TeaM CABLES

European Tools and Methodologies for an efficient ageing management of nuclear power plant Cables

Using Non-destructive THz-waves to characterise aged polymers

Polymers in Nuclear application, 17th march 2023, Ringhals/online

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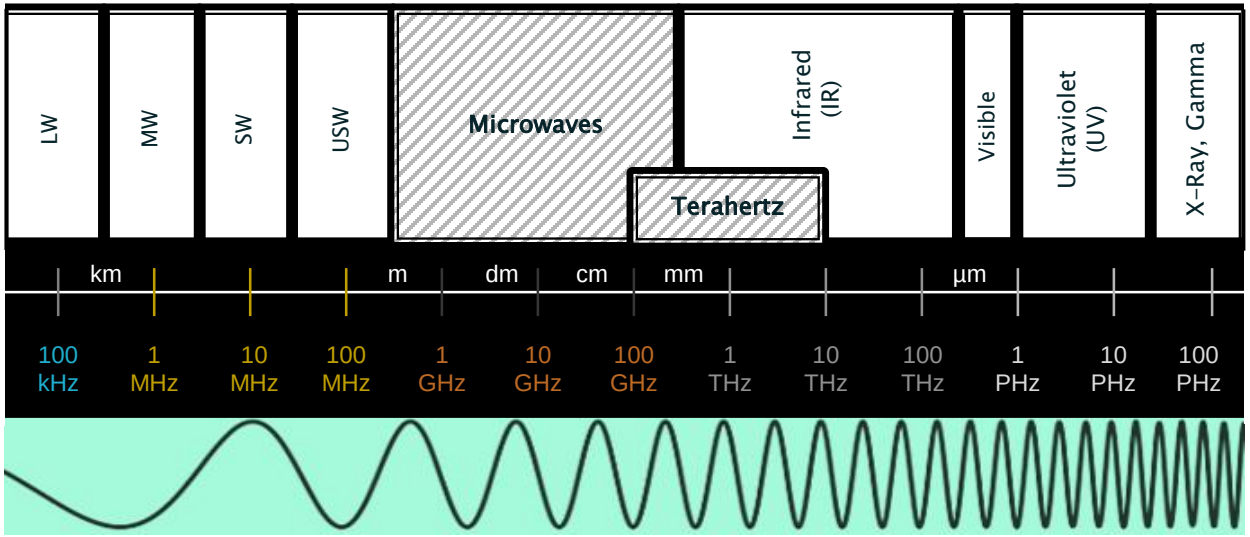
Basics: Electromagnetic spectrum

- Non-ionising (low energy)
- Penetrates many non-polar dielectric and organic materials

→ Materials can be distinguished in THz-frequency range:

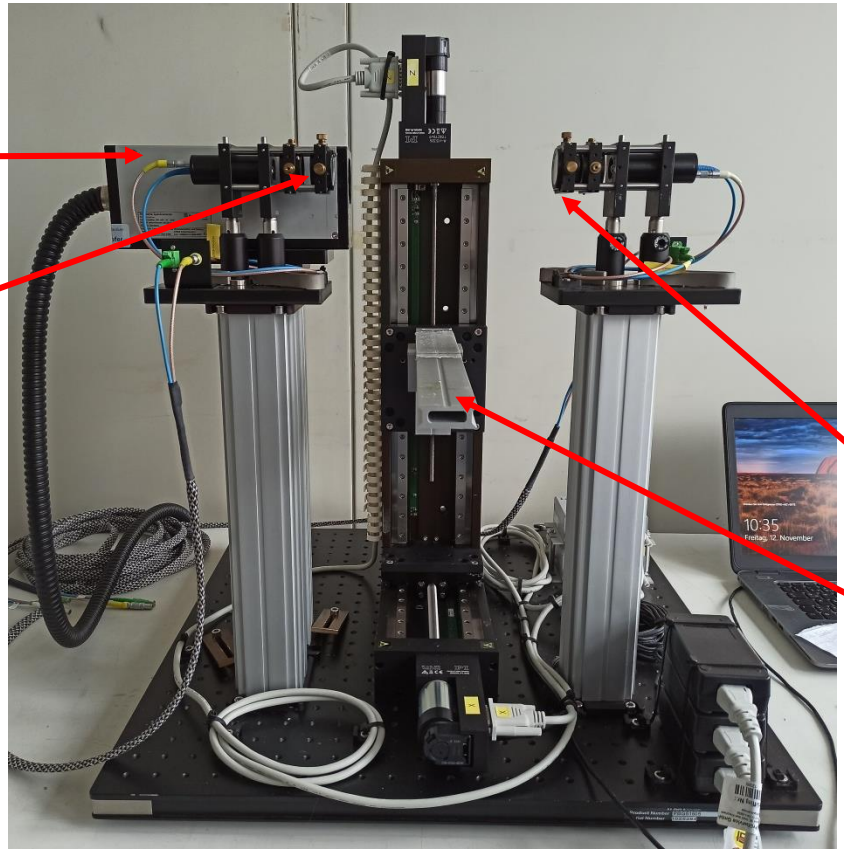
- Metals: total reflectors
- Water: total absorbants
- Polymers: more or less transparent



Basics: THz time-domain spectrometer

Reflection
– Emitter +
Detector

Transmission
– Emitter

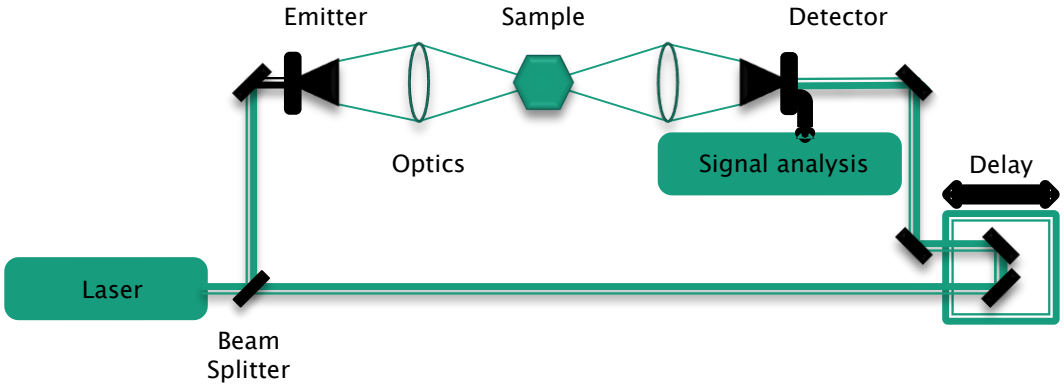


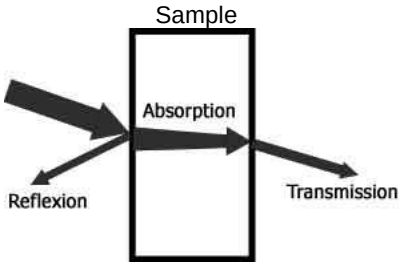
Transmission –
Detector

Sample manipulator

Signal generator:
Femtosecond-Laser
Frequency range: 0.3 – 3 THz

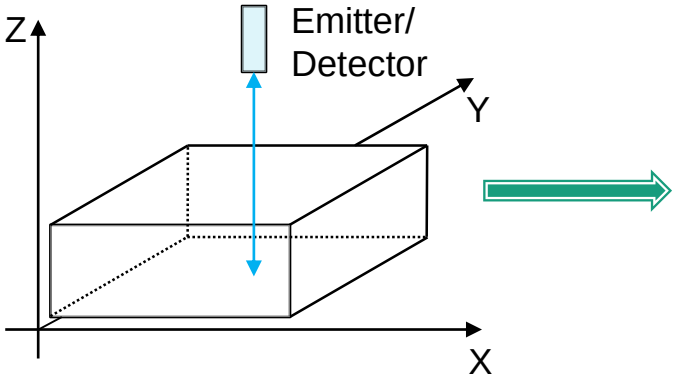
Basics: Measurement process

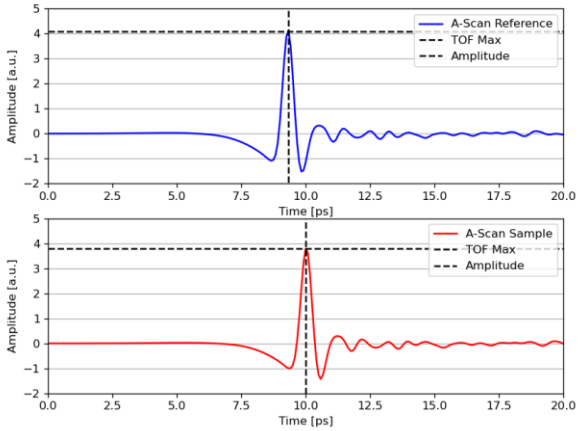




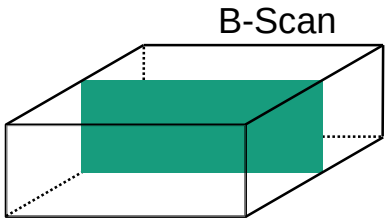
In addition:
Refraction
Scattering
Diffraction
Polarisation

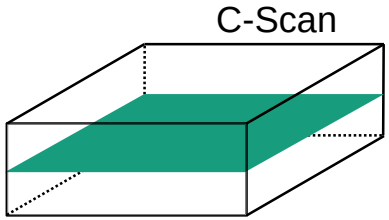
Basics: Measurement process

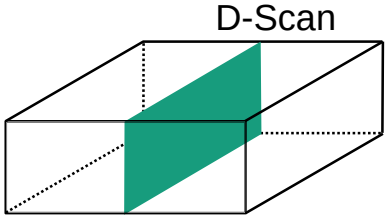




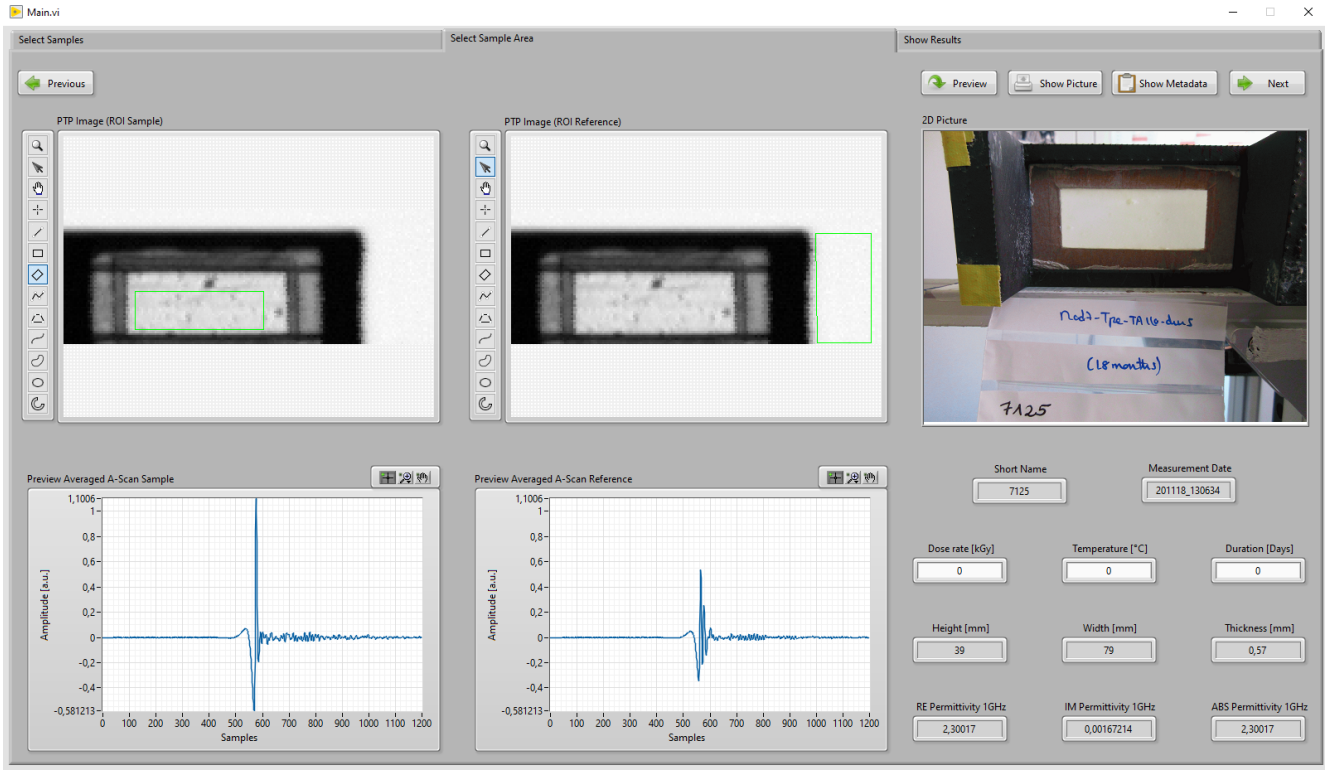
- Time resolution: 0.0833 ps
- Lateral resolution: 1 mm
- 1201 points of depth information per measurement point







Basics: Example for a measurement

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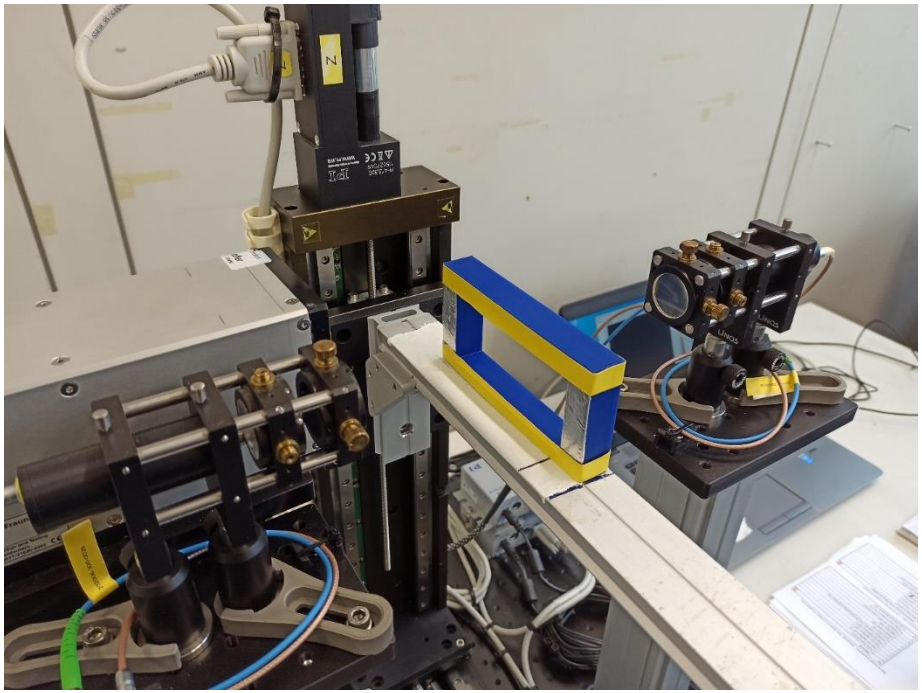
Project: Measurements

- Measurements done for 576 specimens
- Specimens devided into several groups:
  - 7 material modifications regarding additives
  - 4 geometric forms (tapes, sheets, twisted-pair, coaxial cables)
  - 7 ageing types (radiation, thermal, combined, low, high)
  - 6 ageing steps (unaged and 5 withdrawals)
- About 60 gigabytes of measurement data

Project: Measurements in transmission mode – Tapes/Sheets

- For measurements in transmission mode, the samples (tapes and sheets) need to be accessible from both sides
- Due to reflection on metal parts of the cables, they cannot be measured in transmission
- But: best way to gather all information for modelling in preparation for reflection mode measurements

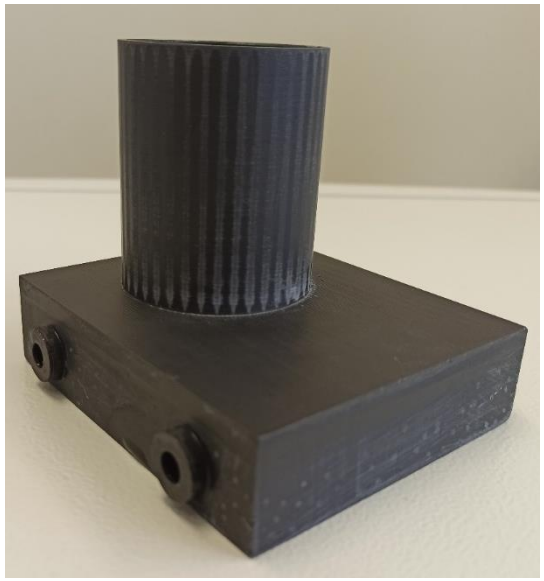
Project: Measurements on tapes/sheets

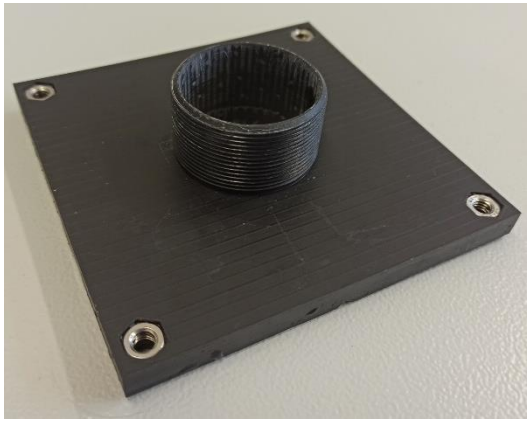


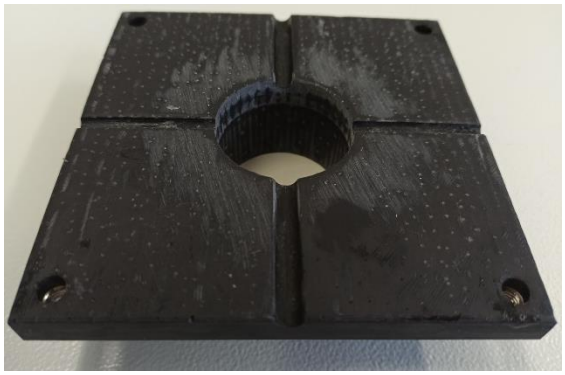
Project: Measurements on cables

- Each sample needs a good reference, e.g. a metal plate
- Distance of the probe to the specimen needs to stay constant during measurement
- Insulation on cables needs to be removed, so materials in TP and coax-cables can be analysed

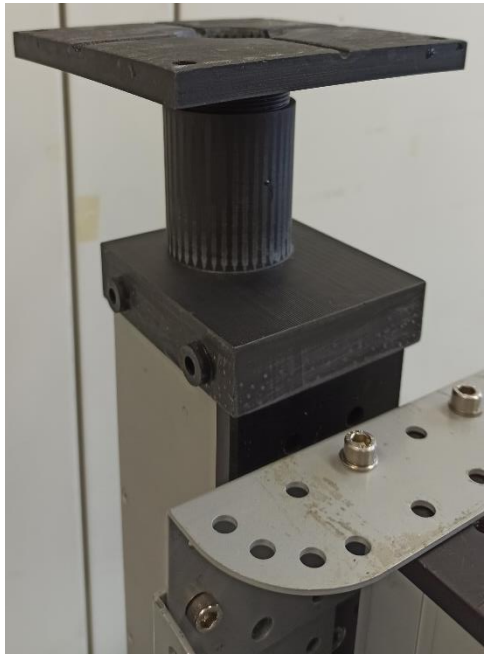
Project: Measurements on cables

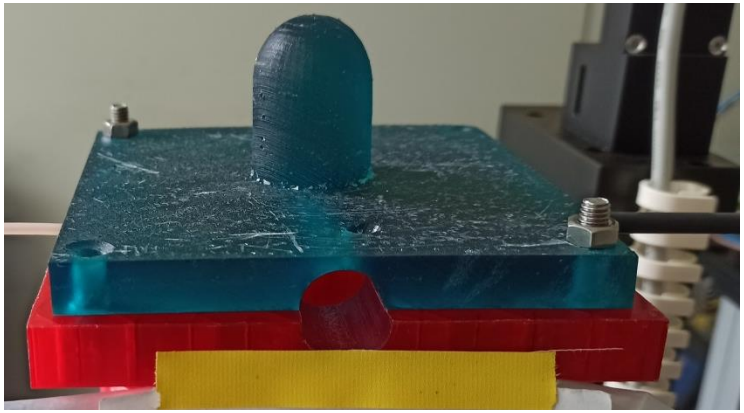






Project: Measurements in reflection mode – Cables





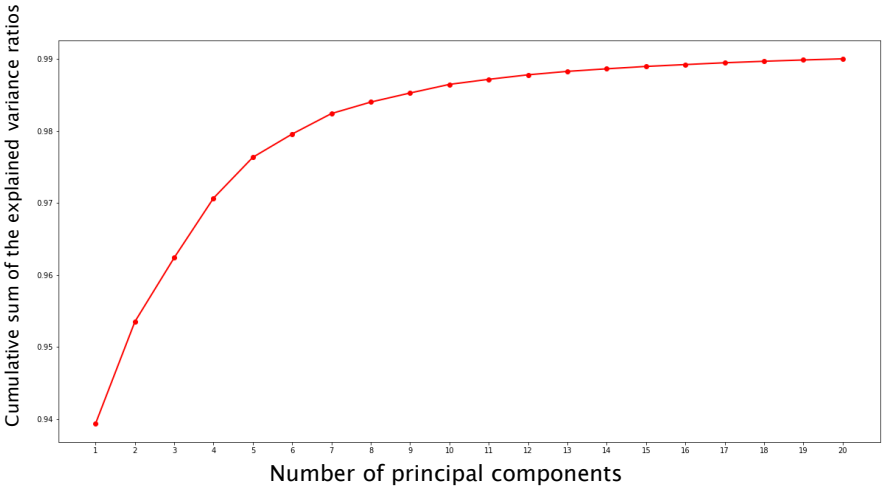
Data: Feature extraction

Each of the1201 measurements per scanned measurement point is made a „feature“

	name	number	material	form	ageing	withdrawal	longName	width_mm	height_mm	thickness_mm	...	ascan_1194	ascan_1195	ascan_1196	ascan_1197	ascan_1198	ascan_1199	ascan_1200	phenol	thioether	ath
0	1100	0	1	1	0	0	Mod1-Tpe-UnA-0-NoAS-THz-IZF	80.0	35.0	0.550	...	0.272735	0.271507	0.270706	0.271027	0.272201	0.273536	0.274568	False	False	False
1	1100	1	1	1	0	0	Mod1-Tpe-UnA-0-NoAS-THz-IZF	80.0	35.0	0.550	...	0.272806	0.271489	0.271062	0.271578	0.272379	0.273874	0.274959	False	False	False
2	1100	2	1	1	0	0	Mod1-Tpe-UnA-0-NoAS-THz-IZF	80.0	35.0	0.550	...	0.273002	0.271596	0.271205	0.271472	0.272717	0.274550	0.275066	False	False	False
3	1100	3	1	1	0	0	Mod1-Tpe-UnA-0-NoAS-THz-IZF	80.0	35.0	0.550	...	0.273002	0.271596	0.271205	0.271472	0.272717	0.274550	0.275066	False	False	False
4	1100	4	1	1	0	0	Mod1-Tpe-UnA-0-NoAS-THz-IZF	80.0	35.0	0.550	...	0.272717	0.271685	0.271134	0.271881	0.273073	0.274585	0.274781	False	False	False
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
659149	6155	1360	6	1	5	5	Mod6-Tpe-RA(RT)5-0-NoAS-THz-IZF	80.5	39.0	0.525	...	0.316357	0.311983	0.312578	0.315657	0.313698	0.316042	0.317092	False	False	True
659150	6155	1361	6	1	5	5	Mod6-Tpe-RA(RT)5-0-NoAS-THz-IZF	80.5	39.0	0.525	...	0.314433	0.312333	0.312438	0.312158	0.315902	0.312928	0.316777	False	False	True
659151	6155	1362	6	1	5	5	Mod6-Tpe-RA(RT)5-0-NoAS-THz-IZF	80.5	39.0	0.525	...	0.317232	0.313698	0.314363	0.314853	0.312543	0.316182	0.315552	False	False	True
659152	6155	1363	6	1	5	5	Mod6-Tpe-RA(RT)5-0-NoAS-THz-IZF	80.5	39.0	0.525	...	0.315342	0.315587	0.314118	0.316252	0.315063	0.314258	0.318282	False	False	True
659153	6155	1364	6	1	5	5	Mod6-Tpe-RA(RT)5-0-NoAS-THz-IZF	80.5	39.0	0.525	...	0.312018	0.313103	0.312858	0.314328	0.312403	0.313663	0.311143	False	False	True

Data: Feature selection / reduction

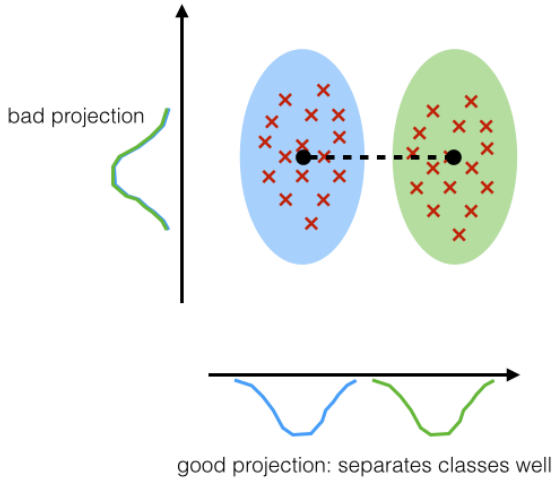
- PCA needs 20 components of 1201 features to explain 99% of the variation

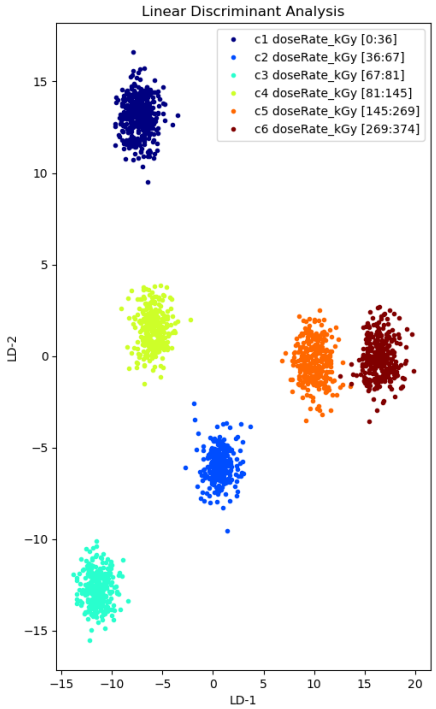


- But PCA cannot separate all kinds of influences
- Thus PCA can only be used as dimension reduction technique

Data: Classification

LDA:
maximizing the component axes for class-separation





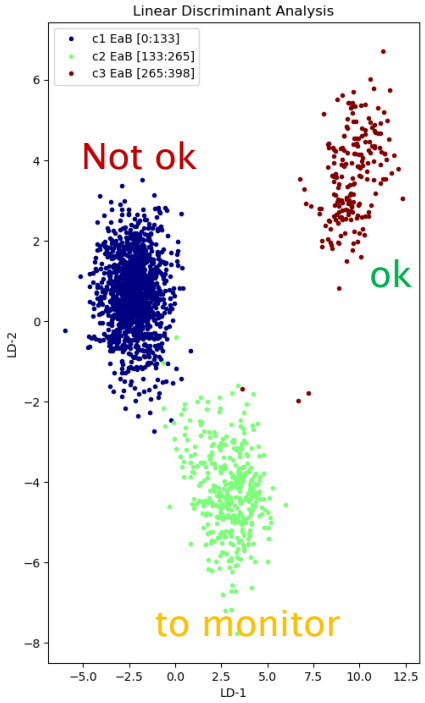
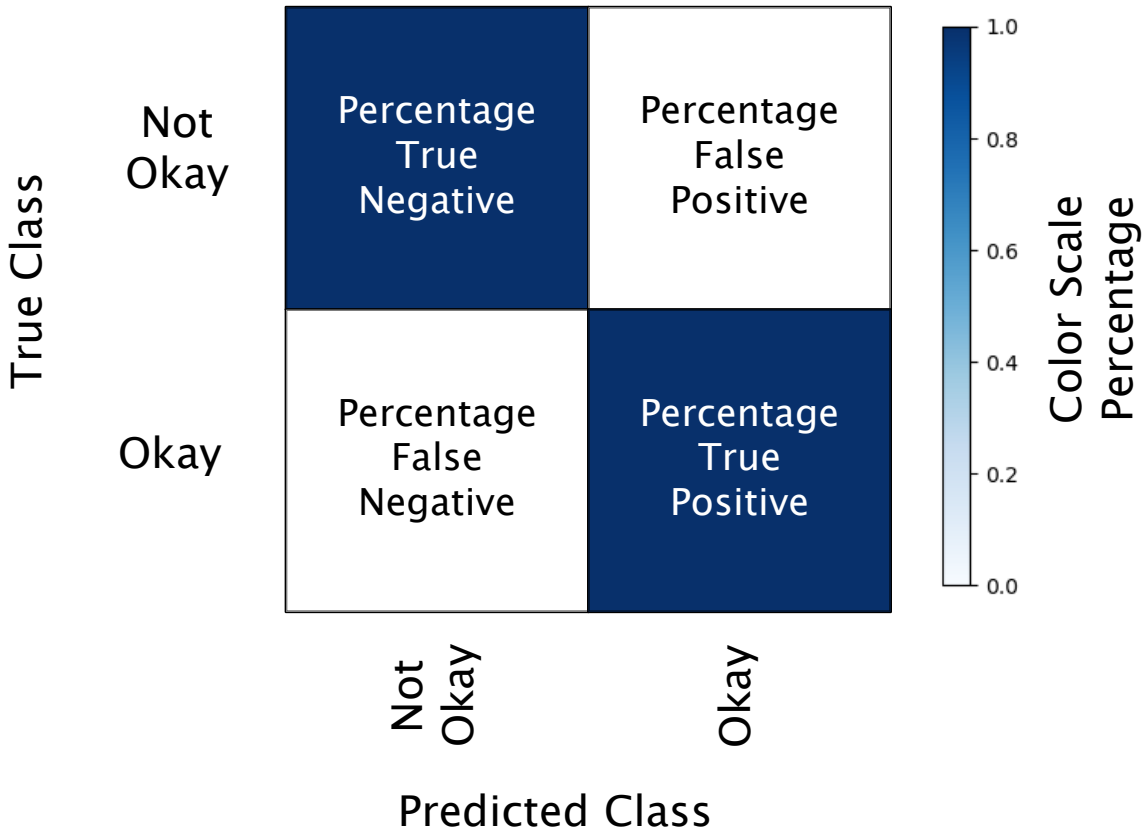


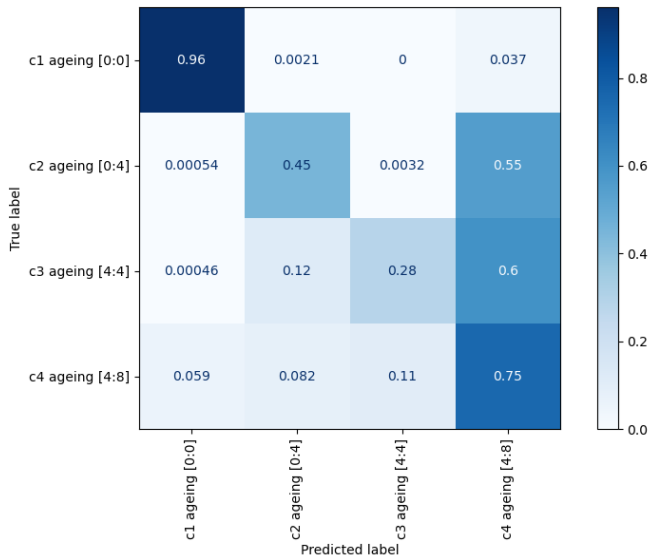
Image Source: https://sebastianraschka.com/images/blog/2014/linear-discriminant-analysis/lda_1.png

Data: Confusion Matrix

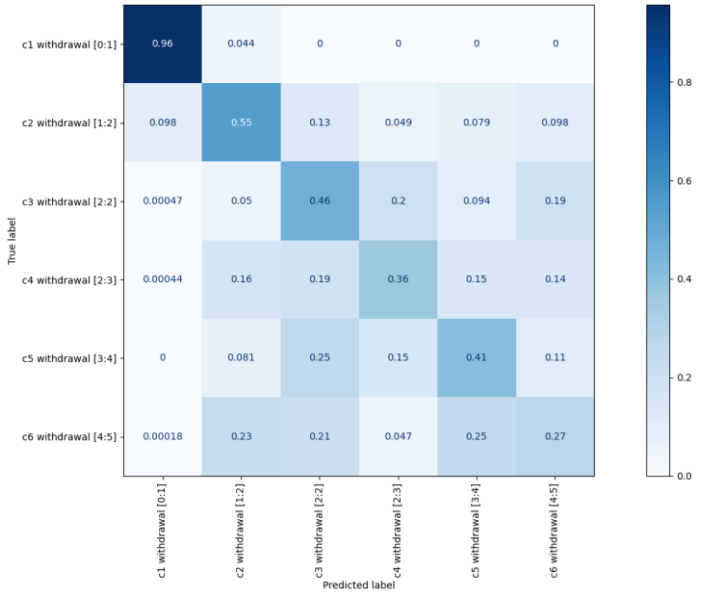


Data: Results of tapes and sheets

- LDA of all tapes and sheets



Target: Ageing, Score: 60.5 %

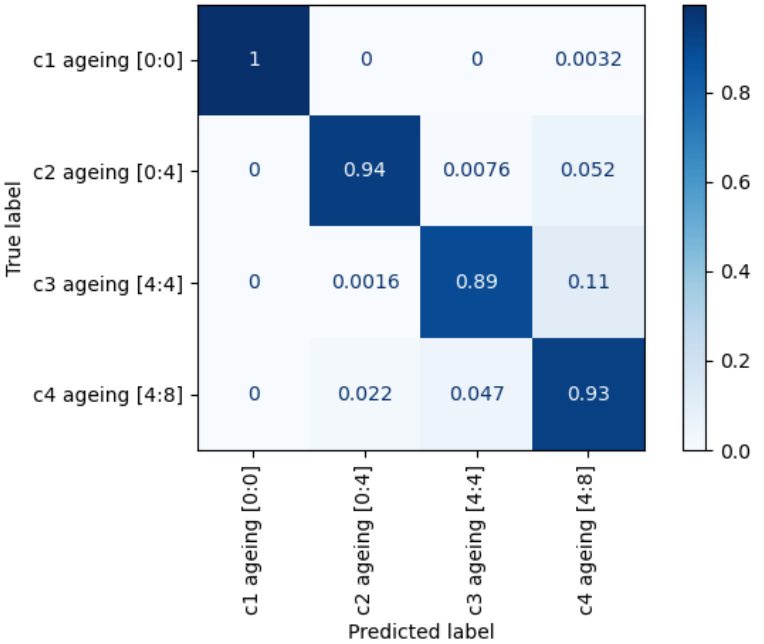


Target: Withdrawal, Score: 46.5 %

Data: Results of tapes and sheets

- LDA regarding ageing method (Material 7)

Class	Ageing Type
C1	unaged
C2	Thermal aged (Temperature 1–3)
C3	Combined aged
C4	Radiation aged (Dose rate 1–3)

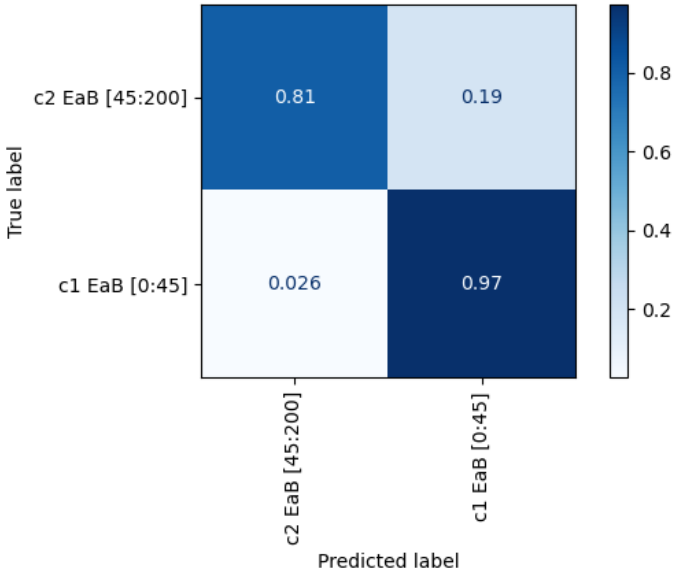


Target: Ageing method, Score: 93.1 %

Data: Results of tapes and sheets

- LDA regarding Elongation at Break (Material 7, Tape)

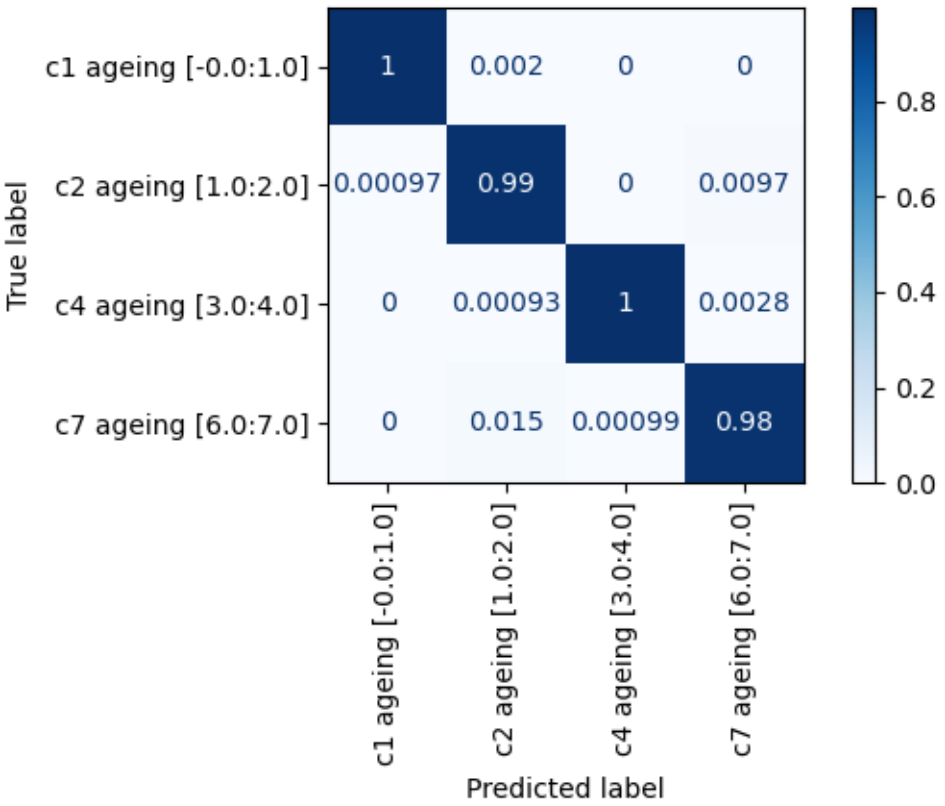
Class	EaB
C1	0–45 %
C2	45–200 %



Target: EaB, Score: 93.8 %

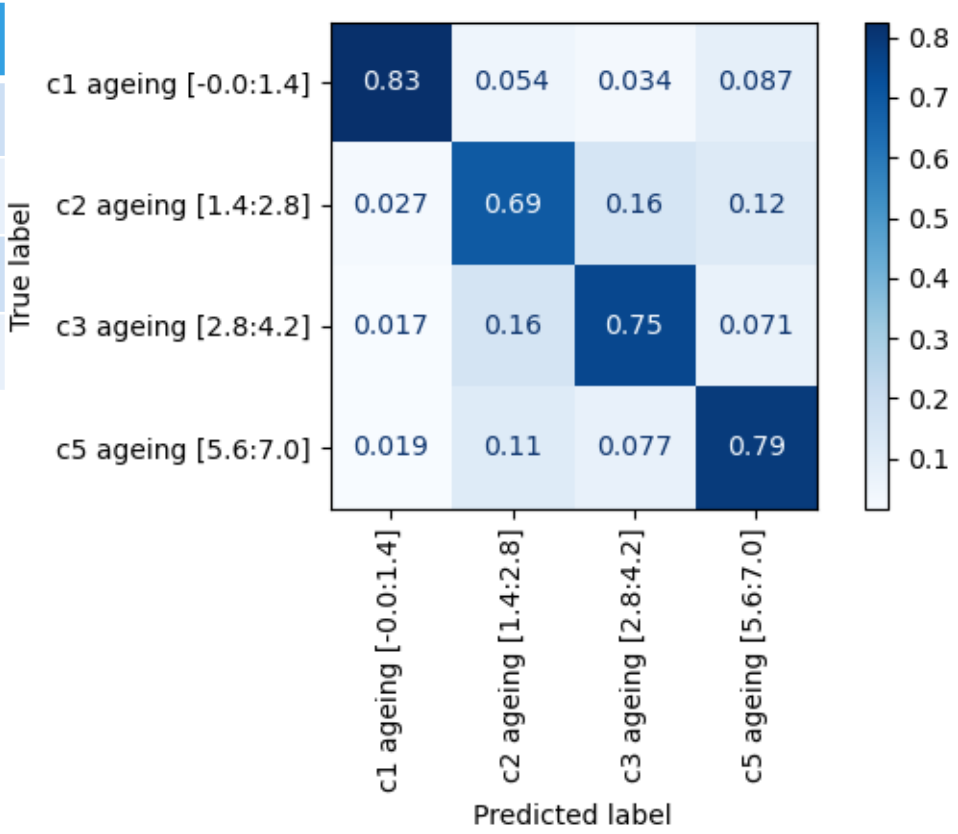
Data: Results Coax – Ageing Type

Class	Ageing Type
C1	unaged
C2	Thermal aged (Temperature 1-3)
C4	Combined aged
C7	Radiation aged (Dose rate 1-3)



Data: Results TP – Ageing Type

Class	Ageing Type
C1	unaged
C2	Thermal aged (Temperature 1-3)
C3	Combined aged
C5	Radiation aged (Dose rate 1-3)



Data: Results EaB < 50%

Coaxial cable	Twisted Pair cable
8400	9400
8423	9423
8425	9425
8443	9443
8445	9445
8473	9475
8475	9475

Green column:
mechanical testing data available

→ Careful: not a lot of data for machine learning

Cable type	Averaged prediction score
All	90.04 %
Coaxial	99.8 %
Twisted pair	96.58 %

Conclusion

- Terahertz measurements produce a lot of data
- This amount of data is hard to model with classical methods
- Thus machine learning / multivariate statistic methods were used

- Possibility to differentiate various influences in terahertz data regarding
  - Macroscale data
    - Material modifications
    - Forms
    - Ageing methods
    - Dose rates
    - Temperatures
  - Microscale data
    - Elongation at break
    - Maybe others?

Thank you!

- Andreas Keller, M.Sc.
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