/P_N	2.5E7		1E7		1E8		1E8
	F		**2.5**					

- Noise Factor $F = SNR_{IN} / SNR_{OUT}$

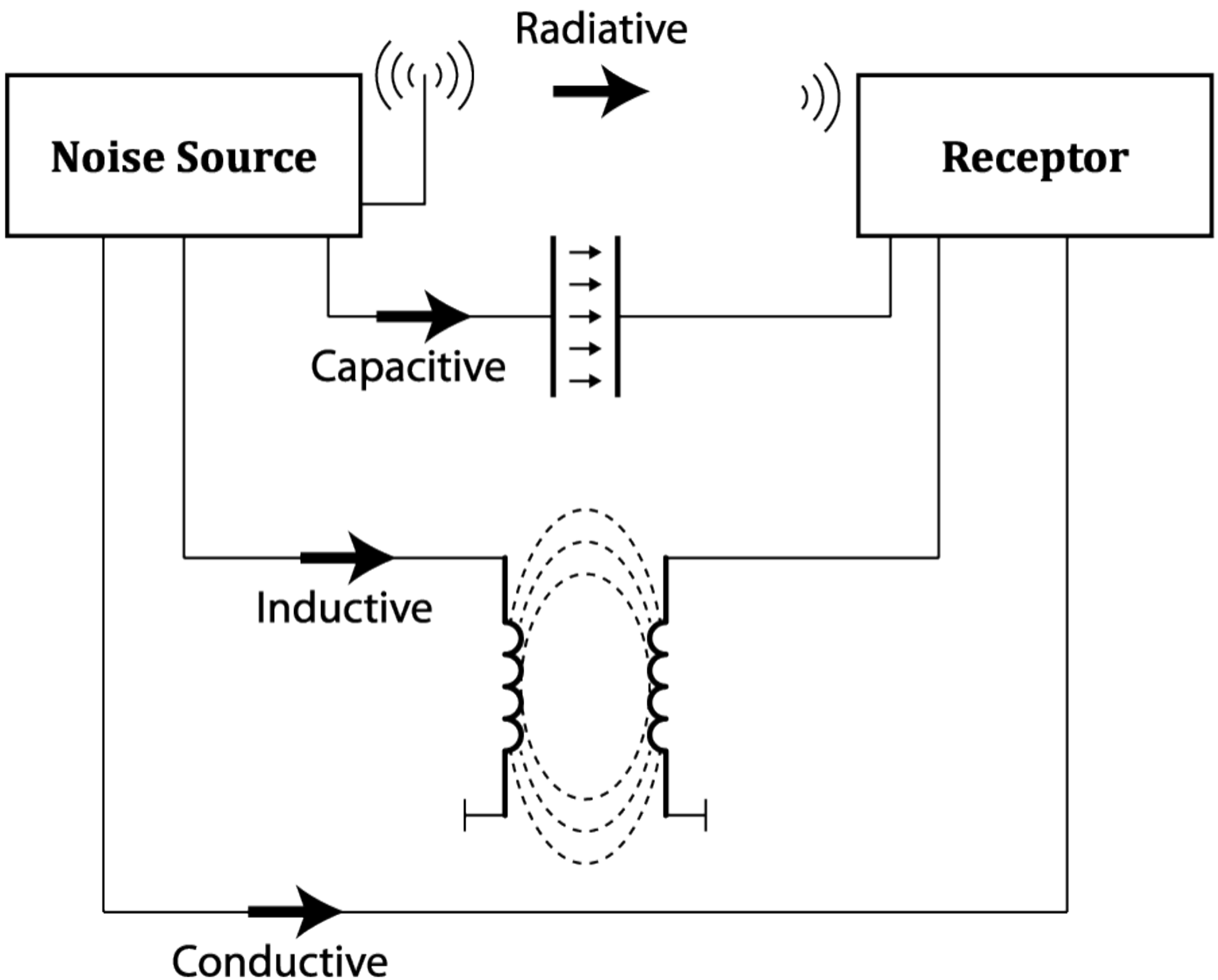
  Ratio of Noise added compared to noiseless device

- *Noise Figure* is the equivalent in dB

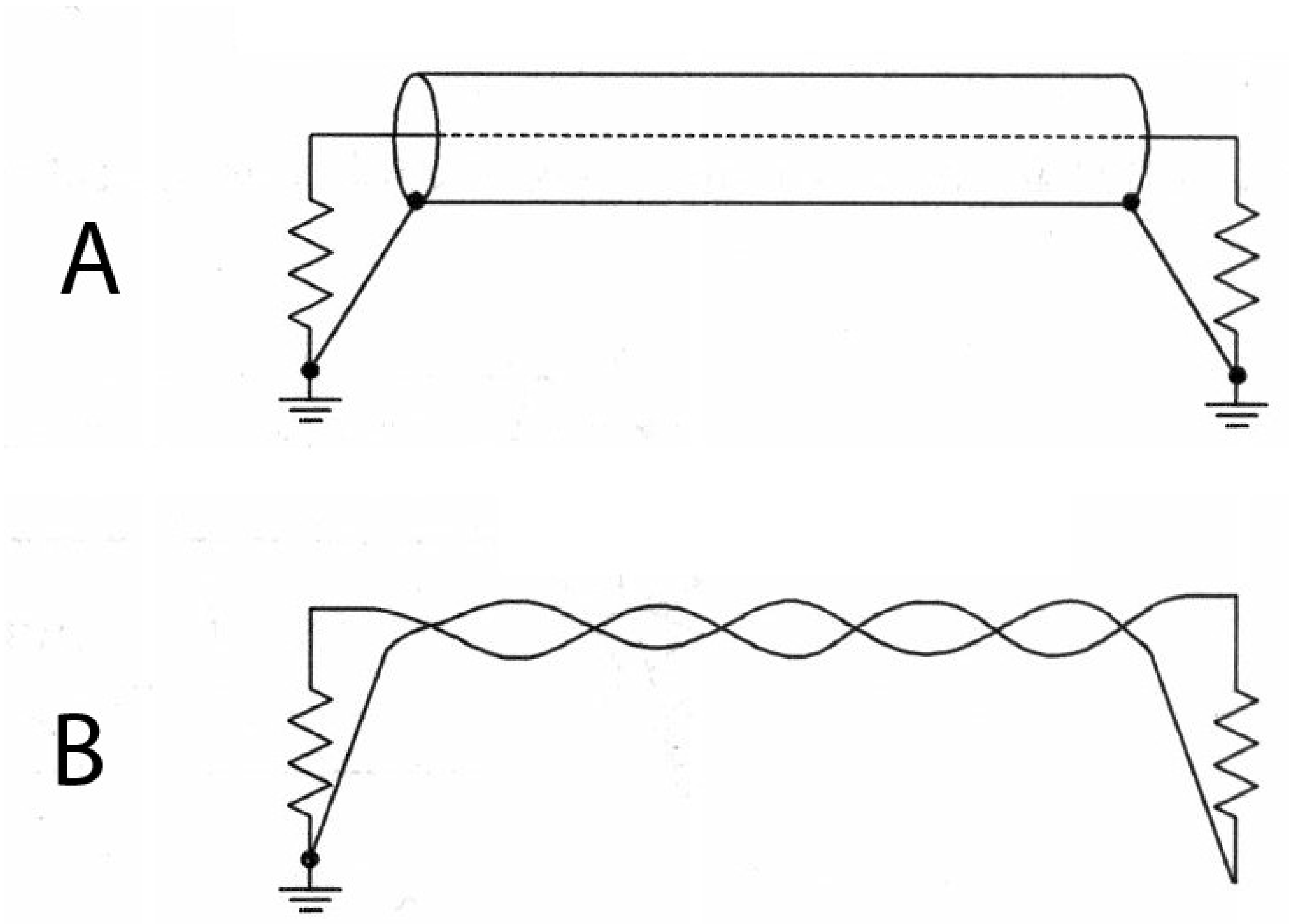
Electromagnetic interference

- Man made noise
- E.g. Motors, Radio, AC mains (50 Hz)
- No gaussian amplitude distribution
- Narrowband
- Reduce noise at source normally easier

Coupling Mechanism



Introduction

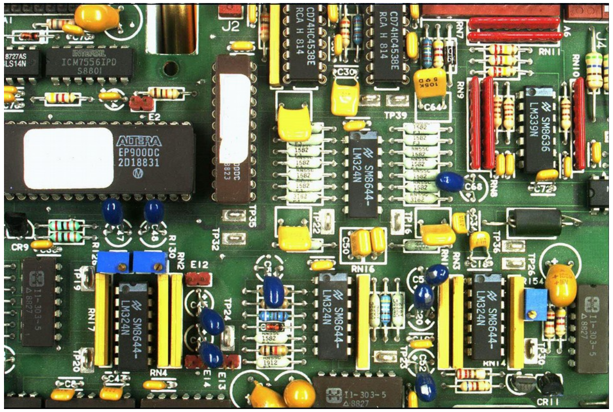


Conductive coupling

Directly connected or over **Common impedances**

- Hardwire connection to source of disturbance

Directly connected:

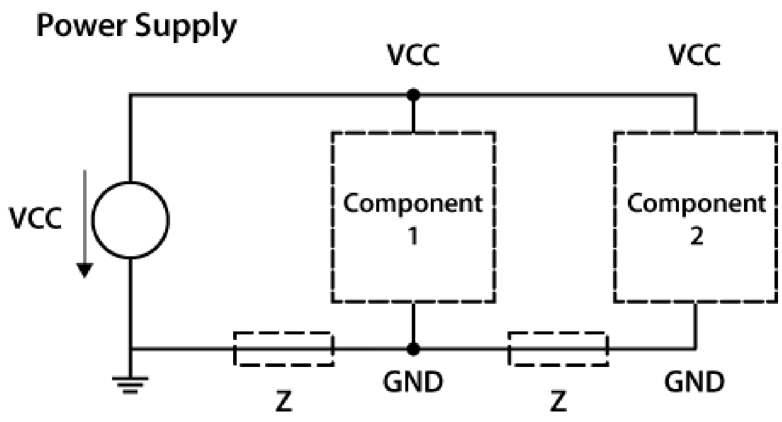


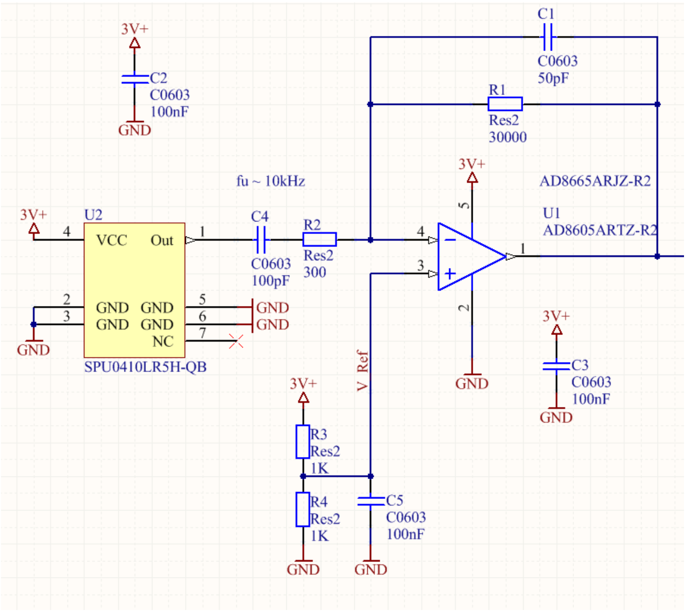
- Disturbance on power supply lines
- E.g. switched-mode power supplies
- Filter at input
- Decoupling: supplying low impedance path to ground
  Typically 100nF for IC

Conductive coupling

Over Common Impedances

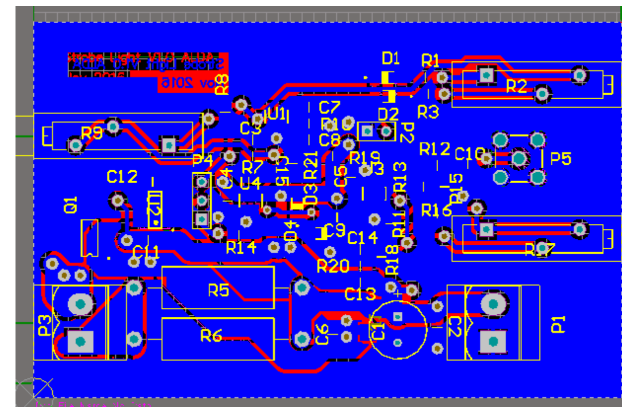
- In return path to ground
- Use short & thick ground connections



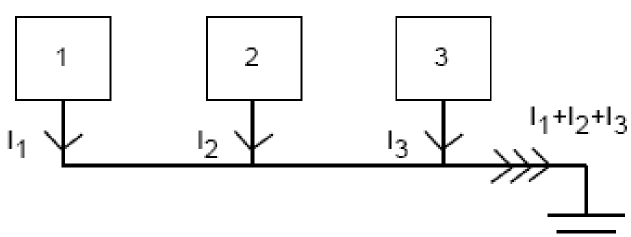


GND Systems

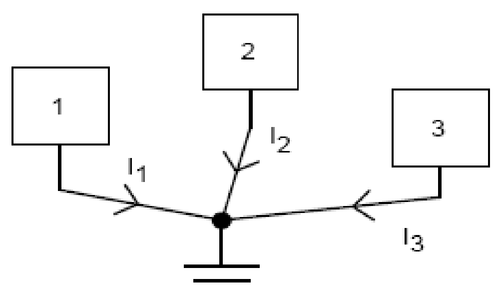
- Daisychain: Acceptable for Digital
- Single Point (Star) for Analog LF
- Multipoint for HF (λ/20)



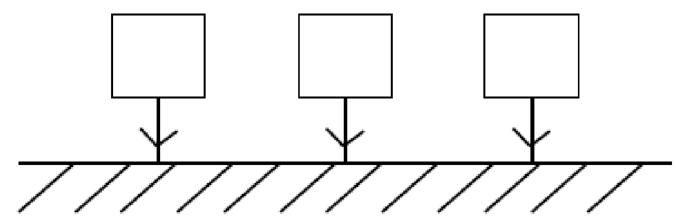
cascaded



star

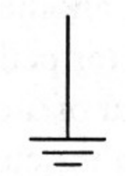


multiple



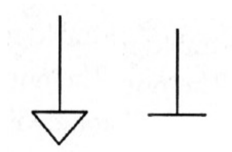
Protective Earth and Ground

Earth Ground (Erde) **PE** – green / yellow

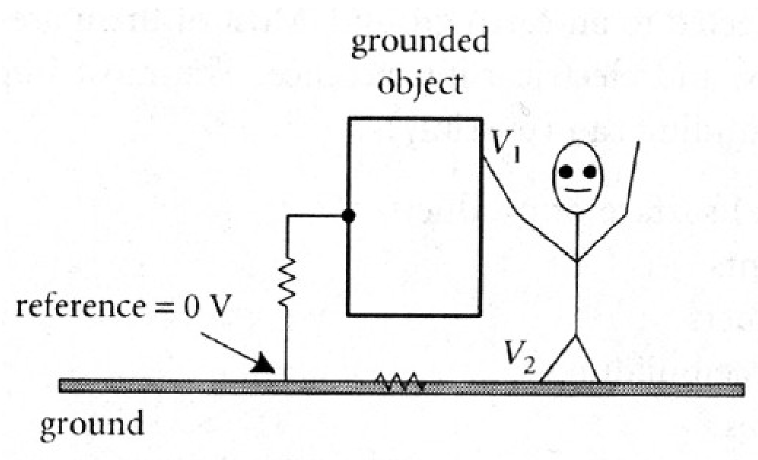


- Safety

Signal Return (Masse) **GND**

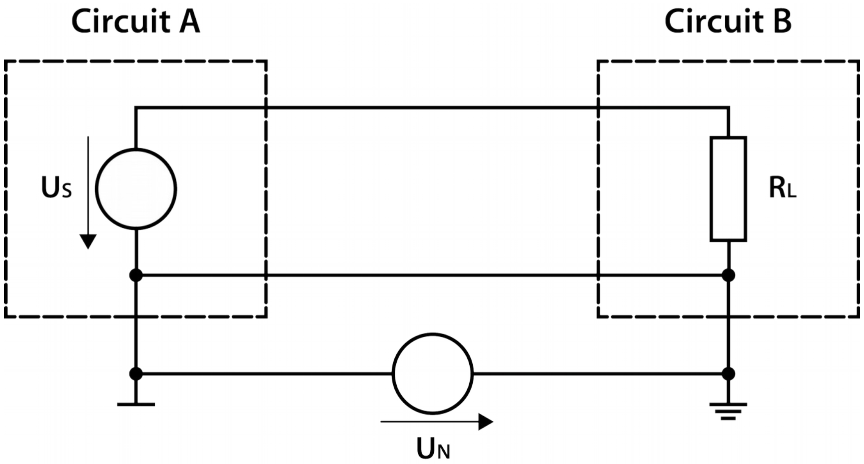


- Common signal reference potential



Ground loops

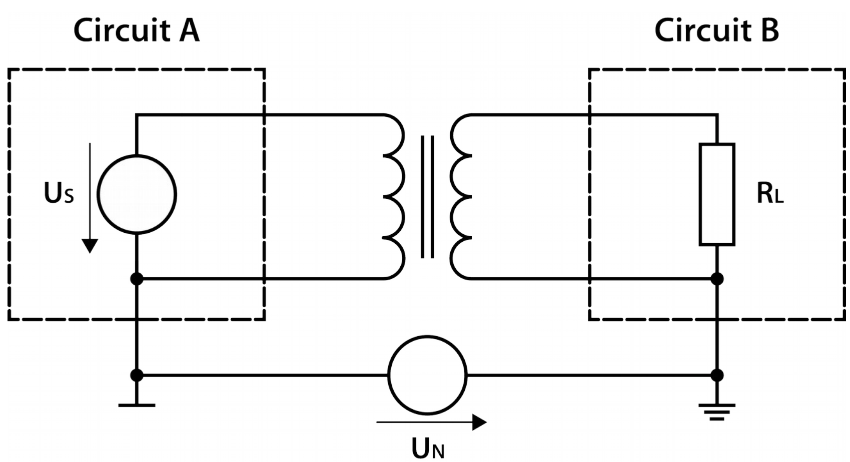
- Multiple paths to GND/Earth of return line
- Can pick up noise current through induction or voltage drop on ground conductors
- If possible using same mains wall socket can help

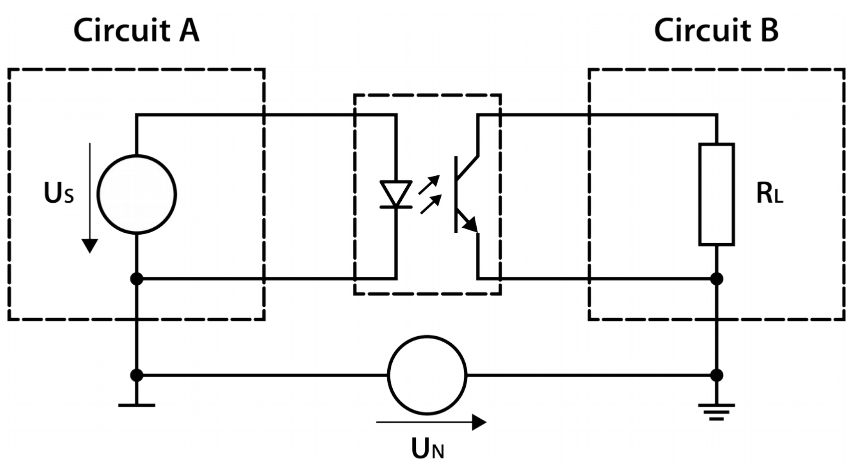


Circuit isolation

- Disconnect one side from PE? No, Dangerous!
- Isolate the circuits:
  - Isolation transformer

    - No DC signal
  - Opto-Coupler / Islolation Amplifier

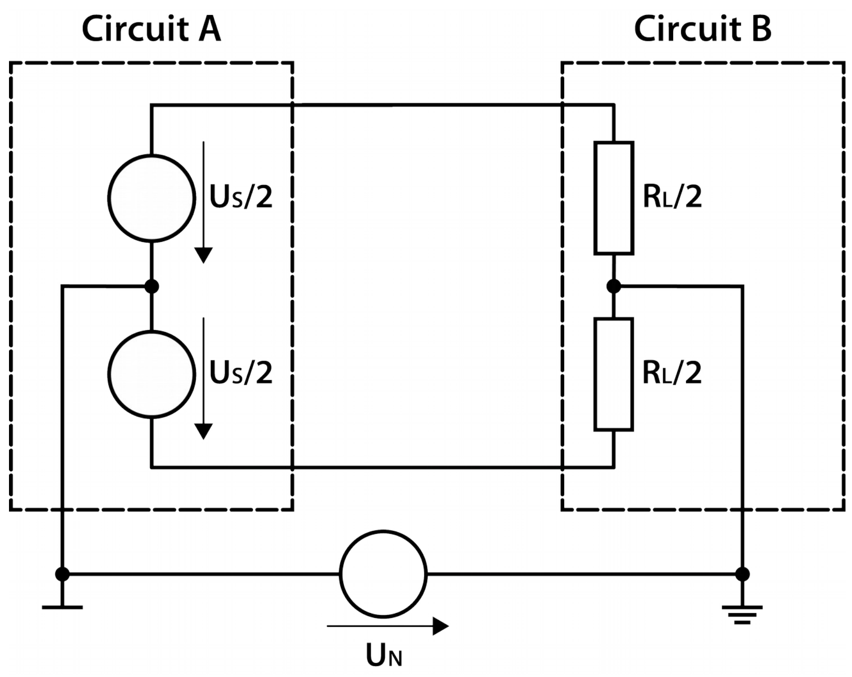


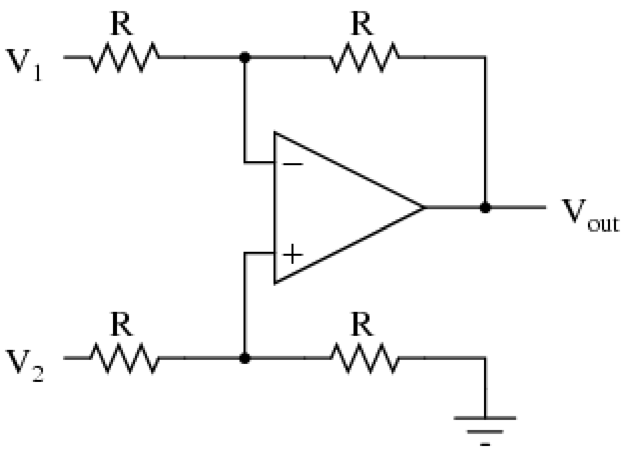


Symmetrical design

Symmetrical design

(can be difficult for High frequency)





Differential Amplifier

Common mode current

Use Common Mode Choke

- Only AC suppression

- For HF: Ferrite Beads

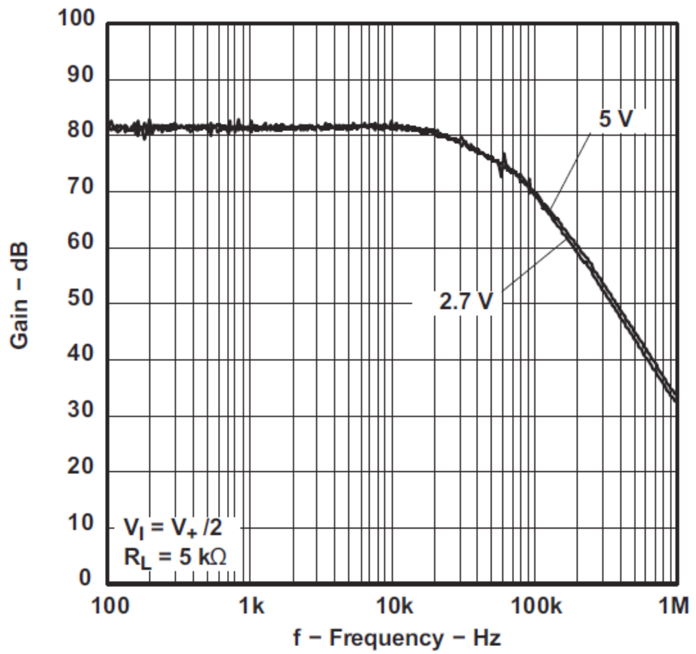
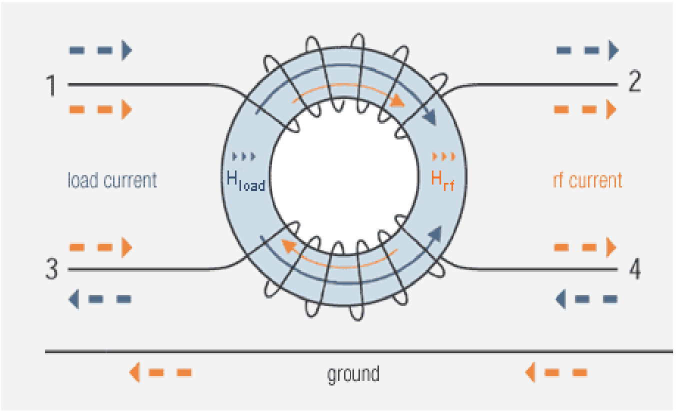
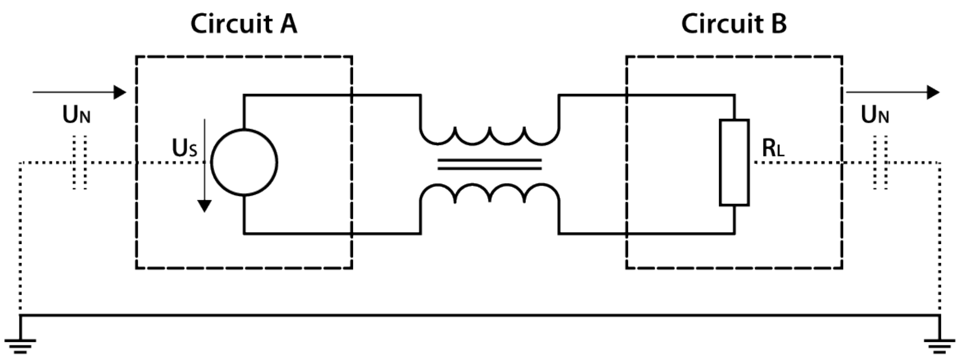
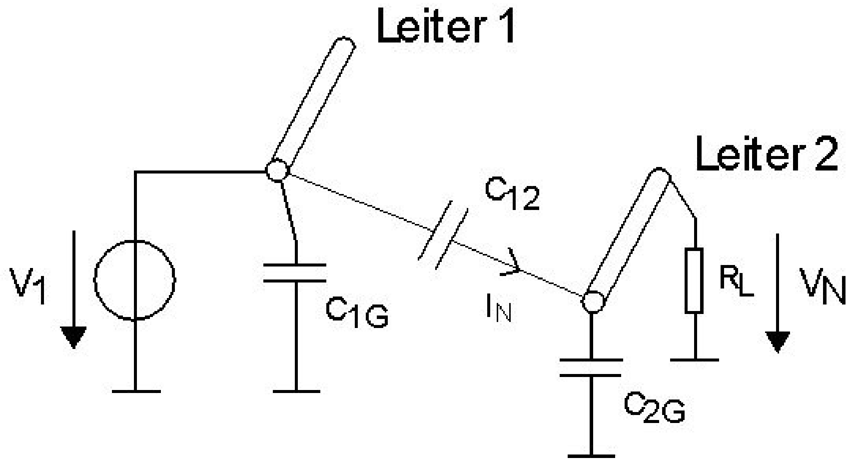


Figure 16. CMRR vs Frequency





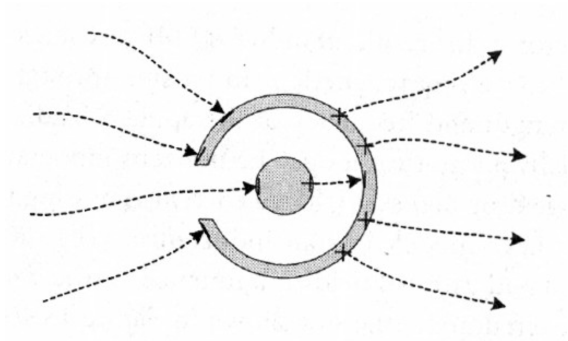
Capacitive coupling



$$I_N = j \cdot \omega \cdot C_{12} \cdot V$$

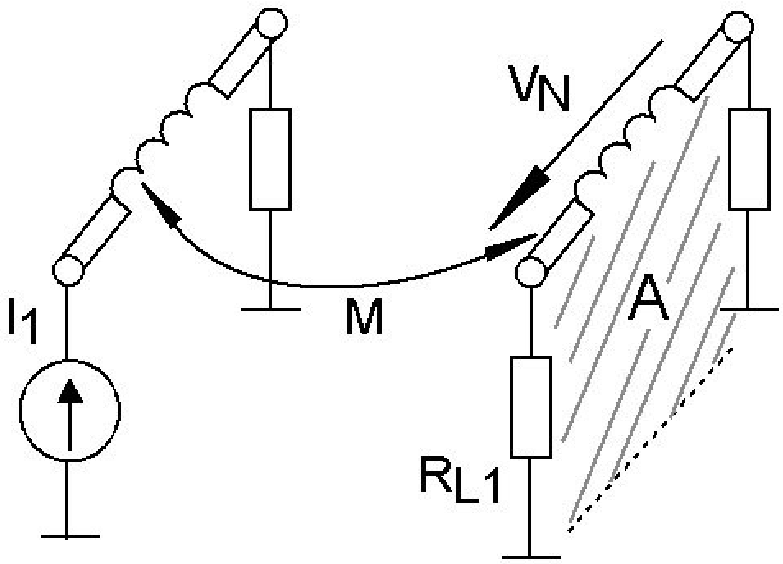
$$C = \frac{\varepsilon \cdot A}{d}$$

- Shield with electrically good conduction wire / surface
- Shield connected to GND



Magnetic coupling

- Current, Inductivity area, Orientation
- Wires near GND plate, Wires not parallel but perpendicular, Twisting Cables

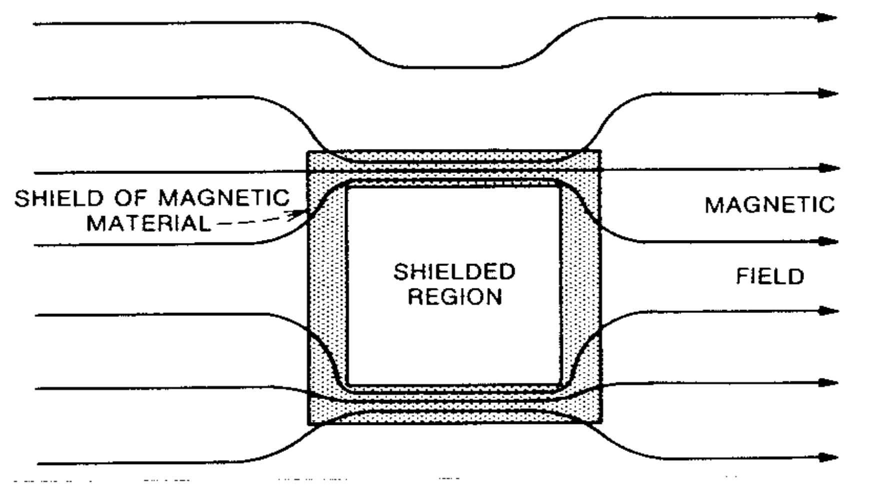


$$V_N = j \cdot \omega \cdot B \cdot A \cdot \cos\theta$$
$$V_N = j \cdot \omega \cdot M \cdot I_1$$

(Magnetic) shielding

DC and LF

- Shielding with permeable material
- Shape of apertures important

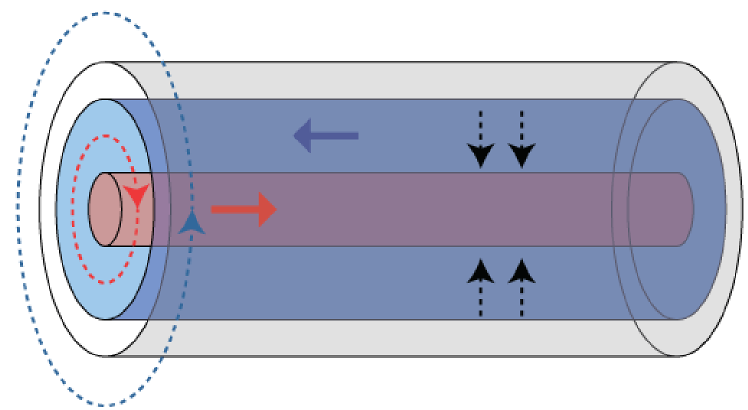


LF and above

- Twisting wires
- Coaxial Cable shielding:

  E-Field : surrounded by conductor

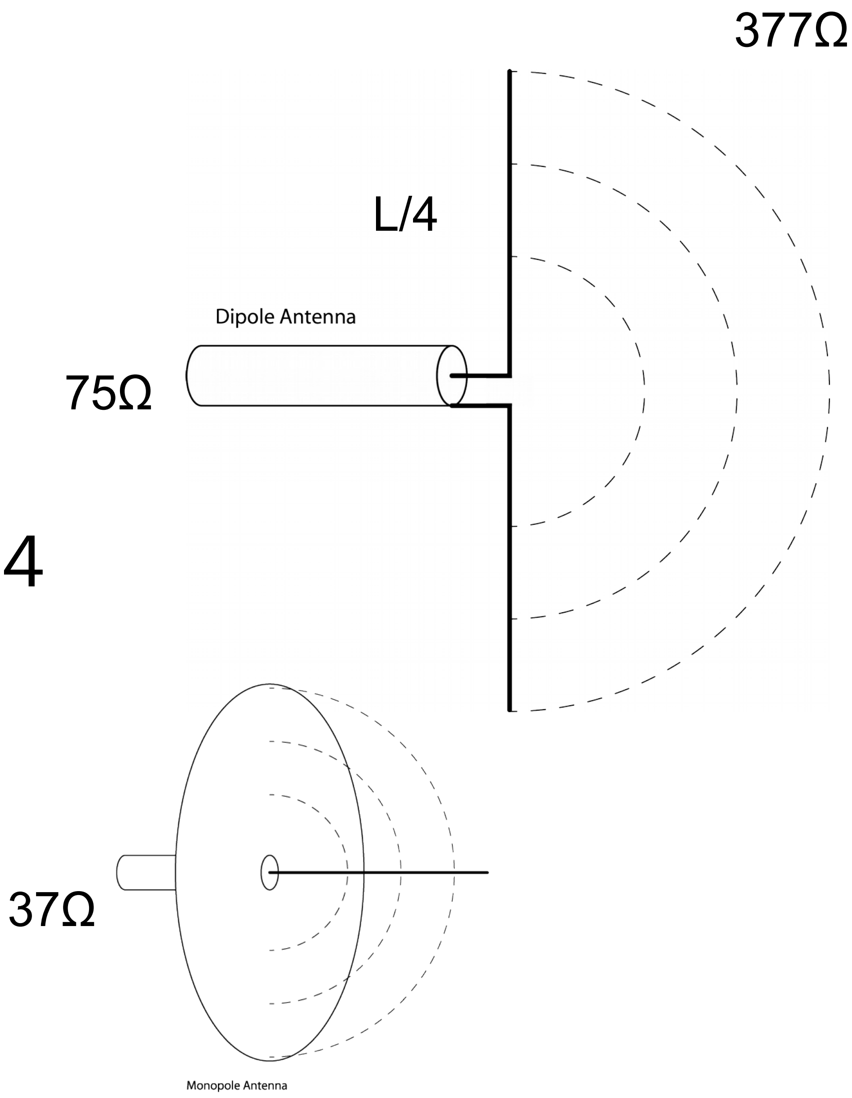
  B-Field : symmetry
- HF Skin depth < shield eddy currents



EM coupling / radiation

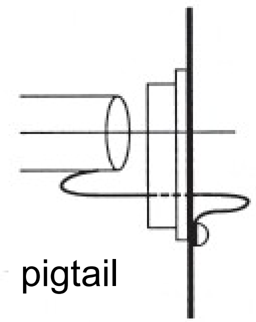
EM coupling:

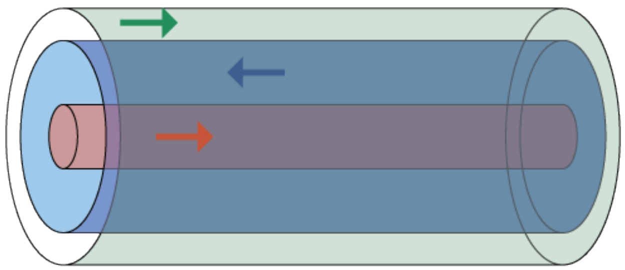
- Far Distance / High frequency
- Wire / Slot acts as an Antenna
- Radiation if wire approaches $\lambda/4$



EM coupling / radiation

- Avoid pigtails at HF connections
- Ferrite beads can prevent cable radiating





Shielding Material

Shielding Material:

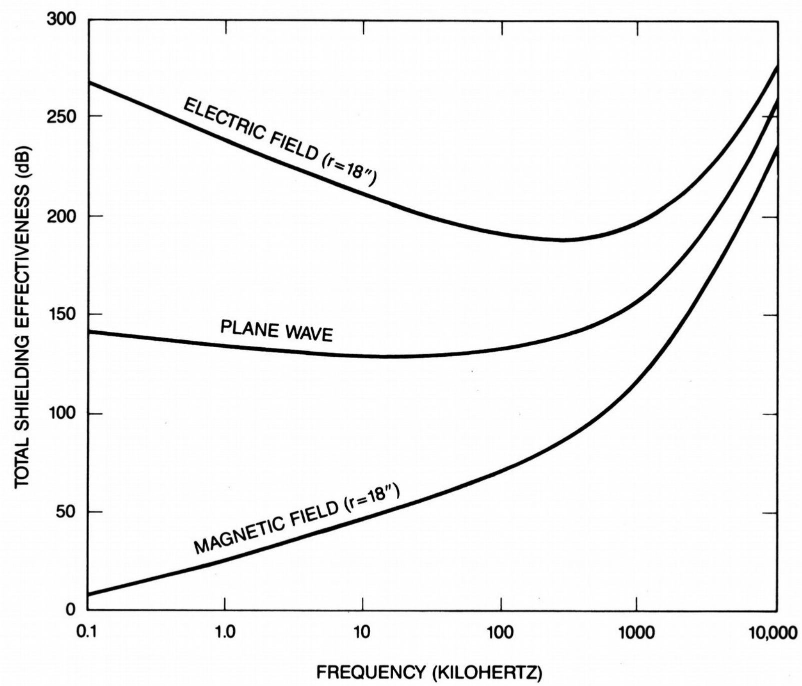
reflection / absorption

Any metal case good except

LF: B-Field

HF: apertures more important

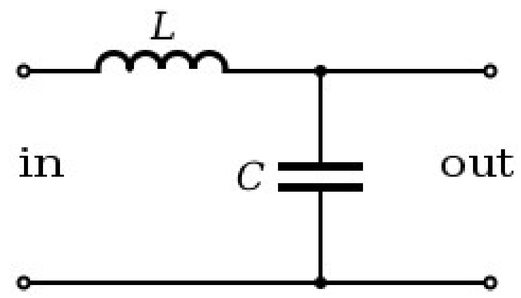
H. W. Ott: Noise Reduction Techniques 2nd Ed.



Shielding effectiveness: 0.5mm aluminium
Source distance: 460mm

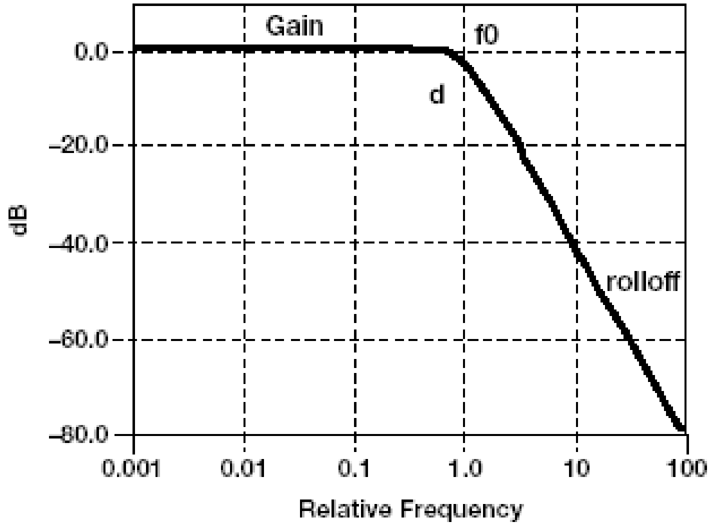
Filtering

- Passive Analog Filter :
  - Inductors block HF
  - Capacitors block LF



Low pass Filter

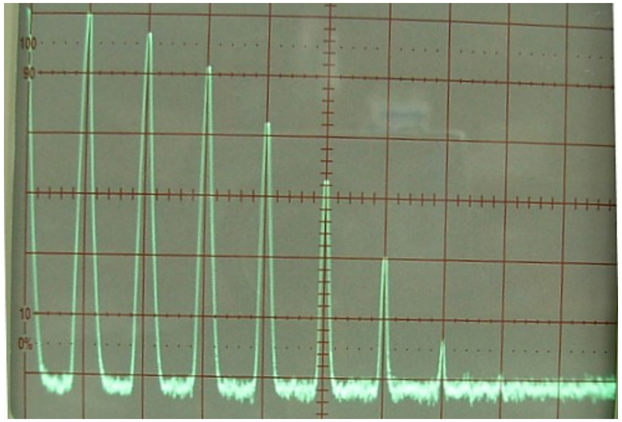
- Reduce Bandwidth



Spectrum Analysis

Swept tuned (Superheterodyne) Spectrum Analyser

- Superposition of oscillations
- + Sensitivity
- + Bandwidth

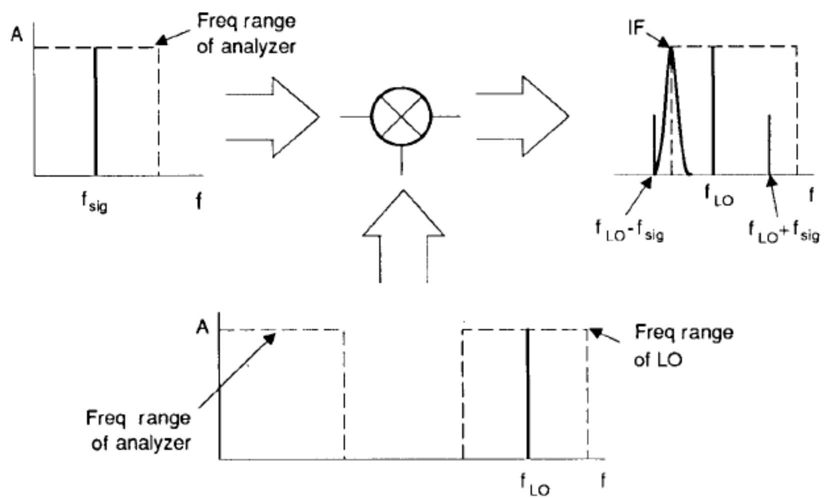


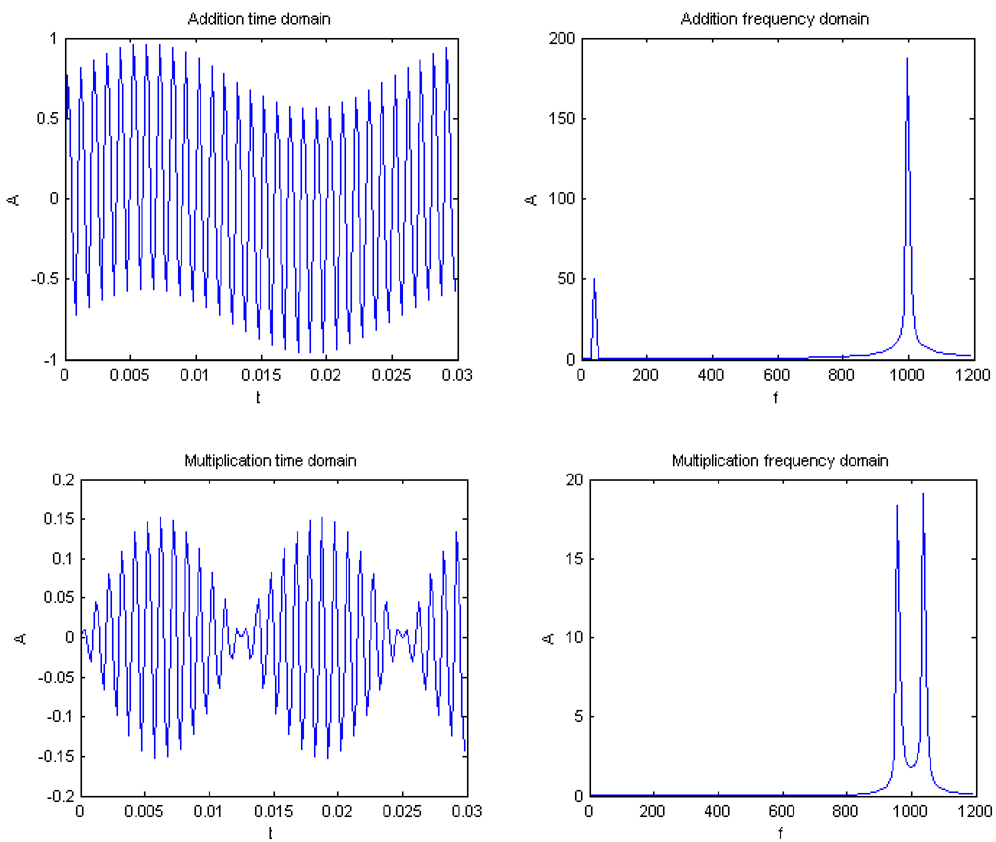
Fast Fourier Transform (FFT) Spectrum Analyser

- Time domain sampling
- Fourier transform
- + Single shot

Mixing

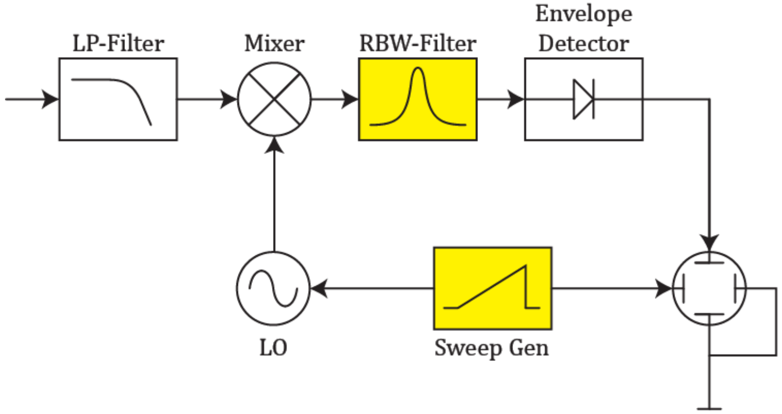
- Mixer creates sum and differences of the oscillations and harmonics
- Nonlinear characteristic
- Low pass filter at Input

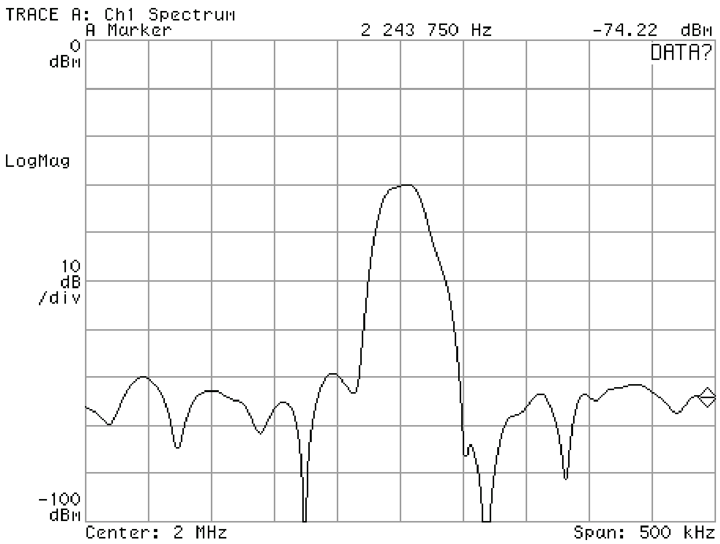


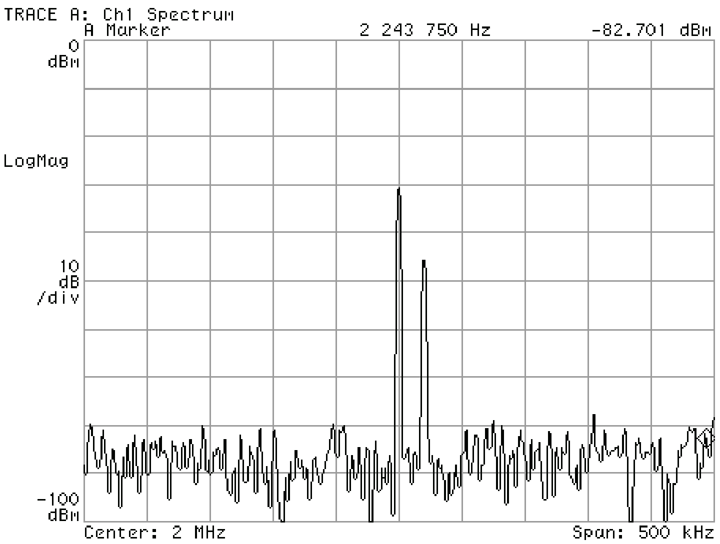


Frequency sweep / RBW-filter

- Frequency sweep (span)
- Adjustable RBW-filter defines the frequency resolution
- Narrow bandwidth increases sweep time

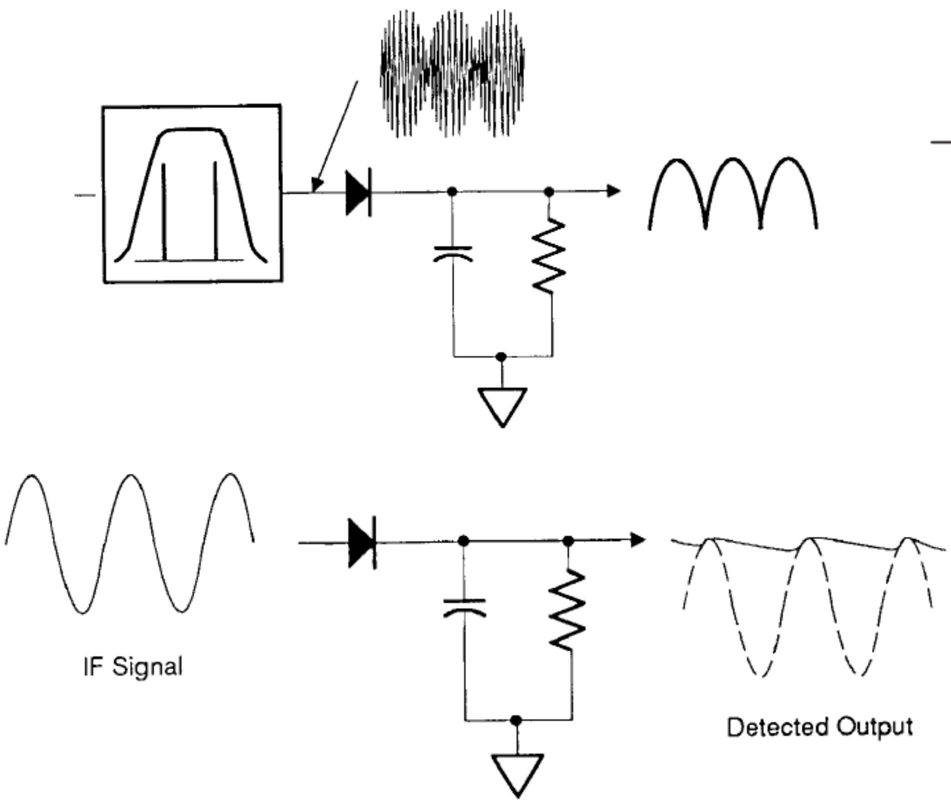


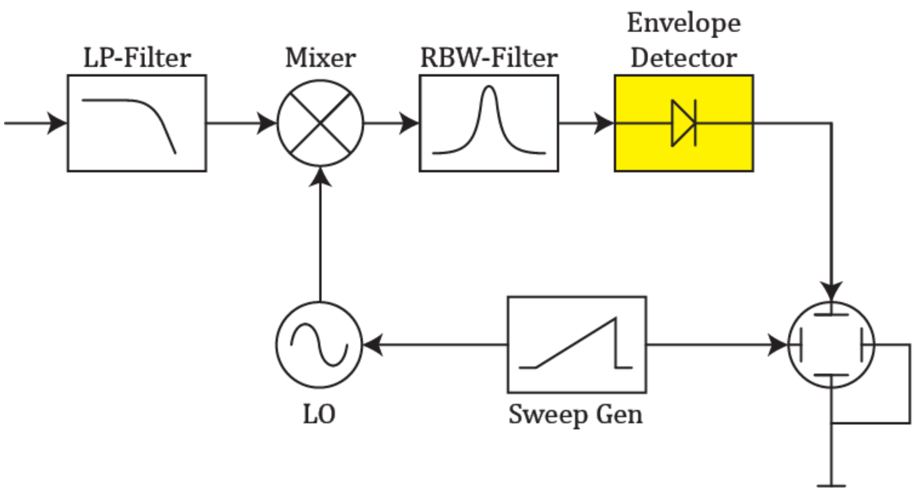




Envelope detector

- Rectifies and smoothens signal
- Adjustable Video Filter

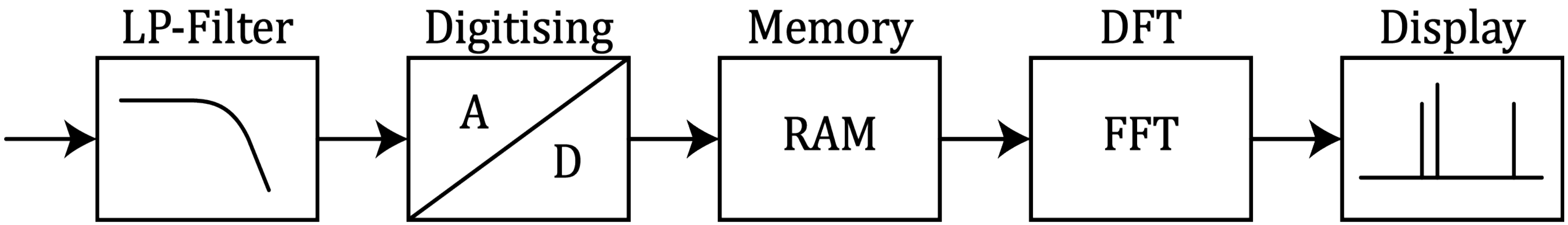




FFT-Analyser

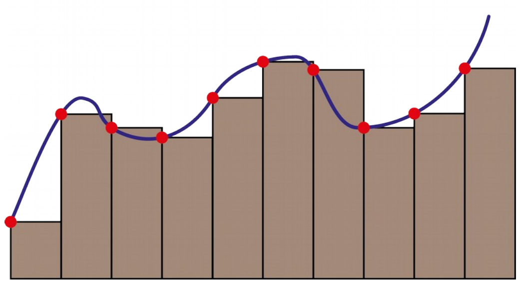
- Based on Discrete Fourier Transformation

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{j 2 \pi k n / N}$$

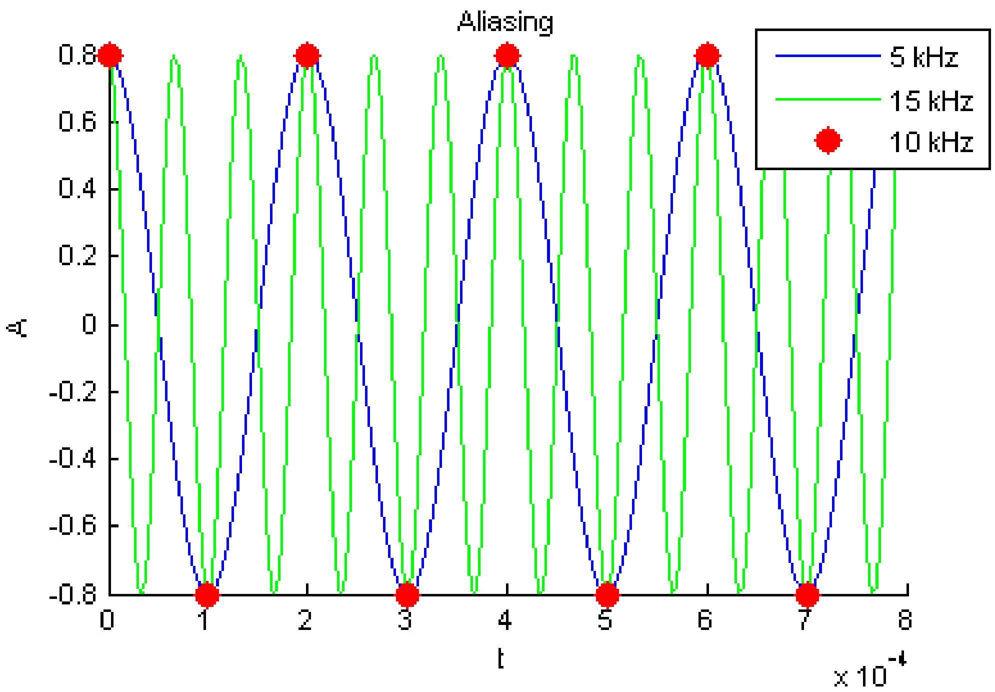


AD-Conversion

- Quantification
- ADC Limited BW and Dynamic Range
- Nyquist–Shannon sampling theorem

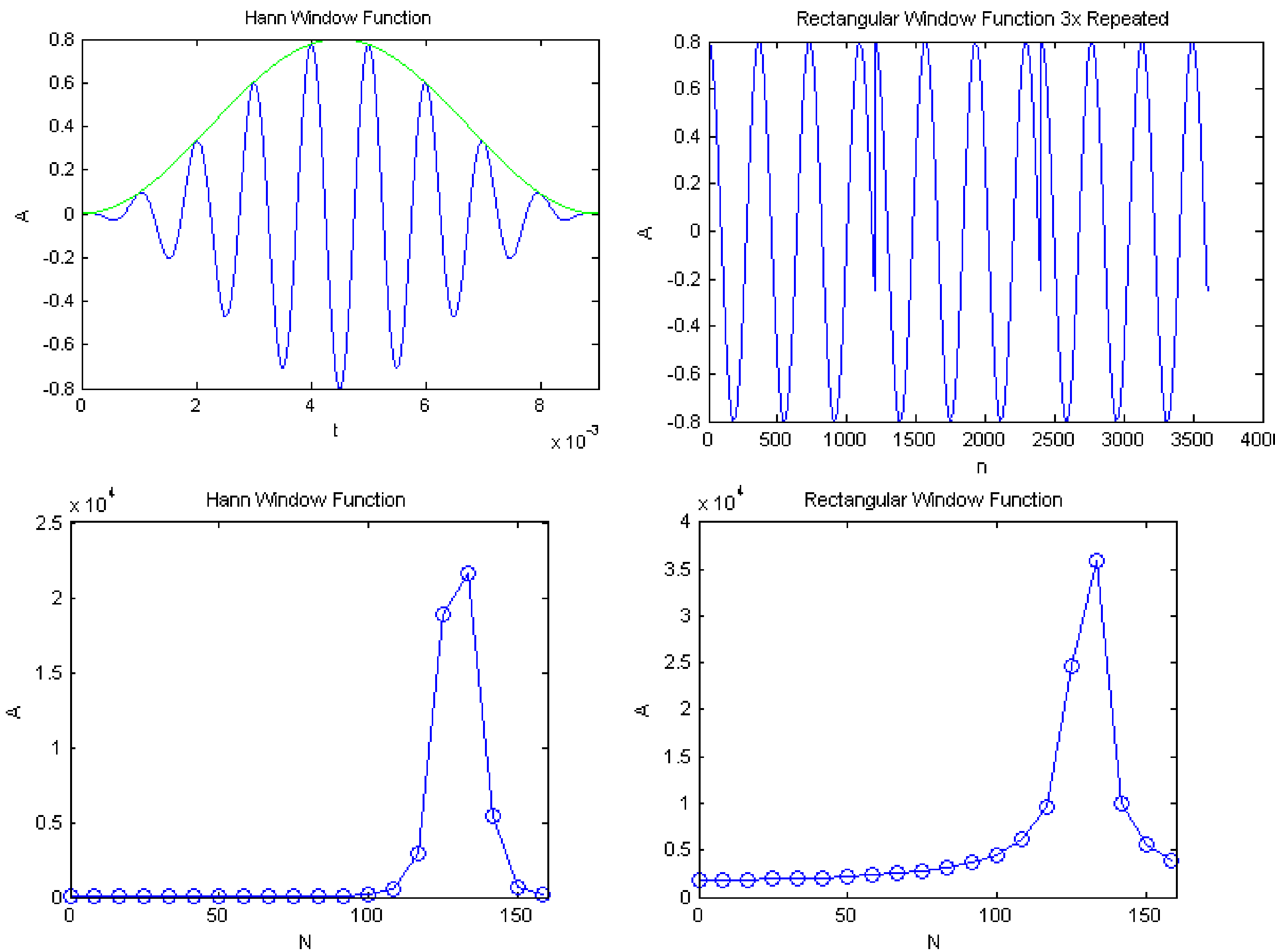


$$f_A \geq 2 \cdot B_{Sig}$$

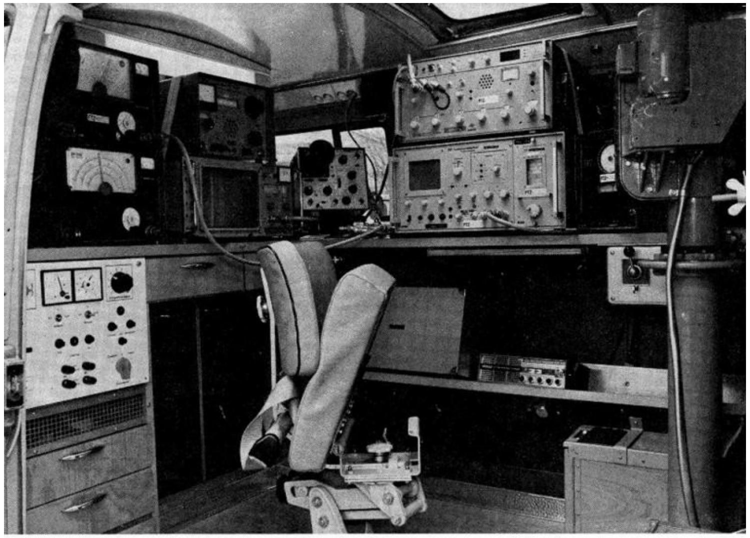


Spectral leakage

- DFT only precise when signal frequency is a multiple of sampling period



Sources



Meßgeräteaufbau im Funkmeßwagen 65 (Werkbild FTZ)

- Elektronikkurs 2010, 2. Teil: Rauschen und Störungen
- Motchenbacher, Fitchen: Low-Noise elecronic Design
- Kenneth L. Kaiser: Electromagnetic Compatibility Handbook
- Henry W. Ott: Noise Reduction Techniques in Electronic System
- Blake Peterson, Agilent Spectrum Analysis Basics, Application Note 150
- G. Vasilescu: Electronic Noise and Interfering Signals
- R. Morrison: Grounding and Shielding: Circuits and Interference