# Using S-Parameters for the Design of EMC Filters

## OMICRON 13th Power Analysis & Design Symposium

Prof. **Arturo Mediano**
I3A, University of Zaragoza (SPAIN)
amediano@unizar.es

Organized by,

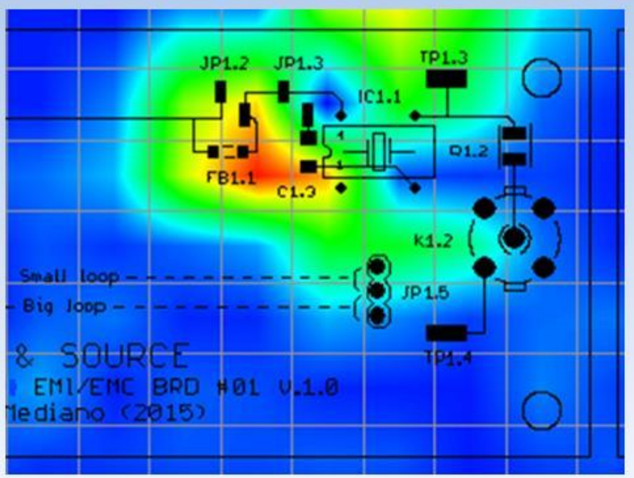
OMICRON LAB

2024

April 17th, 2024

# A High Frequency Lab for

## design, diagnostic, troubleshooting and training




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

Contact: Arturo Mediano
amediano@unizar.es
www.cartoontronics.com

# About the speaker ...

Prof. **Arturo Mediano**
*Teaching Professor in EMI/EMC/RF/SI*
**I3A, University of Zaragoza** (SPAIN)

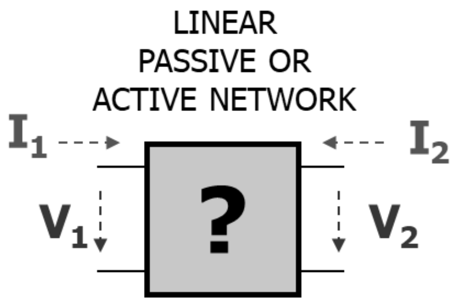
Arturo Mediano is the founder of The HF-Magic Lab®, a specialized laboratory for design, diagnostic, troubleshooting, and training in the EMI/EMC, Signal Integrity, and RF fields at I3A (University of Zaragoza).

He received his M.Sc. (1990) and his Ph. D. (1997) in Electrical Engineering from the University of Zaragoza (Spain), where he has held a teaching professorship in EMI/EMC/RF/SI since 1992.

For more than 30 years Arturo has been involved in R&D projects with many companies in the EMI/EMC, Signal Integrity and RF fields for communications, industry, medical, and scientific applications. He regularly shares his knowledge and expertise with students and engineers in teaching courses and seminars.

Email: amediano@unizar.es LinkedIn: www.linkedin.com/in/amediano

# 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]**

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

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

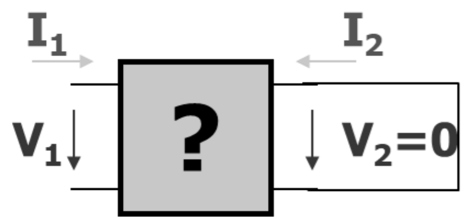
DEPENDENT VARIABLES (RESPONSE)

INDEPENDENT VARIABLES (EXCITATION)

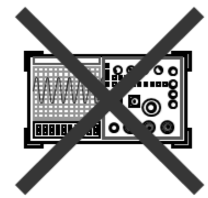
## EXTRACTION OF Z, H & Y parameters

**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.

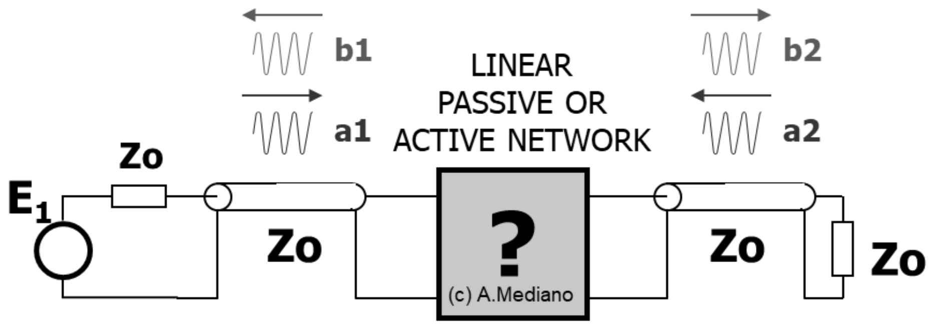
b) Shorts and Opens difficult to implement.

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

# S parameters: introduction

## *Scattering parameters*

**Agilent AN 154**
**S-Parameter Design**
Application Note



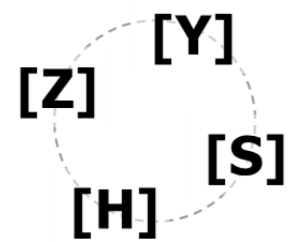

$$[b]=[S]\times[a]$$

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

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

**IMPORTANT IDEAS**

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




Forward and reflected signals are variables result from linear combination of voltage and current in test ports:

Independent variables are normalized INCIDENT voltages:

$$a_1 := \frac{V_{i1}}{\sqrt{Z_o}}$$

$$a_2 := \frac{V_{i2}}{\sqrt{Z_o}}$$

Dependent variables are normalized REFLECTED voltages:

$$b_1 := \frac{V_{r1}}{\sqrt{Z_o}}$$

$$b_2 := \frac{V_{r2}}{\sqrt{Z_o}}$$

$(|a_1|)^2$ = Incident power on input port

$(|a_2|)^2$ = Incident power on output port (power reflected from load)

$(|b_1|)^2$ = Reflected power on input port =
= Power incident on input port - Power delivered to input port

$(|b_2|)^2$ = Incidentpower to load

# S parameters: meaning

ALWAYS PORTS TERMINATED IN CHARACTERISTIC IMPEDANCE (i.e. 50 OHMS)

## s11 y s22 ⇒ INPUT AND OUTPUT REFLECTION COEFFICIENTS

$s_{11} := \frac{b_1}{a_1}$ when $a_2 := 0$ $s_{11} :=$ Input reflection coefficient when output port terminated in Zo

$s_{22} := \frac{b_2}{a_2}$ when $a_1 := 0$ $s_{22} :=$ Ouput reflection coefficient when input port terminated in Zo

## s21 ⇒ FORWARD GAIN/INSERTION LOSS

$s_{21} := \frac{b_2}{a_1}$ when $a_2 := 0$ $s_{21} :=$ Forward transmission gain with output port terminated in Zo

## s12 ⇒ REVERSE GAIN

$s_{12} := \frac{b_1}{a_2}$ when $a_1 := 0$ $s_{12} :=$ Reverse transmission gain with input port terminated in Zo

# Example: RF LP commercial filter

*Coaxial*

## Low Pass Filter

**SLP-50+**

**SLP-50**

50Ω DC to 48 MHz

CASE STYLE: FF99

| Connectors | Model | Price | Qty. |
|---|---|---|---|
| **SMA** | SLP-50(+) | $34.95 ea. | (1-9) |

*+ RoHS compliant in accordance with EU Directive (2002/95/EC)*

*The +Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications.*

### Maximum Ratings

| | |
|---|---|
| Operating Temperature | -55°C to 100°C |
| Storage Temperature | -55°C to 100°C |
| RF Power Input | 0.5W max. |

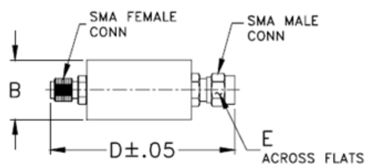
### Features
- good attenuation rate, 1.35 typ. 20dB/ 3dB BW ratio
- rugged shielded case
- other SLP models available with wide selection of cut-off frequencies

### Applications
- lab use
- test equipment
- video equipment

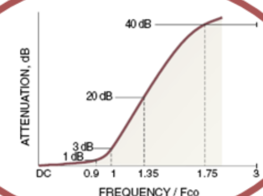
### Low Pass Filter Electrical Specifications

| PASSBAND (MHz) (loss < 1 dB) | fco (MHz) Nom. (loss 3 dB) | STOPBAND (MHz) (loss > 20 dB) | STOPBAND (MHz) (loss > 40 dB) | VSWR (:1) Passband Typ. | VSWR (:1) Stopband Typ. |
|---|---|---|---|---|---|
| DC-48 | 55 | 70-90 | 90-200 | 1.7 | 18 |

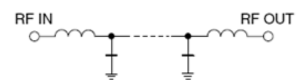
### Outline Drawing




**typical frequency response**

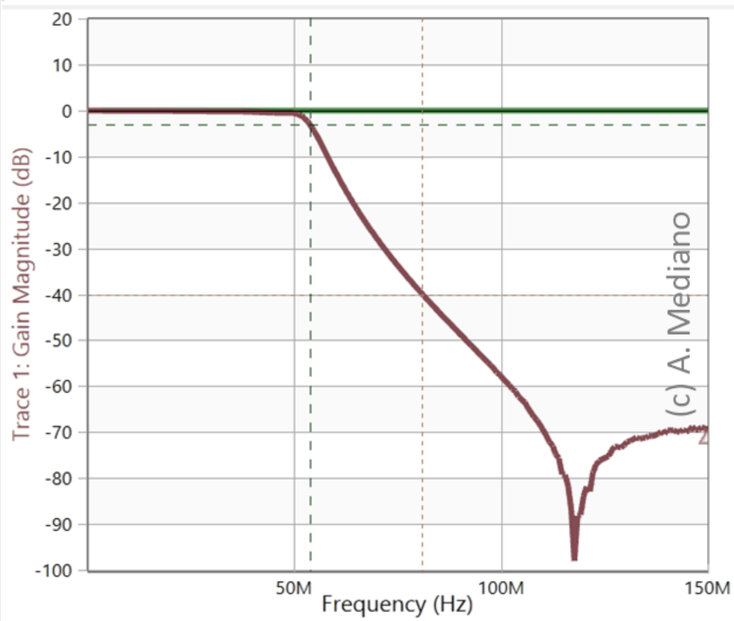



**electrical schematic**

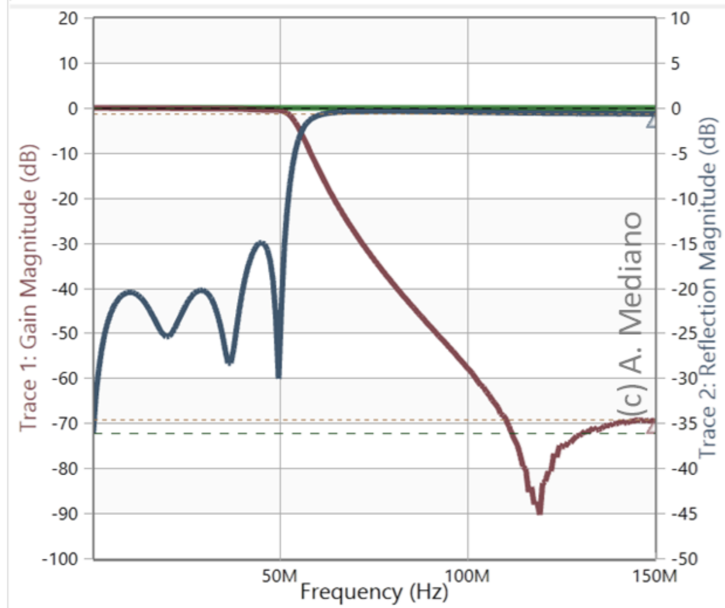


# Example: LP filter response

| | Frequency | Trace 1 |
|---|---|---|
| Cursor 1 | 53,807055 MHz | -3 dB |
| Cursor 2 | 81,036685 MHz | -40 dB |
| Delta C2-C1 | 27,22963 MHz | -37 dB |

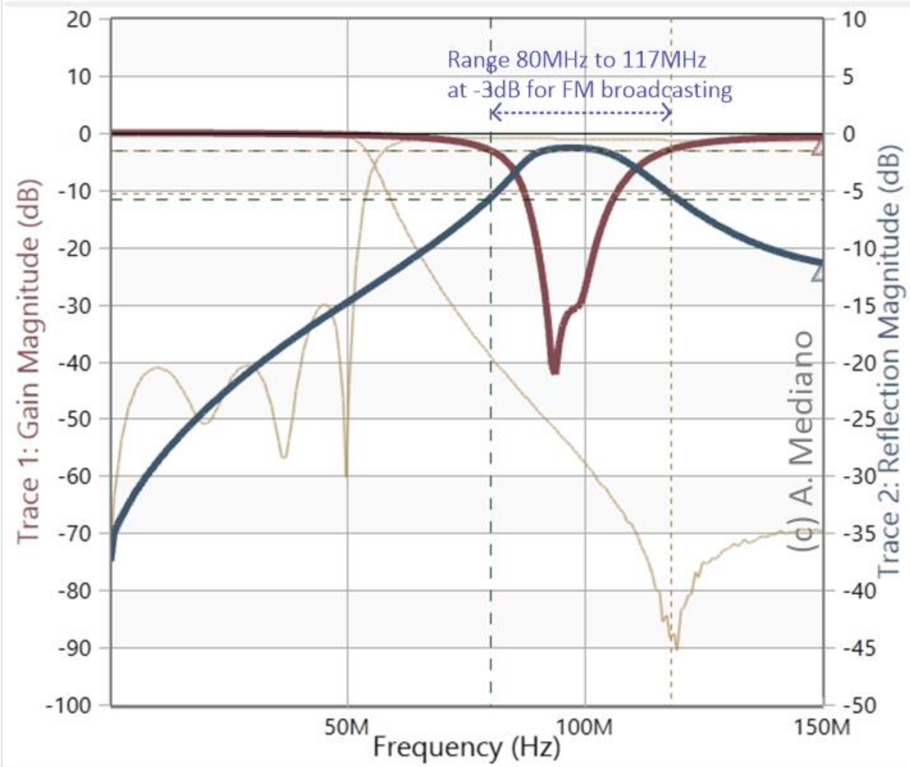



| | Frequency | Trace 1 | Trace 2 |
|---|---|---|---|
| Cursor 1 | 100 kHz | -43,684 mdB | -36,075 dB |
| Cursor 2 | 150 MHz | -69,154 dB | -687,299 mdB |
| Delta C2-C1 | 149,9 MHz | -69,11 dB | 35,388 dB |



# Example: Comparing a bandreject filter

| | Frequency | Trace 1 | Trace 2 |
|---|---|---|---|
| Cursor 1 | 80,026559 MHz | -3,053 dB | -5,745 dB |
| Cursor 2 | 117,899855 MHz | -3 dB | -5,305 dB |
| Delta C2-C1 | 37,873295 MHz | 53,054 mdB | 439,376 mdB |



# Commercial filters: **an important point**

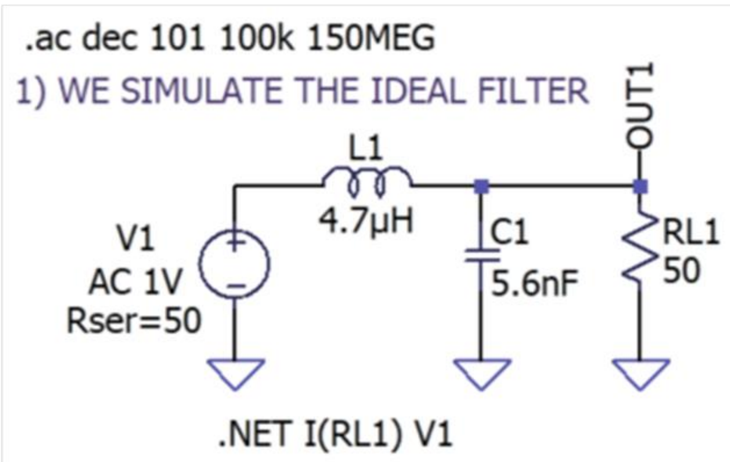
For RF/wireless applications terminal impedances are usually 50Ω and the filter response is easy to characterize and specify.

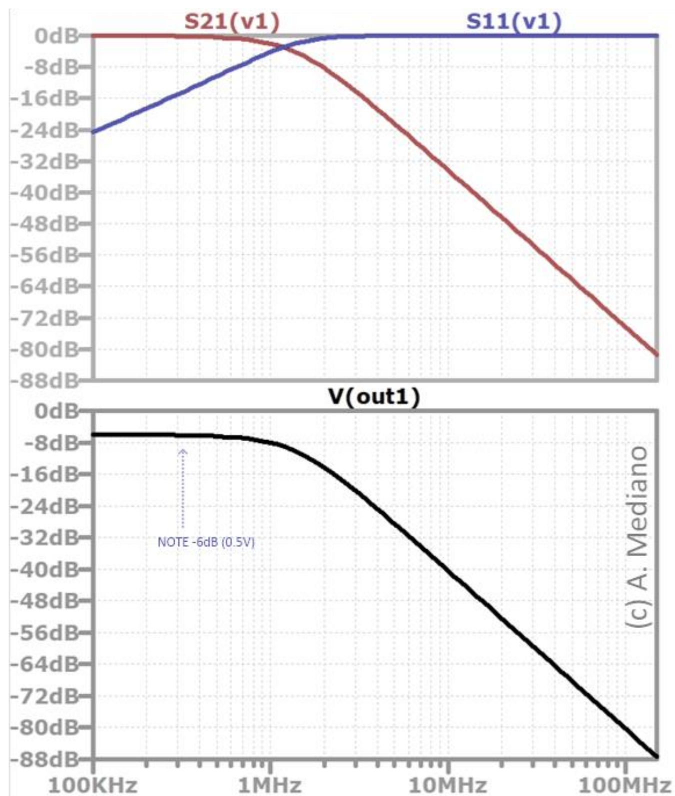
## What about EMI/EMC filters?

Remember filter response is dependent of terminal impedances and **we do not know how they are in EMI applications** !!!!!

# Example: LP EMI filter

Note that, in EMI, terminal impedances are unknown!!!!!!.
Let's think the user design the filter with 50-50ohms:



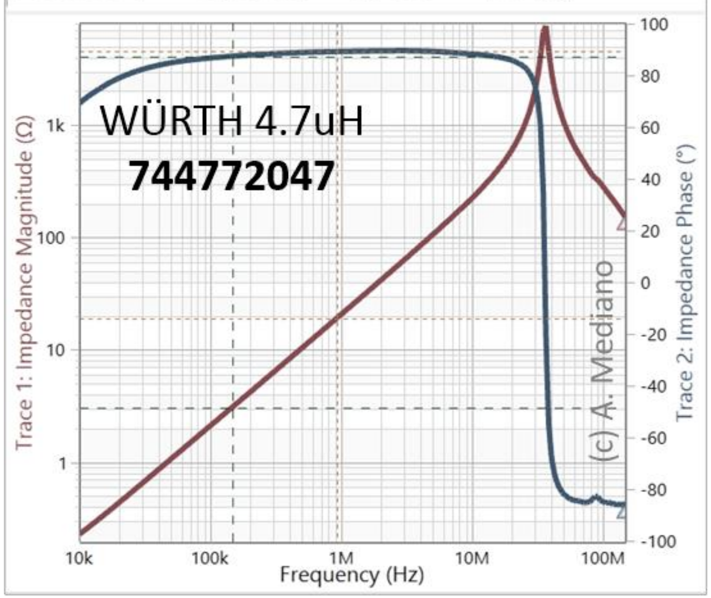



# Example: LP EMI filter and components

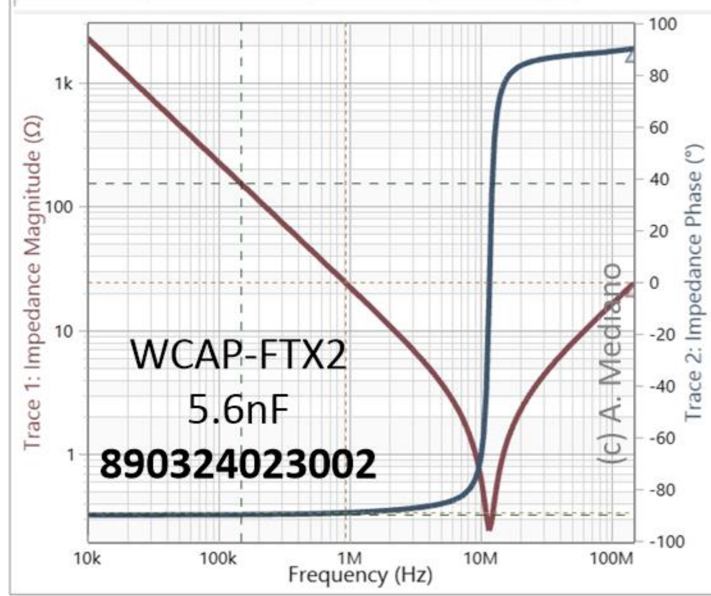
WÜRTH
4.7uH
**744772047**

WCAP-FTX2
5.6nF
**890324023002**

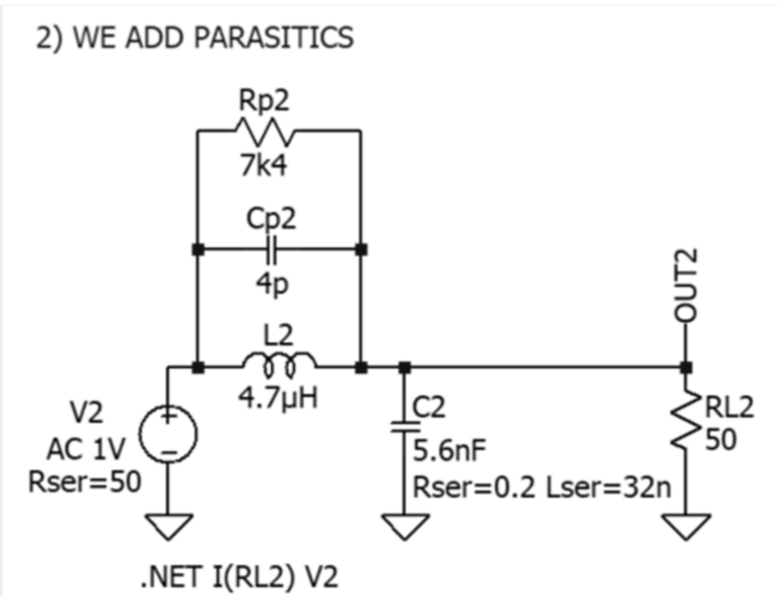
| | Frequency | Trace 1 | Trace 2 |
|---|---|---|---|
| Cursor 1 | 147,441 kHz | 3,091 Ω | 87,426 ° |
| Cursor 2 | 929,479 kHz | 19,139 Ω | 89,198 ° |
| Delta C2-C1 | 782,038 kHz | 16,048 Ω | 1,773 ° |

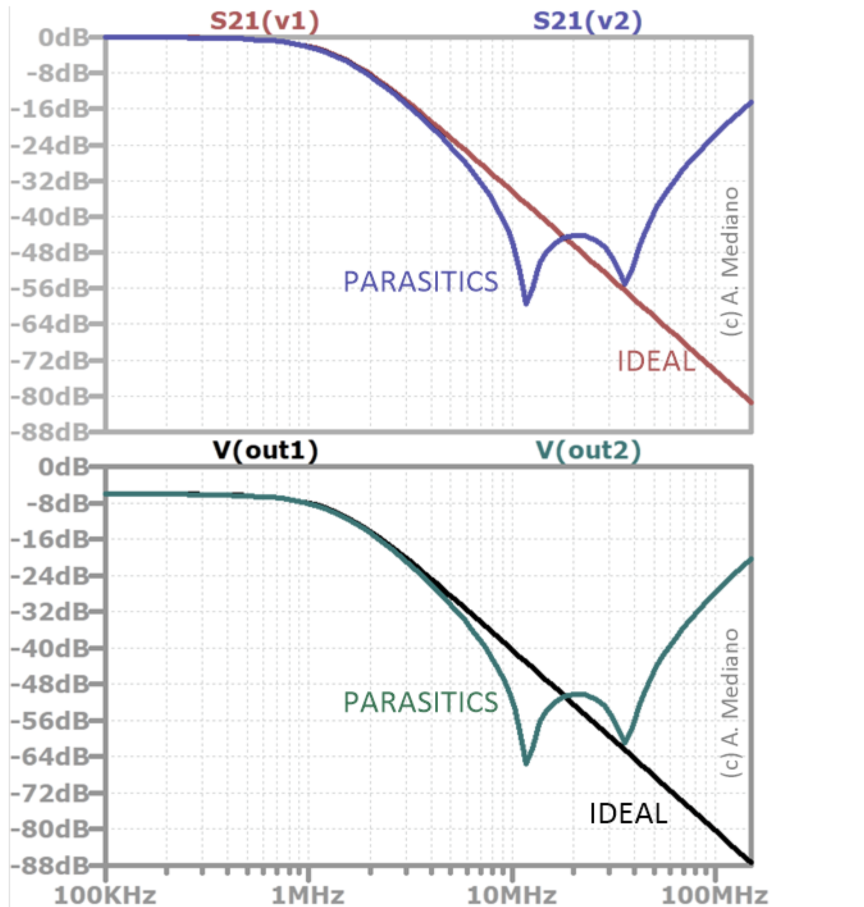



| | Frequency | Trace 1 | Trace 2 |
|---|---|---|---|
| Cursor 1 | 147,441 kHz | 154,202 Ω | -89,847 ° |
| Cursor 2 | 929,479 kHz | 24,351 Ω | -89,136 ° |
| Delta C2-C1 | 782,038 kHz | -129,851 Ω | 710,513 m° |

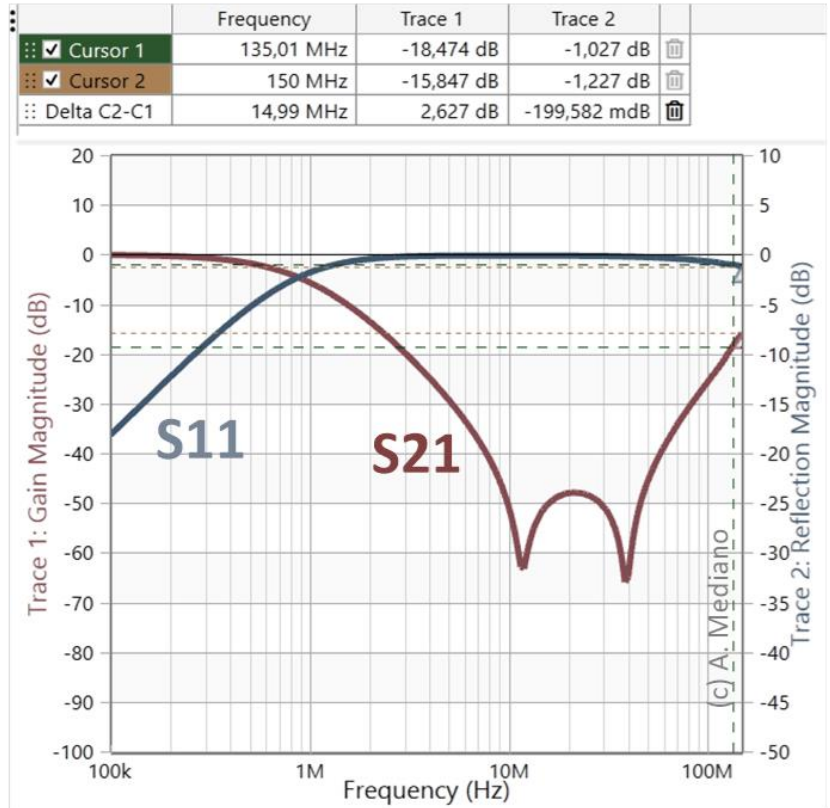


# Example: LP EMI filter and parasitics

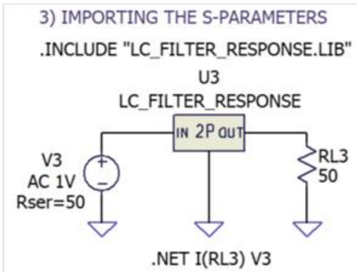


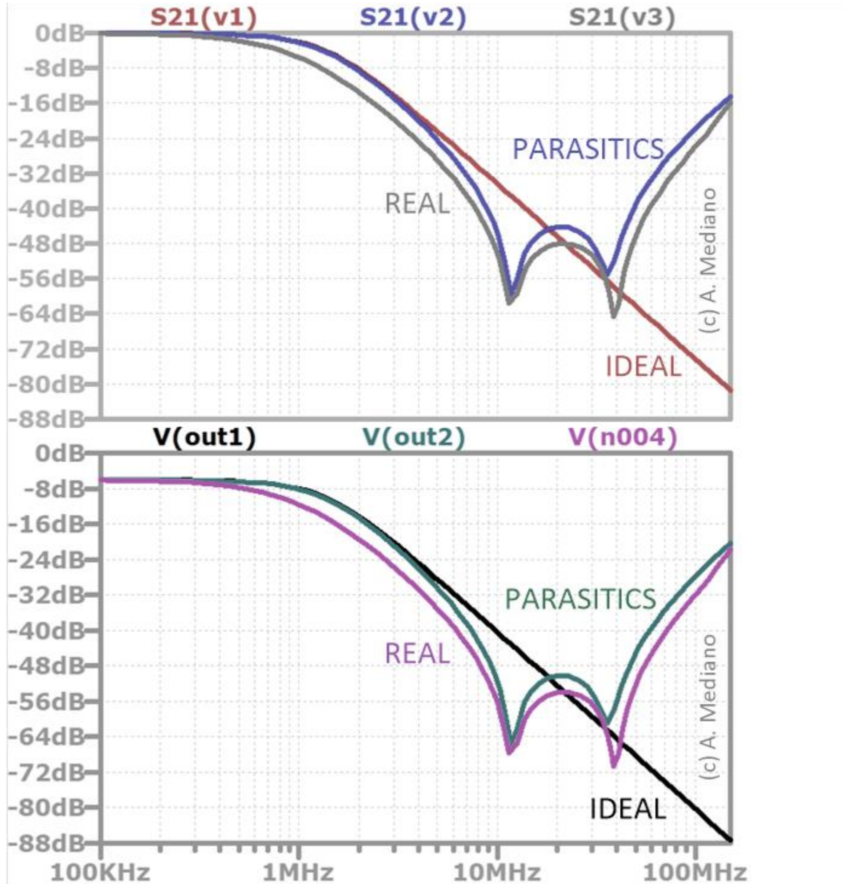



# Example: LP EMI filter real response

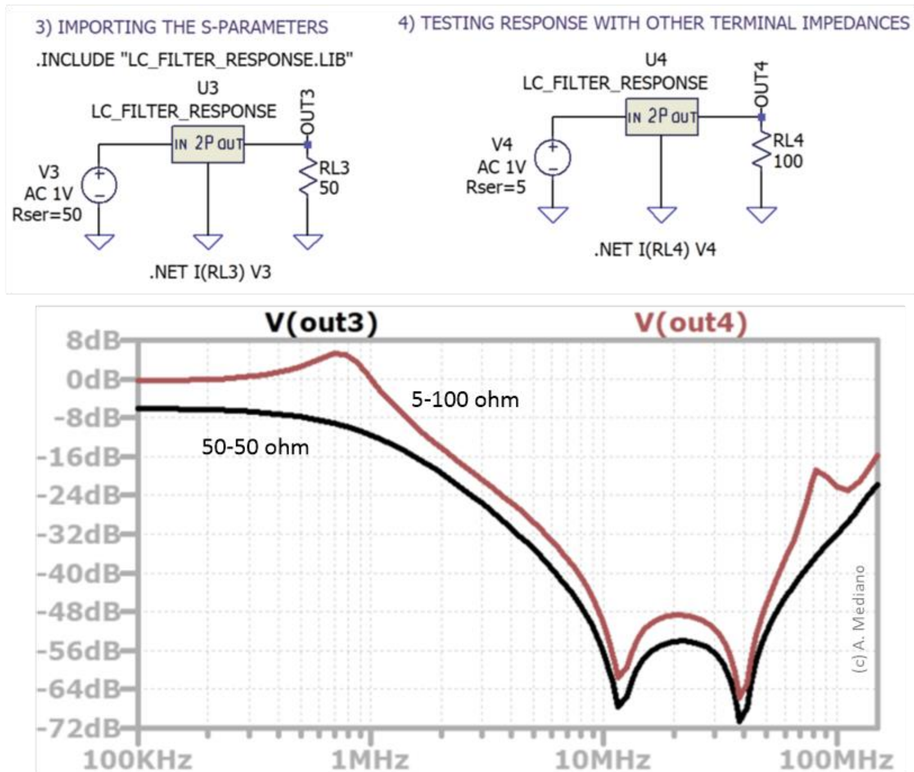



# Example: LP EMI filter response and LTSPICE



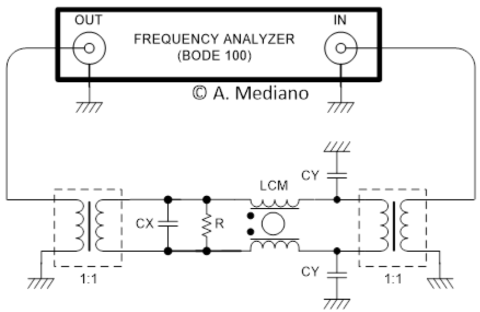
# Example: Analyzing terminal impedances

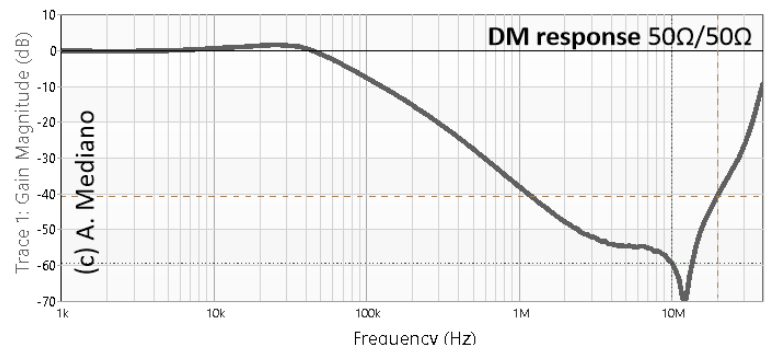



NOTE THE RINGING (UNDERDAMPED RESPONSE!!!!

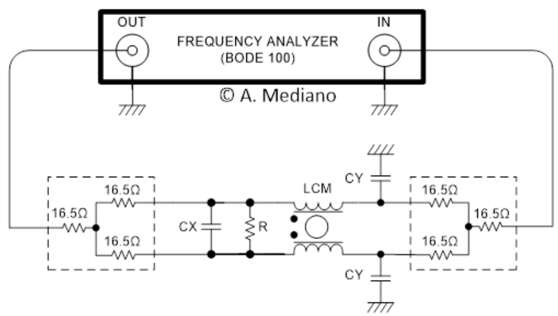
# Measuring EMC filters: DM and CM

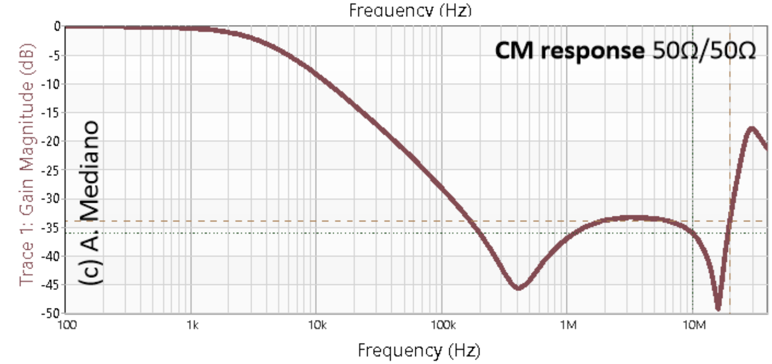
## MEASURING DM




## MEASURING CM




**Mar 18**

INTERFERENCE TECHNOLOGY

interferencetechnology.com

***Review of the EMC Filters Kit from Würth Elektronik*** by Arturo Mediano.

# THANK YOU!

Prof. **Arturo Mediano**
University of Zaragoza (SPAIN)
amediano@unizar.es