Signal and power integrity fundamentals

Theory and demos

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A **practical and useful seminar** discovering the fundamentals of Signal and Power Integrity for electronic circuits.

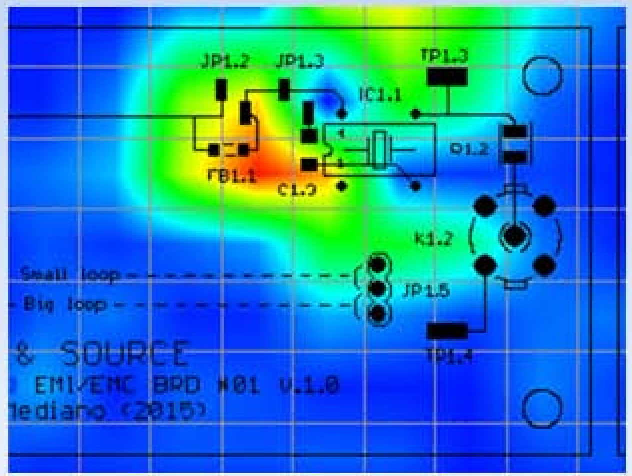
Organized by

ROHDE&SCHWARZ

2017-18
V.1.0

The HF Magic Lab(R)

A High Frequency Lab for design, diagnostic, troubleshooting and training



Interferences (**EMI**)
Electromagnetic Compatibility (**EMC**)
Signal Integrity (**SI**)
Radiofrequency(**RF**)

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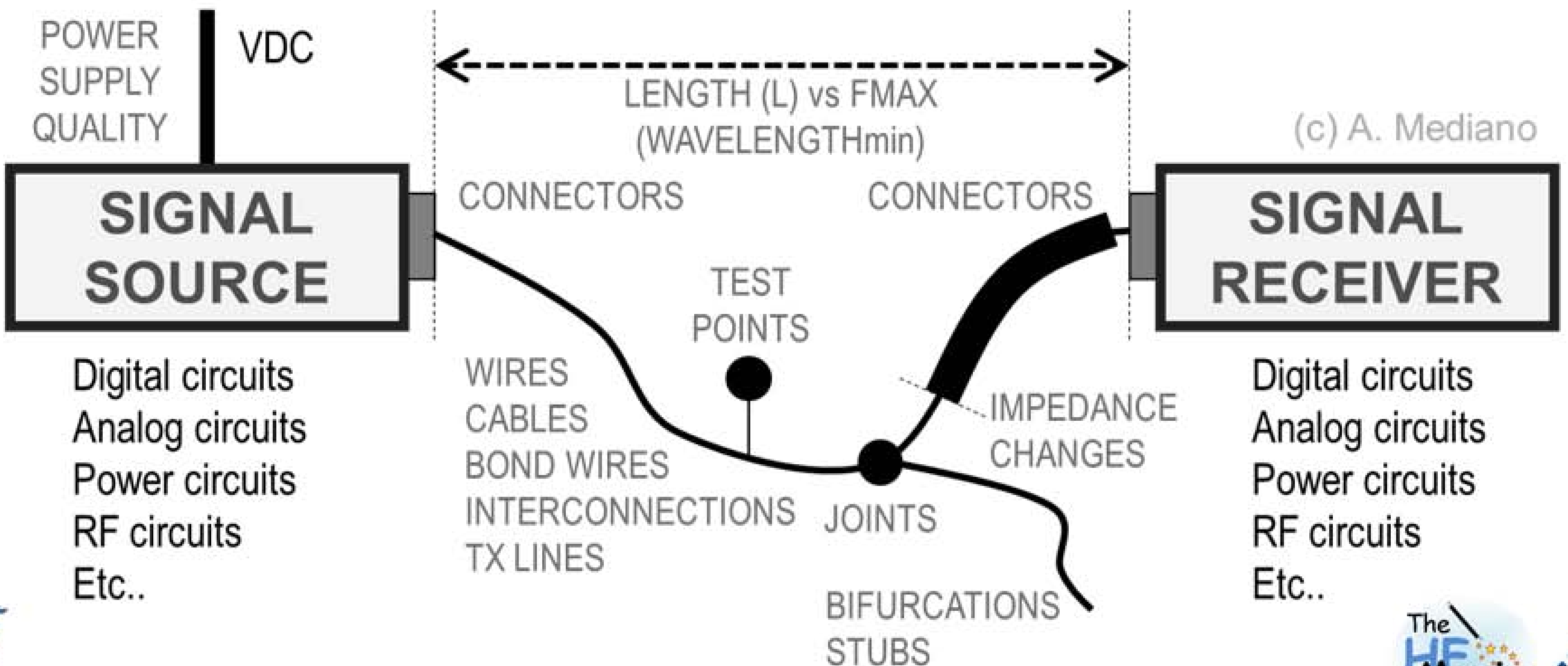
Outline: for this session.

- Signals and bandwidth
- Return path
- TX lines
- S-parameters
- Smith chart
- Eye diagram and jitter
- Matching
- Power integrity: decoupling
- Instrumentation

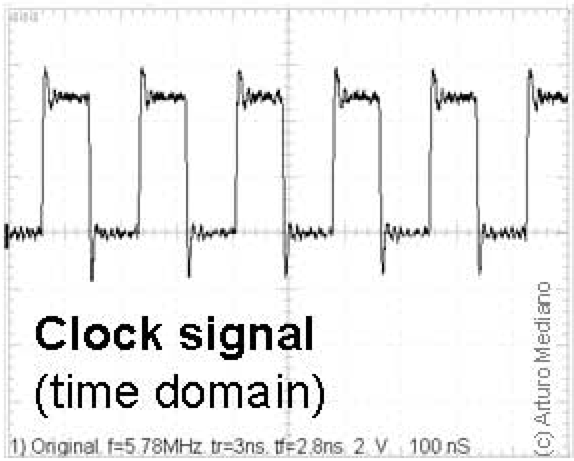
Introduction: SI/PI general picture

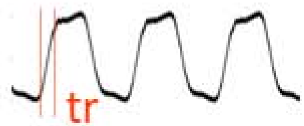
SI IS RELATED WITH THE EFFECT OF INTERCONNECTIONS QUALITY BETWEEN A SIGNAL SOURCE AND ITS RECEIVER CIRCUITS

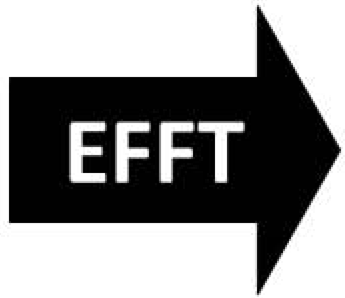
REFLECTIONS · CROSSTALK · RAIL COLLAPSE (PI)

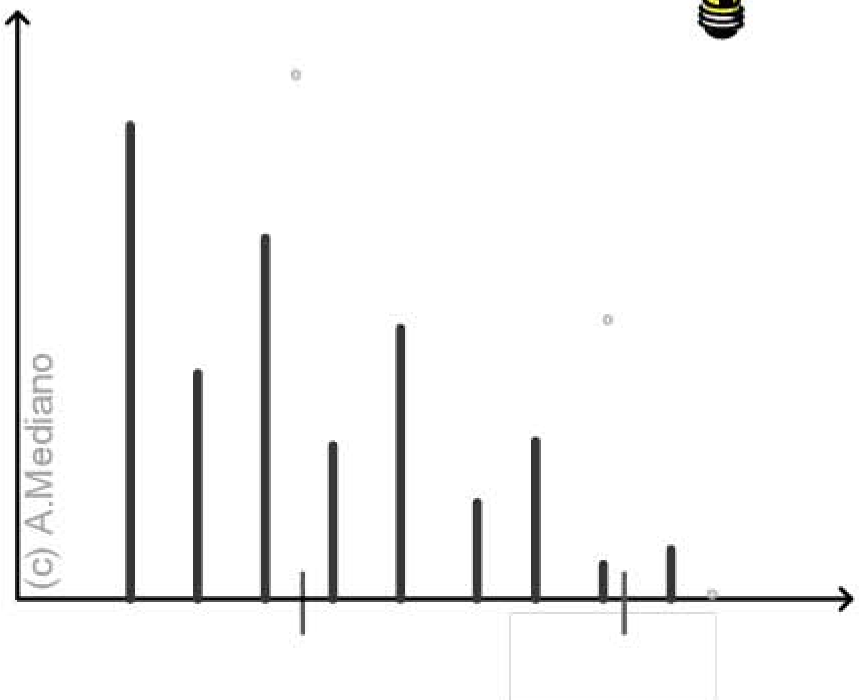


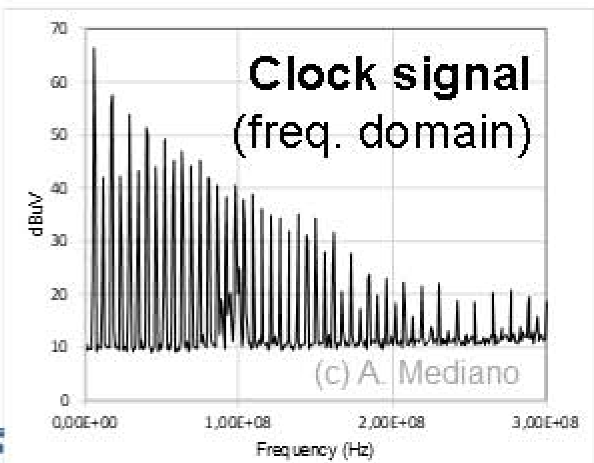
Spectrum: the EFFT and bandwidth











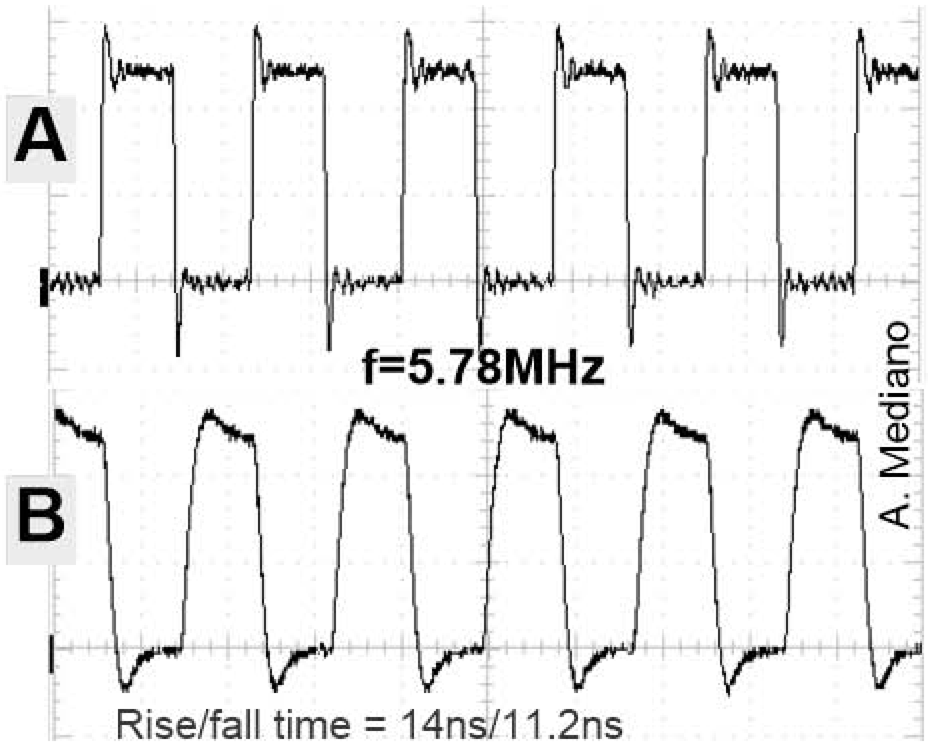
Example:

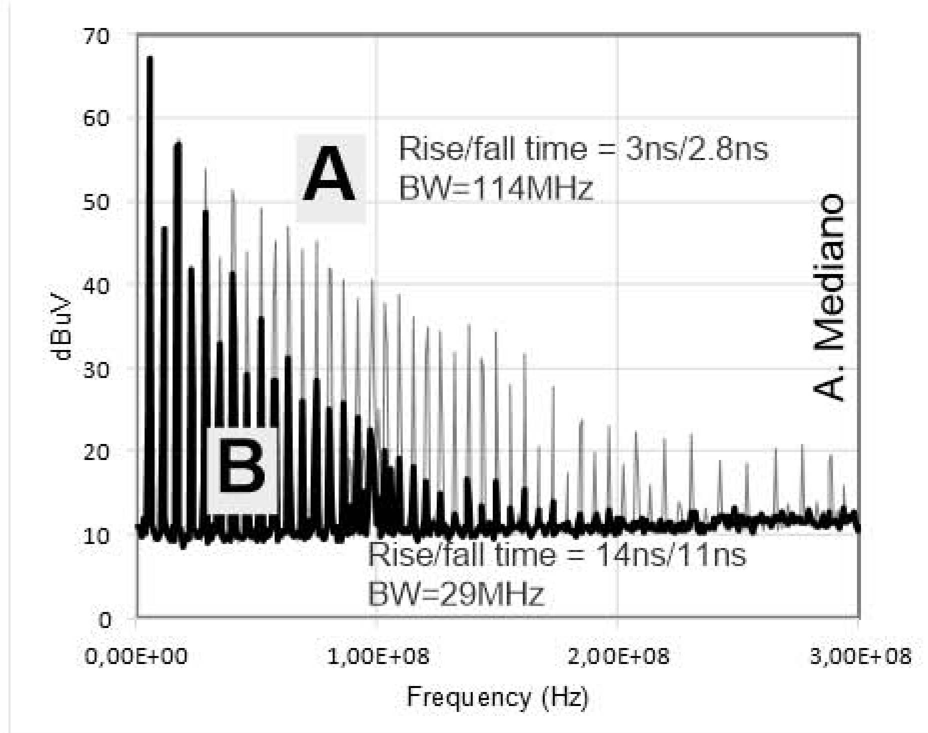
1ns → 300MHz

Same thing for non periodic signals (e.g. ESD).

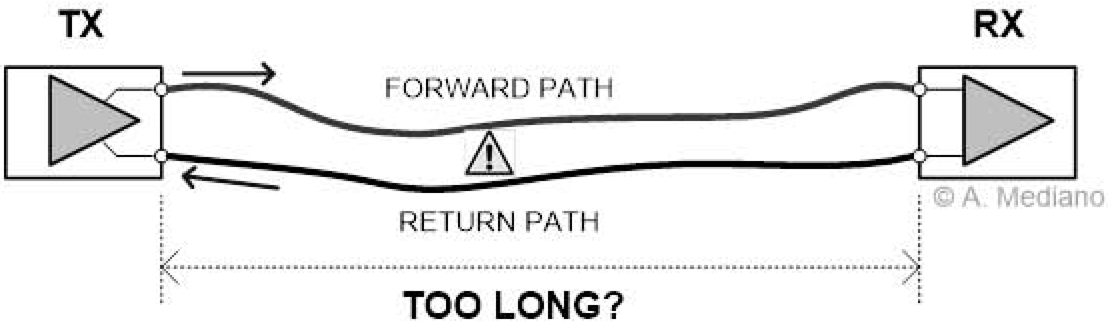
$\frac{dv}{dt} \uparrow\uparrow \quad \frac{di}{dt} \uparrow\uparrow$ **= DANGER!!!**

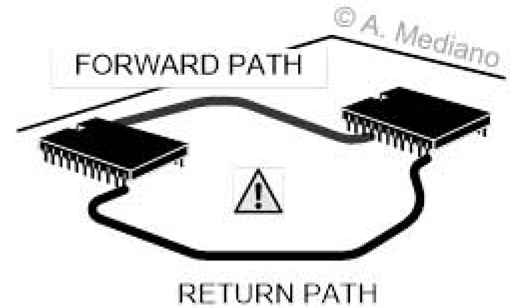
Spectrum: the EFFT and bandwidth

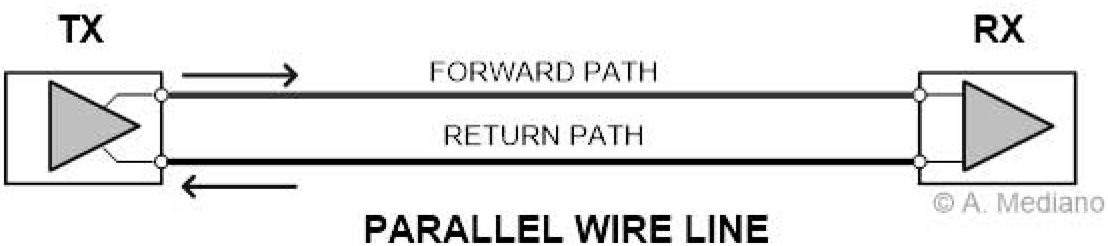


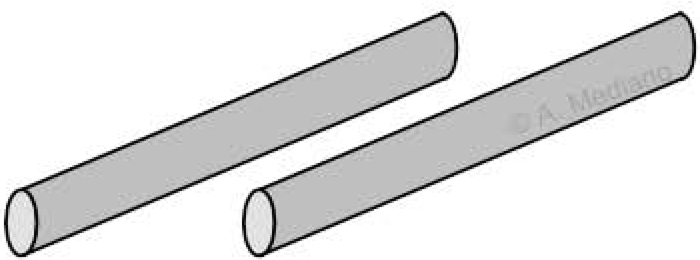


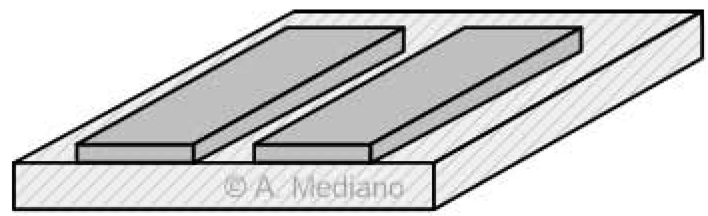
SI: layout of high BW signals



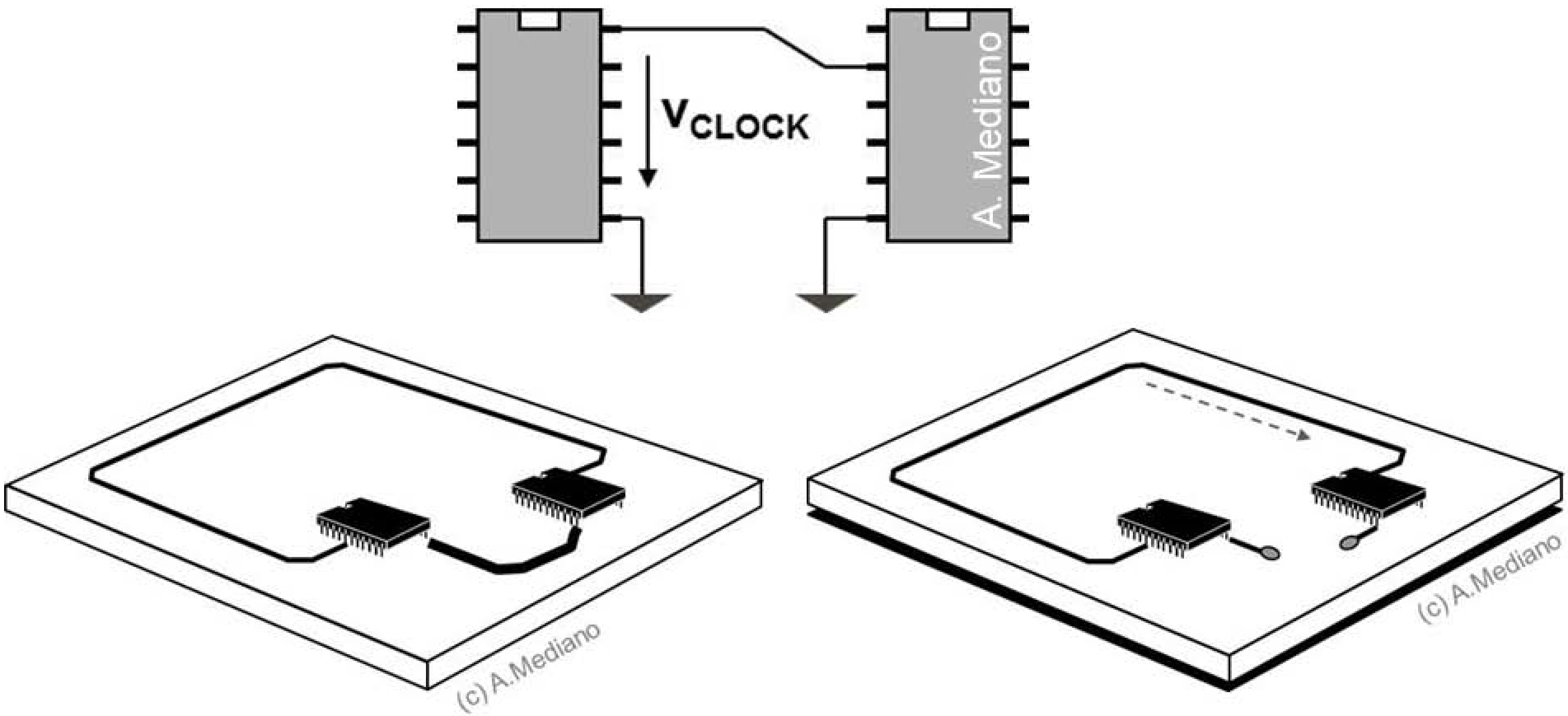






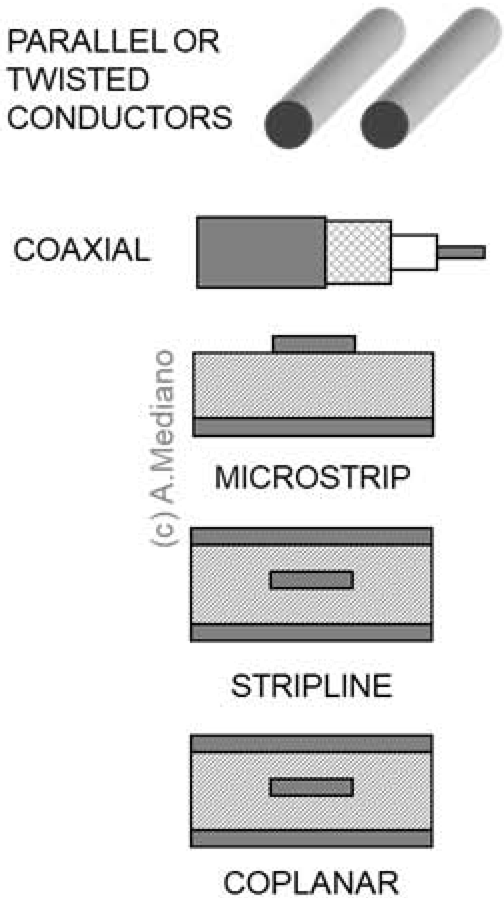


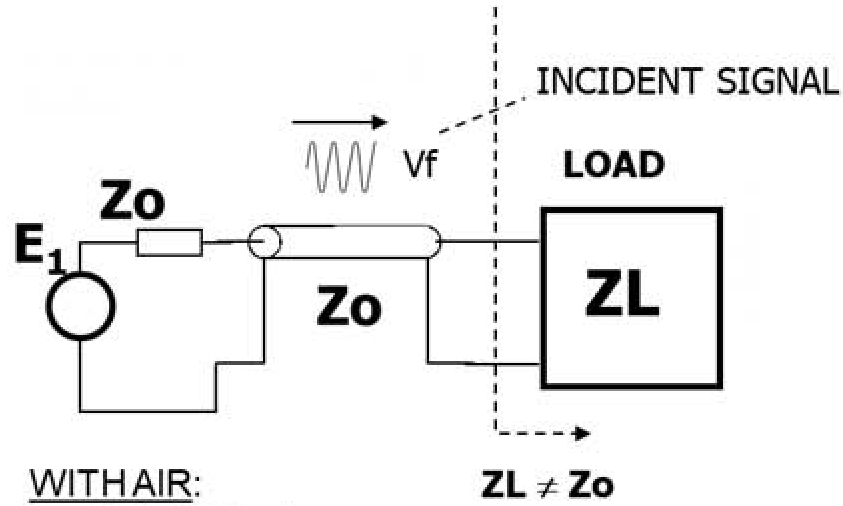
SI: ground layout



TX lines: basic behavior

SOME EXAMPLES:

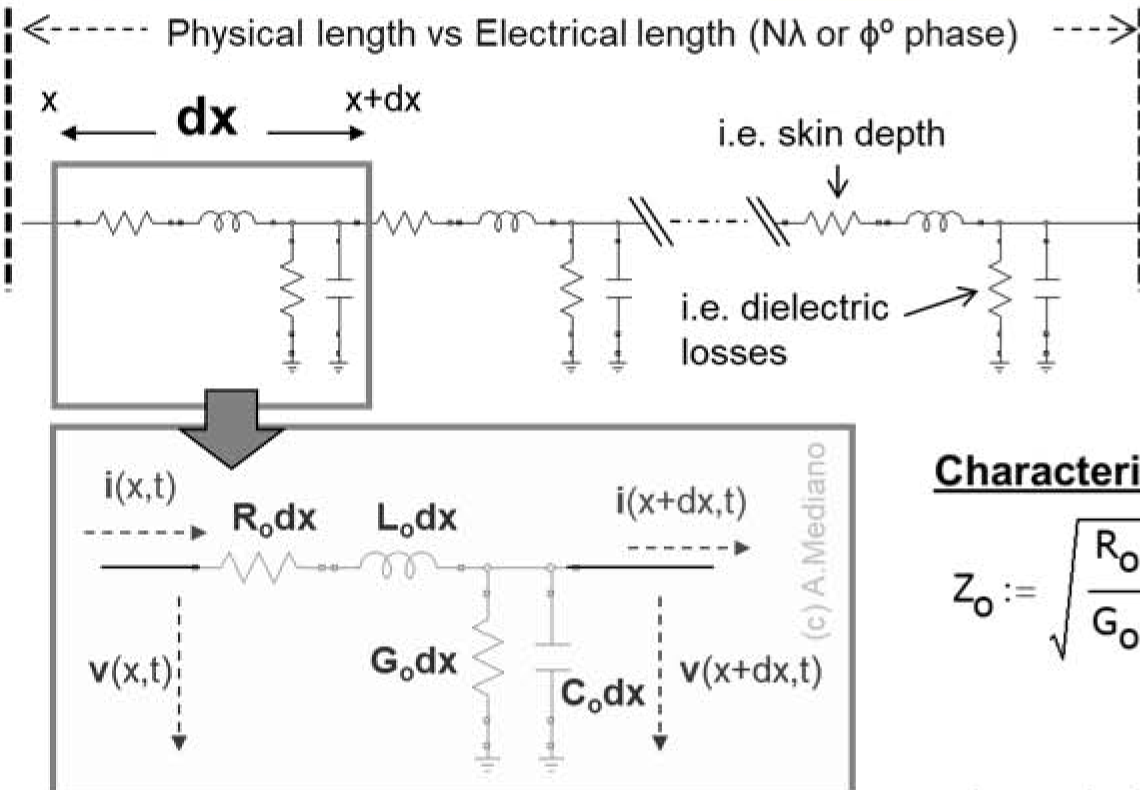




WITH AIR:
c = 300.000 km/s

WITH DIELECTRIC:
The dielectric slows the signal: $vs := \frac{c}{\sqrt{\varepsilon eff}}$

TX lines: circuital model



Propagation velocity:

$$v_p(\varepsilon_{r\_eff}) := \frac{c_o}{\sqrt{\varepsilon_{r\_eff}}} := \frac{1}{\sqrt{L_o \cdot C_o}}$$

Propagation delay

$$\tau_{pd} := \sqrt{L_o \cdot C_o} \quad \text{ps/mm}$$

Characteristic impedance

$$Z_o := \sqrt{\frac{R_o + j \cdot \omega \cdot L_o}{G_o + j \cdot \omega \cdot C_o}} \cong \sqrt{\frac{L_o}{C_o}} \quad \Omega$$

$$Lo := Zo \cdot \tau pd$$

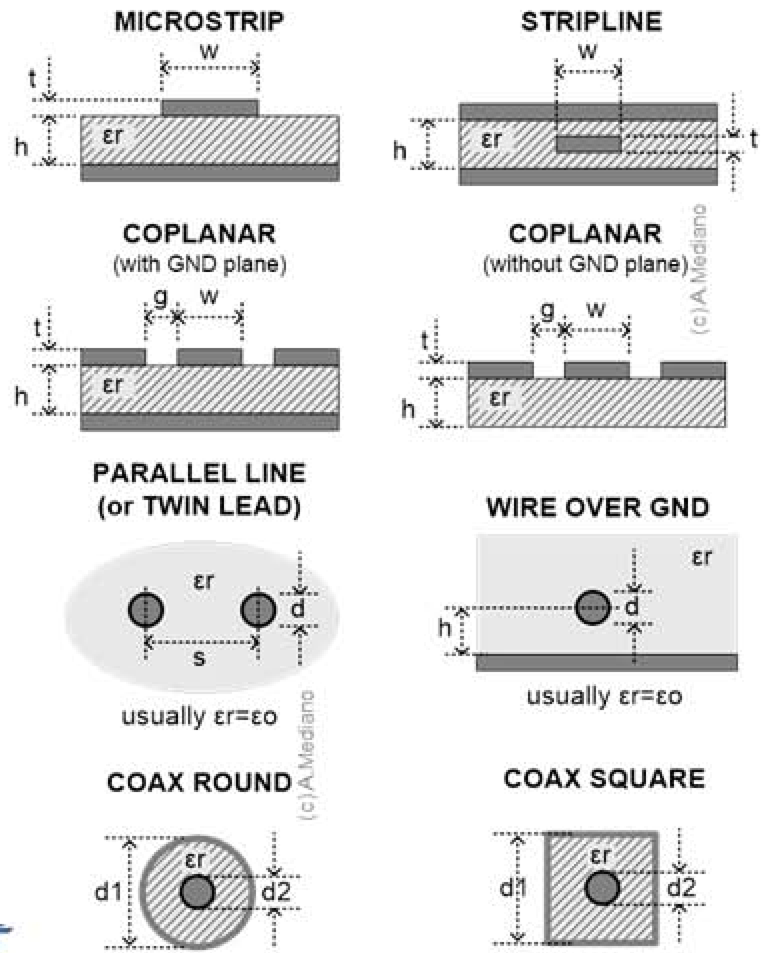
$$Co := \frac{\tau pd}{Zo}$$

$$V(x,t) := V\left(t - \frac{x}{\nu}\right) + V\left(t + \frac{x}{\nu}\right) \qquad I(x,t) := \left(\frac{Vi}{Zo}\right) - \left(\frac{Vr}{Zo}\right)$$

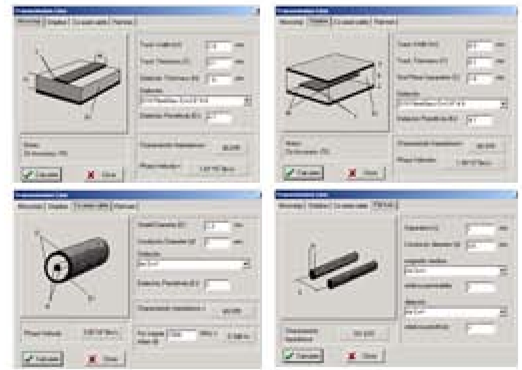
Incident $\mathbf{V_i}$ Reflected $\mathbf{V_r}$

Loss in TX lines = **Attenuation + Risetime degradation** [because loss(f)]

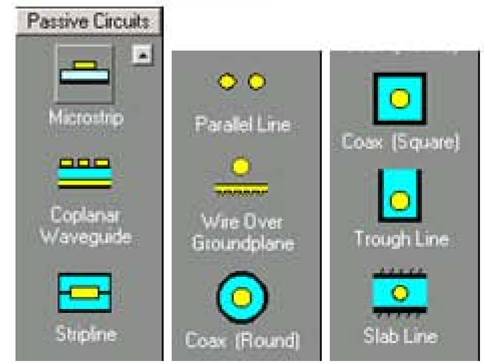
TX lines: analysis/synthesis

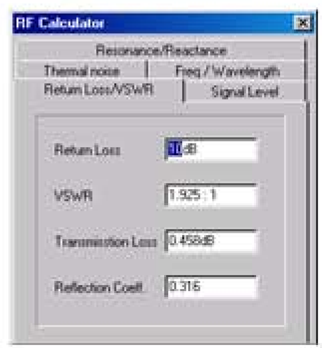


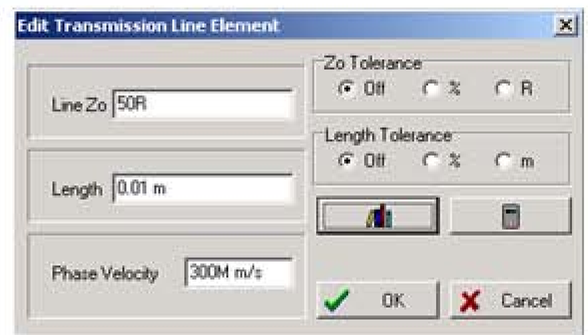
RFSIM



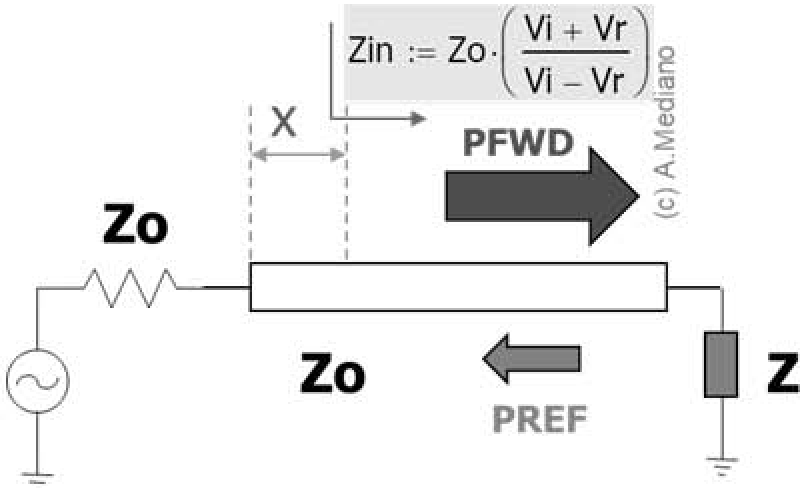
AppCAD







TX lines: specifying matching



REFLECTION COEFICIENT ...

$$\Gamma := \frac{Vr}{Vi} \rightarrow \boxed{\Gamma := \frac{Z - Zo}{Z + Zo}}$$

Γ=-1 (full negative reflection, short circuit)
Γ=0 (no reflection, perfect match)
Γ=1 (full positive reflection, open circuit)

STANDING WAVE RATIO ...

|Vmax| = |Vi| + |Vr| = |Vi| (1+|Γ|)
|Vmin| = |Vi| - |Vr| = |Vi| (1-|Γ|)

20LOG(Vmax/Vmin) = 20LOG[(1+ |Γ|)/(1- |Γ|)]

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$$VSWR := \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$0 \leq |\Gamma| \leq 1 \rightarrow VSWR \geq 1$

Ej.: **1.4:1**

INPUT REFLECTION COEFFICIENT RC ...

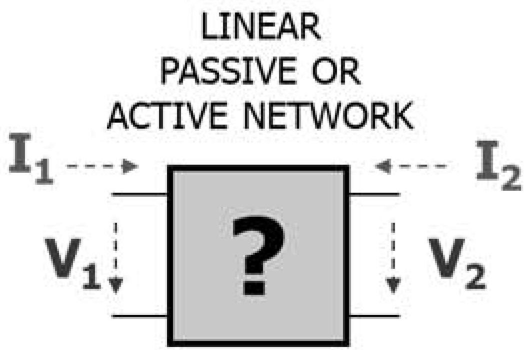
s11 = Input reflection coef. = Vref/Vfwd
$s11_{dB}$ = 20 LOG s11 → **Negative number**

Pref = Γ^2 x Pfwd

1542

The HF Magic Lab®

S parameters: introduction.



IMPEDANCES **[Z]**

$$V_1 := z_{11} \cdot I_1 + z_{12} \cdot I_2$$
$$V_2 := z_{21} \cdot I_1 + z_{22} \cdot I_2$$

ADMITANCES **[Y]**

$$I_1 := y_{11} \cdot V_1 + y_{12} \cdot V_2$$
$$I_2 := y_{21} \cdot V_1 + y_{22} \cdot V_2$$

HYBRID **[H]**

$$V_1 := h_{11} \cdot I_1 + h_{12} \cdot V_2$$
$$I_2 := h_{21} \cdot I_1 + h_{22} \cdot V_2$$

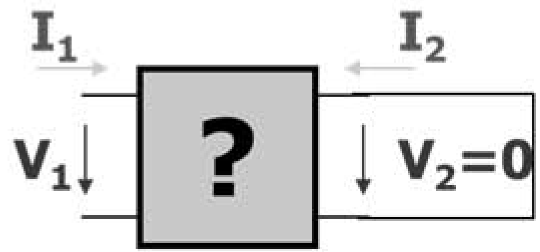
DEPENDENT VARIABLES (RESPONSE)

INDEPENDENT VARIABLES (EXCITATION)

EXTRACTION OF Z, H & Y parameters

Example:

$$h_{11} := \left. \frac{V_1}{I_1} \right|_{V_2=0}$$

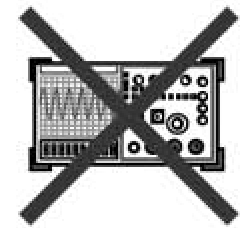


High frequency limitations

a) Limitations for instruments to measure V and I.

b) Shorts and Opens difficult to implement.

c) Some active networks can oscillate with shorts or opens in their ports.



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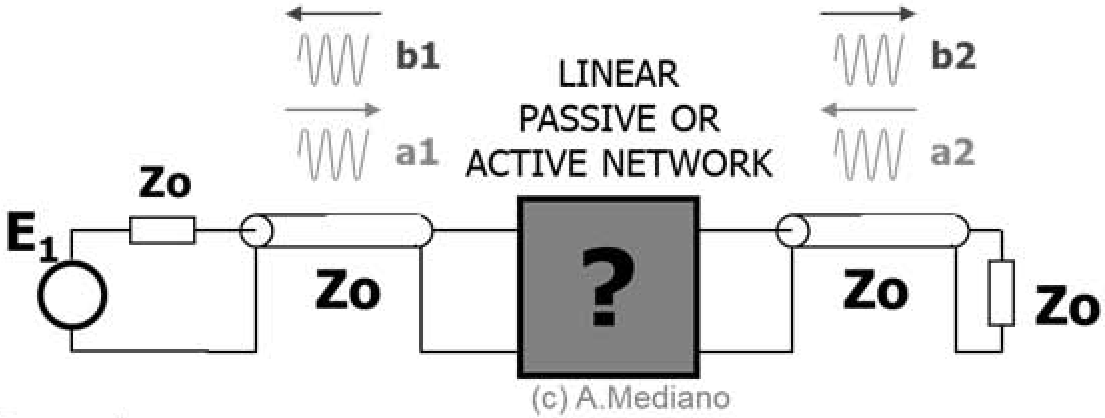
S parameters: definition.

Scattering parameters



$$[b]=[S]\times[a]$$

$$b_1 := s_{11}\cdot a_1 + s_{12}\cdot a_2$$

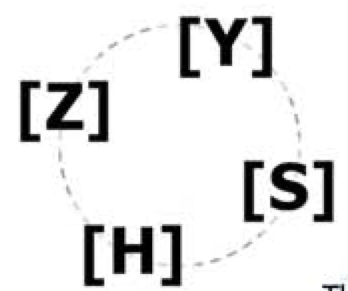
$$b_2 := s_{21}\cdot a_1 + s_{22}\cdot a_2$$

Procedure

- Excitation of both ports with sinusoidal signal in the frequency range of interest.
- Transmission lines with known impedance (Zo) are used to generate stationary waves.
- Non excitated port is terminated in Zo.
- Measure forward and reflected signals in excited port.

IMPORTANT IDEAS

- The system is defined with s11, s12, s21, s22 and Zo.
- S parameters are complex numbers
- It is easy to convert parameters:



S parameters: Touchstone format

! Comments — Title — Test conditions — Data format

```
! 2N5179A.S2P
! VCE=6V; IC=1.5mA
# GHZ S MA R 50
! S-PARAMETER DATA
```

f	s_{11}		s_{21}		s_{12}		s_{22}	
0.1	0.86	-25	3.59	145	0.03	74	0.95	-10
0.2	0.68	-44	3.02	122	0.06	66	0.88	-15
0.35	0.49	-61	2.21	100	0.08	62	0.82	-22
0.5	0.4	-72	1.71	86	0.1	61	0.8	-28
0.65	0.33	-80	1.37	75	0.12	61	0.79	-33
0.8	0.27	-88	1.15	66	0.13	61	0.78	-39
1	0.2	-105	0.95	56	0.14	62	0.76	-47
1.25	0.14	-130	0.79	46	0.16	64	0.75	-57
1.5	0.09	-177	0.67	37	0.19	69	0.75	-66

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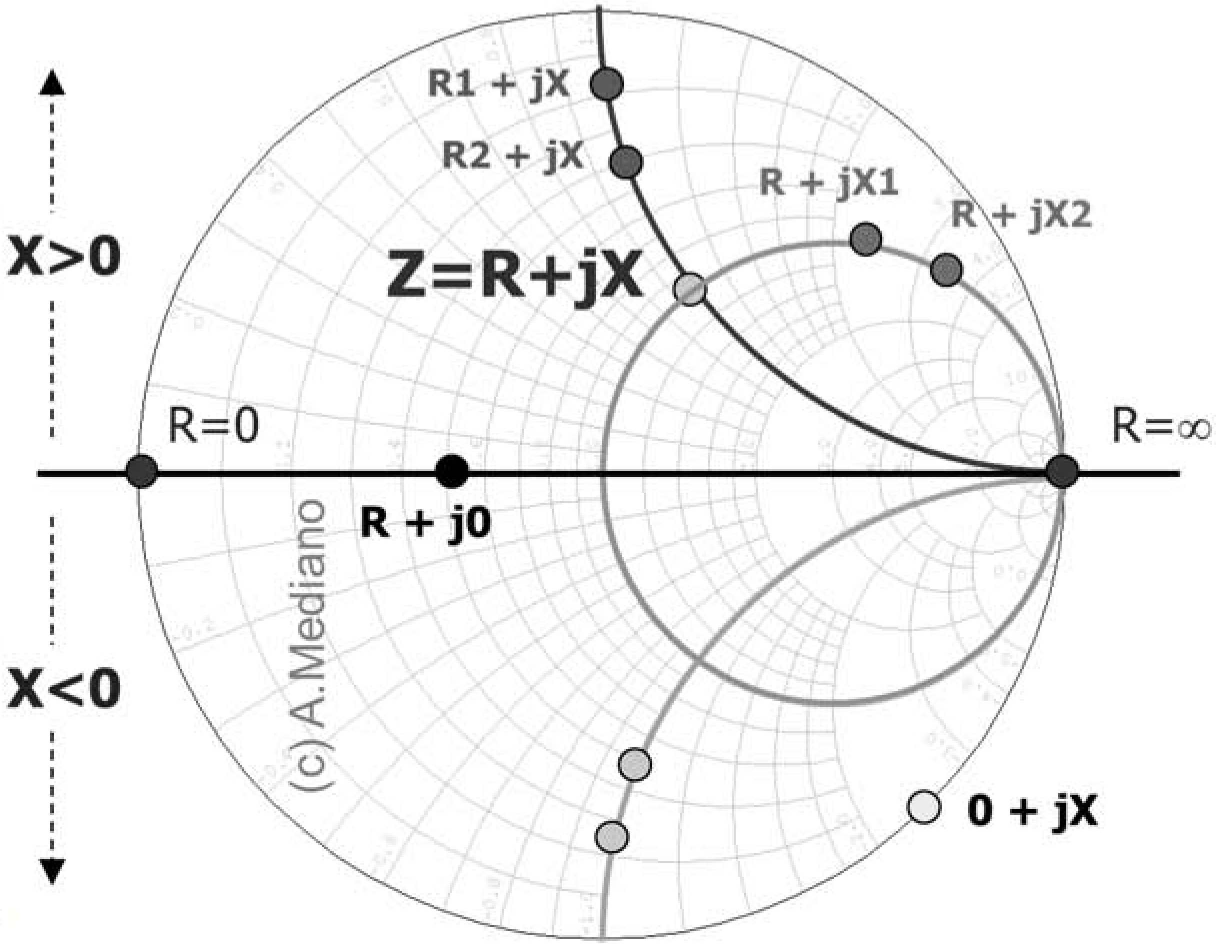
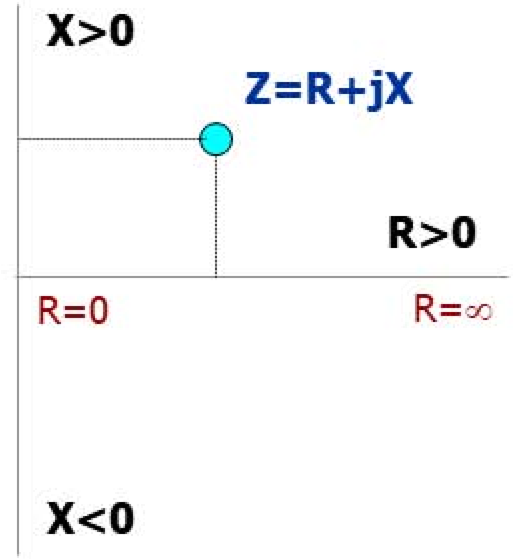
 # GHZ S MA R 50

- MHZ / GHZ
- S / Y / Z
- MA / DB
- Ref. Zo

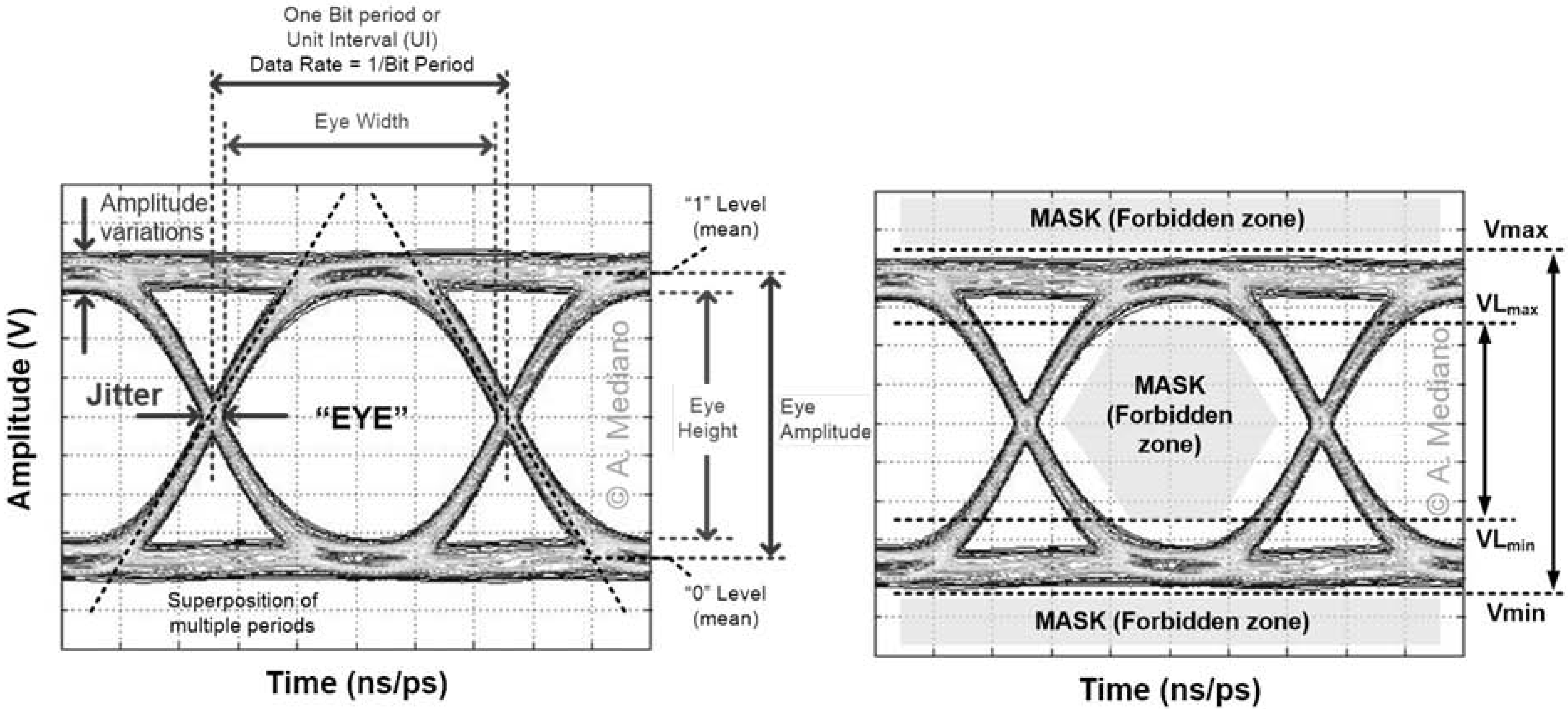
***.s2p FILES**

Smith chart: graphical tool.

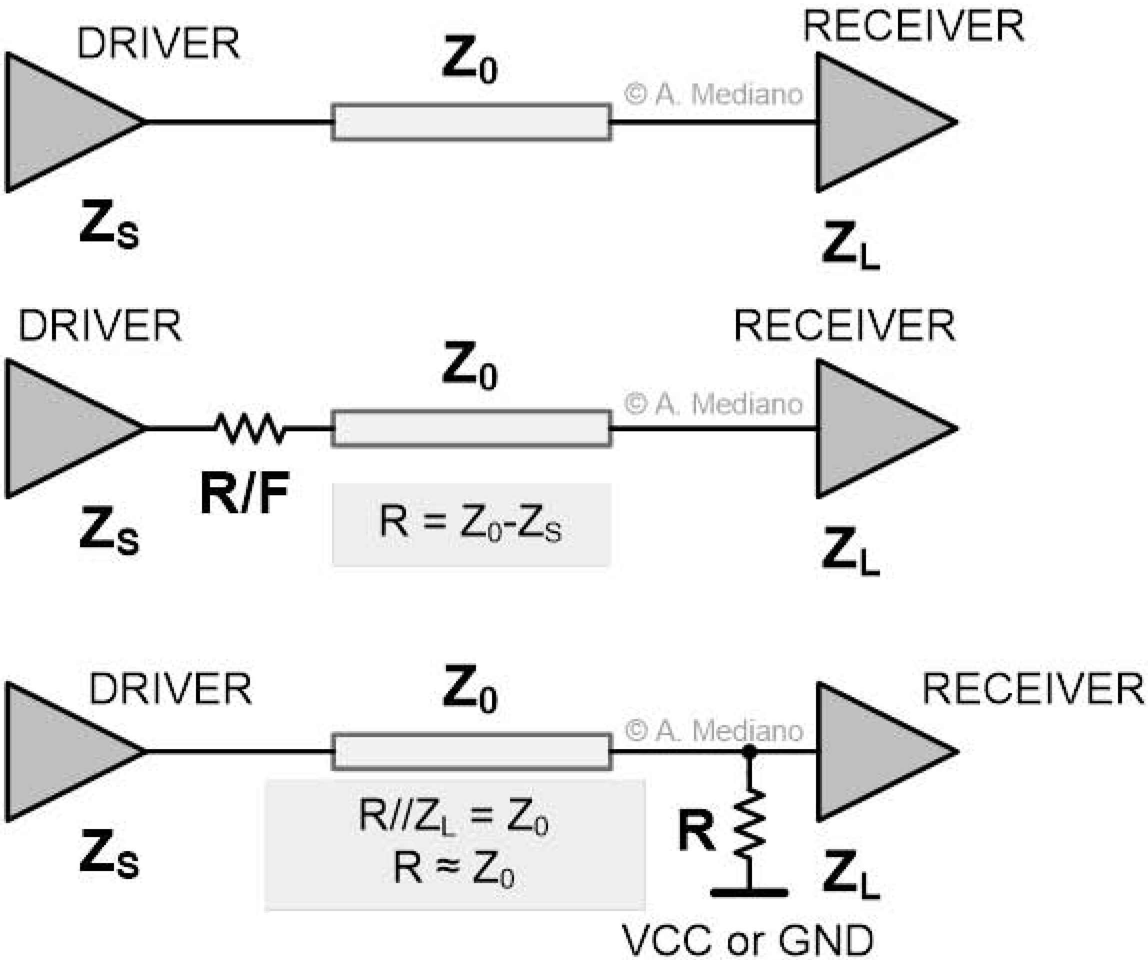




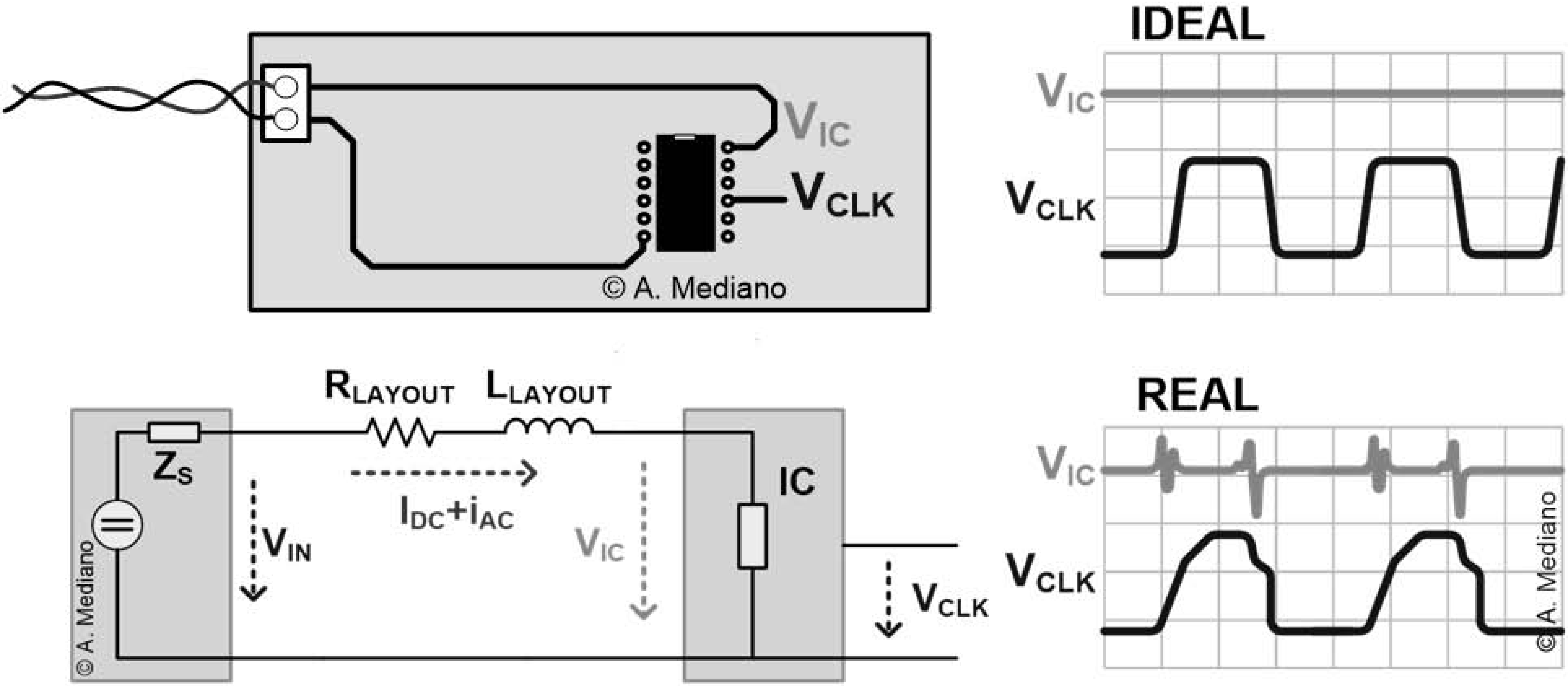
SI: Eye diagram



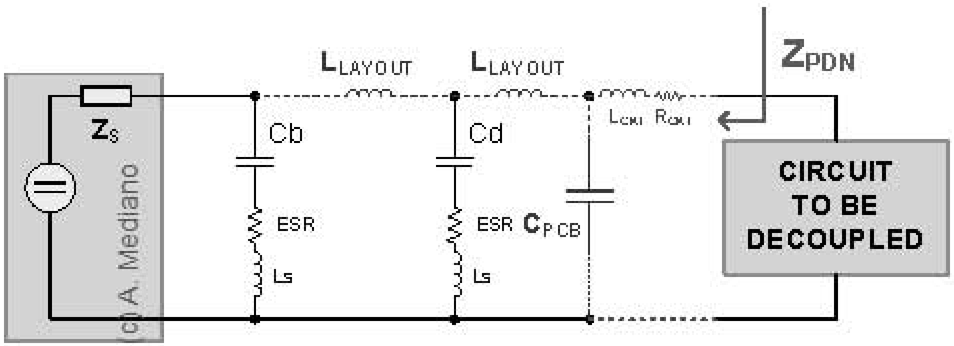
PCBs: TX lines and matching



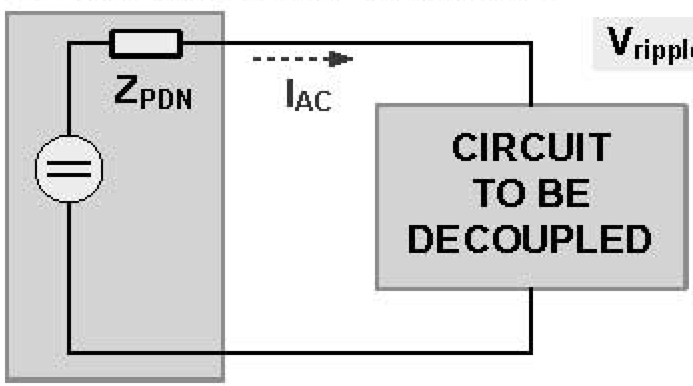
PCBs: Decoupling



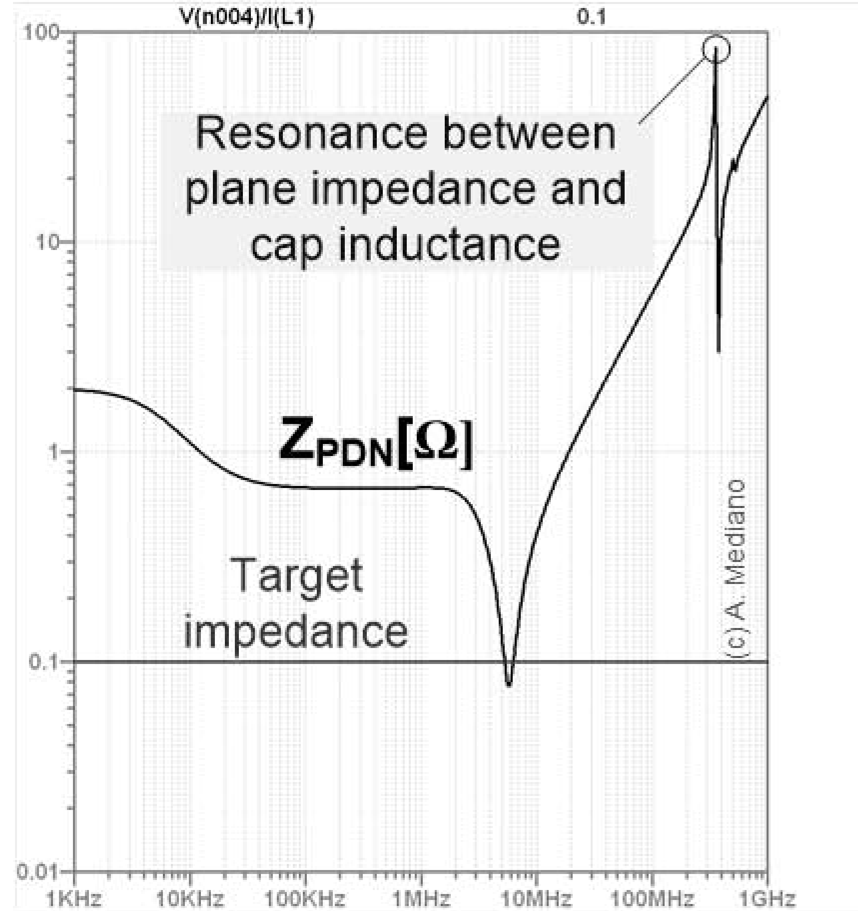
PCBs: PDN



EQUIVALENT CIRCUIT



$V_{ripple} = Z_{PDN} \times I_{AC}$



Rohde & Schwarz: RTO/RTE scopes

- **Time domain** and **frequency domain** in one instrument (synchronized!!).
- **Big record length** ensuring that you capture enough information.
- **Sample rate >2 x f_{MAX}** (e.g. 2.5 GS/s in DC to 1GHz)
- Inputs: **"High" impedance and 50Ω.**
- Vertical scale: good sensitivity (i.e. dynamic range) **1 - 5mV/DIV**
- **Powerful frequency analysis**:

  Advanced FFT ≠ Traditional FFT

  Spectrum analyzer "style": CENTER FREQ, SPAN and RBW.

  FFT analysis not time domain setup configuration dependence.

  FFT with ZOOM.

  FFT with GATING technique: easy to identify spurious EMI in time domain.
- **Display**:

  i) color table; ii) powerful persistence mode to detect CW signals vs burst
- **Masks** with configurable actions !!!!

Rohde & Schwarz: ZNL network analyzers

- **Frequency range:**
  5 kHz to 3 GHz: R&S®ZNL3
  5 kHz to 6 GHz: R&S®ZNL6
- **Two-port vector network analyzer**
  for bidirectional measurements
- **Wide dynamic range** of typ. 130 dB
- **Output power** range from **–40dBm to +3dBm**
- **Measurement bandwidths** from 1Hz-500kHz
- **Fast measurements**
- **Compact size and low weight** (6 kg to 8 kg)
- **Optional battery pack available**