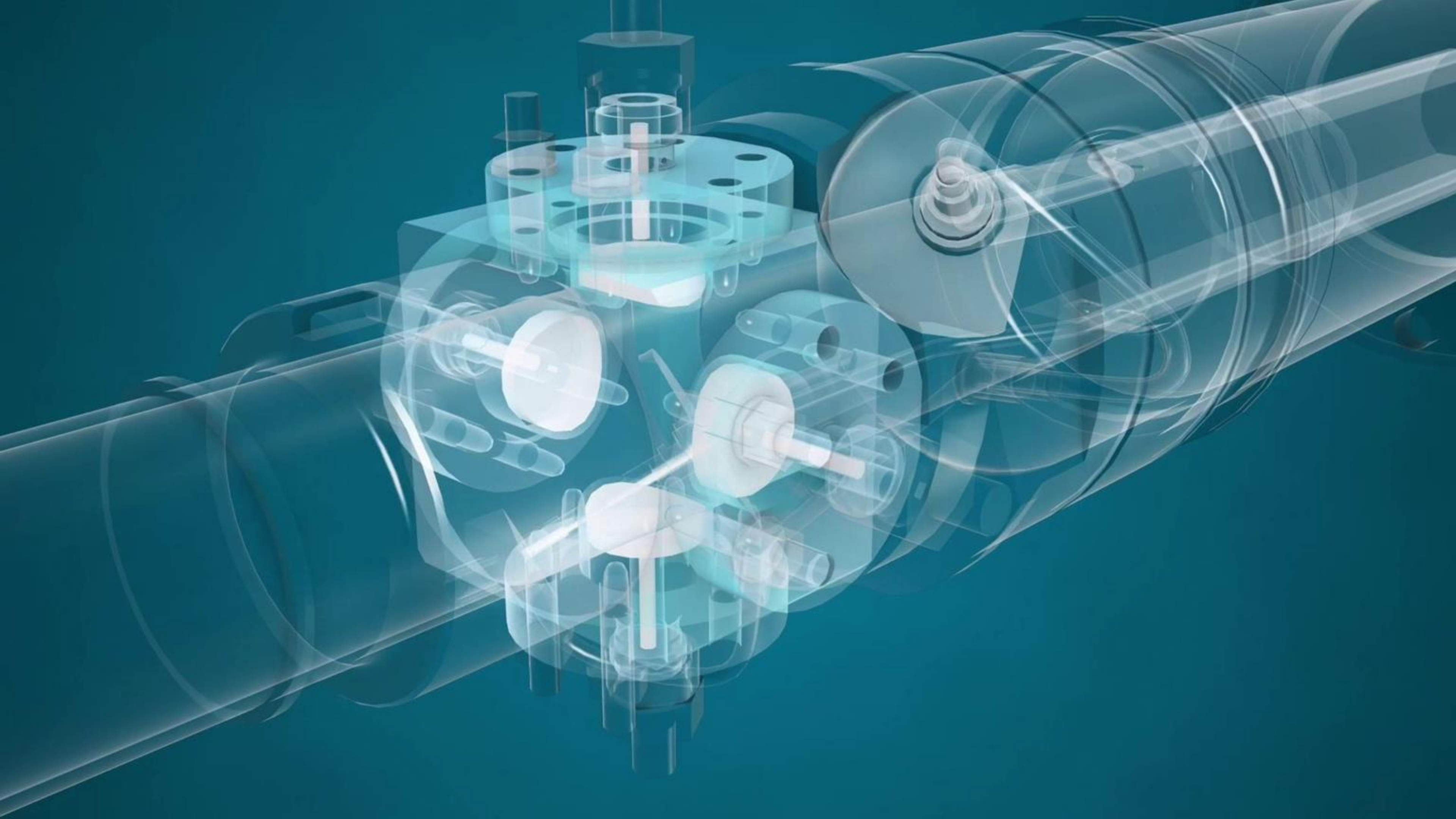
Radio Frequency Measurement Techniques

By Isabel and Felix



Comparison Oscilloscope and Signal Analyzer

Oscilloscope:

Domain between time & voltage

Signal Analyzer:

- Domain between frequency & voltage
- Uses dBm(Decibel) instead of volt
- To show a large dynamic range
  - dB expresses relative differences in signal power or level
    - P[dB] = 10 log (P/Pref)
    - V[dB] = 20 log (V/Vref)

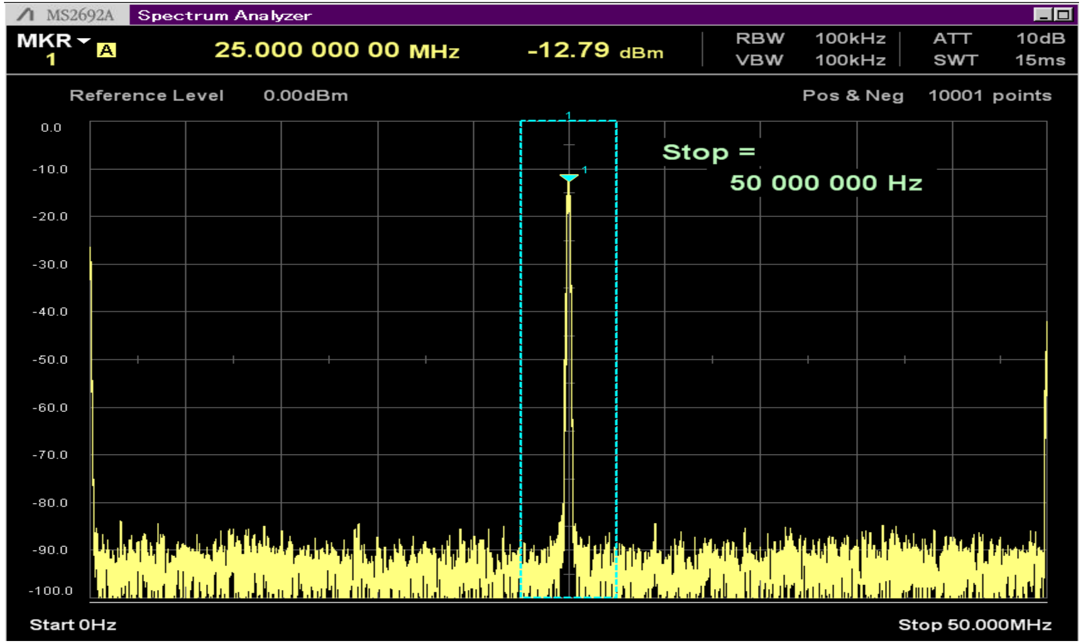
Sine function:

Frequency: 25 MHz Amp: 150mV

T: 40 ns

$$v(t) = A \cdot sin(2\pi f \cdot t) + \phi$$

$$v(t) = 150\ mV \cdot sin(2\pi (25\ MHz) \cdot t)$$

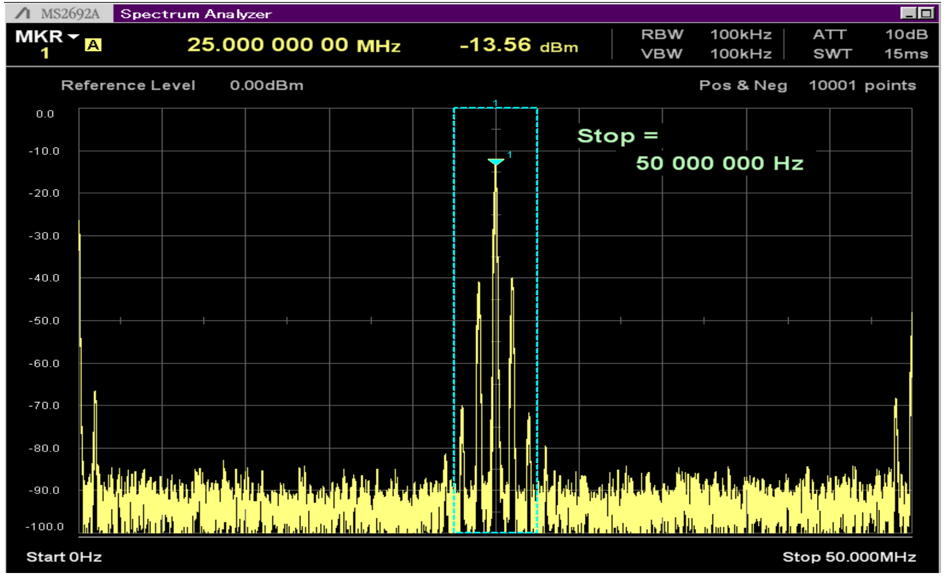


Modulated Sine function:

‘Original function’: Frequency: 25 MHz Amp: 150mV T: 40 ns

‘Modulation: AM index: 0.70 AM depth: 70 %

$$x_a(t) = [1 + \alpha \cdot a_m(t)] \cdot A_c \cdot \sin(\omega_c \cdot t + \phi_c) \qquad x_a(t) = [1 + 0,70 \cdot \sin(2\pi \cdot 1MHz \cdot t)] \cdot 150\ mV \cdot \sin(2\pi(25\ MHz) \cdot t)$$

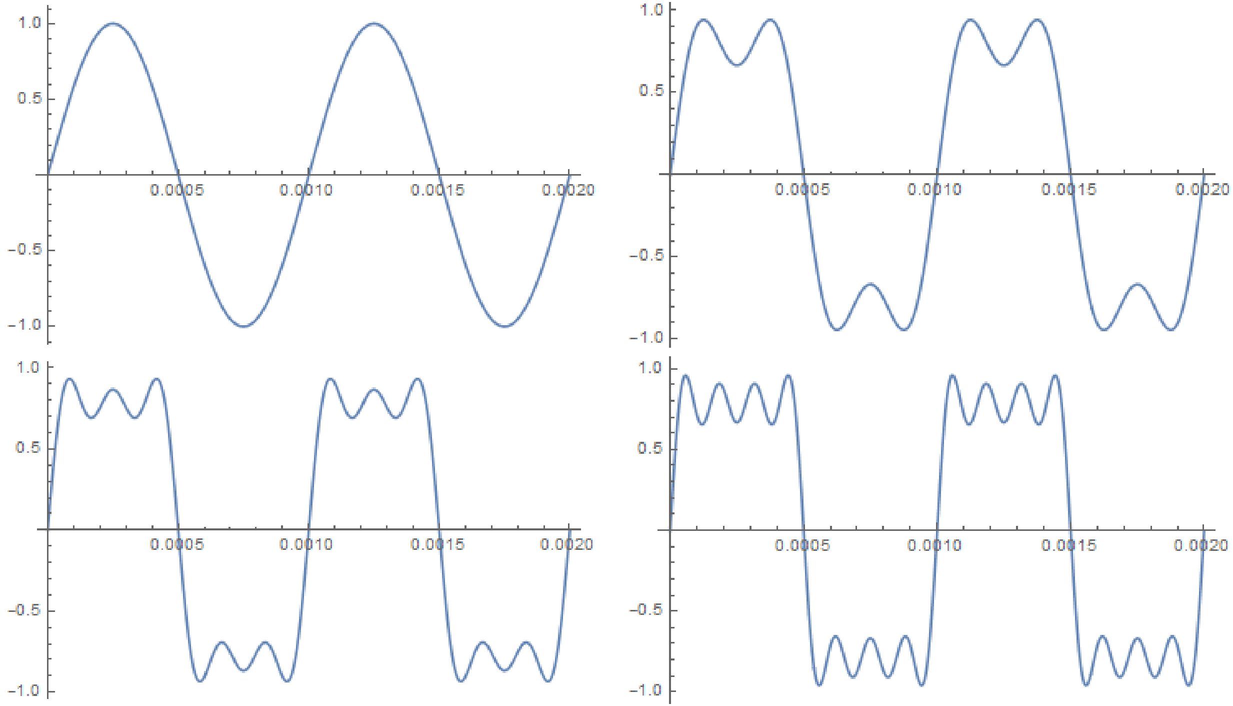


Fourier Series

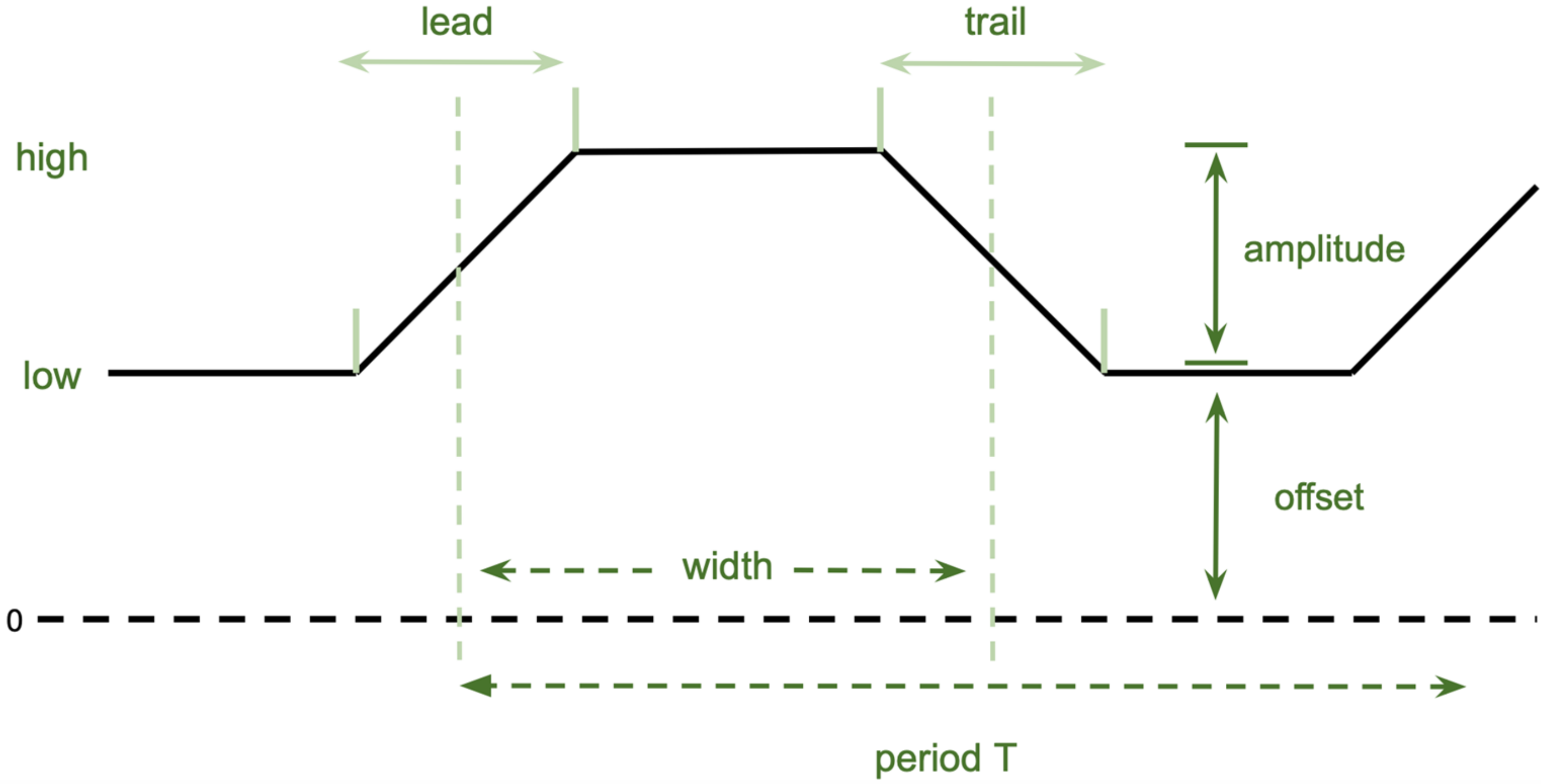
- Every periodic function can be expressed as a superposition of sine waves of different amplitudes and frequencies
  - Create any function by adding up different sine functions
- Example square function:

$$(n \in \mathbb{N} | \frac{n}{2} \neq 0)$$

$$f(t) = \sum_{n=1}^{\infty} \frac{1}{n} sin\,(n \cdot 2\pi f t)$$



Pulse Generator:

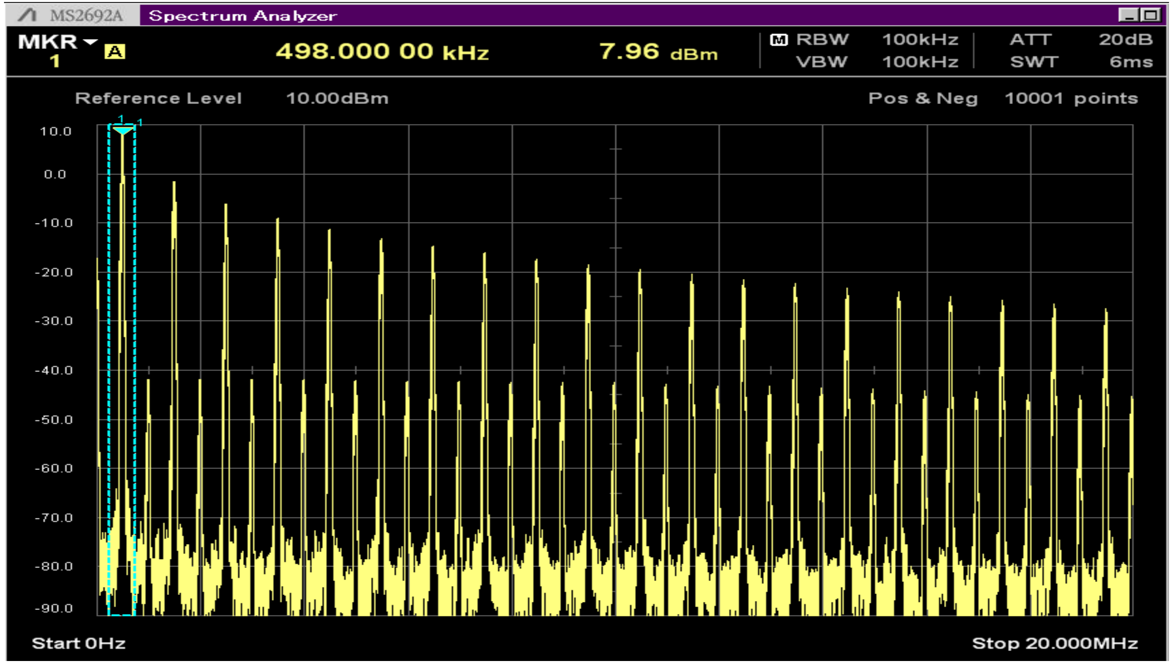


Square Function:

$$(n \, \varepsilon \, \mathbb{N} | \tfrac{n}{2} \neq 0)$$

$$f(x) = \frac{4 \cdot 2V}{\pi} \left(sin\,(x) + \tfrac{1}{3} sin\,(3x) + \tfrac{1}{5} sin\,(5x) \;...... \right)$$

$$f(t) = \sum_{n=1}^{\infty} \frac{1}{n} sin\,(n \cdot 2\pi f t)$$

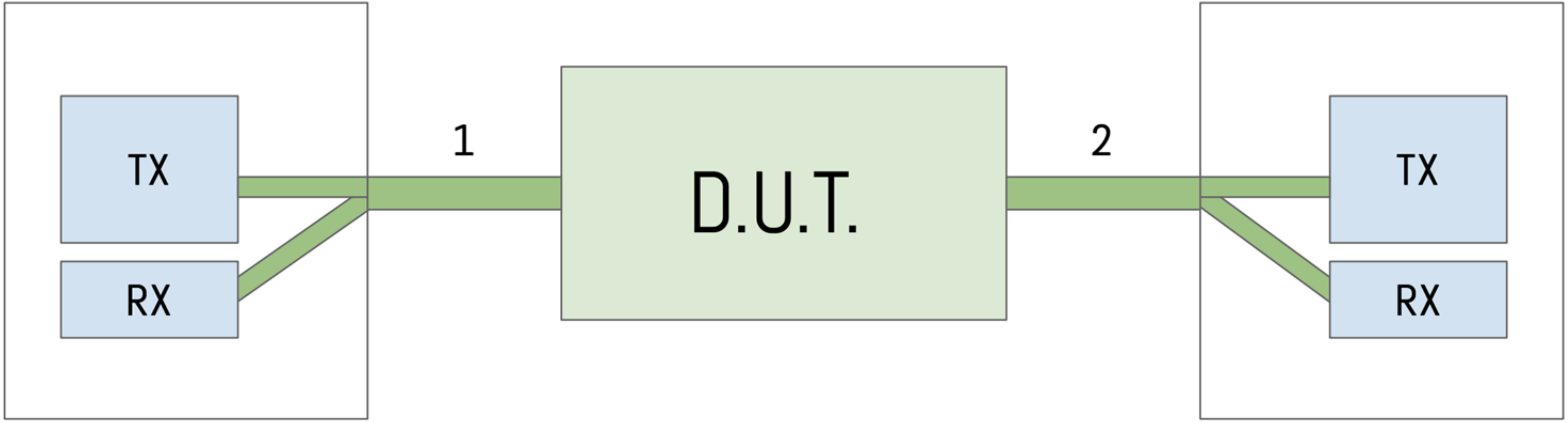


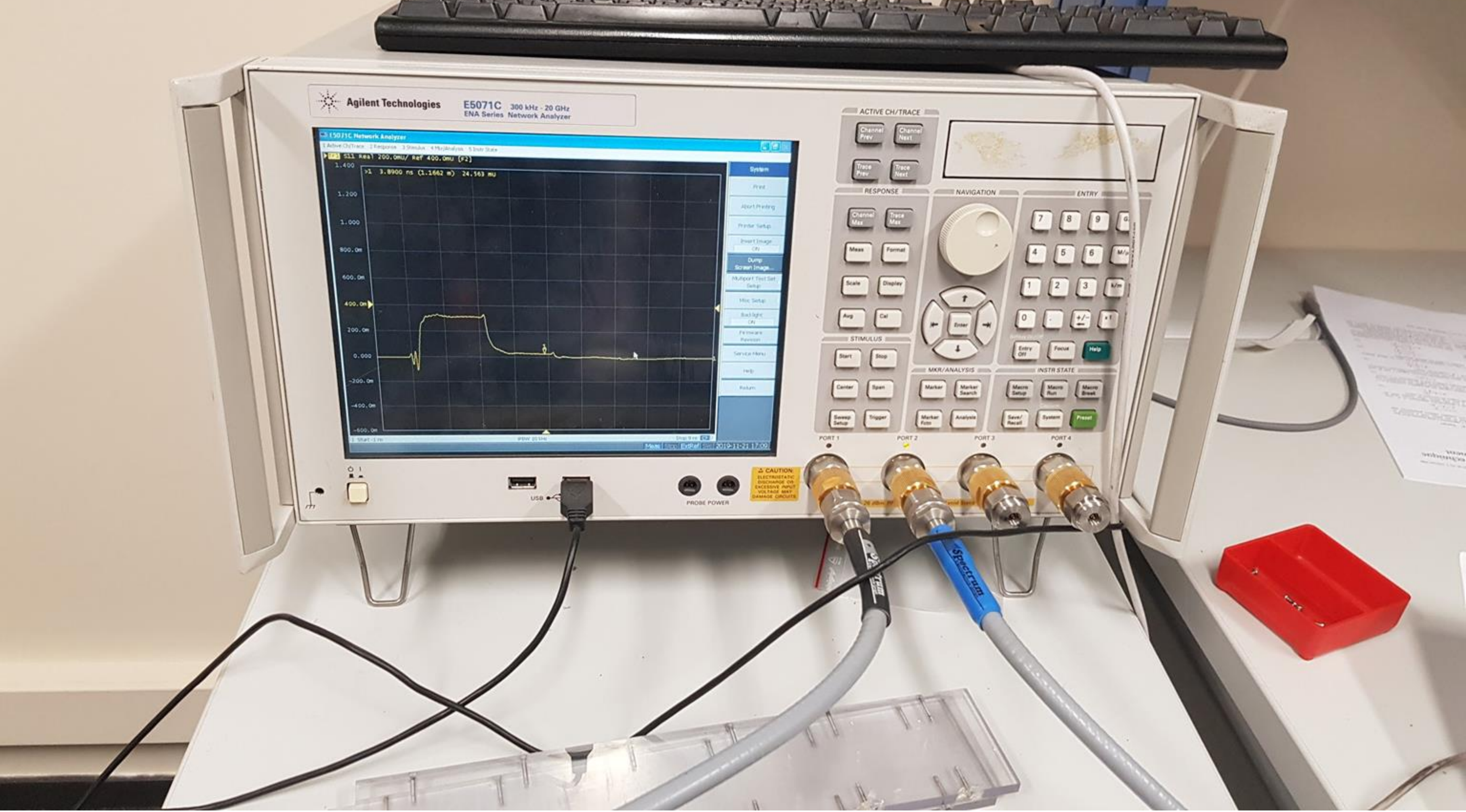
Vector Network Analyser

RX: Receiver (A)
TX: Generator (B)

→ S_{AB} → S_{11} S_{12} S_{22} S_{21}

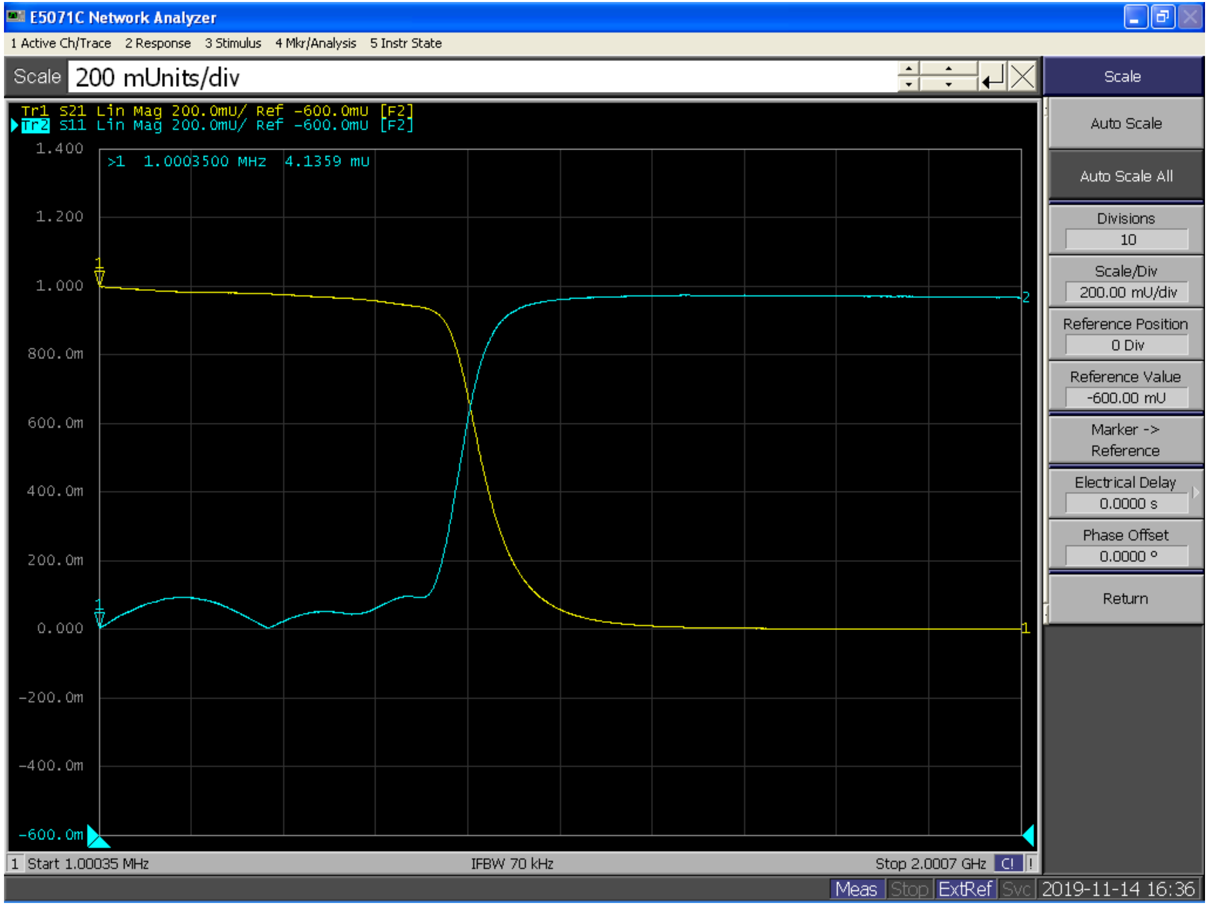
(Scattering parameters)




Agilent Technologies
E5071C 300 kHz - 20 GHz
ENA Series Network Analyzer
E5071C Network Analyzer
S11 Real 200.0mU/ Ref 400.0mU (F2)
>1 3.8900 ns (1.1662 m) 24.563 mU
System
ACTIVE CH/TRACE
RESPONSE
NAVIGATION
ENTRY
STIMULUS
MKR/ANALYSIS
INSTR STATE
PORT 1
PORT 2
PORT 3
PORT 4
USB
PROBE POWER
CAUTION
Spectrum

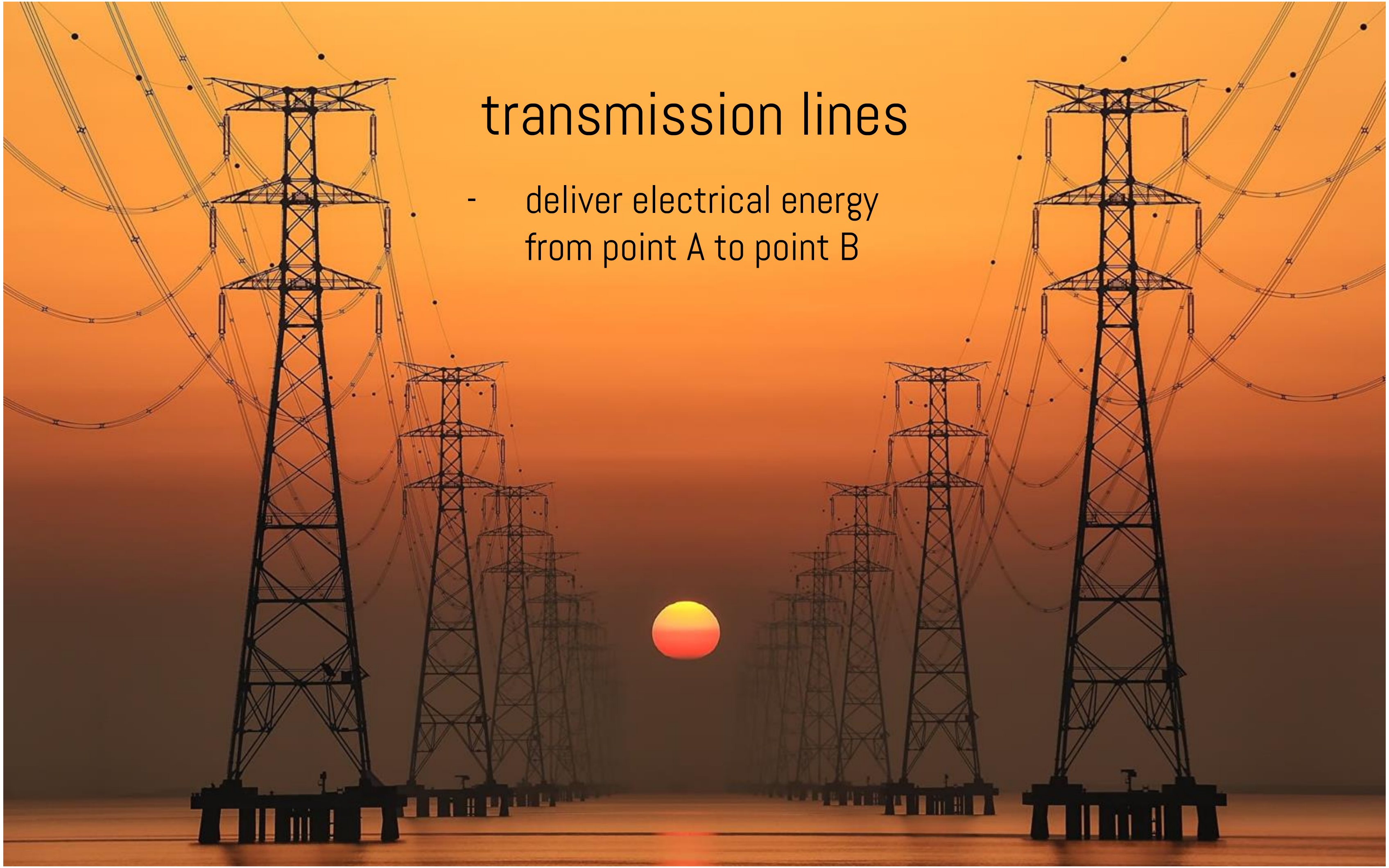
Lowpass

- Measuring the output signals (S21)
- Lower frequencies can pass through the device
  - Shown in yellow
  - Till about 750 MHZ
- Rest gets reflected back
  - S11
  - Shown in blue



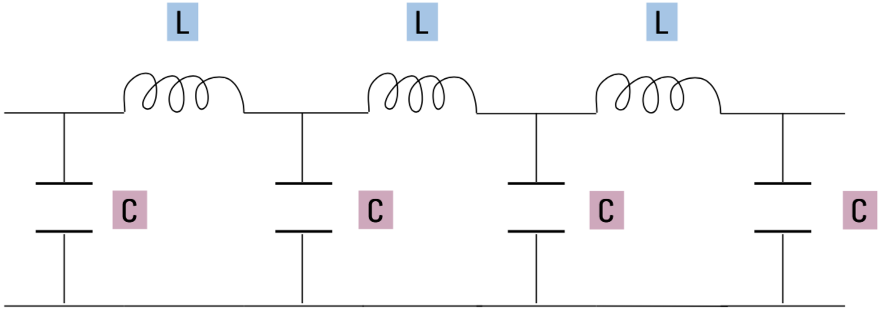
transmission lines

- deliver electrical energy from point A to point B



Transmission Lines

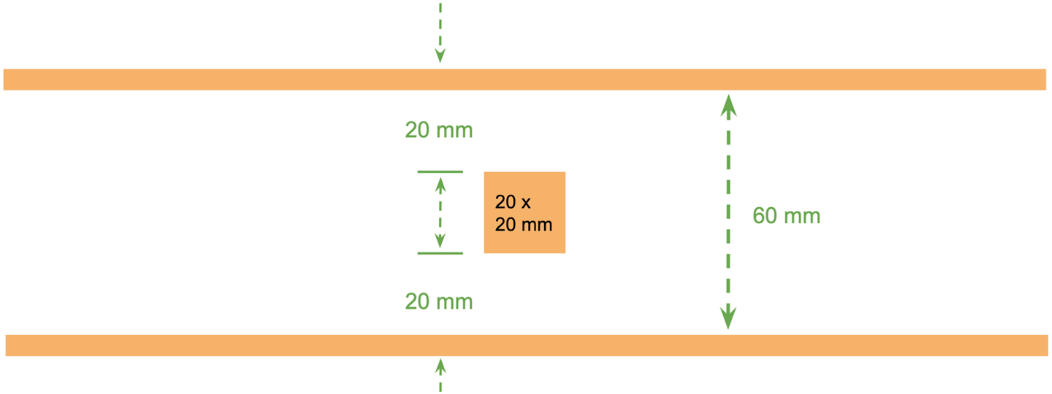
- Equivalent circuit =>
- Characteristic impedance
- Diameter of wire will determine inductivity L
- Space between wires determines cap. C
- Length of line does not impact the ch. Im.
  - Ratio stays the same



$$Z_0 = \sqrt{\frac{L'}{C'}}$$

The TEM line & isolator measurement

- Goal: Measuring the permittivity of a material
- Characterize the fill material with the VNA



- Inner conductor
  - 20mm * 20mm * 300mm
- Ground plane
  - 30cm * 22.5cm
  - 2 ground planes
    - Upper one not on pictures

Measurements

General:

- Impedance of cable:
  - 50 Ohm

With air:

- Reflection Factor
  - 0.173
- Runtime
  - 2ns

$$Z_1 = 70,917\ \Omega$$

$$\varepsilon_{r1} \approx 1$$

With aluminium:

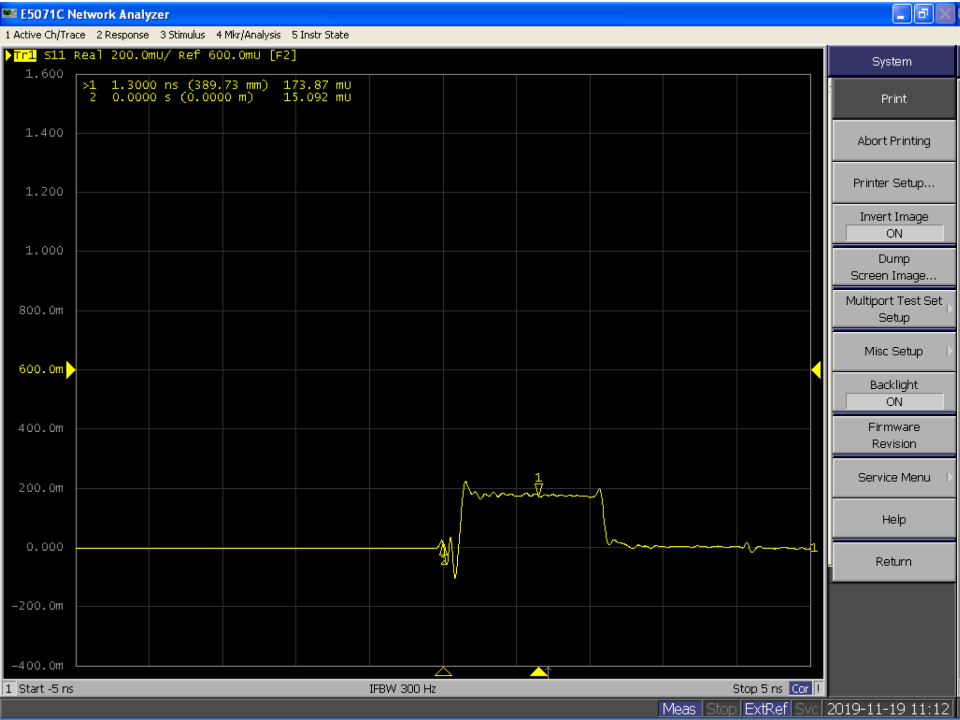
- Reflection Factor
  - -0.284
- Runtime
  - 3.72ns

$$Z_2 = 27\ \Omega$$

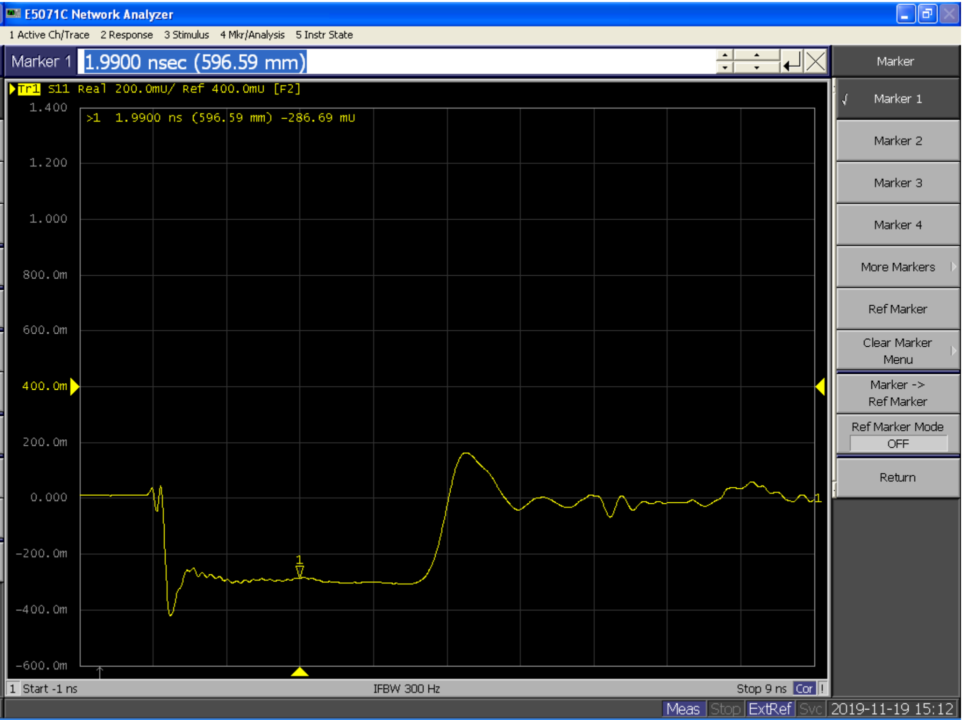
$$\varepsilon_{r2} \approx 7.7$$

Comparison:

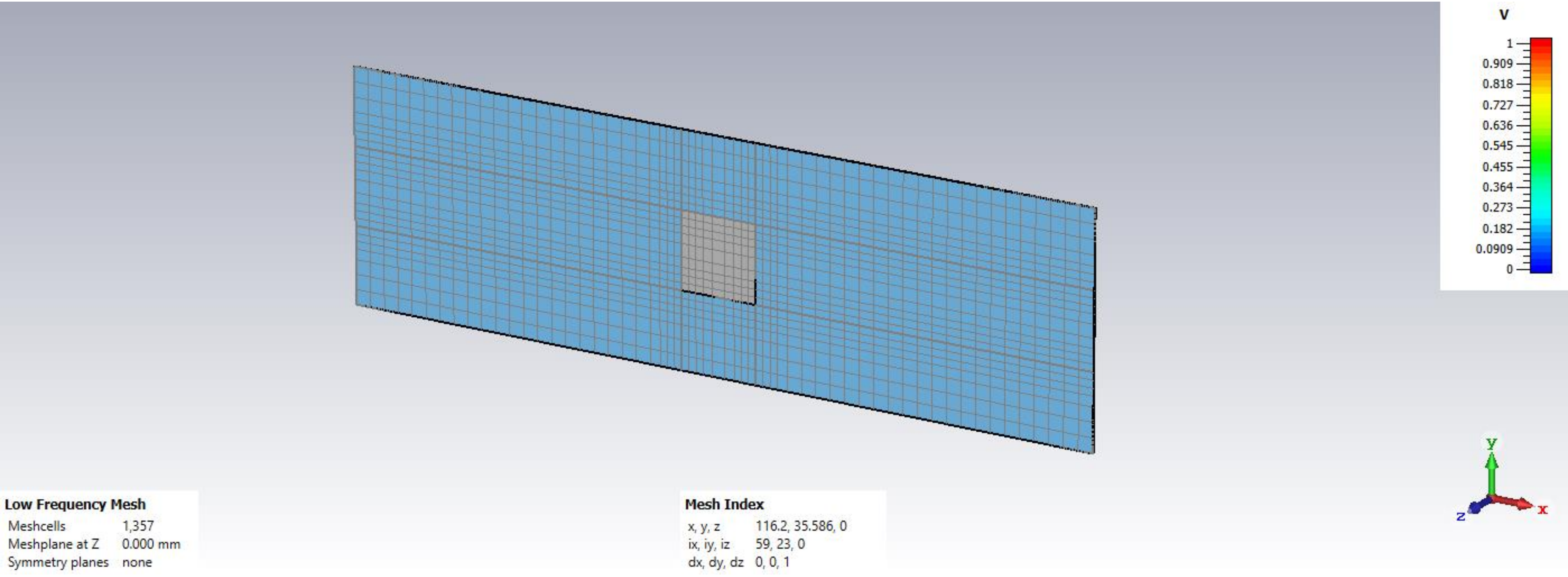
Air



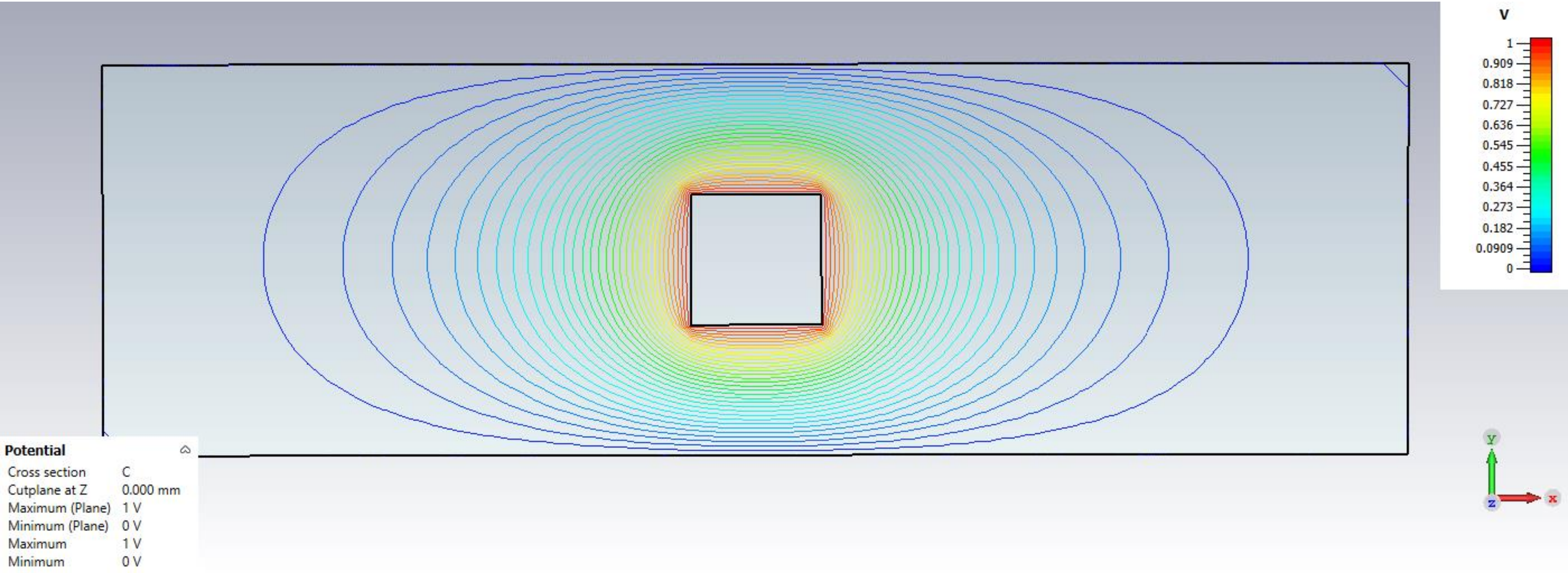
Aluminium



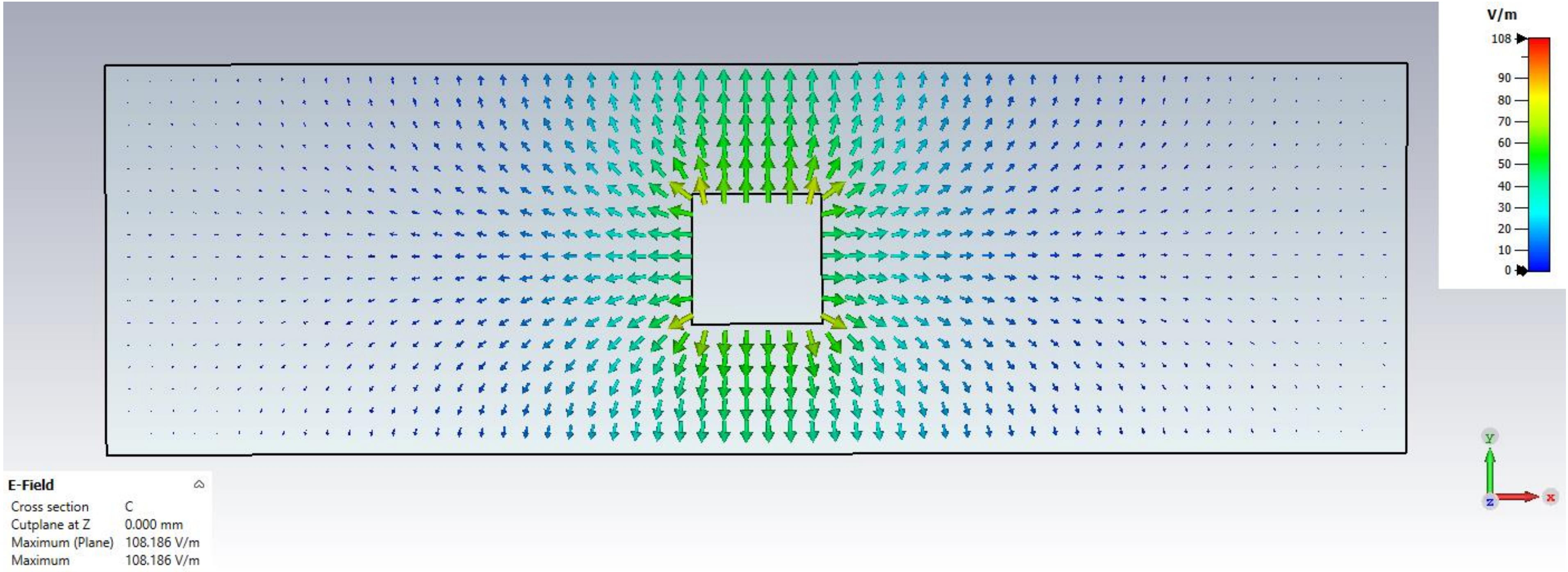
Computer simulated static transmission line



Electric potential



Electric field



bibliography

“Wallpaper Flare." *Black Transmission Posts, Sunset, Sun, Power Lines, Electricity HD Wallpaper | Wallpaper Flare*, www.wallpaperflare.com/black-transmission-posts-sunset-sun-power-lines-electricity-wallpaper-296649.

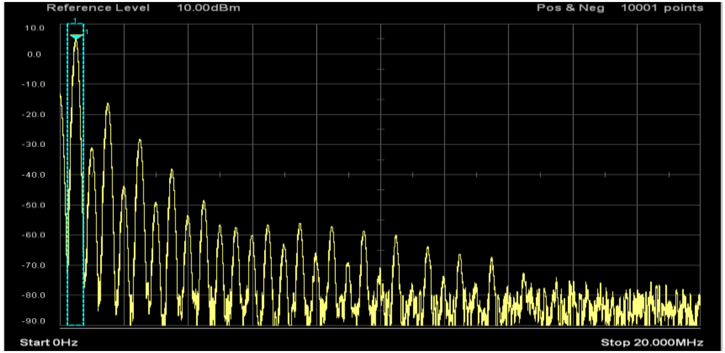
Digitales Oszilloskop – mit Flüssigkristallanzeige

https://de.wikipedia.org/wiki/Oszilloskop

Siglent SSA3021X Spectrum analyzer + FREE TG LICENSE
https://www.siglent.eu/siglent-ssa3021x-spectrum-analyser.html

Thanks for your attention

$$f(x) = \frac{8 \cdot 2V}{\pi}\left(\frac{1}{1^2} \cdot sin(x) - \frac{1}{3^2} sin(3x) + \frac{1}{5^2} sin(5x) -+ ......\right)$$

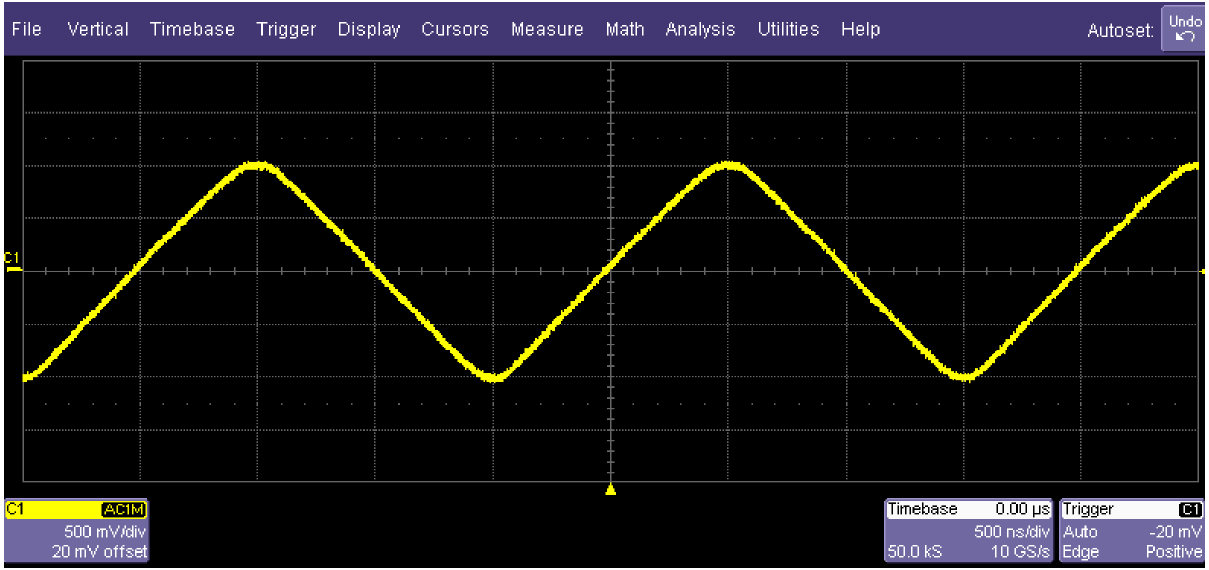


Triangle funktion

$$(n \in \mathbb{N} \mid \tfrac{n}{2} \neq 0)$$

$$\sum_{n=1}^{\infty} = \frac{1}{n^2} sin(2\pi f \cdot n)$$

- Shown on signal analyzer and oszilloskop
- Signal analyzer:
  - Different frequencies visible
  - Every 2nd peak is a Mistake



Working with wave units

- High frequencies (starts at 50 Hz) have short wavelength
    - If linear geometric size of devices ⪷ λ/10
    - Highly complicated to use voltage and current
        - Values differ at various points of the waves
    - Easier to use wave units
        - Characteristic impedance
        - Inductivity
        - Capacity
        - ...

The Material

- Aluminium 995
  - 99.5% Al
- 20mm * 200mm * 200mm

Calculations

Equations:

With air:

With aluminium:

$$Z = Z_0 \frac{1+\Gamma}{1-\Gamma}$$

$$Z_1 = 50\Omega \cdot \frac{1+0.173}{1-0.173} = 70,917\ \Omega$$

$$Z_2 = 50\Omega \cdot \frac{1+(-0.286)}{1-(-0.286)} = 27\ \Omega$$

$$v_s = \frac{c_0}{\sqrt{\varepsilon_r}} \Leftrightarrow \varepsilon_r = \frac{c_0^2}{\frac{s^2}{t^2}}$$

$$\varepsilon_{r1} = \frac{c_0^2}{\frac{0.6^2}{2ns^2}} \Leftrightarrow \varepsilon_r \approx 1$$

$$\varepsilon_{r2} = \frac{c_0^2}{\frac{0.4^2}{3.7ns^2}} \Leftrightarrow \varepsilon_r \approx 7.7$$

$$\frac{t_1}{t_2} = \frac{\sqrt{\varepsilon_{r1}}}{\sqrt{\varepsilon_{r2}}} \Leftrightarrow \varepsilon_{r2} = \left(\frac{t_2 \cdot \sqrt{\varepsilon_{r1}}}{t_1}\right)$$

$$30\ cm \rightarrow 2\ ns$$

$$20\ cm \rightarrow \frac{4}{3} ns$$

$$\varepsilon_{r2} = \left(\frac{3.7ns \cdot 1}{\frac{4}{3}ns}\right) \Leftrightarrow \varepsilon_{r2} = 7.7$$