Repeatability of FRA Measurement Techniques

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2005 Nürnberg

Table of Measuring-Team and -Technique

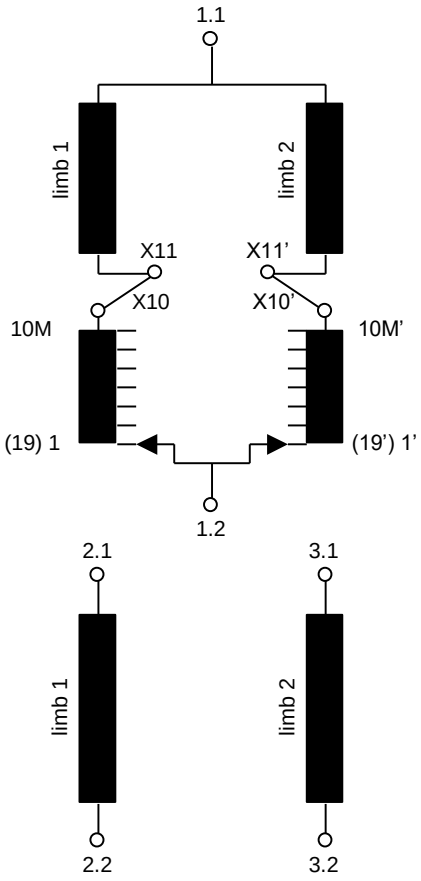
ID of the Measuring Team	FRA technique	input impedance of the equipment	measured physical output value
A	Swept frequency	high	Voltage
B	Impulse	high	Voltage
C	Swept frequency	50 Ω	Voltage
D	Swept frequency	50 Ω	Voltage
E	Swept frequency	CT	Current with Pearson-Probe
F	Impulse	50 Ω	Voltage
G	Swept frequency	50 Ω	Voltage
H	Impulse	10 Ω	Current with Shunt
I	Swept frequency	high + CT	Current with Pearson-Probe

6 different FRA techniques:

- TF of transferred voltage, high resistive input on measurement equipment, frequency-domain
- TF of transferred voltage, high resistive input on measurement equipment, time-domain
- TF of transferred voltage, low resistive (50 Ω) input on measurement equipment, frequency-domain
- TF of transferred voltage, low resistive (50 Ω) input on measurement equipment, time-domain
- TF of transferred ground current, pearson probe for current measuring, frequency-domain
- TF of transferred ground current, 10 Ω Shunt for current measuring, time-domain

Test-Object und Test-Circuits

Electrical winding assembly



Layout of the single phase transformer

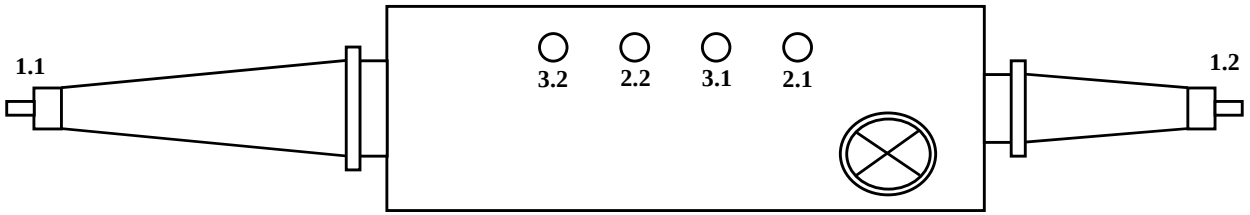
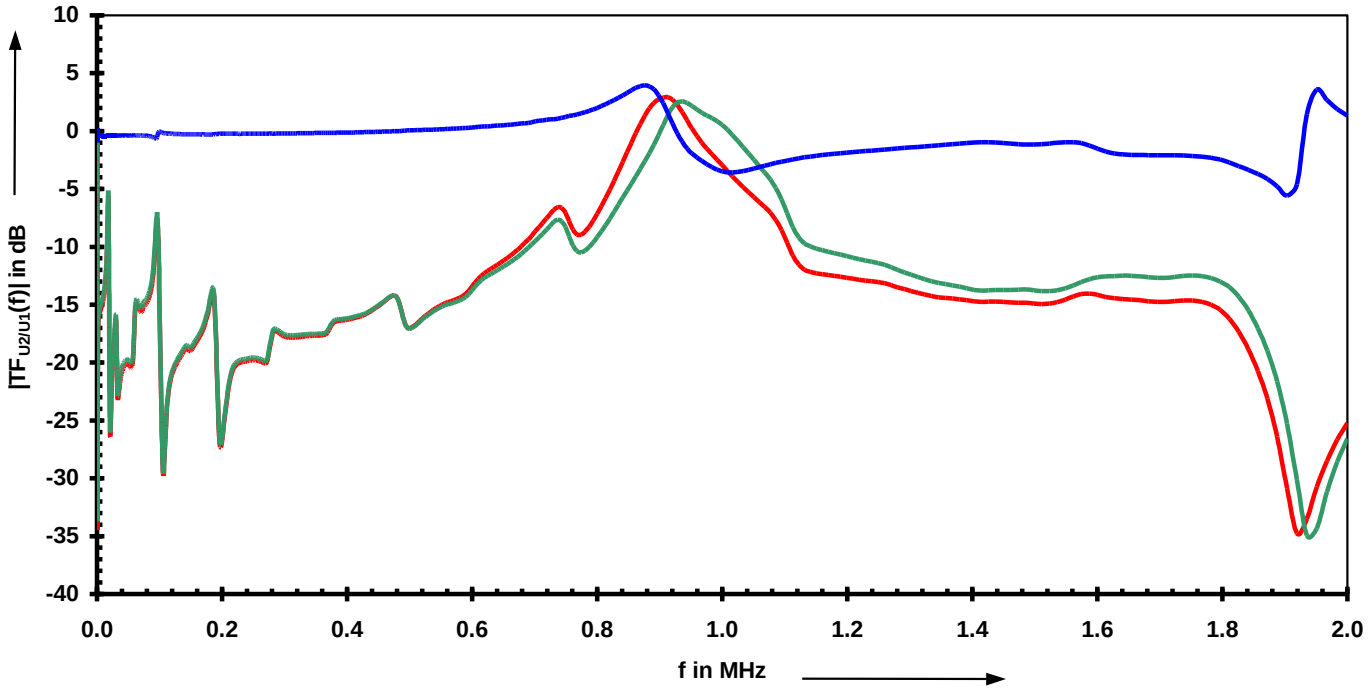


Table of the test-circuits

Test #	Inject on	Measure on	Tap pos	Short-circuit	Remark
1	1.2	1.2	Max		Separate leads for input and output
2	1.1	1.1	Max		Separate leads for input and output
3	1.1	1.2	Max		
4	1.2	1.1	Max		
5	1.1	1.2	Max		LAST TEST+Take cables off+ move equipment+repeat test3
6	1.1	1.2	Max-1		
7	2.1	2.2	Max		
8	3.1	3.2	Max		
9	1.1	1.2	Max	2.1-2.2	
10	1.1	1.2	Max	3.1-3.2	

Repeatability of the Measurements (Team A)



Reference Measurements

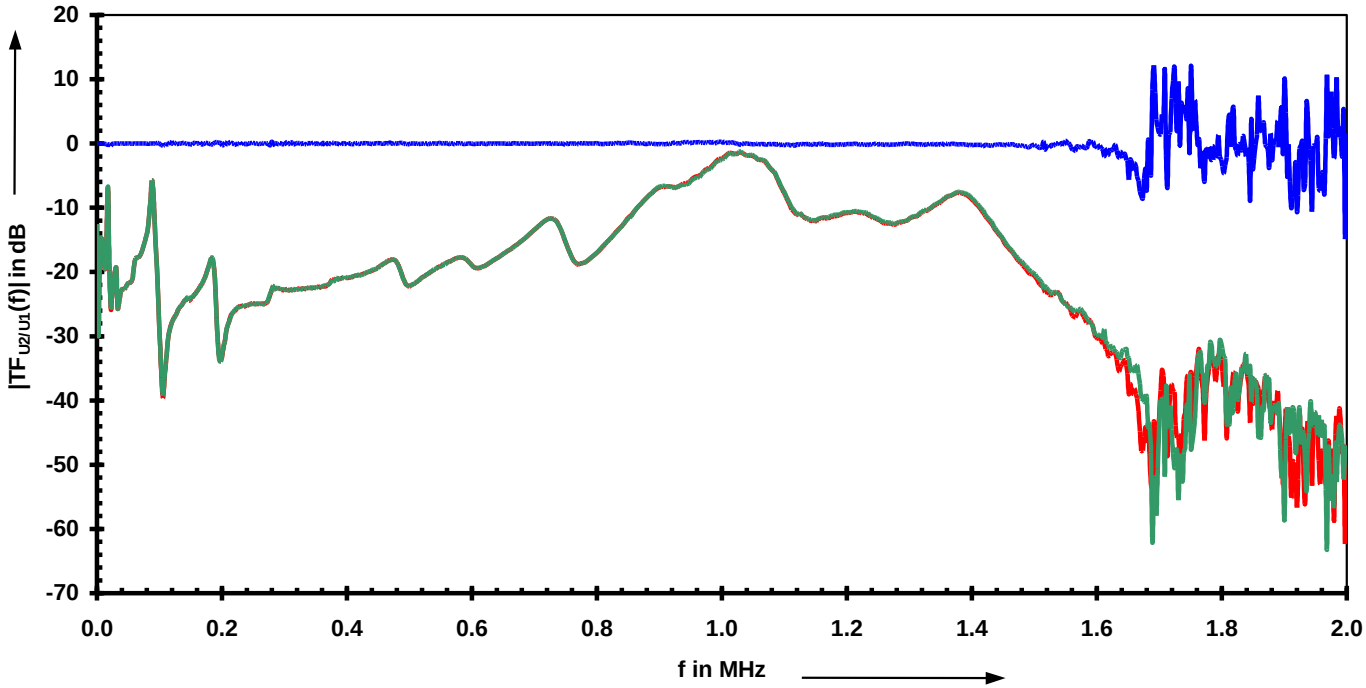
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team A:

- Good accordance up to 0.6 MHz
- for frequencies > 0.6 MHz:
  - different damping of the repeat measurements
  - shifting of the resonance frequencies
  - similar characteristics of the repeat measurements

Repeatability of the Measurements (Team B)



Reference Measurements

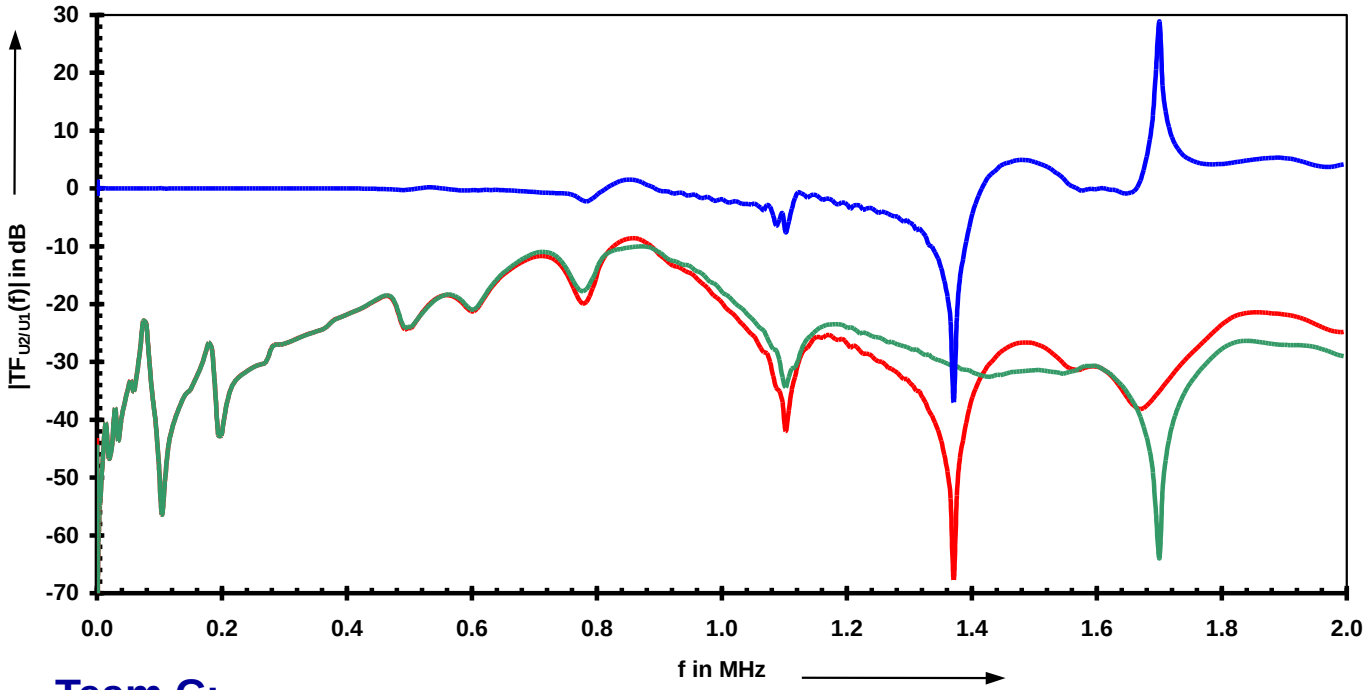
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team B:

- Good accordance up to 1.5 MHz
- for frequencies > 1.5 MHz:
  - noise dominate the signal (for time domain measurements the signal-to-noise-ratio becomes lower with higher frequency
  - no information in this frequency range

Repeatability of the Measurements (Team C)



Reference Measurements

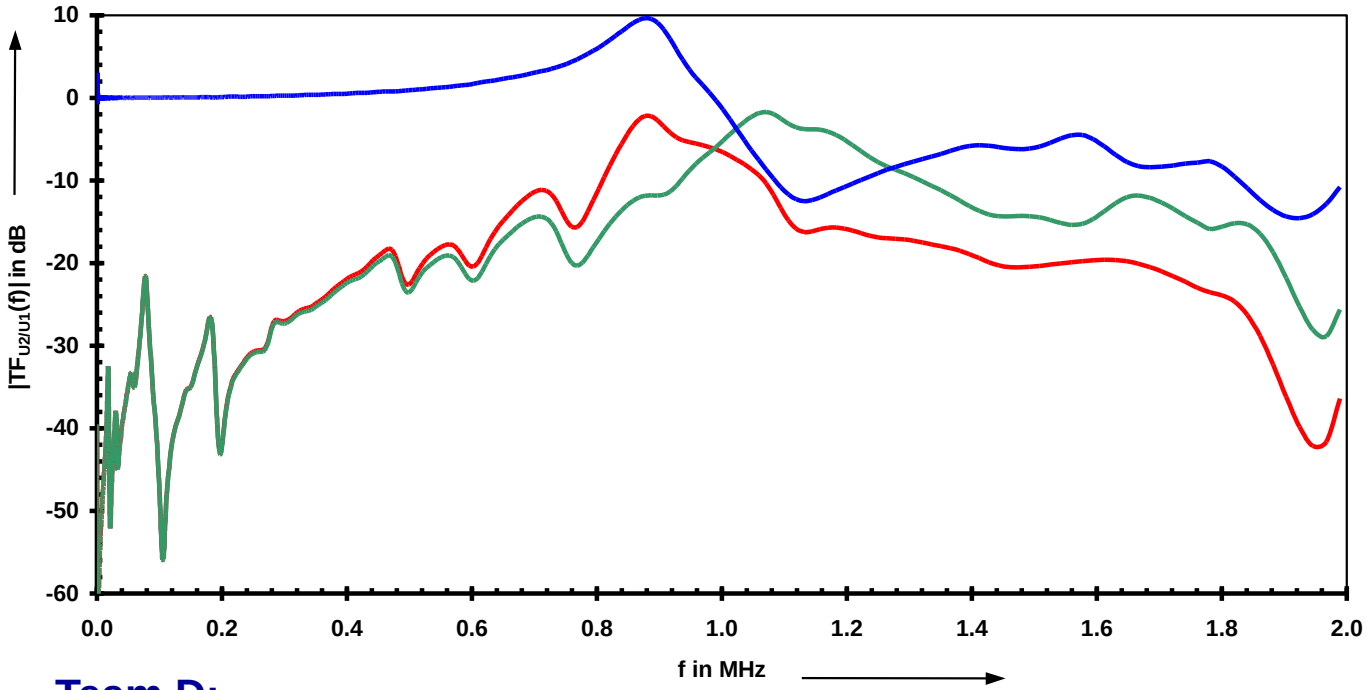
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team C:

- Good accordance up to 0.65 MHz
- for frequencies between 0.65 MHz and 1.3 MHz:
  - another damping of the repeat measurements
- for frequencies between 0.3 MHz and 1.45 MHz:
  - no valley of the repeat measurement
- for frequencies > 1.45 MHz
  - worst identicalness of the repeat measuremnt (shifting of the valley and another damping)

Repeatability of the Measurements (Team D)



Reference Measurements

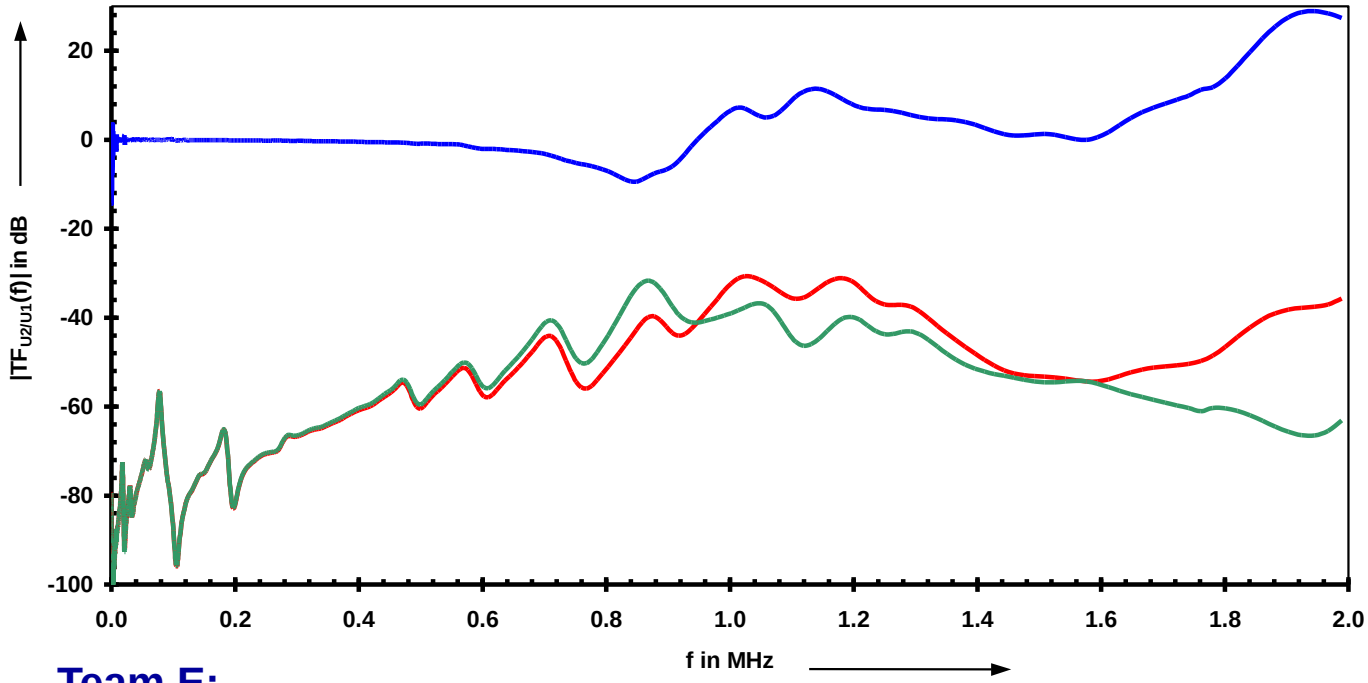
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team D:

- Good accordance up to 0.3 MHz
- for frequencies between 0.3 MHz and 0.9 MHz:
  - another damping of the repeat measurements
- for frequencies between 0.9 MHz and 1.1 MHz:
  - another value of the resonance frequency of the repeat measurements on 0.9 MHz
  - additional resonance frequency on 1.1 MHz
- for frequencies > 1.1 MHz
  - similar characteristics of the repeat measurements with another damping

Repeatability of the Measurements (Team E)



Reference Measurements

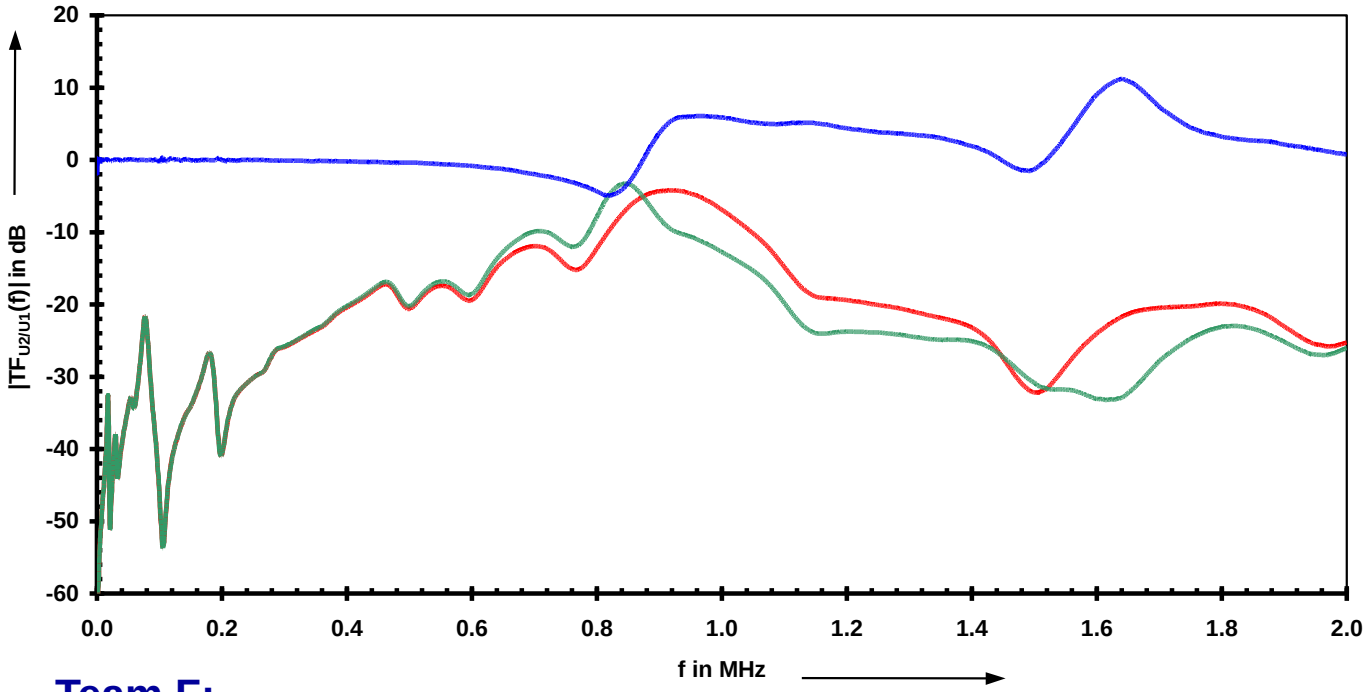
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team E:

- Good accordance up to 0.5 MHz
- for frequencies between 0.5 MHz and 0.9 MHz:
  - another damping of the repeat measurements
- for frequencies between 0.9 MHz and 1.4 MHz:
  - shifting of the resonance frequencies
  - similar characteristics of the repeat measurements
- for frequencies > 1.4 MHz:
  - no accordance

Repeatability of the Measurements (Team F)



Reference Measurements

Repeat Measurements

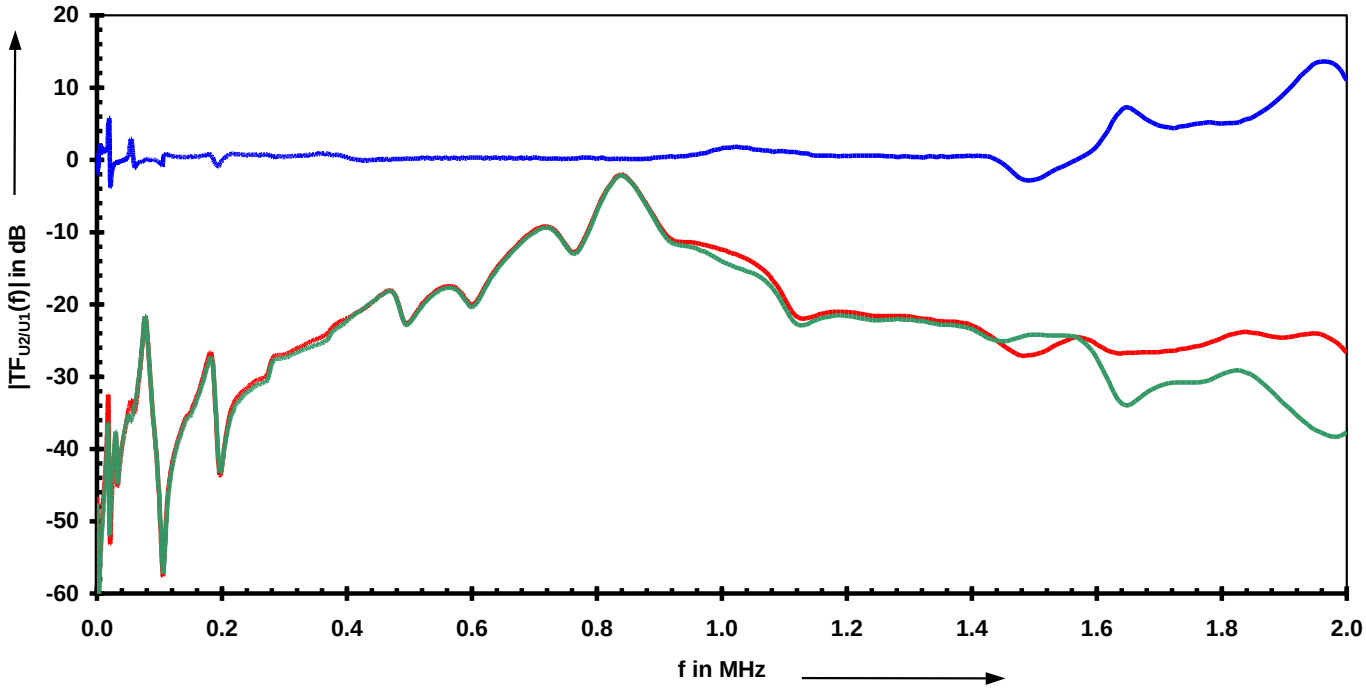
Difference between Reference- and Repeat-Measurements

Team F:

- Good accordance up to 0.5 MHz
- for frequencies between 0.5 MHz and 0.8 MHz:
  - another damping of the repeat measurements
- for frequencies > 0.8 MHz:
  - shifting of the resonance frequncy on 0.9 MHz
  - shifting of the valley on 1.5 MHz
  - additional valley on 1.65 MHz

  $\Rightarrow$ no accordance

Repeatability of the Measurements (Team G)



Reference Measurements

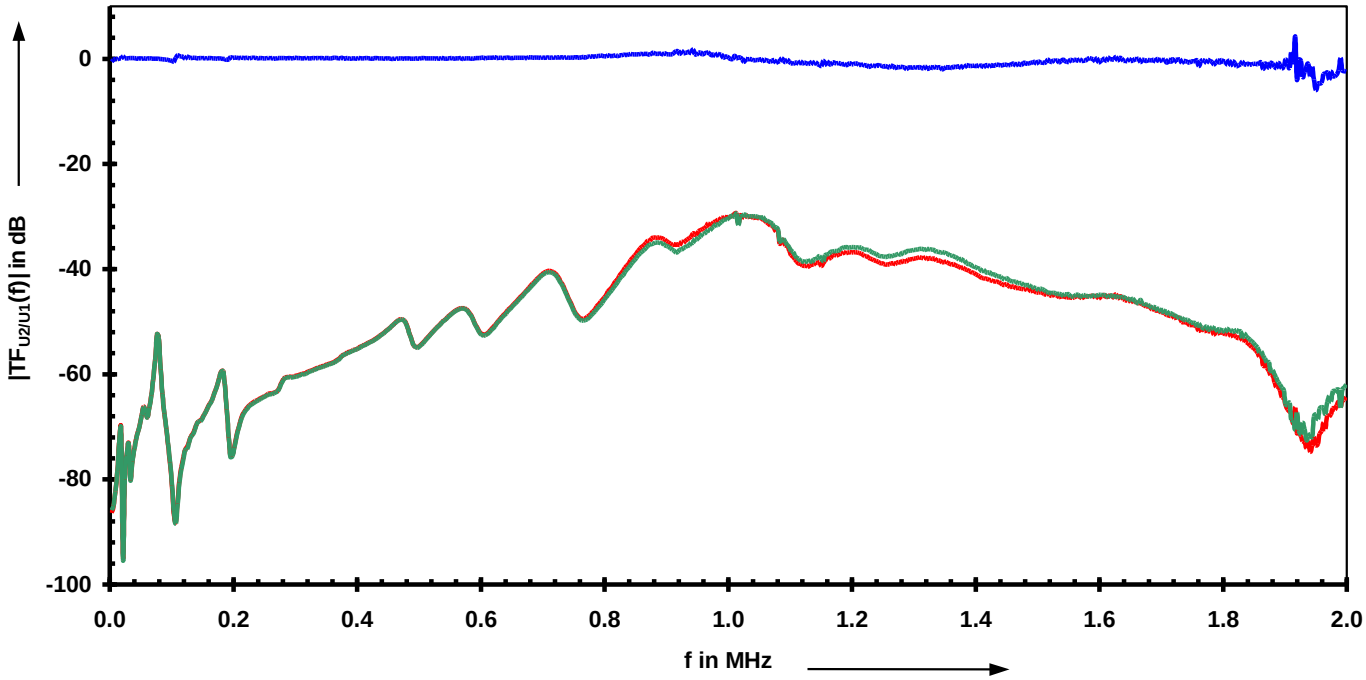
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team G:

- Good accordance up to 0.9 MHz
- for frequencies between 0.9 MHz and 1.4 MHz:
  - another damping of the repeat measurements
- for frequencies > 1.4 MHz:
  - no accordance of the measurements

Repeatability of the Measurements (Team H)



Reference Measurements

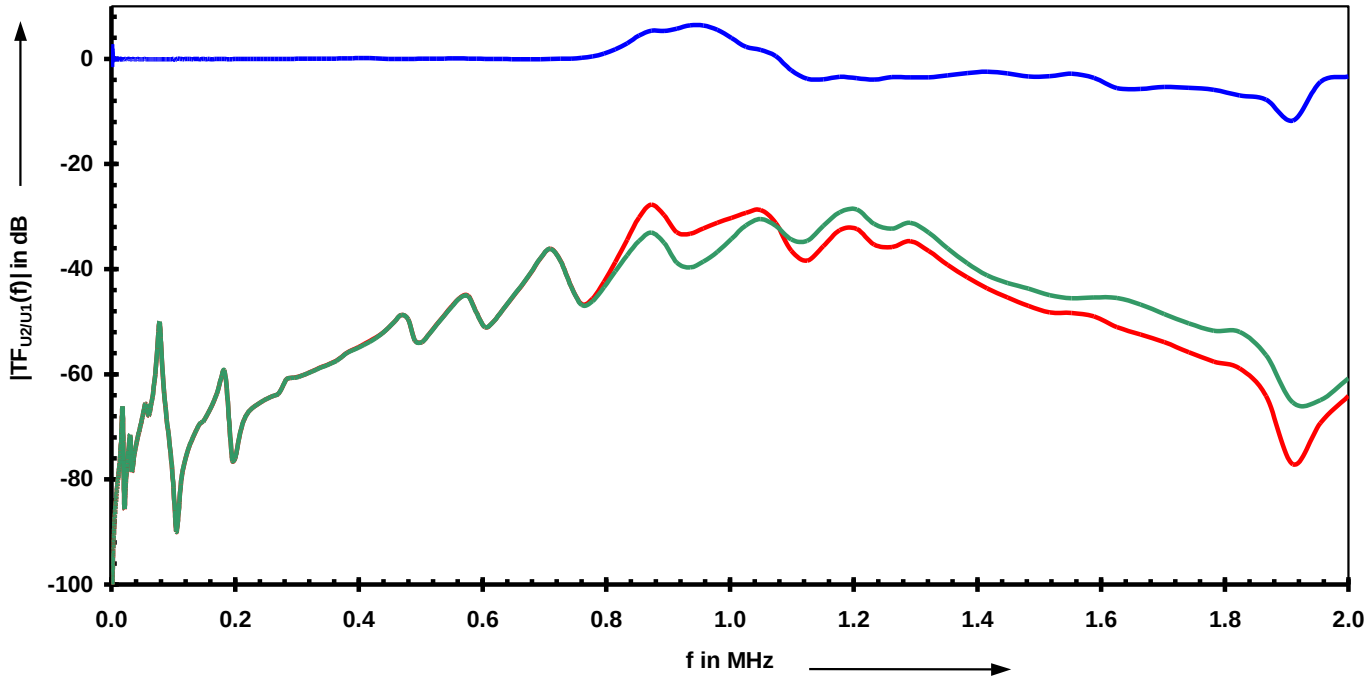
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team H:

- Good accordance up to 0.9 MHz
- for frequencies > 0.9 MHz:
  - minimal other damping of the repeat measurements
  ⇒ same characteristics of the repeat measurements

Repeatability of the Measurements (Team I)



Reference Measurements

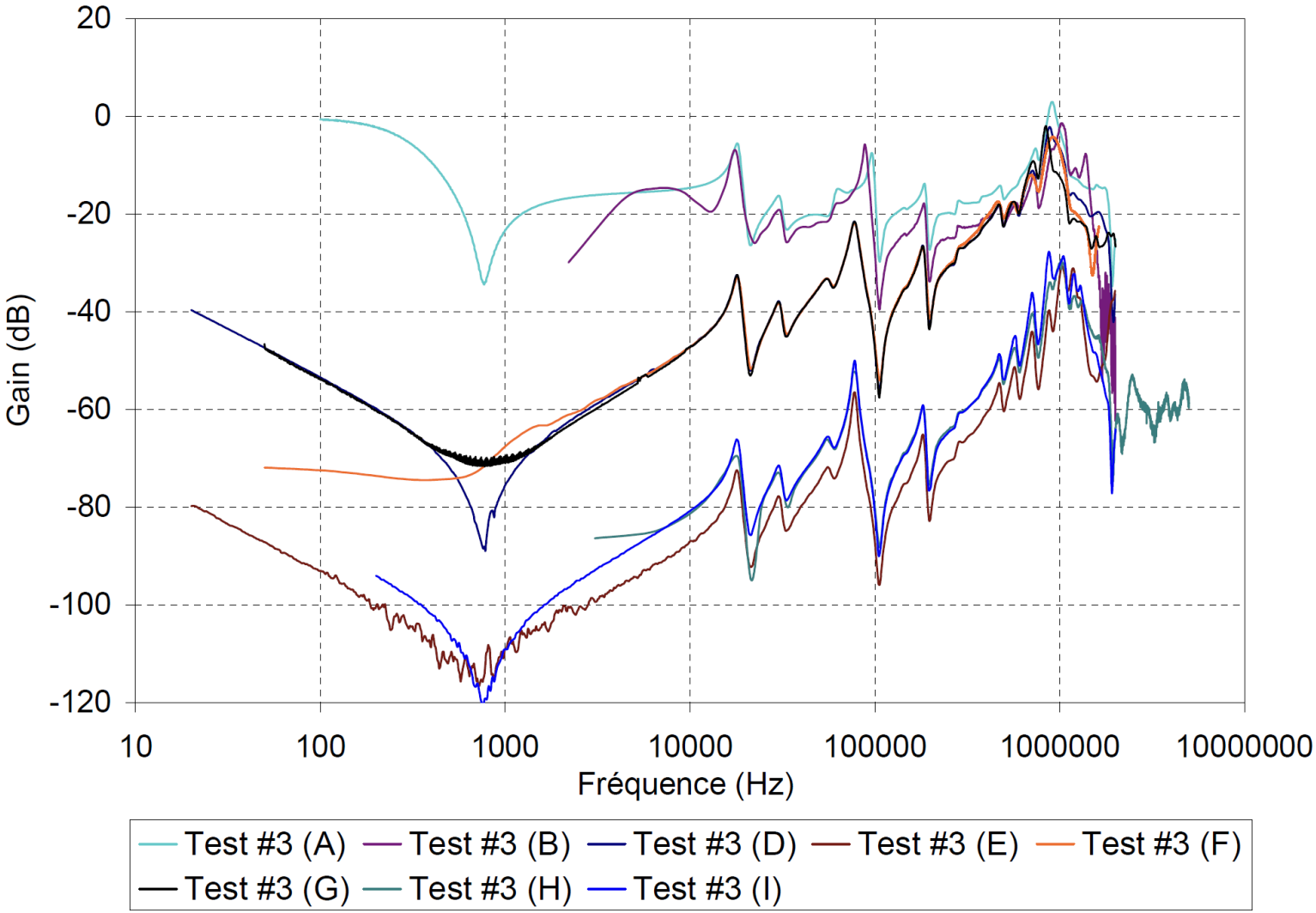
Repeat Measurements

Difference between Reference- and Repeat-Measurements

Team I:

- Good accordance up to 0.75 MHz
- for frequencies > 0.75 MHz:
  - another damping of the repeat measurements
  - similar characteristics of the repeat measurements

Evaluation of Repeatability



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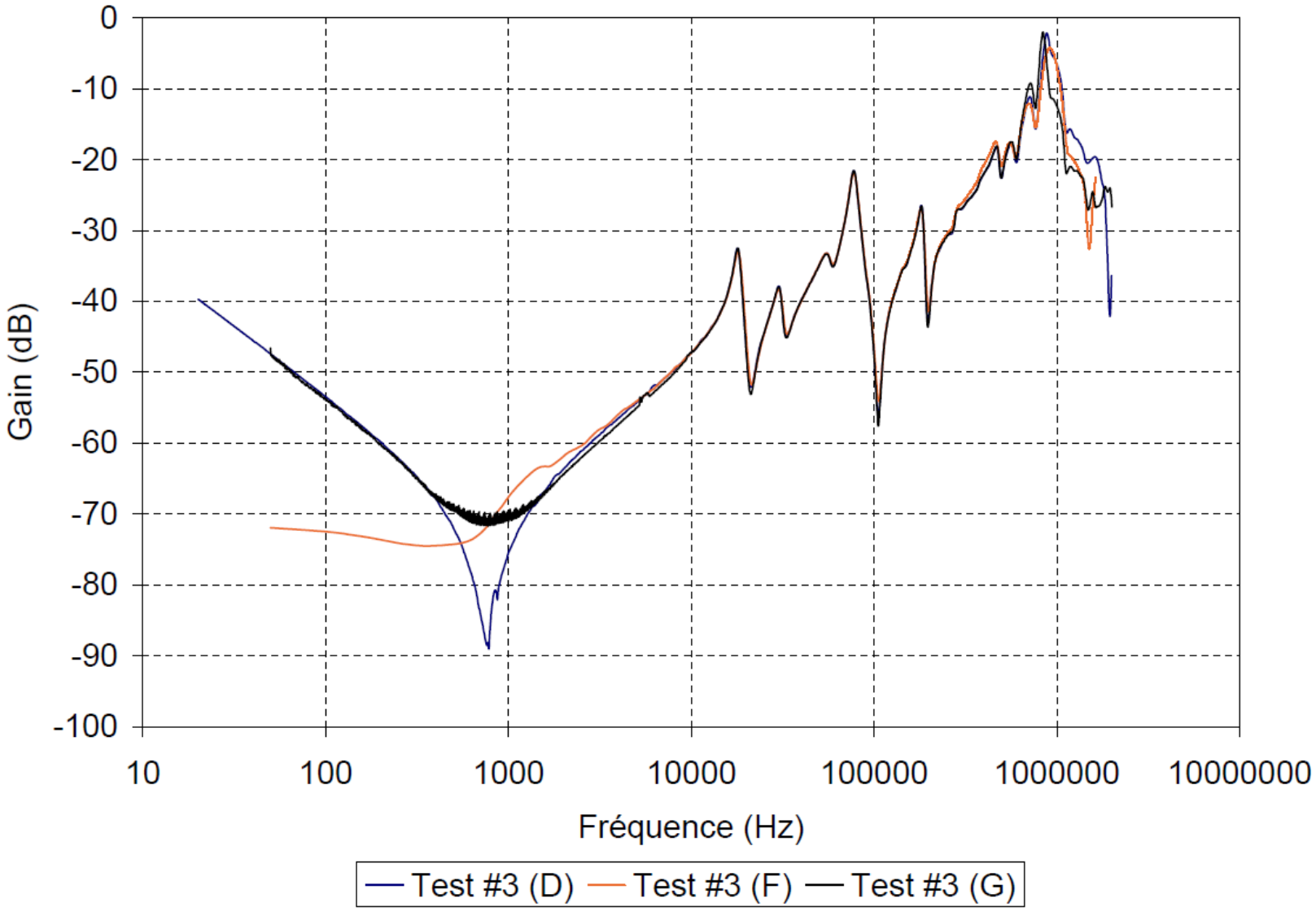
Evaluation of Repeatability



Evaluation of Repeatability

		Up to 1 MHz			Up to 2 MHz		
	Accor-dance up to [kHz]	highest variance (dB)	exceed of 1 dB boundary	Area between reference and repeat measurement curve (dBMHz)	highest variance (dB)	exceed of 1 dB boundary	Area between reference and repeat measurement curve (dBMHz)
Siemens (A)	600	+3.95 -3.49	X	5.95	+3.95 -5.59	X	8.06
Univ. Stuttgart (B)	1500	+0.29 -0.33		0.06	+12.17 -14.87	X	1.61
ESBI (C)	650	+1.54 -2.22	X	0.43	+28.88 -36.99	X	5.21
Doble (D)	300	+9.65 -0.76	X	2.15	+9.65 -14.56	X	10.68
Kinectrics (E)	500	+5.57 -14.24	X	2.21	28.93 -14.24	X	11.62
Starlogic (F)	500	+6.09 -4.97	X	1.44	+11.22 -4.97	X	5.5
B&C (G)	900	+5.8 -3.7	X	3.28	+13.6 -3.7	X	6.74
Phenix (H)	900	+1.78 -0.54	X	0.31	+4.23 -5.94	X	1.29
SINTEF (I)	750	+6.38 -1.52	X	1.02	+6.38 -11.73	X	5.34

Conclusion

- **Good repeatability is achieved by all teams up to 300 kHz**
- **50% of the teams achieved good repeatability above 700 kHz**
- **The changes of the TF is in the range of effects of winding faults**
- **Repeatability is not sufficient to detect winding faults although measurements were done at same place and time by same person**
- **The measuring set-up (cable, grounding concept, connection to the terminals, etc) of each team must be improved**