Lecture 1

2022/2023

Microwave Devices and Circuits for Radiocommunications

2022/2023

- 2C/1L, **MDCR**
- **Attendance at minimum 7 sessions (course or laboratory)**
- Lectures- **associate professor Radu Damian**
  - Tuesday 12-14, ~~Online~~, P8
  - E – 50% final grade
  - **problems** + (2p atten. lect.) + (3 tests) + (bonus activity)
    - first test L1: 21-28.02.2023 (t2 and t3 not announced, lecture)
    - 3att.=+0.5p
  - **all materials/equipments authorized**

2022/2023

- Laboratory – **associate professor Radu Damian**
  - Tuesday 08-12, II.13 / (08:10)
  - L – 25% final grade
    - ADS, 4 sessions
    - Attendance + **personal results**
  - P – 25% final grade
    - ADS, 3 sessions (-1? 21.02.2022)
    - personal homework

Materials

- http://rf-opto.etti.tuiasi.ro

Laboratorul de Microunde si Opt

Not secure | rf-opto.etti.tuiasi.ro/microwave_cd.php?chg_lang=0

Main **Courses** Master Staff Research Students Admin

Microwave CD Optical Communications Optoelectronics Internet Antennas Practica Networks Educational software

Microwave Devices and Circuits for Radiocommunications (English)

Course: MDCR (2017-2018)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: EDOS412T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assoc.P. Dr. Radu-Florin Damian, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Examen**

A: 50%, (Test/Colloquium)
B: 25%, (Seminary/Laboratory/Project Activity)
D: 25%, (Homework/Specialty papers)

Grades

Aggregate Results

Attendance

Course
Laboratory

Lists

Bonus-uri acumulate (final)
Studenti care nu pot intra in examen

Materials

Course Slides

MDCR Lecture 1 (pdf, 5.43 MB, en,)
MDCR Lecture 2 (pdf, 3.67 MB, en,)
MDCR Lecture 3 (pdf, 4.76 MB, en,)
MDCR Lecture 4 (pdf, 5.58 MB, en,)

RF-OPTO

English | Romana |

Main Courses Master Staff Rese

Grades Student List **Exams** Photos

Online Exams

In order to participate at online exams you must get ready following

Materials

- RF-OPTO
  - **http://rf-opto.etti.tuiasi.ro**
- **David Pozar, "Microwave Engineering"**, Wiley; 4th edition , 2011
  - 1 exam problem ← Pozar
- Photos
  - sent by ~~email~~/online exam
  - used at lectures/laboratory

Photos

Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Finantare	Buget
Bursa	Fara Bursa

Observatii

Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5244

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Finantare	Buget
Bursa	Bursa de Studii

Observatii

Date:

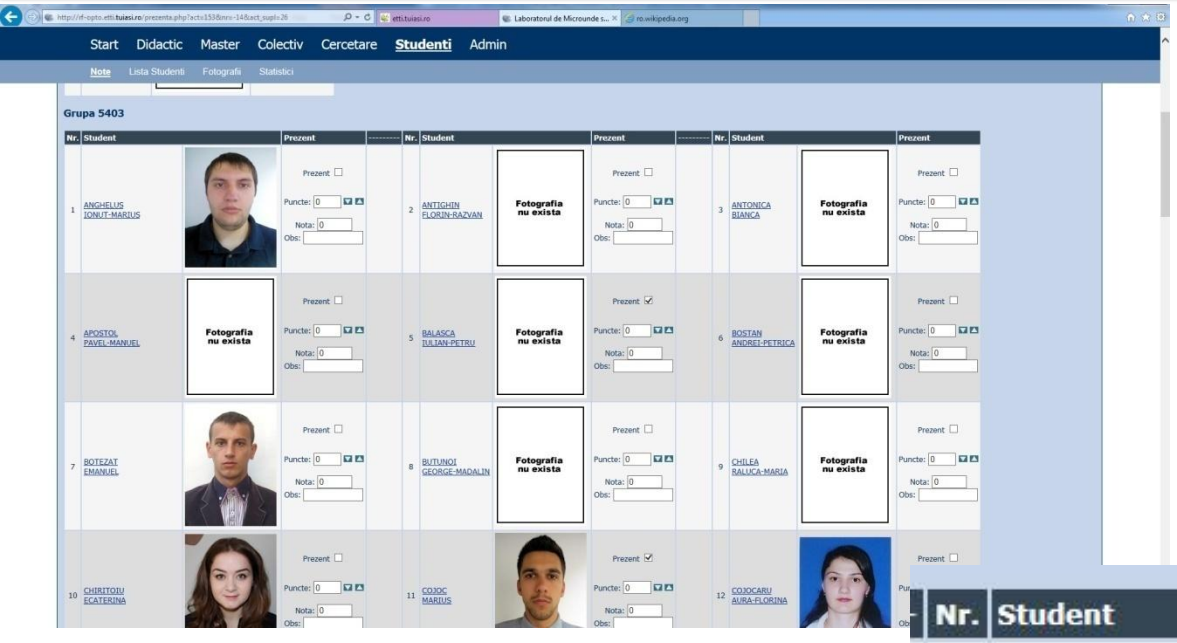
Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

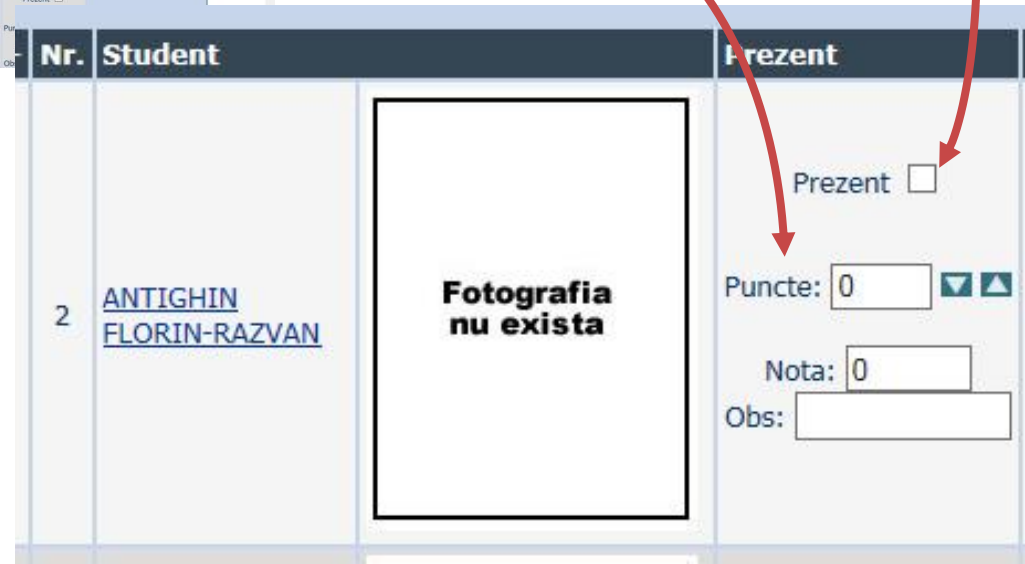
Acceseaza ca acest student

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Credite	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Calculul Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Photos


Start Didactic Master Colectiv Cercetare Studenti Admin
Note Lista Studenti Fotografii Statistici
Grupa 5403
Nr. Student Prezent
1 ANGHELUS IONUT-MARIUS
2 ANTIGHIN FLORIN-RAZVAN
3 ANTONICA BIANCA
4 APOSTOL PAVEL-MANUEL
5 BALASCA IULIAN-PETRU
6 BOSTAN ANDREI-PETRICA
7 BOTEZAT EMANUEL
8 BUTUNOI GEORGE-MADALIN
9 CHILEA RALUCA-MARIA
10 CHIRITOIU ECATERINA
11 COJOC MARIUS
12 COJOCARU AURA-FLORINA
Fotografia nu exista
Prezent
Puncte: 0
Nota: 0
Obs:


Nr.
Student
Prezent
2
ANTIGHIN FLORIN-RAZVAN
Fotografia nu exista
Prezent
Puncte: 0
Nota: 0
Obs:

Access

- ~~Not customized~~

Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

Acceseaza ca acest student

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Nume

Email

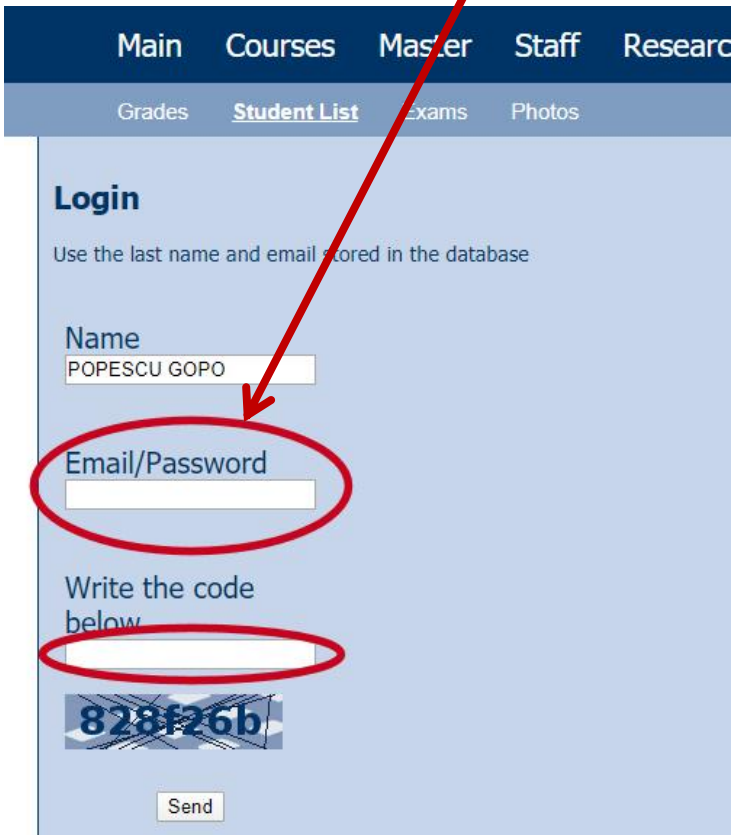
Cod de verificare

344bd9f

Trimite

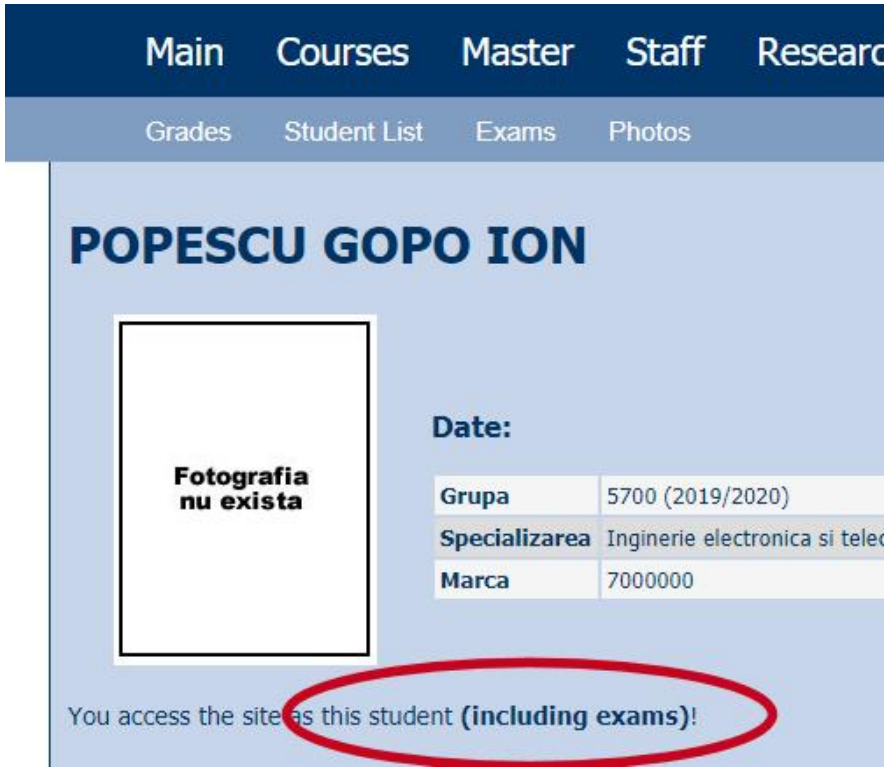
Online

- access to **online exams** requires the **password** received by email



Online

- access email/password



Password

- received by email

Important message from RF-OPTO Inbox ×

Radu-Florin Damian
to me, POPESCU

Romanian > English Translate message

Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentia: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este
Parola: [redacted]

Identificati-va pe server, cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

---

Attention: POPESCU GOPO ION

The password to access the exams on the **rf-opto** server is
Password: [redacted]

Login to the server, with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Reply Reply all Forward

Subject	Correspondents
Important message from RF-OPTO	POPESCU GOPO ION
Validation of MDCR exam from 02/05/2020	[redacted]
[redacted]	[redacted]

From Me <rdamian@etti.tuiasi.ro>
Subject **Important message from RF-OPTO**
To [redacted]
Cc Me <rdamian@etti.tuiasi.ro>

Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentia: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este
Parola: [redacted]

Identificati-va pe server, cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

---

Attention: POPESCU GOPO ION

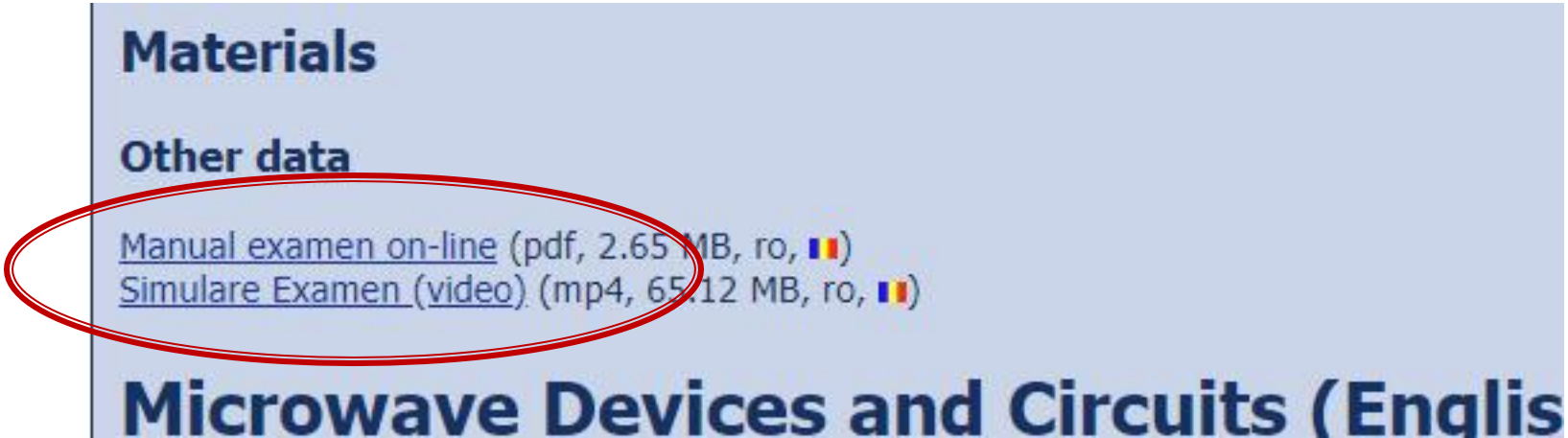
The password to access the exams on the **rf-opto** server is
Password: [redacted]

Login to the server, with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

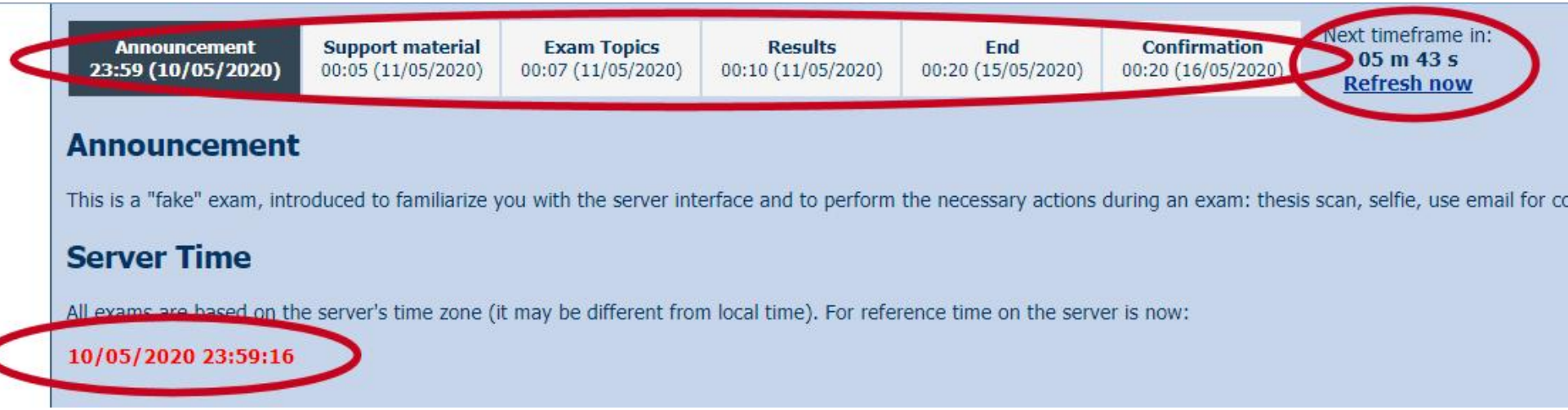
Manual examen online

- The online exam app used for:
  - ~~lectures (attendance)~~
  - laboratory
  - project
  - ~~examinations~~



Examen online

- always against a **timetable**
  - long period (lecture attendance/laboratory results)
  - ~~short period (tests: 15min, exam: 2h)~~

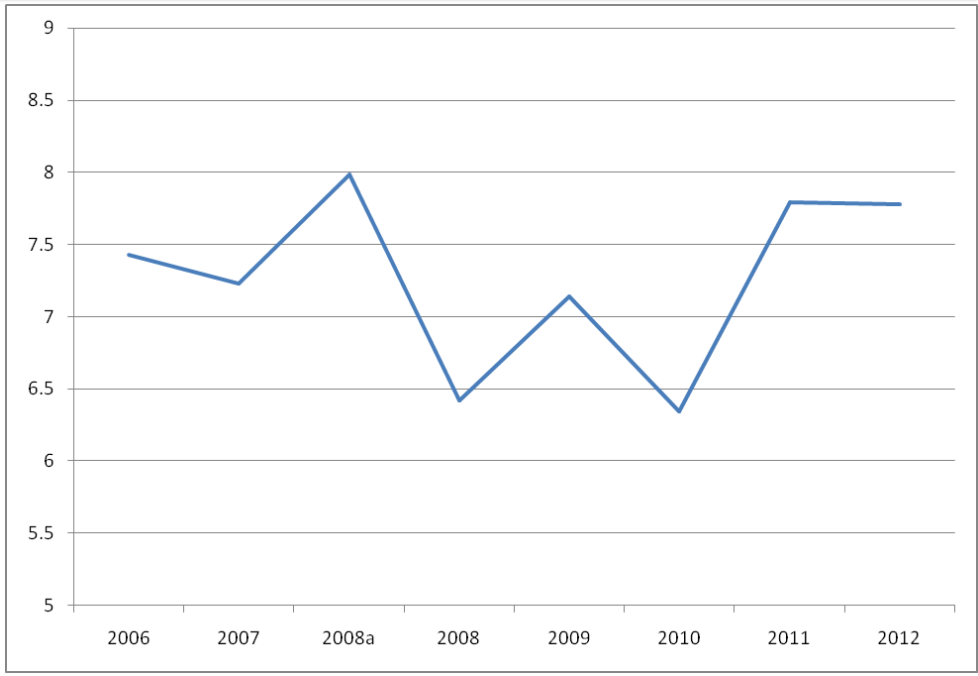


MOTTO (RO)

- “Universitatea nu e pentru mase locul de unde emana cunoasterea, ci un obstacol intre individ si diploma pe care i-a harazit-o destinul”
- “Universitatea fiind ceva care se interpune in mod imoral intre individ si dreptul lui natural de a fi diplomat, individul are obligatia morala sa triumfe asupra universitatii prin orice mijloace”
  - Sursa citat: Internet, user: ”un student batran si plesuv”

Exam

- individual topics
- Grades
  - 2006: 7.43
  - 2007: 7.23
  - 2008: 7.98
  - 2008: 6.42
  - 2009: 7.14
  - 2010: 6.34
  - 2011: 7.79
  - 2012: 7.77



- First time (unannounced)
  - 50% of the students left the exam in the first 10 minutes
  - 50% of those who stayed did not pass
  - overall passing percentage 25%, litigation rate: 0%
- Next examinations (announced)
  - litigation rate : 0%

Exam

Grades

Microwave Devices and Circuits (English)

Course: MDC (2020-2021)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: EDID407
Discipline Type: DID; Required, Domain
Credits: 3
Enrollment Year: 4, **Sem.** 8

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assoc.P. Dr. Radu-Florin Damian, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Colloquium**

A: 50%, (Test/Colloquium)
B: 25%, (Seminary/Laboratory/Project Activity)
D: 25%, (Homework/Specialty papers)

Grades

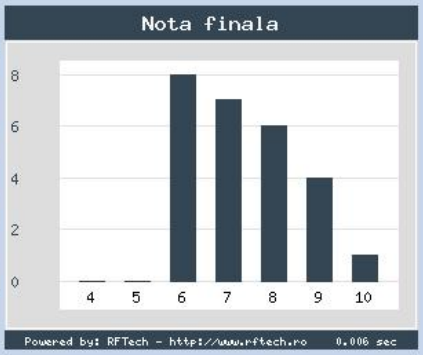
Aggregate Results

Lists

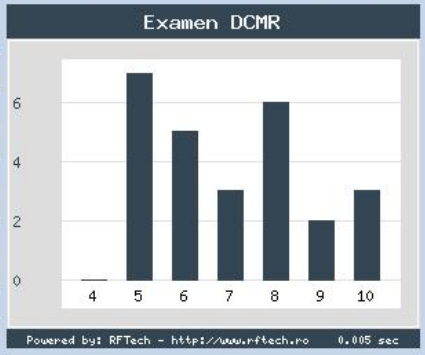
Bonus points (final)

Statistici

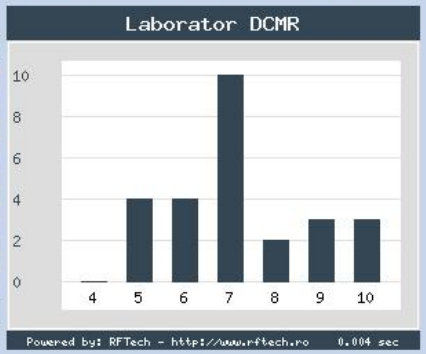
Nota.	Numar
4	0
5	0
6	8
7	7
8	6
9	4
10	1
TOTAL	26



Exam.	Numar
4	0
5	7
6	5
7	3
8	6
9	2
10	3
TOTAL	26

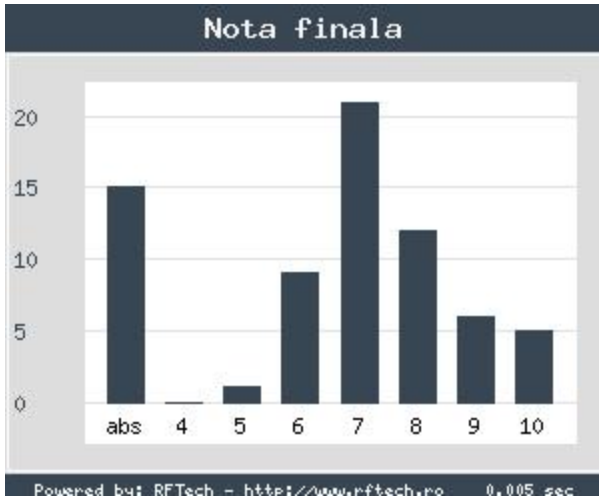


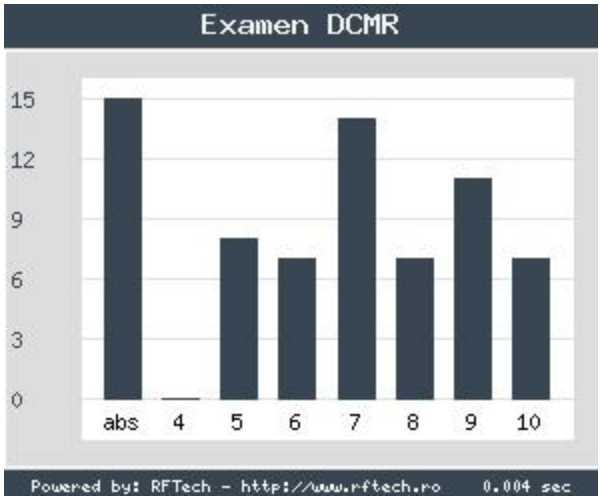
Labo.	Numar
4	0
5	4
6	4
7	10
8	2
9	3
10	3
TOTAL	26

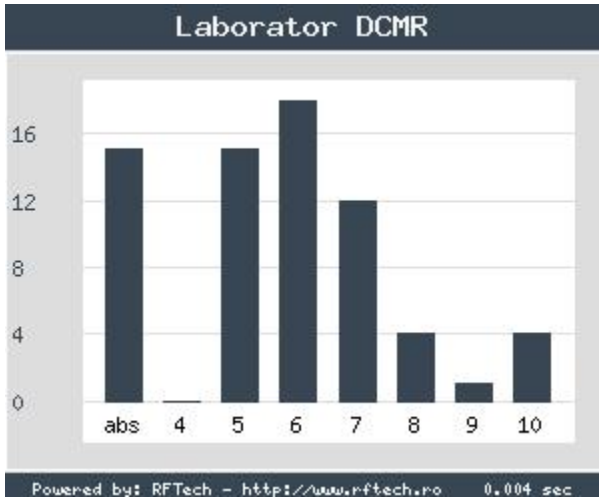


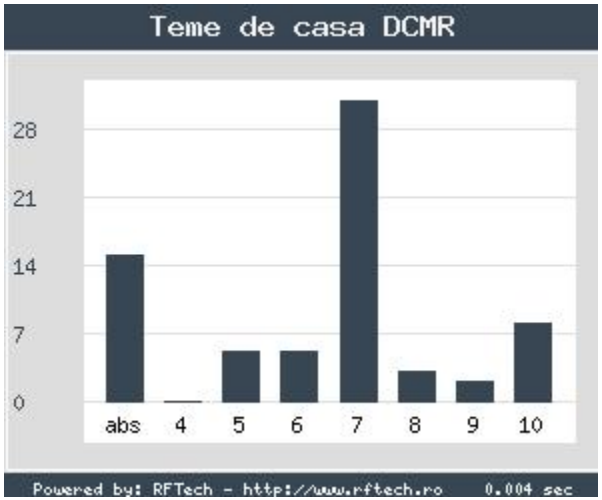
Grades

- 2019/2020



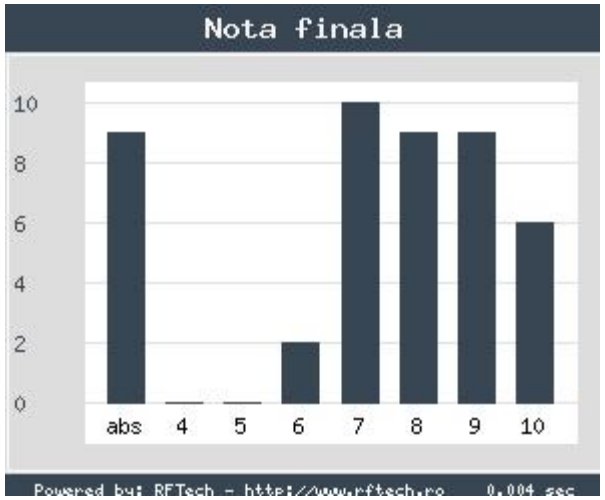


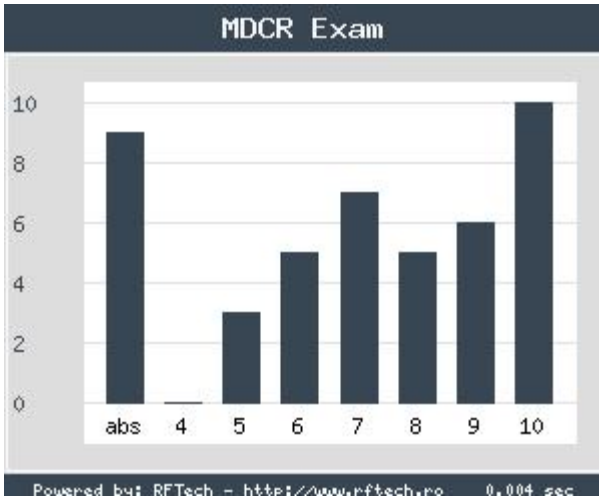


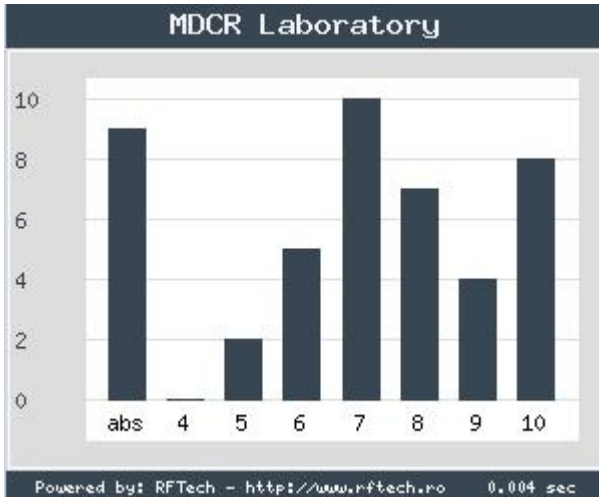


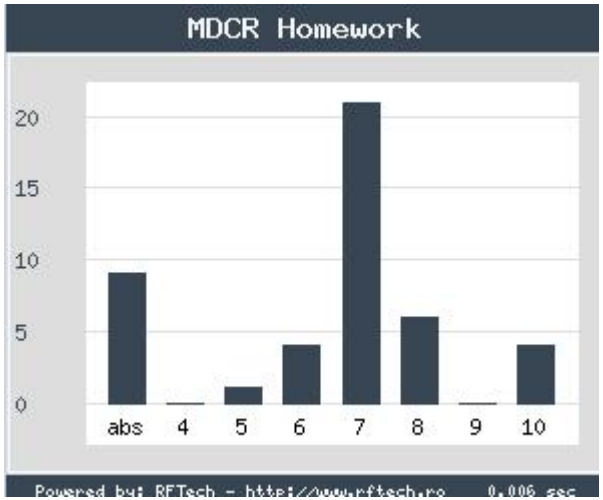
Grades

- 2019/2020 - eng



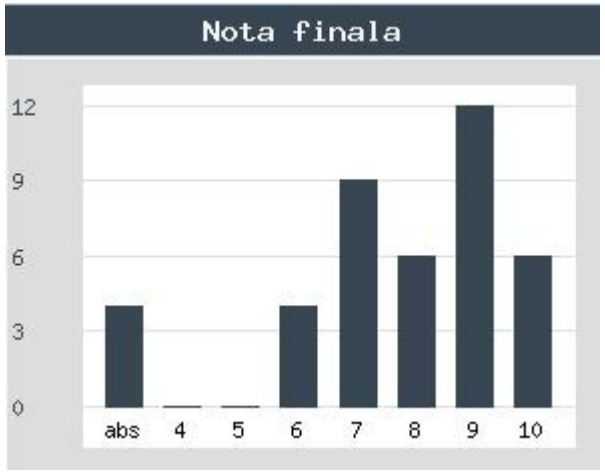


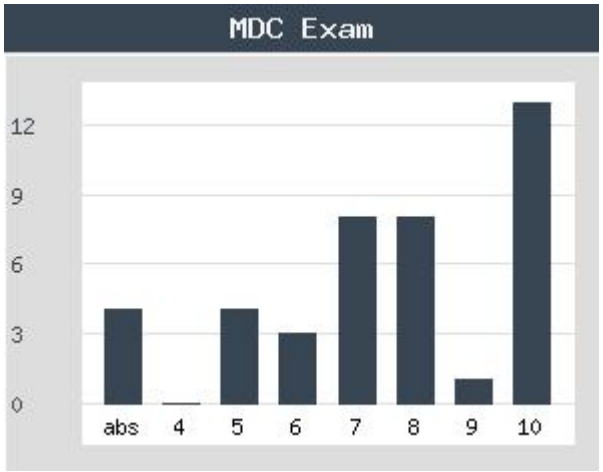


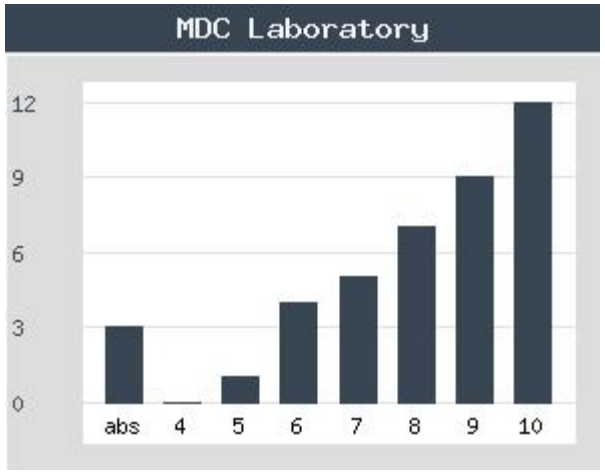


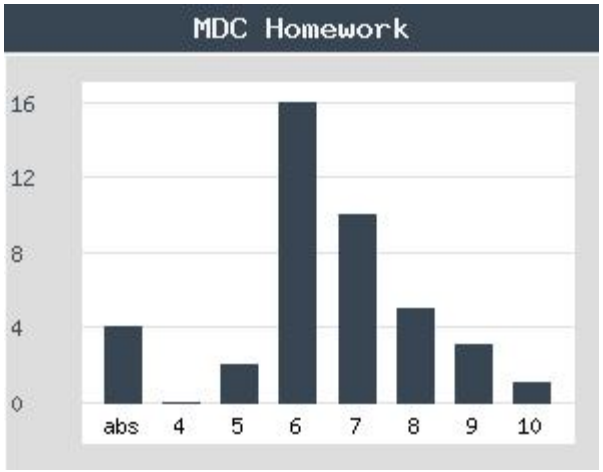
Grades

- 2020/2021 - eng

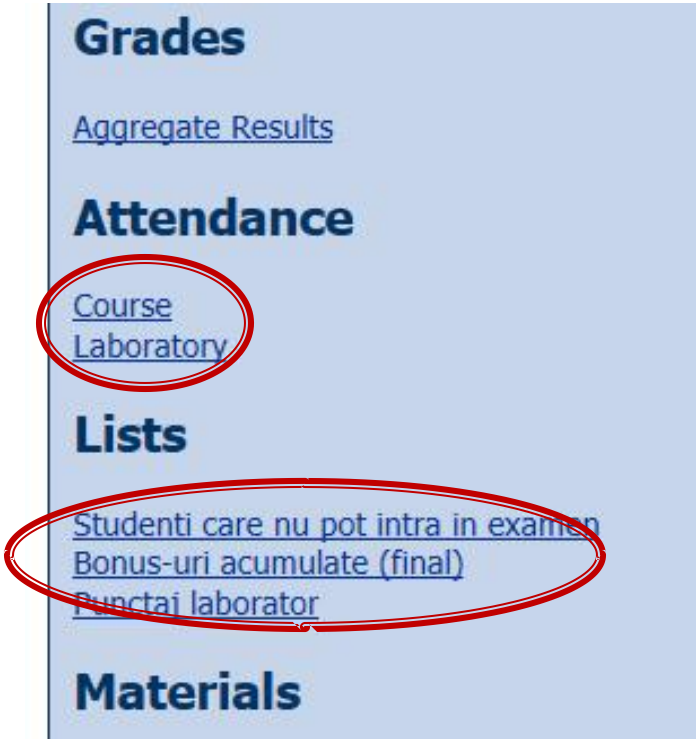








Attendance, Lists



- Attendance
- minimum 7 sessions
- Activity bonus
- Homework individual data
- etc.

Bonus

Group	Course attendance	B. attendance	B. supplemental	B. photo	B. T1	B. T2	B. T3	Total Bonus	Obs.
5411	4.6	0.5		1		0	0.1	1.6	-
5411	17	2.5		1	0.75	0	0.5	4.75	-
5411	12.6	2		1		0	0.1	3.1	-
5411	9.6	1.5		1	0.25		0	2.75	-
5411	5.2	0.5		1		0	0	1.5	-
5411	12	2		0.5		0		2.5	-
5411	16.15	2.5		0.5	0.5	0.3		3.8	-
5411	18	2.5	1.5	1	0		0.1	5.1	-
5411	15.725	2.5		1	0.75	0	0	4.25	-
5411	18	2.5	1.75	1	0.63	0	1	6.88	-
5411	1.2	0		1				1	-
5411	13	2	0.5	1	0.13	0	0	3.63	-
5411	15.375	2.5		1	1	0		4.5	-
5411	5.075	0.5	0.05	0				0.55	-
5411	1.8	0		0.5			0.1	0.6	-
5411	17.5	2.5	0.4	1	1		0.2	5.1	-

Previous years

Optoelectronics

Course: OPTO (2019-2020)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DID405M
Discipline Type: DID; Required, Domain
Credits: 4
Enrollment Year: 4, **Sem.** 8

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Colloquium**

A: 50%, (Test/Colloquium)
B: 30%, (Seminary/Laboratory/Project Activity)
C: 20%, (Tests during semester)

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | More years...

Server-ul "rf-opto" pastreaza istoricul materialelor pentru anii anteriori
Alegeti anul recent corespunzator pentru vizualizare sau "More years" pentru a afisa mai multi ani din istoric

Previous years

Microwave CD | Optical Communications | Optoelectronics | Internet | Antennas | Practica | Networks | Educational software

Examen DCMR 10 feb 2019 (pdf, 934.2 KB, ro,)
Rezolvari DCMR 10 feb 2019 (pdf, 825.2 KB, ro,)
Detalii notare DCMR/MDCR 2018 2019 (htm, 13.05 KB, ro,)

Other data

Factorul "Andrei" (pdf, 15.85 MB, ro,)

Previous years

2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | 2013-2014 | More years...

Microwave Devices and Circuits for Radiocommunications

Course: DCMR (2017-2018)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DOS412T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assoc.P. Dr. Radu-Florin Damian, 1 Hours/Week, Group, Timetable:

.tuiasi.ro/microwave_cd.php?more=2013

Previous years, 2004-2021

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | More years...

Optoelectronics

Course: OPTO (2018-2019)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DIS405M
Discipline Type: DID; Required, Domain
Credits: 3
Enrollment Year: 4, **Sem.** 8

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Se
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Group, Ti

Evaluation

Type: **Colloquium**

A: 50%, (Test/Colloquium)
B: 30%, (Seminary/Laboratory/Project Activity)
C: 20%, (Tests during semester)

Grades

Aggregate Results

Attendance

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | 2013-2014 | 2012-201

Optoelectronics, Structures, Technologies, Circuits

Course: OSTC (2013-2014)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DIS405M
Discipline Type: DIS; Required, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Half Group, Timetable:

Evaluation

Type: **Colloquium**

A: 66%, (Test/Colloquium)
B: 17%, (Seminary/Laboratory/Project Activity)
D: 17%, (Homework/Specialty papers)

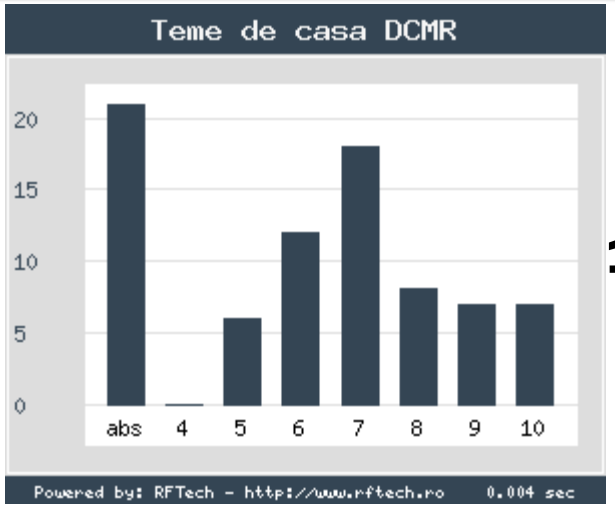
Grades

Aggregate Results

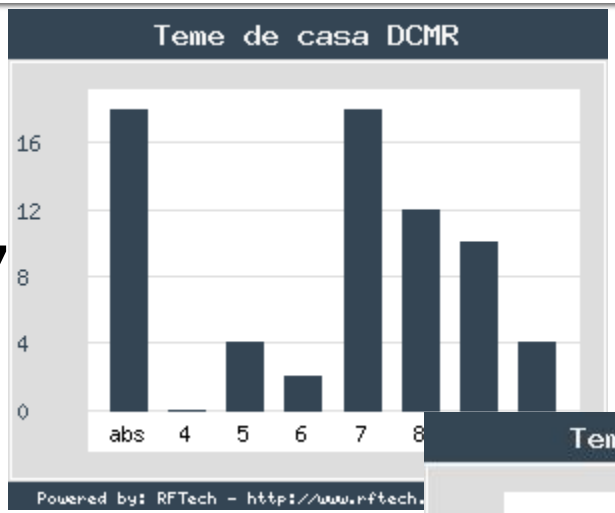
Materials

Effect? – "andrei" factor

15/6

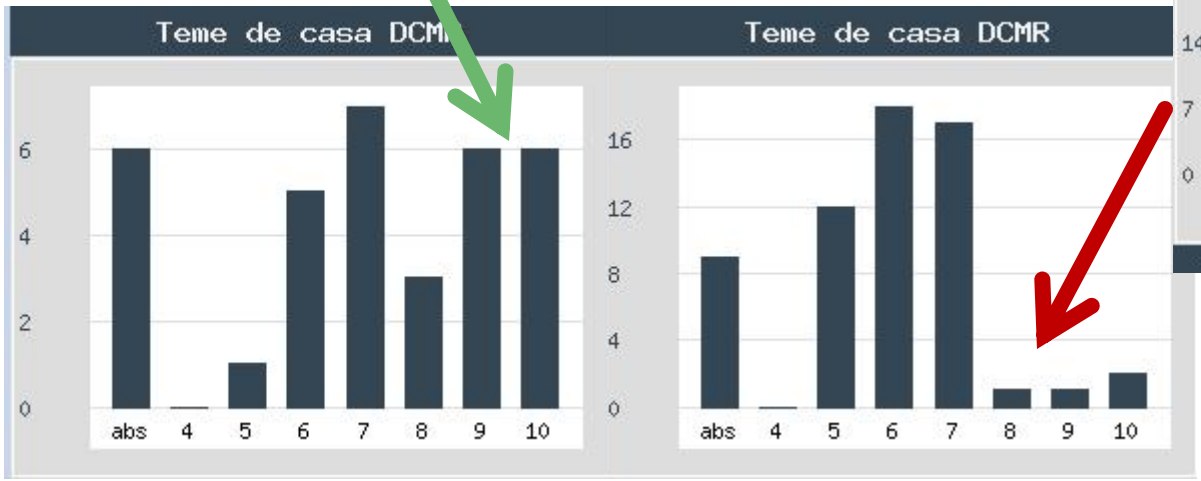


16/7



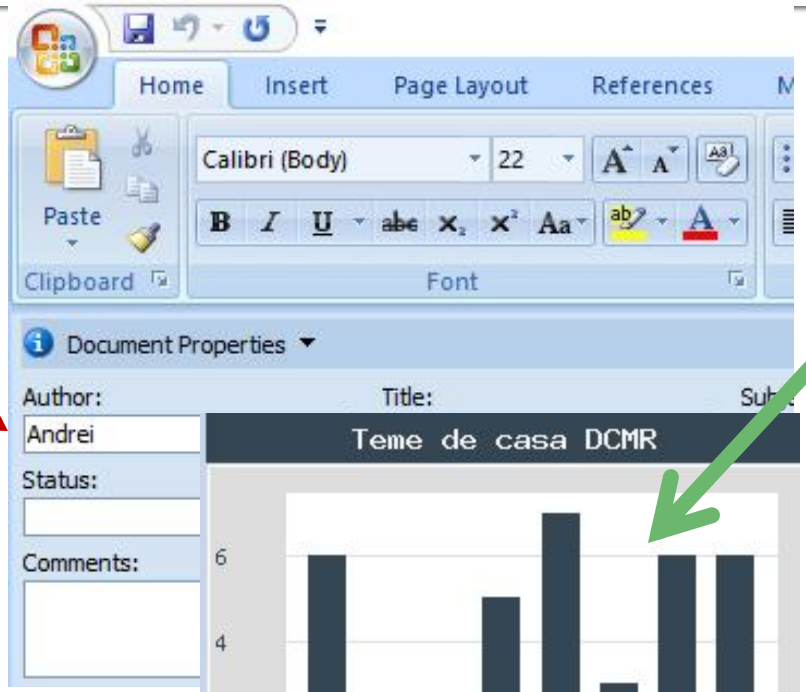
17/8

18/9

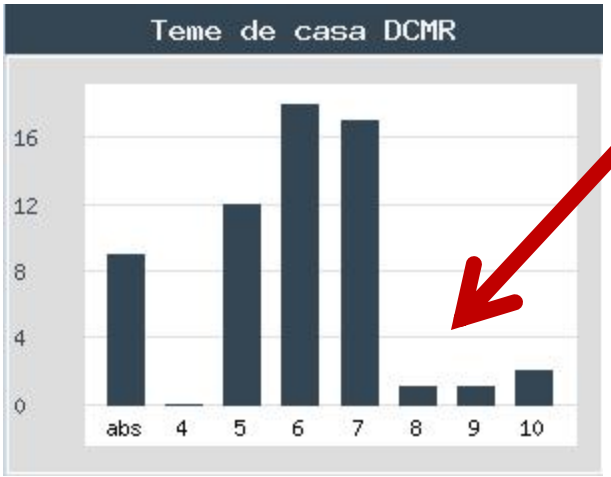


Project 2019/2020

- factorul “andrei” = **-2p**

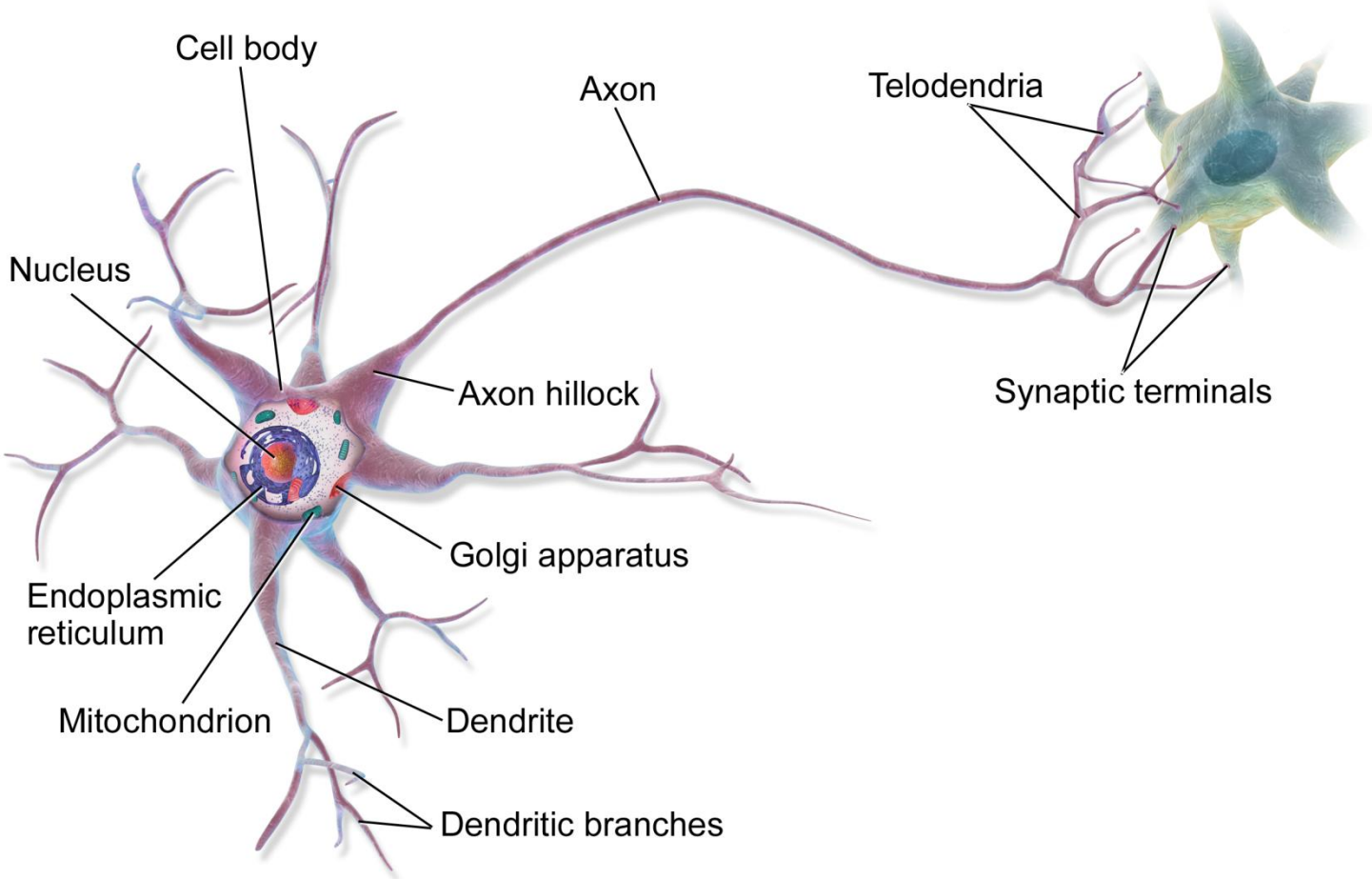


2018/9

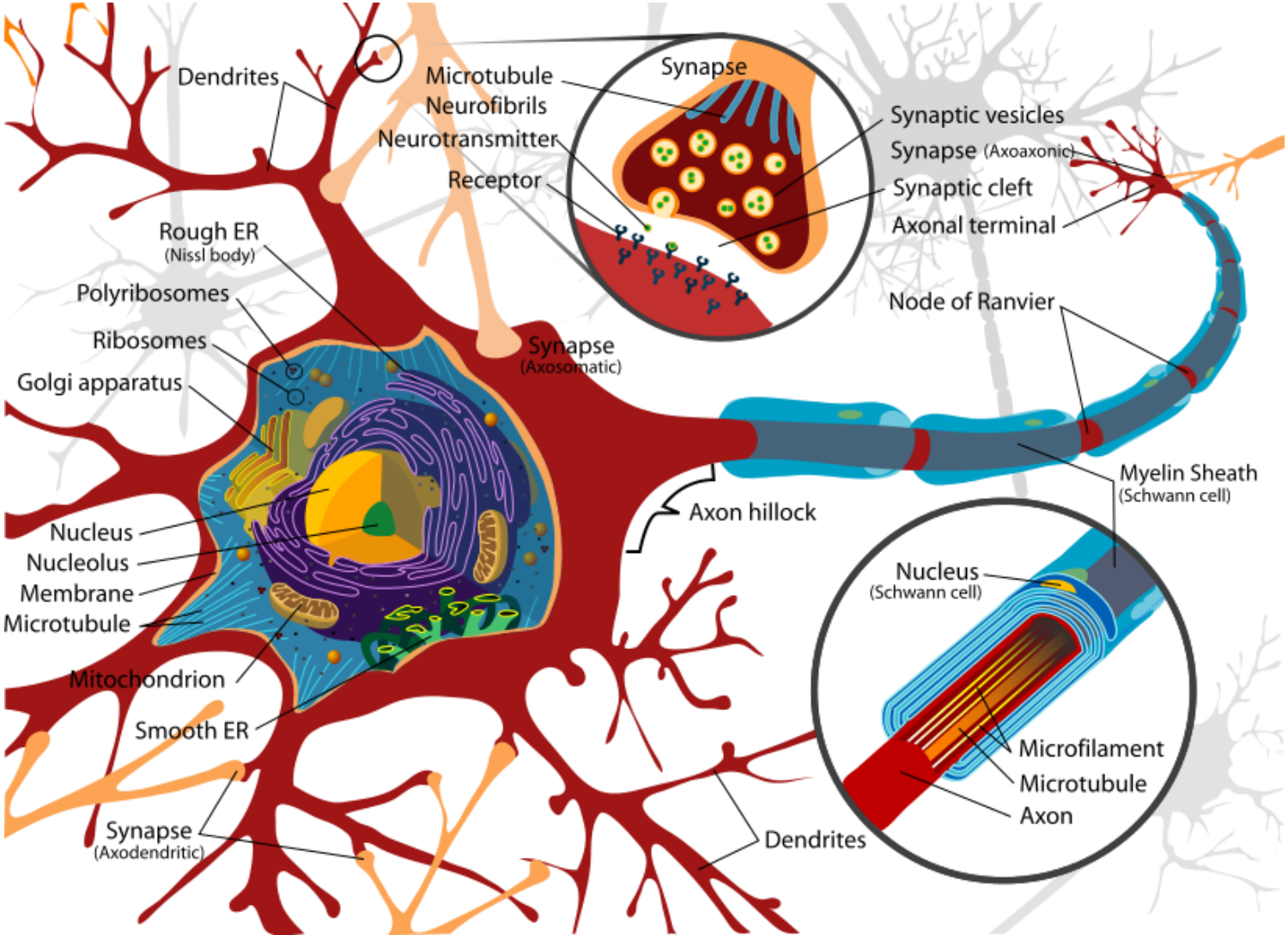


2018/9 (e)

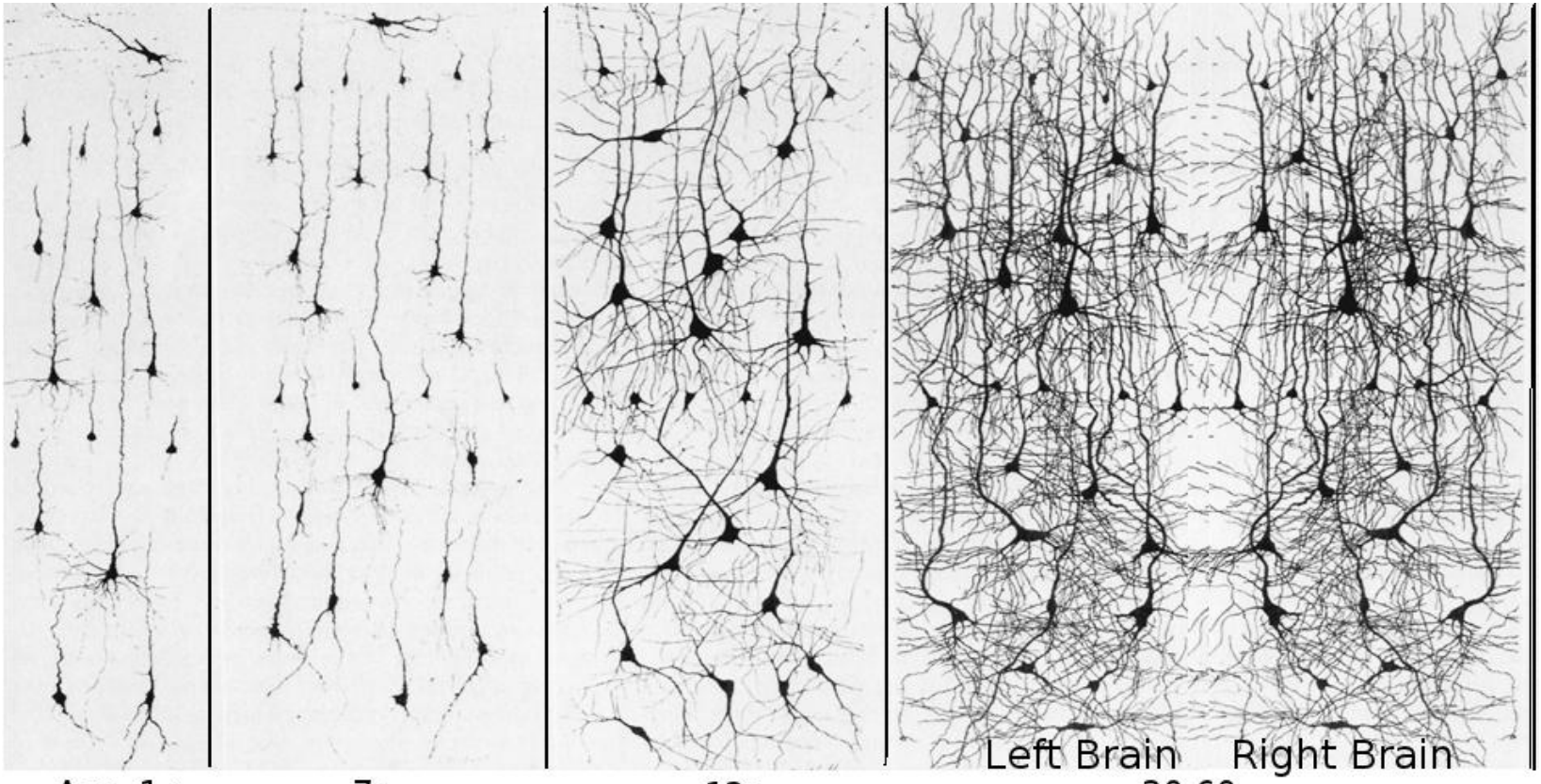
Course Objectives 1



Course Objectives 2



Course Objectives 3



Age 1+
Infant-
-birth

7+
Child-

13+
-Teen

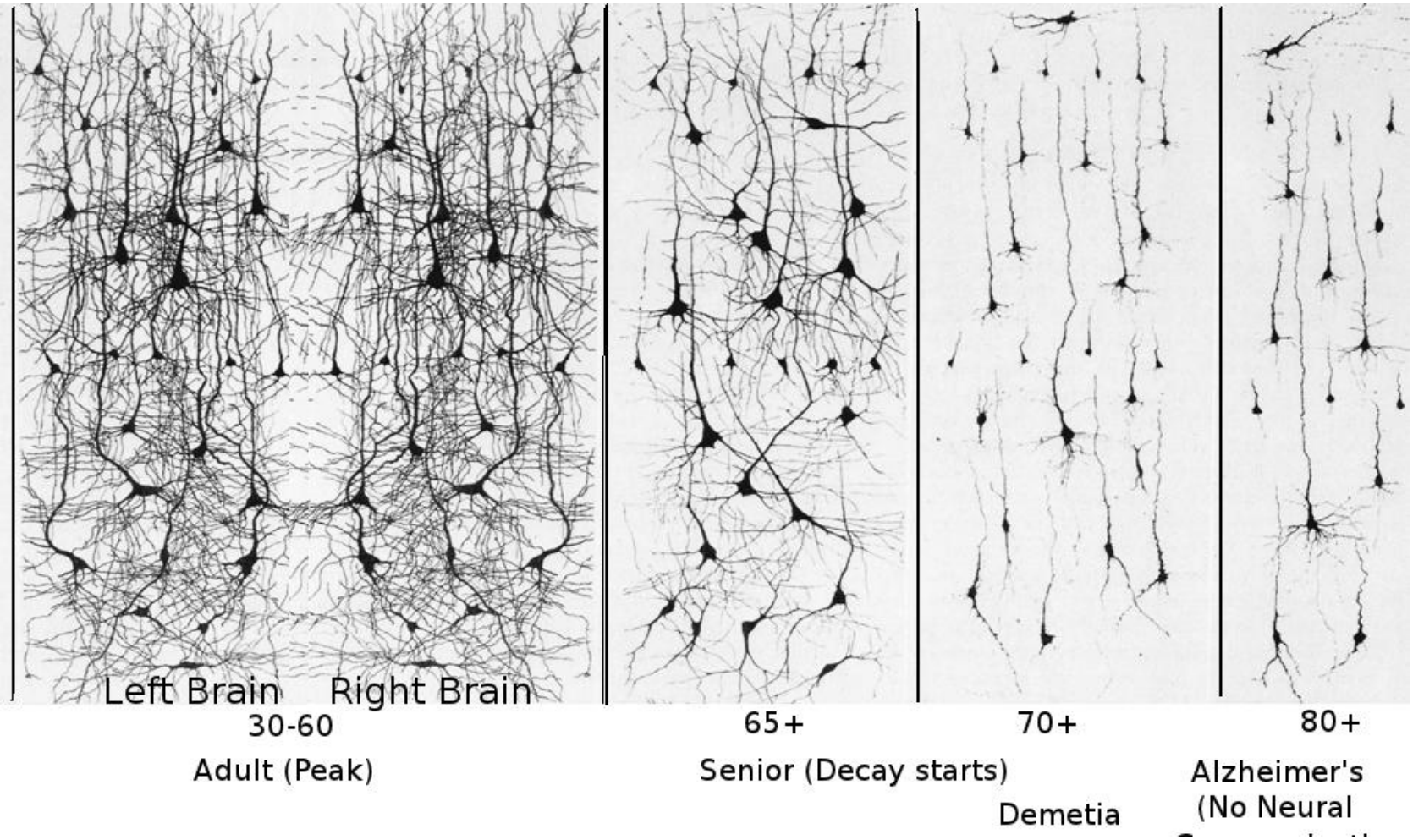
30-60
Adult (Peak)

(Stimulation and Growth)

Course Objectives 4

"Engineering"
Sinapses

Deadline


Left Brain
Right Brain
30-60
Adult (Peak)
65+
Senior (Decay starts)
70+
Demetia
80+
Alzheimer's
(No Neural

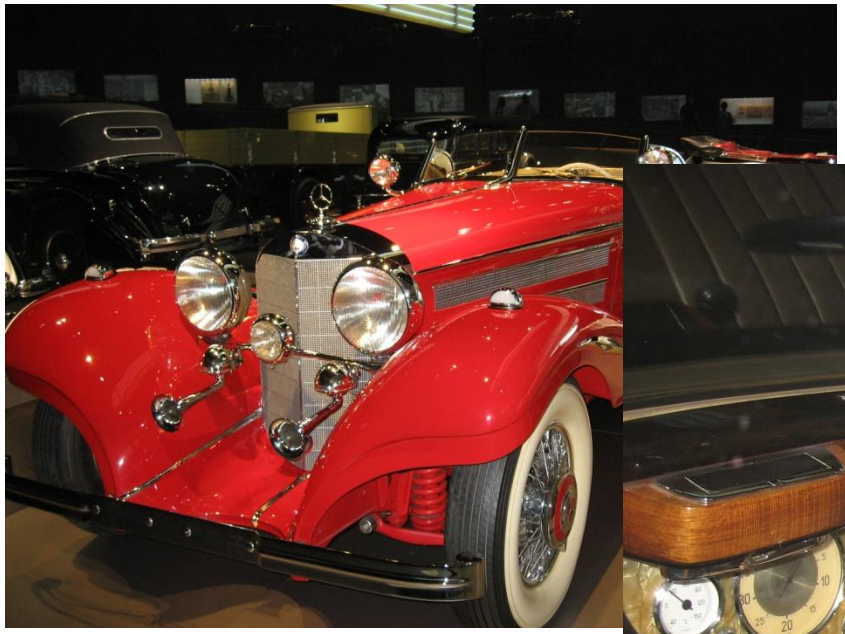
Course Topics

- Transmission lines
- Impedance matching and tuning
- Directional couplers
- Power dividers
- Microwave amplifier design
- Microwave filters
- ~~Oscillators and mixers~~ ?

Textbooks

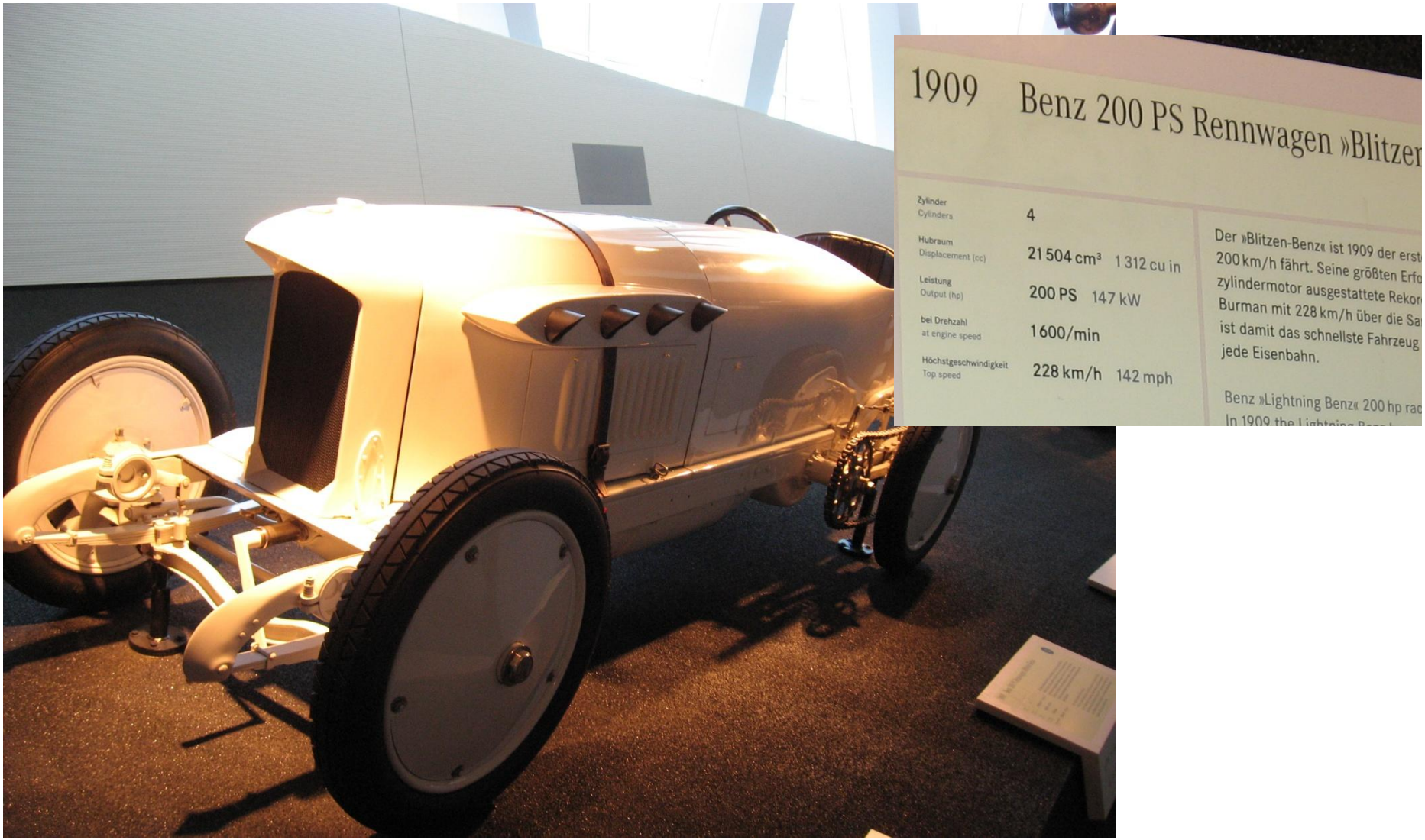
- http://rf-opto.etti.tuiasi.ro
- Irinel Casian-Botez: "Microunde vol. 1: Proiectarea de circuit", Ed. TEHNOPRES, 2008
- David Pozar, Microwave Engineering, Wiley; 4th edition , 2011, ISBN : 978-1-118-29813-8 (E), ISBN : 978-0-470-63155-3 (P)

~1930



~1930

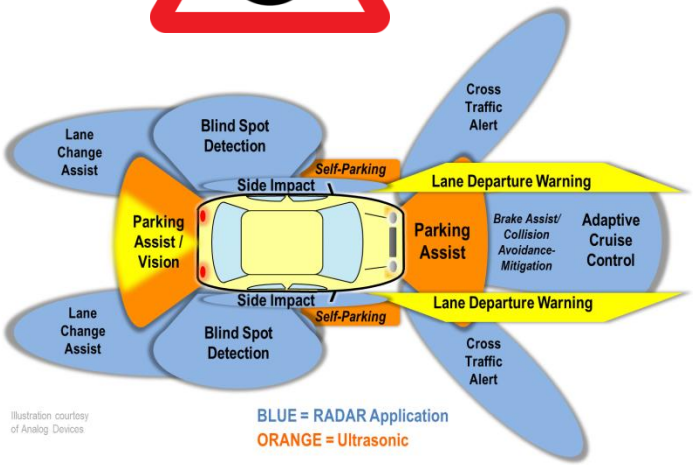
1909


1909
Benz 200 PS Rennwagen »Blitzen
Zylinder
Cylinders
4
Hubraum
Displacement (cc)
21 504 cm³ 1 312 cu in
Leistung
Output (hp)
200 PS 147 kW
bei Drehzahl
at engine speed
1 600/min
Höchstgeschwindigkeit
Top speed
228 km/h 142 mph
Der »Blitzen-Benz« ist 1909 der erst
200 km/h fährt. Seine größten Erfo
zylindermotor ausgestattete Rekor
Burman mit 228 km/h über die Sa
ist damit das schnellste Fahrzeug
jede Eisenbahn.
Benz »Lightning Benz« 200 hp rac

1930-1950

Technology

> 2010



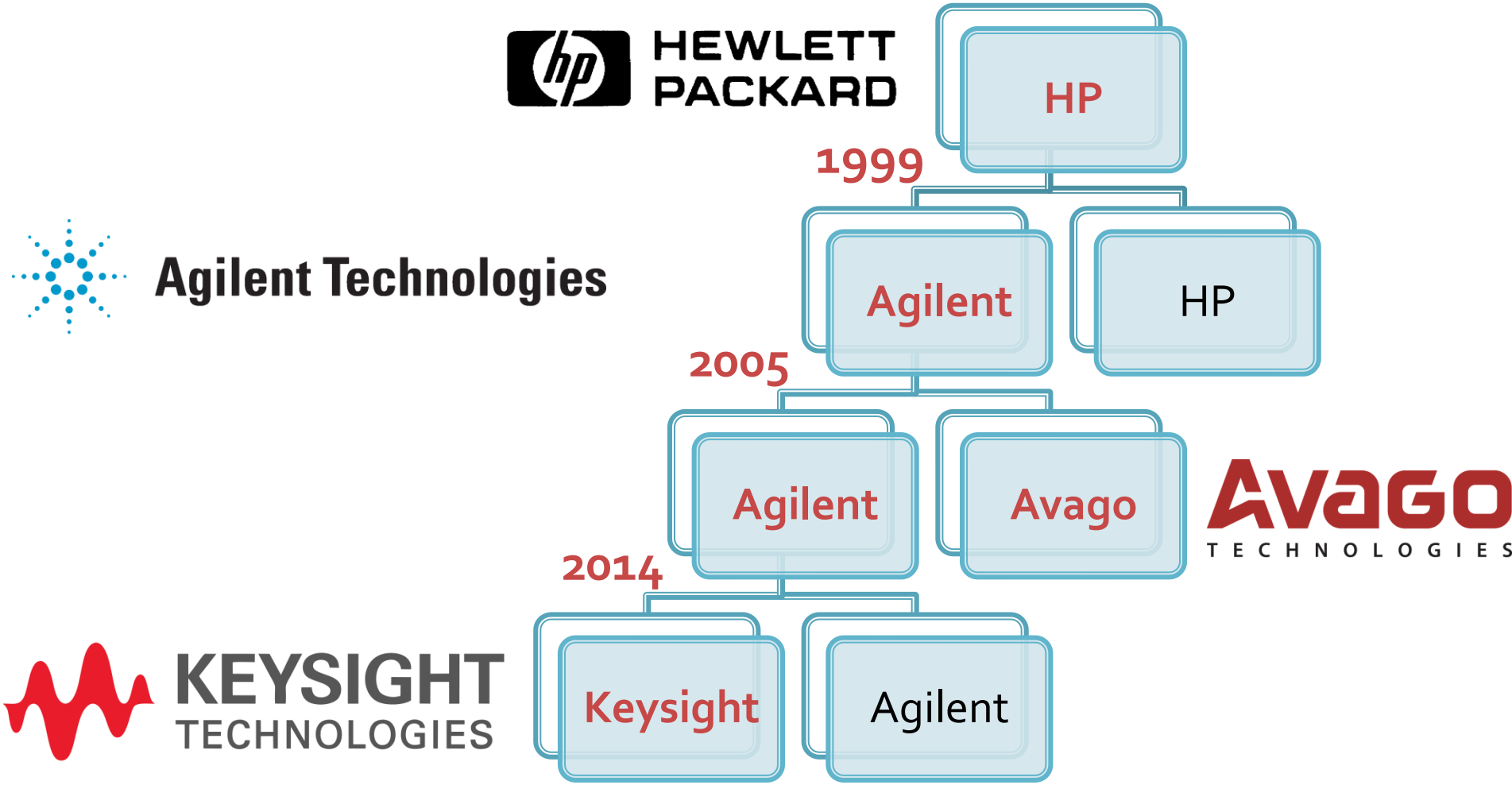
< 1950

Technology

1x1 = 1 1x2 = 2 1x3 = 3 1x4 = 4 1x5 = 5 1x6 = 6 1x7 = 7 1x8 = 8 1x9 = 9 1x10 = 10	2x1 = 2 2x2 = 4 2x3 = 6 2x4 = 8 2x5 = 10 2x6 = 12 2x7 = 14 2x8 = 16 2x9 = 18 2x10 = 20	3x1 = 3 3x2 = 6 3x3 = 9 3x4 = 12 3x5 = 15 3x6 = 18 3x7 = 21 3x8 = 24 3x9 = 27 3x10 = 30	4x1 = 4 4x2 = 8 4x3 = 12 4x4 = 16 4x5 = 20 4x6 = 24 4x7 = 28 4x8 = 32 4x9 = 36 4x10 = 40	5x1 = 5 5x2 = 10 5x3 = 15 5x4 = 20 5x5 = 25 5x6 = 30 5x7 = 35 5x8 = 40 5x9 = 45 5x10 = 50
6x1 = 6 6x2 = 12 6x3 = 18 6x4 = 24 6x5 = 30 6x6 = 36 6x7 = 42 6x8 = 48 6x9 = 54 6x10 = 60	7x1 = 7 7x2 = 14 7x3 = 21 7x4 = 28 7x5 = 35 7x6 = 42 7x7 = 49 7x8 = 56 7x9 = 63 7x10 = 70	8x1 = 8 8x2 = 16 8x3 = 24 8x4 = 32 8x5 = 45 8x6 = 48 8x7 = 56 8x8 = 64 8x9 = 72 8x10 = 80	9x1 = 9 9x2 = 18 9x3 = 27 9x4 = 36 9x5 = 45 9x6 = 54 9x7 = 63 9x8 = 72 9x9 = 81 9x10 = 90	10x1 = 10 10x2 = 20 10x3 = 30 10x4 = 40 10x5 = 50 10x6 = 60 10x7 = 70 10x8 = 80 10x9 = 90 10x10 = 100

Most used!!

2x1 = 2
2x2 = 4
2x3 = 6
2x4 = 8
2x5 = 10
2x6 = 12
2x7 = 14
2x8 = 16
2x9 = 18
2x10 = 20

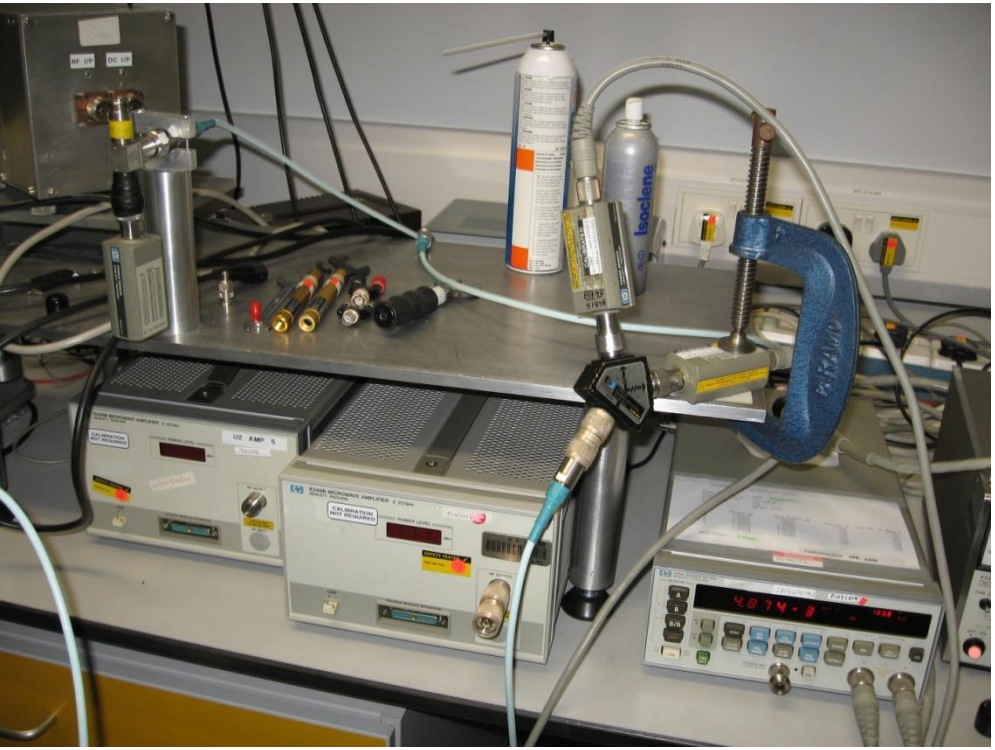

HEWLETT PACKARD
HP
1999
Agilent Technologies
Agilent
HP
2005
Agilent
Avago
AVAGO TECHNOLOGIES
2014
KEYSIGHT TECHNOLOGIES
Keysight
Agilent

NPL, Londra


HEWLETT PACKARD
8510


NATIONAL PHYSICAL LABORATORY
HEWLETT PACKARD
NETWORK ANALYZER
8510
SAFETY TESTED

NPL, Londra




8349B MICROWAVE AMPLIFIER 2-20GHz
HEWLETT PACKARD
CALIBRATION NOT REQUIRED
POWER LE


438A POWER METER
HEWLETT • PACKARD
SENSOR
A
B


8349B MICROWAVE AMPLIFIER 2-20GHz
HEWLETT PACKARD
CALIBRATION NOT REQUIRED
POWER LEVEL

Examen: Logarithmic scales

$dB = 10 \cdot \log_{10} (P_2 / P_1)$

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
-3 dB	= 0.5
-10 dB	= 0.1
-20 dB	= 0.01
-30 dB	= 0.001

$dBm = 10 \cdot \log_{10} (P / 1\ mW)$

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
-3 dBm	= 0.5 mW
-10 dBm	= 100 μW
-30 dBm	= 1 μW
-60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

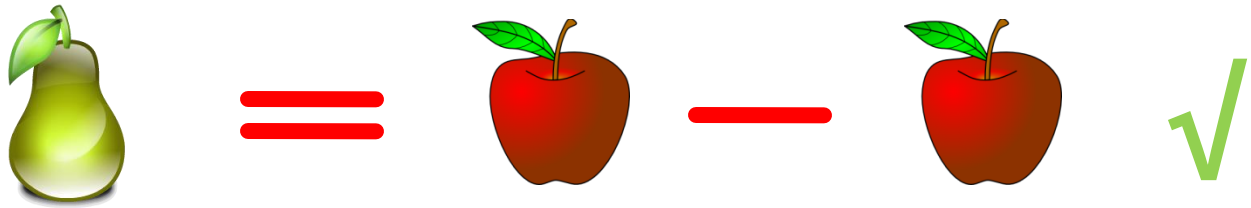
Computing Loss in circuits

$$\text{Loss} = \frac{P_{out}}{P_{in}}$$

$$\text{Loss}[\text{dB}] = [-]10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

$$\text{Loss}[\text{dB}] = [-]10 \cdot \log_{10}\left(\frac{P_{out}}{P_0} \cdot \frac{P_0}{P_{in}}\right) = [-]10 \cdot \left[\log_{10}\left(\frac{P_{out}}{P_0}\right) - \log_{10}\left(\frac{P_{in}}{P_0}\right)\right]$$

$$\text{Loss}[\text{dB}] = [-]\left(P_{out}[\text{dBm}] - P_{in}[\text{dBm}]\right)$$

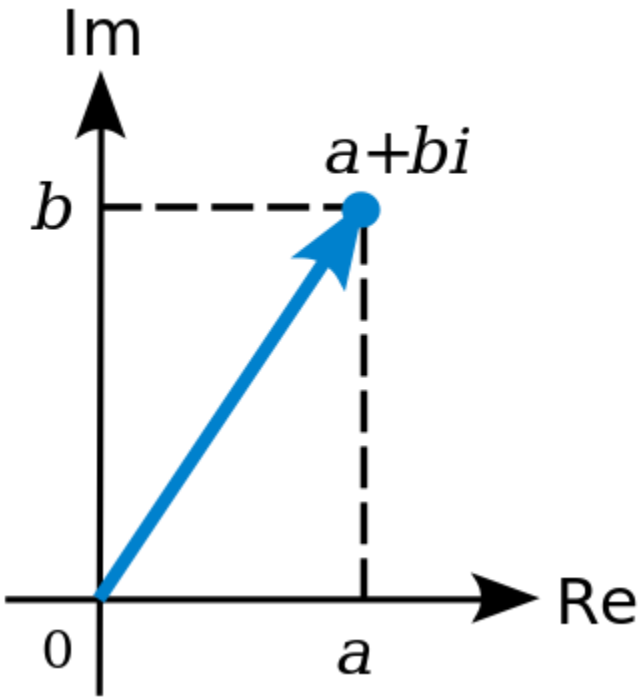


Examen

- Complex numbers arithmetic!!!!
- $z = a + j \cdot b$; $j^2 = -1$

Complex plane

- abscissa – real part
- ordinate – imaginary part
- any of them can be negative, whole plane, 4 quadrants



Elementary operations

- Addition

$$z+w=(a+j\cdot b)+(c+j\cdot d)=(a+c)+j\cdot(b+d)$$

- Subtraction

$$z-w=(a+j\cdot b)-(c+j\cdot d)=(a-c)+j\cdot(b-d)$$

- Multiplication

$$z\cdot w=(a+j\cdot b)\cdot(c+j\cdot d)=(a\cdot c-b\cdot d)+j\cdot(b\cdot c+a\cdot d)$$

- Division

$$z/w=\frac{a+j\cdot b}{c+j\cdot d}=\frac{(a+j\cdot b)\cdot(c-j\cdot d)}{(c+j\cdot d)\cdot(c-j\cdot d)}=\left(\frac{a\cdot c+b\cdot d}{c^2+d^2}\right)+j\cdot\left(\frac{b\cdot c-a\cdot d}{c^2+d^2}\right)$$

Conjugate

- z $\quad z = a + j \cdot b$
- z^* $\quad z^* = a - j \cdot b$
- Symmetry over the real axis

$$\mathrm{Re}(z) = a = \frac{1}{2} \cdot \left(z + z^*\right)$$

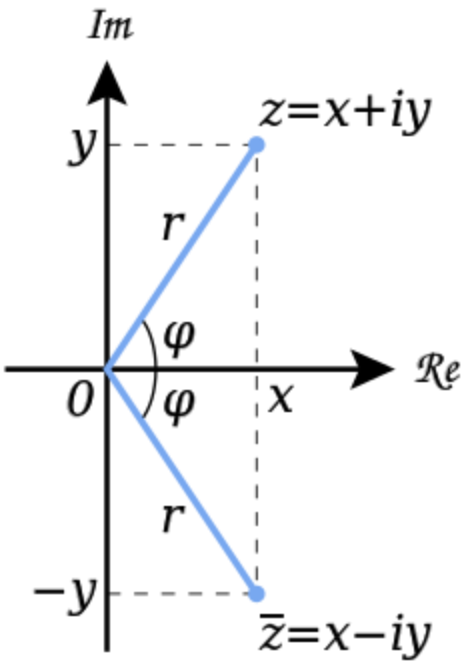
$$\mathrm{Im}(z) = b = \frac{1}{2 \cdot j} \cdot \left(z - z^*\right) = \frac{j}{2} \cdot \left(z^* - z\right)$$

$$\left(z + w\right)^* = z^* + w^*$$

$$\left(z - w\right)^* = z^* - w^*$$

$$\left(z \cdot w\right)^* = z^* \cdot w^*$$

$$\left(z / w\right)^* = z^* / w^*$$



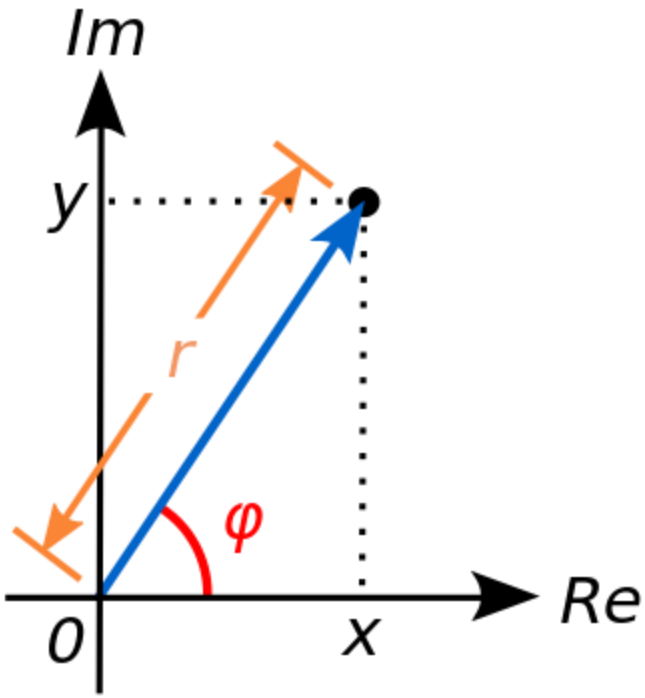
Polar representation

- Polar representation
  - modulus
  - phase relative to the real axis

$$z = a + j \cdot b = |z| \cdot (\cos\varphi + j \cdot \sin\varphi)$$

$$|z| = \sqrt{a^2 + b^2}$$

$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, nedefinit & a = 0 \end{cases}$$

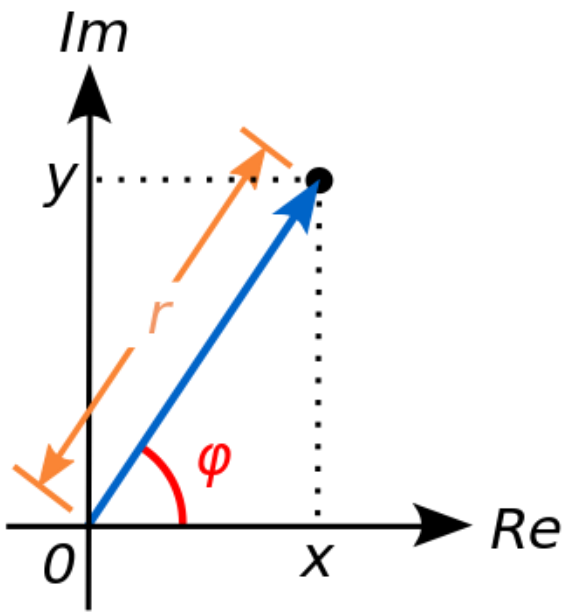


Polar representation

- Euler's formula

$$e^{j\cdot x} = \cos x + j\cdot \sin x; \forall x \in R$$

- Polar representation



$$z = a + j\cdot b = |z|\cdot e^{j\cdot\varphi}$$

$$z = a + j\cdot b = |z|\cdot(\cos\varphi + j\cdot\sin\varphi)$$

$$z^n = \left(|z|\cdot e^{j\cdot\varphi}\right)^n = |z|^n\cdot e^{j\cdot n\cdot\varphi} = |z|^n\cdot\left[\cos(n\cdot\varphi) + j\cdot\sin(n\cdot\varphi)\right]$$

$$\sqrt{z} = \left(|z|\cdot e^{j\cdot\varphi}\right)^{1/2} = \sqrt{|z|}\cdot e^{j\cdot\frac{\varphi}{2}} = \sqrt{|z|}\cdot\left(\cos\frac{\varphi}{2} + j\cdot\sin\frac{\varphi}{2}\right)$$

$$z\cdot w = |z|\cdot e^{j\cdot\varphi}\cdot|w|\cdot e^{j\cdot\theta} = |z|\cdot|w|\cdot e^{j\cdot(\varphi+\theta)} = |z|\cdot|w|\cdot\left[\cos(\varphi+\theta) + j\cdot\sin(\varphi+\theta)\right]$$

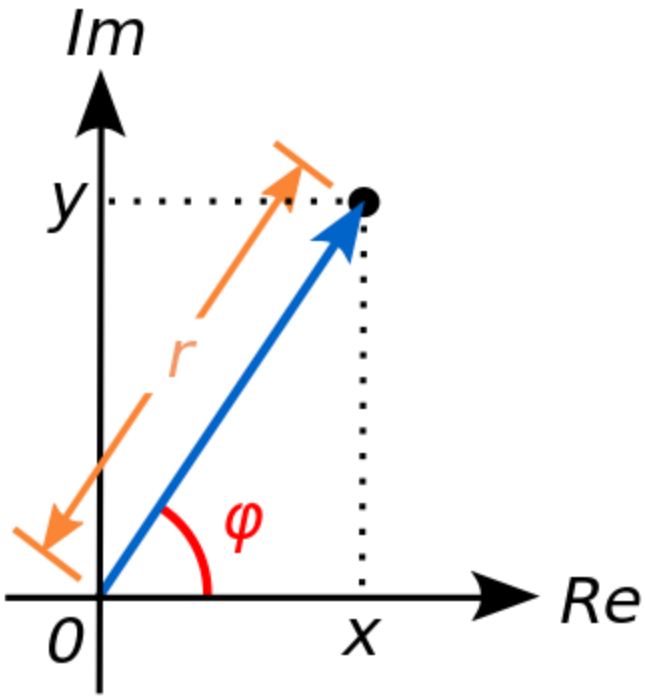
$$z/w = \frac{|z|\cdot e^{j\cdot\varphi}}{|w|\cdot e^{j\cdot\theta}} = \frac{|z|}{|w|}\cdot e^{j\cdot\varphi}\cdot e^{-j\cdot\theta} = \frac{|z|}{|w|}\cdot\left[\cos(\varphi-\theta) + j\cdot\sin(\varphi-\theta)\right]$$

Polar representation

- Polar representation

$$|z| = \sqrt{a^2 + b^2}$$

$$|z|^2 = z \cdot z^*$$



$$\left|e^{j\cdot x}\right| = \left|\cos x + j \cdot \sin x\right| = \sqrt{\cos^2 x + \sin^2 x} = 1$$

$$\left|e^{j\cdot x}\right| = 1; \quad \forall x \in R$$

$$z^* = \left(|z| \cdot e^{j\cdot\varphi}\right)^* = |z| \cdot \left(\cos\varphi + j \cdot \sin\varphi\right)^* = |z| \cdot \left(\cos\varphi - j \cdot \sin\varphi\right) =$$

$$= |z| \cdot \left[\cos(-\varphi) + j \cdot \sin(-\varphi)\right] = |z| \cdot e^{-j\cdot\varphi}$$

Polar representation

- standard unit for angles – radians
- microwaves traditional unit for angles – **degrees in decimal form** (55.89°)

$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, nedefinit & a = 0 \end{cases}$$

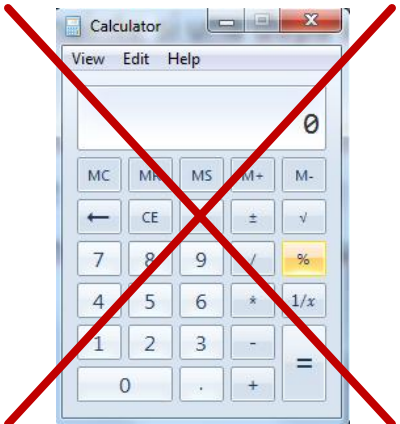
$$\varphi[°] = 180° \cdot \frac{\varphi[rad]}{\pi} \qquad \varphi[rad] = \pi \cdot \frac{\varphi[°]}{180°}$$

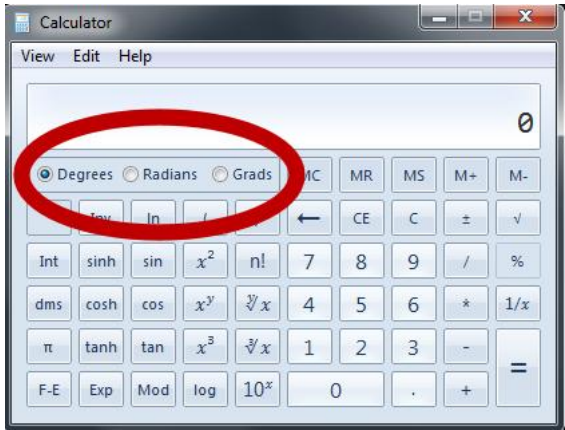
Polar representation

- **Attention to angle numerical values!!**
  - math software – work in standard unit: radians
    - a **conversion** is necessary before and after using a trigonometric function (sin, cos, tan, atan, tanh)
  - scientific calculators have the built-in option of choosing the angle unit
    - always **double check** current working unit

$$\varphi[°] = 180° \cdot \frac{\varphi[rad]}{\pi}$$

$$\varphi[rad] = \pi \cdot \frac{\varphi[°]}{180°}$$





Contact

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