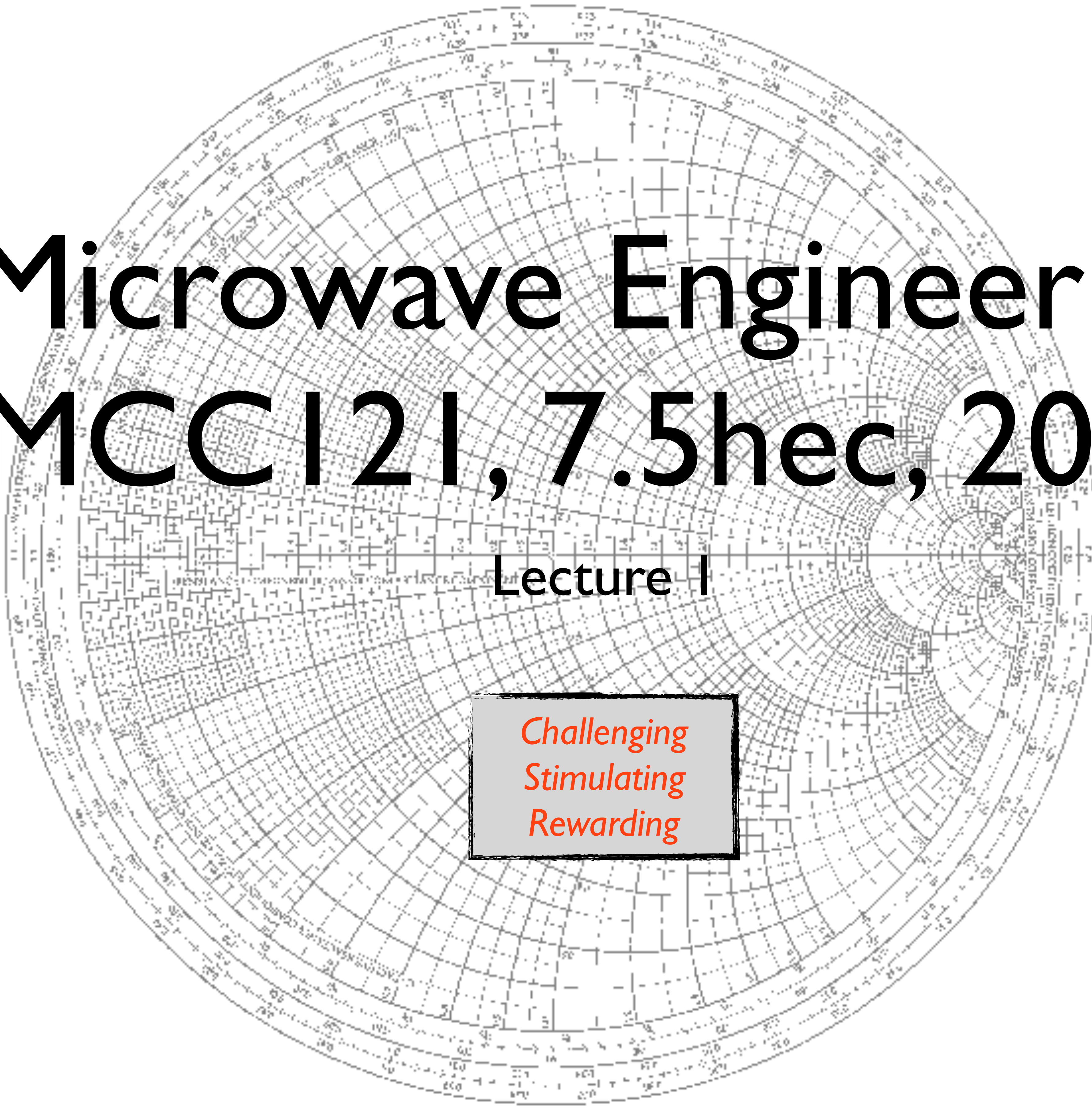
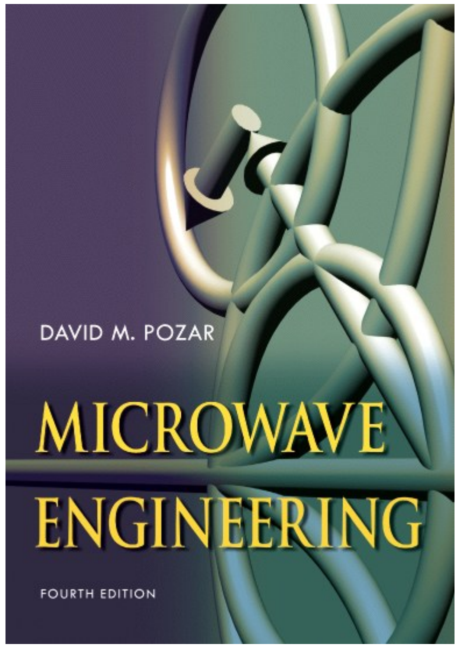


Microwave Engineering
MCC121, 7.5hec, 2014

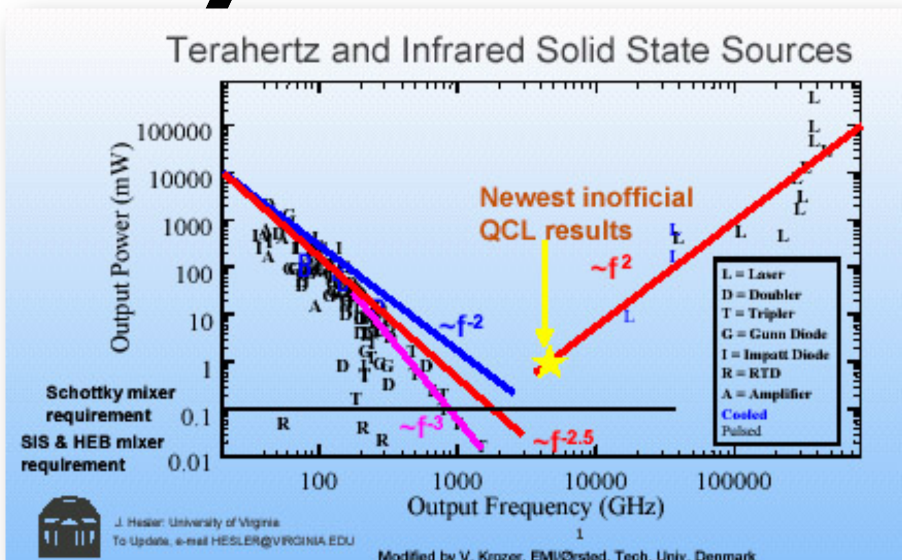
Lecture 1

Challenging
Stimulating
Rewarding

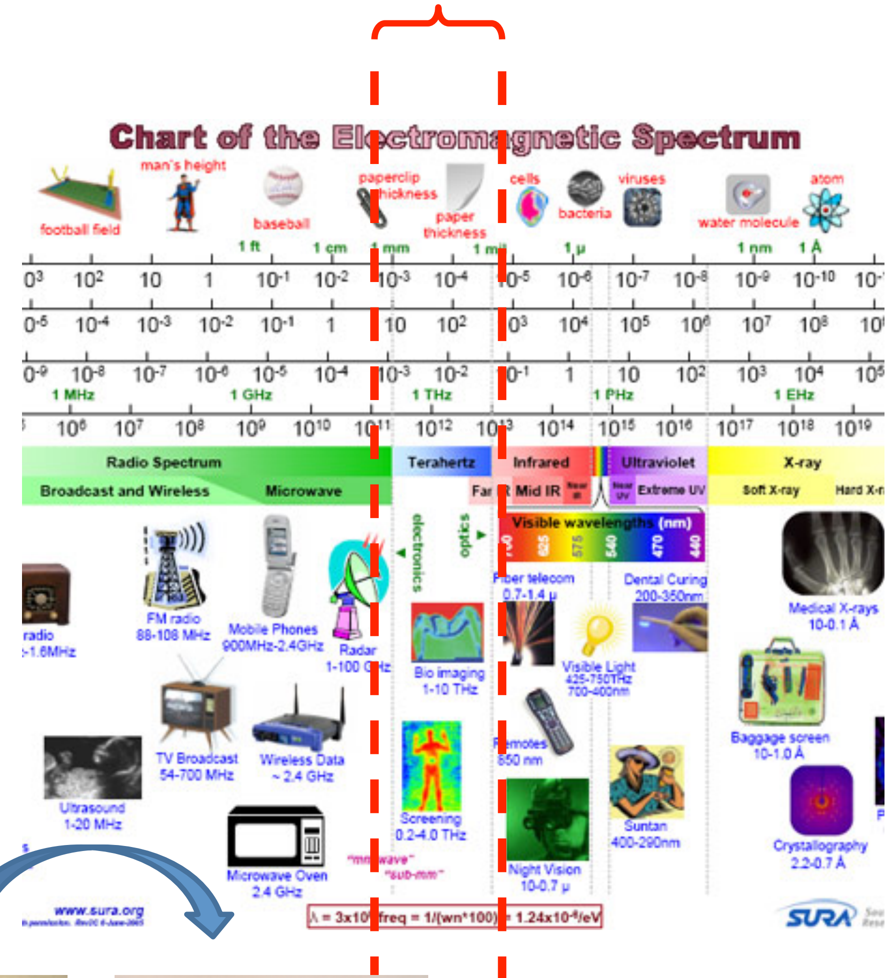


Presentation

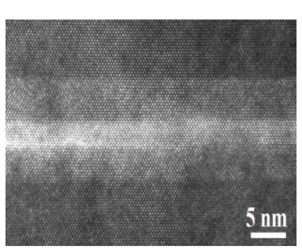
my research interest

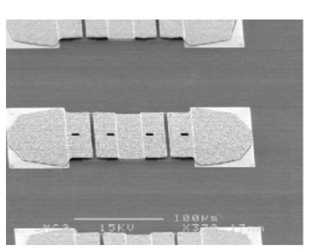


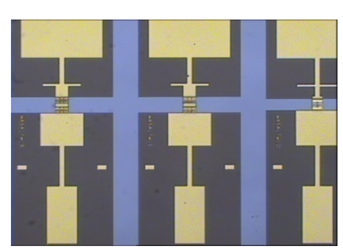
Terahertz range :
0.1-10THz

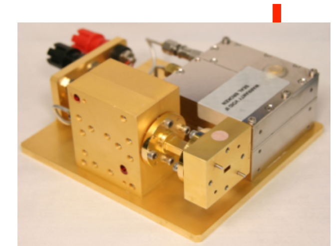


Bridge the THz gap!

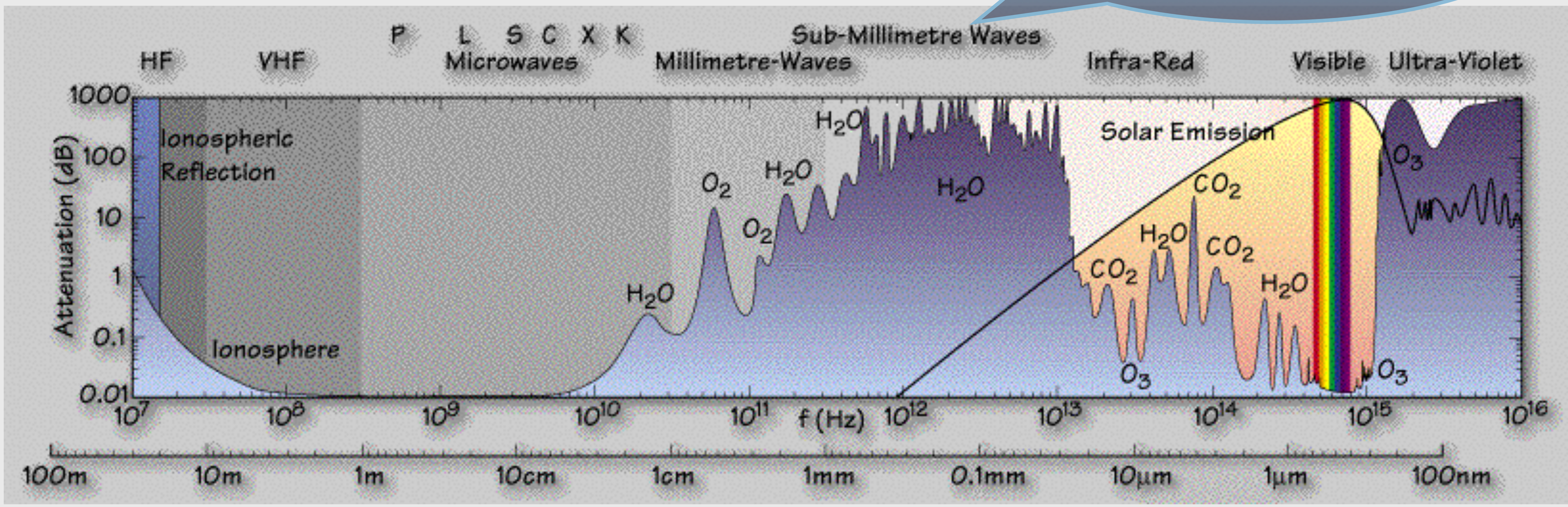








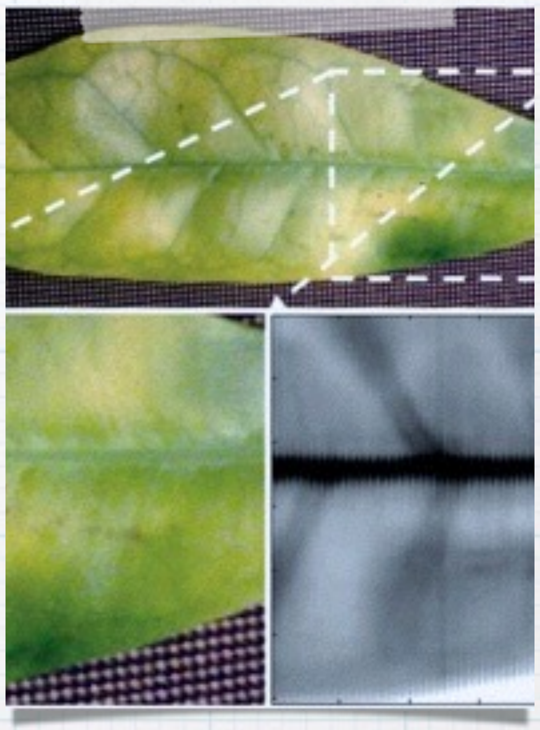
"Terahertz technology: the most scientifically rich, yet under-utilised region of the electromagnetic spectrum"

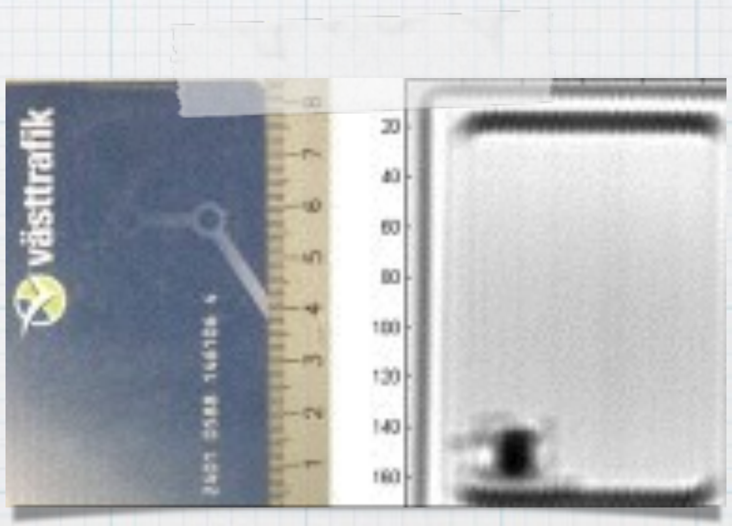


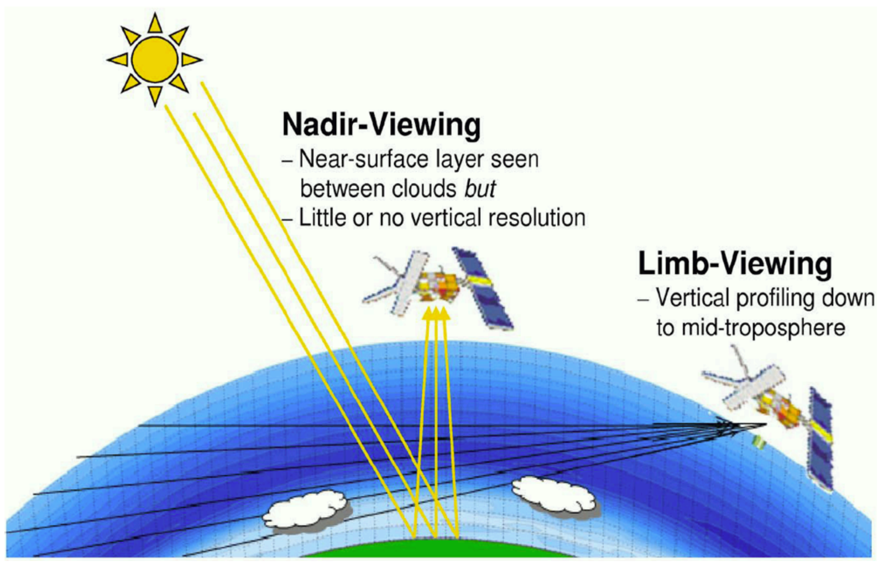
THz spectrum

THz Properties

* Terahertz frequencies: 300 GHz-1 0THz
    * Submillimetre waves: 30µm - 1mm
    * Photon Energy levels: 1.2-40 meV
* Non-ionisation
* Terahertz interactions with matter involve intermolecular, rather than atomic transitions
* Terahertz waves can penetrate a wide variety of non-conductive materials (as microwaves)

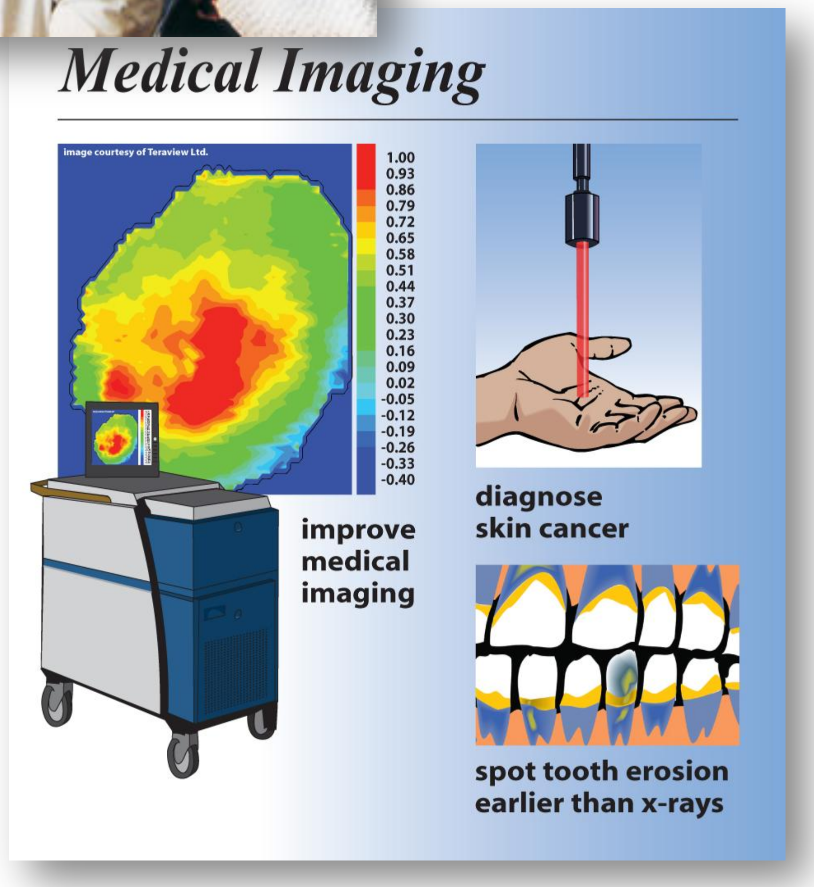




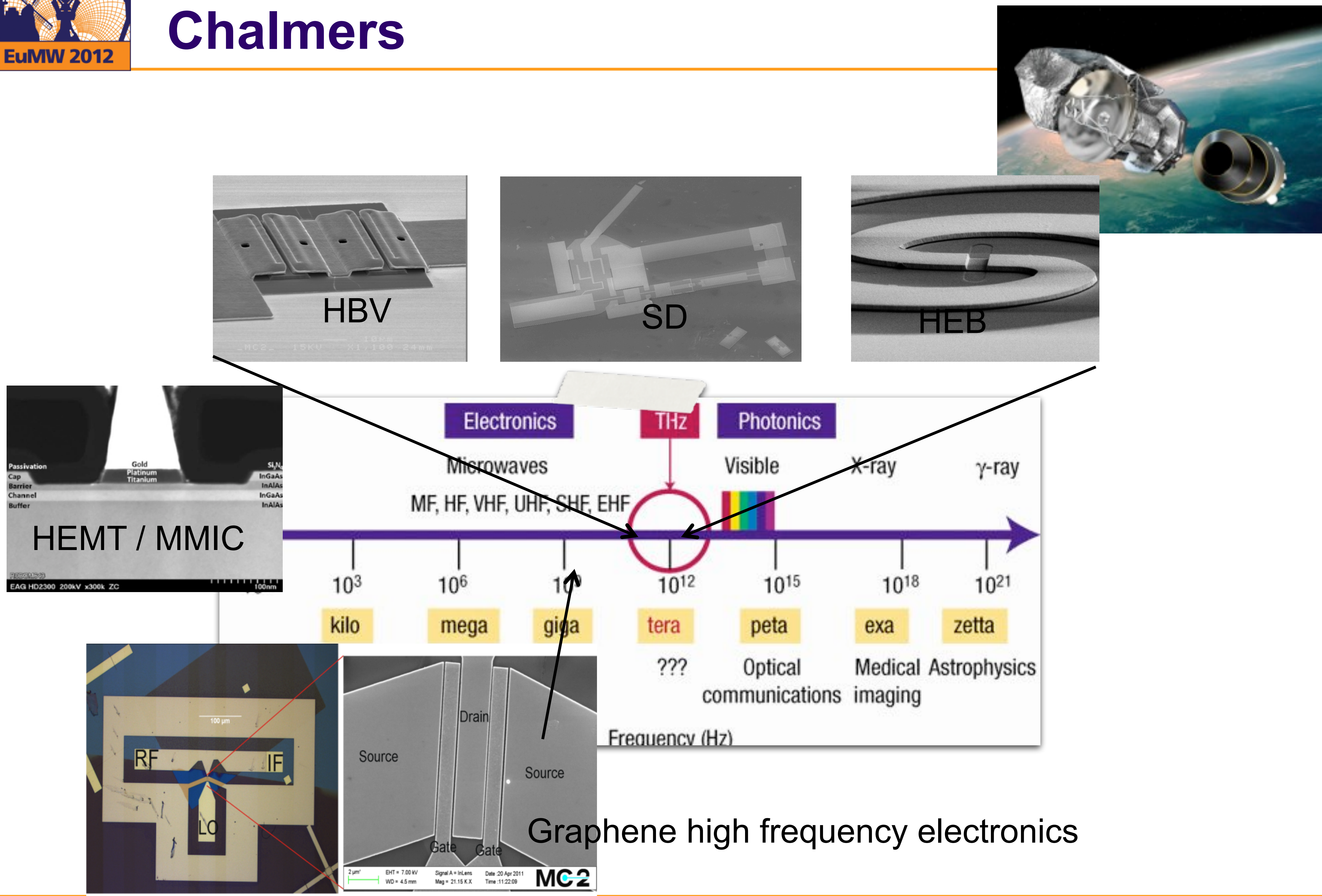

Nadir-Viewing
– Near-surface layer seen between clouds *but*
– Little or no vertical resolution
Limb-Viewing
– Vertical profiling down to mid-troposphere

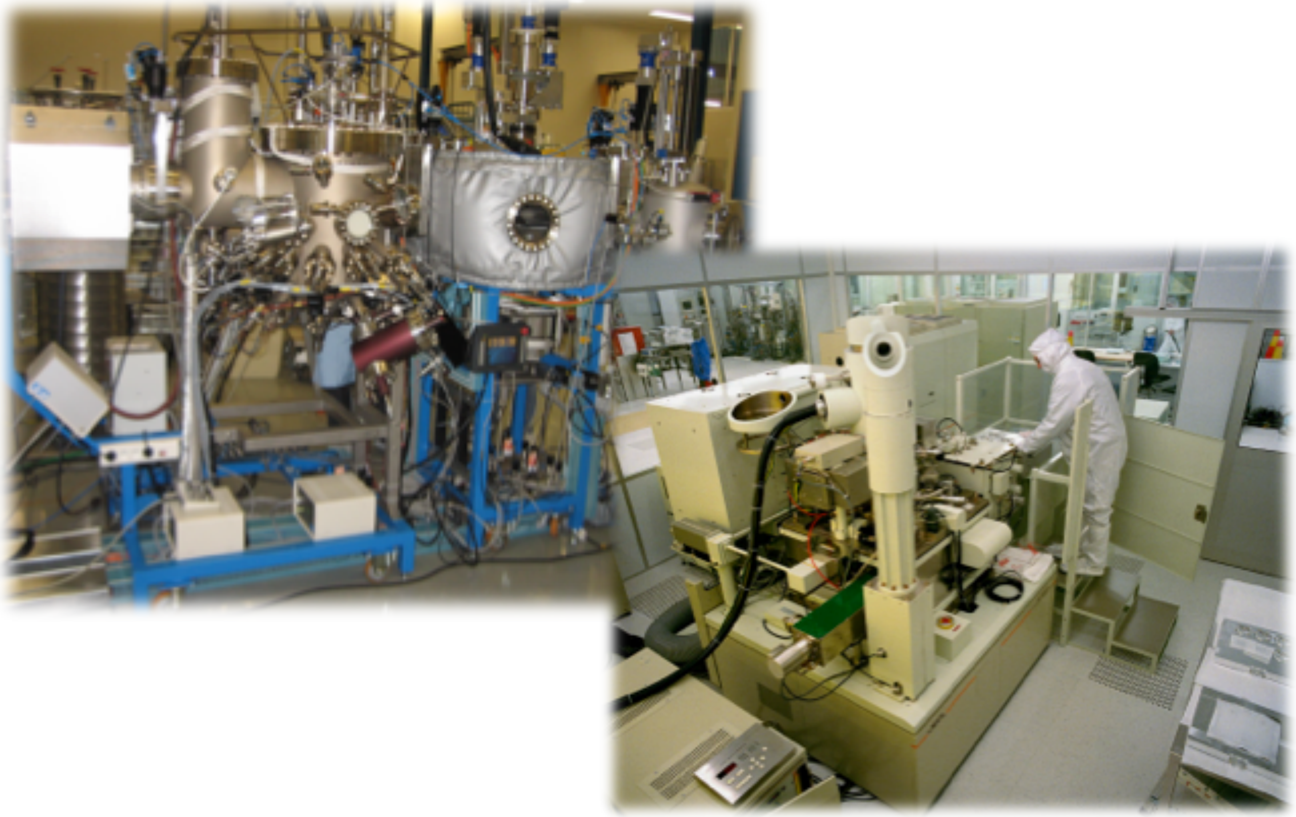

The Eagle Nebula
as seen with Hubble

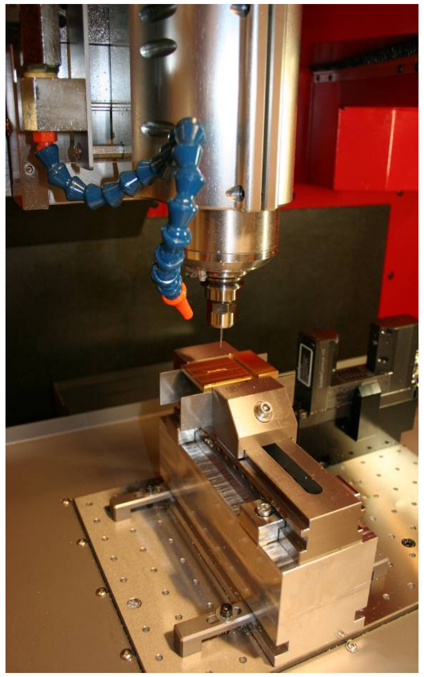

The Eagle Nebula
as seen in the infrared

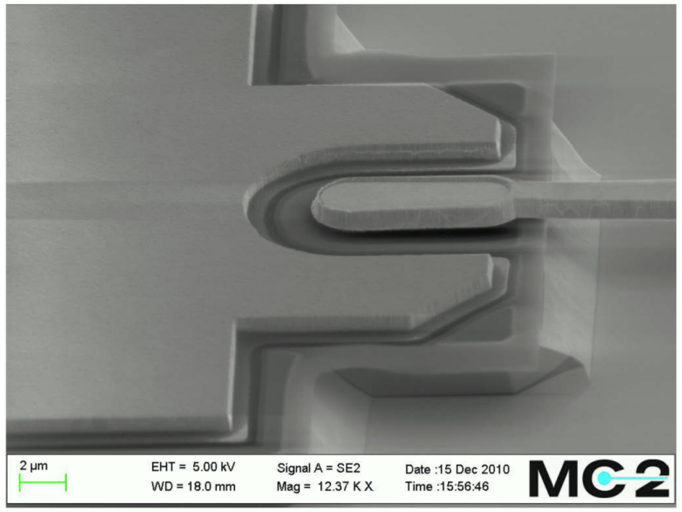

Medical Imaging
image courtesy of Teraview Ltd.
1.00
0.93
0.86
0.79
0.72
0.65
0.58
0.51
0.44
0.37
0.30
0.23
0.16
0.09
0.02
-0.05
-0.12
-0.19
-0.26
-0.33
-0.40
improve medical imaging
diagnose skin cancer
spot tooth erosion earlier than x-rays

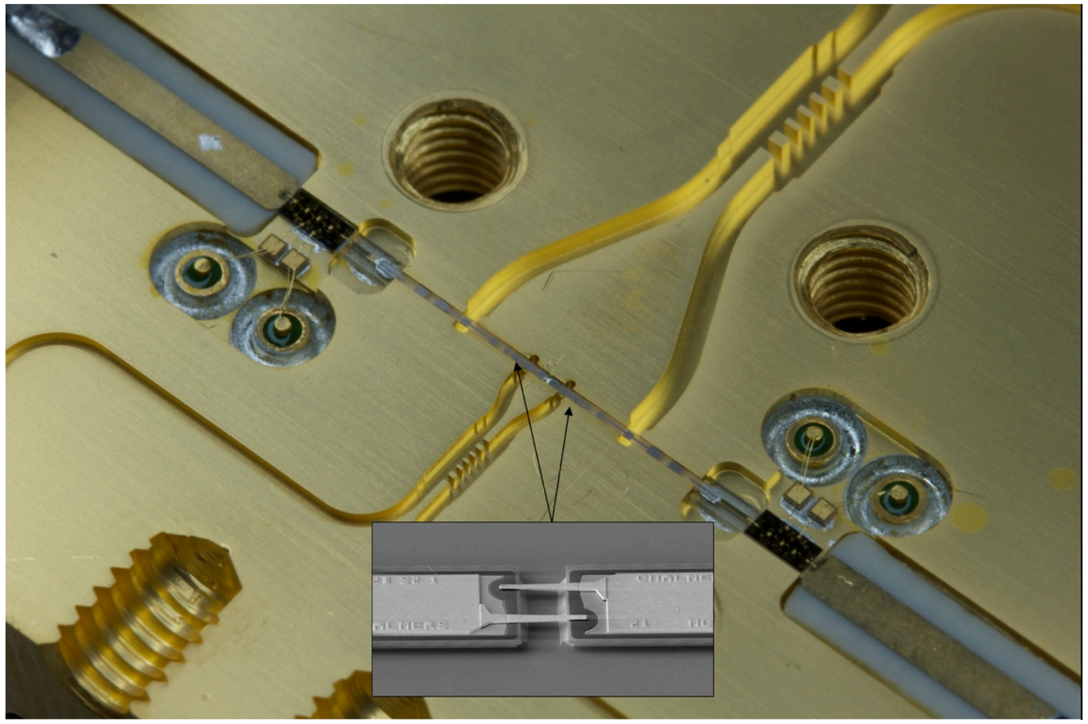
THz technology - research activities at Chalmers

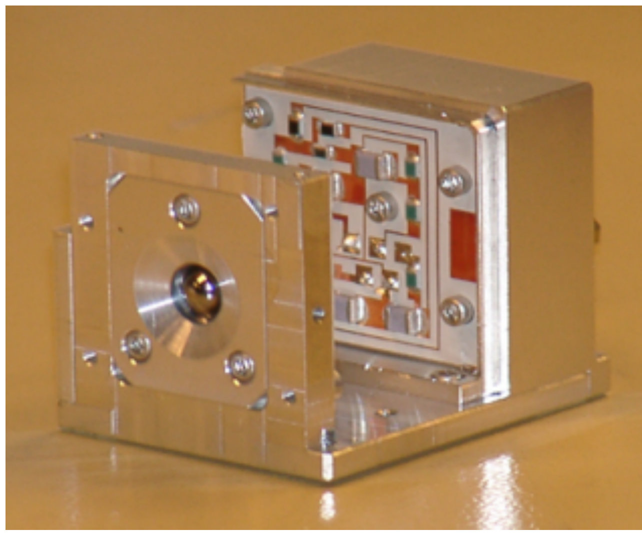


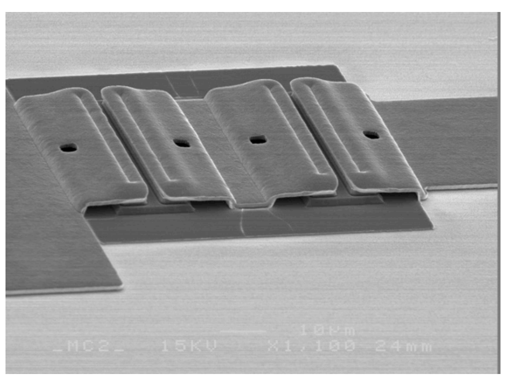


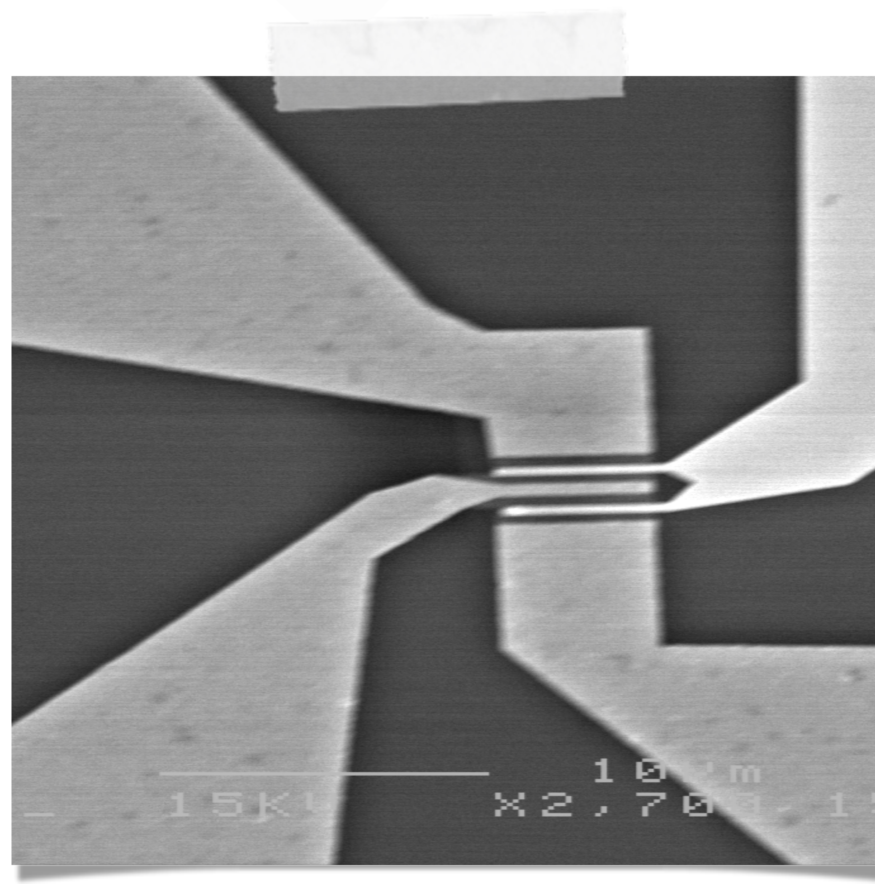


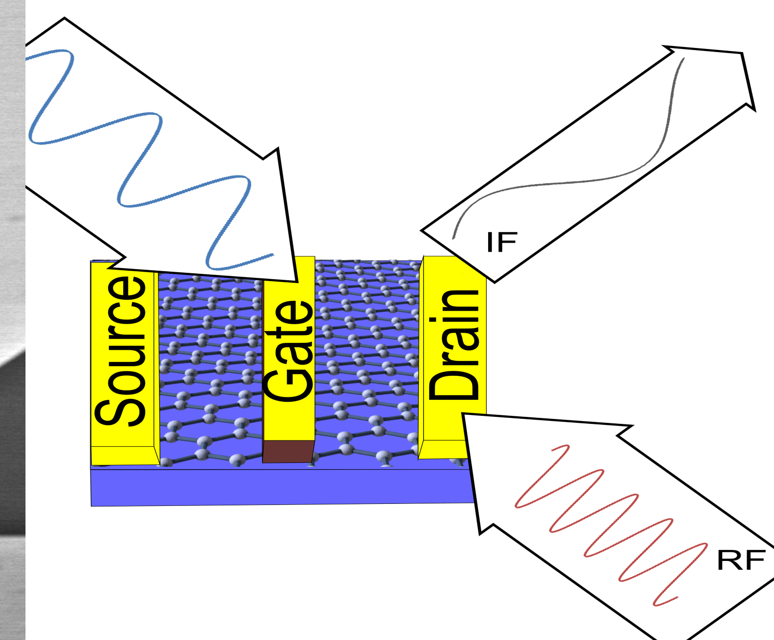

2 µm
EHT = 5.00 kV
WD = 18.0 mm
Signal A = SE2
Mag = 12.37 K X
Date :15 Dec 2010
Time :15:56:46
MC2

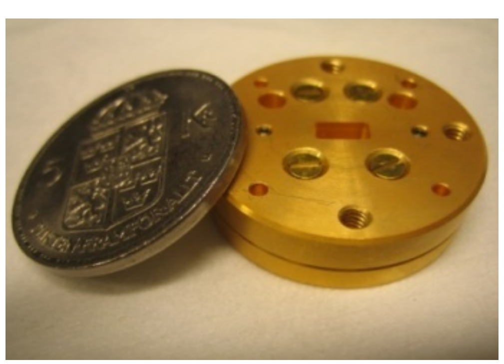






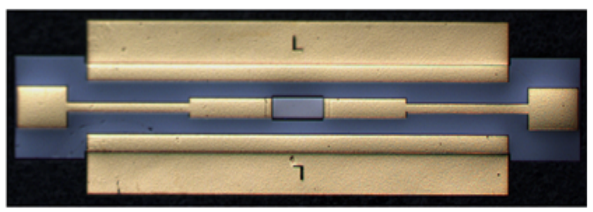


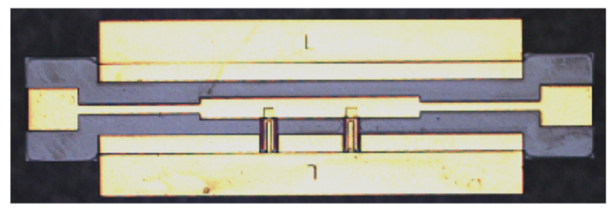

IF
Source
Gate
Drain
RF

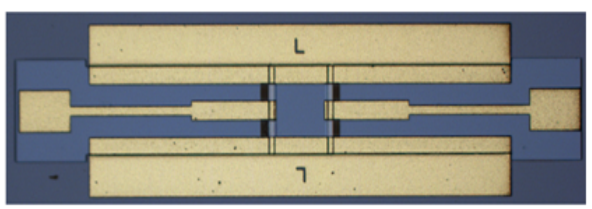


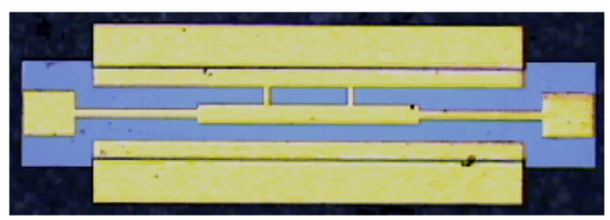
Membrane circuit technology

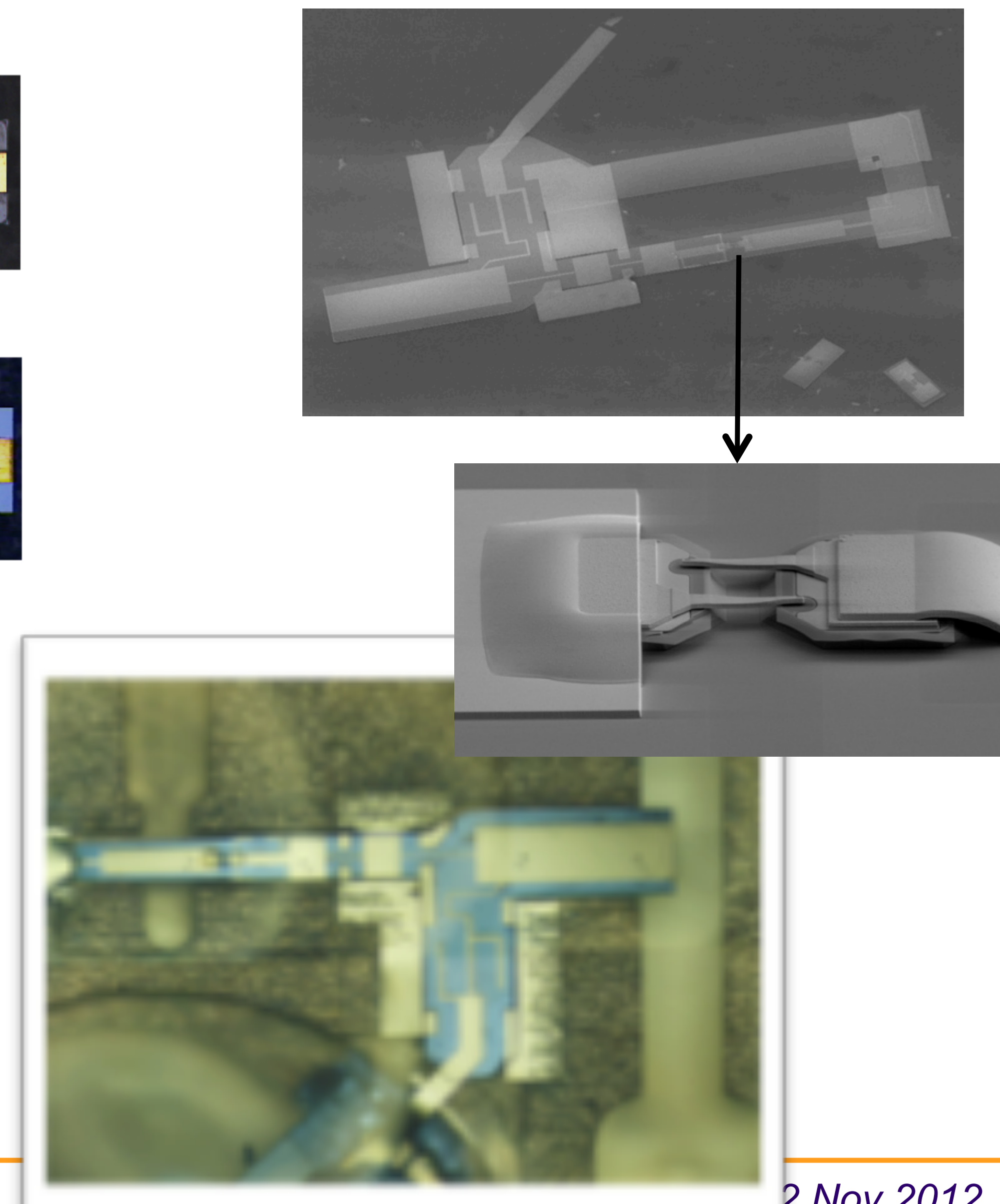
THz MMICs: Fabricating integrated circuits on 3 µm thick GaAs. Low parasitics & superior process control.

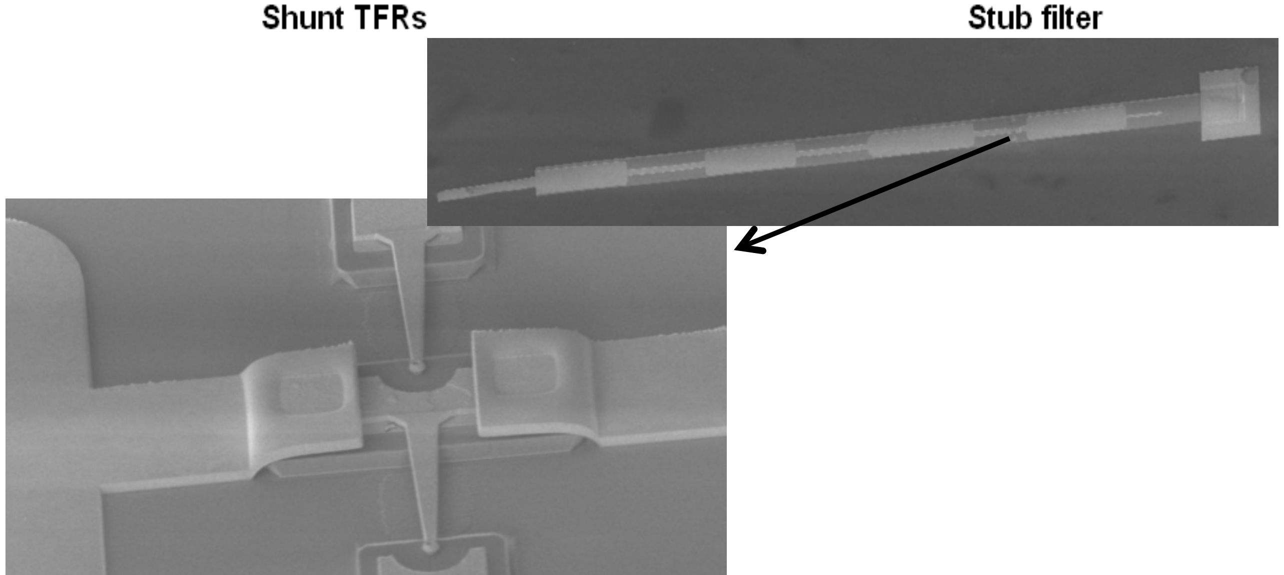

Series TFR


TFC

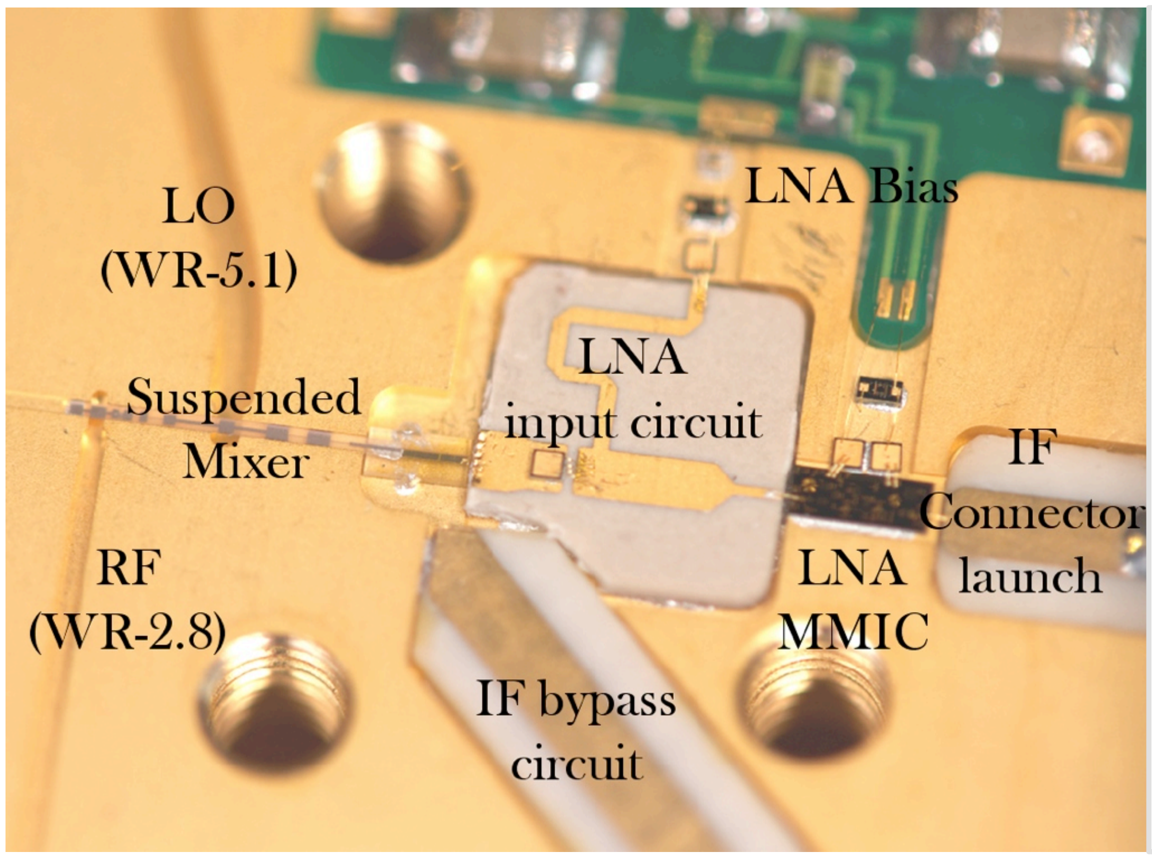

Shunt TFRs

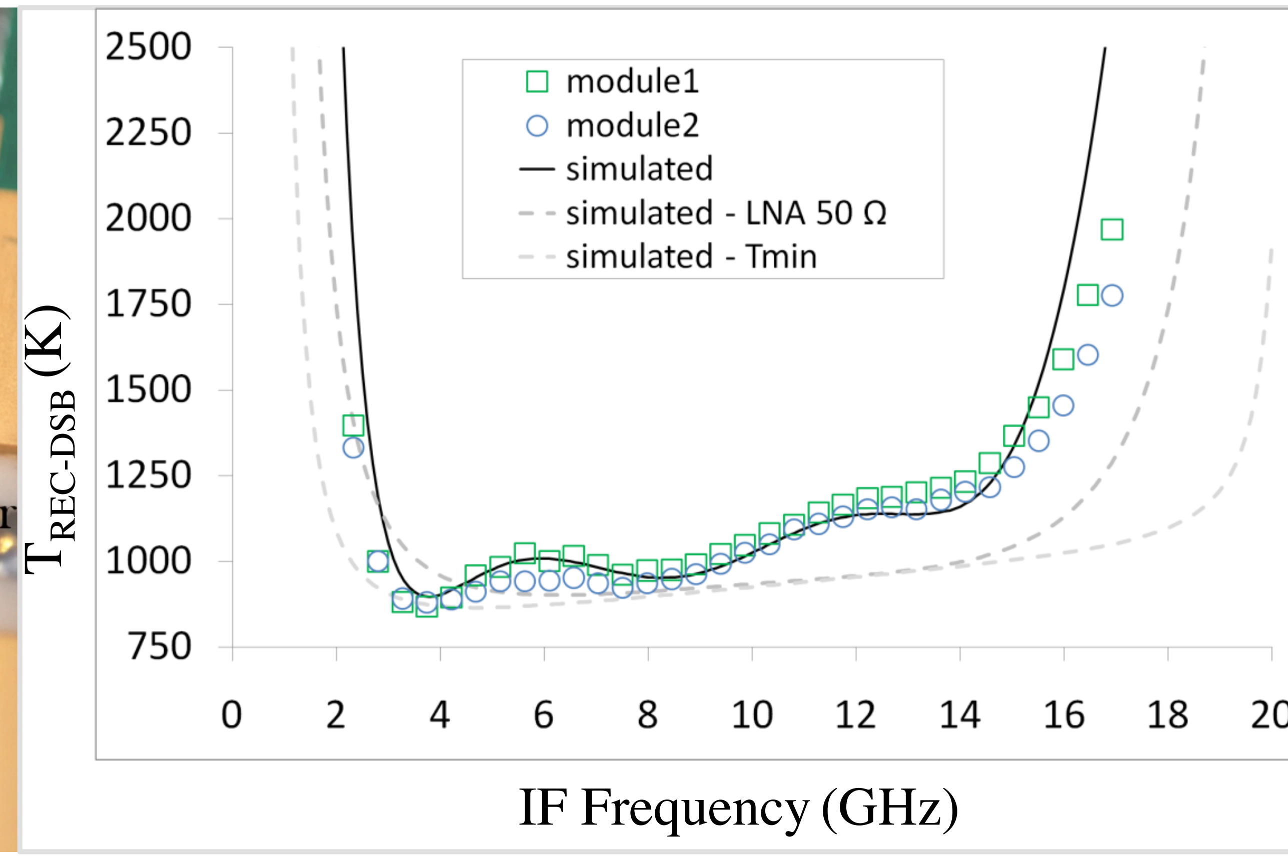

Stub filter





STEAMR Integrated 340 GHz Receiver Module





- **340 GHz Hybrid Schottky Mixer**
- **3-16 GHz m-HEMT LNA MMIC (NF=0.7dB)**
- ➢ **Need for close integration, co-design!**

P. J. Sobis, N. Wadefalk, A. Emrich, and J. Stake, "A Broadband, Low Noise, Integrated 340 GHz Schottky Diode Receiver," *IEEE Microw. Wireless Compon. Lett.*, vol. 22, no. 7, pp. 366–368, Jun. 2012.

EuMW 2012

More advanced circuit topologies

IEEE TRANSACTIONS ON TERAHERTZ SCIENCE AND TECHNOLOGY, VOL. 1, NO. 2, NOVEMBER 2011 403

A Low VSWR 2SB Schottky Receiver

Peter J. Sobis, *Student Member, IEEE*, Anders Emrich, and Jan Stake, *Senior Member, IEEE*

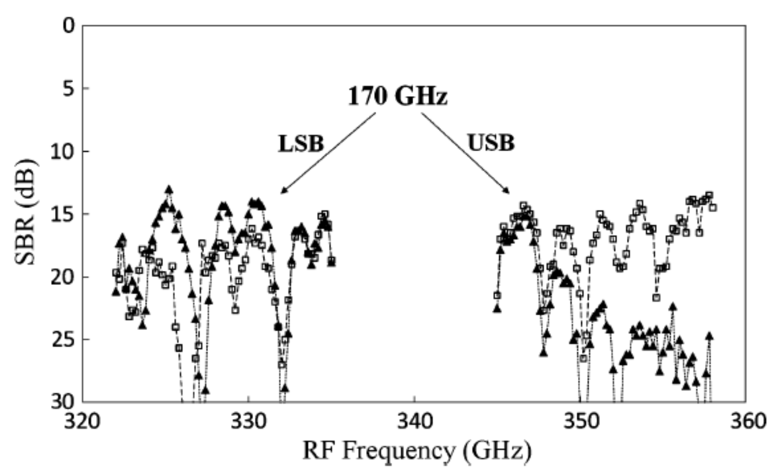


Fig. 9. Measured image rejection in a 5–18 GHz IF frequency range, at an LO drive of 6 mW at 170 GHz, for nominal IF system setup (▲) and for the case of flipping the IF system IQ-interconnects (□).

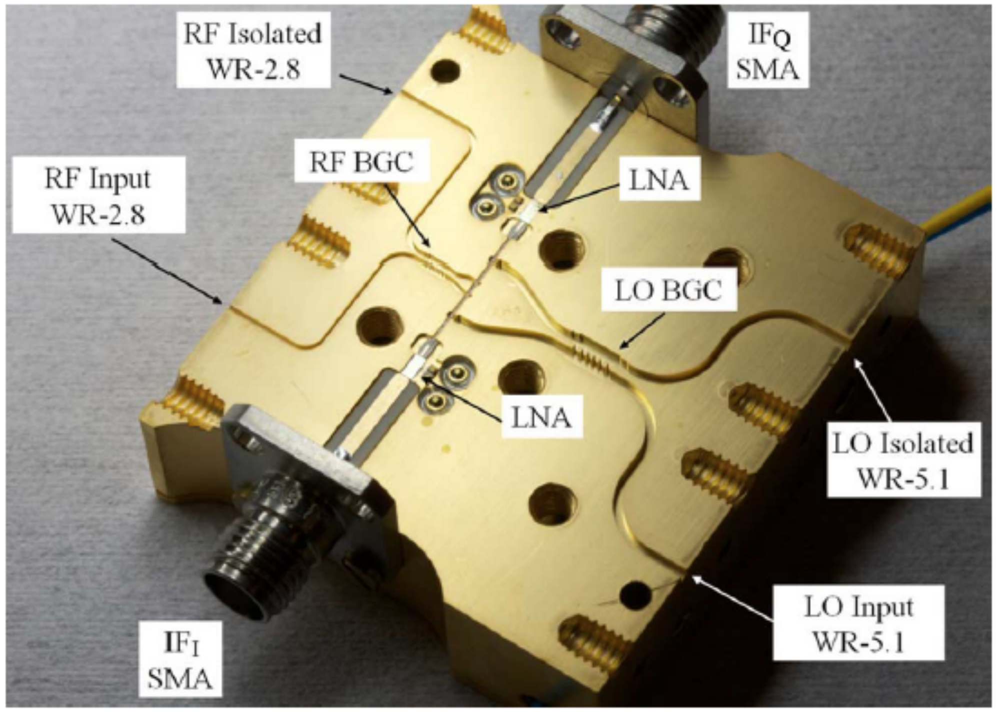
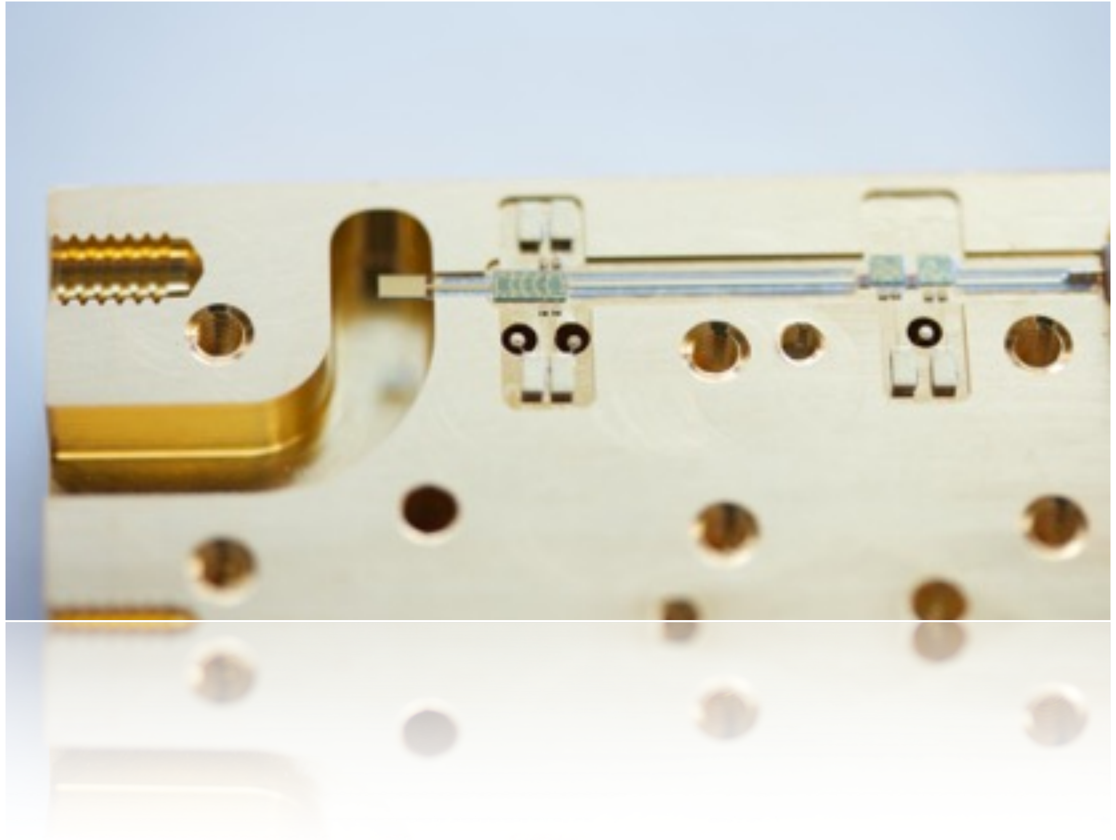
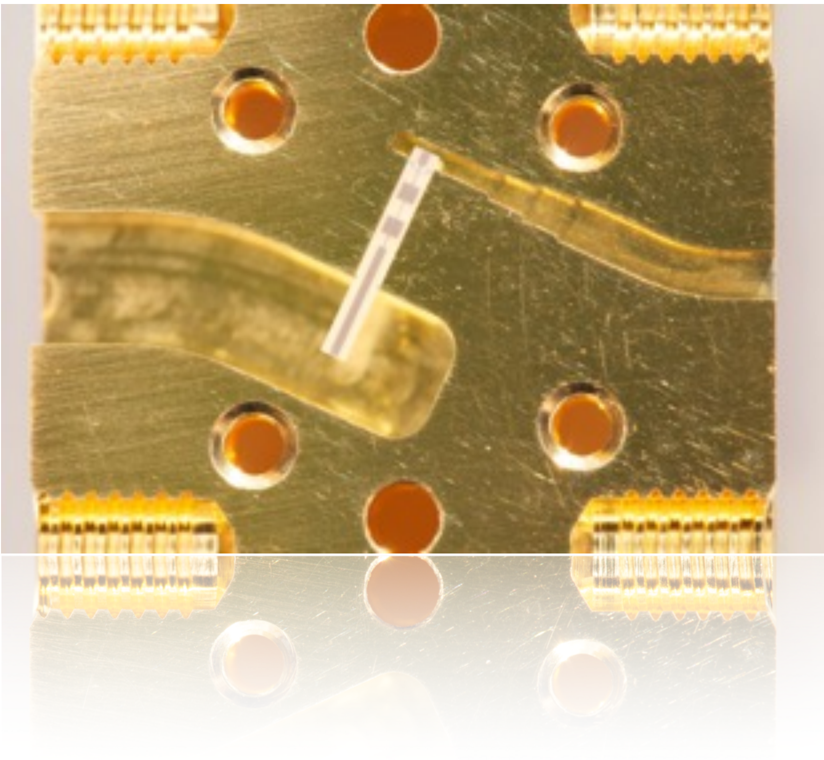


Fig. 4. Photo of the 2SB receiver module split block assembly, the module outer dimensions are roughly 40 by 40 mm.

Higher circuit functionality: Need for advanced integration techniques, including passive elements (R/L/C), and high yield.





THz

100 GHz MMIC packaging

MCC121 - Microwave engineering

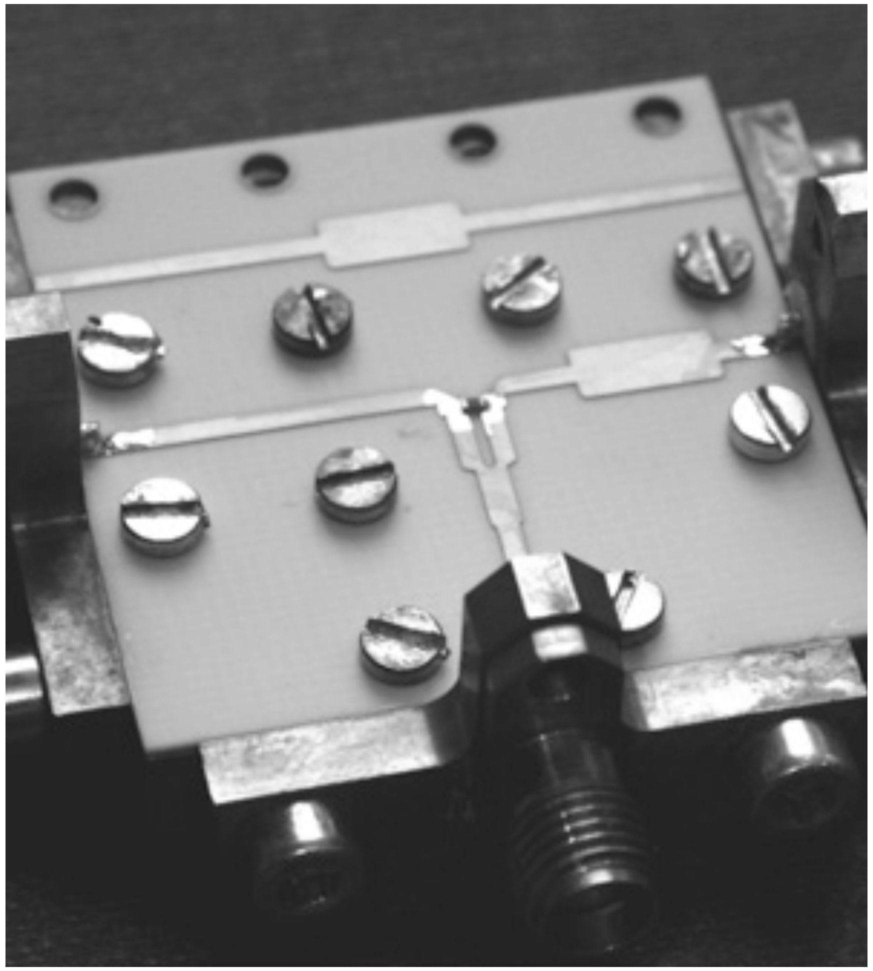
- Based on MCC120 - Foundations for microwave engineering
- Strong heritage: Challenging - Rewarding
- Examiner: Professor Jan Stake, Terahertz and millimetre wave laboratory, MC2. Room: D615. jan.stake@chalmers.se

MCC121 - Microwave engineering

- Lectures: JS, Vincent Desmaris, Klas Yhland
- Tutorials: Arvid Hammar & Sascha Kraus
- Labs: Evgenii Novoselov, Parisa Aghdam

Aim

- ☑ *Microwave way of thinking*



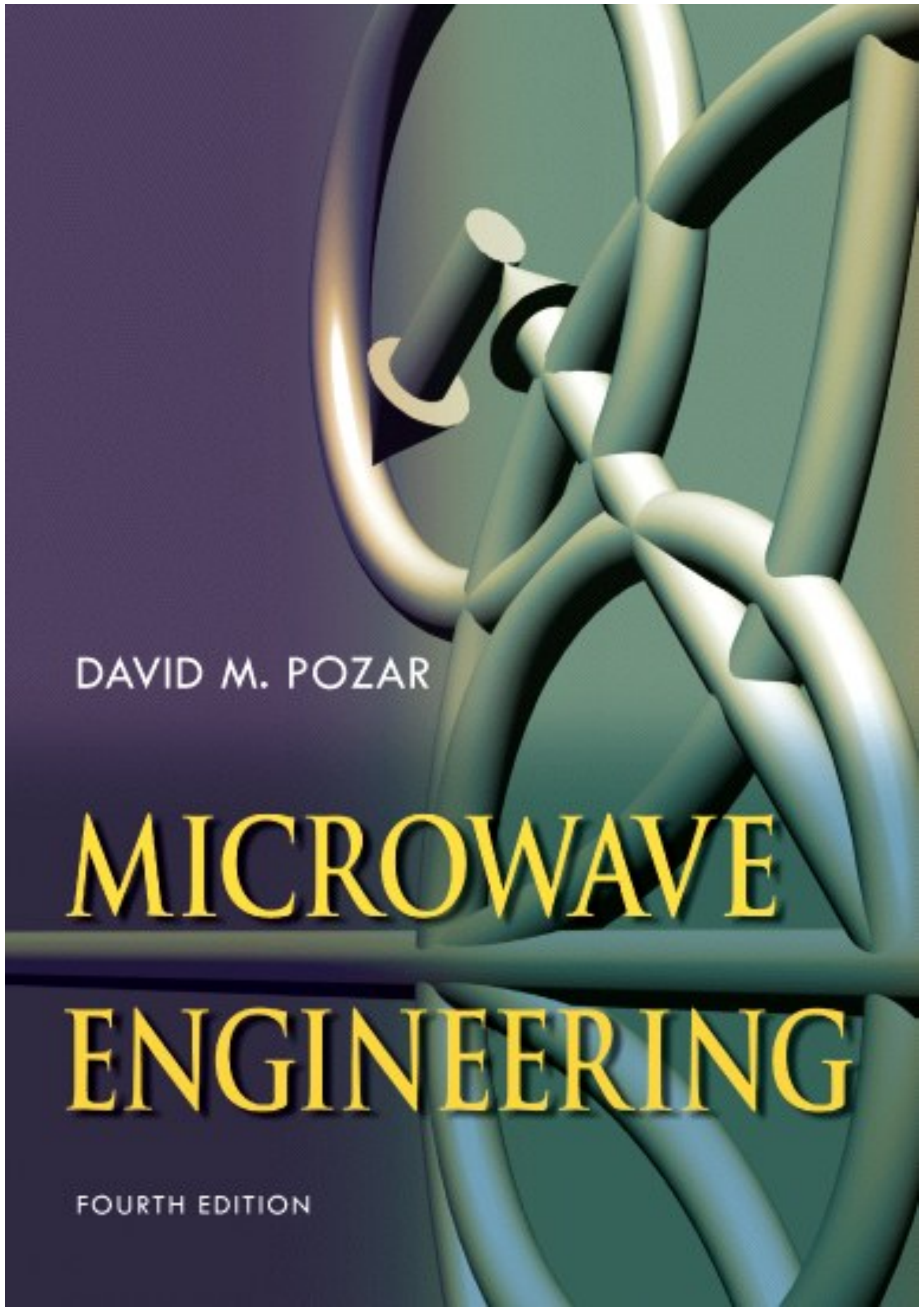
Objectives

On completion of this course unit you should be able to:

1) Analyse wave propagating properties of guided wave structures (TE, TM, TEM waves, microstrip, stripline, rectangular and circular waveguides, coupled lines)
2) Apply N-port representations for analysing microwave circuits
3) Apply the Smith chart to evaluate microwave networks
4) Design and evaluate impedance matching networks
5) Design, evaluate and characterise directional couplers and power dividers
6) Design and analyse attenuators, phase shifters and resonators
7) Explain basic properties of ferrite devices (circulators, isolators)

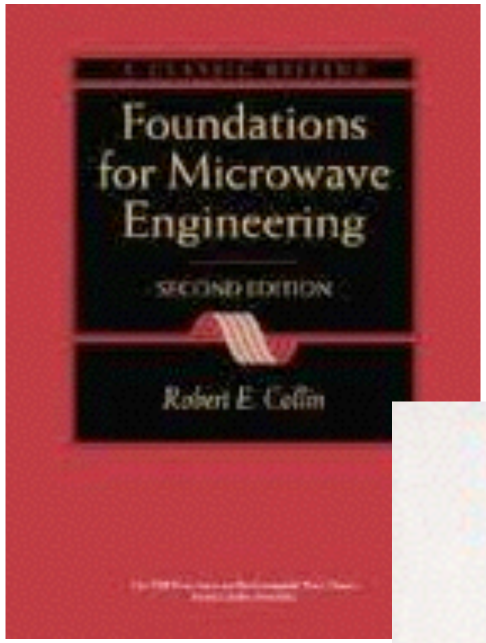
Literature

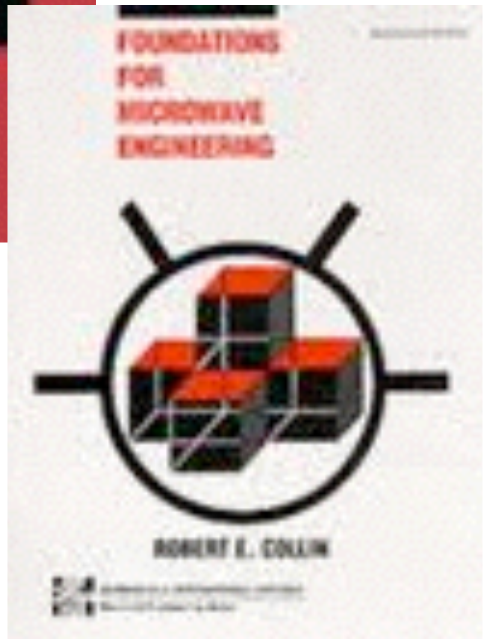
Microwave Engineering, 4th ed,
by David M. Pozar



Additional reading

Foundations for microwave engineering, by Robert E. Collin





This book has been used in the past, and serves well as a good reference for the microwave engineer.

Organisation

- Lectures and classes (MC2-building, Kollektorn)
- Three labs (Design and test your passive microwave circuit, + 3D EM lab)
- Visit to Omnisys!? to be announced
- One assignment
- Written exam (16/1)

ping-pong

- Learning management system
- All material will be available via ping-pong
  - https://pingpong.chalmers.se/login/
- Hand-outs are usually posted in ping-pong after the lecture
- WWW links, with relevance for your future career

MTT-S®

microwave road

Lectures and tutorials

- Check schedule! but mainly as:
  - Lectures (Jan, Vincent, Klas),
    - Tuesdays 13:15-15:00 in A423
    - Thursdays 13:15-15:00 in A423
  - Tutorials (starts from Thursday with Arvid)
    - Tuesdays 15:15-17:00 in A423
    - Thursdays 15:15-17:00 in A423
- Guest lecture on measurement techniques by Dr. Klas Yhland (11/12).

Lectures - tentative schedule

w45	**4/11**	**L1**	**Introduction (Ch1)**
	4/11	**L2**	**Transmission lines theory, Smith Chart (Ch2)**
w46	11/11	L3	Transmission lines and waveguides (Ch3.1-3,5)
	13/11	L4	Transmission lines and waveguides (Ch3.6-3.11)
w47	18/11	L5	Circuit theory / Matrix representations (Ch4)
	20/11	L6	Impedance matching (Ch5.1-5.4)
	20/11	L7	Impedance transformers (Ch5.5-5.9)
w48	25/11	L8	Attenuators, loads, basic properties of power dividers and couplers
	28/11	L9 (VD)	Microwave resonators (Ch 6)
w49	2/12	L10	Directional couplers (Ch7)
w50	9/12	L11	Periodic structures (Ch8.1)
	11/12	L12 (KY)	Microwave measurement techniques (guest lecture)
w51	16/12	L13 (VD)	Isolators, circulators, ferrites (Ch 9)
	18/12	L14	Reserve

Labs and assignments

- Design of a branch line coupler (microstrip lines). Week 4
- Measurements in week 6
- 3D EM Lab (hollow waveguides, Chebyshev transformers, etc)
- Assignment - impedance matching. Week 4
- To be posted...

Lab 3: 3D EM demo

- Introduction to EM software (Ansoft HFSS), ca 45 minutes. Parisa Aghdam
- Friday, 7/11, 1315!

Course representatives

- Course representatives

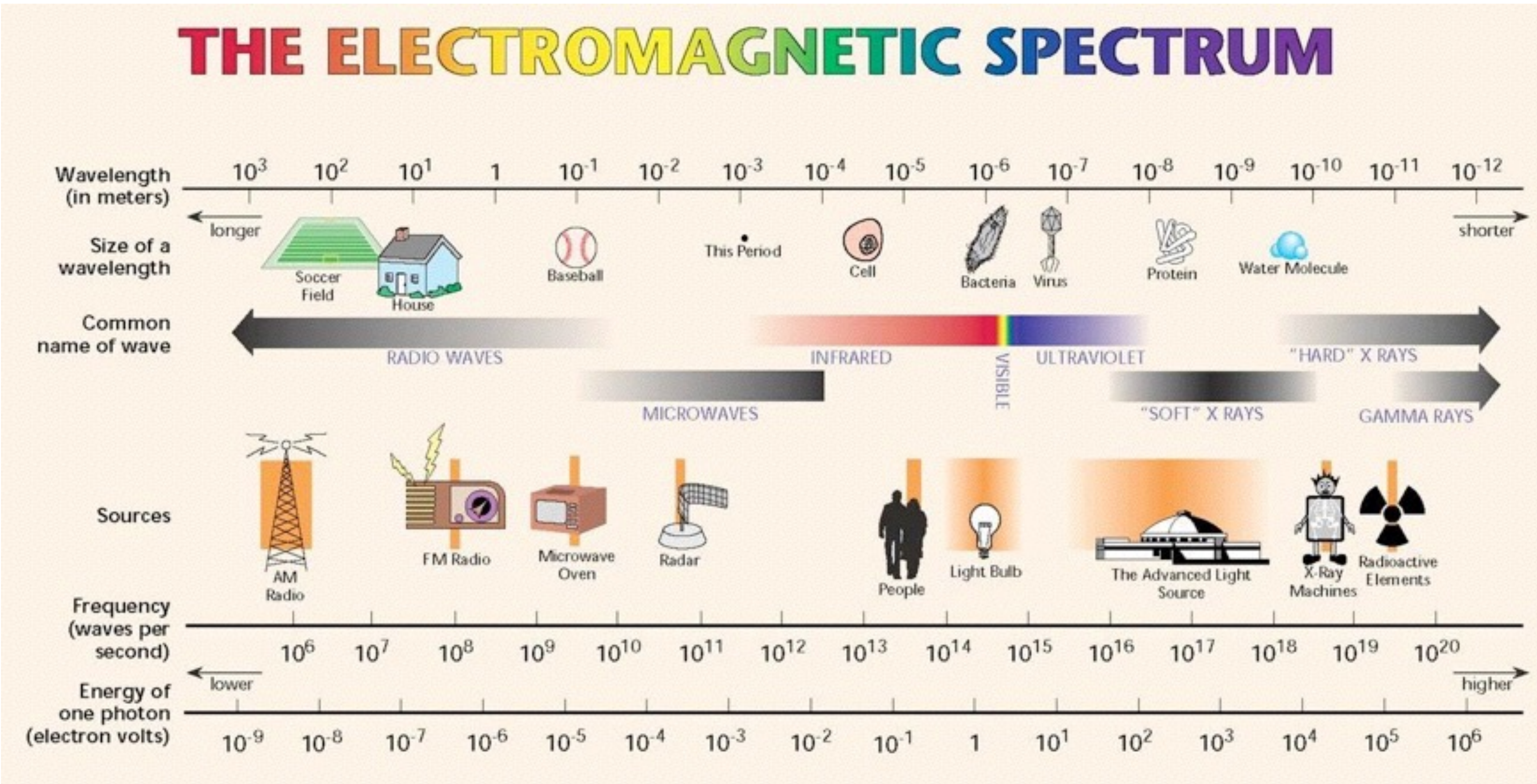
Course representatives for MCC121 Microwave engineering, Study Period 2 2014

MPWPS	uttam@student.chalmers.se	UTTAM NANDI
MPWPS	stafylas@student.chalmers.se	THOMAS STAFYLAS
MPWPS	teleanu@student.chalmers.se	ELENA LUIZA TELEANU
MPWPS	yaxin@student.chalmers.se	ZHANG YAXIN

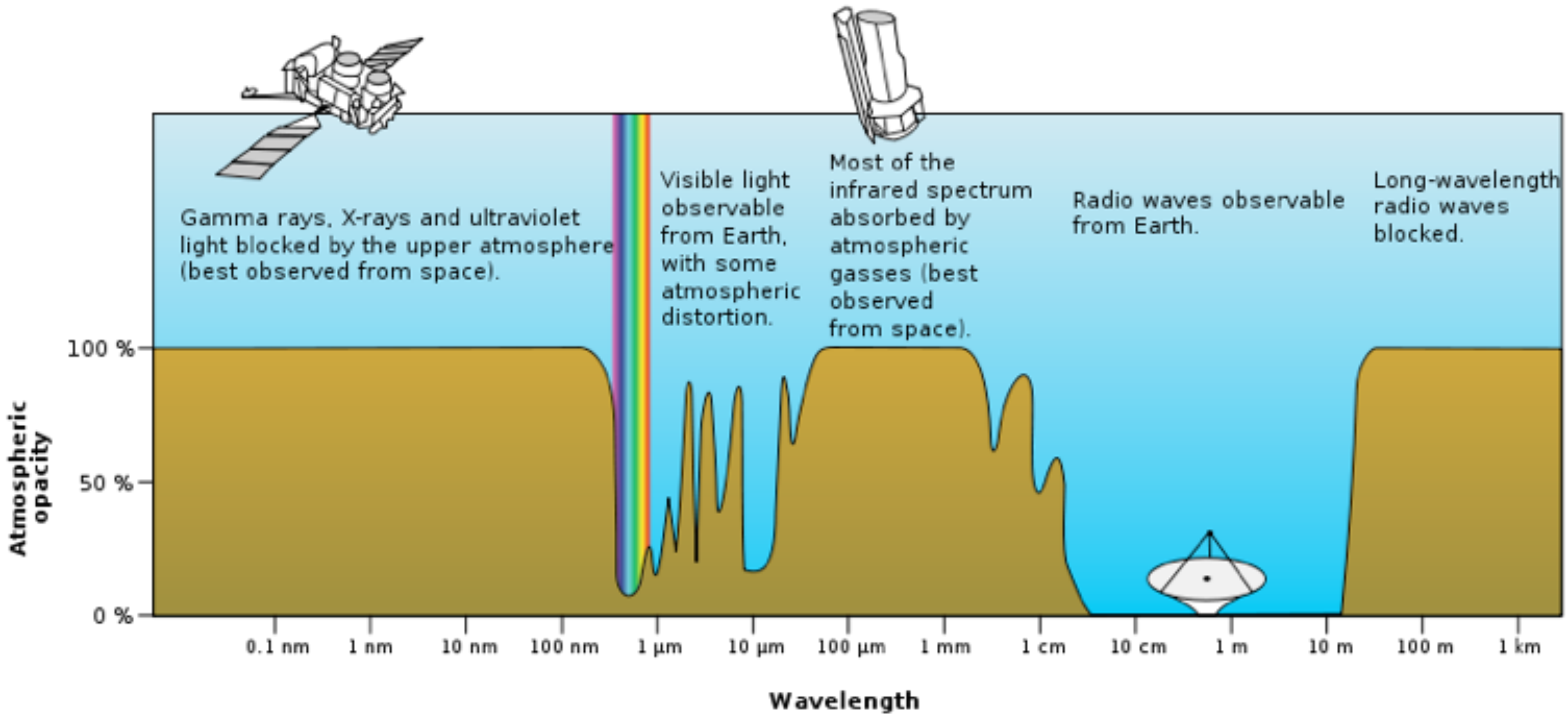
- Meetings
  - Course Week 1
  - Course week 3-4
  - After examination (Early next year)

Examination MCC121 - 7.5 hec

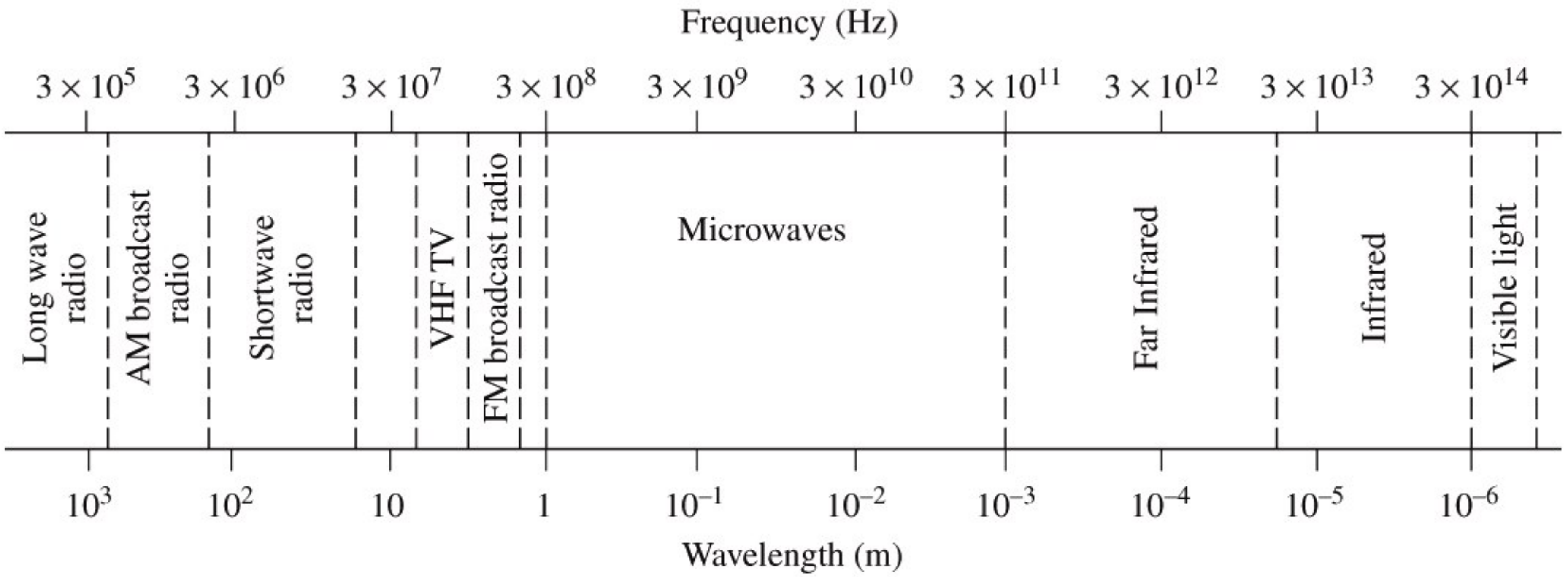
- List of compulsory tasks:
  - Lab 1-3 : Pass/Not passed
  - Assignment: 10p (Pass $\geq$4p)
- Written exam: 6x10p=60p (Pass $\geq$24p)
- Total number of points: 70p. Note! Bonus from assignment only counted at first exam.
- You need to pass each task described above
- Final grades: 3 ($\geq$28p), 4($\geq$42p) and 5 ($\geq$56p)



The EM spectrum



Microwave applications



Typical Frequencies

AM broadcast band	535–1605 kHz
Short wave radio band	3–30 MHz
FM broadcast band	88–108 MHz
VHF TV (2–4)	54–72 MHz
VHF TV (5–6)	76–88 MHz
UHF TV (7–13)	174–216 MHz
UHF TV (14–83)	470–890 MHz
US cellular telephone	824–849 MHz
	869–894 MHz
European GSM cellular	880–915 MHz
	925–960 MHz
GPS	1575.42 MHz
	1227.60 MHz
Microwave ovens	2.45 GHz
US DBS	11.7–12.5 GHz
US ISM bands	902–928 MHz
	2.400–2.484 GHz
	5.725–5.850 GHz
US UWB radio	3.1–10.6 GHz

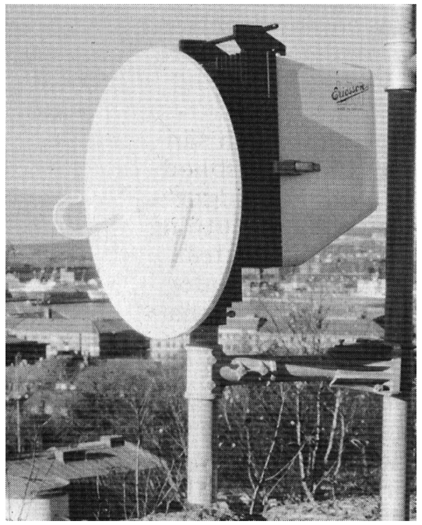
Approximate Band Designations

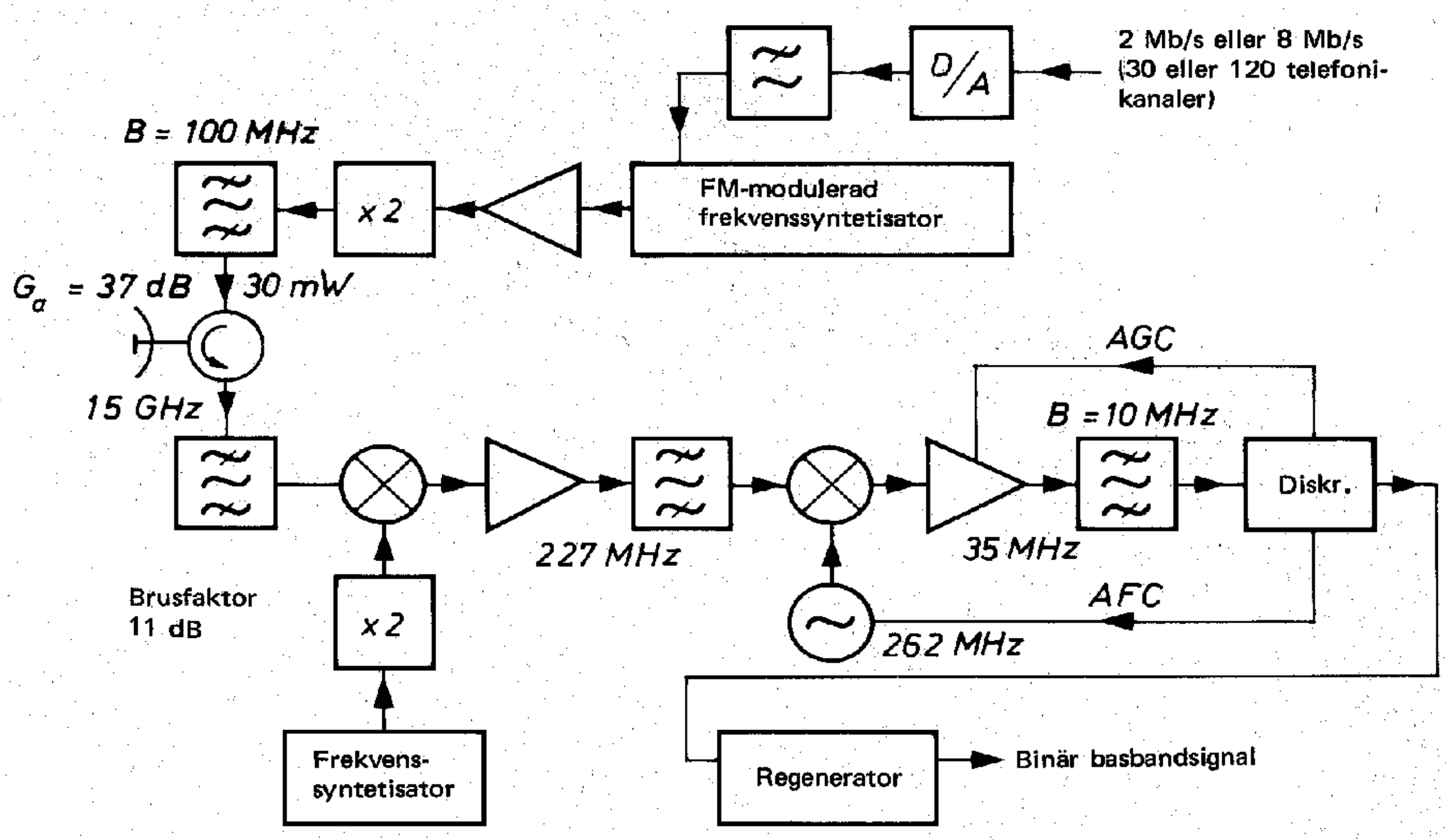
Medium frequency	300 kHz–3 MHz
High frequency (HF)	3 MHz–30 MHz
Very high frequency (VHF)	30 MHz–300 MHz
Ultra high frequency (UHF)	300 MHz–3 GHz
L band	1–2 GHz
S band	2–4 GHz
C band	4–8 GHz
X band	8–12 GHz
Ku band	12–18 GHz
K band	18–26 GHz
Ka band	26–40 GHz
U band	40–60 GHz
V band	50–75 GHz
E band	60–90 GHz
W band	75–110 GHz
F band	90–140 GHz

Figure 1.1

communication links

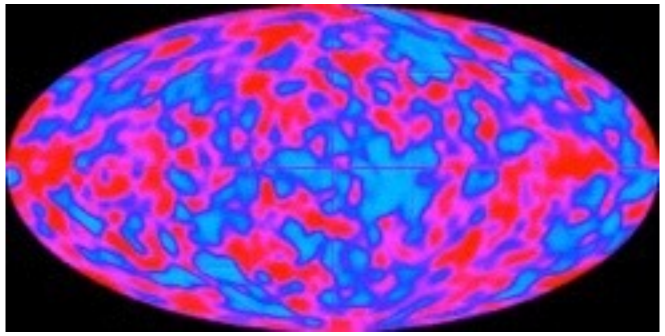
example: point-to-point data link





other

- RADARs for safety and security
  - Weather
  - Traffic control
  - Military applications
  - Cars
- Heating (industrial, medical, food)
- High speed data transfer
- Science (radio astronomy, atmosphere)



Cosmic microwave background - Noble prize 2006

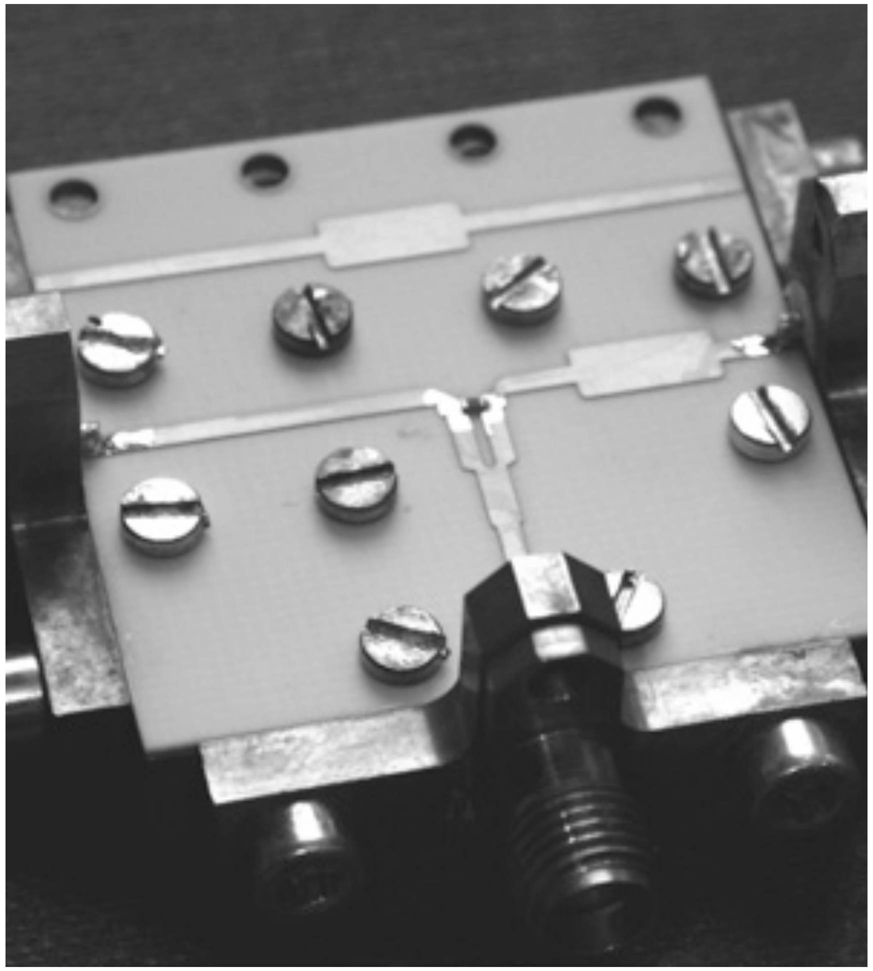
Microwaves?

Microwave engineering

- RF/Microwaves (0.3 - 30 GHz)
  - $\lambda \in (1\text{cm}, 1\text{m})$
- Millimetre waves (30 - 300 GHz)
  - $\lambda \in (1\text{mm}, 10\text{mm})$
- Sub-millimetre waves (0.3 - 3 THz)
  - $\lambda \in (0.1\text{mm}, 1\text{mm})$

Aim

- ☑ *Microwave way of thinking*



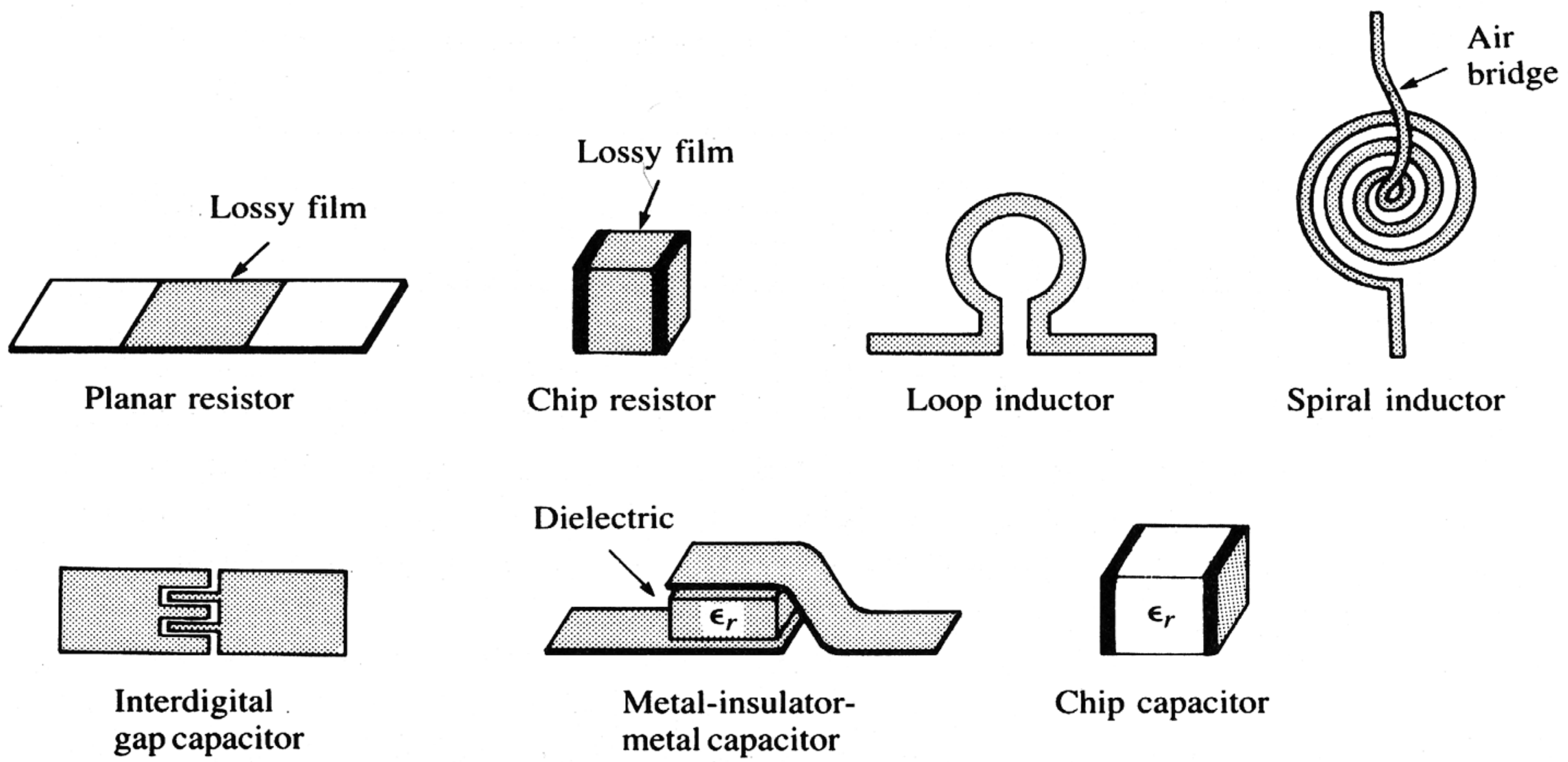
Microwave way of thinking

- short wavelengths -> same order of magnitude as the circuit elements and devices employed
  - jump between EM / Equivalent circuits
- calculates everything in dB
- and like to use Smith charts for almost everything

Frequency	**Type of components**
f<xx GHz	lumped ($\lesssim \lambda/10$)
f >xx GHz	distributed

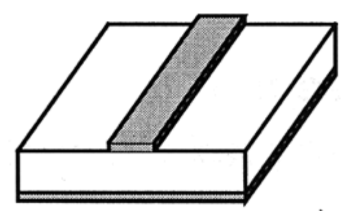
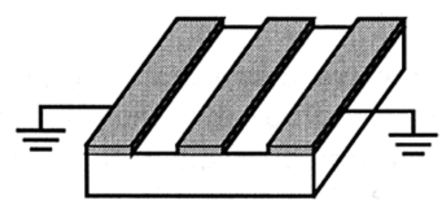
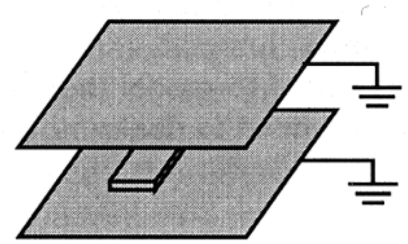
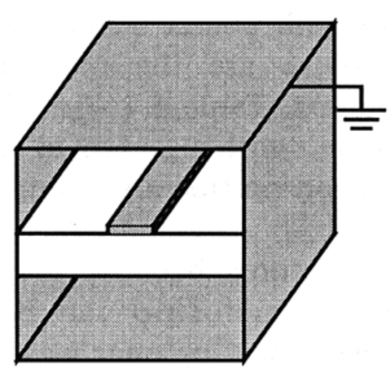
- short wavelength gives propagation time comparable with the period of the propagating wave
- Kirchhoff's laws are not applicable, standard voltage-current concepts are no longer sufficient (but still convenient...)

Lumped (discrete) components

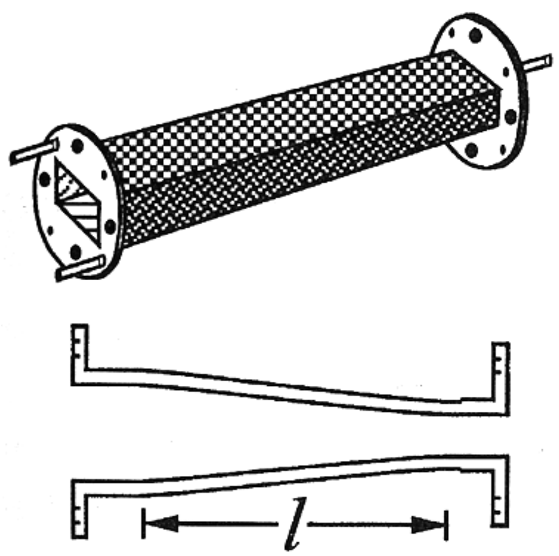


Parasitics: equivalent circuit becomes more complicated as frequency increases

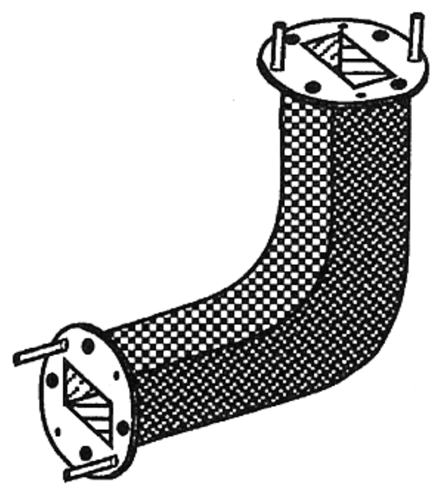
Distributed components
Transmission lines

Transmission Line	Structure	Properties
Microstrip		The most common type of transmission line, suitable for both hybrids and monolithic circuits. Moderately dispersive at high frequencies. See Section 1.3.3.
Coplanar waveguide (CPW)		Somewhat lossier and more dispersive than microstrip, but minimizes the parasitic inductance of ground connections. Good transition to coaxial lines. Spurious slotline and microstrip modes are possible. See Section 1.3.4.
Stripline		Does not allow convenient mounting of discrete circuit elements; best for passive components. Difficult to cascade with microstrip or other planar transmission lines. Low loss, TEM, good transition to coax. See Section 1.3.5.
Suspended-substrate stripline (SSSL)		Similar to stripline, but easier to fabricate in many types of circuits. Low loss, low effective dielectric constant, good transition to coax. Waveguide-like modes can be a problem. See Section 1.3.6.

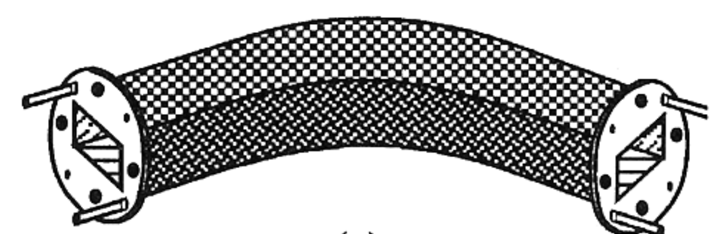
Distributed components
Waveguides



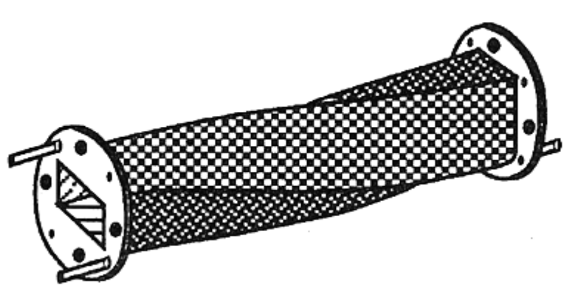
(a)

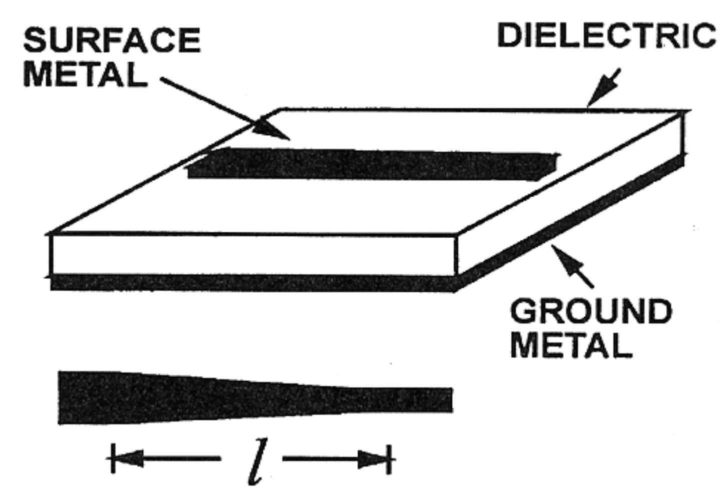


(b)



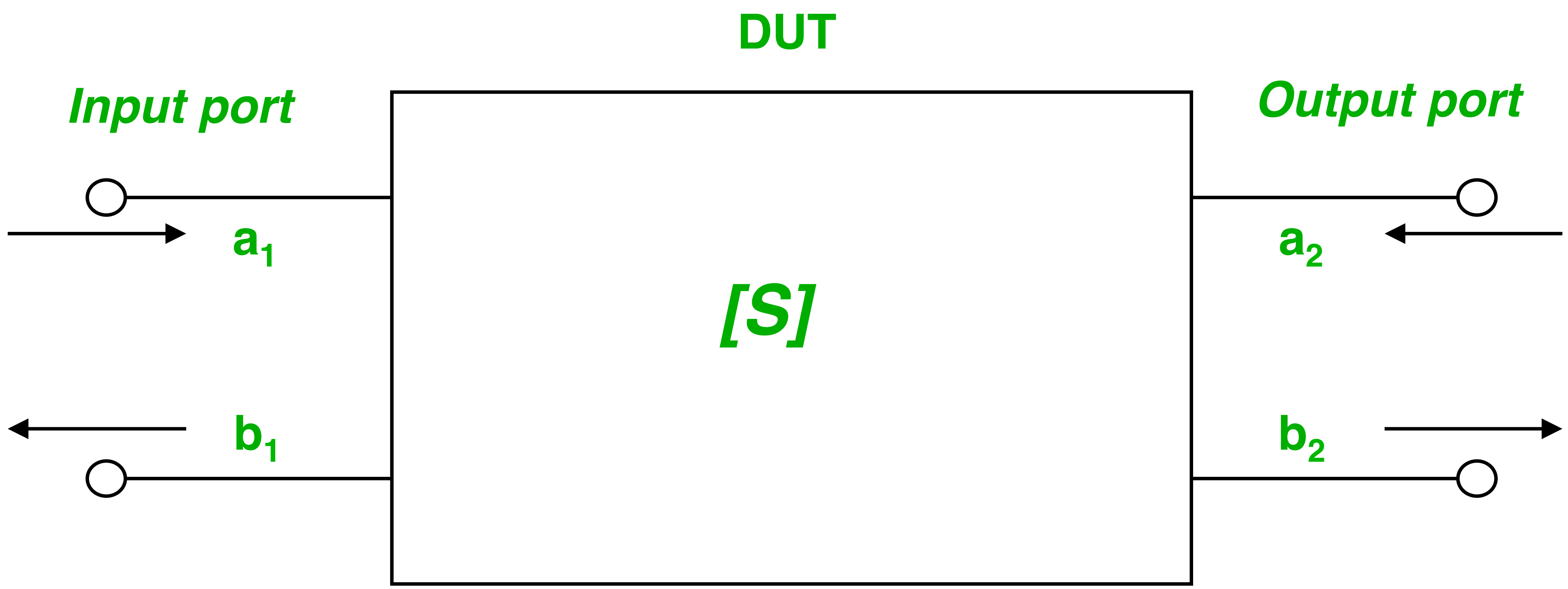
(c)



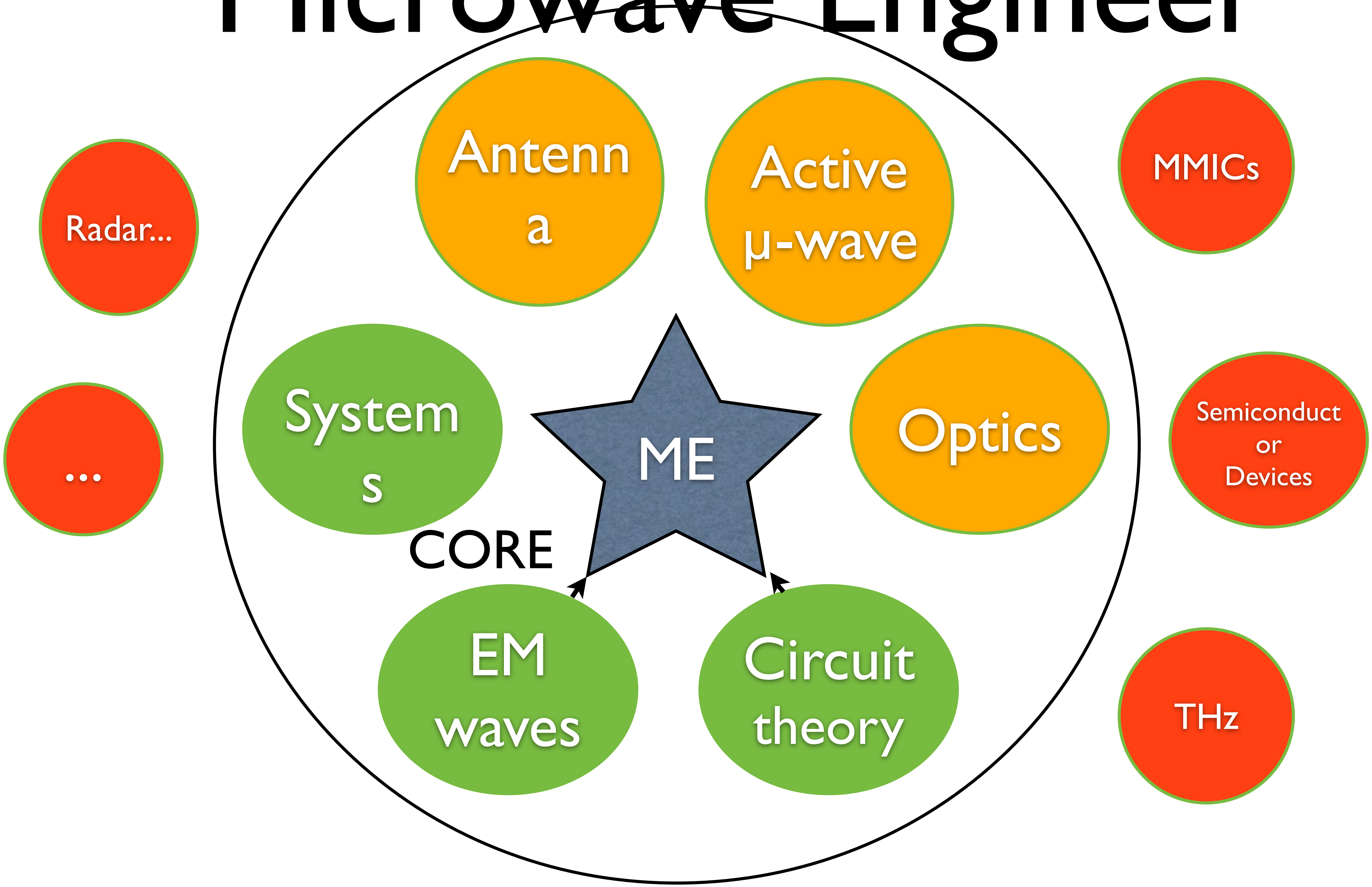


Scattering parameters

for analysis and characterisation



Microwave Engineer



Microwave Engineering (ME) in a context

History of Microwaves milestones

Maxwell's equations

$\nabla \cdot \mathbf{D} = \rho_f$ Gauss's law

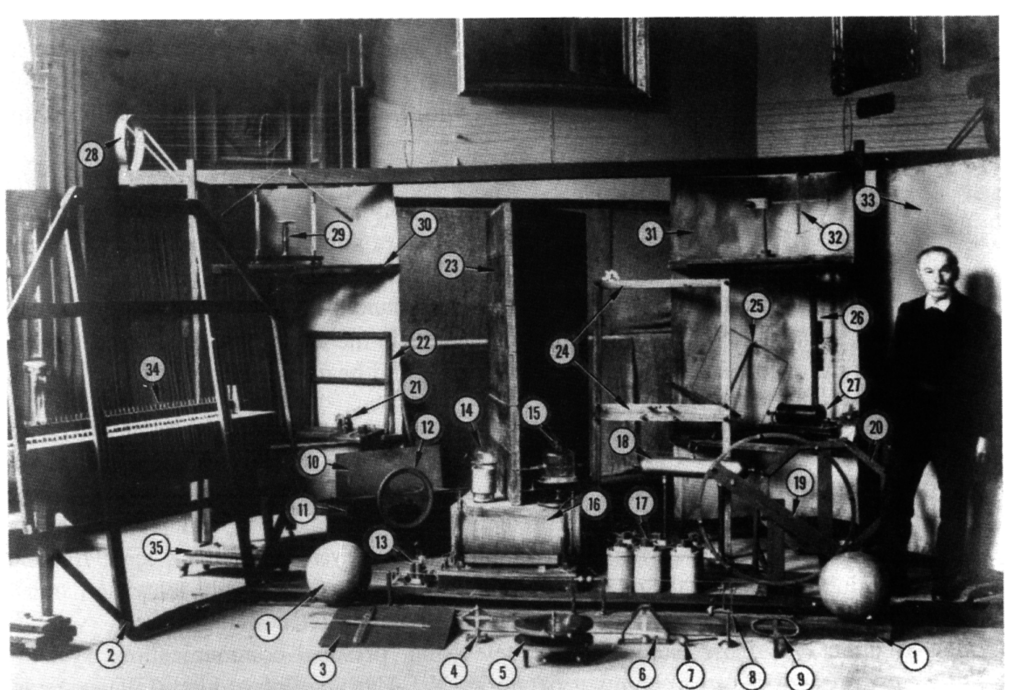
$\nabla \cdot \mathbf{B} = 0$

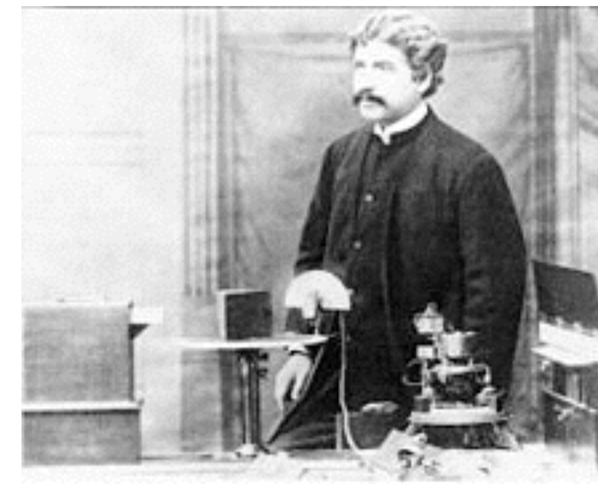
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ Faraday's law

$\nabla \times \mathbf{H} = \mathbf{J}_f + \frac{\partial \mathbf{D}}{\partial t}$ Ampere's law with Maxwell's correction

Experimental work (1880 - 1900)

Heinrich Hertz



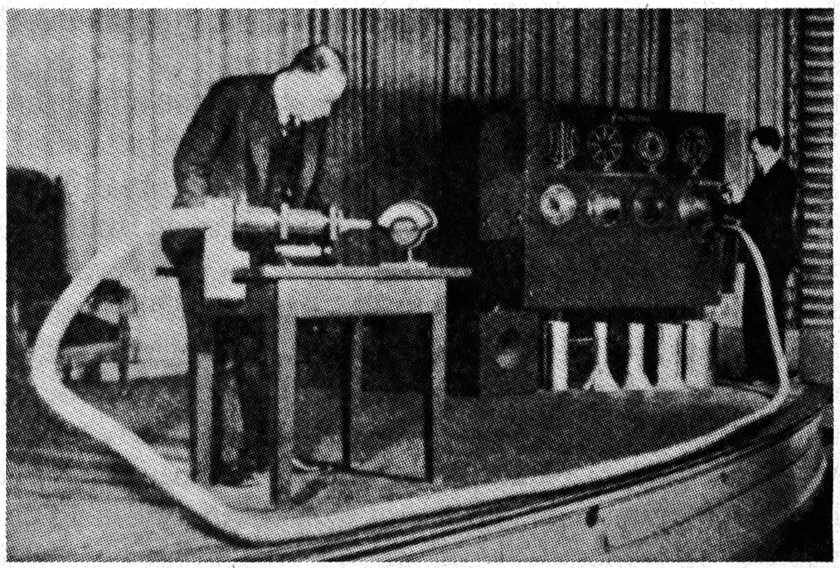


Jagadish Chandra Bose (horns, polarisers, semiconductors, detectors, even up to 60GHz

Theory for guided waves

John William Strutt = Lord Rayleigh
(1897), theory for waveguides

t<1939



G. Southworth (1932) & W. L. Barrow (1936), experiments with waveguides

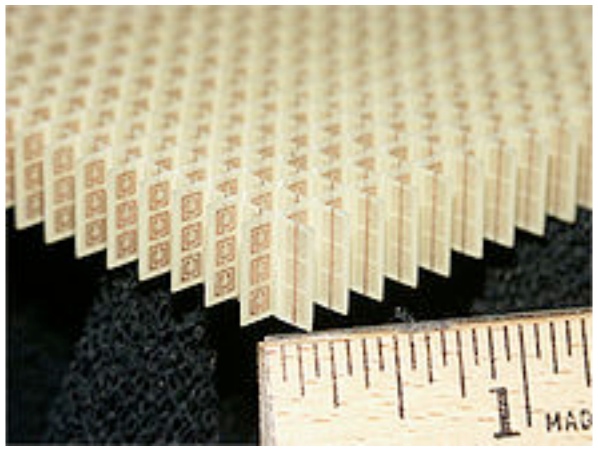
During WW2 (1939-1945)

- RADAR
- Magnetron
- Radiation laboratory, MIT
- Microwave Research Institute, Brooklyn, NY

Post WW2 (>1945)

- Planar transmission lines
- RF transistors BJT, FET, HEMT, HBT
- Integrated circuits: MMICs
- Direct Broadcasting Satellites
- Remote sensing
- Cellular telephony, WIFI, consumer electronics

Passive microwave research today



- Periodic structures! But called photonic band gaps and metamaterials...
- Miniaturised THz waveguides, antennas
- Filters, couplers, phase shifters, etc.
- EDA tools etc.

http://mtt.org

Summary of lecture 1

- Read chapter 1-2,
- Milestones of Microwaves
  - EM wave theory
  - Waves on transmission lines
  - Overview of microwave engineering