7th M4DT Day - SIM

Reliability Through Digitalization of Traceable Data

JULY| 2021

Guillermo Monasterios

RF & Microwave Metrology

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Ministerio de Desarrollo Productivo Argentina

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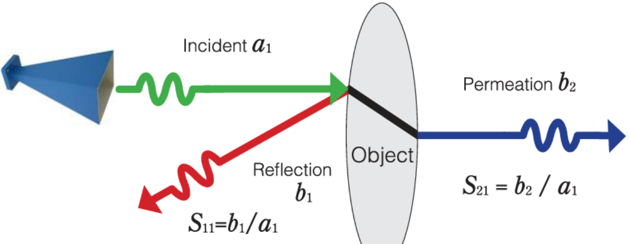
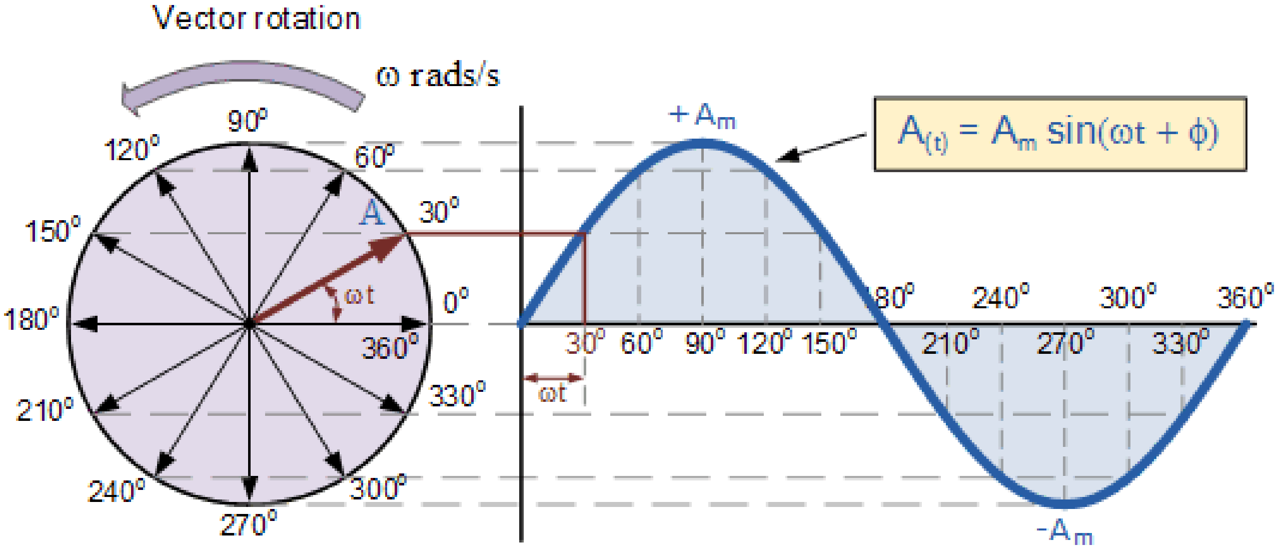
Graphical Representation of a Wave:



$$S11 = \frac{reflected}{incident}$$

$$S21 = \frac{transmitted}{incident}$$

S-parameters: n^2



Rotating Phasor

Sinusoidal Waveform in the Time Domain

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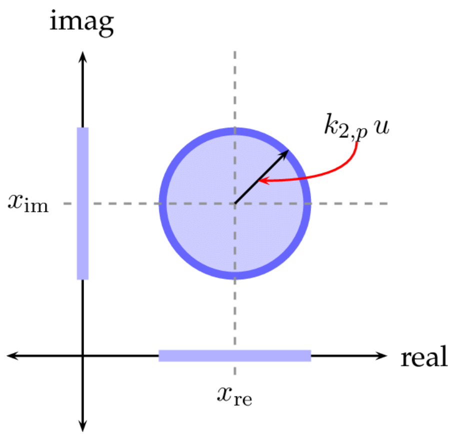
Frequency (GHz)	S1,1 Zr: 50 Ω Real	S1,1 Zr: 50 Ω Imag
1,000	0,005	0,001

Frequency (GHz)	S1,1 Zr: 50 Ω Real	S1,1 Zr: 50 Ω Imag
1,000	0,005	0,001

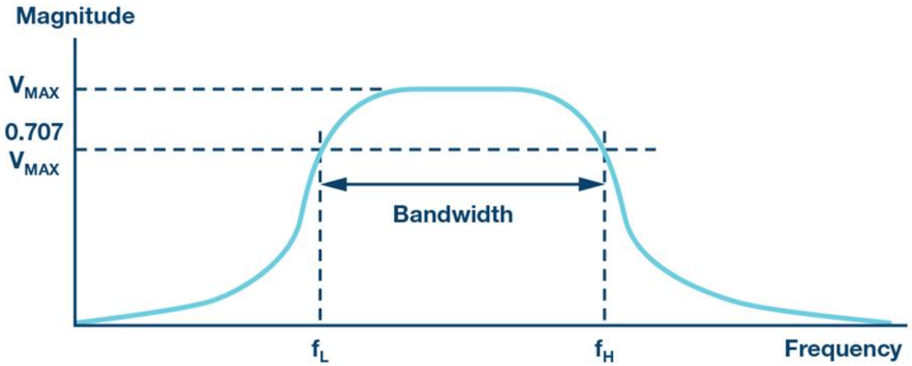
Frequency (GHz)	S1,1 Zr: 50 Ω Real	S1,1 Zr: 50 Ω u(Real)	S1,1 Zr: 50 Ω Imag	S1,1 Zr: 50 Ω u(Imag)
1,000	0,005	0,003	0,001	0,003



2 port example:

Band-pass filter

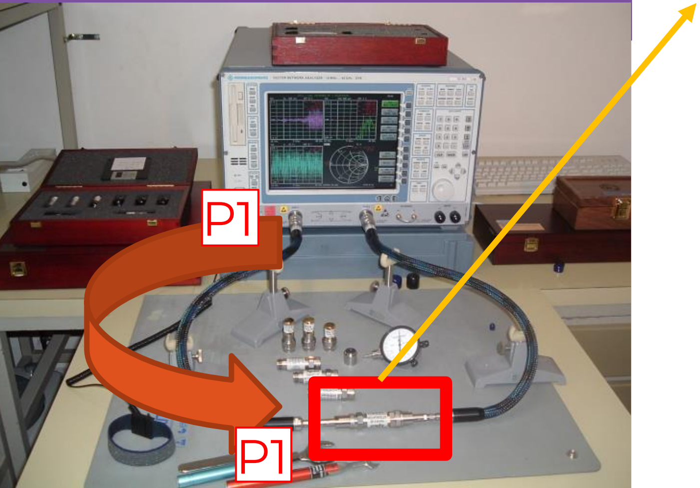
S-parameters: 4



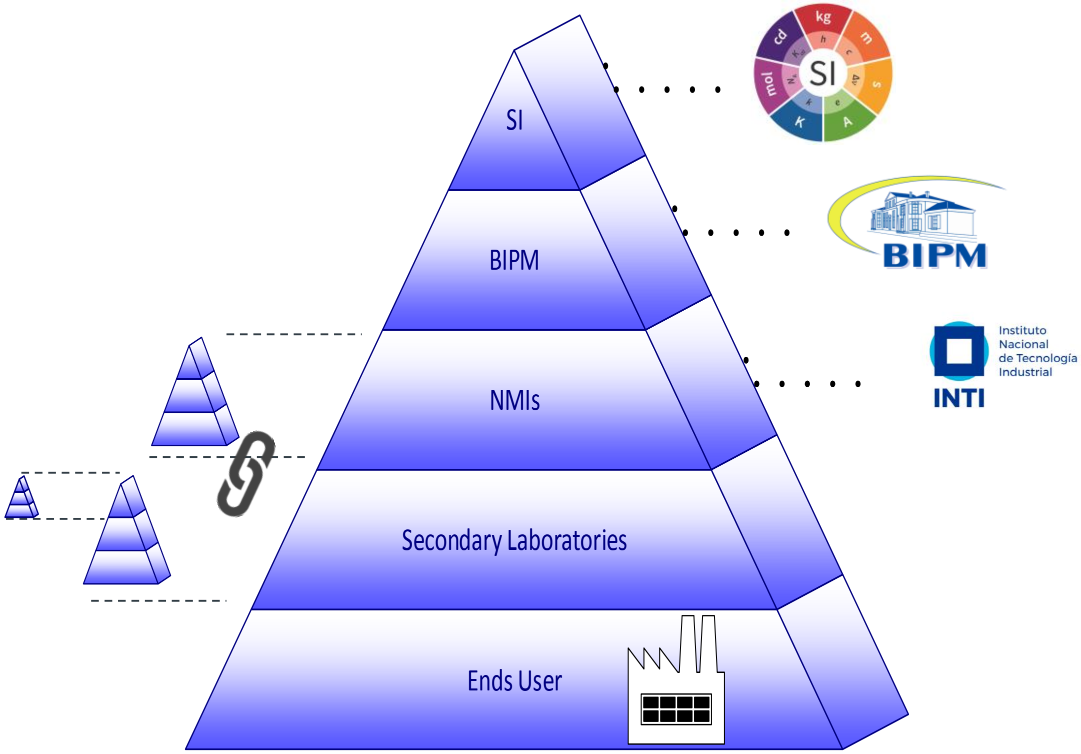
Frequency (GHz)	S1,1 Zr: 50 Ω Real	S1,1 Zr: 50 Ω Imag	S2,1 Zr: 50 Ω Real	S2,1 Zr: 50 Ω Imag	S1,2 Zr: 50 Ω Real	S1,2 Zr: 50 Ω Imag	S2,2 Zr: 50 Ω Real	S2,2 Zr: 50 Ω Imag
1,000	0,005	0,001	0,027	-0,100	0,027	-0,100	0,004	0,000
1,500	0,006	-0,001	-0,039	-0,096	-0,039	-0,096	0,004	-0,001
2,000	0,004	-0,002	-0,089	-0,053	-0,089	-0,052	0,002	-0,004
2,500	0,001	-0,002	-0,102	0,012	-0,102	0,012	-0,001	-0,003
3,000	-0,002	-0,001	-0,074	0,071	-0,074	0,071	-0,003	0,001
3,500	-0,005	0,002	-0,016	0,101	-0,016	0,101	-0,001	0,006
4,000	-0,007	0,007	0,049	0,090	0,049	0,090	0,004	0,008
4,500	-0,007	0,013	0,093	0,042	0,093	0,042	0,010	0,005
5,000	-0,002	0,018	0,100	-0,023	0,099	-0,024	0,013	-0,001
5,500	0,005	0,020	0,065	-0,079	0,065	-0,079	0,010	-0,008
6,000	0,012	0,019	0,003	-0,102	0,003	-0,102	0,002	-0,011
6,500	0,019	0,014	-0,060	-0,083	-0,060	-0,083	-0,006	-0,008
7,000	0,024	0,006	-0,098	-0,029	-0,098	-0,029	-0,010	0,000

Correlations between …

- Real/Imaginary parts
- Real/Imaginary parts at different frequencies
- Different S-parameters
- Different DUTs
- Uncertainty components
- Measured values vs. temperature, humidity, time.



Traceability pyramid



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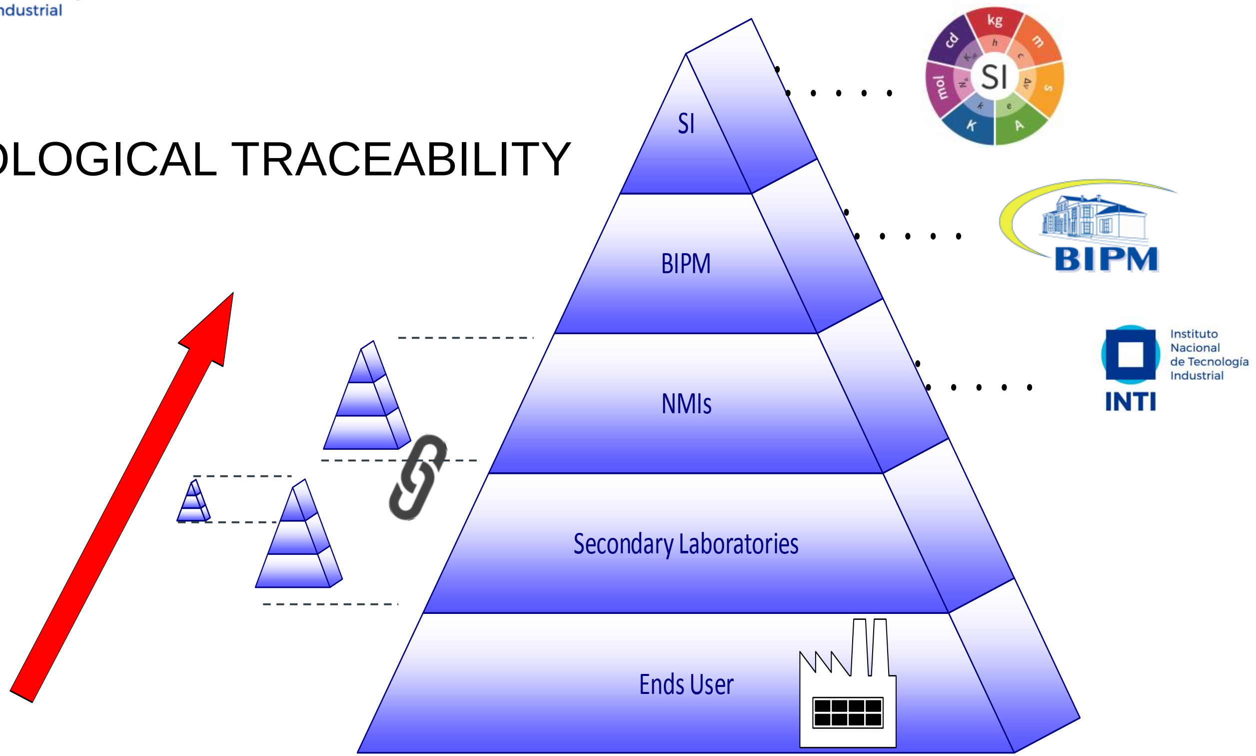
Traceability pyramid

METROLOGICAL TRACEABILITY



[VIM3] 2.41

property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

set of quantity values being attributed to a measurand together with any other available relevant information

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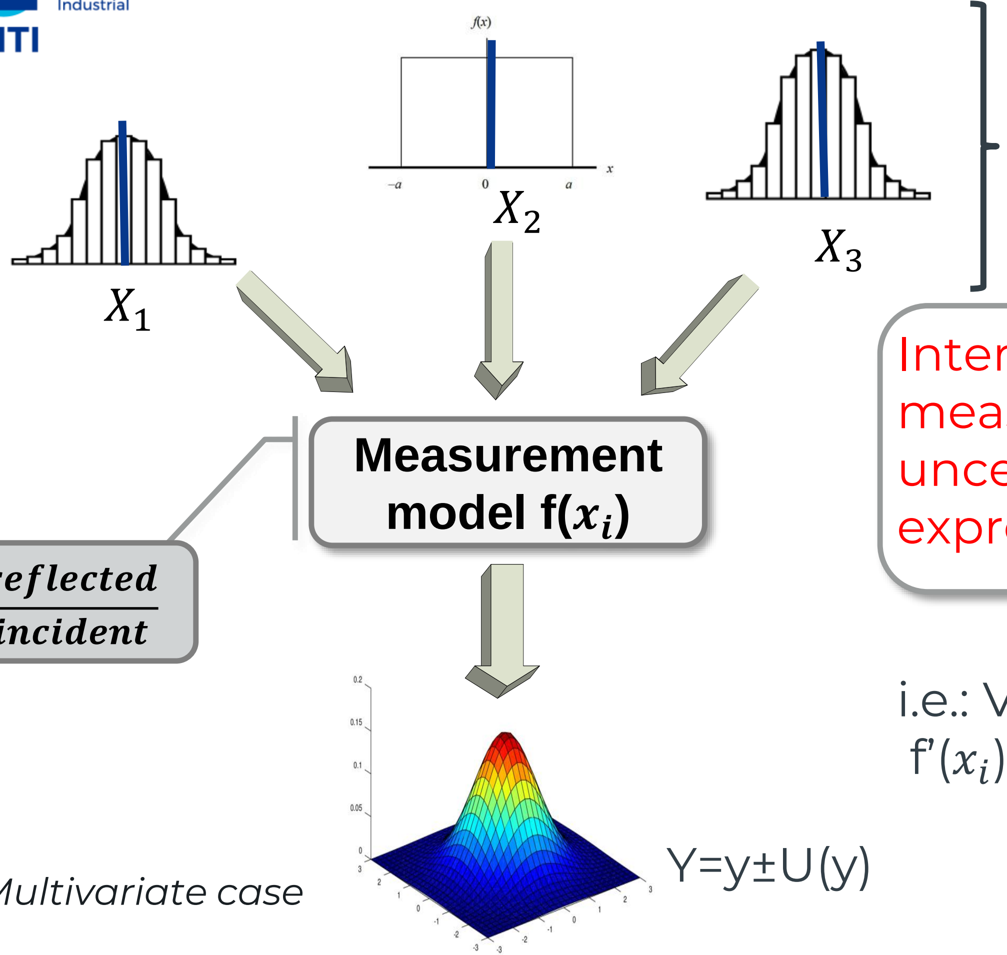


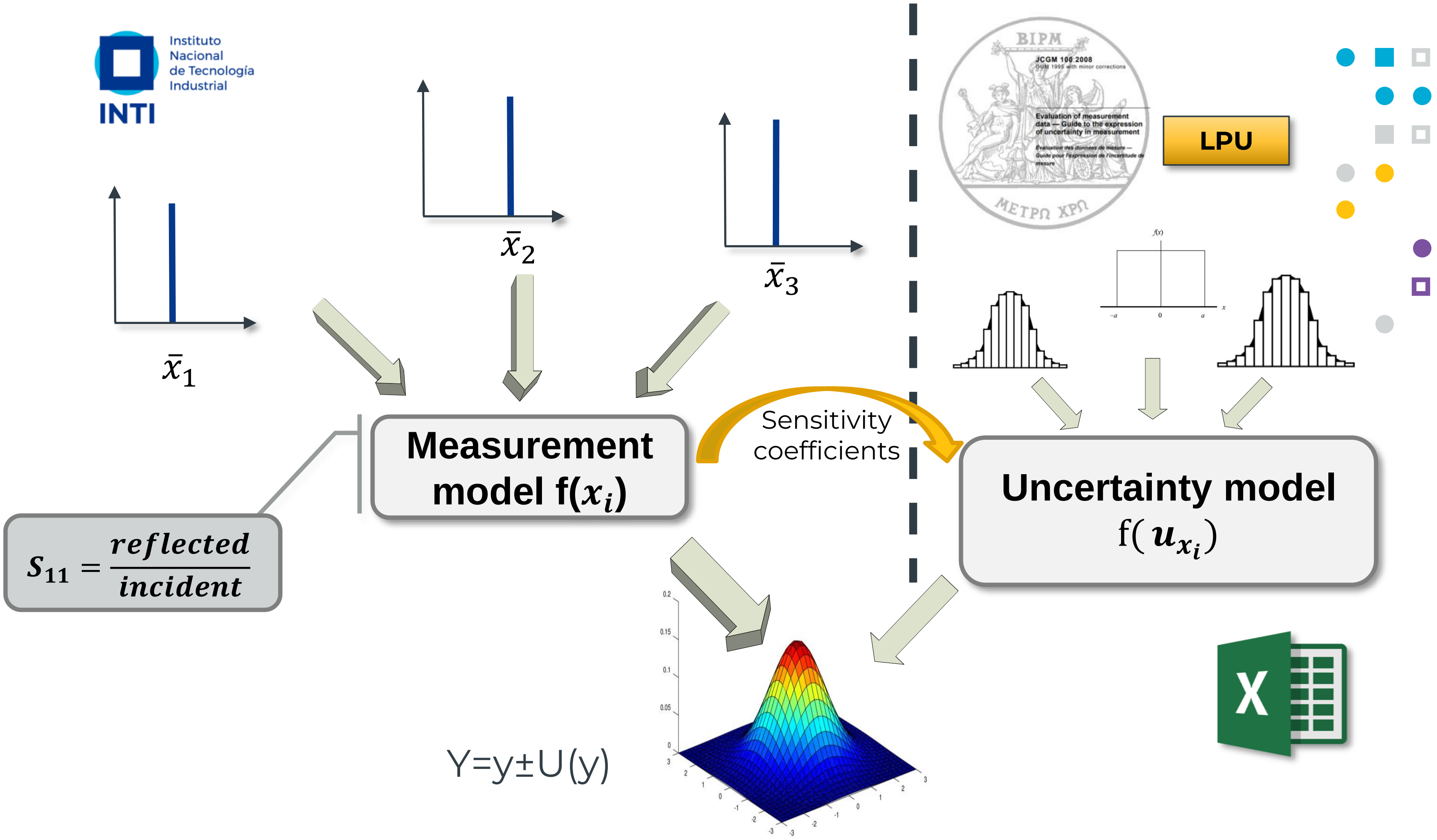
Influence quantities (x_i)

Interaction between measurand and uncertainty in the same expression.

$$S_{11} = \frac{reflected}{incident}$$

Multivariate case

i.e.: Value=1 ; unc.= 0.001
f'(x_i)=1 x (1±0.001)=?



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$\bar{x}_1$
$\bar{x}_2$
$\bar{x}_3$
BIPM
JCGM 100:2008
GUM 1995 with minor corrections
Evaluation of measurement data — Guide to the expression of uncertainty in measurement
LPU
Measurement model f(x_i)
Sensitivity coefficients
Uncertainty model f(u_{x_i})
$S_{11} = \frac{reflected}{incident}$
Y=y±U(y)

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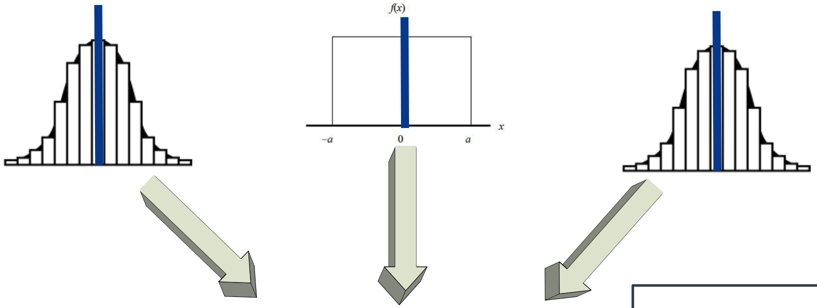
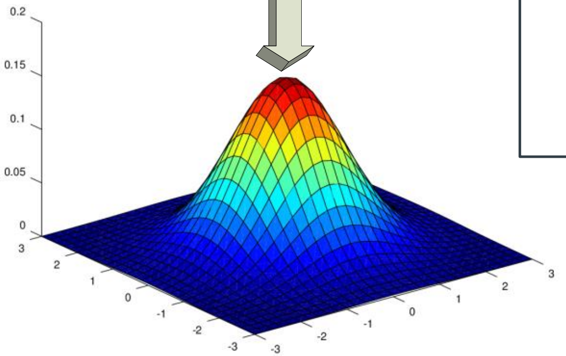
Rigorous method



Measurement model f(xi)

$$S_{11} = \frac{reflected}{incident}$$



$$S_{11} = \frac{\frac{S^m_{11}-N_L}{N_H L} - E'_{00} - kC_{00}E'_{01}}{(C_{11}+kC_{01}C_{10}E'_{11})\left(\frac{S^m_{11}-N_L}{N_H L} - E'_{00} - kC_{00}E'_{01}\right) + k^2 C_{10}C_{01}E'_{01}}.$$

$$\begin{aligned} E'_{00} &= E_{00} + D_{00} \\ E'_{01} &= E_{01} D_{01} \\ E'_{11} &= E_{11} + D_{11} \\ k &= \frac{1}{1 - E'_{11} C_{00}}. \end{aligned}$$

Issues /Solutions

- Different models ⇨ Only 1 model (rigorous method)

Issues /Solutions

- Different models → Only 1 model (rigorous method)
- Mixed data types → Uncertainty objects

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Issues /Solutions

- Different models → Only 1 model (rigorous method)
- Mixed data types → Uncertainty objects

Case 1:

Measured voltaje: V= 5V
U(V)=1uV

Calibration certificate

Uncertainty object V=(5 , 1e-6)

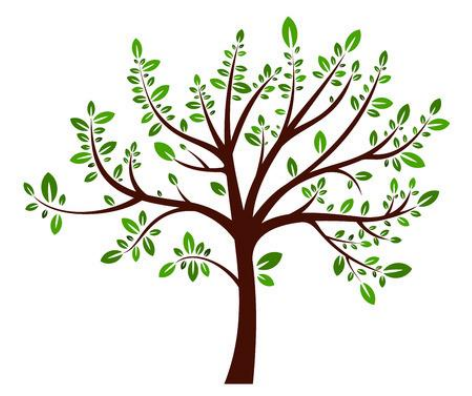
```
Command Window
>> v = unc(5,1e-6)

v =

    (5 ± 1e-06)

fx >>
```

Case 2:

Measured voltaje: V=(5 , 0)

U(V) = (0 , 1e-6) Additive uncertainty

U(V) = (1 , 1e-6) Multiplicative uncertainty

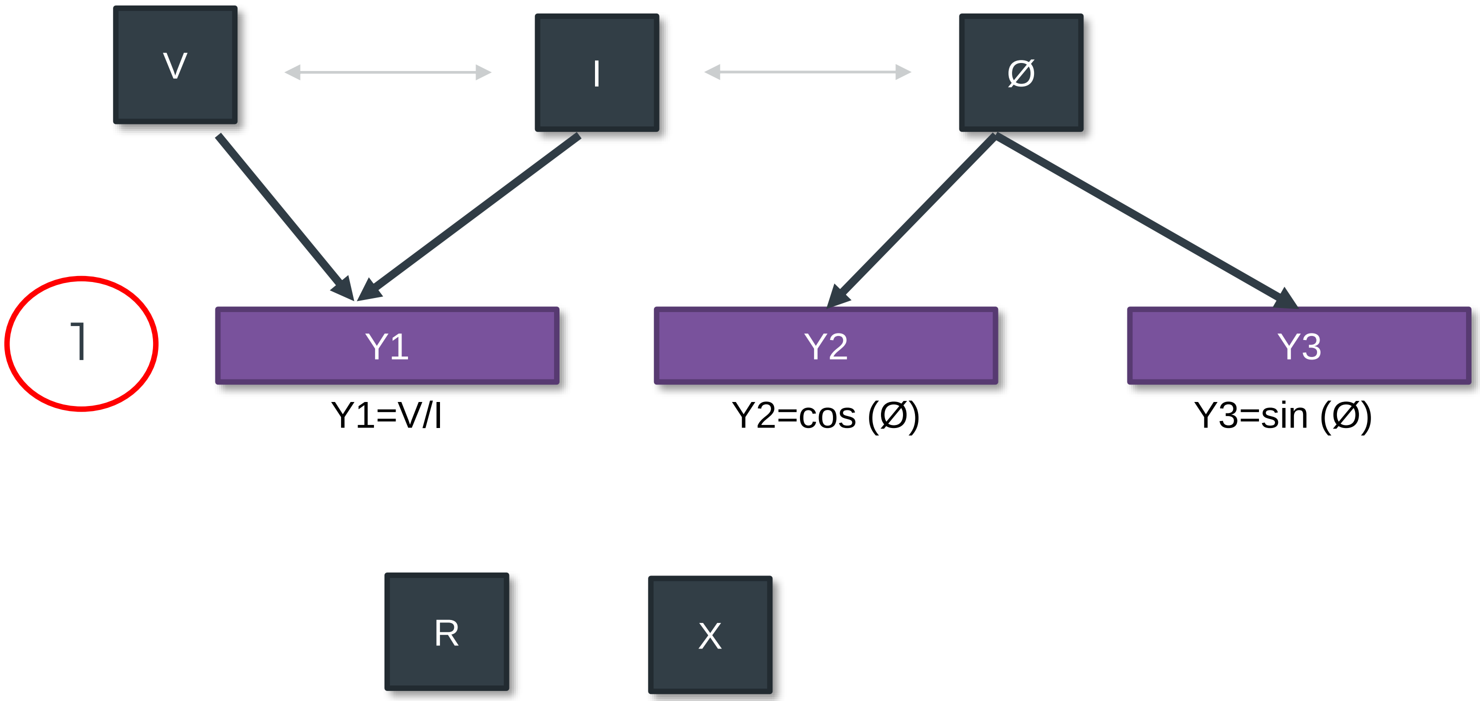


Issues /Solutions

- Different models → Only 1 model (rigorous method)
- Mixed data types → Uncertainty objects
- Complicated calculations → Authomatic uncertainty propagation through authomatic differentiation

$$R = \frac{V}{I}\cos \emptyset \qquad X = \frac{V}{I}\sin \emptyset$$

MEASUREMENT MODEL

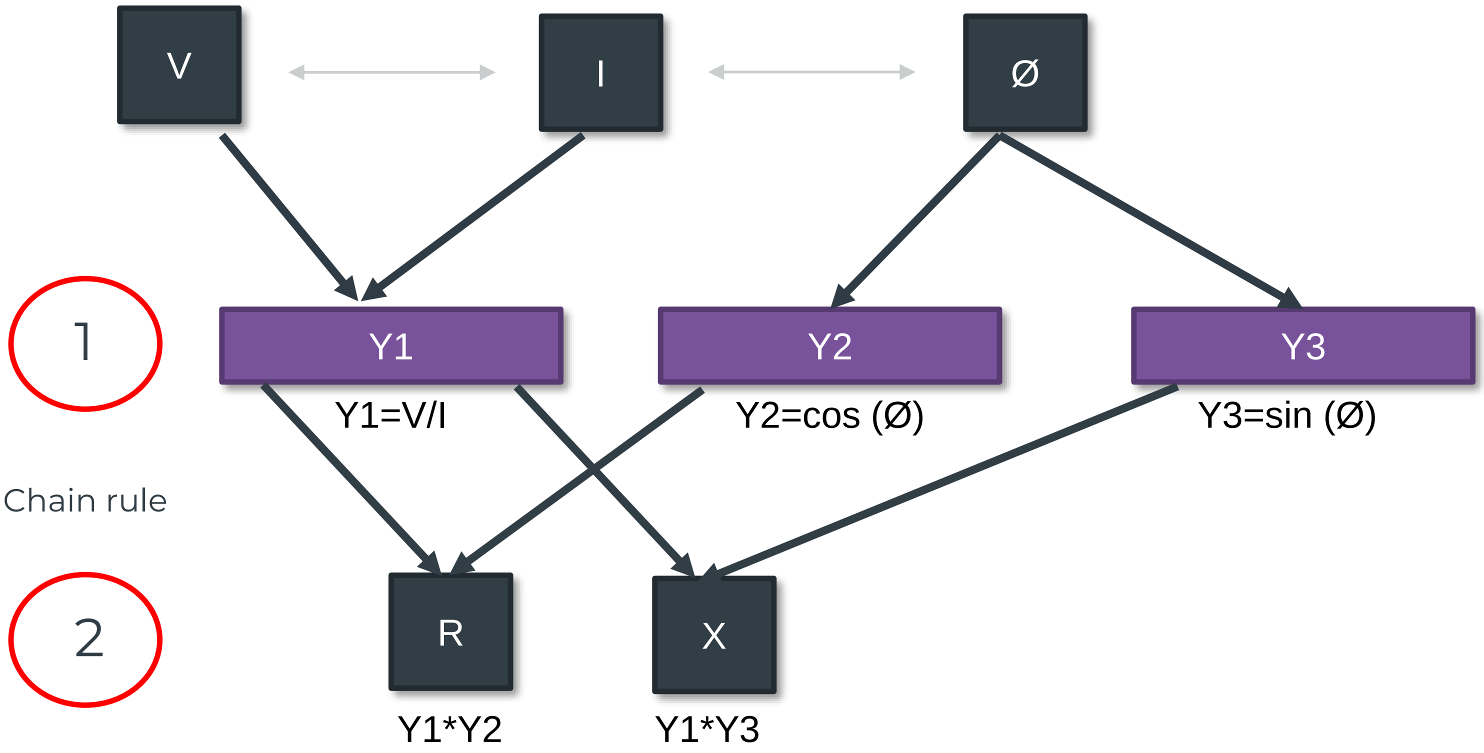


Graphical decomposition of a measurement model

$$R = \frac{V}{I} \cos \emptyset$$

$$X = \frac{V}{I} \sin \emptyset$$

MEASUREMENT MODEL



Graphical decomposition of a measurement model

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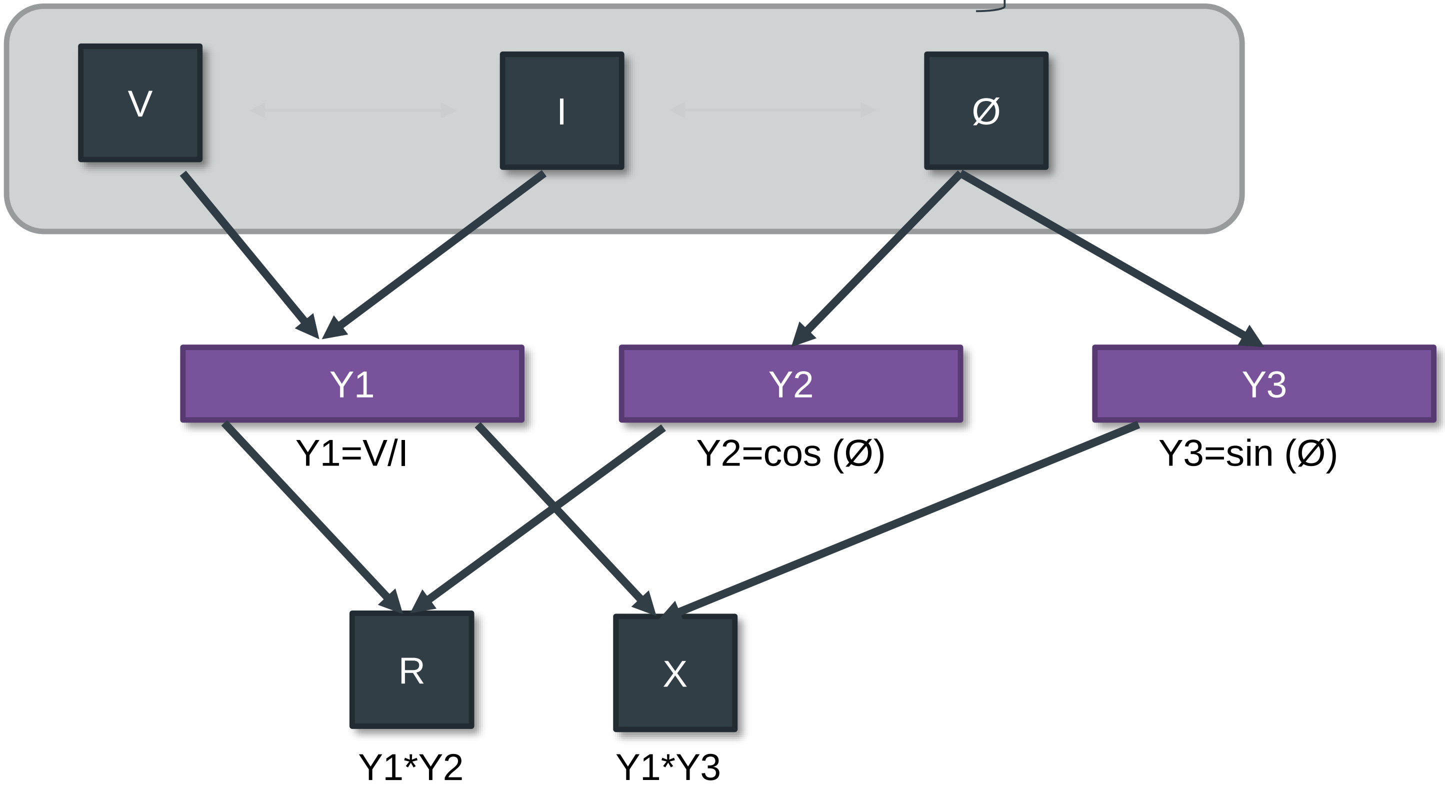
$$R = \frac{V}{I}\cos\emptyset \qquad X = \frac{V}{I}\sin\emptyset$$

MEASUREMENT MODEL



Graphical decomposition of a measurement model

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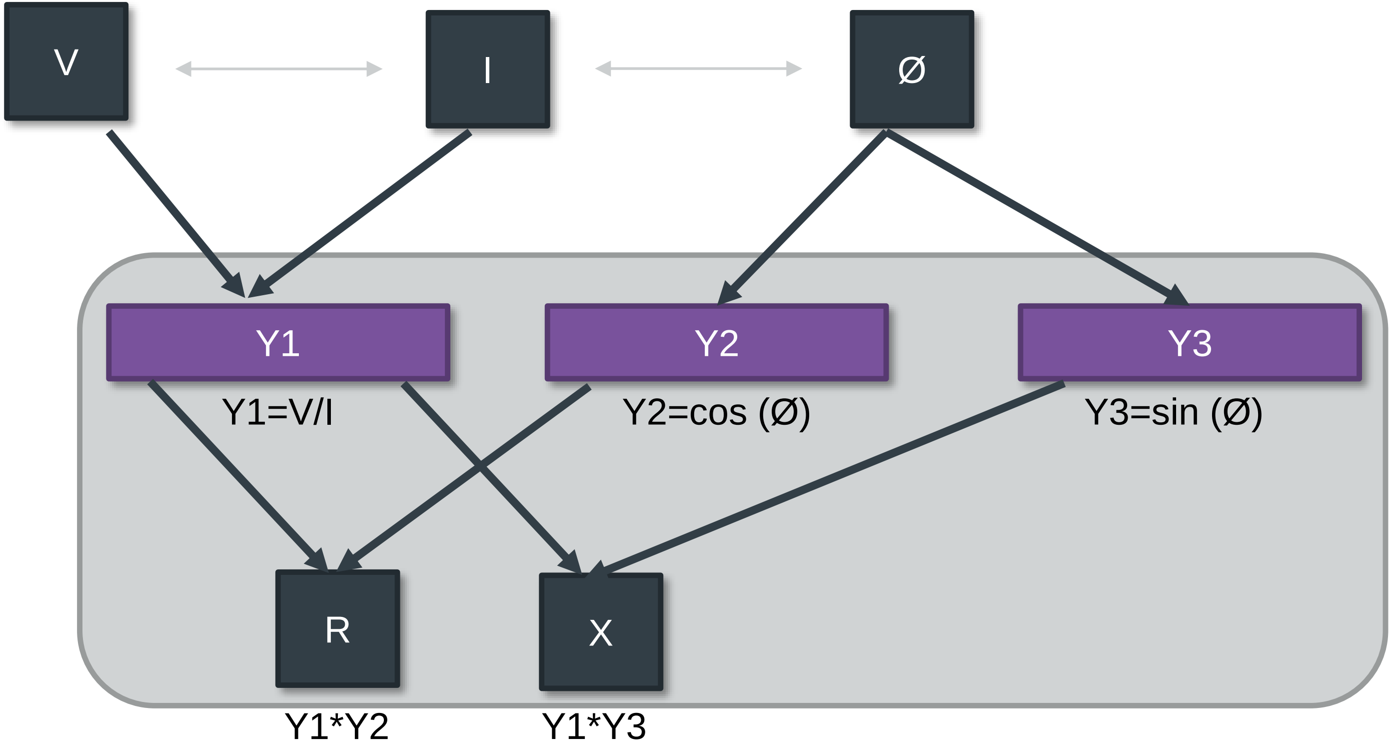
MEASUREMENT MODEL



Graphical decomposition of a measurement model

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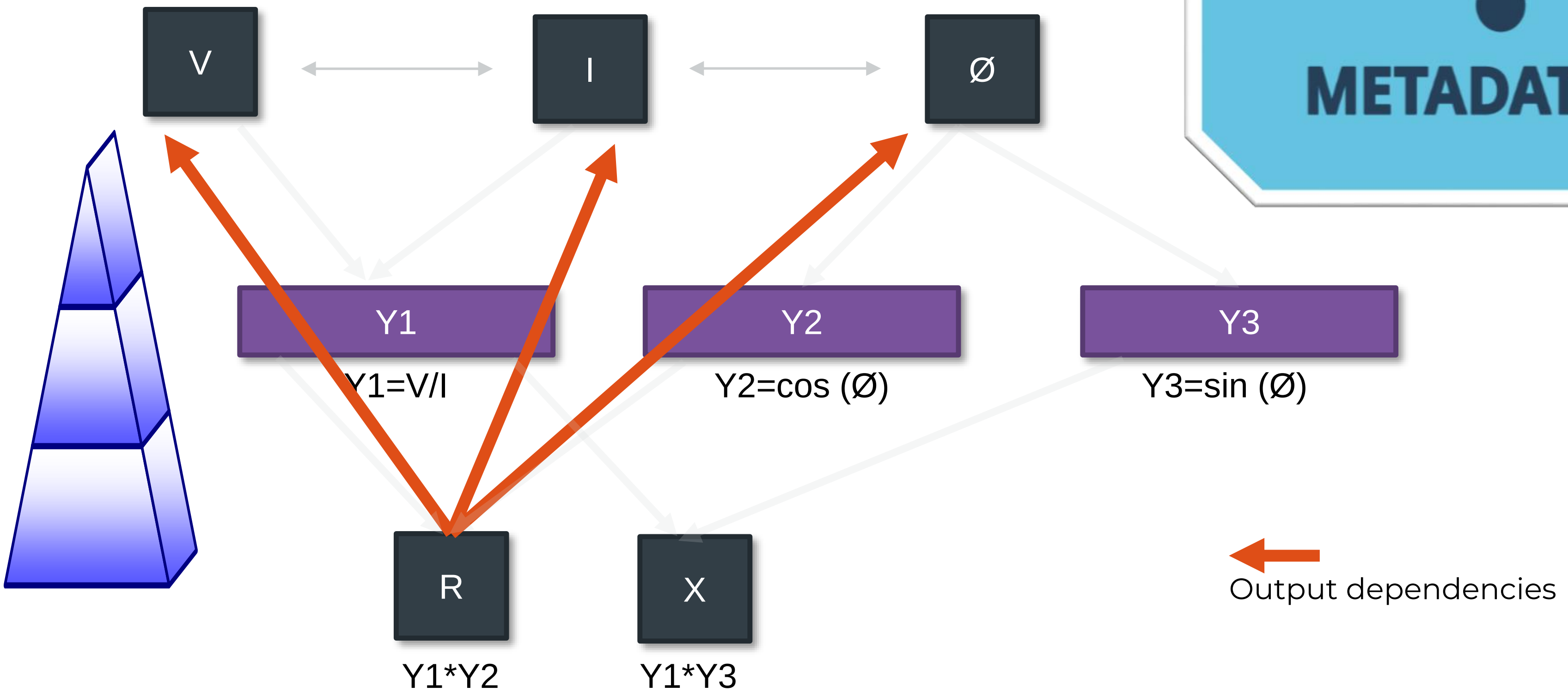
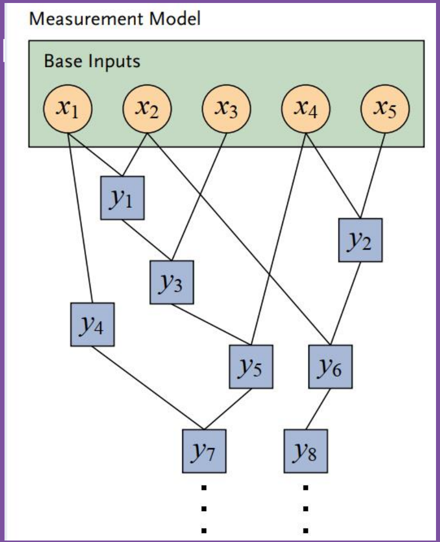
$$R = \frac{V}{I}\cos\emptyset \qquad X = \frac{V}{I}\sin\emptyset$$

METADATA



Graphical decomposition of a measurement model



Value: y_i

Dependencies: $(x_1\ x_2\ x_3\ \ldots)$

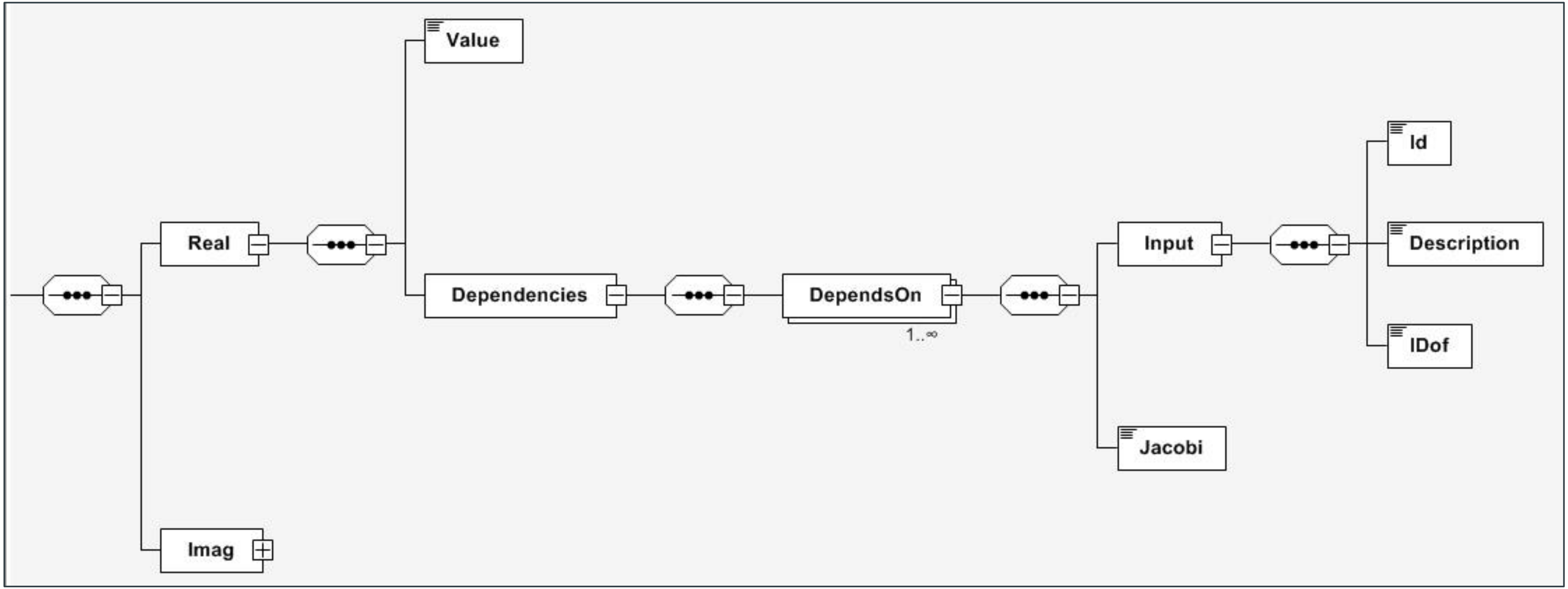
Derivatives: $\left(\frac{\partial y_i}{\partial x_1}\ \frac{\partial y_i}{\partial x_2}\ \frac{\partial y_i}{\partial x_3}\ \ldots\right)$

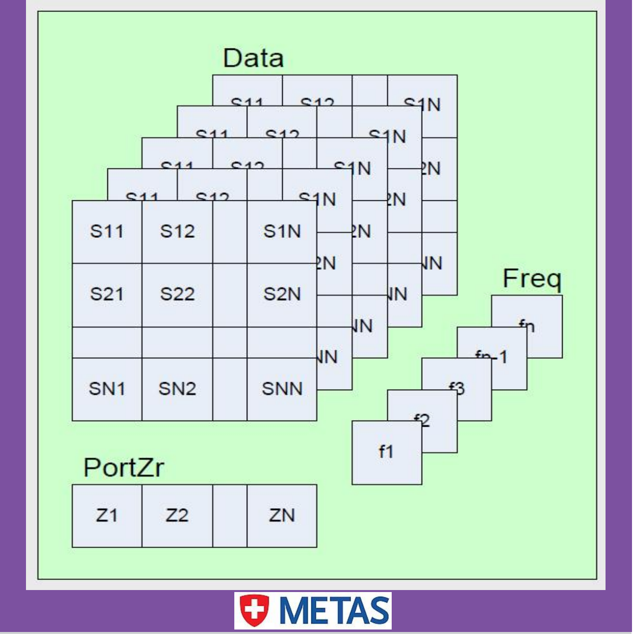
Uncertainty Number (METAS UncLib)

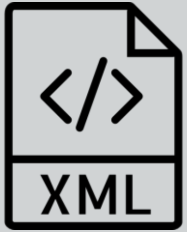
Issues /Solutions

- Different models → Only 1 model (rigorous method)
- Mixed data types → Uncertainty objects
- Complicated calculations → Authomatic uncertainty propagation through authomatic differentiation
- Lack of correlations → Record of dependencies. Correlations on demand (or explicitly saved)

XSD STRUCTURE





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    <Port>2</Port>
  </PortList>
  <PortZrList>
  <Data>
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          <Real>
          <Imag>
        </SourcePort>
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          <Imag>
        </SourcePort>
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          <Imag>
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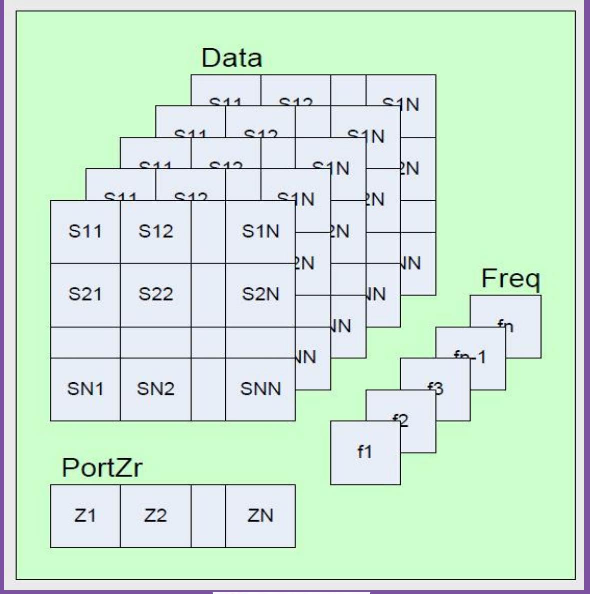
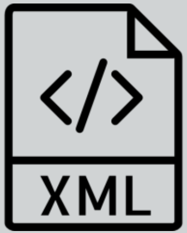
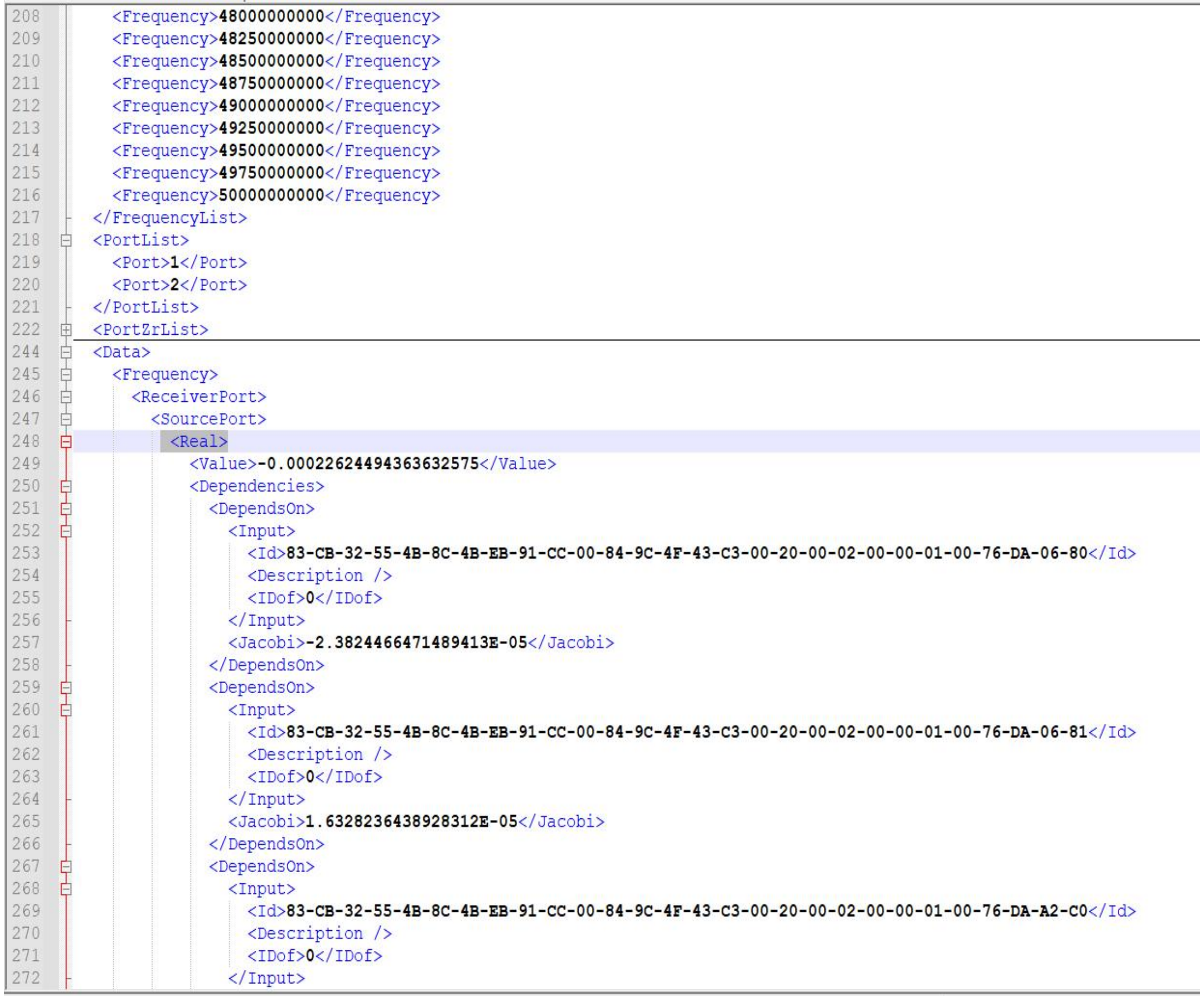


METAS





```xml
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    <Frequency>48500000000</Frequency>
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    <Frequency>49250000000</Frequency>
    <Frequency>49500000000</Frequency>
    <Frequency>49750000000</Frequency>
    <Frequency>50000000000</Frequency>
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    <Port>2</Port>
  </PortList>
  <PortZrList>
  <Data>
    <Frequency>
      <ReceiverPort>
        <SourcePort>
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            <Dependencies>
              <DependsOn>
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                </Input>
```


eXtensible Markup Language file   length : 181.235.125   lines : 4.215.852

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GET_CORRELATION()

1-Port correlation @f0

	Real S1,1	Imag S1,1
Real S1,1	1,000e+000	-3,860e-002
Imag S1,1	-3,860e-002	1,000e+000

Correlación Mag 2 puertos @f

	Real S1,1	Imag S1,1	Real S2,1	Imag S2,1	Real S1,2	Imag S1,2	Real S2,2	Imag S2,2
Real S1,1	1,000e+000	-3,860e-002	3,917e-002	-5,402e-003	3,921e-002	-5,835e-003	8,870e-002	-9,785e-004
Imag S1,1	-3,860e-002	1,000e+000	3,088e-003	1,564e-001	3,204e-003	1,571e-001	-5,773e-003	3,136e-001
Real S2,1	3,917e-002	3,088e-003	1,000e+000	5,608e-001	1,000e+000	5,609e-001	9,933e-001	-7,535e-001
Imag S2,1	-5,402e-003	1,564e-001	5,608e-001	1,000e+000	5,608e-001	1,000e+000	5,772e-001	-2,250e-002
Real S1,2	3,921e-002	3,204e-003	1,000e+000	5,608e-001	1,000e+000	5,609e-001	9,933e-001	-7,535e-001
Imag S1,2	-5,835e-003	1,571e-001	5,609e-001	1,000e+000	5,609e-001	1,000e+000	5,772e-001	-2,229e-002
Real S2,2	8,870e-002	-5,773e-003	9,933e-001	5,772e-001	9,933e-001	5,772e-001	1,000e+000	-7,401e-001
Imag S2,2	-9,785e-004	3,136e-001	-7,535e-001	-2,250e-002	-7,535e-001	-2,229e-002	-7,401e-001	1,000e+000

GUI METAS VNA Tools

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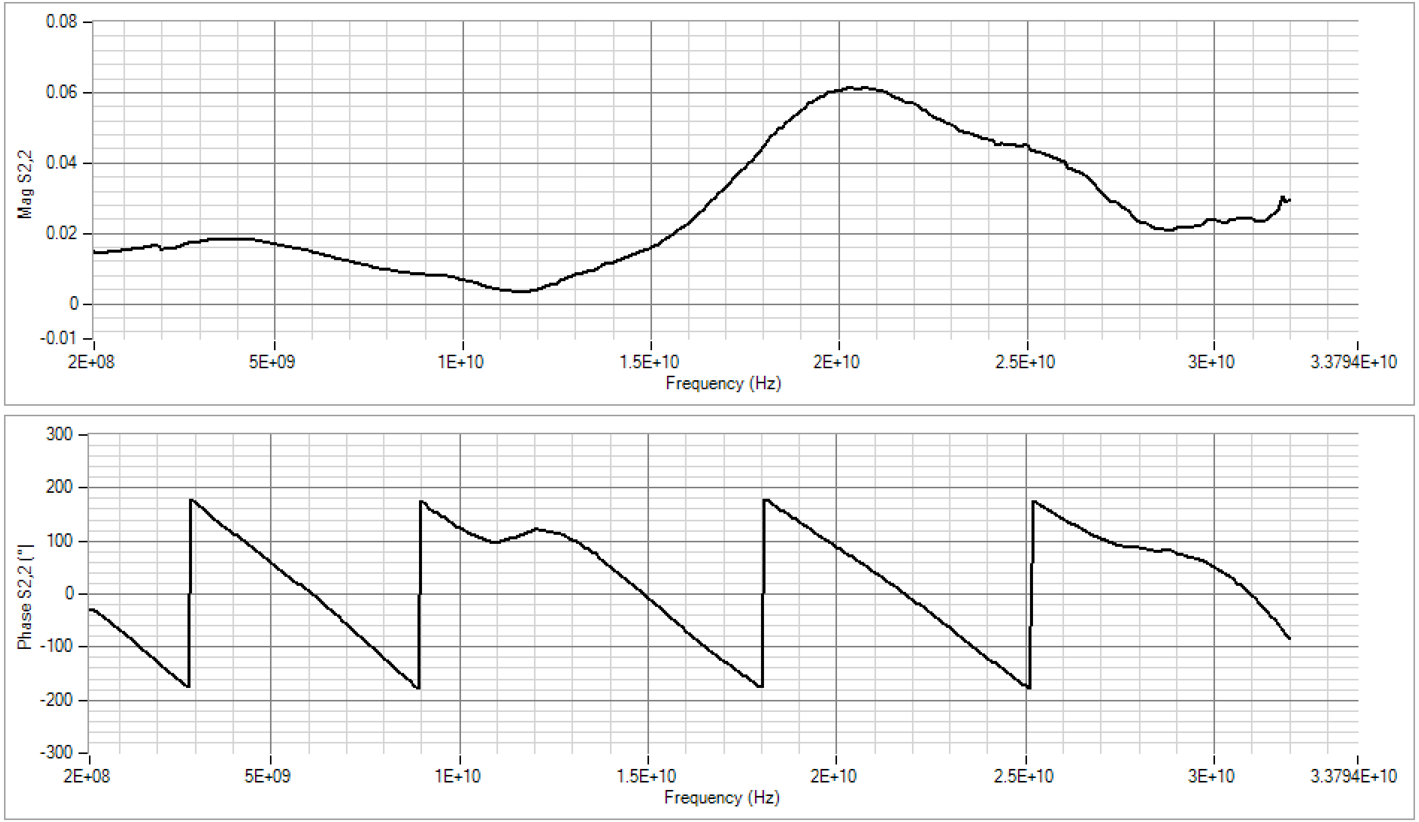
GET_CORRELATION()

|S11| correlation between different frequencies

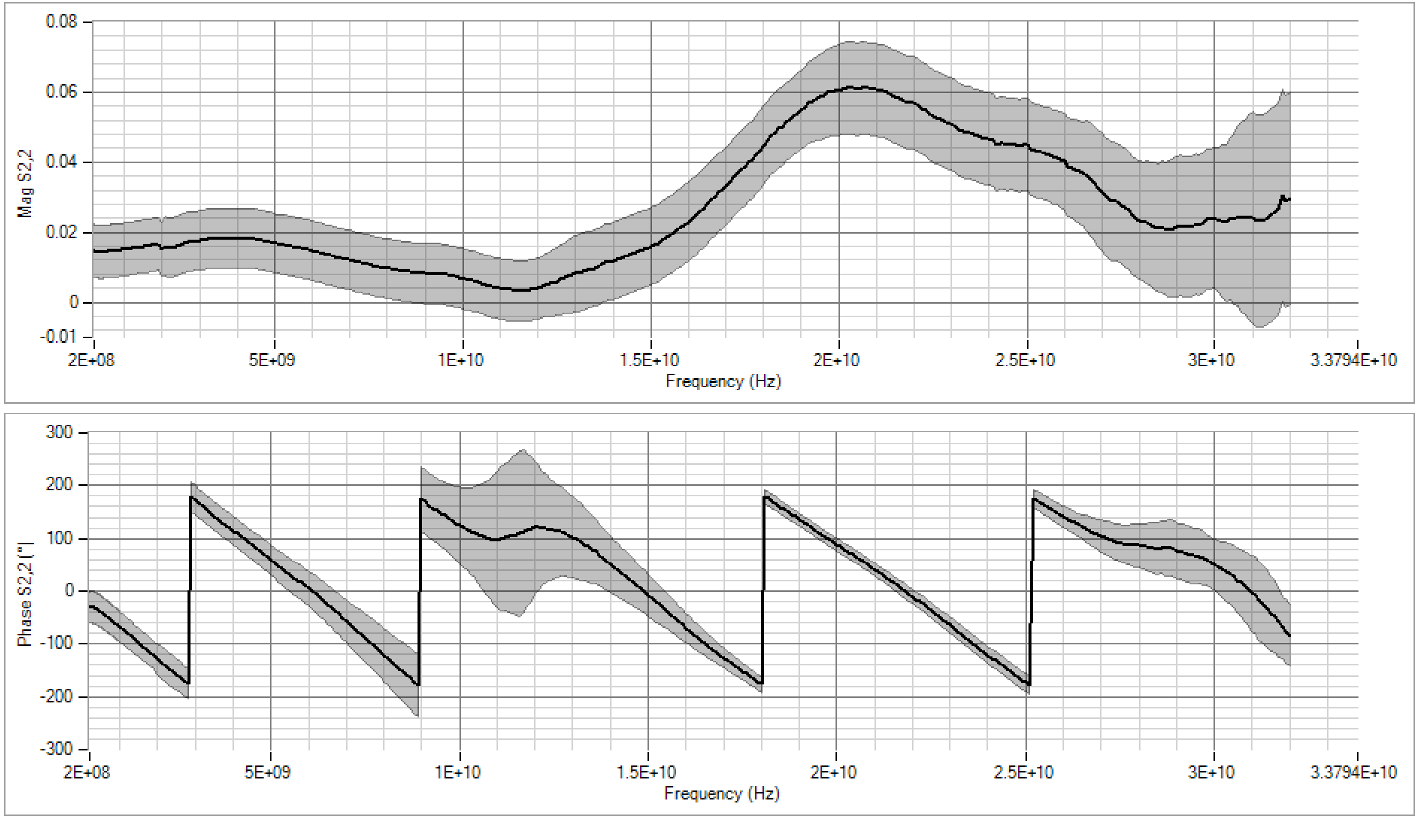
		95,000e+06 Hz	100,000e+06 Hz	150,000e+06 Hz	200,000e+06 Hz	250,000e+06 Hz	300,000e+06 Hz	350,000e+06 Hz	400,000e+06 Hz
45,000e+06 Hz	0,92	0,92	0,91	0,79	-0,34	0,00	0,00	0,00	
50,000e+06 Hz	0,94	0,94	0,93	0,82	-0,35	0,00	0,00	0,00	
55,000e+06 Hz	0,96	0,95	0,95	0,84	-0,35	0,00	0,00	0,01	
60,000e+06 Hz	0,97	0,96	0,96	0,86	-0,36	0,00	0,00	0,00	
65,000e+06 Hz	0,98	0,97	0,97	0,87	-0,35	0,00	0,00	0,00	
70,000e+06 Hz	0,98	0,98	0,97	0,88	-0,35	0,01	0,00	0,00	
75,000e+06 Hz	0,99	0,98	0,98	0,89	-0,35	0,00	0,00	0,00	
80,000e+06 Hz	0,99	0,98	0,98	0,90	-0,34	0,00	0,01	0,00	
85,000e+06 Hz	0,99	0,99	0,99	0,91	-0,33	0,00	0,00	0,00	
90,000e+06 Hz	1,00	0,99	0,99	0,92	-0,32	0,00	0,00	0,00	
95,000e+06 Hz	0,99	1,00	0,99	0,92	-0,31	0,00	0,00	0,00	
100,000e+06 Hz	0,99	0,99	1,00	0,93	-0,30	0,00	0,00	0,00	
150,000e+06 Hz	0,92	0,92	0,93	1,00	0,00	0,00	0,00	0,00	
200,000e+06 Hz	0,32	-0,31	-0,30	0,00	1,00	0,00	0,00	0,00	
250,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	
300,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	
350,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	
400,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	
450,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01	
500,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	
550,000e+06 Hz	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	

GET_VALUE(y)



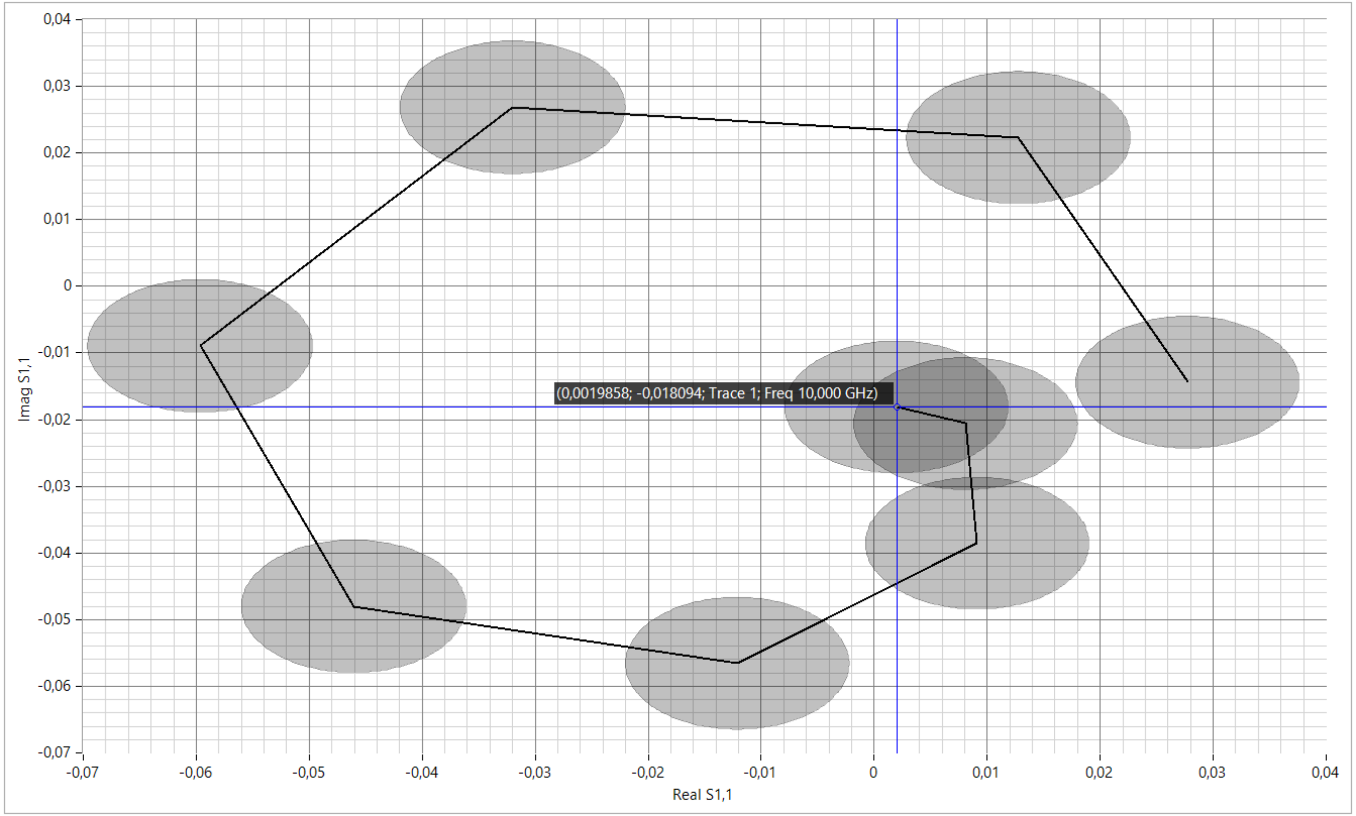
GUI METAS VNA Tools

GET_VALUE(y) ; GET_STDUNC(y)



GUI METAS VNA Tools

Uncertainty on Complex plane
10GHz-18GHz @1GHz step



GUI METAS VNA Tools

BUDGET(y)

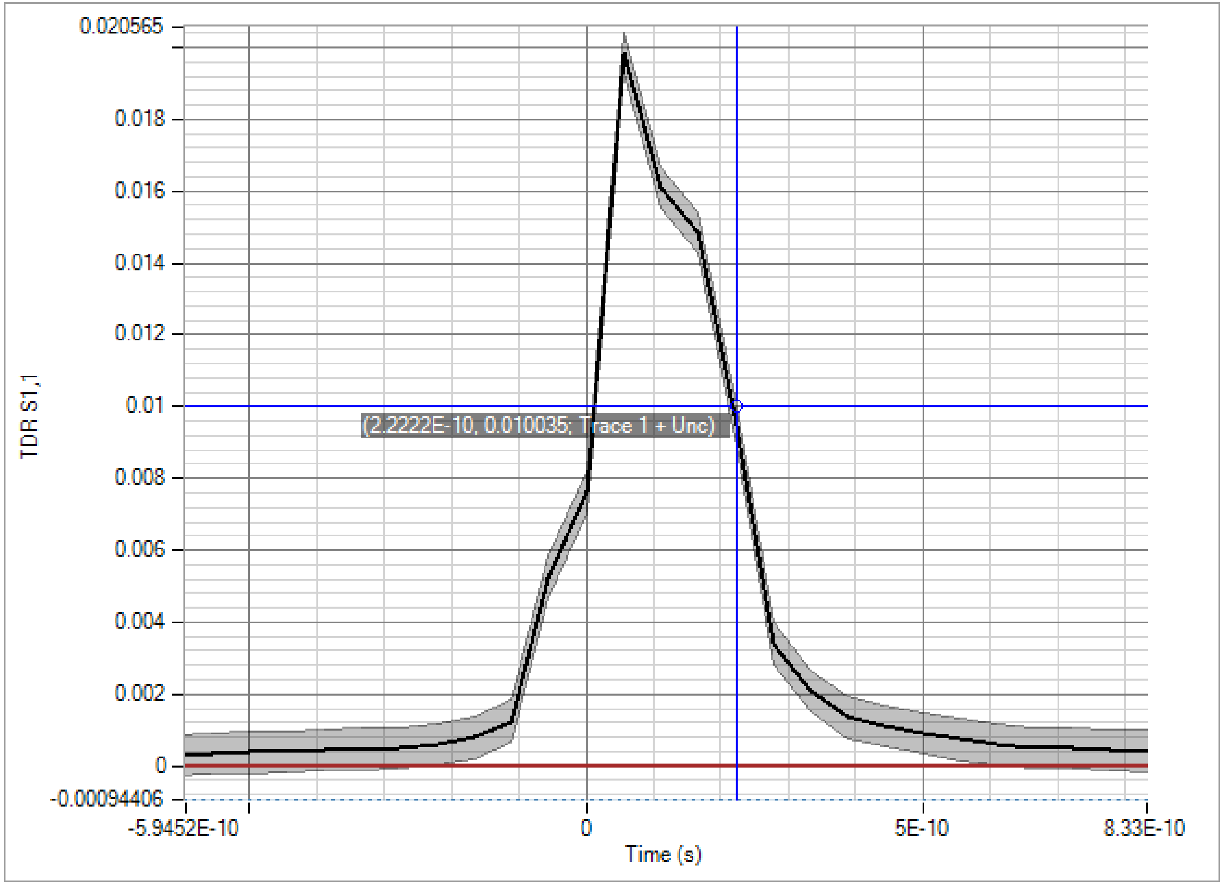
Frequency: 2800.000 MHz, Parameter: S1,1 Zr: 50 Ω Phase (°)

Id | Flat | Expand All | Collapse All | Numeric Format: f6 | Copy

Value	Std Unc	U95
-29.681245	29.561606	59.123212

Description	Unc Component	Unc Percentage
Cable Stability	4.972430	2.829
Connector Repeatability	19.795602	44.842
Reflection	19.795602	44.842
load(m)	20.925102	50.105
open(f)	0.222150	0.006
open(m)	0.121464	0.002
short(f)	0.222593	0.006
short(m)	0.120965	0.002
VNA Drift (Ideal VNA correlated)	4.389481	2.205
Directivity	4.389394	2.205
Match	0.027649	0.000
VNA Linearity	0.147518	0.002
VNA Noise	0.141953	0.002

Time Domain



GUI METAS VNA Tools

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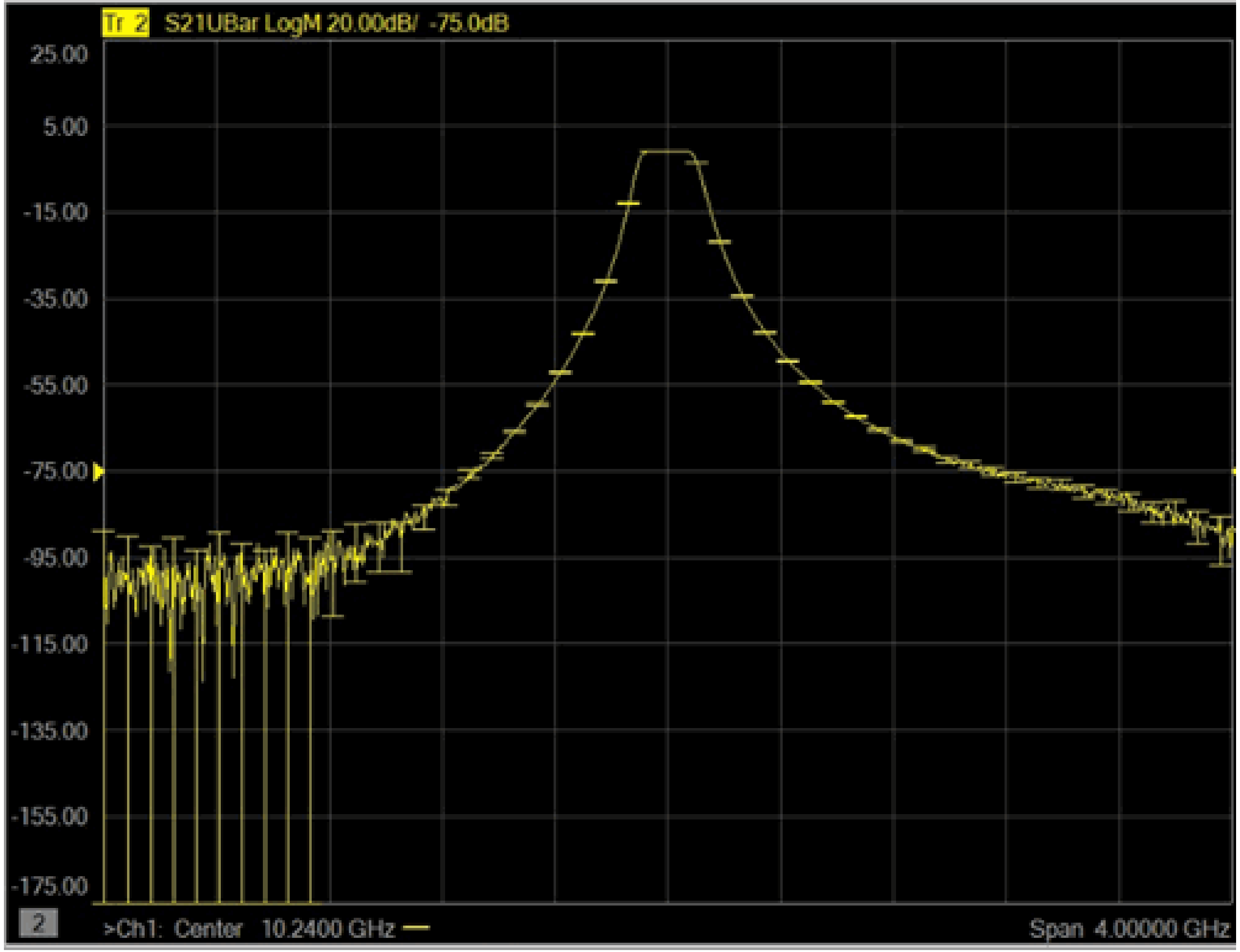

Tr 2 S21UBar LogM 20.00dB/ -75.0dB
25.00
5.00
-15.00
-35.00
-55.00
-75.00
-95.00
-115.00
-135.00
-155.00
-175.00
2
>Ch1: Center 10.2400 GHz
Span 4.00000 GHz

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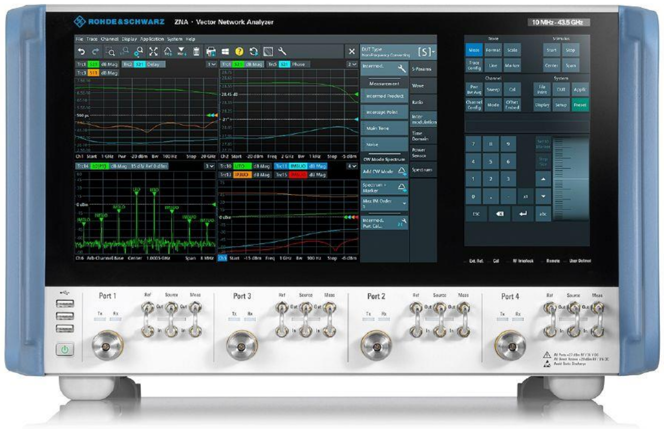
Maury Microwave
Your Calibration, Measurement & Modeling Solutions Partner!

MT940A Insight Calibration and Measurement software



ROHDE&SCHWARZ

R&S ZNA-K50 Real time measurement uncertainty analysis

EXAMPLE ISO-GUM H2 with GTC

INPUT VARIABLES

```
V = ureal(4.999,3.2E-3,independent=False)      # volt
I = ureal(19.661E-3,9.5E-6,independent=False)  # amp
phi = ureal(1.04446,7.5E-4,independent=False)  # radian

set_correlation(-0.36,V,I)
set_correlation(0.86,V,phi)
set_correlation(-0.65,I,phi)
```

MODEL

```
R = result( V * cos(phi) / I )
X = result( V * sin(phi) / I )
Z = result( V / I )
```

```
print 'R = {}'.format(R)
print 'X = {}'.format(X)
print 'Z = {}'.format(Z)
print
print 'Correlation between R and X = {:+.2G}'.format( get_correlation(R,X) )
print 'Correlation between R and Z = {:+.2G}'.format( get_correlation(R,Z) )
print 'Correlation between X and Z = {:+.2G}'.format( get_correlation(X,Z) )
```

OUTPUT

```
R = 127.732(70)
X = 219.85(30)
Z = 254.26(24)

Correlation between R and X = -0.59
Correlation between R and Z = -0.49
Correlation between X and Z = +0.99
```

EXAMPLE ISO-GUM H2 with GTC

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```
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set_correlation(-0.65,I,phi)
```

PyVISA

MODEL

```
R = result( V * cos(phi) / I )
X = result( V * sin(phi) / I )
Z = result( V / I )
```

```
print 'R = {}'.format(R)
print 'X = {}'.format(X)
print 'Z = {}'.format(Z)
print
print 'Correlation between R and X = {:+.2G}'.format( get_correlation(R,X) )
print 'Correlation between R and Z = {:+.2G}'.format( get_correlation(R,Z) )
print 'Correlation between X and Z = {:+.2G}'.format( get_correlation(X,Z) )
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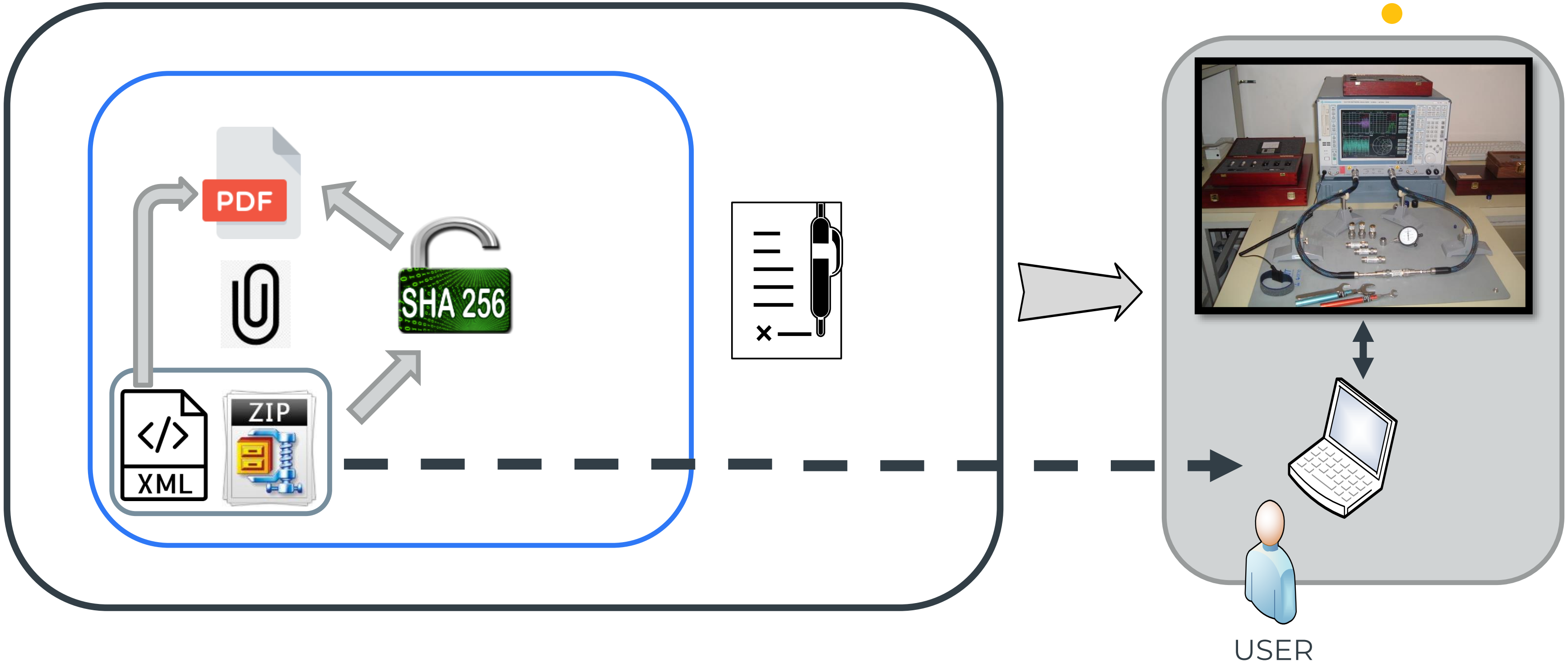
non-PTB DCC



METAS

Developer: Michael Wollensack

UncLib (Python)

https://pypi.org/project/metas-unclib/

```
pip install metas-unclib
```

UncLib (MATLAB, C#)

https://www.metas.ch/metas/en/home/fabe/hochfrequenz/unclib.html

MSL

GUM TREE CALCULATOR (GTC) (Python)

Developer: Blair Hall

https://pypi.org/project/GTC/

https://gtc.readthedocs.io/en/latest/install.html (Documentation)

```
pip install gtc
```

Thank you !

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