Advanced Wireless Communications, 2020

Academic course for 4th year engineering students

Sami Shamoon College of Engineering

Main course reference, Mazar ,Wiley book 2016 ‘Radio Spectrum Management: Policies, Regulations, Standards and Techniques’

RF: Regulation, RFI and Human Hazards

identifier DOI 10.13140/RG.2.2.29984.74247

1. International, Regional and National RF Spectrum Management
2. EMC and RFI
3. RF Human Hazards; EMF

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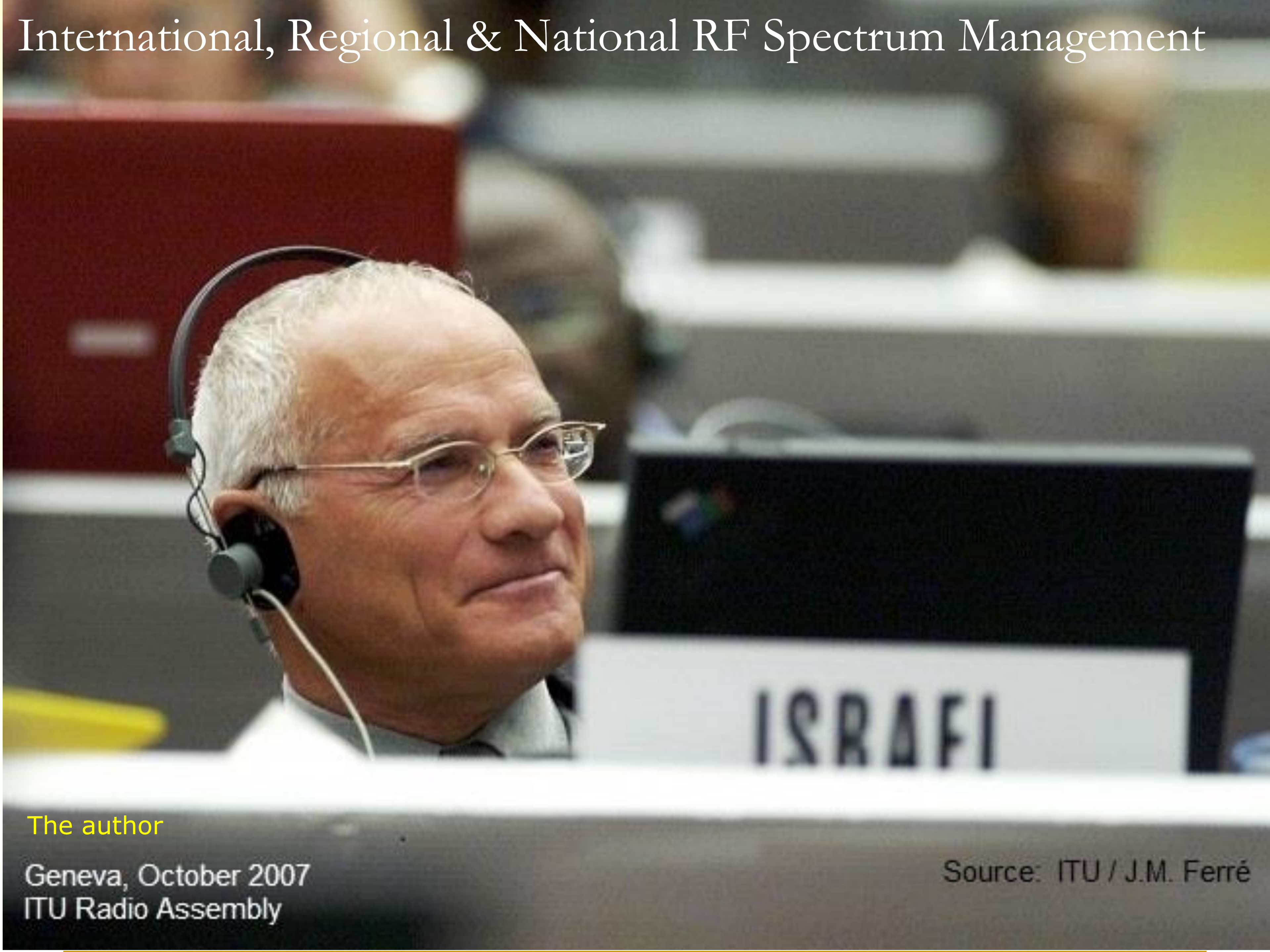
כל החומר בהרצאות הנו מקורי או 'שימוש הוגן ביצירות לצרכי הוראה ומחקר'

Last updated on
13 January 2022

Not all slides will be presented during the academic course

Dr. Haim Mazar (Madjar), ITU & World-Bank expert;
reelected vice-chair ITU-Radio Study Group 5 (terrestrial services)

International, Regional & National RF Spectrum Management



The author

Geneva, October 2007
ITU Radio Assembly

Source: ITU / J.M. Ferré

Items which need to be regulated

1. RF allocations to radio services; follow ITU Radio Regulations
2. Assignment of licence and RF to Tx Stations
3. Fee collection: RF License & annual fees
4. Equipment Type approval (?!); EU RED is liberal
5. Coordination with neighbour countries (no borders to the ElectroMagnetic waves)
6. Notifying ITU to the Master International Frequency Register (MIFR) e.g. http://www.itu.int/ITU-R/eBCD/ePub.aspx
7. External relations: toward ITU, International and Regional orgs see http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 179

Roles of the National Spectrum Management

See https://mazar.atwebpages.com/Downloads/ITU_RRS22AsiaSpectrumManagementMazarKeyNotePresentationFiji19Dec22.pdf

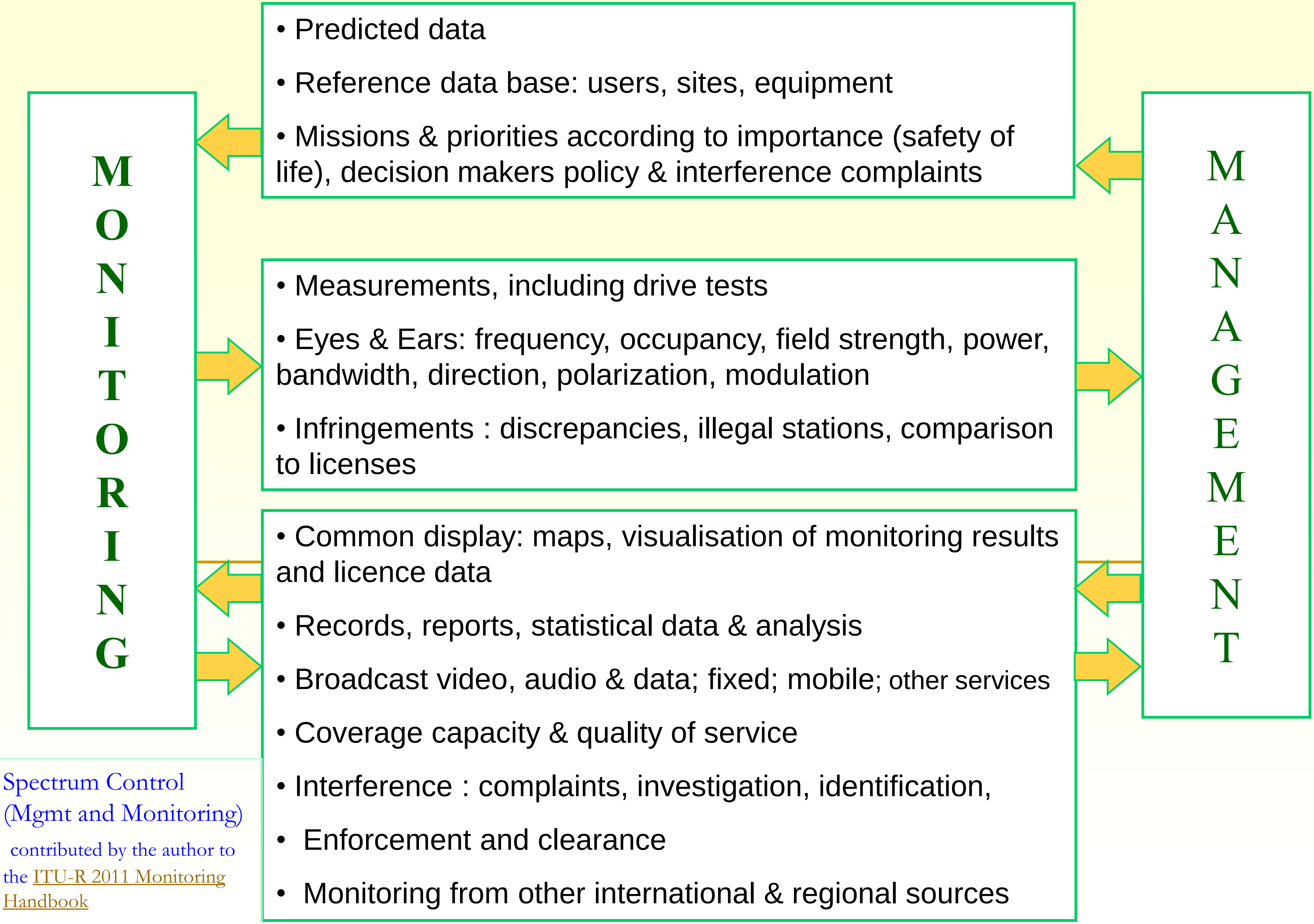
1. Follow RR Allocations
2. Reduce interference: lower-power, lower-altitude Above Sea Level, lower-altitude Above Ground Level
3. No discrimination; fairness, transparency & efficiency
4. Market-Dynamics: Intervene only when market-failure: lack of competition
5. Unused RF is a waste to economy: there is available RF: due to digital-dividends more RF than cellular competitors
6. For cellular efficient usage, consider to oblige active RF sharing
7. Efficient use of spectrum: assign spectrum to those that will generate the greatest socio-economic benefit from its use
8. Promote investment and innovation in the sector
9. New technologies improve b/Hz/second
10. Convergence of mobile, fixed, broadcasting and Internet services
11. Try not to allocate RF when the Transmitter & the Receiver are fixed
12. Put most attention on Short Range Devices

Theories and Policies

1. So begins Leo Tolstoy's Anna Karenina: ‘All happy families are alike; each unhappy family is unhappy in its own way’
2. Between 2 points in planar geometry there is only one simple line, but indefinite curves
3. 'Great minds think alike' (Michaelian)
4. ‘Stand on the shoulders of giants‘ (also I. Newton)
5. 'Okham’s Razor': ‘if you have to choose between competing theories, choose the simplest theory- it is most likely to be true’

How to manage the RF Spectrum

1. Follow Regional Allocations and Assignments; try to ease circulation of equipment
2. Coordinate (bi-lateral and multi-lateral) with your neighbours
3. Don’t invent specific allocations; with whom do you want to be identified? Follow its rules and standards
4. Transparency; Light Touch (?); central-based or market-oriented?
5. Try **not** to allocate to fixed transmitters and receivers (e.g. TV from air), if there is an alternative (cable or satellite)
6. Allocate RF spectrum with a vision towards implementing in many cases markets
7. Ensure the effective (reuse) and efficient (bits/hertz) use of the RF Spectrum
8. Decrease Interference by assigning to transmitters: min power, min bandwidth, min. elevation above sea-level



MONITORING

MANAGEMENT

- Predicted data
- Reference data base: users, sites, equipment
- Missions & priorities according to importance (safety of life), decision makers policy & interference complaints

- Measurements, including drive tests
- Eyes & Ears: frequency, occupancy, field strength, power, bandwidth, direction, polarization, modulation
- Infringements : discrepancies, illegal stations, comparison to licenses

- Common display: maps, visualisation of monitoring results and licence data
- Records, reports, statistical data & analysis
- Broadcast video, audio & data; fixed; mobile; other services
- Coverage capacity & quality of service
- Interference : complaints, investigation, identification,
- Enforcement and clearance
- Monitoring from other international & regional sources

Spectrum Control (Mgmt and Monitoring)

contributed by the author to the ITU-R 2011 Monitoring Handbook

ITU structure

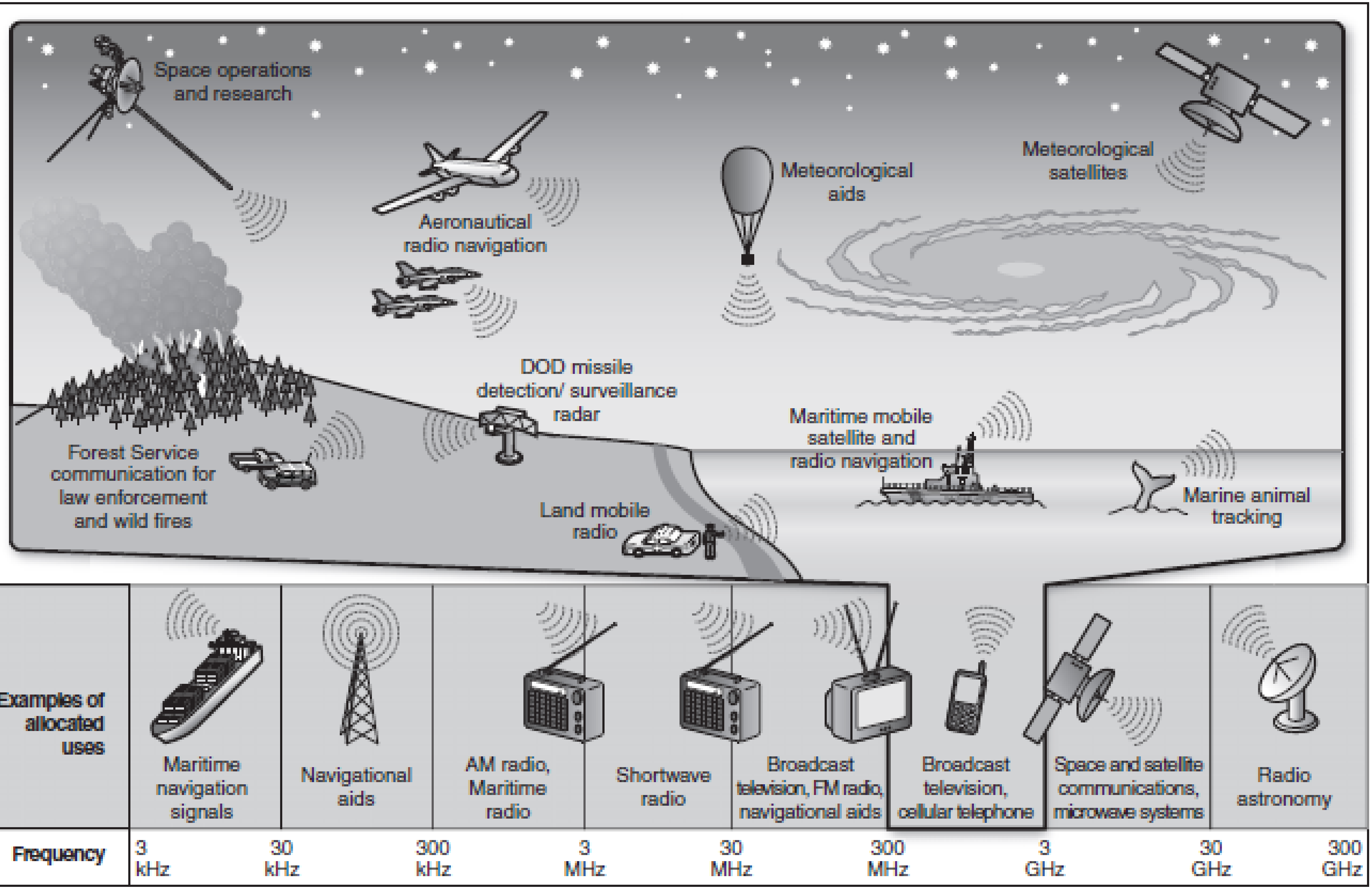
ITU Radio Regulations

RR 5.1: Allocation, Allotment and Assignment

Frequency distribution to:	
Services	Allocation (to allocate)
Areas or countries	Allotment (to allot)
Stations	Assignment (to assign)

Designation	Symbol	Frequency range	Metric subdivision
Very Low Frequency	VLF	3 to 30 kHz	Myriametric waves
Low Frequency	LF	30 to 300 kHz	Kilometric waves
Medium Frequency	MF	300 to 3,000 kHz	Hectometric waves
High Frequency	HF	3 to 30 MHz	Decametric waves
Very High Frequency	VHF	30 to 300 MHz	Metric waves
Ultra High Frequency	UHF	300 to 3,000 MHz	Decimetric waves
Super High Frequency	SHF	3 to 30 GHz	Centimetric waves
Extremely High Frequency	EHF	30 to 300 GHz	Millimetric waves
Tera High Frequency	THF (?)	300 to 3,000 GHz	Decimillimetric waves

Examples of Allocated Spectrum Uses, & Federal Spectrum use; NTIA



World Radio Conference 2019 (WRC-19)

ITU-R Radio Communications Assembly

ITU-R Study Group Structure

Study Group 1 (SG 1) - Spectrum management

Study Group 3 (SG 3) - Radiowave propagation

Study Group 4 (SG 4) - Satellite services

Study Group 5 (SG 5) - Terrestrial services

Study Group 6 (SG 6) - Broadcasting service

Study Group 7 (SG 7) - Science services

Coordination Committee for Vocabulary (CCV)

Conference Preparatory Meeting (CPM)

Special Committee (SC)

World Radiocommunication Conference 2019, Signing and Closing Plenary
Sharm el-Sheikh, Egypt, 28 October to 22 November 2019

WRC-19

ITU RR-20 already published

- WRC-19 was attended by over 3,540 delegates from 165 Countries out of ITU’s 193 Member States
- Senior governments officials, hundred participants representing circa 130 other entities, incl. industry, as observers

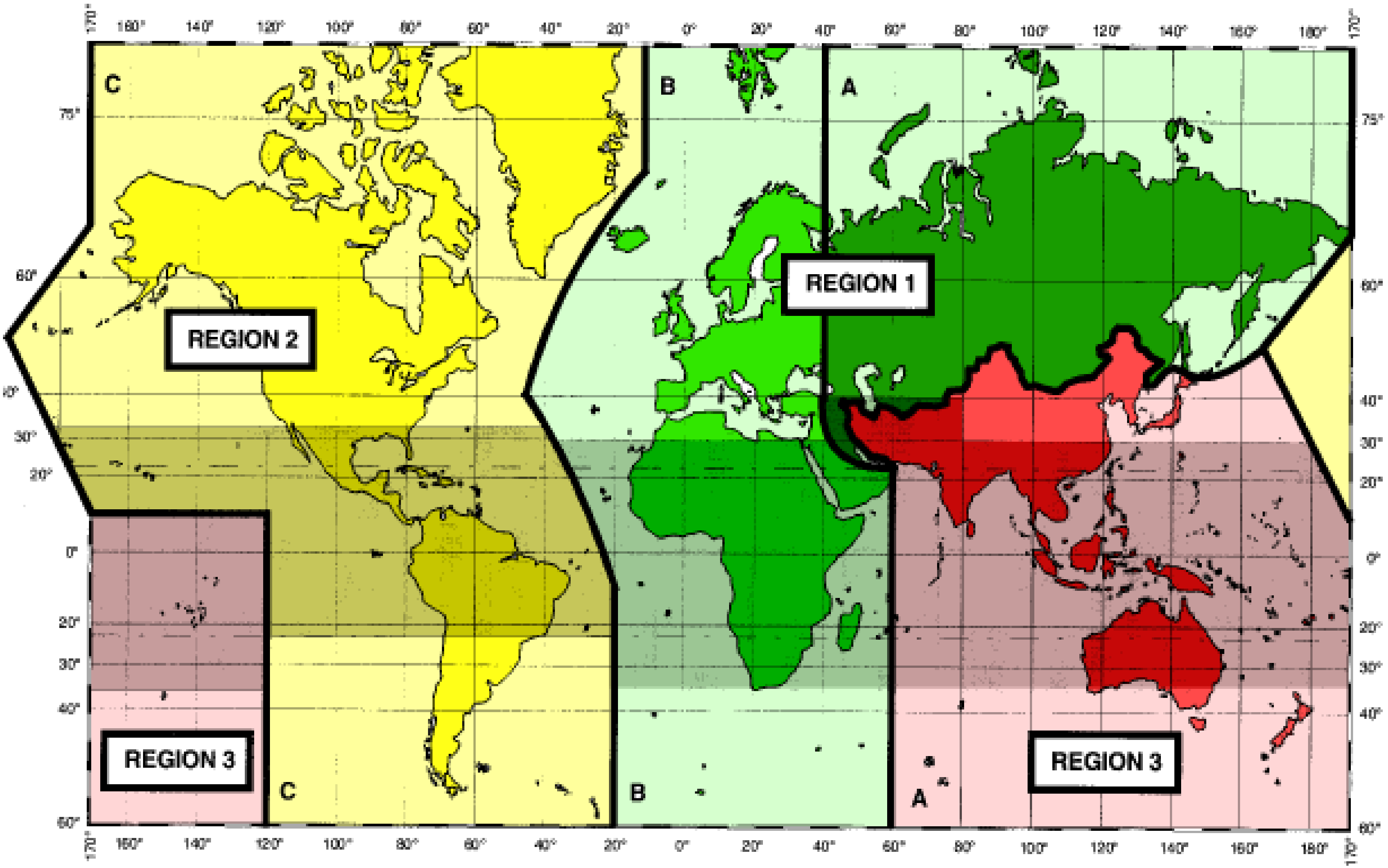
World Radio Conference 2019 (WRC-19)

ITUWRC SHARM EL-SHEIKH2019

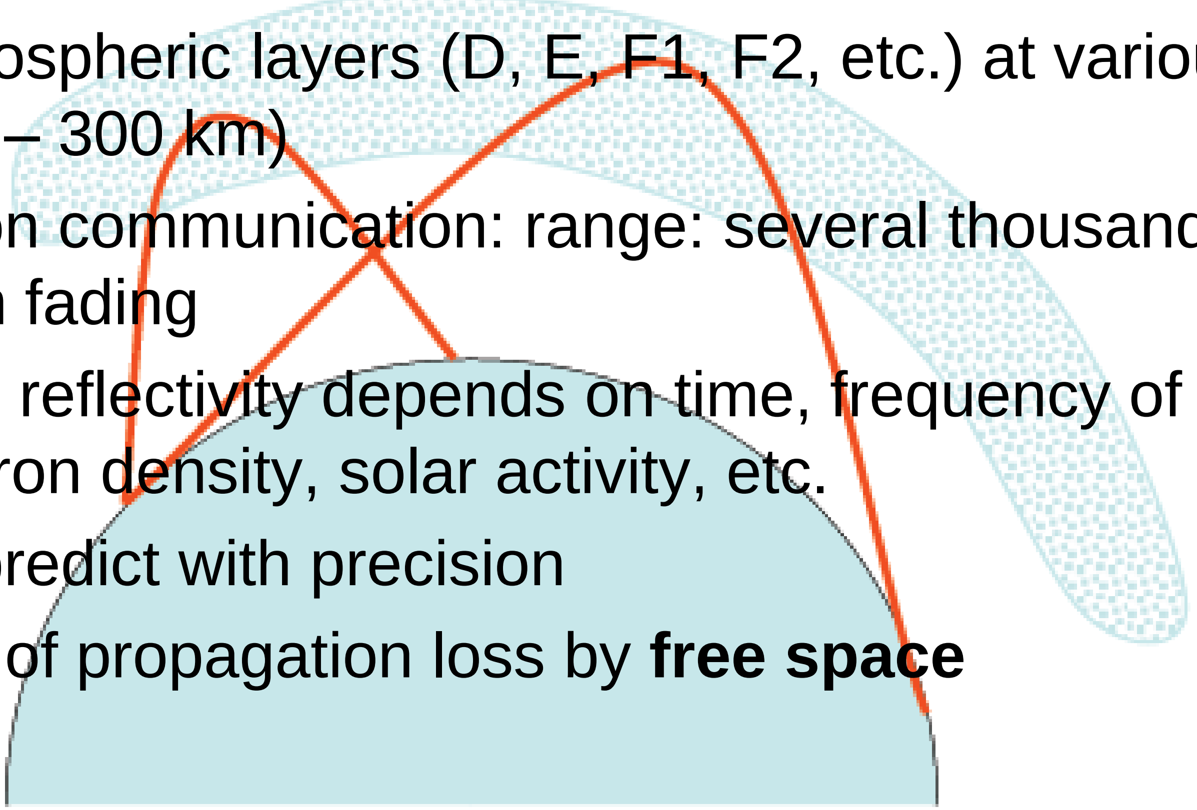
28 October - 22 November
Sharm El-Sheikh, Egypt

1. WRCs are held every three to four years. It is the job of WRC to review, and, if necessary, revise the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made on the basis of an agenda determined by the ITU Council, which takes into account recommendations made by previous world radiocommunication conferences.
2. The general scope of the agenda of WRCs is established four to six years in advance, with the final agenda set by the ITU Council two years before the conference, with the concurrence of a majority of Member States.
3. Under the terms of the ITU Constitution, a WRC can:
    1) revise the Radio Regulations and any associated Frequency assignment and allotment Plans;
    2) address any radiocommunication matter of worldwide character;
    3) instruct the Radio Regulations Board and the Radiocommunication Bureau, and review their activities;
    4) determine Questions for study by the Radiocommunication Assembly and its Study Groups in preparation for future WRCs.
4. On the basis of contributions from administrations, the Study Groups, and other sources (see Article 19 of the Convention (Geneva, 1992)) concerning the regulatory, technical, operational and procedural matters to be considered by World and Regional Radiocommunication Conferences, the Conference Preparatory Meeting (CPM) shall prepare a consolidated report to be used in support of the work of such conferences.

Three ITU RF Allocation Regions (appears at RR 5-1)



Satellite Coordination is crucial.
Why coordination is needed for HF



- Ionospheric “reflections”
- Ionosphere is transparent for μwaves but reflects HF waves
- Various ionospheric layers (D, E, F1, F2, etc.) at various heights (50 – 300 km)
- Over-horizon communication: range: several thousand km; suffers from fading
- Ionospheric reflectivity depends on time, frequency of incident wave, electron density, solar activity, etc.
- Difficult to predict with precision
- Calculation of propagation loss by **free space**

Main regional telecoms regulators

Name	Regional Intergovernmental Telecoms Regulators
APT	Asia Pacific Telecommunity, 38 countries
ASMG	Arab States Spectrum Management Group, 23 countries (22, without suspended Syria)
ATU	African Telecommunications Union, 44 countries
CEPT	European Conference of Postal and Telecoms Administrations, 48 countries
CITEL	Inter-American Commission of Telecoms, 36 countries
CRASA	Communications Regulators' Association of Southern Africa, 13 regulators
EACO	East African Communications Organization Burundi, Kenya, Rwanda, Tanzania, Uganda (like EAC)
FACSMAB	Frequency Assignment Committee Singapore, Malaysia and Brunei
RCC	Regional Commonwealth in the Field of Communication, 12 countries
REGULATEL	Latin American Forum of Telecom Regulator, 20 regulators
SADC	Southern African Development Community, 16 Member States
WATRA	West Africa Telecommunications Regulators Assembly,15 countries

Related International Organizations https://www.apt.int/related-organizations

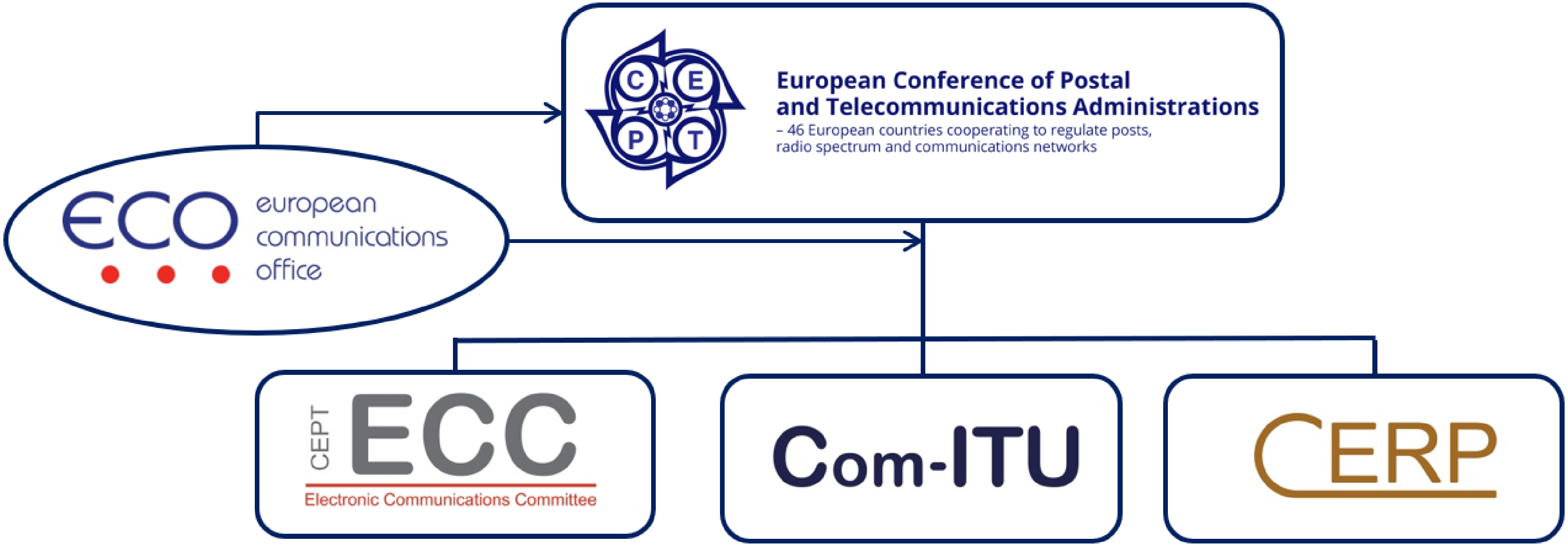
ICAO	International Civil Aviation Organization
ITU	International Telecommunication Union
UNDP	United Nations Development Programme
UN	United Nations
UN-ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
ABU	Asia-Pacific Broadcasting Union
ADB	Asian Development Bank
APEC	Asia-Pacific Economic Cooperation
APSCC	Asia-Pacific Satellite Communications Council
ATU	African Telecommunications Union
CEPT	European Conference of Postal and Telecommunications Administrations
CITEL	Inter-American Telecommunication Commission
CTO	The Commonwealth Telecommunications Organization
ECO	European Communications Office
InfoDev	The Information for Development Program
PECC	Pacific Economic Cooperation Council
PIFS	Pacific Islands Froum Secretariat
PITA	The Pacific Islands Telecommunications Association
PTC	Pacific Telecommunications Council
UMTS	UMTS Forum
WB	The World Bank
Wimax Forum	Wimax Forum
WTO	The World Trade Organization

Standards Development Organizations influencing wireless standardization

Name	Organization (Country)
3GPP	3rd Generation Partnership Project
3GPP2	Third Generation Partnership Project
ARIB	Association of Radio Industries and Businesses (Japan)
ATIS*,**	Alliance for Telecommunications Industry Solutions ATIS Committee WTSC (Wireless Technologies and Systems Committee)
CCSA	China Communications Standards Association (China)
CDG	CDMA Development Group
GISFI**	Global ICT Standardization Forum for India (India)
ETSI*,**	European Telecommunications Standards Institute (Europe)
GS1	Global Standards One
IEEE- SA*	Institute of Electrical and Electronics Engineer - Standards Association
ISO*,**	International Organization for Standardization
SAE	Society of Automotive Engineering
TIA	Telecommunications Industry Association (US)
TTA	Telecommunications Technology Association (Korea)
TTC	Telecommunications Technology Committee (Japan)
UL Standards	Underwriters Laboratories Inc.

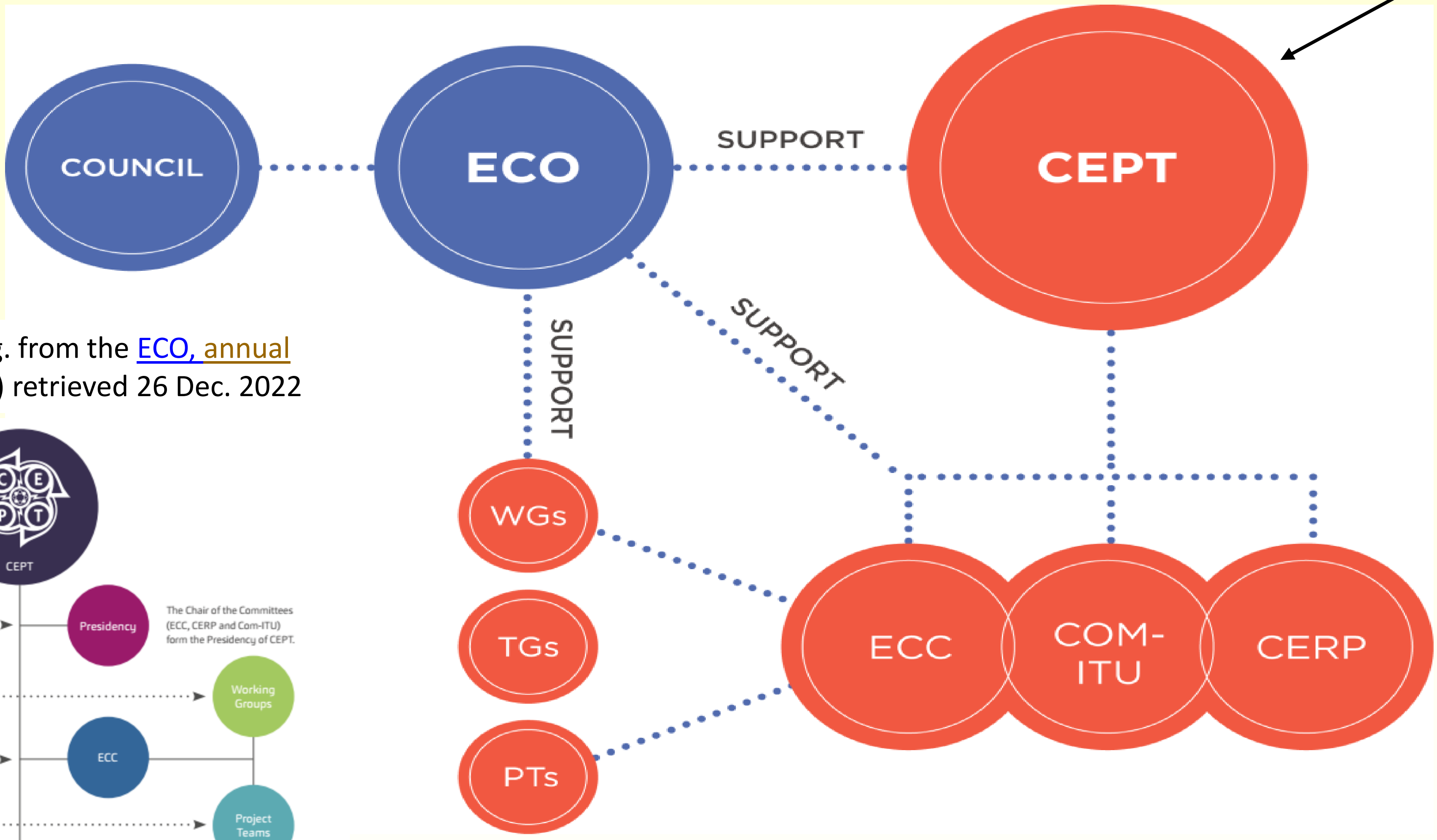
Map of EU Member States

retrieved on 26 Dec. 22

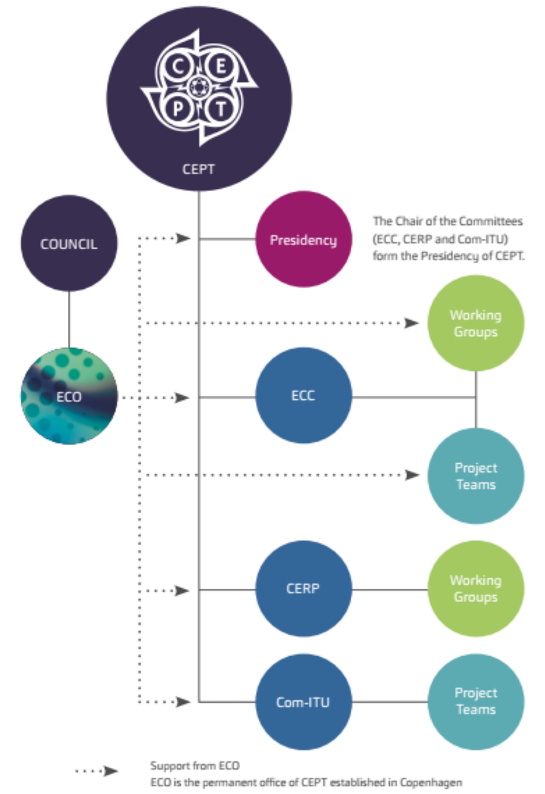


The European Communications Office (ECO) provides a secretariat for the European Conference of Postal and Telecommunications Administrations (CEPT) (including its Presidency) and its three autonomous business committees : Electronic Communications Committee (ECC), European Committee for Postal regulation(CERP) and the COMmittee for ITU policy (Com-ITU). The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz ECA Table(ECA Table) Approved on October 2021, Editorial update 14 October 2022

ECO supports CEPT and its three business committees (ECO, annual report; July 2013)



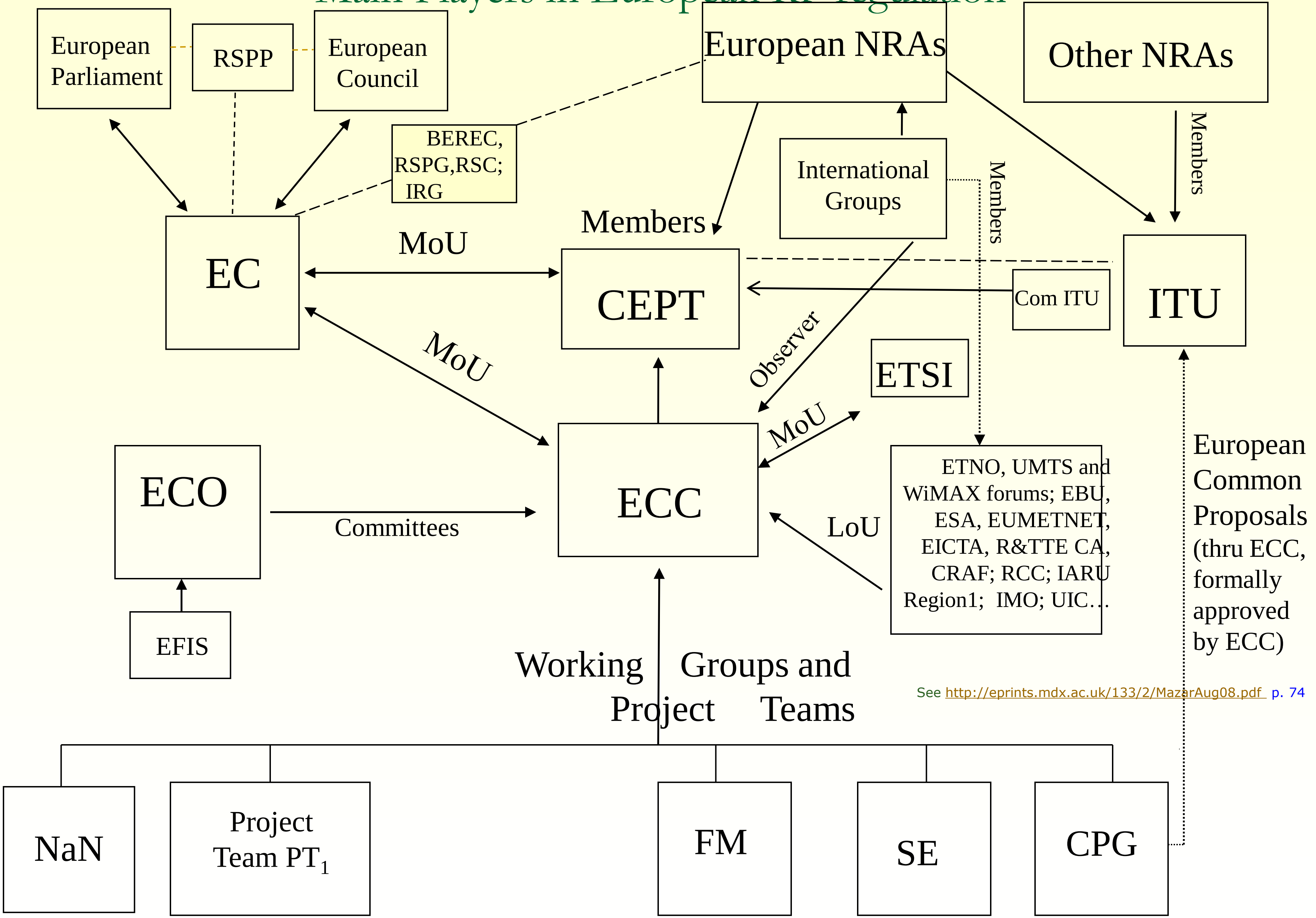
Structure, fig. from the ECO, annual Report 2021) retrieved 26 Dec. 2022



The Chair of the Committees (ECC, CERP and Com-ITU) form the Presidency of CEPT.

ECO is the permanent office of CEPT established in Copenhagen

Main Players in European RF regulation



European Parliament

RSPP

European Council

European NRAs

Other NRAs

BEREC, RSPG,RSC; IRG

International Groups

Members

Members

Members

EC

MoU

CEPT

Com ITU

ITU

MoU

Observer

ETSI

MoU

ECO

Committees

ECC

LoU

ETNO, UMTS and WiMAX forums; EBU, ESA, EUMETNET, EICTA, R&TTE CA, CRAF; RCC; IARU Region1; IMO; UIC…

EFIS

European Common Proposals (thru ECC, formally approved by ECC)

Working Groups and Project Teams

See http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 74

NaN

Project Team PT_1

FM

SE

CPG

Key of Abbreviations

CPG: Conference Preparatory Group (preparations for ITU Conferences); CRAF: Committee on Radio Astronomy Frequencies; EBU: European Broadcasting Union; EC: European Commission; ECC: Electronic Communications Committee (formerly European Radiocommunications Committee ERC); EICTA: European Information and Communications Technology Industry Association; ERG: European Regulators Group (EC body); ERO: European Radiocommunications Office; ESA: European Space Agency; ESOA: European Satellite Operators Association; ETNO: European Telecommunications Network Operators; EUMETNET: European National Meteorological Services; FLO Forward Link Only; FM: Frequency Management; IARU: International Amateur Radio Union; IMO International Maritime Organisation; IRG: Independent Regulators Group (pan-European body); NRA: National Regulatory Authority; NNA: Numbering, Naming and Addressing (non RF); Project Teams PT PT$_1$: IMT2000, PT$_2$: TRIS Technical Regulation and Interconnection Standards, PT$_9$: Maritime issues; Task Groups TG: UWB (TG3) and Digital Dividend (TG4). RA: Radio Affairs (Radio and e-Communications); RRC: Regional Commonwealth in Communications; R&TTE CA: The Radio and Telecommunications Terminal Equipment Compliance Association; RSPG: Radio Spectrum Policy Group (EC body); RSC: Radio Spectrum Committee (EC body); SE: Spectrum Engineering. Industry Stakeholders, namely companies, consultants, industry groups and international agencies, contribute to the ECC Working Groups.

European tables that can optimize RF spectrum in all ITU Region 1*

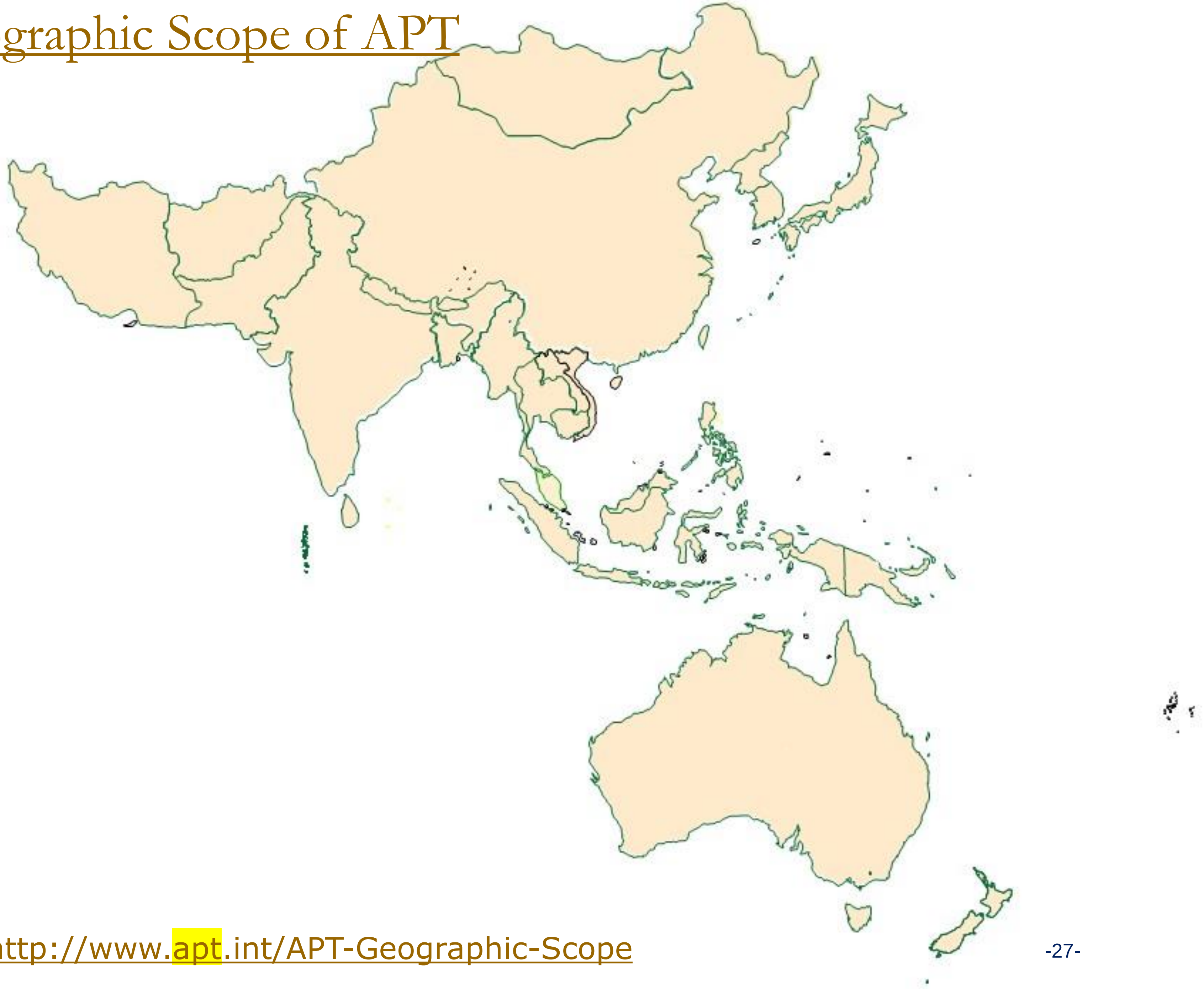
*Europe, Africa, the Middle East west of the Persian Gulf including Iraq, the former Soviet Union and Mongolia

- The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz (ECA Table) Approved October 2021, Editorial update 14 October 2022
- ERC Recommendation 70-03 relating to the use of Short Range Devices (SRD)

Geographic Scope of APT

see http://www.apt.int/APT-Geographic-Scope

Geographic Scope of APT



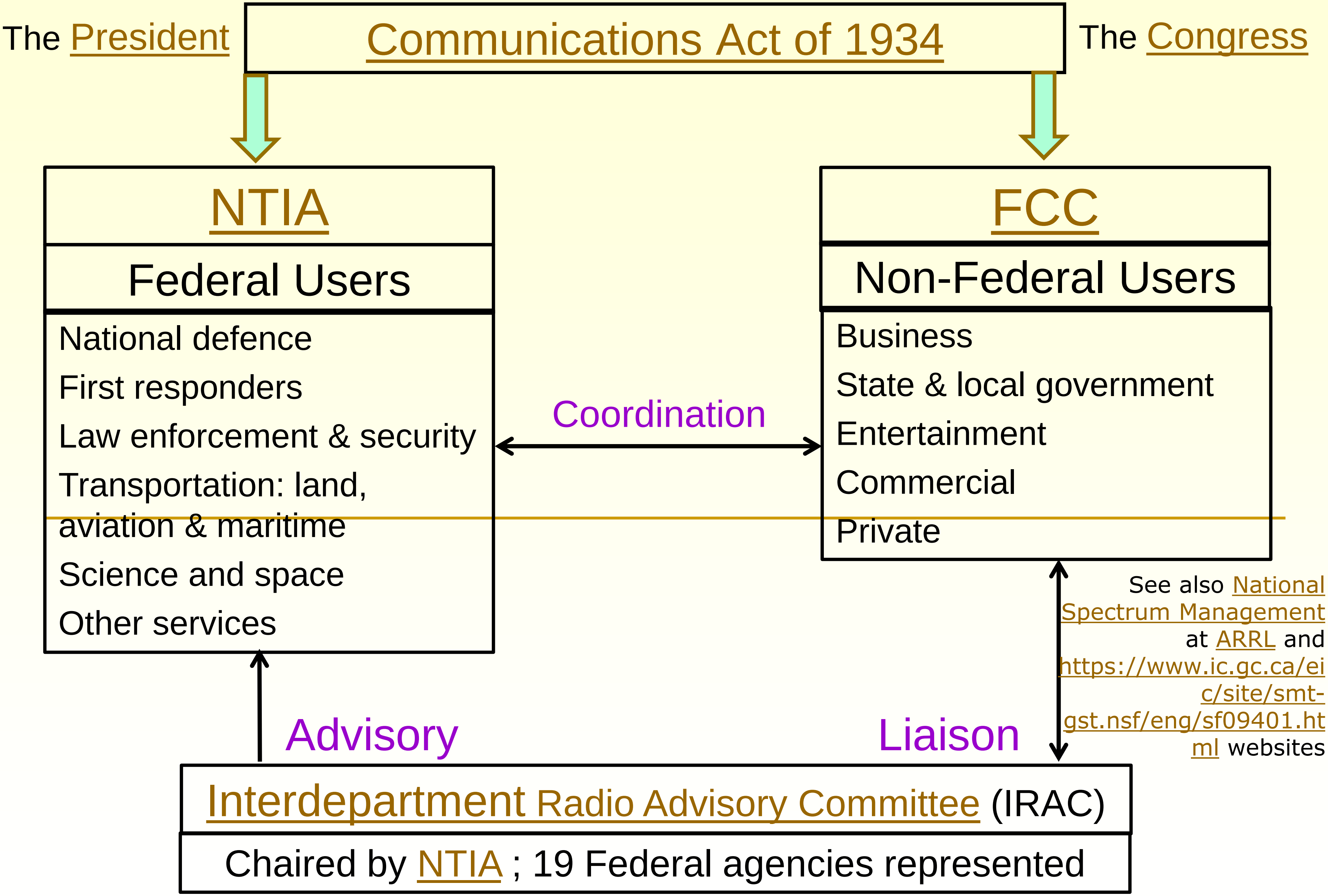
see http://www.apt.int/APT-Geographic-Scope

African Telecommunications Union (ATU) Member States

Southern African Development Community (SADC) Member States

SADC is a Regional Economic Community comprising 16 Member States; Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, United Republic Tanzania, Zambia and Zimbabwe.

US National Spectrum Management



The President

Communications Act of 1934

The Congress

NTIA

Federal Users

- National defence
- First responders
- Law enforcement & security
- Transportation: land, aviation & maritime
- Science and space
- Other services

Coordination

FCC

Non-Federal Users

- Business
- State & local government
- Entertainment
- Commercial
- Private

See also National Spectrum Management at ARRL and https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09401.html websites

Advisory

Liaison

Interdepartment Radio Advisory Committee (IRAC)

Chaired by NTIA ; 19 Federal agencies represented

19 federal agencies in IRAC; +FCC as Observer

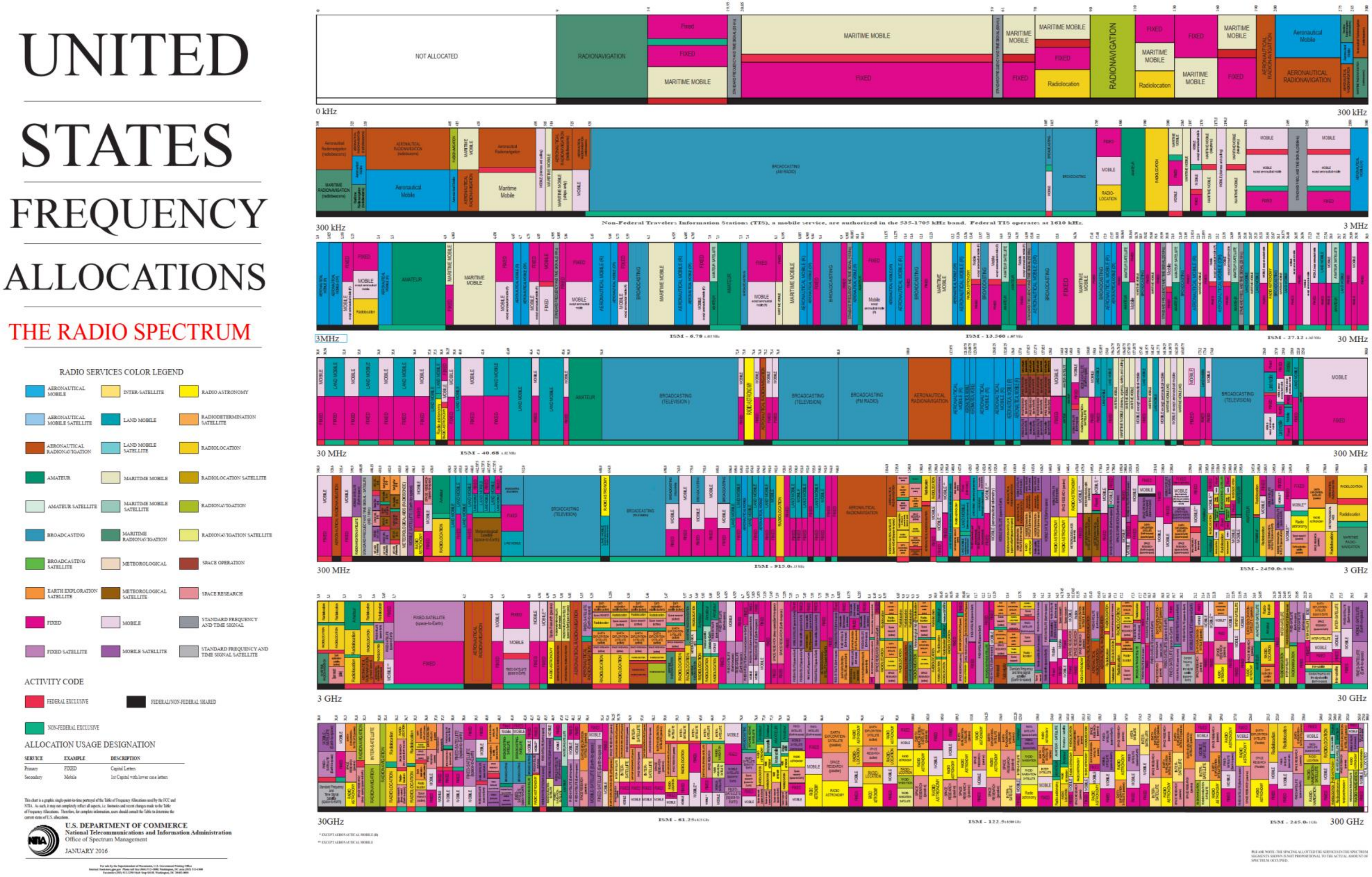
National Telecommunications & Information Administration (NTIA)

NTIA Manual of Regulations & Procedures for Federal RF Management (Redbook)

The US Wall Chart

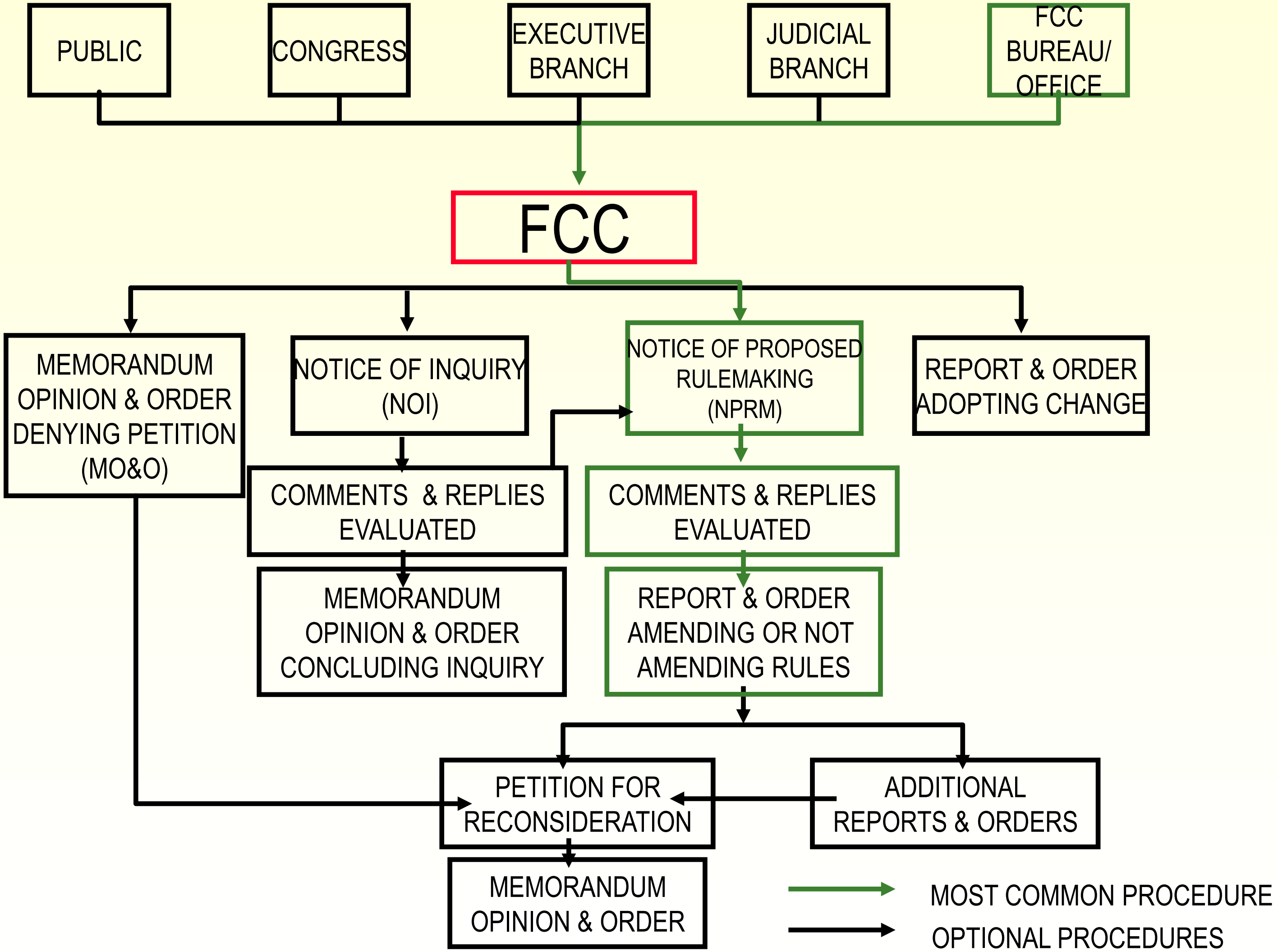
https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

US RF Allocations 2016



https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

How Federal Communications Commission (FCC) rules are made (Bill Luther)



PUBLIC

CONGRESS

EXECUTIVE BRANCH

JUDICIAL BRANCH

FCC BUREAU/ OFFICE

FCC

MEMORANDUM OPINION & ORDER DENYING PETITION (MO&O)

NOTICE OF INQUIRY (NOI)

NOTICE OF PROPOSED RULEMAKING (NPRM)

REPORT & ORDER ADOPTING CHANGE

COMMENTS & REPLIES EVALUATED

COMMENTS & REPLIES EVALUATED

MEMORANDUM OPINION & ORDER CONCLUDING INQUIRY

REPORT & ORDER AMENDING OR NOT AMENDING RULES

PETITION FOR RECONSIDERATION

ADDITIONAL REPORTS & ORDERS

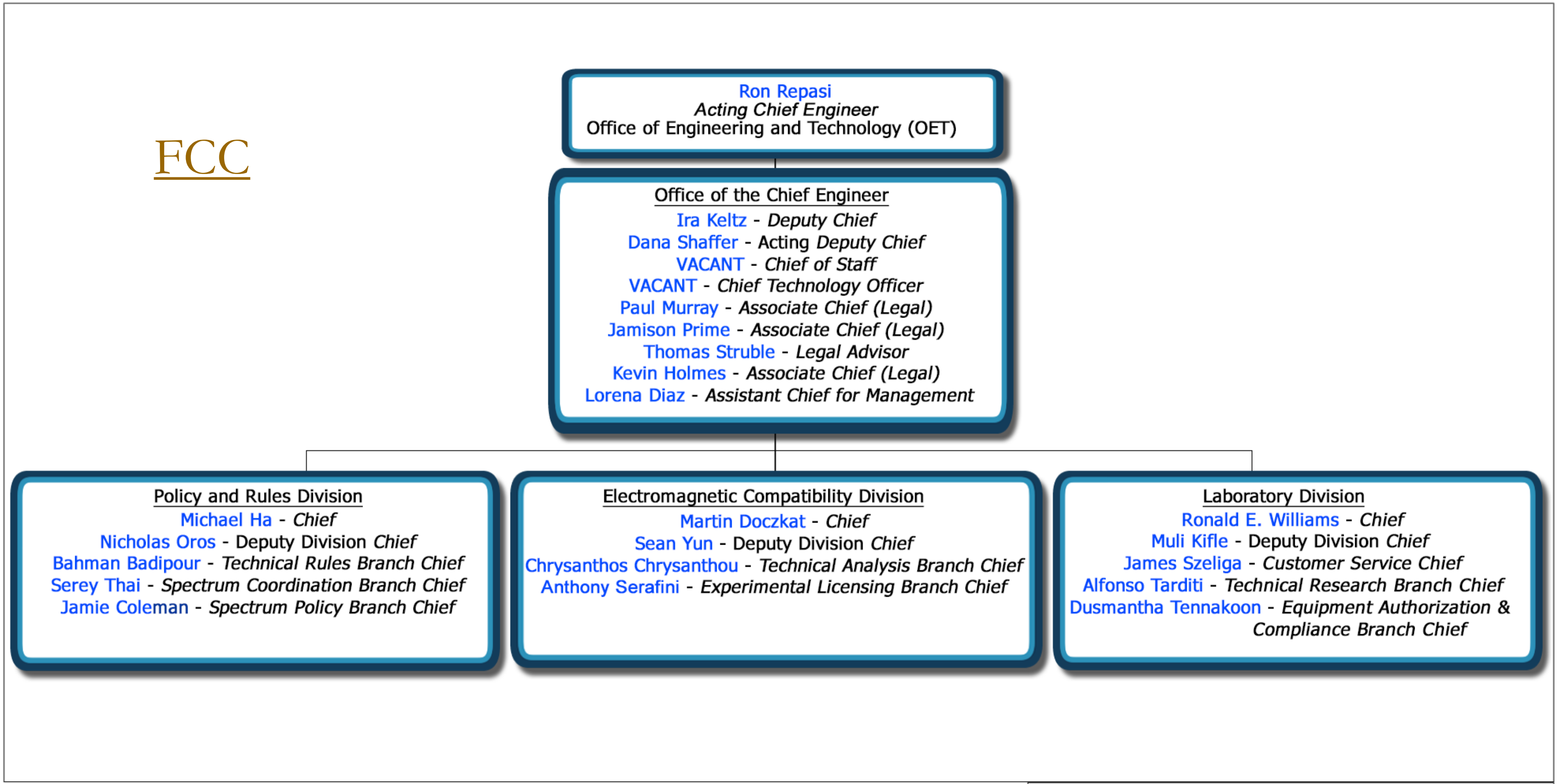
MEMORANDUM OPINION & ORDER

MOST COMMON PROCEDURE

OPTIONAL PROCEDURES

Office of Engineering and Technology (OET) - Organization Chart

FCC



Ron Repasi
Acting Chief Engineer
Office of Engineering and Technology (OET)

Office of the Chief Engineer
Ira Keltz - *Deputy Chief*
Dana Shaffer - Acting *Deputy Chief*
VACANT - *Chief of Staff*
VACANT - *Chief Technology Officer*
Paul Murray - *Associate Chief (Legal)*
Jamison Prime - *Associate Chief (Legal)*
Thomas Struble - *Legal Advisor*
Kevin Holmes - *Associate Chief (Legal)*
Lorena Diaz - *Assistant Chief for Management*

Policy and Rules Division
Michael Ha - *Chief*
Nicholas Oros - Deputy Division *Chief*
Bahman Badipour - *Technical Rules Branch Chief*
Serey Thai - *Spectrum Coordination Branch Chief*
Jamie Coleman - *Spectrum Policy Branch Chief*

Electromagnetic Compatibility Division
Martin Doczkat - *Chief*
Sean Yun - Deputy Division *Chief*
Chrysanthos Chrysanthou - *Technical Analysis Branch Chief*
Anthony Serafini - *Experimental Licensing Branch Chief*

Laboratory Division
Ronald E. Williams - *Chief*
Muli Kifle - Deputy Division *Chief*
James Szeliga - *Customer Service Chief*
Alfonso Tarditi - *Technical Research Branch Chief*
Dusmantha Tennakoon - *Equipment Authorization & Compliance Branch Chief*

Front Office - (202) 418-2470
Policy and Rules Division - (202) 418-2470
Electromagnetic Compatibility Division - (202) 418-2470
Laboratory Division - (301) 362-3000

Updated on 08.16.21

CFR 47, the Code of Federal Regulations

National Archives and
Records Administration

Federal
Communications
Commission

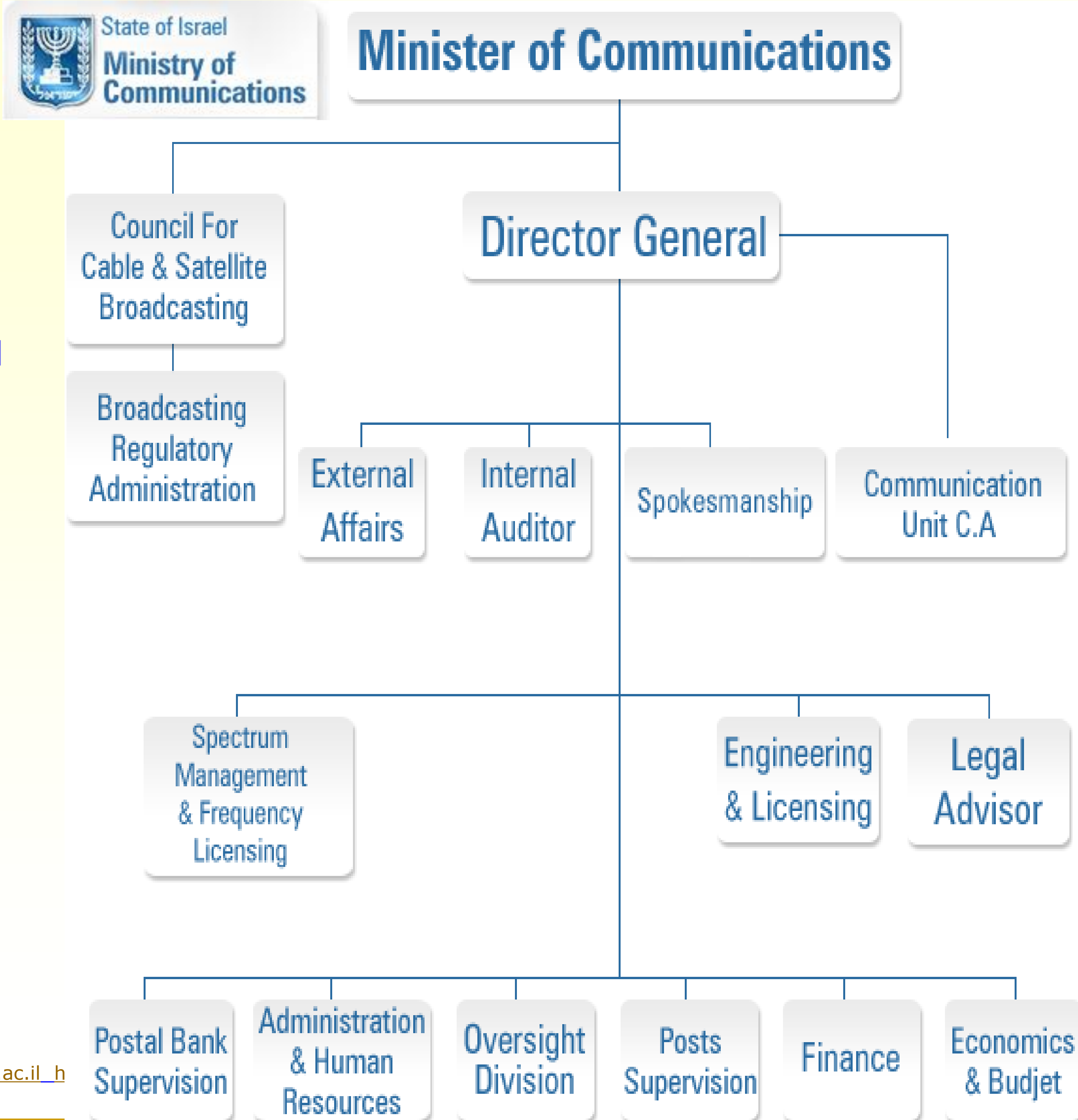
1. CFR 47 Parts 0 to19
2. Part 15 Radio Frequency Devices
3. Part 22: Public Mobile Services Subpart H—Cellular Radiotelephone Service

1. Wireless regulation & standardisation are divided into two major camps: Europe and N. America
    - Different approach to top-down mandated standards: collectivism and intervention vs. *individualism* and '*light touch*'
    - Licensing: US Part 15 and European RED; influence of EU on the rest Europe (& Region 1) is parallel to the influence of the US on Canada
    - Harmonisation: *E Pluribus Unum*, probability of interference
    - Europe: 50 Hertz, 9 KHz audio MW AM BW, GSM, 7-8MHz PAL&SECAM TV into DVB-T
    - N. America: 60 Hertz, 10 KHz audio MW AM BW, CDMA, 6 MHz NTSC TV switched to ATSC
2. Diverse cellular penetration and digital TV standards are derived from dissimilar coverage zones and population densities

Organization Structure

https://www.gov.il/en/Departments/ministry_of_communications

2015 Scheme,
didn't find more updated



Taking the floor. 28 Nov. 2022; ITU Headquarters; Geneva

Advanced Wireless Communications, 2020

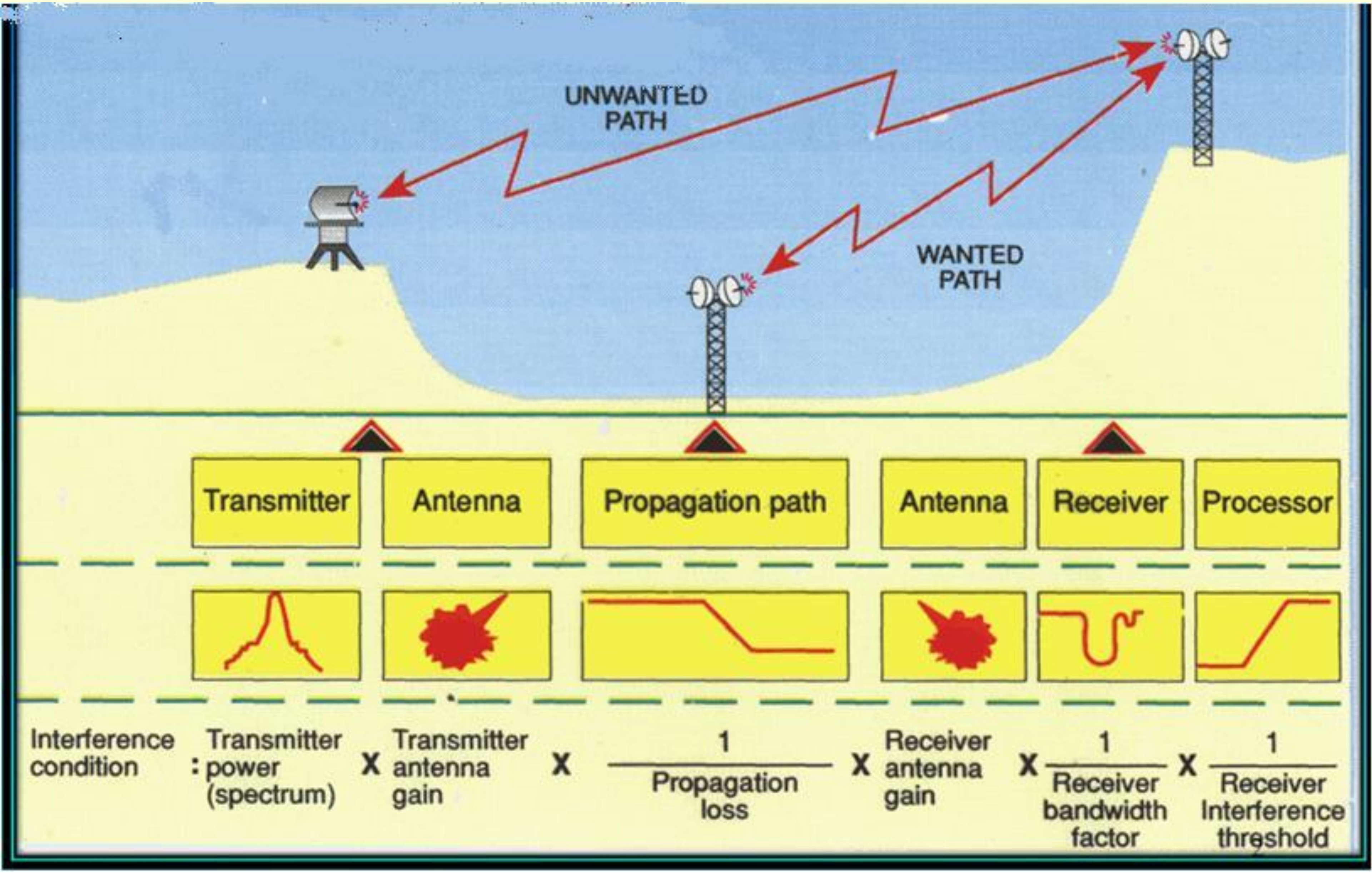
Academic course for 4th year engineering students

Sami Shamoon College of Engineering

EMC and RFI

http://mazar.atwebpages.com/

Antenna to Antenna Coupling, RFI

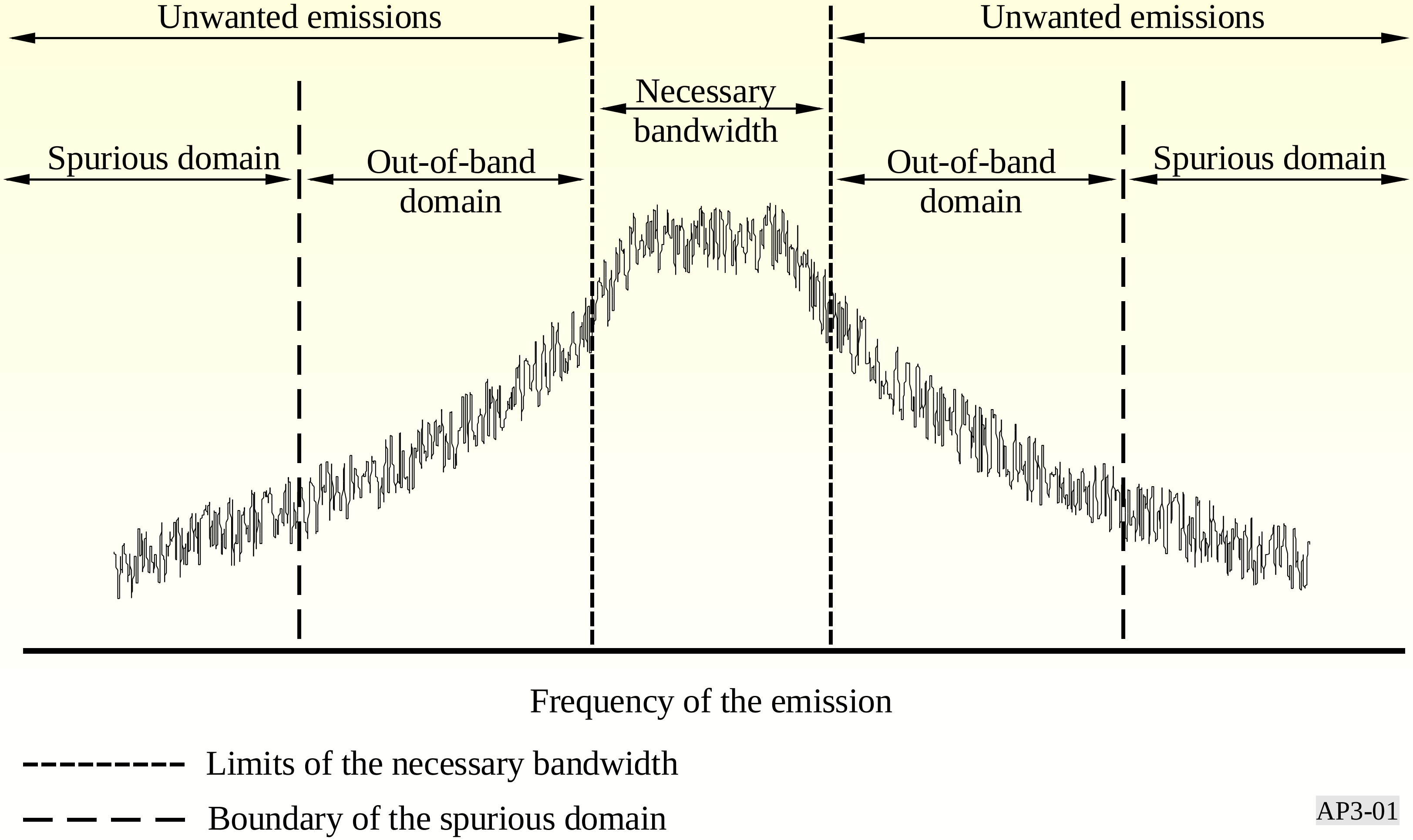


Interference condition : Transmitter power (spectrum) X Transmitter antenna gain X $\frac{1}{\text{Propagation loss}}$ X Receiver antenna gain X $\frac{1}{\text{Receiver bandwidth factor}}$ X $\frac{1}{\text{Receiver Interference threshold}}$

Appendix 3 (REV.WRC 12) Maximum permitted power levels for unwanted emissions in the spurious domain (WRC 12) see ITU Radio Regulations 2020

FIGURE 1 (WRC-03)

Out-of-band and spurious domains



Unwanted emissions in the spurious domain see ITU-R Rec.329 (2)

1.3 **Unwanted emissions (RR Article 1, No. 1.146)**

Consist of spurious emissions and out-of-band emissions

1.3*bis* Out-of-band domain (of an emission)

The frequency range, immediately outside the necessary bandwidth but excluding the spurious domain, in which out-of-band missions generally predominate.

1.3*ter* **Spurious domain** (of an emission):

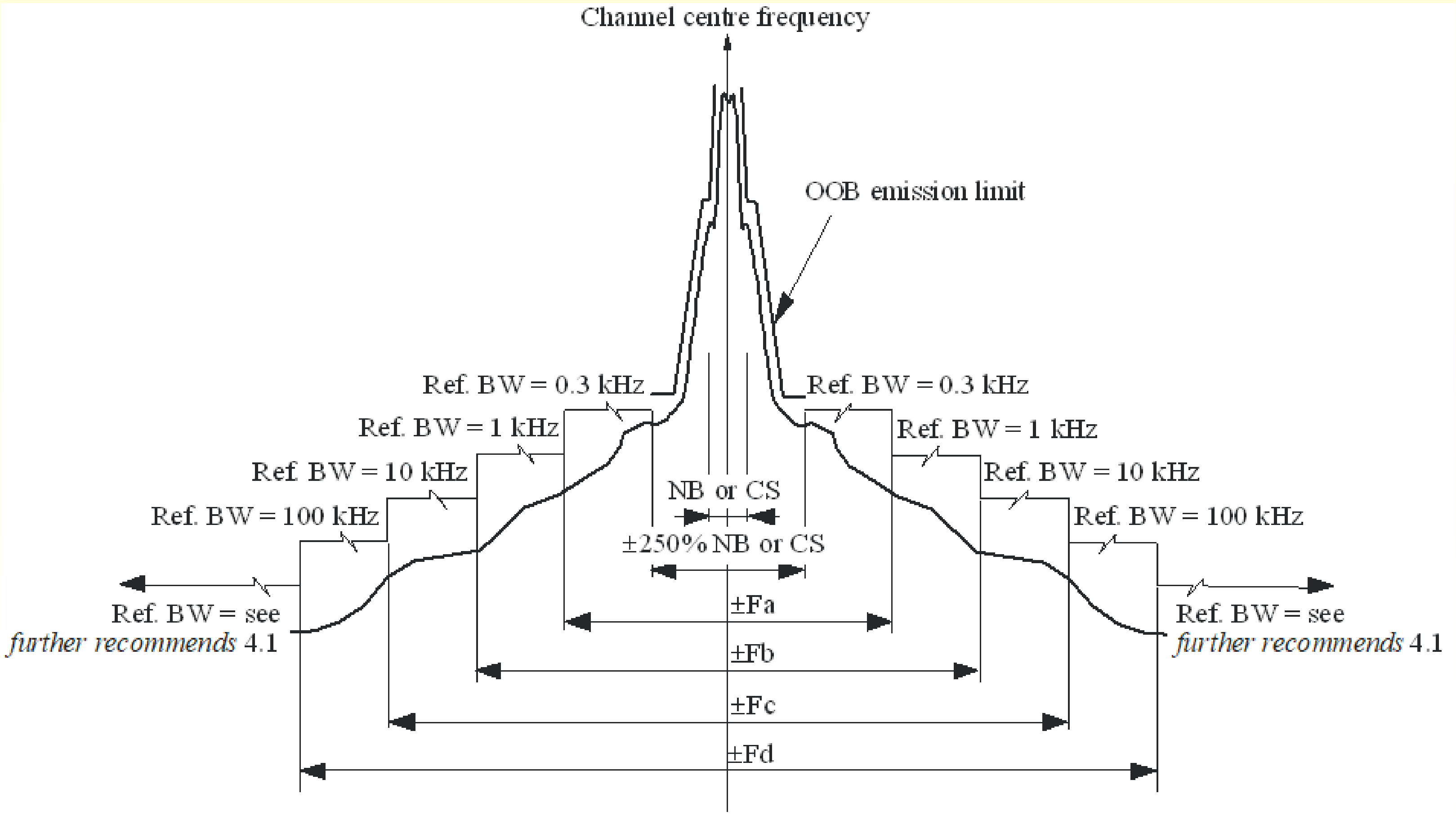
The frequency range beyond the out-of-band domain in which spurious emissions generally predominate.

1.4 **Necessary bandwidth** (RR Article 1, No. 1.152)

For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

Unwanted emissions in the spurious domain see Rec.329 Fig 3 (1)

fixed service mask for unwanted emissions in the spurious domain



Note 1 – ±Fd frequency steps are not applicable if lower than 1 GHz.
±Fc frequency steps are not applicable if lower than 30 MHz.
±Fb frequency steps are not applicable if lower than 150 kHz.

SM.0329-03

Interference Types and Modes

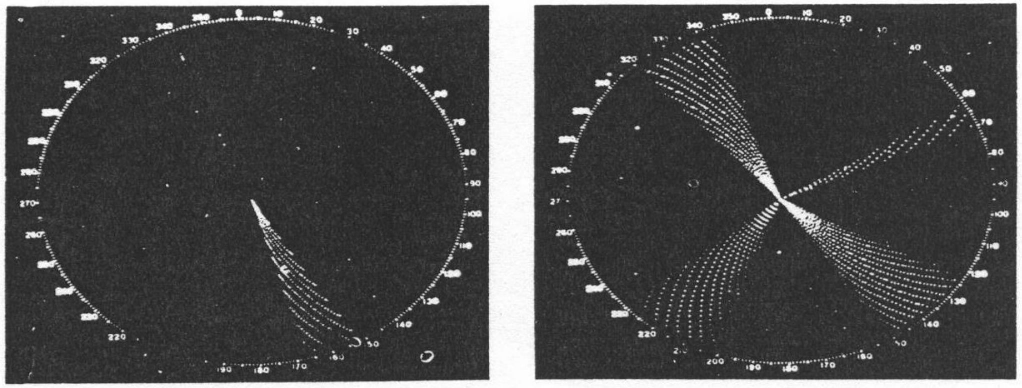
Linear Interference

- Co-Channel
- Adjacent Channel
- Harmonics

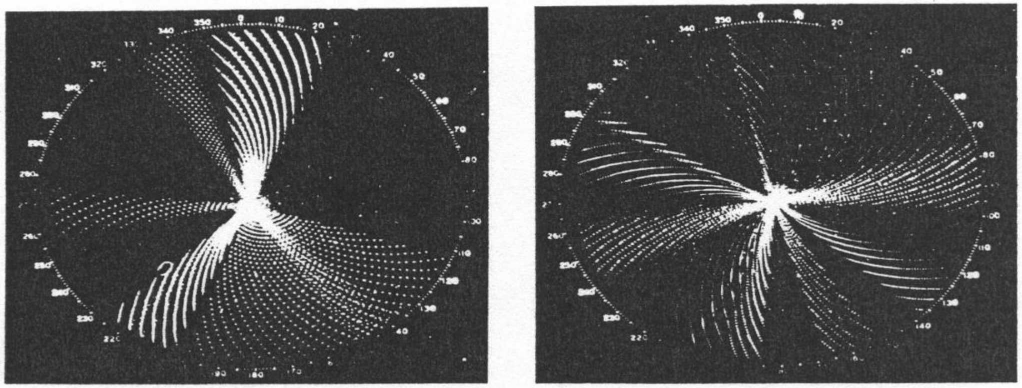
Non-linear Interference

- Desensitization
- Cross-Modulation
- Inter-modulation
- Power Line Noise (PLN)

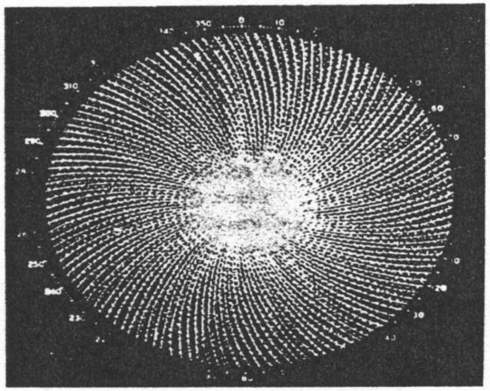
Five Degrees of Interference to Radar Systems



Condition 1 Condition 2

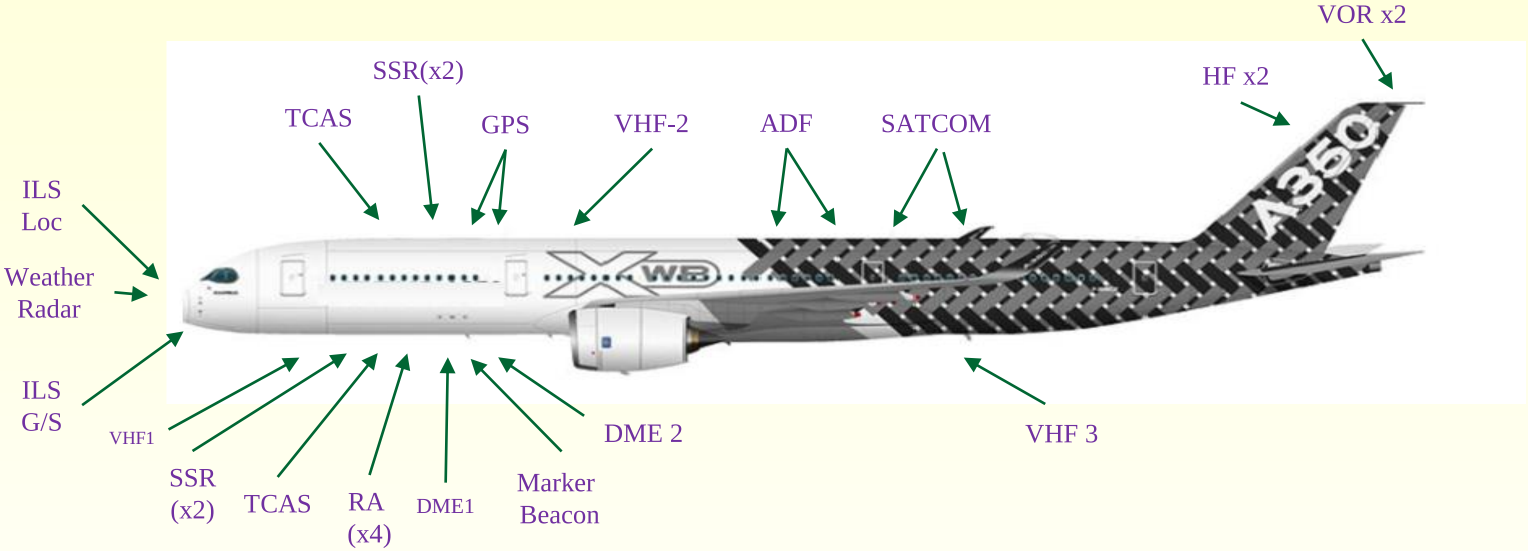


Condition 3 Condition 4



Aeronautical communication compatibility & Coupling

Airbus A350 antennas



1. A scaled prototype & ATACAP (Antenna To Antenna Compatibility) were used at Israel Aerospace Industries (IAI) to analyze and to avoid interference in the Lavi jet-fighter
2. This presentation doesn’t detail refer to aircraft Lightning , EMP protection or Military Standards such as STD-461G ‘the control of electromagnetic interference characteristics of subsystems and equipment’

Source https://atdi-group.com/

ADF :	Automatic Direction Finder	Loc	Localizer
DME:	Distance Measuring Equipment	RA:	Radio Altimeter
GPS:	Global Positioning System	SATCOM:	Satellite Communication
G/S:	Glide Slope	SSR:	Secondary Surveillance Radar
HF:	High Frequency	TCAS:	Traffic Collision Avoidance System
ILS:	Instrument Landing System	VOR:	VHF Omni ranging

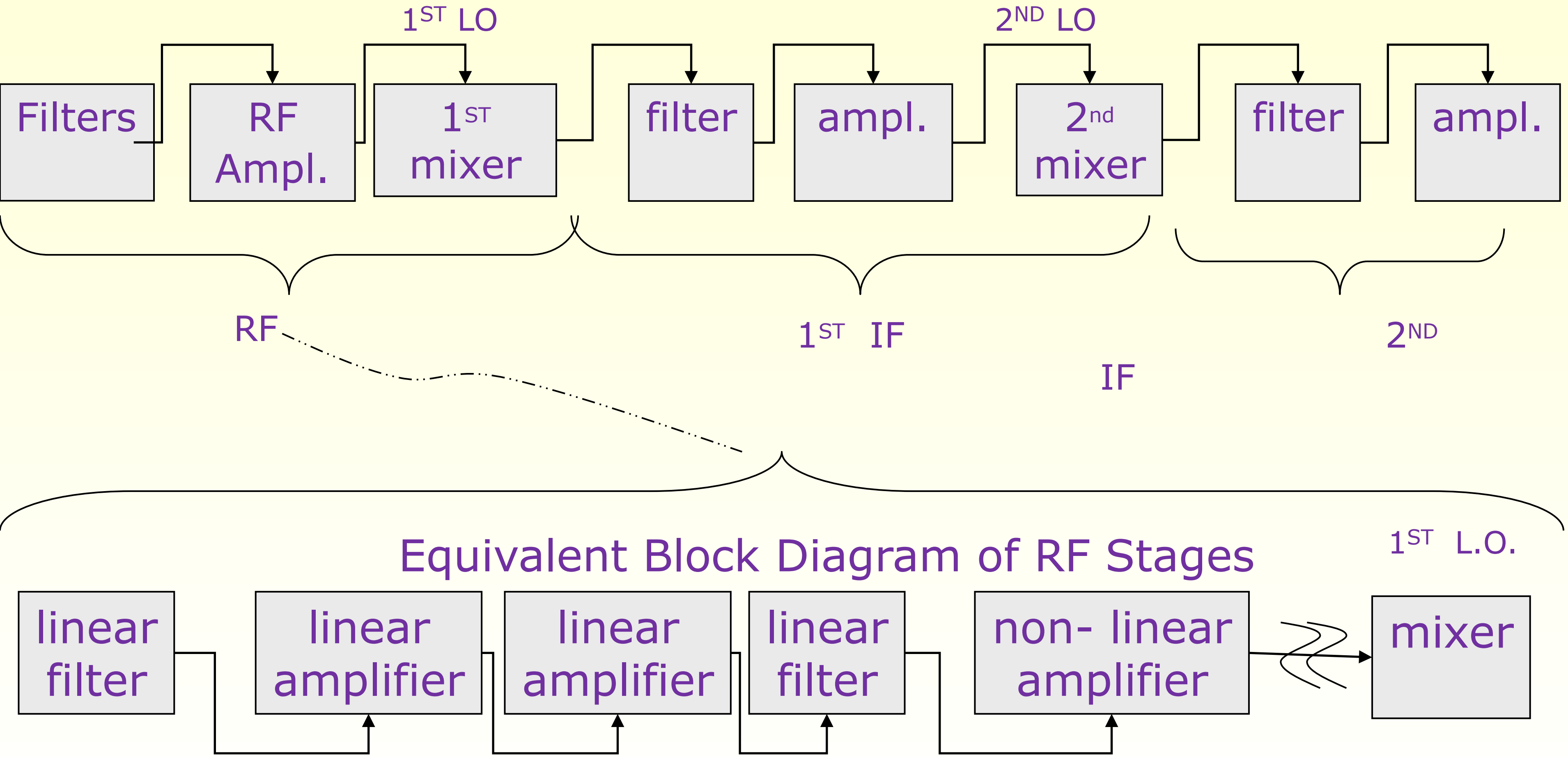
Antenna Coexistence - Mitigation

- Amplitude *(power, sensitivity, distance & ant. orientation)*
- Frequency *(assignment, filtering, bandwidth reduction)*
- Time *(time sharing, blanking)*
- Coding *(modulation, spread spectrum, matched filter)*

Example :Intra-system and inter-system RFI

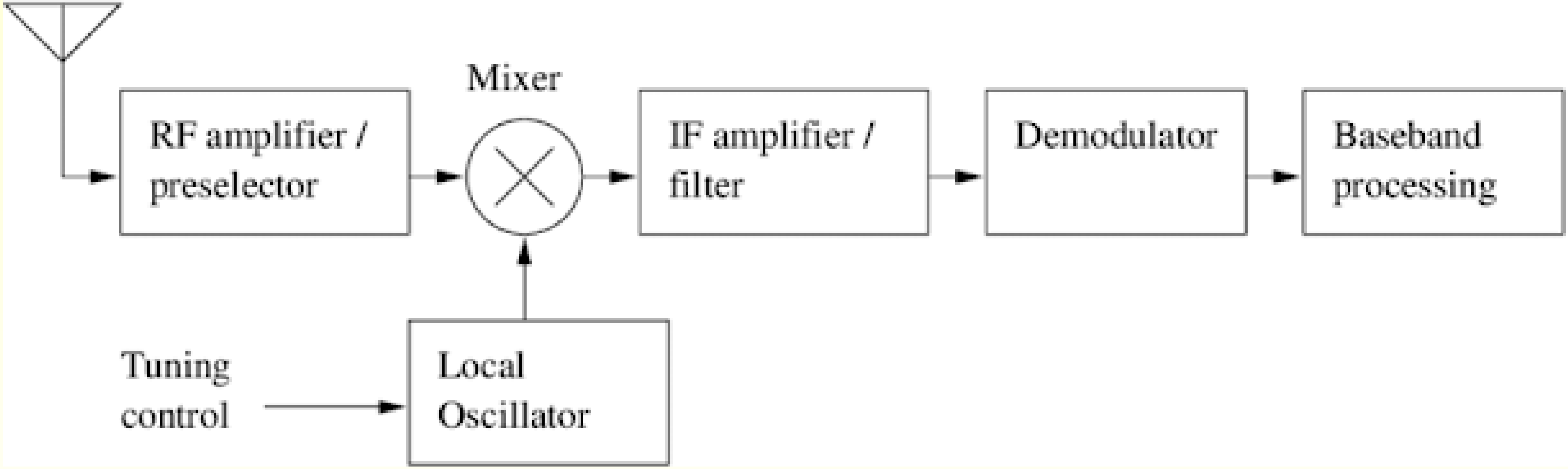
VICTIM SOURCE	IFF	TACAN	SURFACE SEARCH RADAR	AIR SEARCH ARADAR	UHF LOS COMM	UHF SATCOM	BRDG-URDG COMM	SHIP-AIR COMM	FLEET BROADCAST VHF	TRANSCEIVERS SSES RECEIVE	SATNAV	OMEGA NAV	HF RECIEVER	HF TRANSMTTERS	
IFF	★	★				★									
TACAN	★														
SURFACE SEARCH RADAR															
AIRborne SEARCH RADAR	★	★	★			★									
UHF LOS COMM					★	★			★			★			
UHF SATCOM					★	★									
BRDG-URDG COMM								★							
SHIP-AIR COM							★								
VHF TRANSCALVERS										★					
HF TRANSMTTERS									★		★			★	★

Super- Heterodyne receiver susceptibility



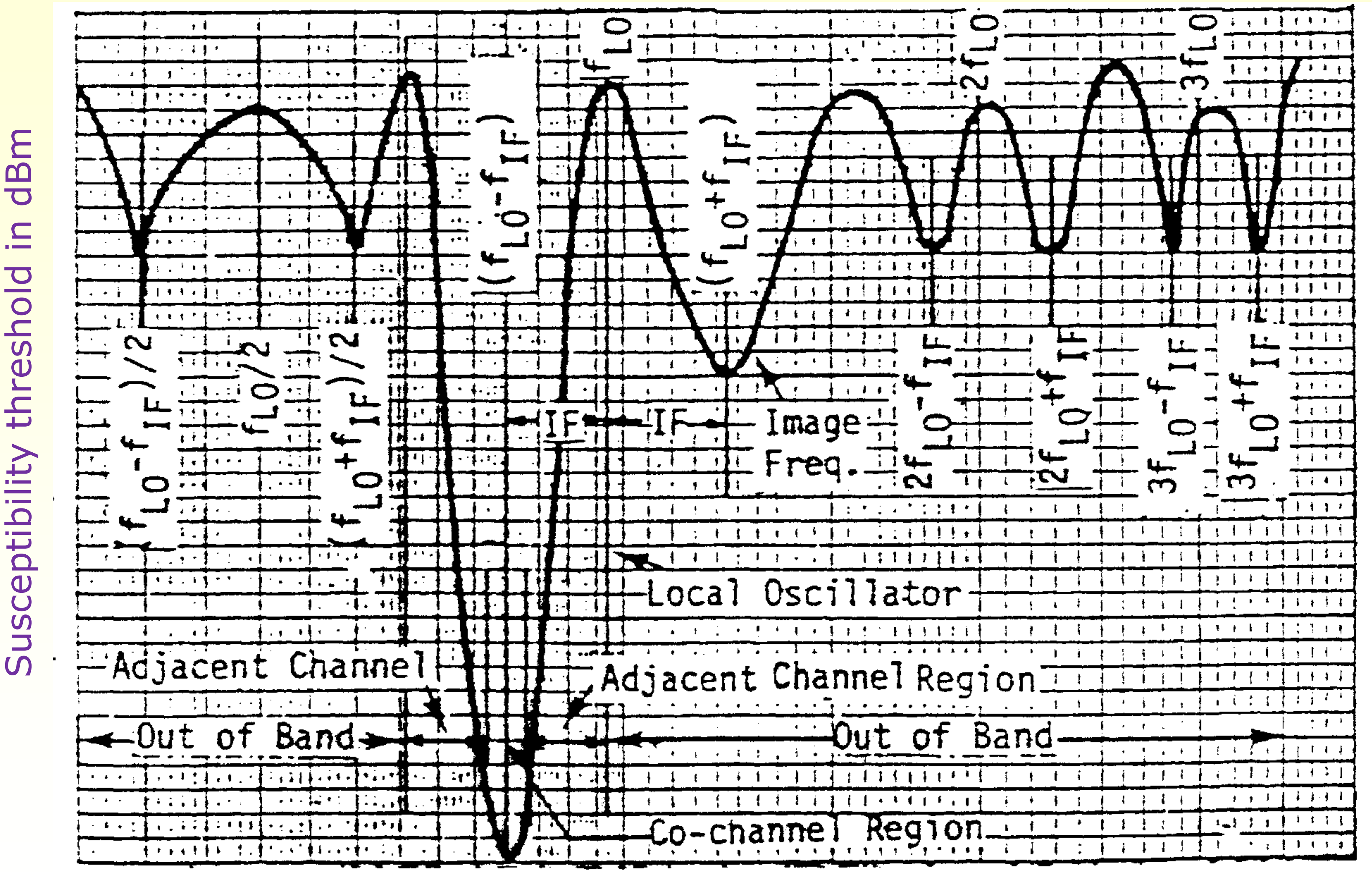
General pre-detection
representation for super-heterodyne receiver

Receiver susceptibility: block diagram of the super heterodyne receiver
Nayan Chaure 4 Jan. 2023

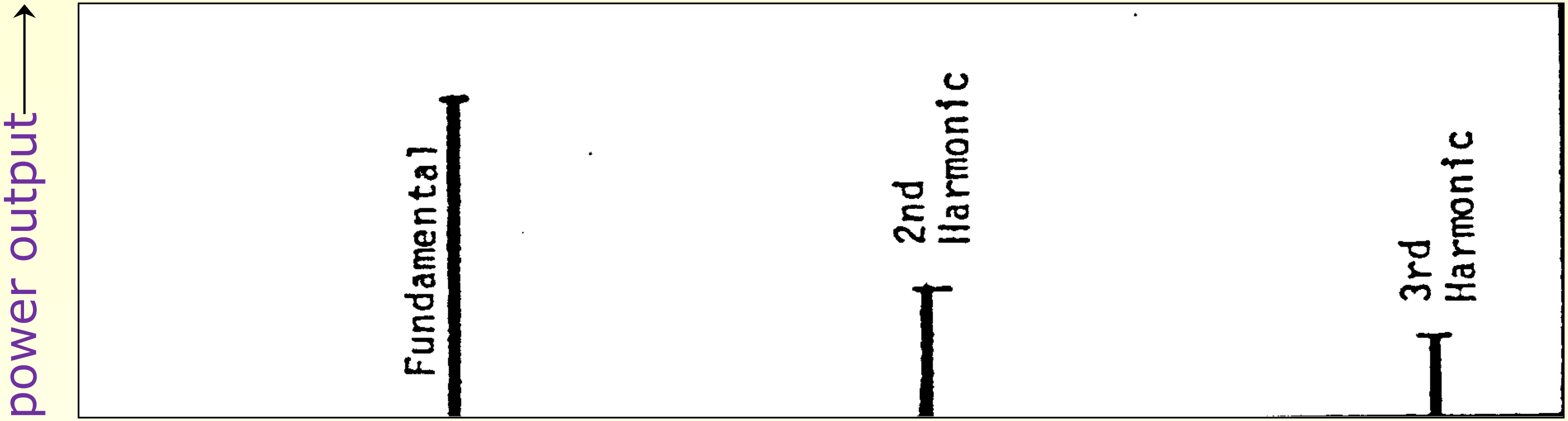


Usually super heterodyne FM receivers operate local oscillators at 10.8 MHz .
Also digital FM receivers use local oscillators

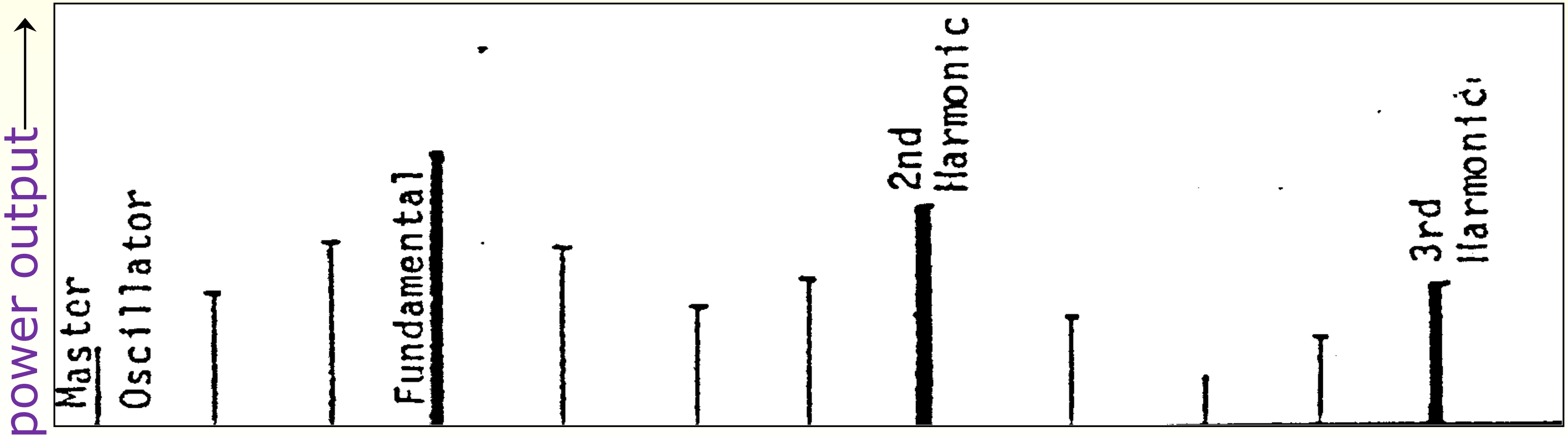
Receiver susceptibility characteristics



TRANSMITTER EMISSIONS



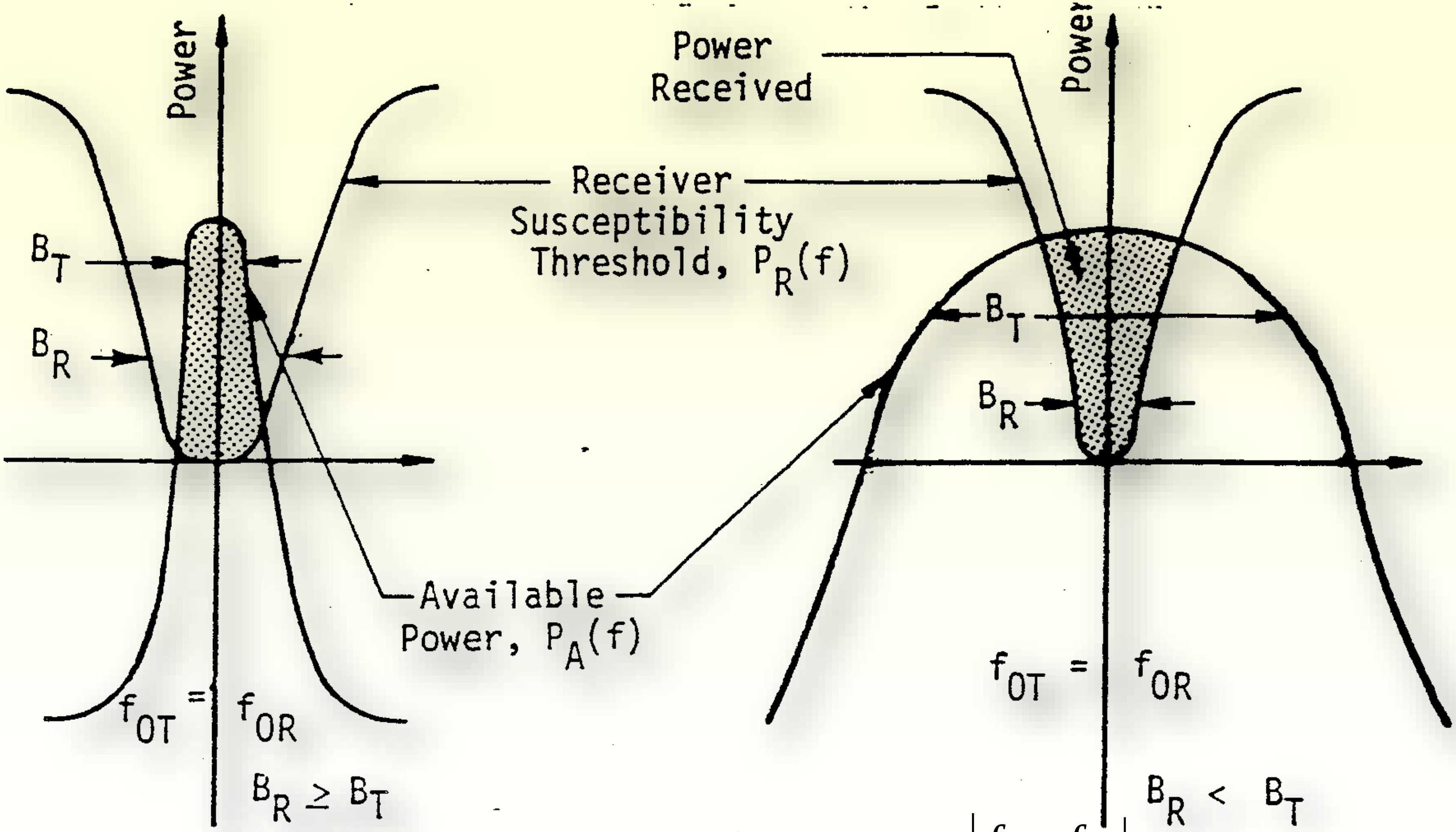
(a) Fundamental and harmonic Emissions *Frequency*



(b) master oscillator, fundamental & harmonics - related emissions

TX - RX CO – Tune Case Channel Coupling

Case Left: power received=int. power available. *Case Right* power received< int. power available
A need of co-channel alignment correction when $BW_R < BW_T$
Receiver 3dB bandwidth: BW_R Transmitter 3dB Bandwidth:BW_T
Transmitter fo: F_T Receiver fo: F_R



$$A_{ttenuation} = 40\log\frac{\Delta f}{f_{mean}} = 40\log 2\frac{|f_t - f_r|}{f_t + f_r}$$

Unwanted Signals

- **Intermodulation**. Unwanted frequency components that are generated from the interaction of two or more spectral components acting on a device with non-linear behaviour. The unwanted components are related to the fundamental components by sums and differences of the fundamentals and various harmonics.

- **Third-order intermodulation** products could cause interference when the difference between one frequency and twice another falls within the pass-band of a receiver. Third-order IMP can occur when one interfering signal is in the proximity of the tuning frequency, e.g. in the adjacent channel. They also could be produced by combination of three interfering signals. 3rd order:

Two Signal Case: $2f_{t1} - f_{t2} = f_r \pm BW$

e.g. The transmitted frequencies are f_1 = 232 MHz (mobile channel), f_2 = 229.75 MHz (Sound Carrier of TV channel 12, for European Standard B) and the interfered frequency is 234.25 MHz (another mobile channel): thus IMP = $2f_{t1} - f_{t2} = f_r \pm BW = 2 \times 232 - 229.75 = 234.25$ MHz

Three Signal Case: $f_{t1} - f_{t2} + f_{t3} = R f \pm BW$ where: $f_{t1} > f_{t2} > f_{t3}$

Passive Intermod (PIM) for different Tx Rx equipment combined to the same ant ports (Txs & Rxs are connected through the same cables to the same port and produce passive, due to their nonlinearity. E.g. 2 Txs deliver 50 watts each (47dBm) and the receiver sensitivity is -120 dBm, it means that a PIM value of up to 167dBc may be required. Ant. spec are -150dBc which is only valid for the antenna. Add the cable and connectors non linearity which degrade with weather, moisture and time

Three-signal case

The most critical combination is the intermodulation of three signals of the same power. To calculate the power of the interfering signal, according to Recommendations ITU-R SM.1134, Table 2 and SM.575 p.3, the power of the intermodulation product for the three-signal equals:

$$P_{IM3} = 3P_S - 2P_{IP3} + 6(\text{dB})$$

Where:

P_{IM3}: power of the 3rd order intermodulation product IM3 (dBm);

P_S: power of each single transmitter involved in the intermodulation (dBm);

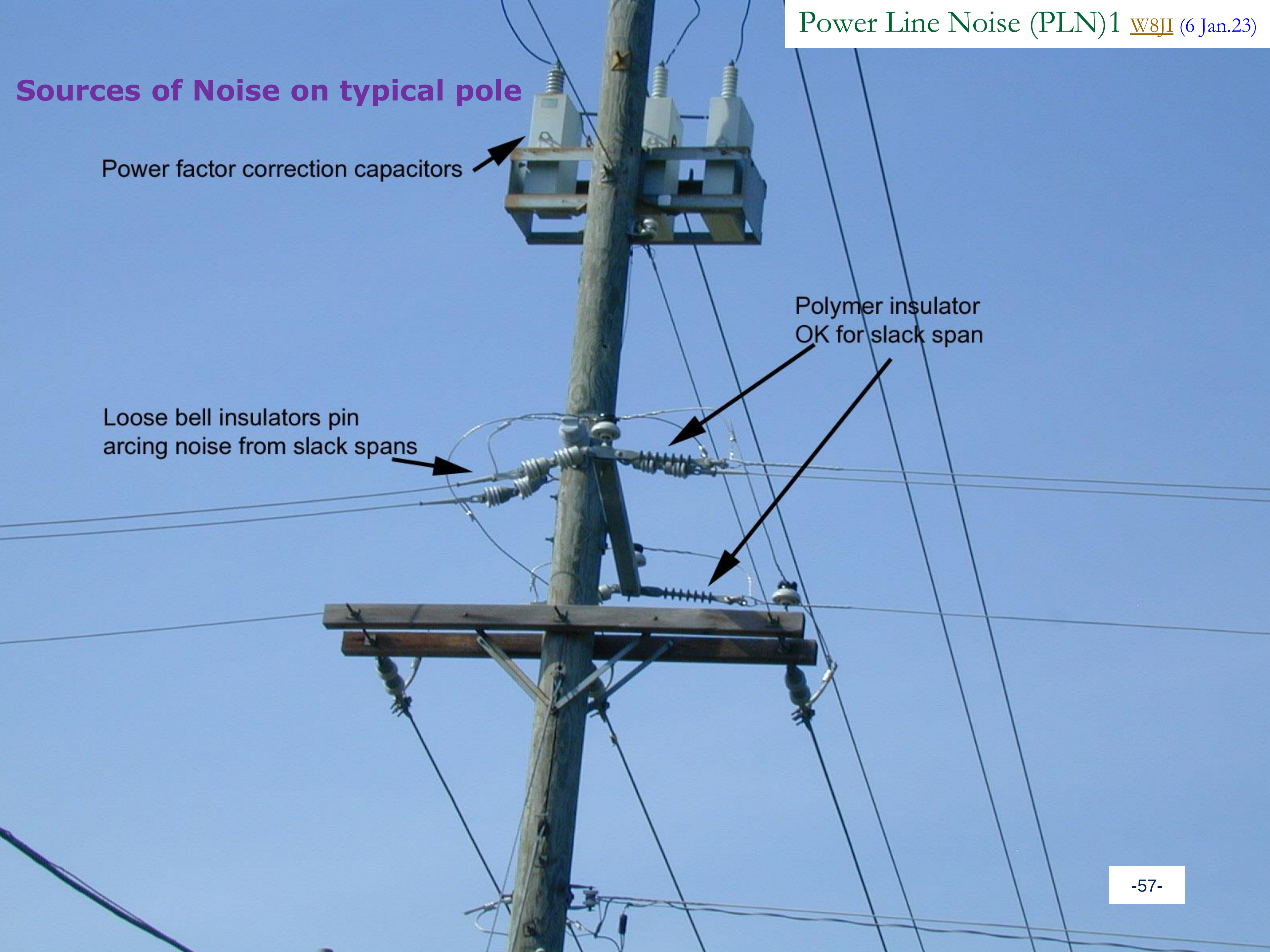
P_{IP3}: 3rd order intercept point (IP3) of the receiver (dBm).

The Handbook on Satellite Communications AP5.2-3 pp. 337-342 also calculates the intermodulation products level.
All three transmitters have similar power.

Power Line Noise (PLN)

Power-line noise is originated from utility company equipment; due to a spark or arcing across some power-line related hardware. A breakdown and ionization of air occurs, and current flows between two conductors in a gap. The gap may be caused by broken or loose hardware such as a cracked insulator. See ARLL 6 Jan.23

Sources of Noise on typical pole

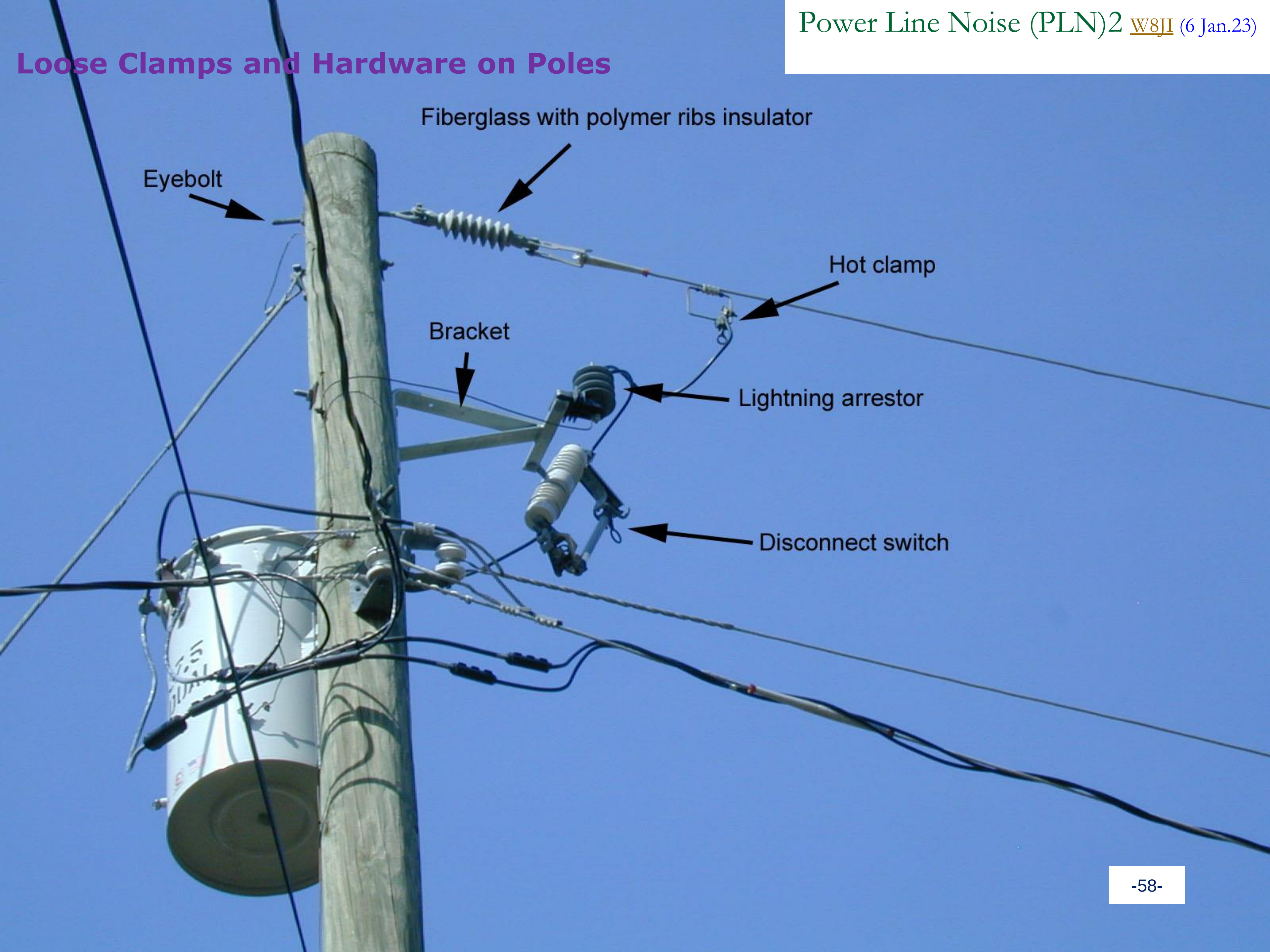


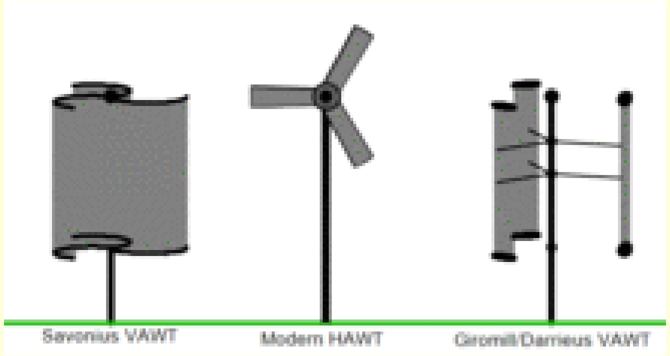
Power factor correction capacitors

Polymer insulator
OK for slack span

Loose bell insulators pin
arcing noise from slack spans

Loose Clamps and Hardware on Poles





ויקיפדיה and US enery.gov

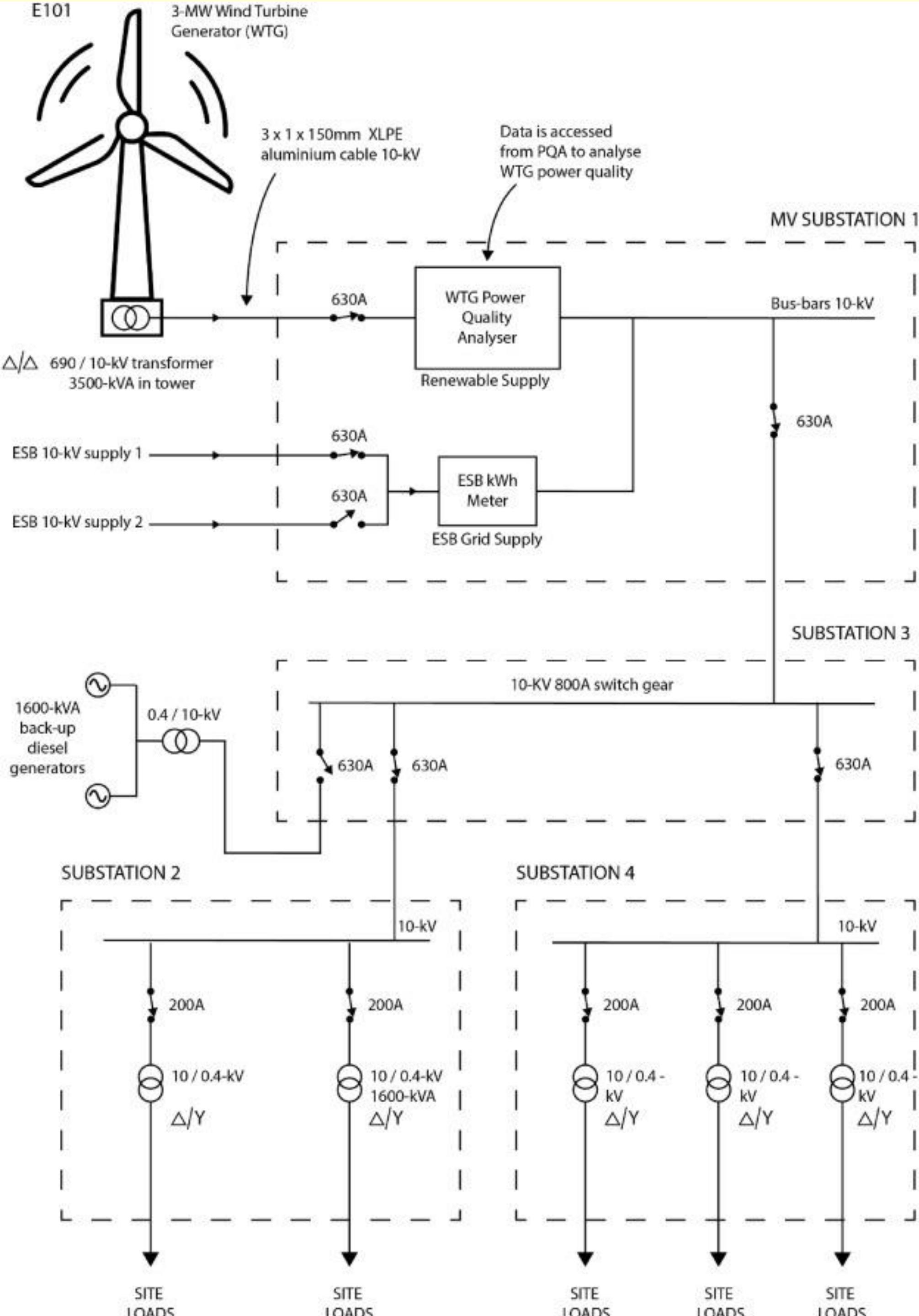
שלושה סוגים נפוצים של טורבינות מימין לשמאל טורבינת ציר אנכי ,טורבינת ציר אופקי וטורבינת מפוח

Wind turbines use wind to make electricity. Wind turns the aerodynamic force of the rotor blades of a turbine around a rotor, which spins a generator, to create electricity.

Horizontal-axis wind profiles commonly use turbines 3 blades, with the turbine pivoting at the top of the tower so the blades face into the wind.

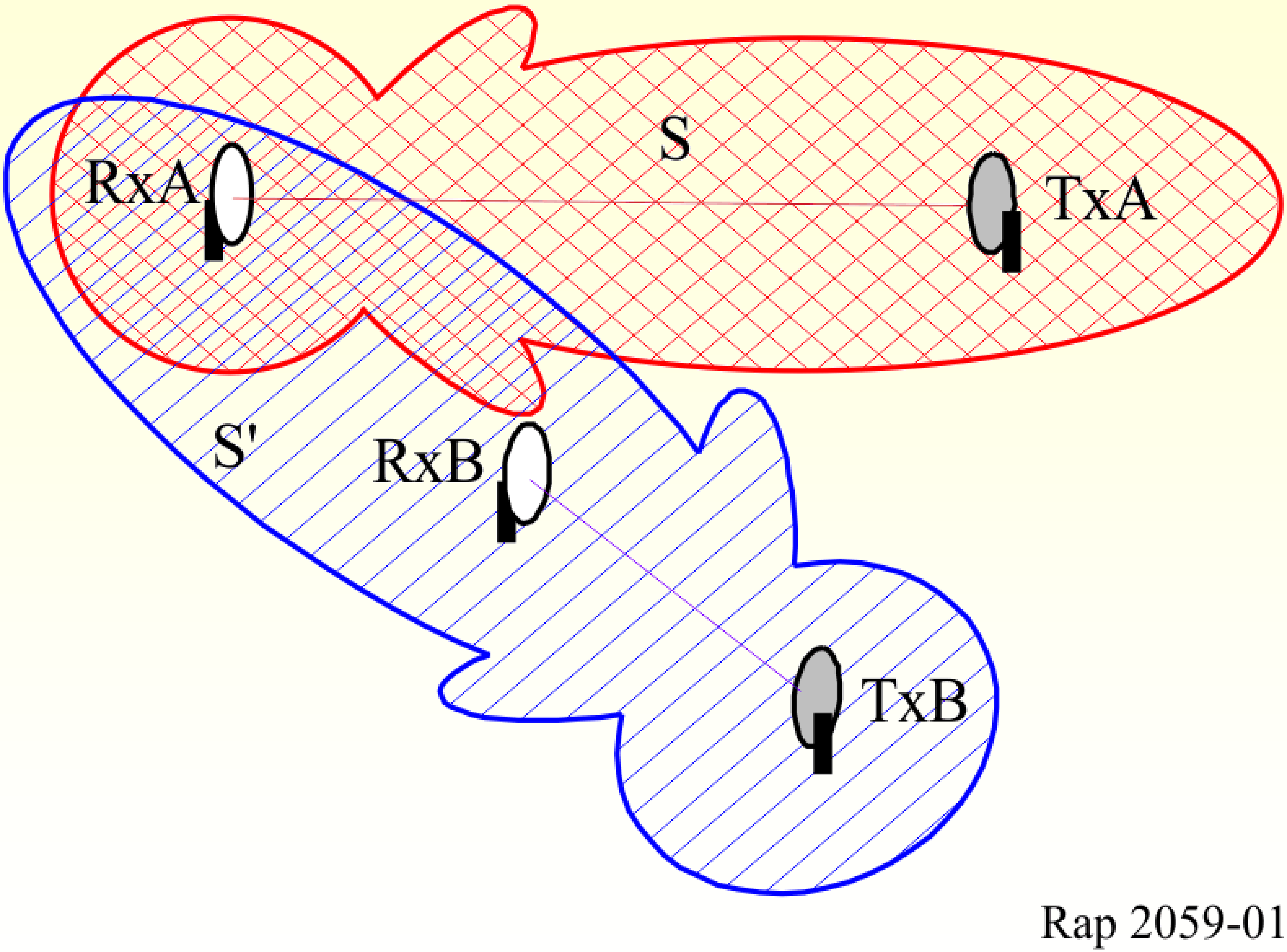
←

חוות הרוח עמק הבכא



Wind turbines use wind to make electricity. Wind turns the aerodynamic force of the rotor blades of a turbine around a rotor, which spins a generator, to create electricity. The units to measure wind-turbines’. Electricity is measured in megawatts and gigawatt. The electricity consumption is measured in kilowatt hours (kWh), an energy unit. electrical-capacity. Horizontal-axis wind commonly use turbines three blades, with the turbine pivoting at the top of the tower so the blades face into the wind.

General interference scenario; RF area (F.2059 2005)



Linear Carrier-to- Interference Ratio (CIR)

where:

φ_1 : interferer off-boresight angle, relative to the victim

φ_2 : victim off-boresight angle, relative to the interferer

P_l: propagation losses

G: antenna gains

$bw_{unwanted}$: bandwidth of the un-wanted signal

bw_{wanted}: bandwidth of the wanted signal

XPD: cross-polarization discrimination

P_l differs as the distance from the wanted and unwanted emitters to the victim is different

The attenuation 10 log $bw_{wanted} / bw_{unwanted}$ is considered only for $bw_{wanted} < bw_{unwanted}$

Disregarding line losses at the transmitter and receiver, according to the logarithmic wanted carrier received signal C equals at standard units:

$$C = P_t + G_t - P_{l\_want} + G_r = EIRP_{wanted} - P_{l\,-want} + G_r$$

The interference I from the interferer INT equals:

$$I = INT + G_{\mathrm{int}}(\varphi 1) - P_{l\_\mathrm{int}} + G_r(\varphi 2) - 10\log\frac{bw_{unwanted}}{bw_{wanted}} - XPD$$

The carrier-to- interference ratio CIR is 10 log c/i = C - I and equals:

$$C - I = EIRP_{wanted} - P_{l\,-want} + G_r - (INT + G_{\mathrm{int}}(\varphi 1) - P_{l\_\mathrm{int}} + G_r(\varphi 2) - 10\log\frac{bw_{unwanted}}{bw_{wanted}} - XPD)$$

DVB-T 1&2 Protection Ratios PR: C/N and C/I

The value of *PR* is established at the threshold of signal failure. Higher *PR* is needed at higher modulation, which provides upper bit rates; see Table 7.8-1, based on Recs. ITU-R BT.1368 2017 tables 1 and 15 & BT.2033 2022 tables 1 and 2 for DVBT-2, at code-rate of 2/3 and Gaussian propagation channel, the carrier to noise *C/N* for BER < 1 × 10^{-11}, and co-channel interference from another DVB-T *C/I* are:

Modulation	**Bit rate (Mbit/s)**		**C/N (dB)**		**C/I (dB)**	
	DVBT-1	DVBT-2	DVBT-1	DVBT-2	DVBT-1	DVBT-2
QPSK	≈ 7	≈ 10*	6.9	3.1*	7	4.5
16-QAM	≈ 13	≈ 20*	13.1	8.9*	13	10.3
64-QAM	≈ 20	≈ 30*	18.7	13.6*	19	15.1
256-QAM	No 256-QAM	40.2		18.1*	No 256-QAM	19.7

* from EBU report Tech 3348 (2020)Table 2.1

The values are similar, as the noise and the interfering co-channel DVB-T signal are flat power density over the entire TV channel range. So for digital technologies PRs *C/N* and *C/I* are similar

Due to technology, DVBT-2 benefits of 2.5 to 3.9 smaller PRs.

S/N protection criterion

Given that all interferer bandwidth signal enters into the victim receiver, the maximum allowed logarithmic interfering threshold power I_{thresh} equals the sensitivity minus Protection Ratio (*PR*). As $S_{min}=K+T_0+B+NF+SNR$. Thus, the threshold interfering power equals:

$$I_{thresh} = S_{min} - PR = K + T_0 + B + NF + SNR - PR$$

As SNR equals approximately Protection Ratio PR

$$I_{thresh} = S_{min} - PR = K + T_0 + B + NF$$

The thermal noise power spectral density at 17°C approximates

$$N_0 = -204 \text{ dBW/Hz} = -174 \text{ dBm/Hz} = -144\ dBm/kHz = -114 \text{ dBm/MHz}$$

Example: Interfering thresholds of radio services and spectrum emission masks from PLT, CATV and ADSL, presentation by the author at COMCAS 11 , on 7 November 2011

S/N protection criterion, example LTE-PPDR

(Public Protection and Disaster Relief)

F: receiver noise figure of the mobile service base or mobile station receivers (dB);
B_i: the BW of the terrestrial interfering stations (MHz); for 790-862 MHz, use Bi = 5 MHz;
G_i: the receiver antenna gain of the station in the mobile service (dBi);
L_F: antenna cable feeder loss (dB);
f: centre frequency of the interfering station (MHz);
P_o: man-made noise (dB) (typical value is 1 dB for the VHF band & 0 dB for the UHF band);
I/N: criterion of interference to land mobile receiver system noise ratio (dB), Rec. ITU-R M.1767. I/N = −6 dB is equivalent to 1 dB increase of the base station receiver noise floor

Rx thermal noise power KTBF at non-loss isotropic antenna for a bandwidth BW = 5 MHz & F of 5 dB equals −114+7 +5 = **−102 dBm**; and **−108 dBm**, for I/N −6 dB; these are the power levels at the BTS receiver input, to protect the IMT-LTE, DIMRS and Project 25, for 5 MHz reference signal. To include Gi(dBi) = 15 and LF(dB) = 3, t power protection level Pr = −108 dBm-12 dB = **−120 dBm**. The sensitivity is derived from the Rx bandwidth BW; a smaller BW is compensated by getting only part of the 5 MHz interfering signal; so the real receiver BW is disregarded in calculating interference. The conversion of the field strength (dBμV/m) to power (dBm) assuming an Isotropic Antenna is given by:

$$P_r = \frac{e^2\ g\lambda^2}{z_0 4\pi} = \frac{e^2 gc^2}{480\pi^2 f^2}$$

P(dBm)= E(dBμV/m)- 77.21- 20Log *f* (MHz)

S/N protection criterion, example LTE-safety systems

LTE and PPDR parameters to derive FS protecting BTS (ITU report M.2241* 2011)

	IMT-LTE BTS	DIMRS	Project 25
Center Frequency 790-862 (MHz)	826	826	
F (dB)	5	5	6
G_i (dBi)	15	15	11
L_F (dB)	3	3	5
Bi (MHz)	5	5	
P_o (dB)	0	0	
$F – G_i + L_F + P_o$	−7	−7	0
Power on Isotropic antenna (dBm)	−120	−120	−113
Field strength (dBµV/m)	15	15	22

*The calculations and the table were drafted by the author on October 2009

Digital Integrated Mobile Radio System (DIMRS)
Motorola Integrated Radio System (MIRS)

Resultant **degradation** in sensitivity due to interference

Receiver sensitivity is the minimum power level at which the receiving node is able to clearly receive the bits being transmitted. Receiver sensitivity degradation means that the receiver is impacted by interference or noise, which results in a certain degradation to the sensitivity of the receiver. sciencedirect.com 28 Dec. 22

interference level relative to Rx thermal noise (dB)	**% increase of thermal noise**	**(i + n)/n**	**Degradation in sensitivity (dB)**
0	100	(i + n)/n=2.00	3
–6	**25**	**(i + n/4)/n=1.25**	**1**
–10	10	(i + n/10)/n=1.10	0.4
–12.2	**6**	**(i +0.06 n)/n=1.06**	**0.25**
–13	5	(i+0.05 n)/n=1.05	0.21
–20	**1**	**(i + n/100)/n=1.01**	**0.04**

Some Author's papers and presentations on Regulation, EMC and RFI

1. Interfering thresholds of radio services and spectrum emission masks from PLT, CATV and ADSL; COMCAS 11; 7 Nov. 2011
2. A Comparison Between European and North American Wireless Regulations Geneva, 2011
3. UHF Global And Regional Ruling and Standardization - The Case Of Different Allocations To Short Range Devices (SRDs) & Electronic Devices , Go Global Compliance Academy TM Webinar, 19 Feb. 2013
4. National Spectrum Control Spectrum Management and monitoring; Beijing, China; 9 July 2015
5. International, Regional & National Regulation of Short Range Devices; Beijing; 9 July 2015
6. Keynote speech: National Spectrum Control – Spectrum Management and Monitoring: New Technologies; Chengdu, China; 12 July 2015
7. Analysis Methodology for Spectrum Sharing between Medical Implants and Digital Broadcasting; EMC Europe 2016; Wroclaw, Poland, 8 May 2016
8. National Spectrum Control Spectrum Management and Monitoring; Bhutan, 7 June2017
9. Regulating and Standardizing Directive Antenna Patterns to Improve Coexistence; Texas, 6 April 2018
10. Comparing Directive Antenna Patterns: Regulation and Standards; SCE, Israel; 23 May 19
11. International, Regional & National regulation of wireless communications; 5G EMC; Israel, 6 June 2019
12. PRIDA Track 1 (T1) On-line English workshop 20th April–1st May2020. First_week_slides_v2
13. PRIDA Track 1 (T1) Atelier de renforcement des capacités sur la gestion moderne du spectre 11-22 mai 2020. First_week_slides_v2; 15 May 2020
14. Academic_Course_Wireless_Communications_Mazar3_Regulation_**EMC**_HumanHazards_2020.pdf

Advanced Wireless Communications, 2020

Academic course for 4th year engineering students

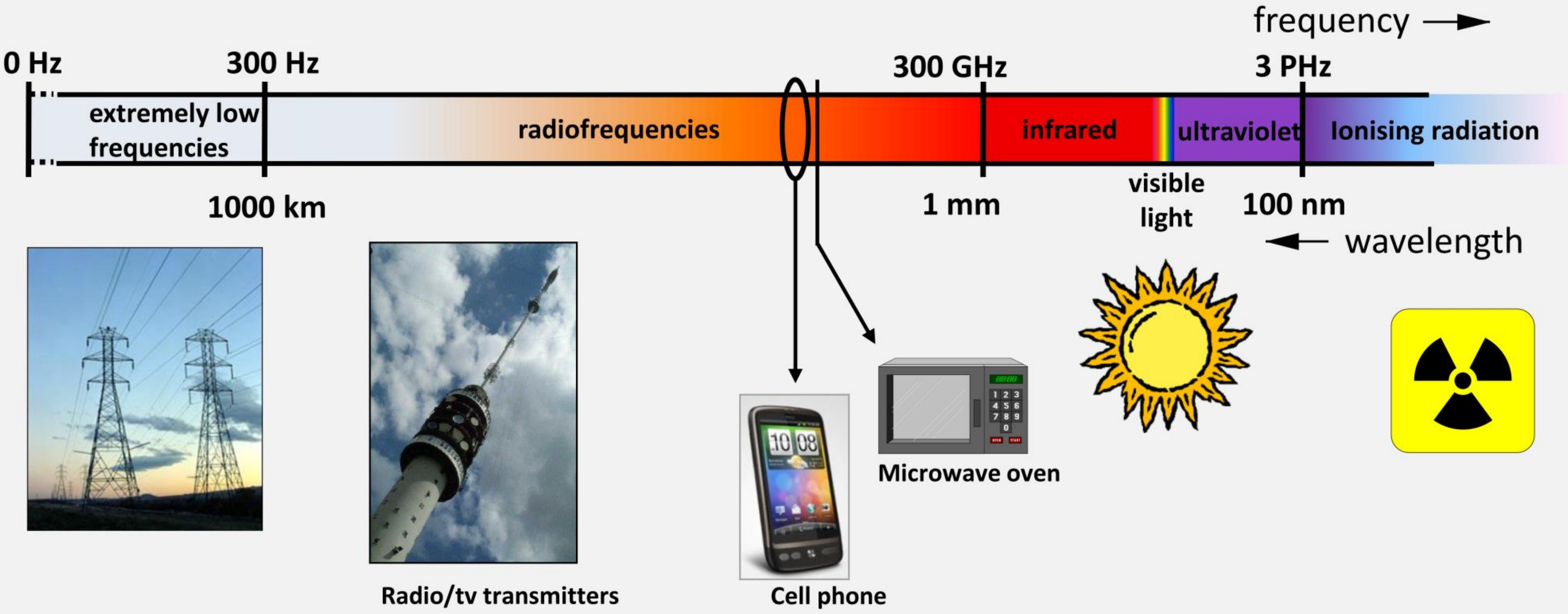
Sami Shamoon College of Engineering

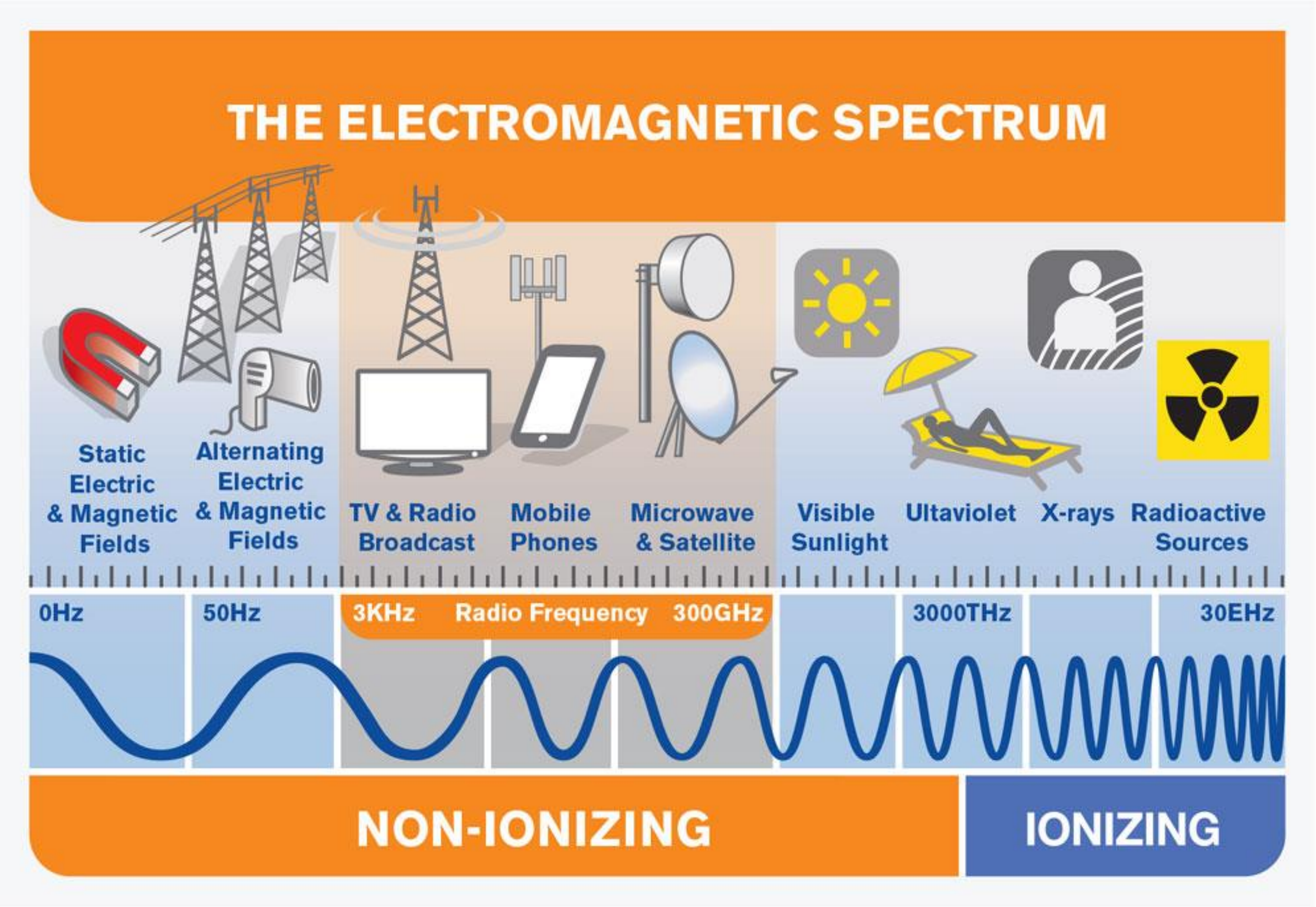
RF Human Hazards; EMF ElectroMagnetic Fields

Dr Haim Mazar, ITU intersector activities officer on RF-EMF and co-rapporteur ITU-D Question 7/2. http://mazar.atwebpages.com/

The Electromagnetic Spectrum

(Source ICNIRP)





Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

Ionizing and non-ionizing radiations

- **Ionizing radiation** (ionising radiation) carries sufficient energy to detach electrons from atoms or molecules, thereby ionizing them. Gamma rays, X-rays, and the higher ultraviolet part of the electromagnetic spectrum are ionizing
- **Non-ionizing radiation:** the lower frequencies-ultraviolet, visible light (including nearly all types of laser light), infrared, microwaves and radio waves

Ionizing and non-ionizing radiations; Planck–Einstein relation

- Planck's constant, denoted *h*, relates the energy carried by a photon to its frequency. A photon's energy is equal to its frequency multiplied by the Planck constant
- The Planck constant $h = 6.62607015 \times 10^{-34}$ Joule**.**s
- Planck–Einstein relation **Energy = *hf***
- The electronvolt is the appropriate unit of energy, and the petahertz the appropriate unit of frequency
- An electronvolt (symbol eV, also written electron-volt and electron volt) is the amount of kinetic energy gained (or lost) by a single electron accelerating from rest through an electric potential difference of one volt in vacuum
- The numerical value of 1 eV in joules (symbol *J*) is equivalent to the numerical value of the charge of an electron in coulombs (symbol C)
- Under the 2019 redefinition of the SI base units, 1 eV equals $1.602176634 \times 10^{-19}$ Joule

Ionizing Radiation

- The boundary between radiations is the photon energy between 10 eV (Federal Communications Commission FCC definition) equivalent to a far ultraviolet wavelength of 124 nanometers in the ultraviolet
- λ wavelength (m.)= $300 \times 10^{6}/f$(Hz); f(Hz)= $300 \times 10^{6}/124 \times 10^{-9}$; as 1THz = 10^{12}Hz; f(THz)= $300 \times 10^{-6}/124 \times 10^{-9} = 300 \times 10^{3}/124 =$ 2,419 THz; $2,419 \times 10^{3}$ GHz; 2.419 PHz (petahertz)
- The ITU Radio Regulations stop at 3,000 GHz; 3 THz; 0.01241 eV, 100 µM
- So, ionizing radiation is an electromagnetic wave propagating at light-speed, but not a radio- transmission

RF adverse effects: low-level effects

- No adverse effects have been established from low-level exposures, despite more than 70 years of research
- No known interaction mechanisms
- No meaningful dose-response relationship
- Speculative
- Inappropriate for standard setting

Exposure limits for radio-frequency fields (public) Data by country; see

https://apps.who.int/gho/data/node.main.EMFLIMITSPUBLICRADIOFREQUENCY?lang=e Last updated: 31 May 201731; retrieved 28 Dec.2022

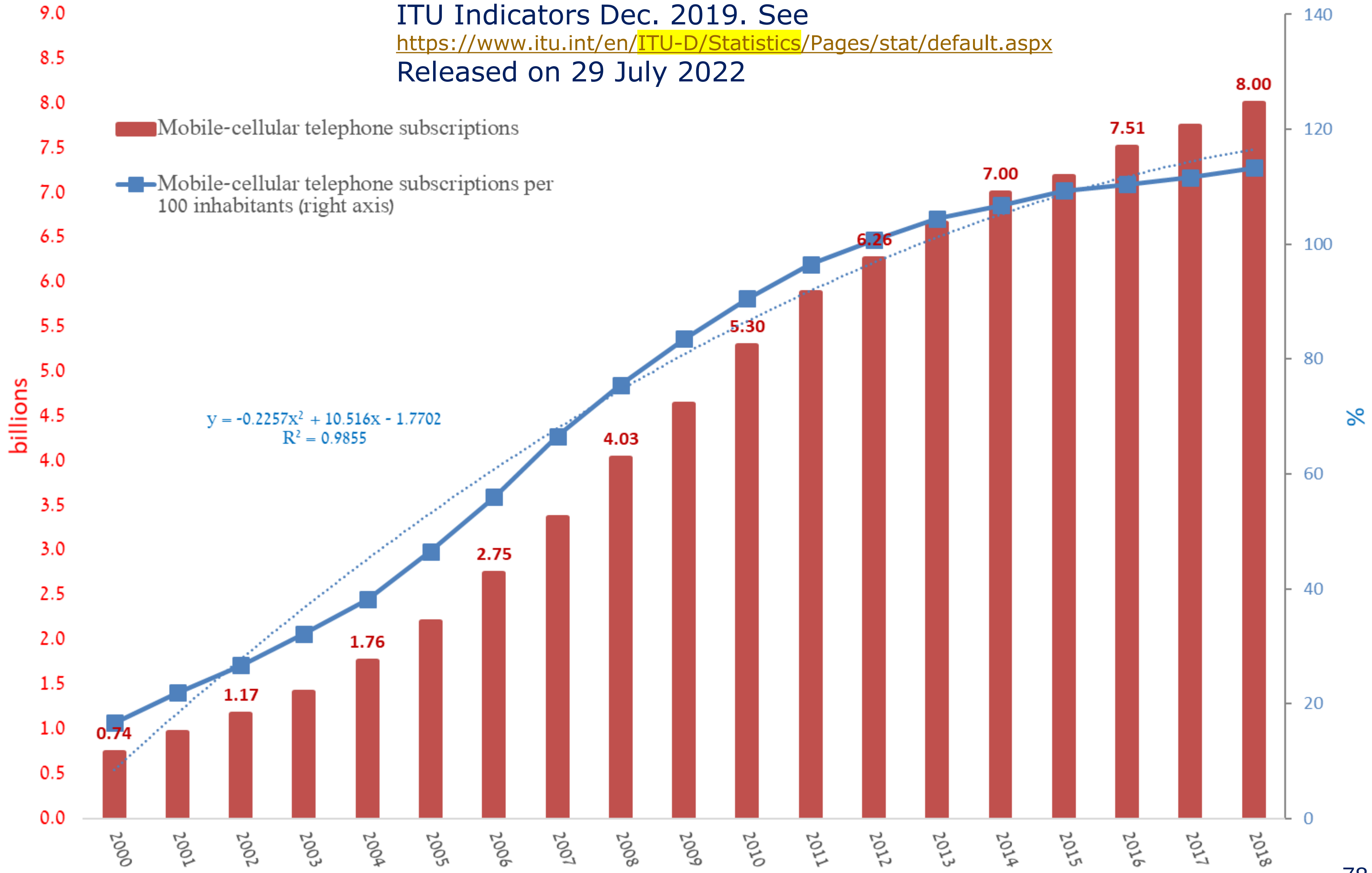
	Electric field (V/m)		Power density (W/m^2)		Specific absorption rate (SAR) (W/kg)		
	900 MHz	1800 MHz	900 MHz	1800 MHz			
Country					Whole body	Head and trunk	Limbs
Argentina	41.25	58.36	4.5	9	0.08	2	4
Australia	41.1	58.1	4.5	9	0.08	2	4
Austria	41.25	58.34	4.5	9	0.08	2	4
Bahrain	41	58	4.5	9	0.08	2	4
Brazil	41.25	58.34	4.5	9	0.08	2	4
Bulgaria	6.14	6.14	0.1	0.1			
Canada	32.1	40.07	2.74	4.4	0.08	1.6	4
Chile			0.1/1.0	0.1/1.0	1.6/2	1.6/2	1.6/2
Cuba						0.8/1.6	
Cyprus	41	58	4.5	9	[0.08]	[2]	[4]
Finland	41.4	58.55	4.5	9	0.08	2	4
France	41	58	4.5	9	0.08	2	4
Germany	41.25	58	4.5	9	0.08	2	4
Greece	31.9/34.5	45.1/48.8	2.7/3.15	5.4/6.3	0.048/0.056/0.08	1.2/1.4/2.0	2.4/2.8/4.0
Iran	41.25	58.34	4.5	9			
Israel	13	18	0.45	0.9	0.08	2	4
Italy	Jun-20	Jun-20	0.1/1.0	0.1/1.0	0.08	2	4
Japan	47.55	61.4	6	10	0.08	2	4
Malaysia	41.25	58.34	4.5	9		2	
Netherlands	41.25	58.34	4.5	9	0.08	2	4
New Zealand	41.25	58.34	4.5	9	0.08	2	4
Norway	41.25	58.34	4.5	9	0.08	2	4
Peru	41.25	58.34	4.5	9	0.08	2	4
Philippines	41.25	58.34	4.5	9	0.08	2	4
Republic of Korea	41.25	58.34	4.5	9	0.08	2	4
Russian Federation			1	1			
Saudi Arabia	41.25	58.34	4.5	9	0.08	2	4
South Africa	[41.0]	[58.0]	[4.5]	[9.0]	[0.08]	[2]	[4]
Sweden	[41.25]	[58.33]	[4.5]	[9]	[0.08]	[2]	[4]
Switzerland	4/41.25	6/58.34					
Tunisia	41	58	4.5	9	0.08	2	4
Turkey	3/10.23/41.0	3/14.5/58	0.27	0.55		2	
United Kingdom	[41.25]	[58.34]	[4.5]	[9.0]	[0.08]	[2]	[4]
USA	47.6	61.4	6	10	0.08	1.6	4
Zambia	41	58	4.5	9	0.08	2	4

The [parentheses] are not clear

EMF Policies

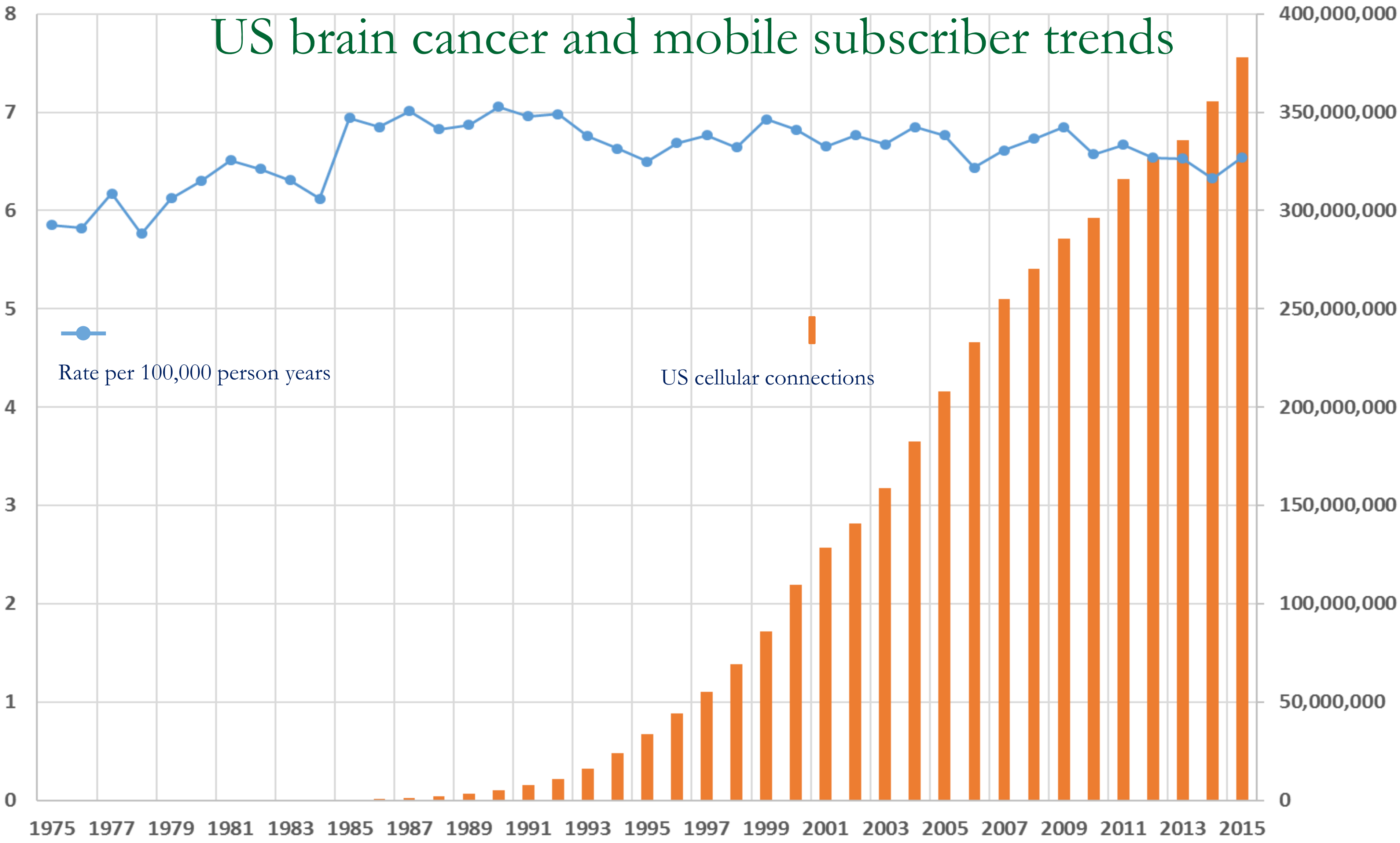
- It is scientifically impossible to prove absolute safety (the null hypothesis) of any physical agent (ANSI/IEEE C95.1-2005:p.2); it is impossible to prove the negative, (i.e. that something does not exist).
- The precautionary-principle and the "As Low As Reasonably Achievable" (ALARA) concept to the RF-EMF health risk management problem may replace the two-state risk management model (above/below the threshold).
- It is a trade-off balance between the remaining uncertainty (and the damage in the case that the worst-case turns true), versus implementing stricter requirements

Mobile-cellular telephone subscriptions (billions) & Mobile-cellular telephone subscriptions per 100 inhabitants, 2000-2018



ITU Indicators Dec. 2019. See
https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx
Released on 29 July 2022

US brain cancer and mobile subscriber trends



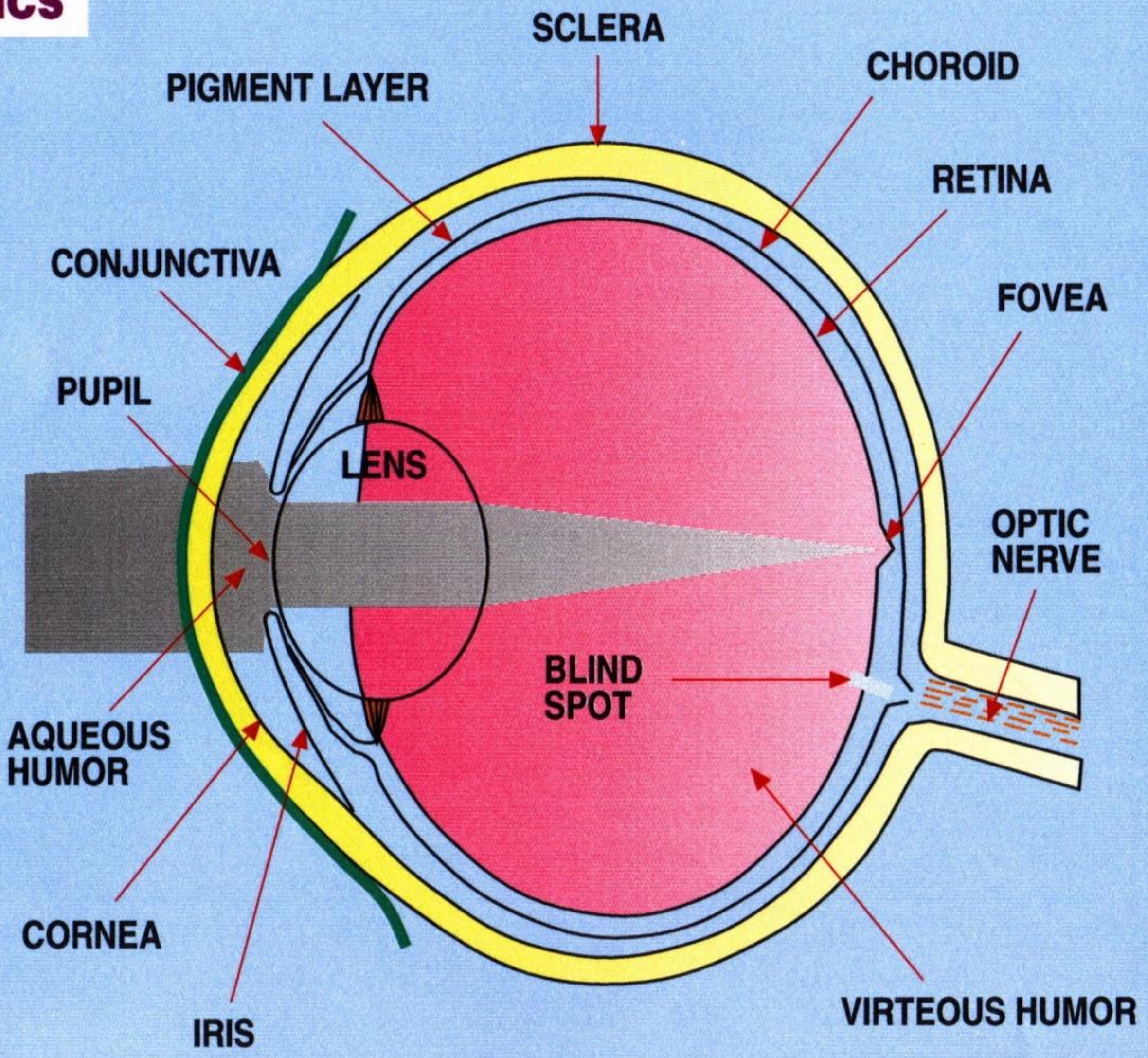
Overall, incidence data of the Surveillance, Epidemiology, and End Results (SEER) do not support the view that cellular phone use causes brain cancer.

Based on CTIA and SEER data, and Inskip et al., 2010;retrieved 28 Dec.2022

The Human Eye (Moshe Netzer)

SUSCEPTIBILITY CHRACTERISTICS

- POOR BLOOD CIRCULATION
- LENSE OPACITY
- CORNEA DAMAGE
- RETINA RAPTURE



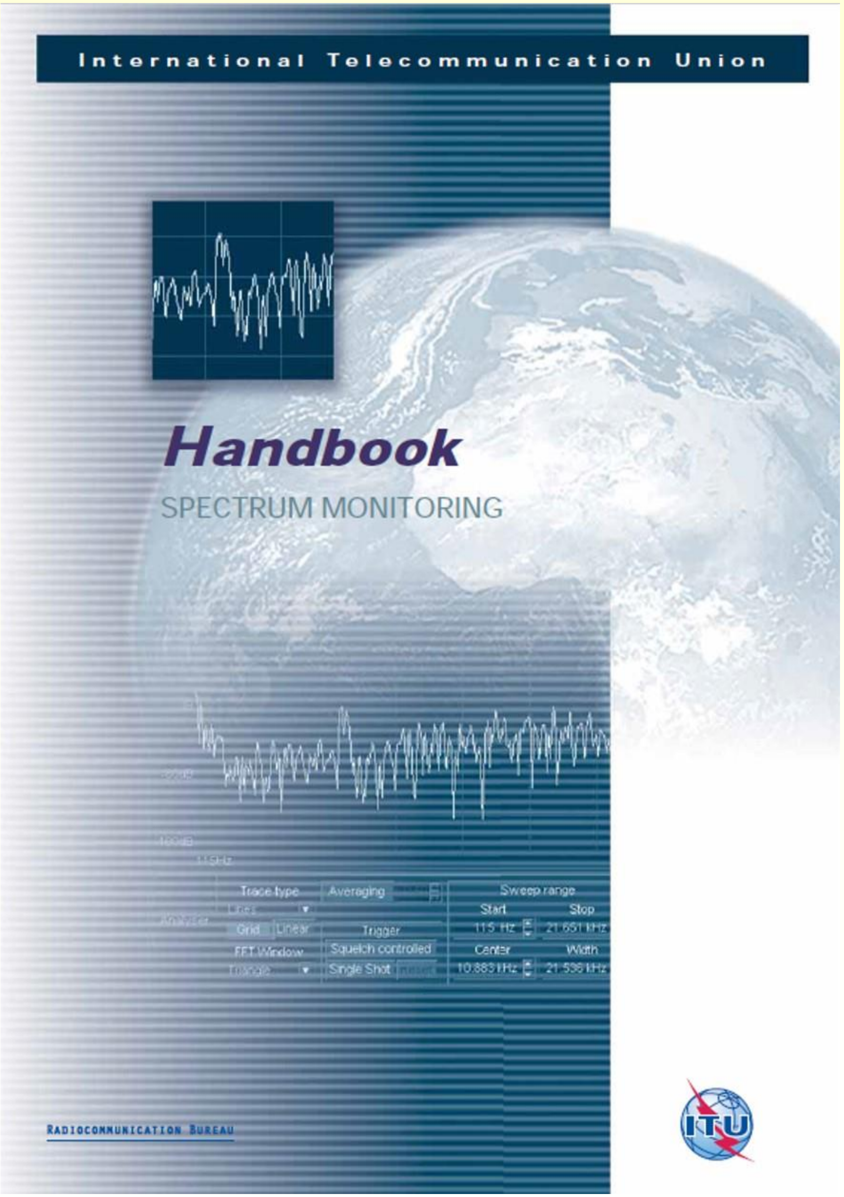
Global monitoring of human exposure : levels are very low, relative to ICNIRP reference levels (1)

1. 2001–2004 (WHO 2007:30), UK conducted radio surveys at 289 schools with base stations on or near them. The highest compliance factor measured anywhere was 3.5 x 10^{-3} (= 12.2 x 10^{-6} of the power density), with the 90% of the schools having a highest compliance factor below 2.9 x 10^{-4} (**8.4 x 10^{-8}** power density) – which are very low values indeed. See also IARC 2013:58, fig. 1.11 specifies a cumulative distribution of exposure quotients corresponding to 3321 spot measurements made by OFCOM at 499 sites where public concern had been expressed about nearby base stations; the quotient values are median 8.1×10^{-6} of ICNIRP power density, ranging from the **5th percentile 3.0×10^{-8} to 95th percentile 2.5×10^{-4}**.
2. Two hundred randomly selected people in urban, sub-urban, and rural subgroups have measured on 2005–2006 in France (Viel et al. 2009; see also IARC 2013:114) for 24 hours a day, 184 daily measurements. At the GSM 900/1800 bands most of the time, the recorded field strength was below detection level (**0.05 V/m); 0.05 V/m is 3.63%** of the ICNIRP level at 900 MHz. 12.3% of measurements at the FM band indicate field strength above the detection threshold; the mean field strength was 0.17 V/m (Viel et al. 2009:552), the maximum field strength was always lower than 1.5 V/m. ANFR 2007 reveals that at 2004-2007, the average measurements are less than 2% of the field strength limit (less than 0.04 % of power density); more than 75% of the measurements were less than 2% of the field strength limit, regardless of the frequency band considered.

Global monitoring : levels are very low, relative to ICNIRP reference levels (2)

1. Ofcom published on February 2020 the results of recent measurements of EMF emissions close to sixteen 5G-enabled mobile phone base stations showing EMF levels at a total of 22 5G sites in 10 UK cities:
2. In 10 cities across the UK; base stations support technologies in addition to 5G, including 2G, 3G and 4G:
    1) EMF emission levels from 5G-enabled base stations remain at small fractions of the reference levels for 1998 general public exposure in ICNIRP Guidelines (400–2,000 MHz) *f* (MHz)/200 (W/m^2), & 2–300 GHz 10 (W/m^2)
    2) the highest level recorded being approximately 1.5% of the **power density** reference level.
    3) In all locations, the largest contribution to the measured levels comes from previous generations of mobile technology (2G, 3G, 4G).
    4) The highest level observed in the band used for 5G was just 0.039% of the reference level

ITU's worldwide recognized reference on Spectrum Monitoring and related issues



International Telecommunication Union

Handbook

SPECTRUM MONITORING

RADIOCOMMUNICATION BUREAU

- Chapter 5.6 on **Non-Ionizing Radiation (NIR) measurements**
- Explains **NIR limits & exposure quotient**
- **Instruments for NIR measurements**
  - Broadband isotropic probes and meters
  - Tri-axis antennas and field strength meters
  - Transportable station
  - standard field strength measurement equipment
- **Measurement procedures** for different radio services (incl. mobile, broadcasting, etc.)
- **Reporting methods**

Source: ITU-R Handbook on Spectrum Monitoring (2011) www.itu.int/pub/R-HDB-23
The Academic course instructor wrote specific Chapters in the 1995, 2002 and 2011 editions

Policies, guidelines, regulations and assessments of human exposure to radio-frequency electromagnetic fields Study period 2018-2021

ITUPublications
Study period 2018-2021

International Telecommunication Union
Development Sector

Study Group 2 Question 7

Policies, guidelines, regulations and assessments of human exposure to radio-frequency electromagnetic fields

Video Report

Final Report of Q7/2

The report focuses on science-based policies, guidelines, regulations and assessments in respect to human exposure to RF-EMF, based on updated international RF-EMF exposure limits defined by the ICNIRP Guidelines 2020 and the IEEE C95.1-2019

'The best practice for administrations that choose to use international RF-EMF exposure limits is to limit the exposure levels to the thresholds specified in ICNIRP (2020) Guidelines.'

French ANFR, RF-EMF 2018 annual survey of over 2,500 public exposure measurements See ANFR Sept. 2018 abstract

Summerised results 2017: 90% of exposure levels measured in 2017 in rural areas are below 0.95 V/m.
* Values below the typical sensitivity threshold of the measuring devices, which equals 0.38 V/m

	Mesuresments nº	**50% (median values)**	**90 %**	**99 %**	**Max**
Rural	425; 16 %	0,25* V/m	0,95 V/m	2,8 V/m	3,95 V/m
Urban	2166; 84 %	0,4 V/m	1,67 V/m	5,6 V/m	11,25 V/m
Indoor	1666; 64%	0,31* V/m	1,34 V/m	4,1 V/m	10,54 V/m
Outdoor	914: 36%	0,52 V/m	1,93 V/m	6,3 V/m	11,25 V/m
Total	**2591**	**0,36* V/m**	**1,57 V/m**	**5,5 V/m**	**11,25 V/m**

Questions to be raised

Compliance calculations and some periodic measurements are essential. However:

1. Why do we need to make so many nation-wide measurements?
2. May be ICNIRP reference levels are too liberal?

EMF, ITU-R SG 1 Report on WPT-EV: SM.2452 July 2022

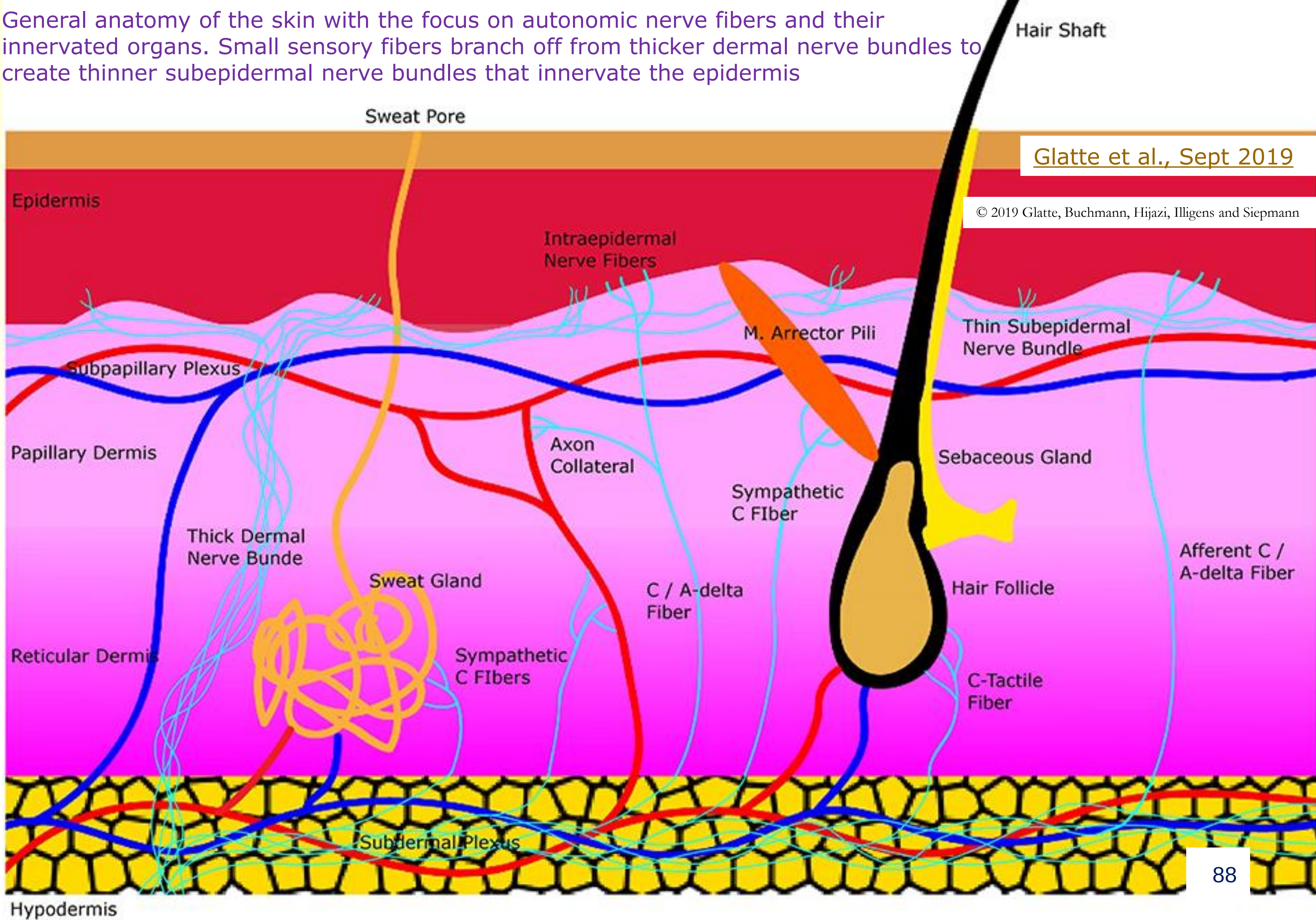
SM.2452 2019: Electromagnetic field measurements to assess human exposure. 20 June 2022, I got from RAI Italy 'Dear colleagues, I would like inform you that in Italy have started works to install WPT systems called DWPT (Dynamic Wireless Power Transfer). The first route is along motorway called BREBEMI (Brescia-Bergamo-Milan). The next steps are intended to cover parking areas, airports and harbors.' I Responded Pls read in 'Dopo Arena del Futuro sull'autostrada A35 in Italia, Electreon lancia un progetto nello Utah. Obiettivo: un circuito entro l'estate'. Electreon is an Israeli company.

The revisions of IEEE 95.1 2019 and ICNIRP 2020 necessitated adjustments to the assessment of human hazards. Sections 3.1 'Basic knowledge for a successful EMF assessment measurement process' and 3.5.2.5 'New Radio base stations', and new Annex 'EMF around an Amateur Radio Station, 14 MHz to 440 MHz' are added.

[91] Draft revision of Report ITU-R SM.2452-0 - Electromagnetic field measurements to assess human exposure, ATDI Q239/1 2022-01-05

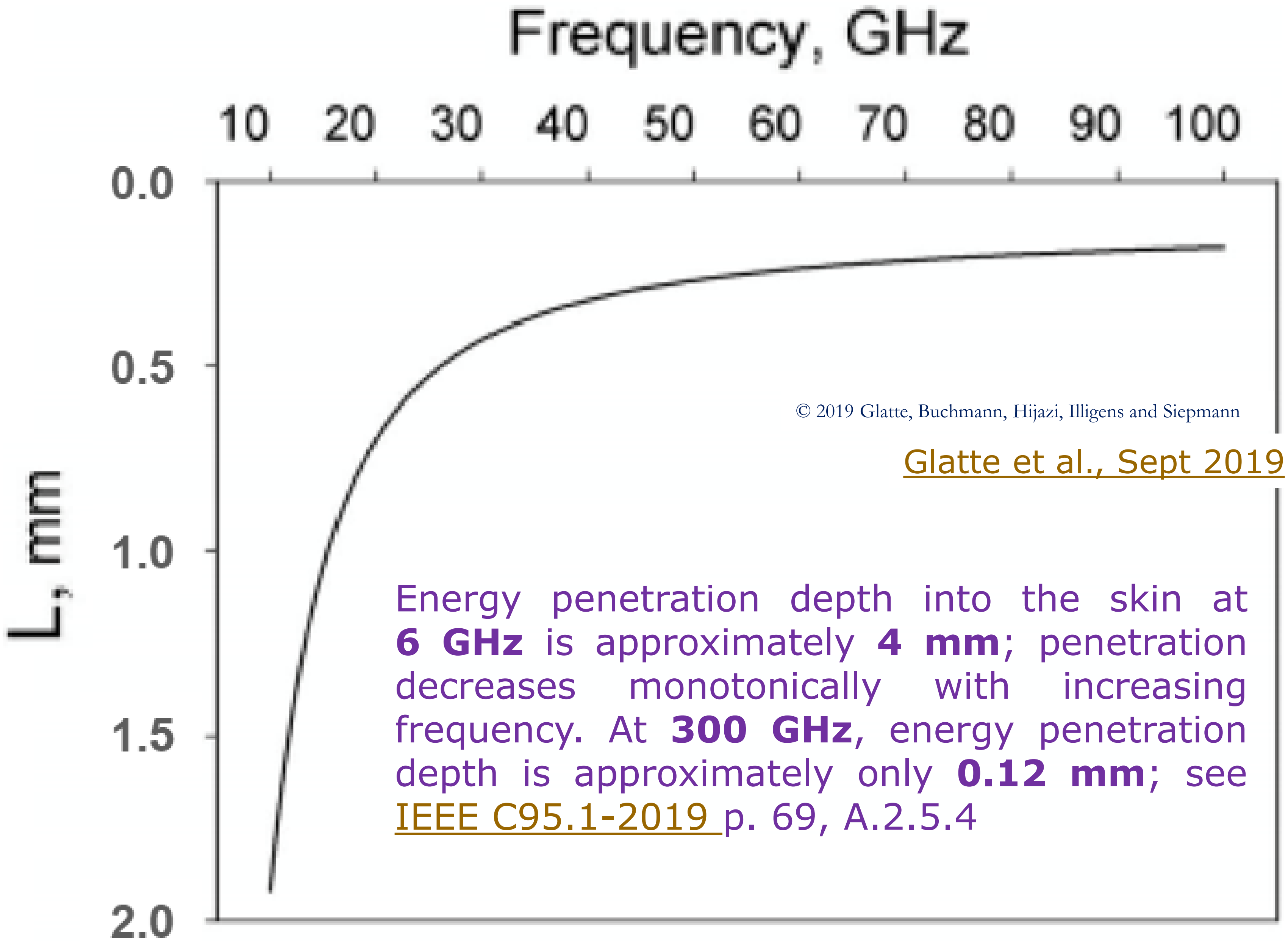
Cross-section human skin

General anatomy of the skin with the focus on autonomic nerve fibers and their innervated organs. Small sensory fibers branch off from thicker dermal nerve bundles to create thinner subepidermal nerve bundles that innervate the epidermis



Glatte et al., Sept 2019

mmWaves mostly absorbed in outer skin layers (1)



© 2019 Glatte, Buchmann, Hijazi, Illigens and Siepmann

Glatte et al., Sept 2019

Energy penetration depth into the skin at **6 GHz** is approximately **4 mm**; penetration decreases monotonically with increasing frequency. At **300 GHz**, energy penetration depth is approximately only **0.12 mm**; see IEEE C95.1-2019 p. 69, A.2.5.4

mmWaves mostly absorbed in outer skin layers (2)

However, ICNIRP 2020 Table 10 details different numbers:

Frequency (GHz)	Relative permittivity	Conductivity (S/m)	Penetration depth (mm)
6	36	4.0	8.1
10	33	7.9	3.9
30	18	27	0.92
60	10	40	0.49
100	7.3	46	0.35
300	5.0	55	0.23

Example: Human Hazards- thresholds; see

http://mazar.atwebpages.com/Downloads/EMC_Europe2016_Wroclaw_Sep%202016_Mazar_20April16_EMF.pdf

1. On June 2020 at 400-1500 MHz, the allowed ICNIRP 1998 (revised in April 2020, see ICNIRP 2020) and EU Power Density for the general public is: ***f* (MHz)/200 (W/m^2)**

2. Europe follows ICNIRP 1998 levels; but: SUI (0.01 ICNIRP for BTS), Italy (0.03 ICNIRP) and Slovenia (0.1 ICNIRP)

3. US & Japan limit is 4/3 higher: ***f* (MHz)/150 (W/m^2)**

4. US & Canada threshold on terminal's SAR is **1.6 W/kg** (5/4 more risk averse). ICNIRP & EU limit is **2.0 W/kg**

7 June 2020, representative general population/ uncontrolled exposure reference levels, still relative to ICNIRP 1998; See http://mazar.atwebpages.com/Downloads/EMC_Europe2016_Wroclaw_Sep%202016_Mazar_20April16_EMF.pdf

	PD 1,000 MHz (W/m^2)	SAR (W/kg)
USA	$f/150$ $=6.67$; 133/%	1.6, averaged over 1g tissue
Japan		2.0 , over 10 g
ICNIRP1998; IEEE 2005; AUS; NZL; EC Directive 004/40/EC	$f/200$ $=5$; 100%	
Korea		1.6, averaged over 1g tissue
Canada	$0.02619f^{0.6834}$ $=2.94$; 59%	
China	0.4; 8%	2.0 , over 10 g

ICNIRP 2020 **Guidelines** for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)

Published in: Health Phys 118(5): 483–524; 2020;

DOI: 10.1097/HP.0000000000001210

- Purpose of the guidelines: to protect people exposed to RF electromagnetic fields 100 kHz–300 GHz
- Two types of restrictions (as next slides see ICNIRP 2020 **Guidelines in brief**; not from the Guidelines https://www.icnirp.org/en/activities/news/news-article/rf-guidelines-2020-published.html)
  - **Basic restrictions** refer to fields in people (cannot be measured easily)
  - **Reference levels** refer to fields in the environment (can be measured easily). Typically used to ensure safety.

ICNIRP 2020 Guidelines- How was it prepared?

1. Identify scientific data on effects of exposure
2. Determine effects considered both
   – adverse to humans
   – scientifically substantiated
3. Identify minimum exposure level needed to produce harm
4. Apply reduction factors: larger for general public than for workers
5. This results in exposure restrictions with a large margin of safety

ICNIRP 2020 Guidelines- Scientific Basis

- Major reviews and original papers
- Only adverse health effects through:

– nerve stimulation (up to ~10 MHz, limits from 2010 guidelines)

– heating (from ~100 kHz)

- No evidence for

– cancer

– electrohypersensitivity

– infertility

– other health effects

ICNIRP 2020 Guidelines-
Adverse Health Effects Identified

- Deep body temperature: increase >1 °C
- Tissue temperature: temperature >41 °C

ICNIRP 2020 Physics & Temperature

- Different quantities used to estimate temperature; depend on frequency, duration of exposure
- For example for local exposures: absorbed energy rate (SAR) at lower frequencies, power density at higher frequencies
- Complex system!

ICNIRP 2020 Guidelines in brief; Basic Restrictions

Parameter	**Frequency range**	**ΔT**	**Spatial averaging**	**Temporal averaging**	**Health effect level**	**Reduction factor**	**Workers**	**Reduction factor**	**General public**
Core ΔT	100 kHz–300 GHz	1°C	WBA (whole body average)	30 min	4 W/kg	10	0.4 W/kg	50	0.08 W/kg
Local ΔT (Head & Torso)	100 kHz–6 GHz	2°C	10 g	6 min	20 W/kg	2	10 W/kg	10	**2 W/kg**
Local ΔT (Limbs)		5°C			40 W/kg		20 W/kg		4 W/kg
Local ΔT (Head & Torso, Limbs)	>6– 300 GHz 30– 300 GHz	5°C	4 cm^2 1 cm^2		200 W/m^2 400 W/m2		100 W/m^2 200 W/m^2		20 W/m^2 40 W/m^2

ICNIRP 2020 Guidelines themselves

- Tables 5 and 6 detail reference levels for exposure, averaged, to EMF 100 kHz–300 GHz (unperturbed rms values)
- The four ICNIRP figures appear in the 'Differences 2020 1998 Guidelines', which are clearer, but could not be included in the Health Phys publication
- The units of the two y-axes (i.e. electric field and power density) are independent of each other

ICNIRP 2020: Table 1. Quantities and corresponding SI units used in these guidelines

Quantity	**Symbol**	**Unit**
Absorbed energy density	U_{ab}	joule per square meter (J m^{-2})
Incident energy density	U_{inc}	joule per square meter (J m^{-2})
Plane-wave equivalent incident energy density	U_{eq}	joule per square meter (J m^{-2})
Absorbed power density	S_{ab}	watt per square meter (W m^{-2})
Incident power density	S_{inc}	watt per square meter (W m^{-2})
Plane-wave equivalent incident power density	S_{eq}	watt per square meter (W m^{-2})
Induced electric field strength	E_{ind}	volt per meter (V m^{-1})
Incident electric field strength	**E_{inc}**	**volt per meter (V m^{-1})**
Incident magnetic field strength	**H_{inc}**	**ampere per meter (A m^{-1})**
Specific energy absorption	SA	joule per kilogram (J kg^{-1})
Specific energy absorption rate	**SAR**	**watt per kilogram (W kg^{-1})**
Electric current	I	ampere (A)
Frequency	**f**	**hertz (Hz)**
Time	**t**	**second (s)**

* *Italicized* symbols represent variables; quantities are described in scalar form because direction is not used to derive the basic restrictions or reference levels.

ICNIRP 2020 Table 2: Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 minutes (NA is Not Available)

Exposure Scenario	Frequency Range	Whole-body average SAR (W kg^{-1})	Local Head/Torso SAR (W kg^{-1})	Local Limb SAR (W kg^{-1})	Local S_{ab} (W m^{-2})
Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General Public	100 kHz to 6 GHz	0.08	**2**	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

ICNIRP 2020 Table 3: Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for integrating intervals **>0 to <6 minutes**

Exposure Scenario	Frequency Range	Local Head/Torso SA (kJ kg^{-1})	Local Limb SA (kJ kg^{-1})	Local U_{ab} (kJ m^{-2})
Occupational	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$3.6[0.05+ 0.95(t/360)^{0.5}]$	$7.2[0.025+ 0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$36[0.05+ 0.95(t/360)^{0.5}]$
General Public	100 kHz to 400 MHz	NA	NA	NA
	>400 MHz to 6 GHz	$0.72[0.05+ 0.95(t/360)^{0.5}]$	$1.44[0.025+ 0.975(t/360)^{0.5}]$	NA
	>6 to 300 GHz	NA	NA	$7.2[0.05+ 0.95(t/360)^{0.5}]$

ICNIRP 2020 Table 4: Basic restrictions for electromagnetic field exposure from 100 kHz to 10 MHz, for peak spatial values

Exposure scenario	Frequency range	Induced electric field; E_{ind} ($V\ m^{-1}$)
Occupational	100 kHz to 10 MHz	$2.70x10^{-4}f$
General public	100 kHz to 10 MHz	$1.35x10^{-4}f$

1. *f* is frequency in Hz.
2. Restriction values relate to any region of the body, and are to be averaged as root mean square (rms) values over 2 mm × 2 mm × 2 mm contiguous tissue (as specified in ICNIRP (2010)).

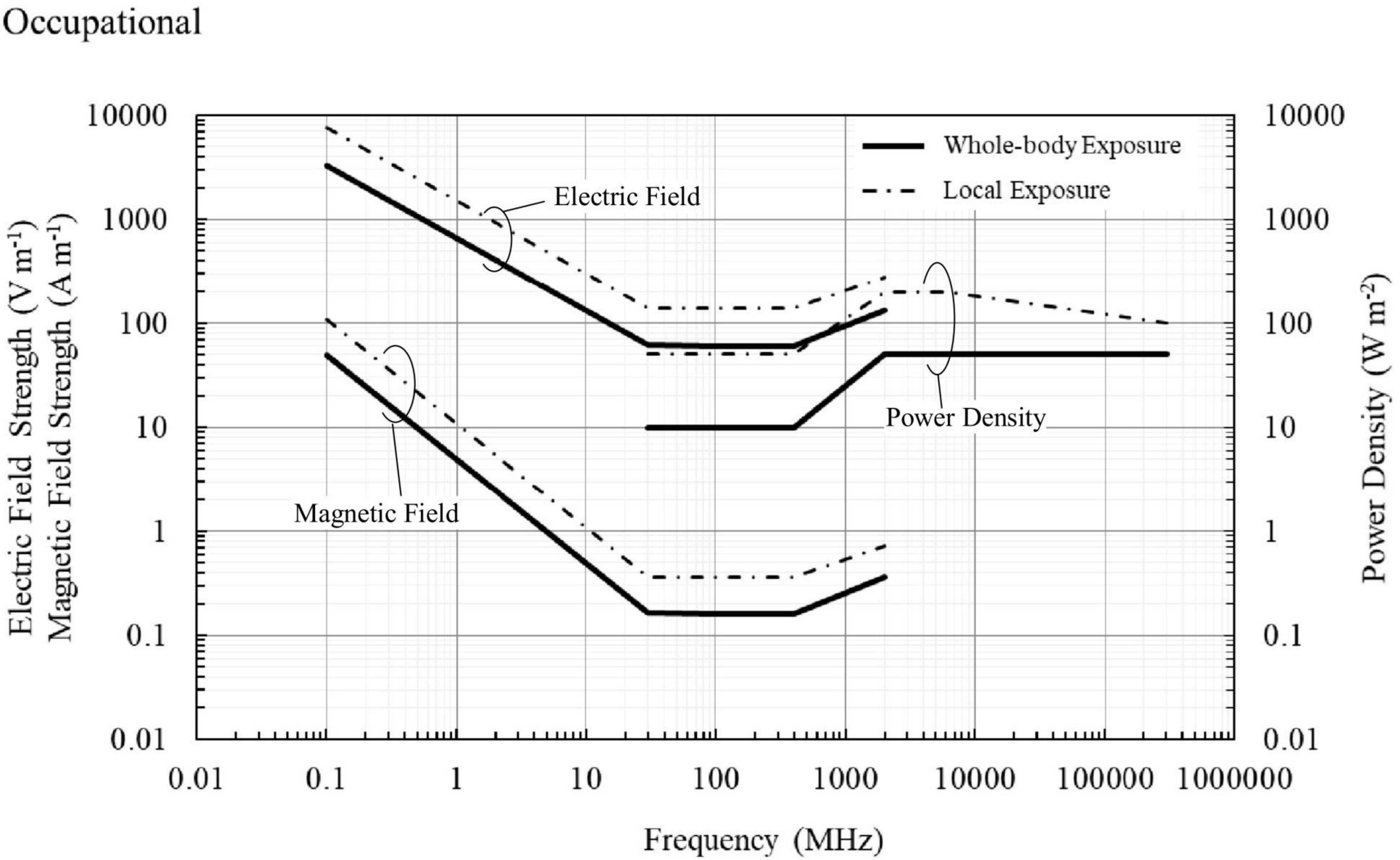
ICNIRP 2020 EMF for occupational & general public exposure, based on **Table 5**, p. 495: averaged over **30 minutes** and the **whole body** (NA is Not Available)

Exposure scenario	Frequency range	Incident E-field strength (V/m)	Incident power-density (W m^{-2})
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	NA
	>30 – 400 MHz	61	10
	>400 – 2000 MHz	$3f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	50
General Public	0.1 – 30 MHz	$300/f_M^{0.7}$	NA
	>30 – 400 MHz	27.7	2
	>400 – 2000 MHz	$1.375f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	10

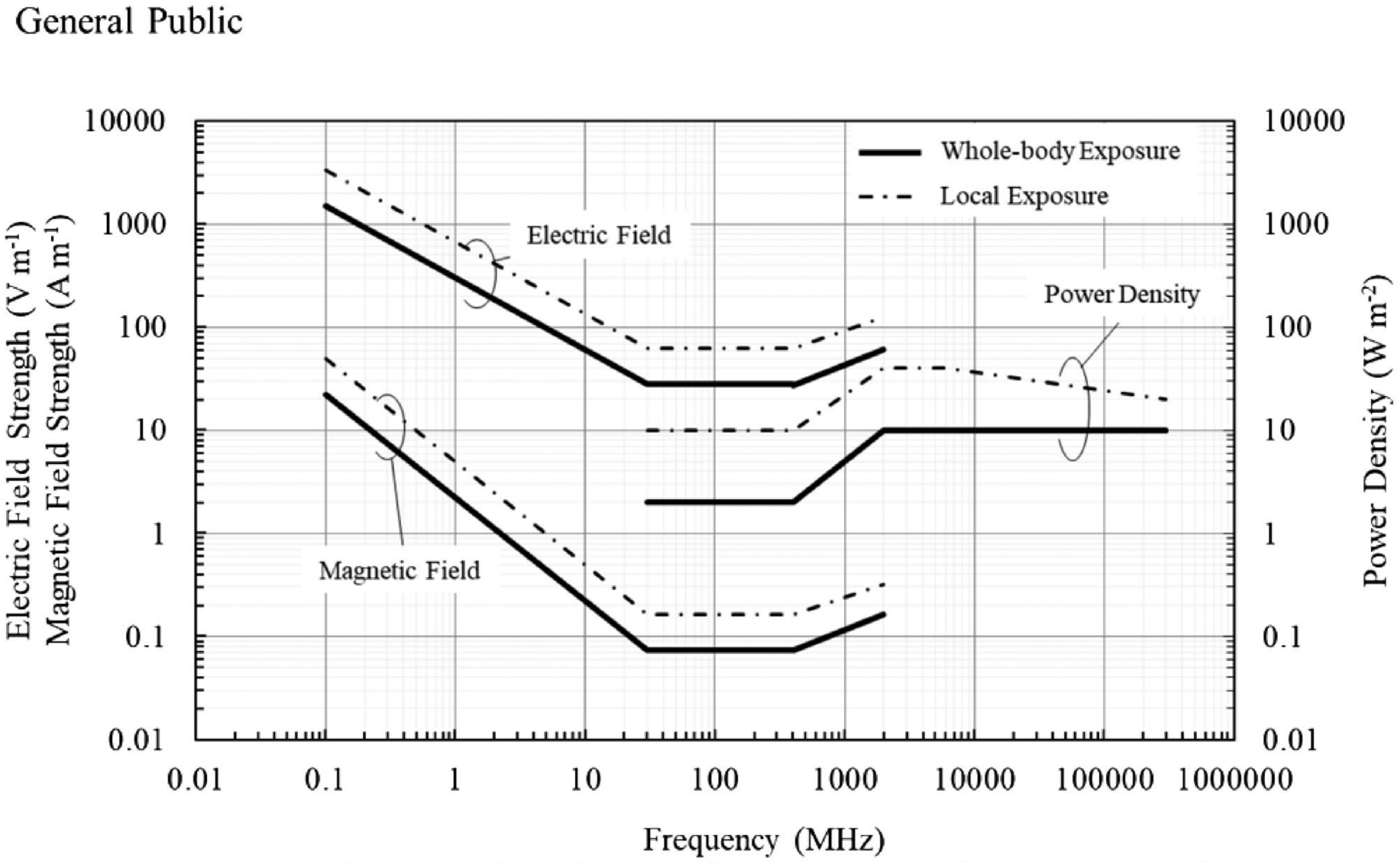
ICNIRP 2020 EMF for occupational & general public exposures, based on **Table 6**, p. 496: **local exposure**, averaged over **6 minutes**

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$1504/f_M^{0.7}$	NA
	>30 – 400 MHz	139	50
	>400 – 2000 MHz	$10.58f_M^{0.43}$	$0.29f_M^{0.86}$
	>2 – 6 GHz	NA	200
	>6 – <300 GHz	NA	$275/f_G^{0.177}$
	300 GHz	NA	100
General Public	0.1 – 30 MHz	$671/f_M^{0.7}$	NA
	>30 – 400 MHz	62	10
	>400 – 2000 MHz	$4.72f_M^{0.43}$	$0.058f_M^{0.86}$
	>2 – 6 GHz	NA	40
	>6 – 300 GHz	NA	$55/f_G^{0.177}$
	300 GHz	NA	20

ICNIRP 2020 based on Tables 5 & 6, Fig.1 ***Occupational*** *exposures ≥ 6 min*

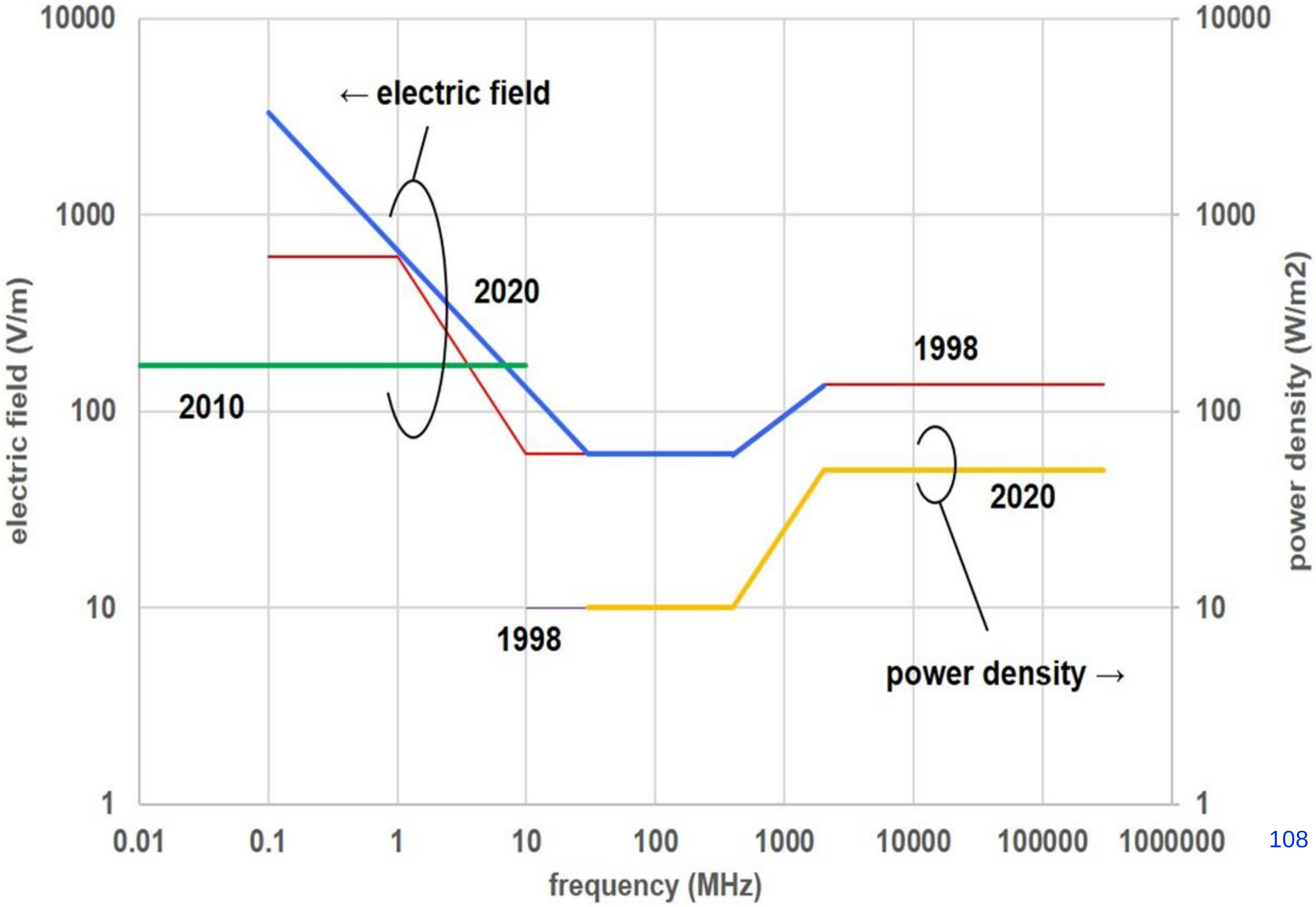


ICNIRP 2020 based on Tables 5 & 6, Fig.2, ***general public*** *exposures ≥6 min*

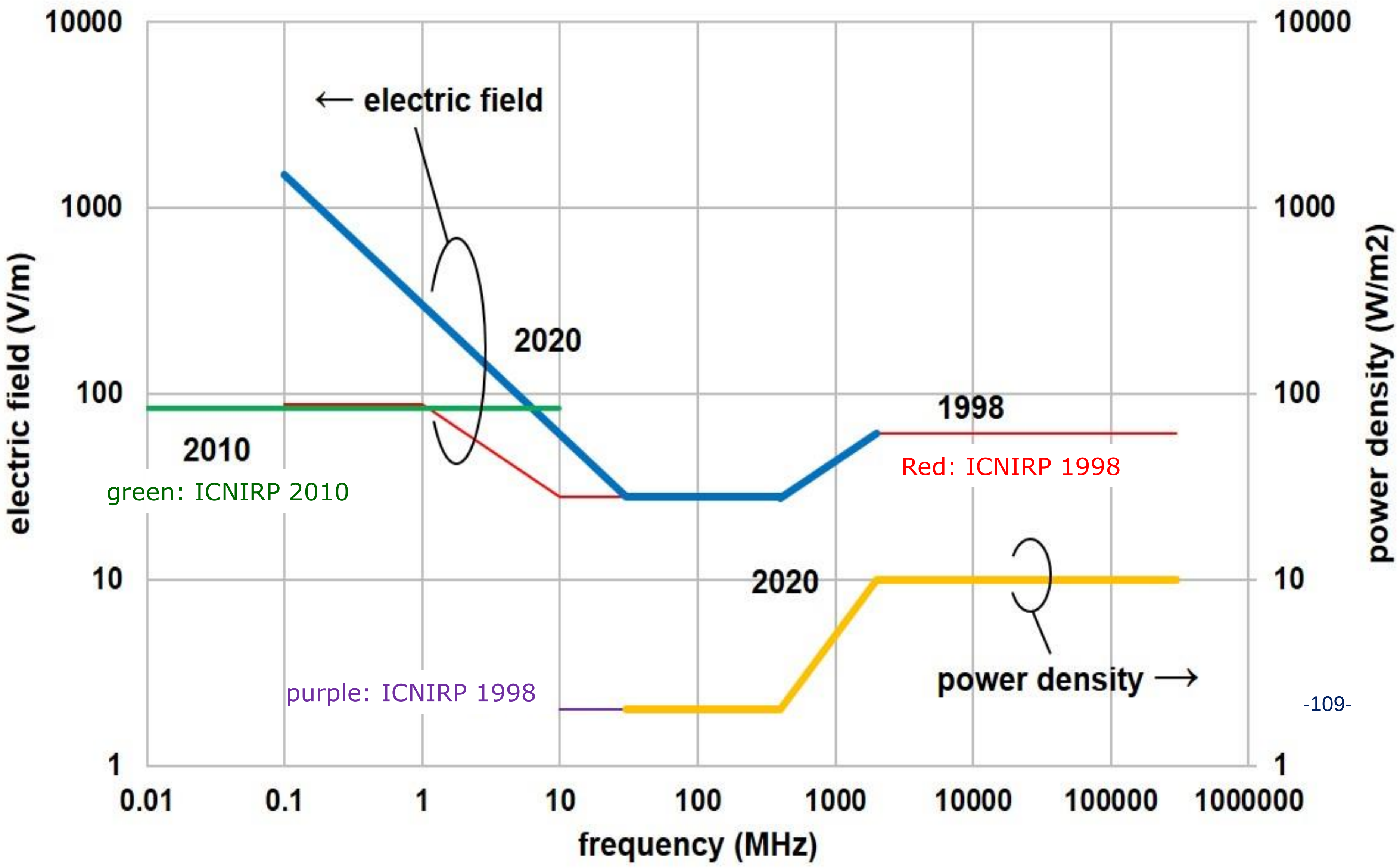


ICNIRP 2020 Web (not Guidelines) Fig.1, **whole-body, occupational, ICNIRP 1998**, **ICNIRP 2010** and **ICNIRP 2020;**

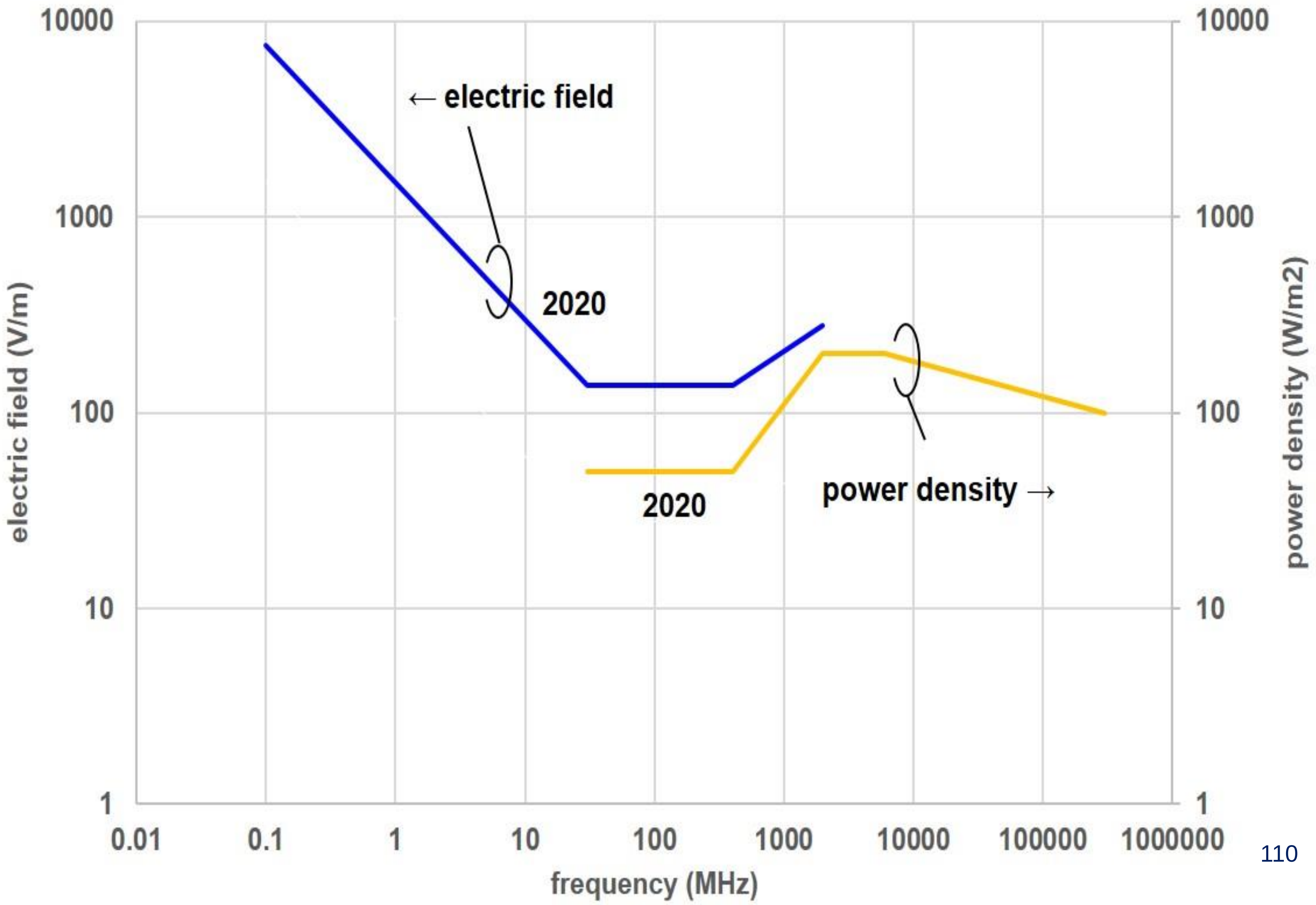
see ICNIRP 2020 Tables 5 & 6 for full specifications



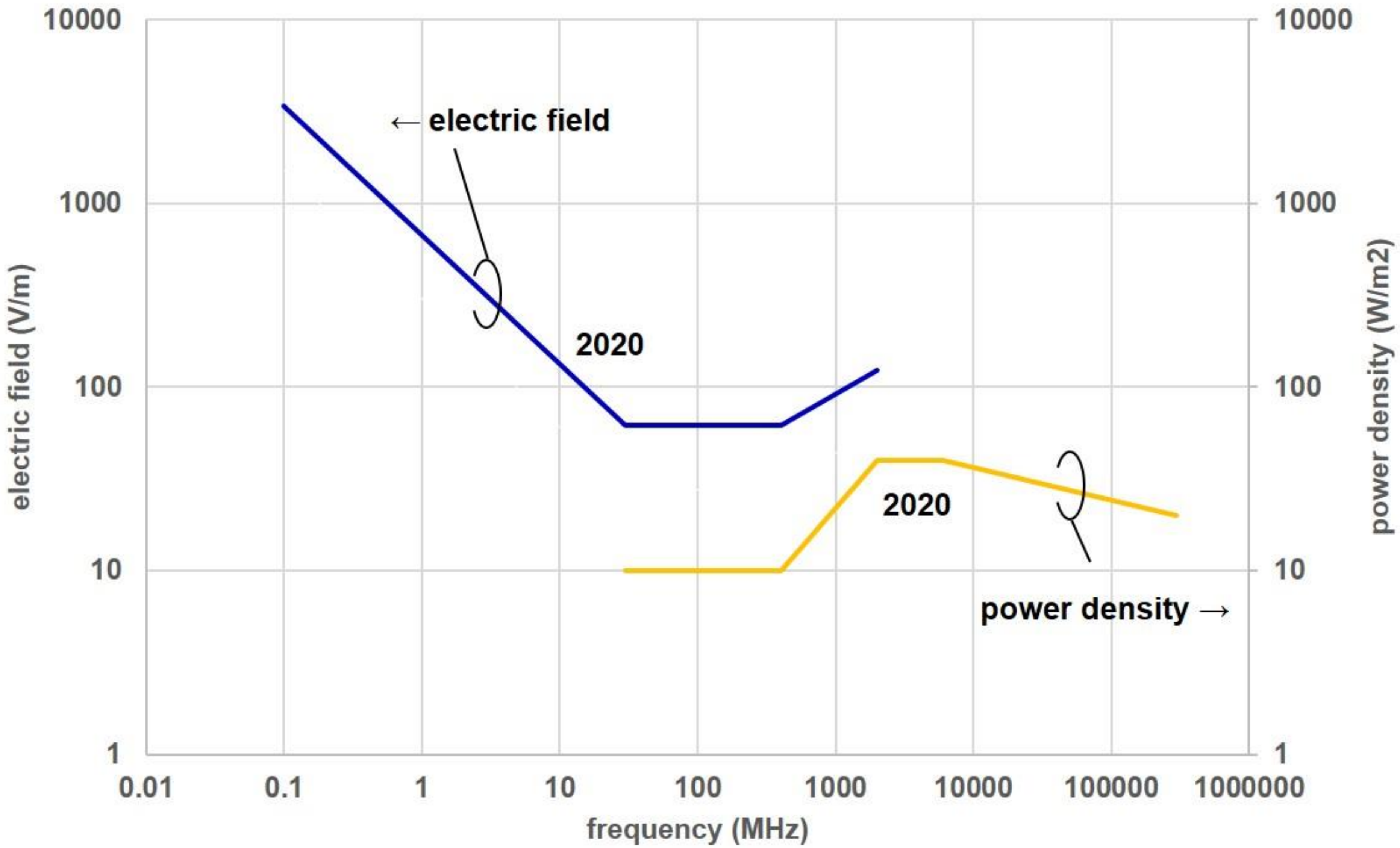
ICNIRP 2020 Web Fig. 2, based on Table 6 the **general public** applying to **whole-body exposures ≥6 min**, for the ICNIRP 2020 guidelines only



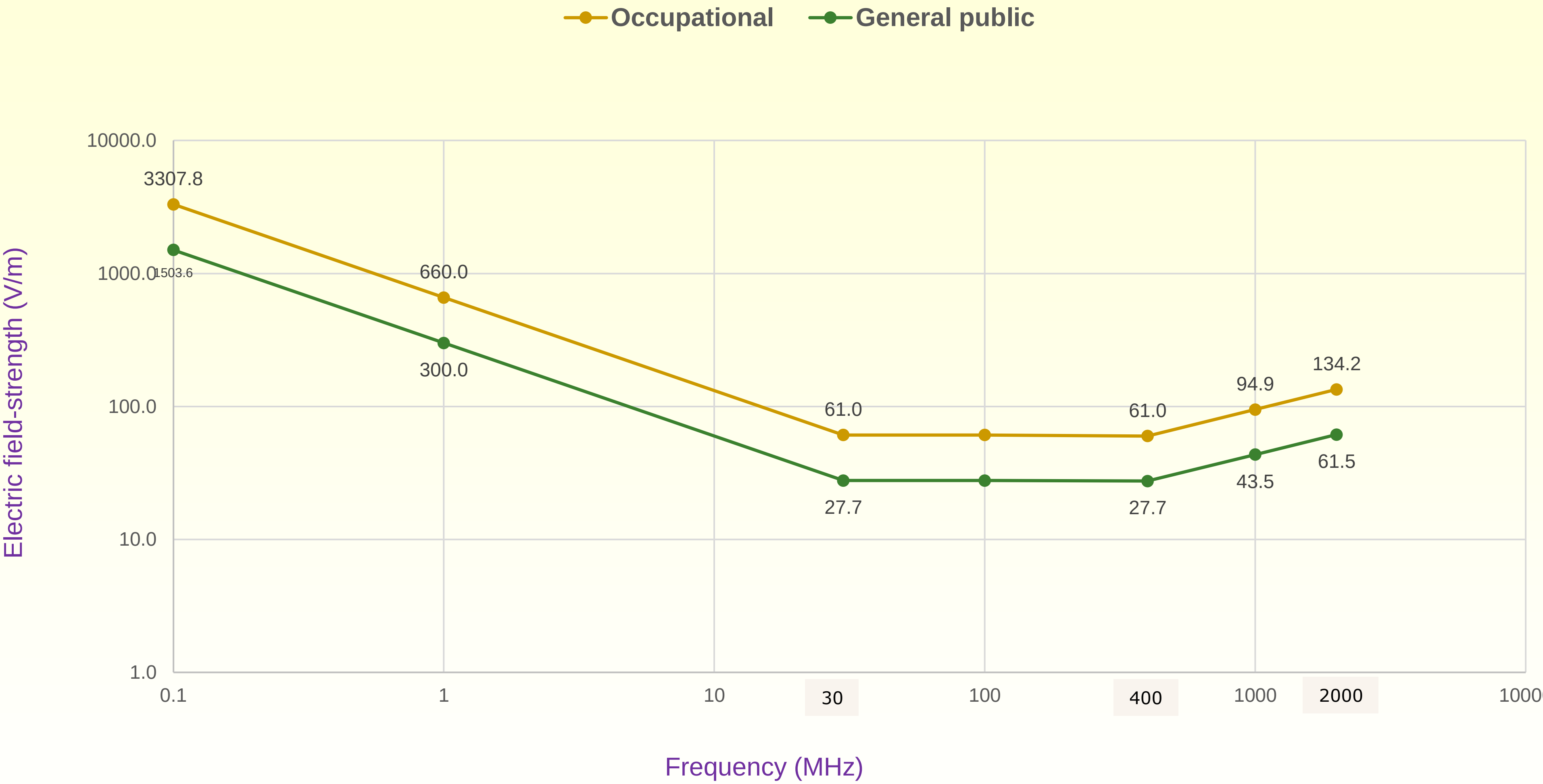
ICNIRP 2020 Web Fig. 3, **occupational, local exposures** of **≥6 minutes**, 100 kHz–300 GHz; see Tables 5 & 6 for full specifications



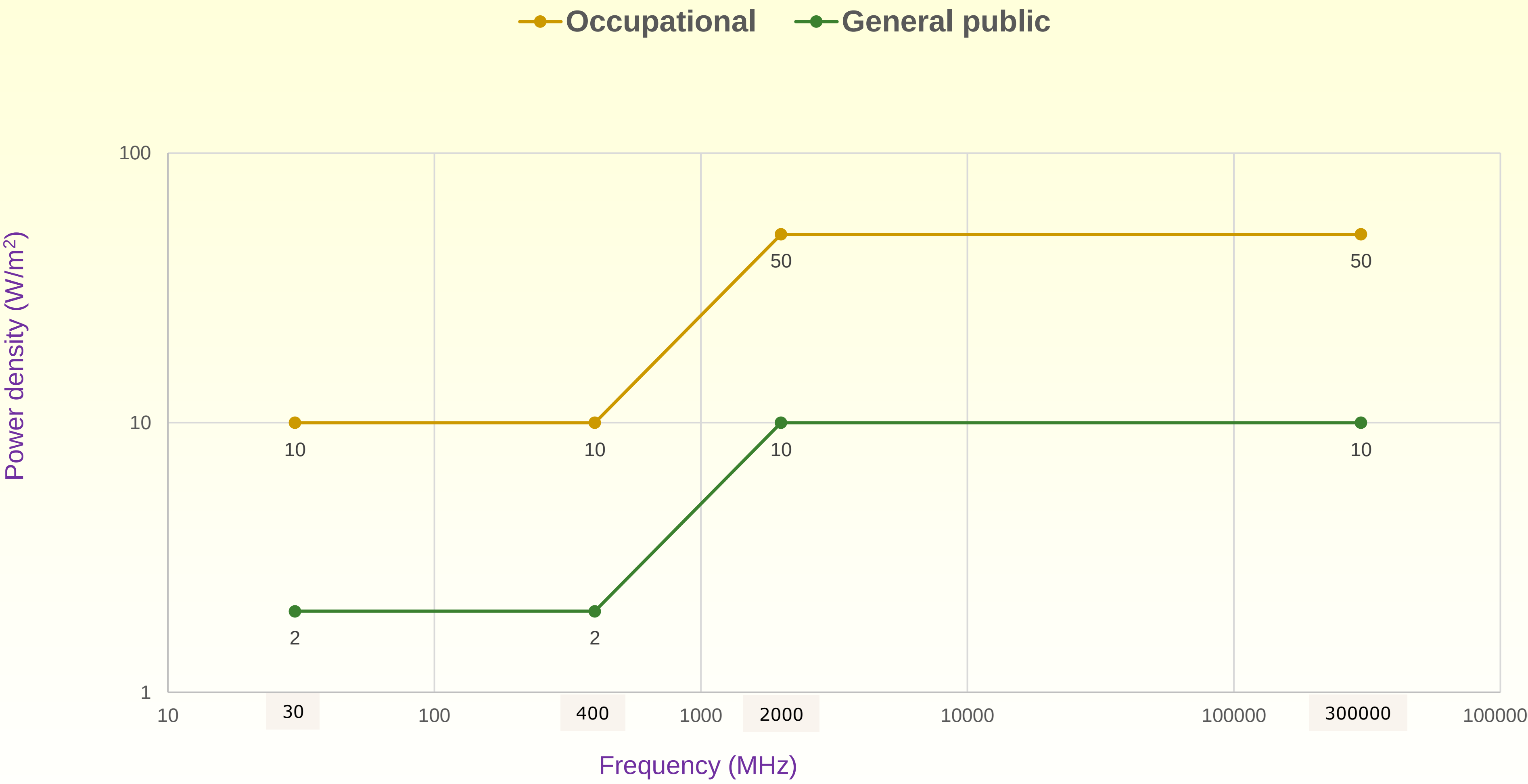
ICNIRP 2020 Web Fig. 4 **general public, local exposures ≥6 min** 100 kHz to 300 GHz



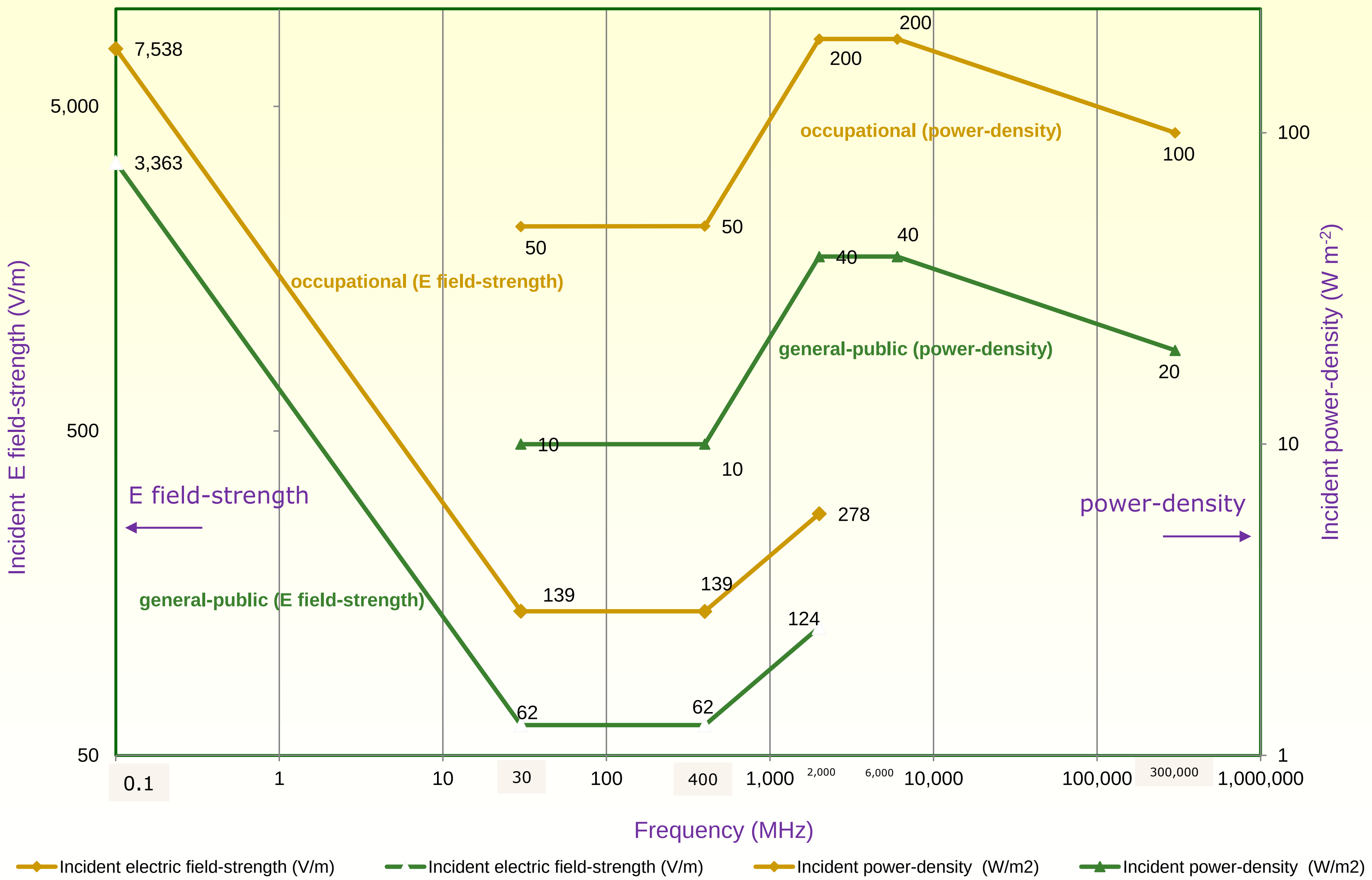
Comparing ICNIRP 2020 **field-strength** for occupational & general-public exposures, **0.1 MHz–2 000 MHz**, based on **Table 5**, p. 495: **averaged over 30 minutes & the whole body** (source, Mazar)



Comparing ICNIRP 2020 **power-density** for occupational & general-public exposures, **30 MHz–300 GHz**, based on **Table 5**, p. 495: **averaged over 30 minutes and the whole body** (source, Mazar)



Comparing ICNIRP 2020 incident electric field-strength & power-density for occupational & general-public exposures, 100 kHz–300 GHz, see **Table 6**, p. 496: **local exposure, averaged over 6 minutes** (source, Mazar)



ICNIRP 2020 Comparison 2020 vs. 1998 (& 2010) Guidelines

- Better biological rationale
- Better dosimetry
- More details
- More complex
- More accurate
- Better future-proof

Updated IEEE C95.1-2019 reference levels: Safety factors applying 100 kHz – 6 GHz

Above 10 MHz Thermal Effects

- Whole body averaged (WBA)
  Behavioral effects in animals over many frequencies, threshold at 4 W/kg
  10x - 0.4 W/kg for upper tier (controlled environment)
  50x - 0.08 W/kg for lower tier (general public)

- Localized exposure (averaged in 10 g)
  Cataract observed in rabbits, threshold at 100 W/kg
  10x - 10 W/kg for upper tier
  50x - 2 W/kg for lower tier

- SAR is averaged over 30 min for WBA exposure and 6 min for local exposure

- Epithelial power density through body surface is averaged over 6 min

To compare: a human adult generates (for the whole body) a total of approximately:

- 1 W/kg at rest (Weyand et al., 2009)
- 2 W/kg – in standing position
- 12 W/kg – in running (Teunissen et al., 2007)

IEEE C95.1-2019 Table 5—DRLs (100 kHz to 6 GHz)

Conditions	**Persons in unrestricted environments SAR (W/kg)[a]**	**Persons permitted in restricted environments SAR (W/kg)[a]**
Whole-body exposure	0.08	0.4
Local exposure[b] (head and torso)	2	10
Local exposure[b] (limbs and pinnae)	4	20

DRL: Dosimetric Reference Limits

[a] SAR is averaged over 30 min for whole-body exposure and 6 min for local exposure (see B.6 for averaging time).

[b] Averaged over any 10 g of tissue (defined as a tissue volume in the shape of a cube). The averaging volume of 10 g of tissue would be represented as a 10 cm^3 cube (approximately 2.15 cm per side)

IEEE C95.1-2019 Table 6—DRLs (6 GHz to 300 GHz)

Conditions	**Epithelial power density (W/m2)**[a,b,c]	
	Persons in unrestricted Environments	**Persons permitted in restricted environments**
Body surface	20	100

[a] Epithelial power density through body surface is averaged over 6 min.

[b] Averaged over any 4 cm^2 of body surface at frequencies between 6 GHz and 300 GHz (defined as area in the shape of a square at surface of the body).

[c] Small exposed areas above 30 GHz: If the exposed area on the body surface is small (< 1 cm^2 as defined by −3 dB contours relative to the peak exposure), the epithelial power density is allowed to exceed the DRL values of Table 6 by a factor of 2, with an averaging area of 1 cm^2 (defined as area in the shape of a square at the body surface).

IEEE C95.1-2019 Table 7—ERLs for whole-body exposure of persons in unrestricted environments (100 kHz to 300 GHz)

Frequency range (MHz)	**Electric field Strength (E)^{a,b,c} (V/m)**	**Magnetic field strength (H)^{a,b,c} (A/m)**	**Power density (S)^{a,b,c} (W/m^2)**		**Averaging time (min)**
			S_E	**S_H**	
0.1 to 1.34	614	$16.3/f_M$	1000	$100\ 000/ f_M^2$	30
1.34 to 30	$823.8/f_M$	$16.3/f_M$	$1800 / f_M^2$	$100\ 000 / f_M^2$	
30 to 100	27.5	$158.3/f_M^{1.668}$	2	$9\ 400\ 000 / f_M^{3.336}$	
100 to 400	27.5	0.0729	2		
400 to 2000			$f_M/200$		
2000 to 300 000			10		

NOTE—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

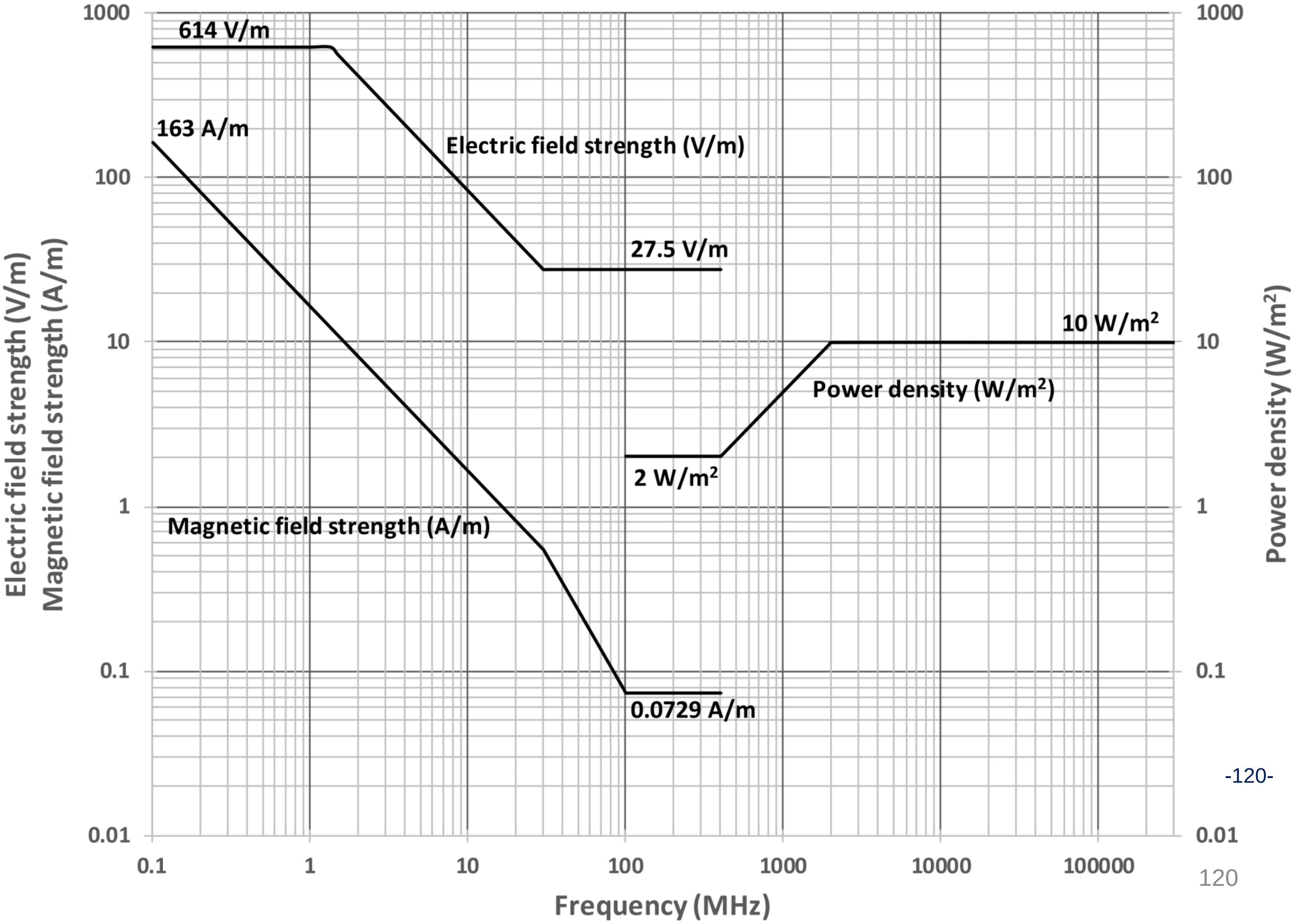
[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in Table 7. For more typical nonuniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7.

[b] f_M is the frequency in MHz.

[c] The E, H, and S values are those rms values unperturbed by the presence of the body.

At frequencies below 30 MHz, the wave-length is longer than 10 m. There is no resonance with our body (shorter than 2 m.). We are not an obstacle to the signal, and low part of the RF energy enters to our body.

IEEE C95.1-2019 Fig. 3: Graphical representations of the ERLs in Table 7 for electric and magnetic fields and plane-wave-equivalent power density—Persons in unrestricted environments



IEEE C95.1-2019 Table 8—ERLs for whole-body exposure of persons permitted in restricted environments (100 kHz to 300 GHz)

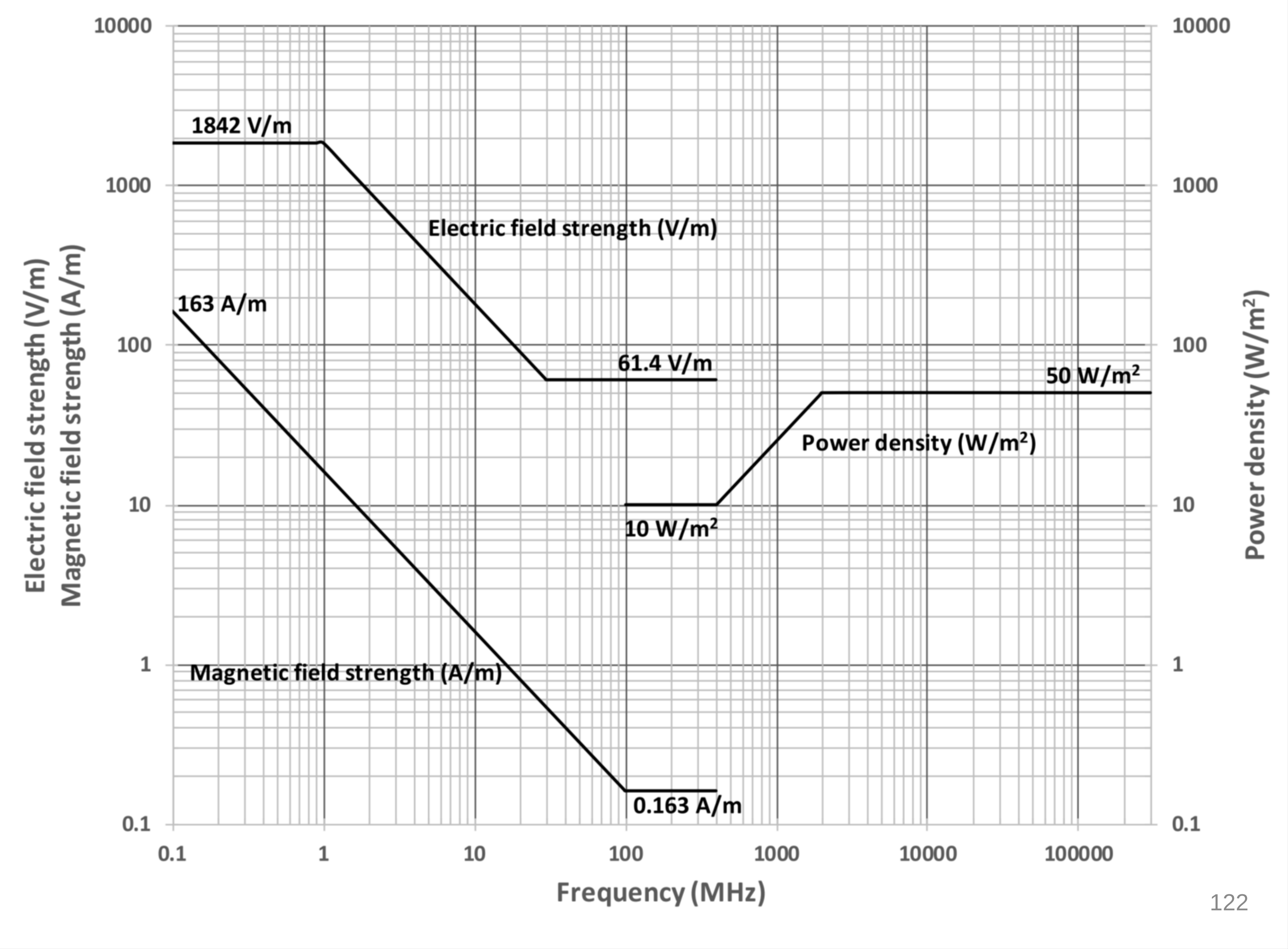
Frequency range (MHz)	Electric field Strength (E)[a,b,c] (V/m)	Magnetic field strength (H)[a,b,c] (A/m)	Power density (S)[a,b,c] (W/m²)		Averaging time (min)
			S_E	S_H	
0.1 to 1.0	1842	$16.3/f_M$	9 000	$100\ 000\ f_M^2$	30
1.0 to 30	$1842/f_M$		$9000\ /\ f_M^2$		
30 to 100	61.4		10		
100 to 400		0.163	10		
400 to 2000			$f_M/40$		
2000 to 300 000			50		

Note—S_E and S_H are plane-wave-equivalent power density values, based on electric or magnetic field strength respectively, and are commonly used as a convenient comparison with ERLs at higher frequencies and are sometimes displayed on commonly used instruments.

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the ERLs in Table 7. For more typical nonuniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the plane-wave-equivalent power densities or the squares of the field strengths, are compared with the ERLs in Table 7.
[b] f_M is the frequency in MHz.
[c] The E, H, and S values are those rms values unperturbed by the presence of the body.

Pay attention that at 100 kHz, E=1842(V/m) here is different than in Table 7 E=614 (V/m).
But Hs are 163 (A/m) in both Tables. Maybe mistake or levels are vey high, so no distinction.

IEEE C95.1-2019 Fig. 4: Graphical representations of the ERLs in Table 8 for electric and magnetic fields and plane-wave-equivalent power density—Persons permitted in restricted

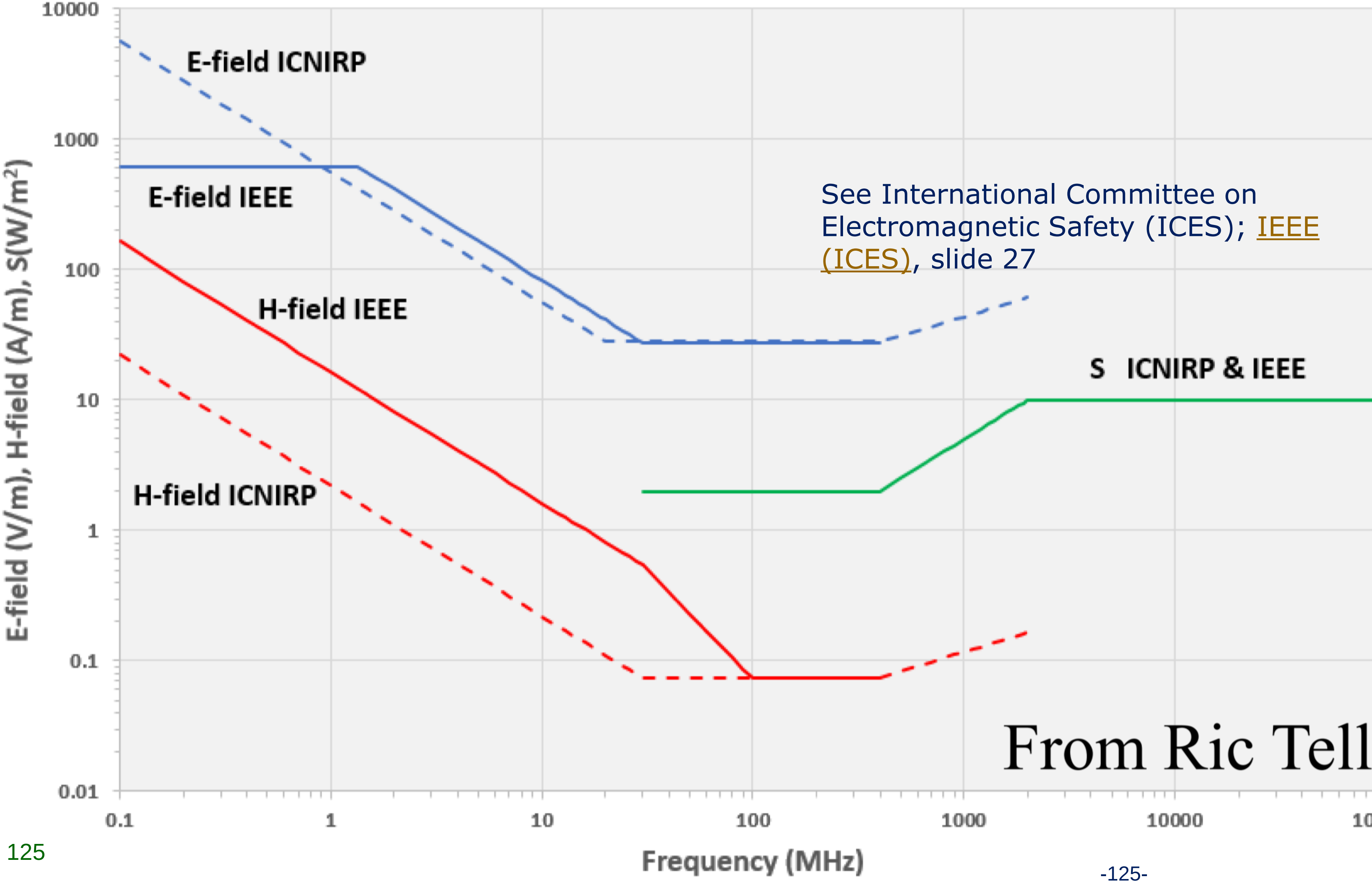


Compare & Contrast
IEEE 95.1 2019 vs
ICNIRP 2020

IEEE C95.1 2019 & ICNIRP 2020 Guidelines are largely harmonized

1. ICNIRP Guidelines (1998, and 2020) & IEEE Standard (2019) separate between general-public and occupational
2. The exposure levels of ICNIRP 2020 & IEEE Standard whole-body levels above 30 MHz are identical!
   1) SAR equals **2 W/kg** for general-public and **10 W/kg** for occupational
   2) Exposure reference-levels equals at:
      - **400 to 2000 MHz f_M/200 W/m^2** for general-public & **f_M/40 W/m^2** for occupational
      - **2000 to 300 000 MHz 10 W/m^2** for general-public & 50 W/m^2 for occupational

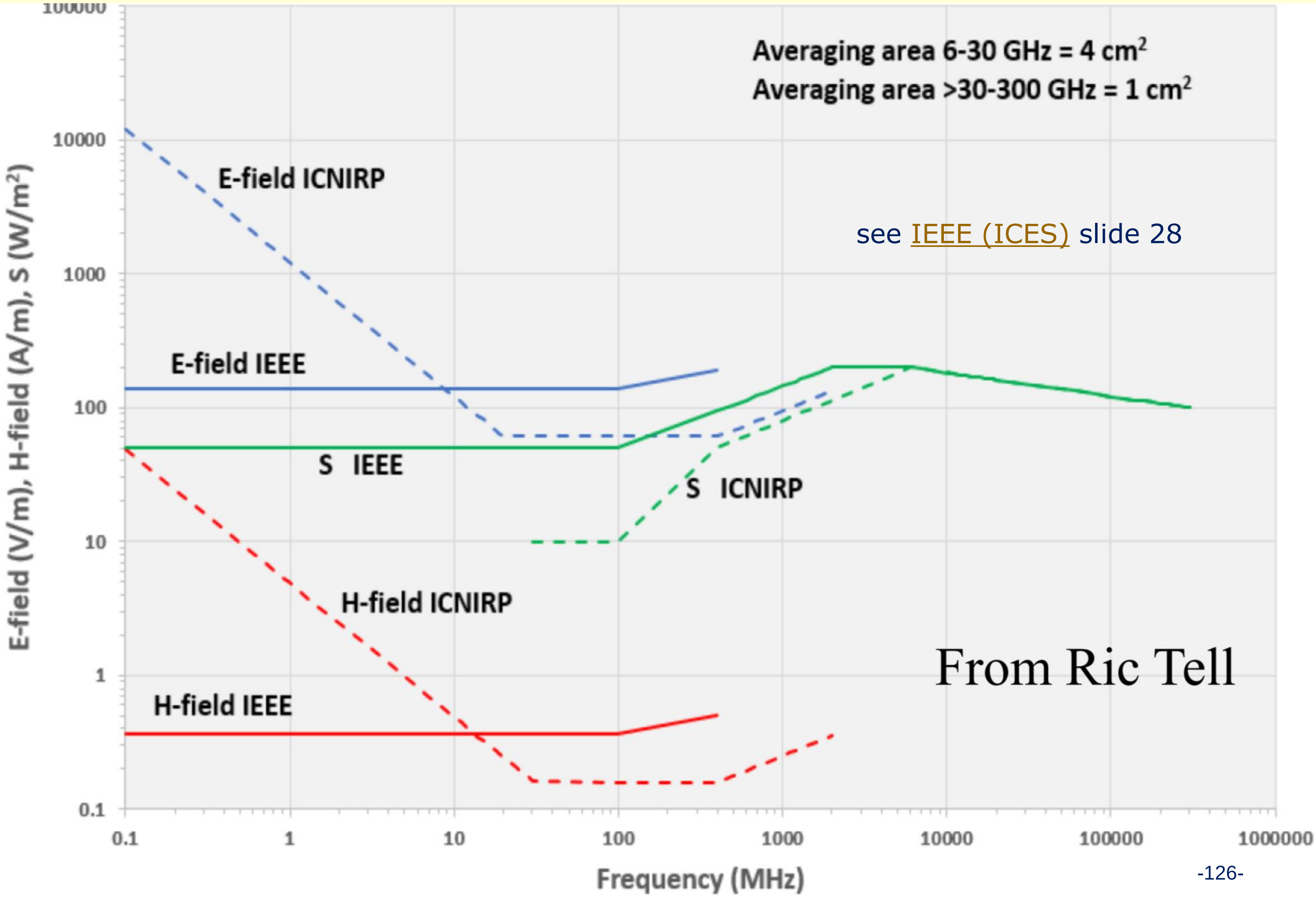
IEEE/ICNIRP differences in limits general public/ unrestricted environment power-densities above 30 MHz are identical (also to ICNIRP 1998)



See International Committee on Electromagnetic Safety (ICES); IEEE (ICES), slide 27

From Ric Tell

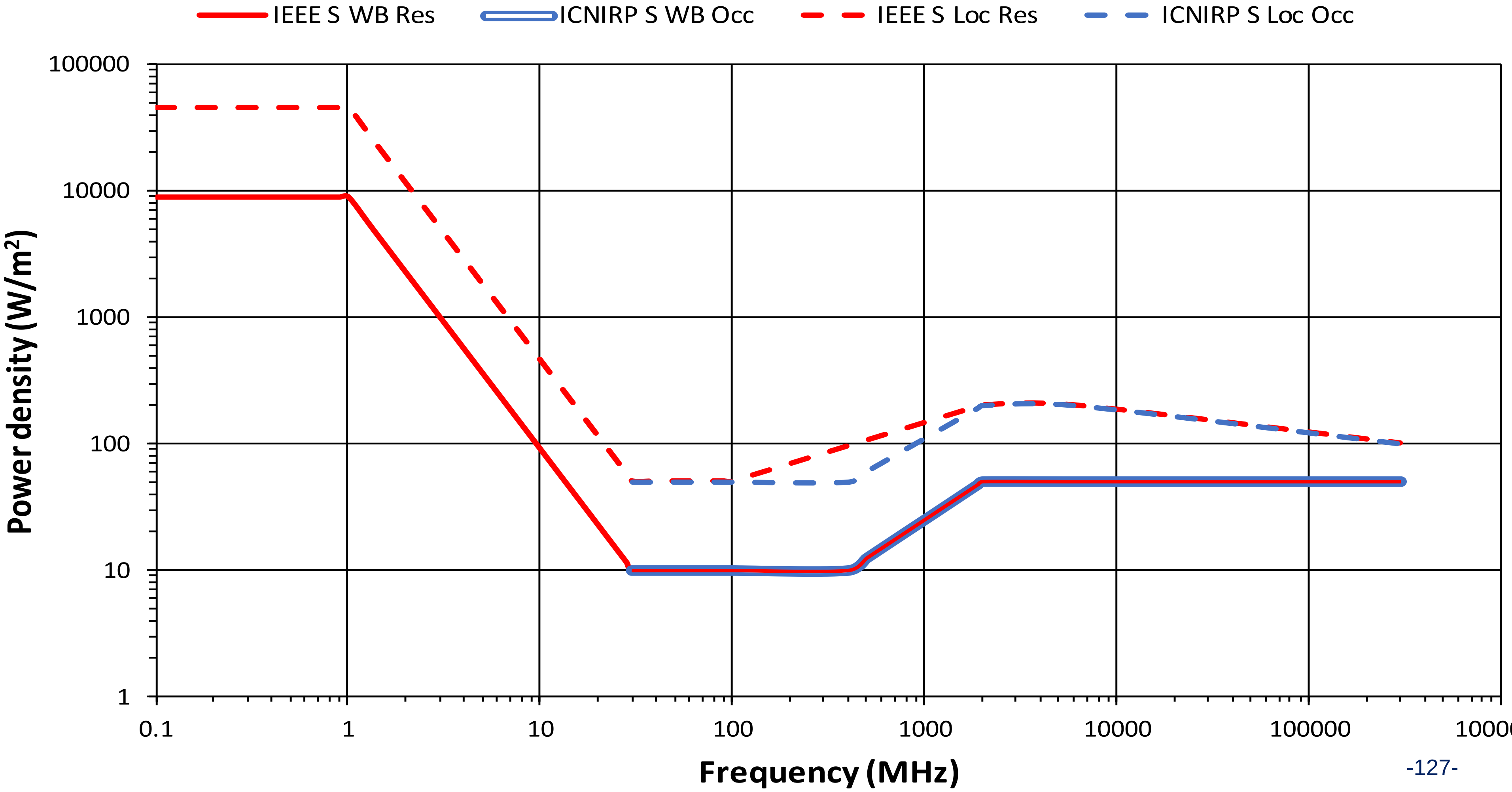
IEEE/ICNIRP differences in limits: local exposure limits (assuming 6-minute exposure); power-densities below 6 GHz are different



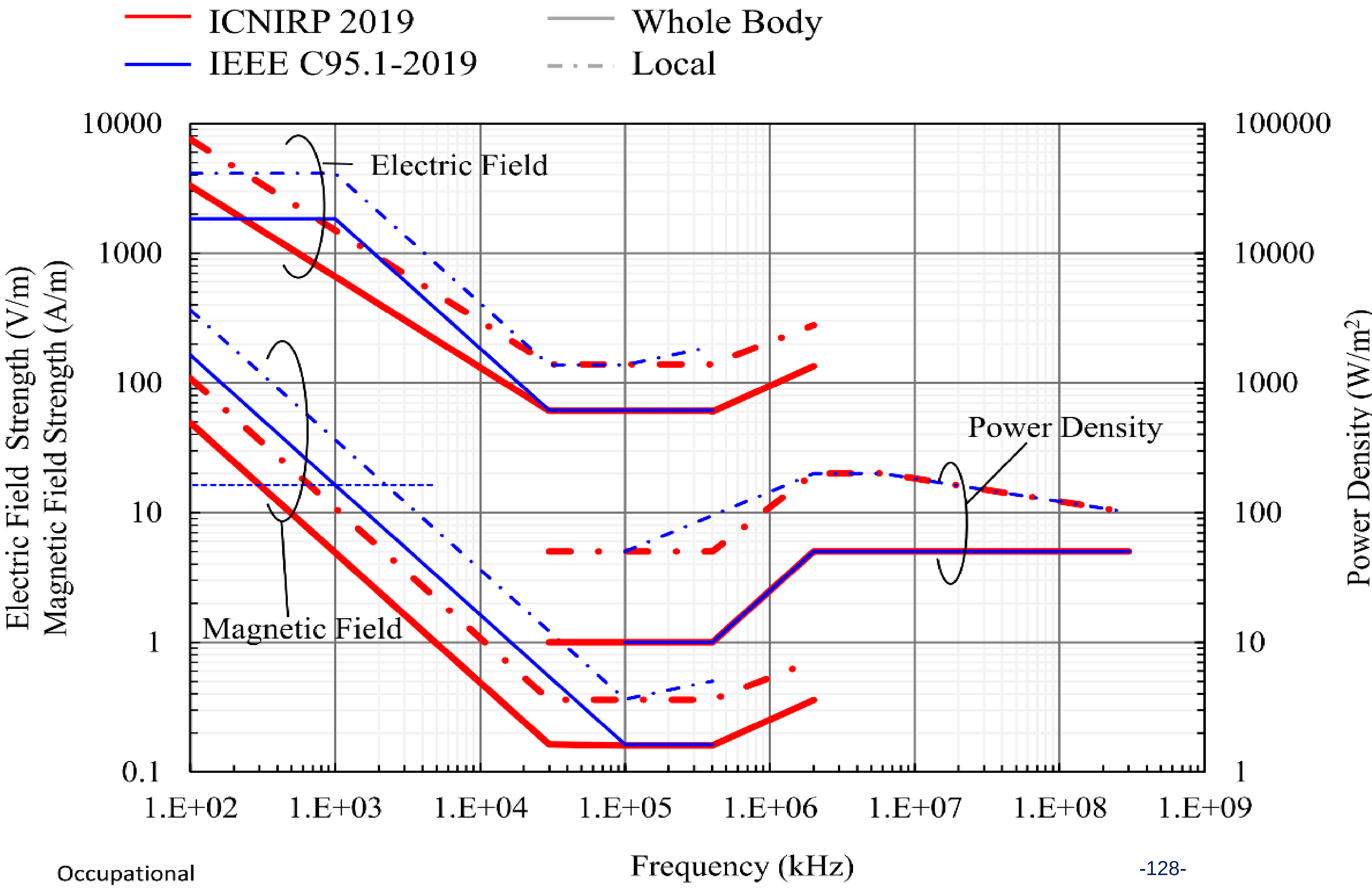
see IEEE (ICES) slide 28

From Ric Tell

source, IEEE/ICES Ric Tell, 4 June 2020)



Comparison of IEEE (2019) and ICNIRP (2020) Whole body & Local Power Density Limits Restricted/Occupational



Occupational

Similarities between IEEE Std C95.1-2005 and the revised IEEE C95.1-2019 Standard; see IEEE (ICES)

- Scientific basis of the adverse effect levels, i.e., electrostimulation for low frequencies and heating for high frequencies.
- Exposure limits for electrostimulation effects are kept the same as in IEEE Stds C95.6- 2002 and C95.1-2005.
- Exposure limits, termed dosimetric reference limits (DRLs), previously called basic restrictions, on whole body average and peak spatial average SARs **remain the same** to prevent **heating effects** from exposure over much of the RF spectrum.
- The exposure reference levels (ERLs), previously called maximum permissible exposure (MPE) levels, for the lower tier (general public) **remain the same as in IEEE C95.1-2005**.
- Continues to support the position of the earlier editions, i.e., upper tier ERLs are protective of public health and safety and that the risk of harm from exposure to fields below the lower tier ERLs has not been confirmed by scientific evidence.

Main changes in the revised IEEE C95.1-2019 Standard: Background; see IEEE (ICES)

- The evaluation of an IEEE standard is a process that is continually ongoing; that is, IEEE standards are “living” documents. The rules and procedures for comments and requests are included in the ICES Policies and Procedures and are approved by the IEEE-SASB.
- The revision process established by the IEEE/ICES is a continuing rigorous and open scientific process that is **transparent** at all levels and includes the opportunity for **scientific input** from all stakeholders.
- IEEE/ICES members are affiliated with government, industry, and academia, as well as of independent professionals and the general public. The background of the membership varies from scientific disciplines such as engineering, physics, statistics, epidemiology, life sciences, medicine, risk assessment, and risk management.
- The IEEE C95.1 standard revises and combines IEEE Std C95.1-2005 [B668] and IEEE Std C95.6-2002 [B671] into a single standard; ; changes on exposure **above 6 GHz/10 GHz**.
- IEEE Std C95.1-2005 was based primarily on research published before 2003; IEEE Std C95.6-2002 was based primarily on research published before 2001. Research has continued since these times, and a reevaluation of the extremely low-frequency (ELF) and radio-frequency (RF) biological effects databases was necessary for this revision.
- IEEE/ICES and ICNIRP organized two major workshops between 2010 and 2015. Conclusions of these workshops indicate that the two major organizations that develop RF safety standards and guidelines agree **that thermal effects are the basis to protect against RF exposure above 100 kHz**

Main changes in the revised IEEE C95.1-2019 Standard: upper tier / lower tier definitions

- Old: in C95.1-2005 two tiers approach was used; an upper tier for “people in controlled environments” and a lower tier “action level” for implementing an RF safety program or MPE for the general public.
- New: in C95.1-2019 standard, maximum exposure limits are established for “**persons in unrestricted environments**” and for “**persons permitted in restricted environments**”.

Main changes in IEEE C95.1-2019 Standard: SAR frequency ranges, DRL & ERL

- The upper frequency boundary for whole body average (WBA) SAR has been changed from **3 GHz to 6 GHz** because of improved measurement capabilities and to harmonize with the proposed new ICNIRP guidelines.
- **DRL** replaces basic restriction (BR), and **ERL** replaces MPE.
- The **safety program initiation level** (previously “action level”) is clarified as the ERL, marking the transition point between the lower (unrestricted) tier and the upper (restricted) tier.

Main changes in IEEE C95.1-2019 Standard: Changing Extremities to Limbs

- The term "extremities" as used in C95.1-2005 is changed to "limbs" involving the whole arms and legs, instead of portions distal to the elbows and knees. This change is to harmonize with C95.6-2002 and the ICNIRP guidelines.
- Frequency dependence instead of fixed factor: local exposure ERL is now frequency dependent, instead of being a fixed factor of 20 times the whole-body ERL regardless of frequency.
- The averaging time is 30 minutes for whole body RF exposure and 6 minutes for local exposure.

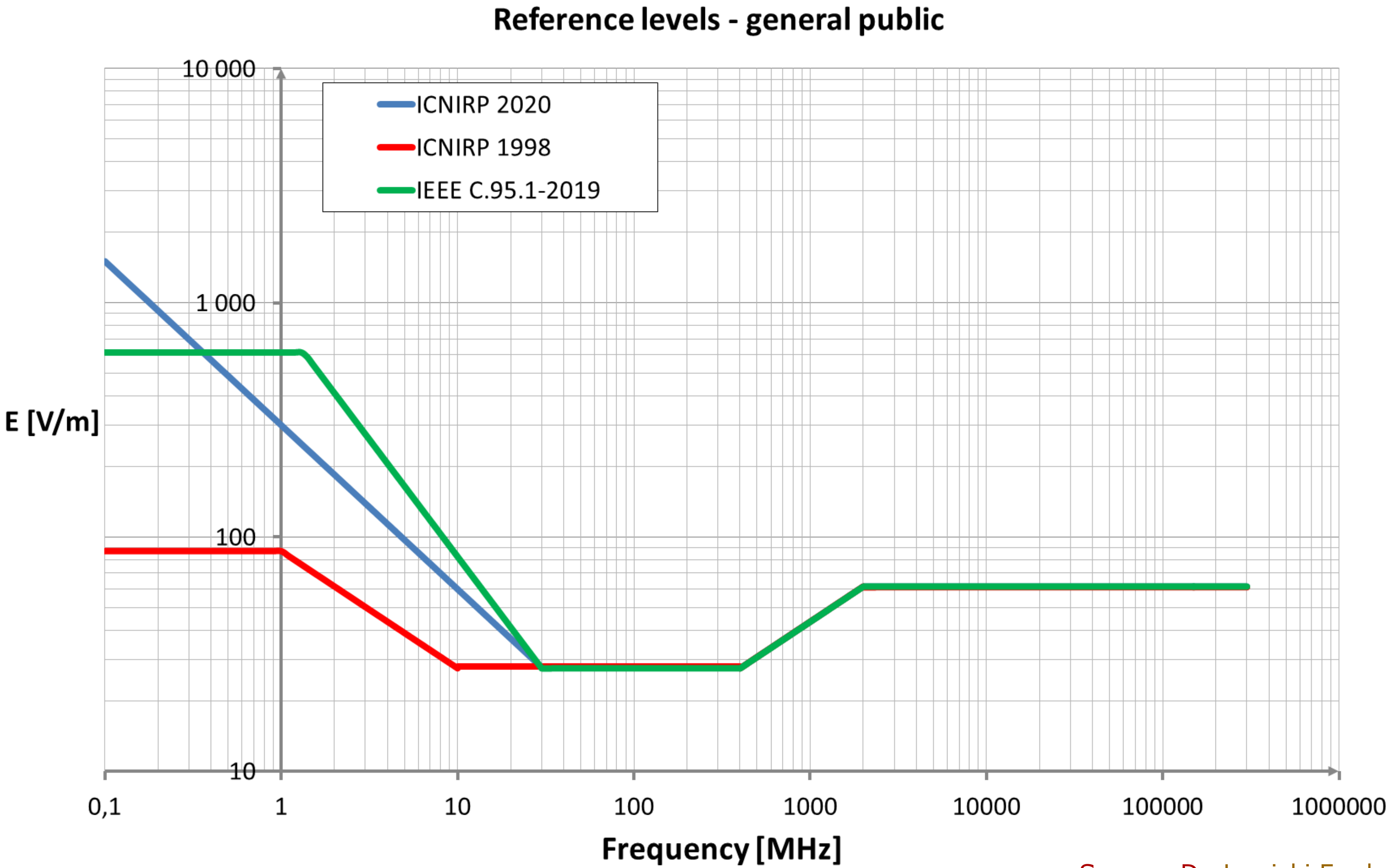
Changes in IEEE C95.1-2019 Standard: Newly introduced Local Exposure DRL and ERL

- The local exposure DRL and ERL for frequencies between 6 GHz and 300 GHz have developed: the DRL is the epithelial power density inside the body surface, and ERL is the incident power density outside the body.
- Averaging power density area is defined as a 4 cm^2 square.
- Small exposed areas above 30 GHz: the epithelial power density is allowed to exceed the DRL or ERL by a factor of 2, with an averaging area of 1 cm^2.
- Peak DRL and ERL limits for local exposures to pulsed RF fields are defined, and new fluence limits for single RF-modulated pulses above 30 GHz are introduced. The averaging area for single pulse fluence is 1 cm^2 square.

Main changes in IEEE C95.1-2019 Standard: General

- The upper tier whole-body exposure ERLs above 300 MHz are different from those in C95.1-2005 to maintain a consistent 5x factor between tiers and to harmonize with ICNIRP guidelines.
- The former induced current limit for both feet is considered an unrealistic condition and is removed. The induced current limits for a single foot are retained.
- rms induced and contact current limits for continuous sinusoidal waveforms (100 kHz to 110 MHz) are changed from those in Table 7 of C95.1-2005 to frequency dependent values

Reference levels- general public (V/m, also above 400 MHz)



Source, Dr. Lewicki Fryderyk

ICNIRP vs IEEE Limits for general public (lower tier)

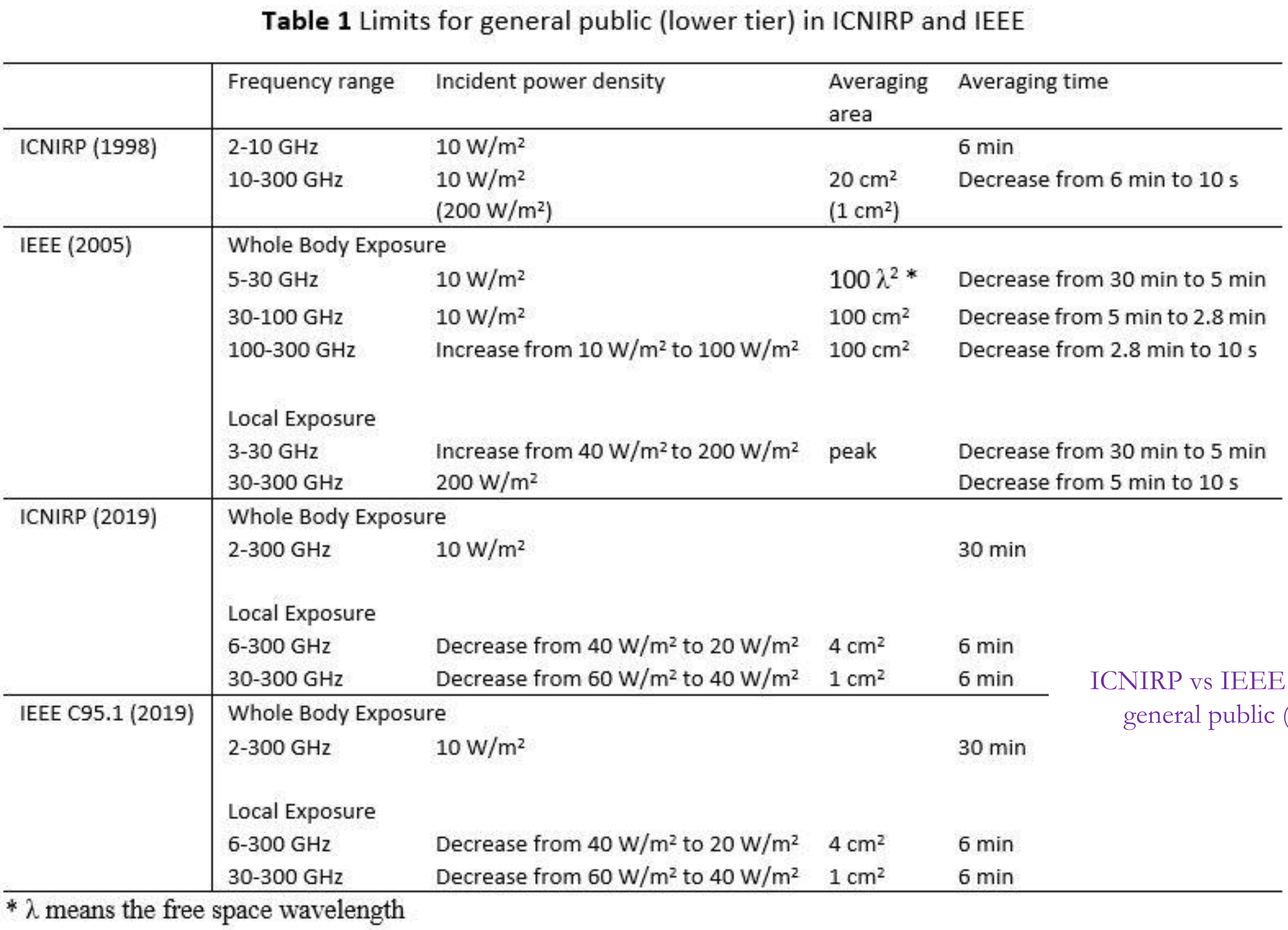


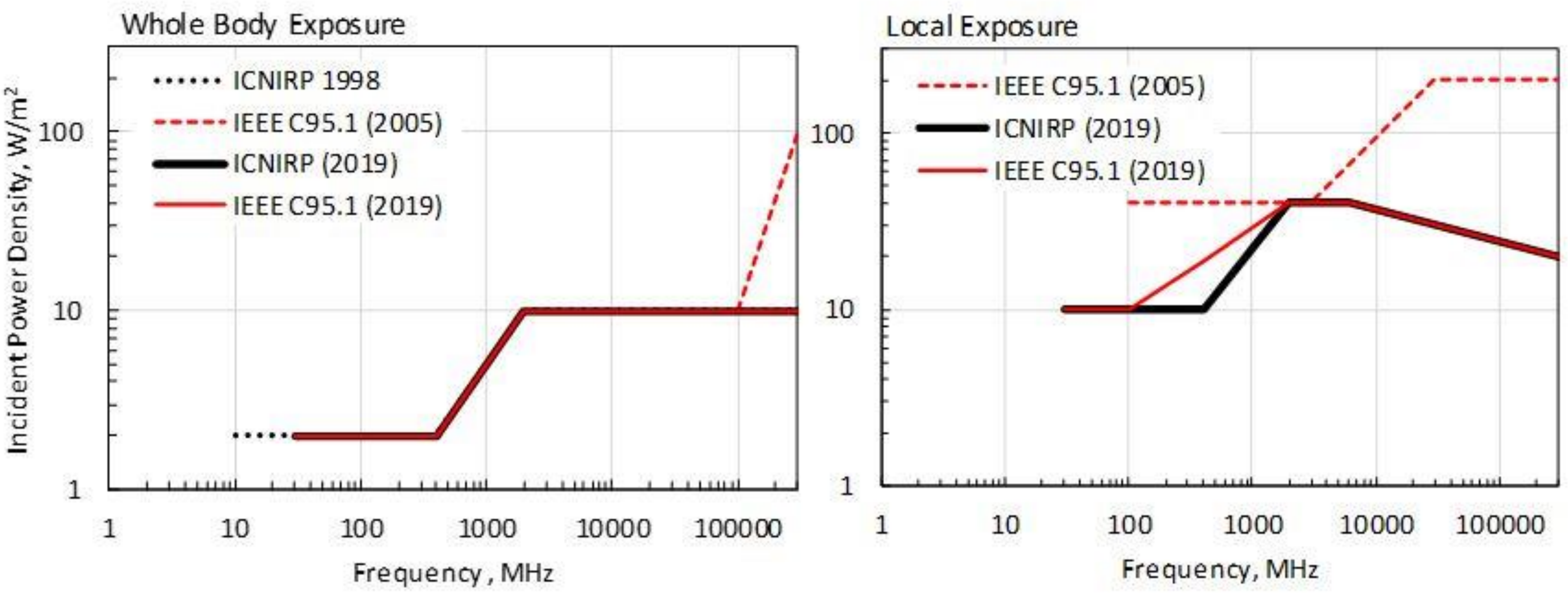
Table 1 Limits for general public (lower tier) in ICNIRP and IEEE

	Frequency range	Incident power density	Averaging area	Averaging time
ICNIRP (1998)	2-10 GHz	10 W/m^2		6 min
	10-300 GHz	10 W/m^2 (200 W/m^2)	20 cm^2 (1 cm^2)	Decrease from 6 min to 10 s
IEEE (2005)	Whole Body Exposure			
	5-30 GHz	10 W/m^2	100 λ^2 *	Decrease from 30 min to 5 min
	30-100 GHz	10 W/m^2	100 cm^2	Decrease from 5 min to 2.8 min
	100-300 GHz	Increase from 10 W/m^2 to 100 W/m^2	100 cm^2	Decrease from 2.8 min to 10 s
	Local Exposure			
	3-30 GHz	Increase from 40 W/m^2 to 200 W/m^2	peak	Decrease from 30 min to 5 min
	30-300 GHz	200 W/m^2		Decrease from 5 min to 10 s
ICNIRP (2019)	Whole Body Exposure			
	2-300 GHz	10 W/m^2		30 min
	Local Exposure			
	6-300 GHz	Decrease from 40 W/m^2 to 20 W/m^2	4 cm^2	6 min
	30-300 GHz	Decrease from 60 W/m^2 to 40 W/m^2	1 cm^2	6 min
IEEE C95.1 (2019)	Whole Body Exposure			
	2-300 GHz	10 W/m^2		30 min
	Local Exposure			
	6-300 GHz	Decrease from 40 W/m^2 to 20 W/m^2	4 cm^2	6 min
	30-300 GHz	Decrease from 60 W/m^2 to 40 W/m^2	1 cm^2	6 min

* λ means the free space wavelength

Source 5G Comms Systems and RF Exposure Limits; IEEE Future Net. Tech Focus, Volume 3, Issue 2, Sept. 2019; Dr. Akimasa **Hirata** et al..

ICNIRP vs IEEE: exposure reference levels for general public



Source 5G Communications Systems and Radiofrequency Exposure Limits; IEEE Future Net. Tech Focus, Volume 3, Issue 2, September 2019; Dr. Akimasa **Hirata** et al.

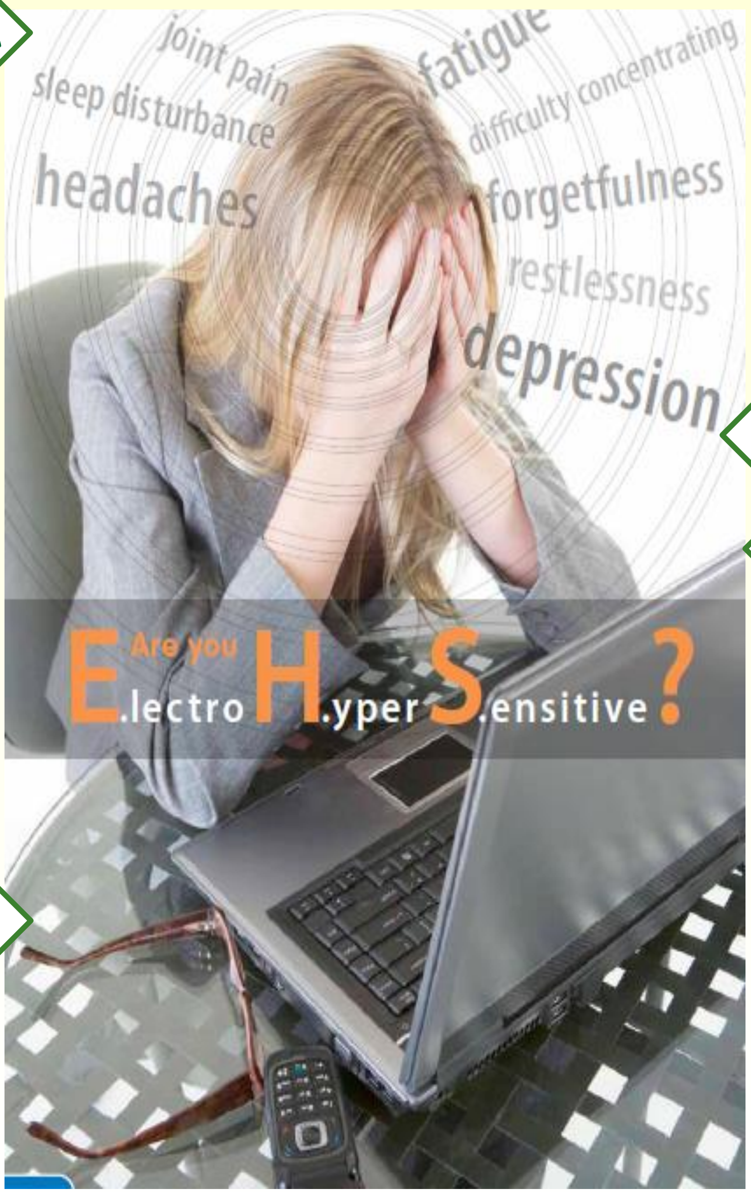
Societal Concerns

Source unknown

Electromagnetic Hyper-Sensitivity; electro-phobia

Subjective phobia, phantom risk (?!)

Precautionary Principle: billions of cellular users phones and millions of base-stations worldwide



Type I error imposes regulatory restrictions on factors that turn out to be harmless.

Type II error : acceptance of a null hypothesis that turns out to be false

Photo's source unknown

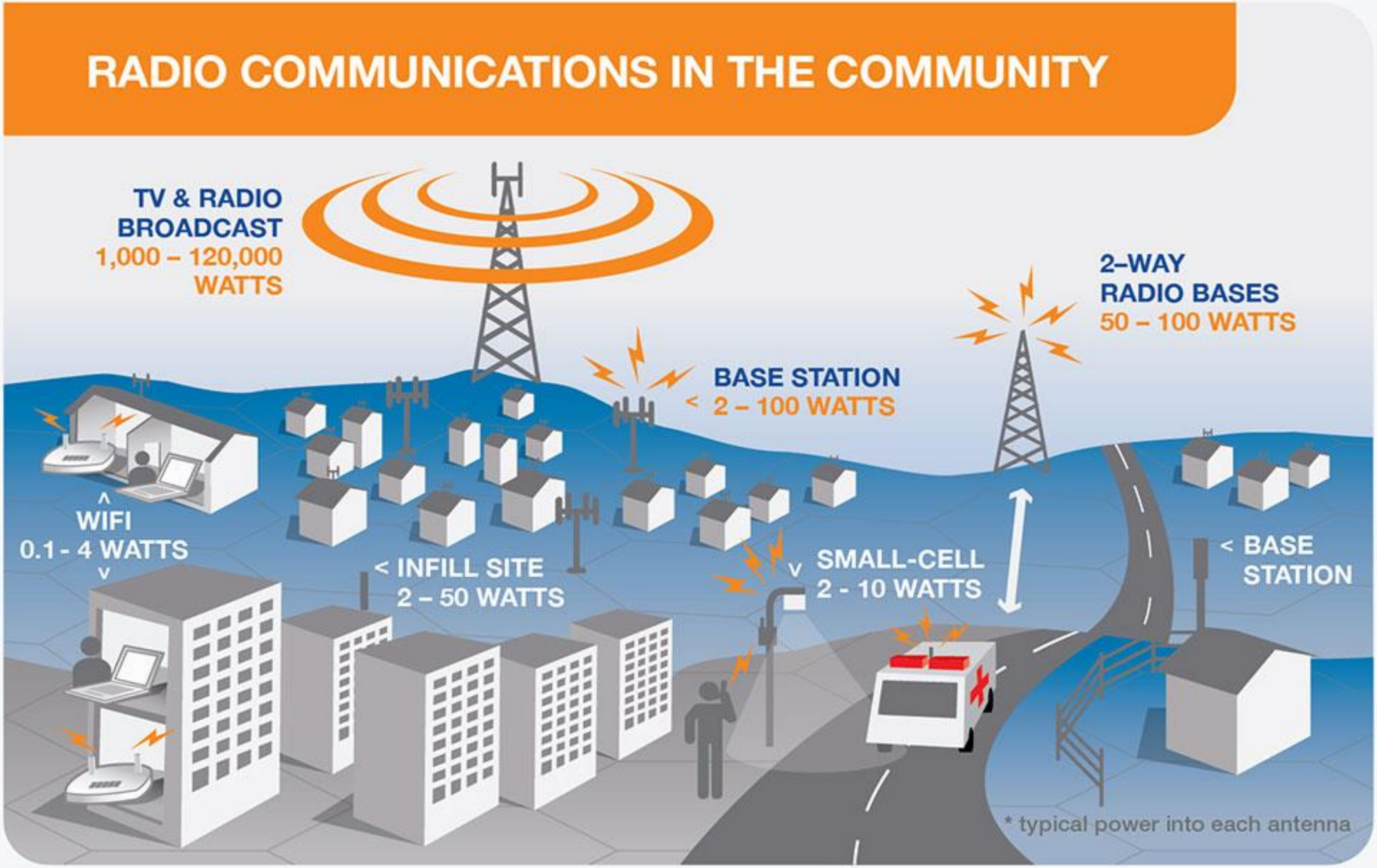
There is no evidence of causality between pains and RF exposure

World Health Organization (1948) definition of “health”: a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.

Hillel (ex) Radio Antenna; annulled due to fears

Yehuda Halevi TelAviv (8.95m)

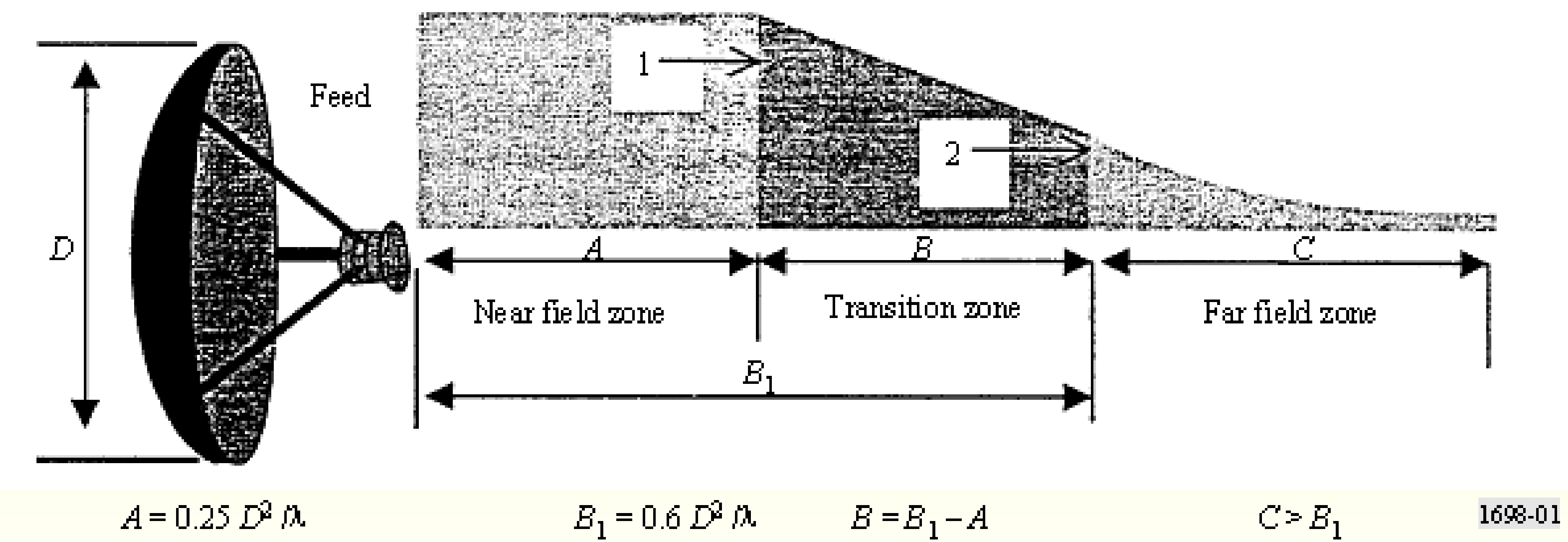
Base Station Antenna Pattern: Azimuth and Elevation (Dr. Zamir Shalita)



Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

Various radiation zones of a parabolic antenna BS1698

a cylinder with a diameter D, along the ant main beam



$$s\ (\mathrm{W/m^2}) = \frac{16\eta\ p}{\pi\ r^2}$$

η: efficiency of parabolic antenna (0.55 is used)
p: power of transmitter (W)
D: diameter of parabolic antenna (m).

$$s\ (\mathrm{W/m^2}) = \frac{pg}{4\pi\ r^2}$$

g: gain of parabolic antenna with respect to an isotropic source
r: distance from the parabolic antenna (m).

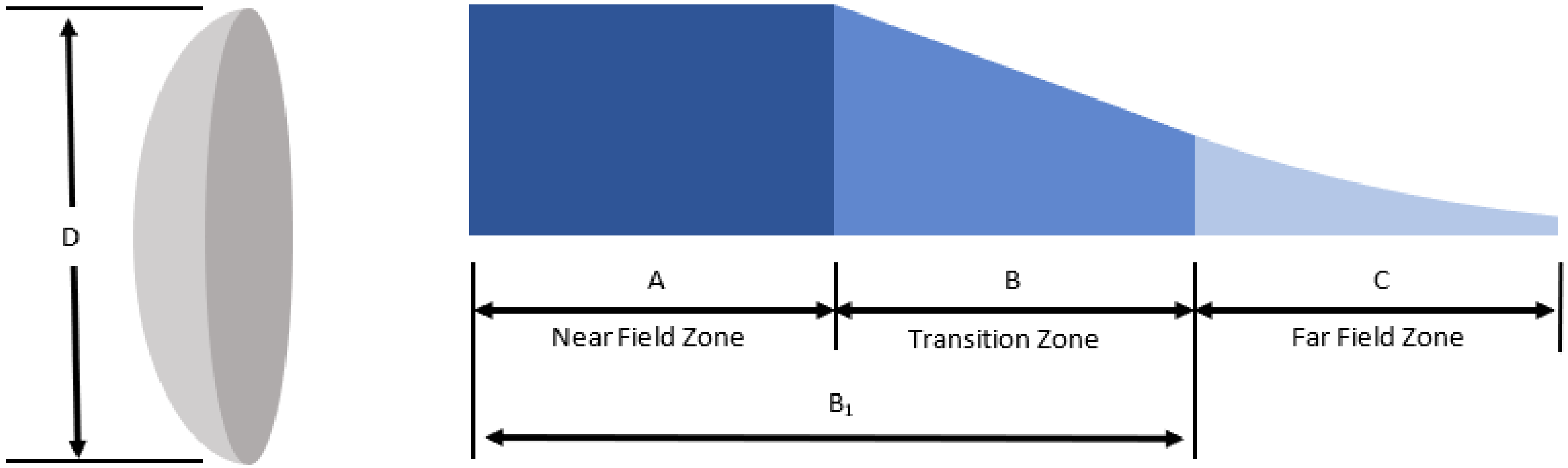
If X >= 2**D**^{2}/λ, **far-field** region

If 2**D**^{2}/λ >X> λ/2∏ **radiating** near-field region

If λ/2∏ >X **reactive** near-field region

Various radiation zones of a parabolic antenna BS1698

a cylinder with a diameter D, along the ant main beam



$$A = \frac{0.25\,D^2}{\lambda} \qquad B_1 = \frac{0.6\,D^2}{\lambda} \qquad B = B_1 - A \qquad C > B_1$$

$$s\ (\mathrm{W/m^2}) = \frac{16\eta\ p}{\pi\ r^2} \qquad\qquad s\ (\mathrm{W/m^2}) = \frac{pg}{4\pi\ r^2}$$

η: efficiency of parabolic antenna (0.55 is used)
p: power of transmitter (W)
D: diameter of parabolic antenna (m).

g: gain of parabolic antenna with respect to an isotropic source
r: distance from the parabolic antenna (m).

If X >= $2\mathbf{D}^2/\lambda$, **far-field** region

If $2\mathbf{D}^2/\lambda$ >X> $\lambda/2\Pi$ **radiating** near-field region

If $\lambda/2\Pi$ >X **reactive** near-field region

Specific Absorption Rate (SAR) limits for portable wireless devices

- The SAR is determined from measurements of the E-field (*e*) in an anatomically-correct phantom model (liquid-filled dielectric shell) of the human head using a robotically-scanned miniature E-field probe
- The SAR (W/kg) is determined from the relationship between E and the tissue properties, i.e.,

$$SAR = \sigma|e^2|/\rho$$

where σ is the liquid conductivity and ρ is the density

ICNIRP- Established Effects of EMF (Paolo_Vecchia)

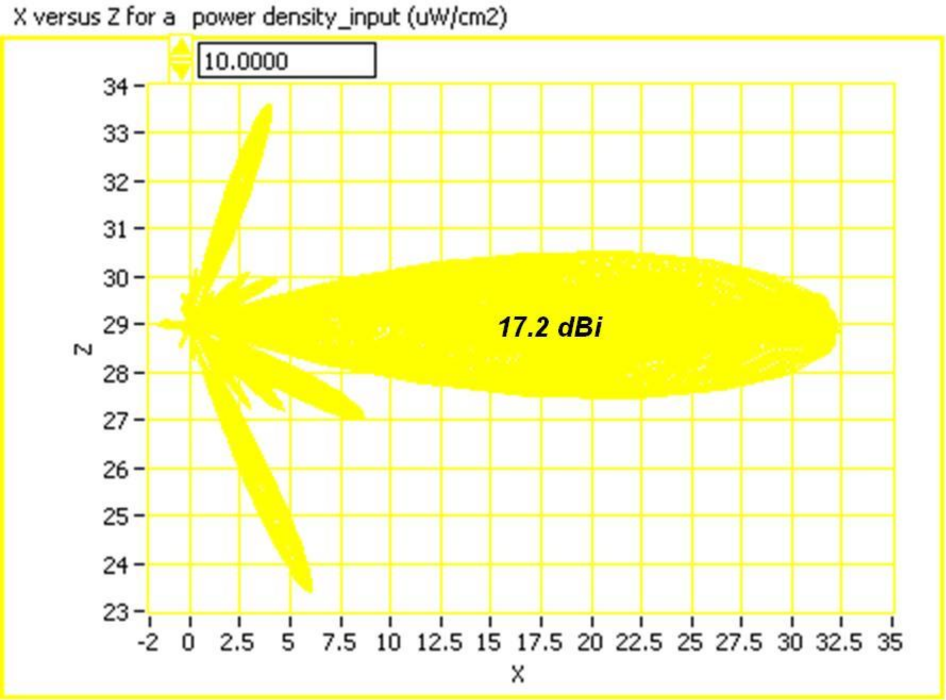
- All effects of EMF that have been established so far are acute in nature

- ELF
- Stimulation of electrically excitable tissues

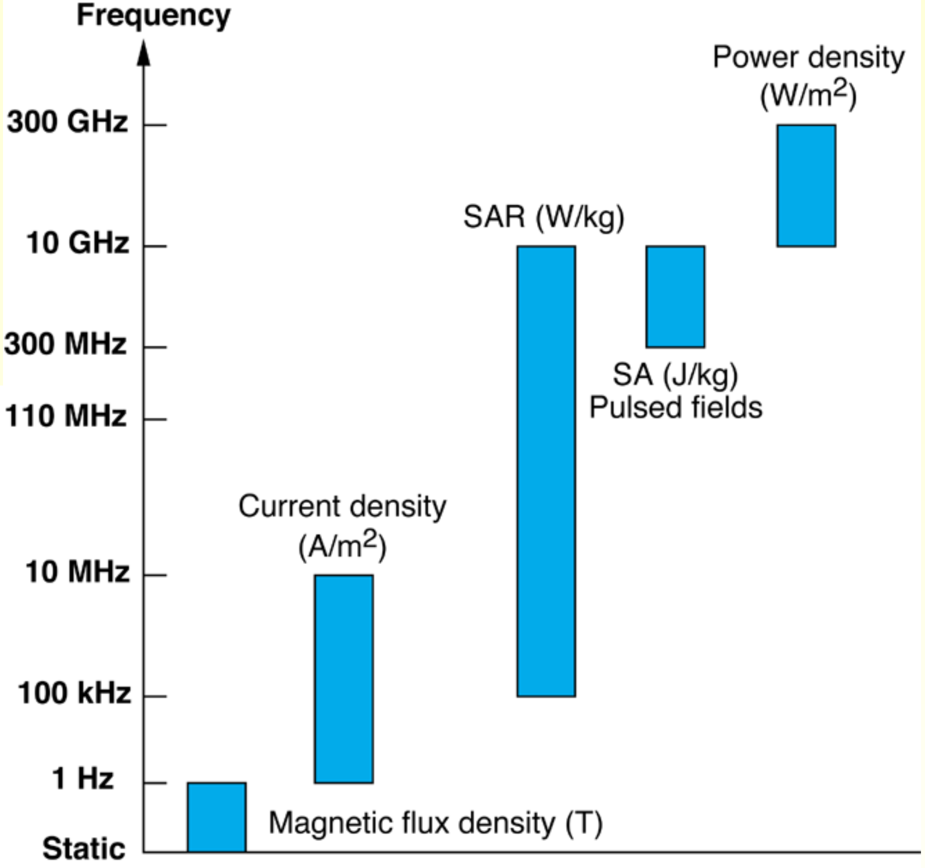
- RF
- Increase of body temperature (general or local)

Such acute effects occur above given exposure thresholds

Biologically Effective Quantities



אנטנה מסוג 739686, עבור תדר 850 מגה-הרץ, בשימוש במתקנים רגילים



SA: Specific Absorption

SAR is “the time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of a given mass density (ϱ_m)” (ITU-T 2012 K.91:9) in W/kg

$$SAR = \frac{d}{dt}\left(\frac{dw}{dm}\right) = \frac{d}{dt}\left(\frac{dw}{\rho_m dv}\right)$$

SAR can be ascertained in three ways as indicated by the following equations:

E : value of the internal electric field strength in the body tissue (V/m)
σ : conductivity of body tissue (S/m) (siemens per meter, or mho per meter)

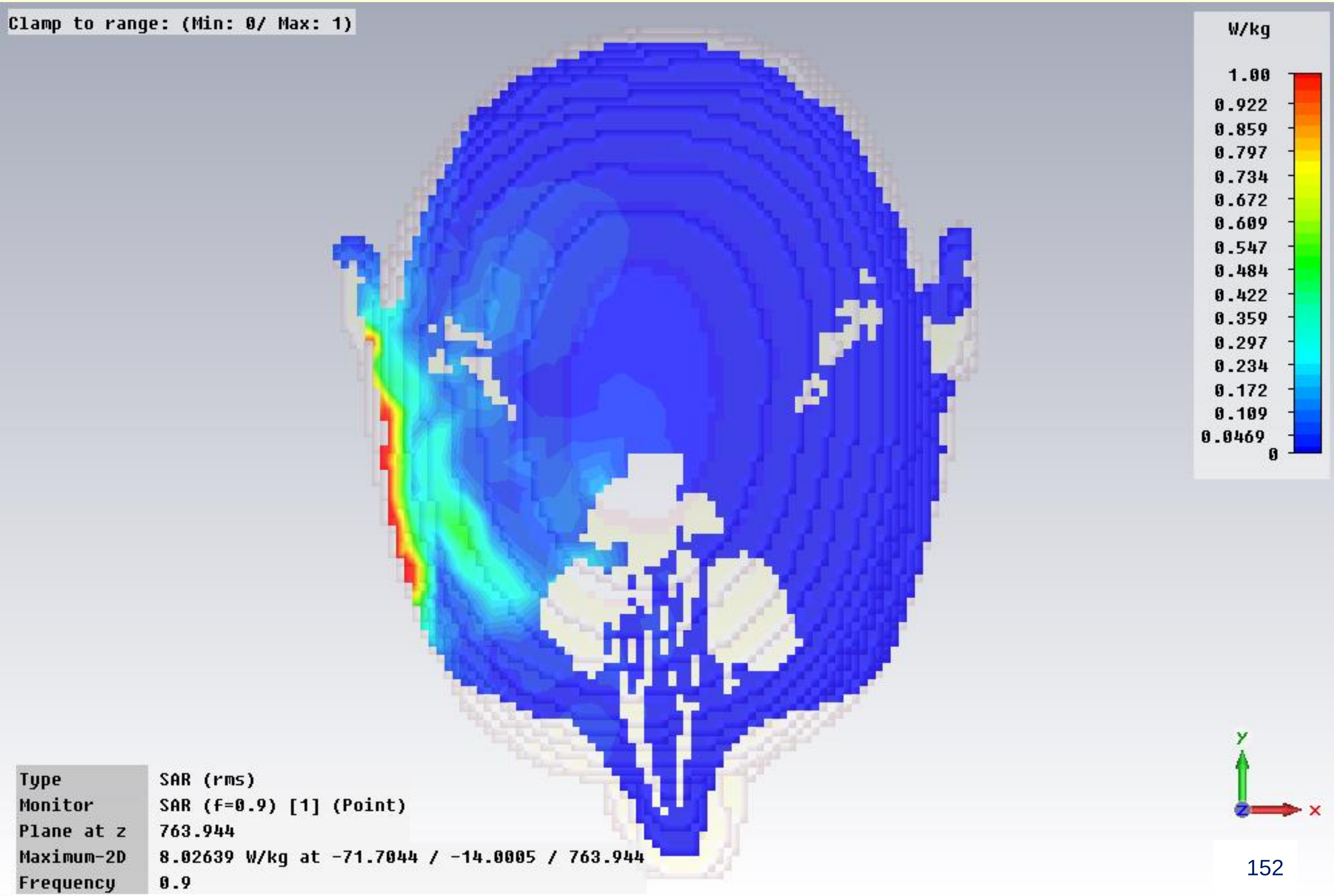
$$\mathrm{SAR} = \frac{\sigma e^2}{\rho} = C_i \frac{dT}{dt} = \frac{J^2}{\sigma\rho}$$

ρ : mass density of body tissue (kg/m³)
C_i : heat capacity of body tissue (J/kg °C)
d*T*/dt : time derivative of temperature in body tissue (°C/s)
J : value of the induced current density in the body tissue (A/m²).

Maximal power from handsets: Specific Absorption Rate, SAR (W/kg). See similar values for ICNIRP 2020

ICNIRP	**European Community**	**USA and Canada**
From 10 MHz to 10 GHz; Localized SAR (Head and Trunk)		Portable Devices; General Population/ Uncontrolled
2.0; averaged over 10 g tissue (also IEEE 2005 and 2019 level)		1.6; averaged over 1g tissue

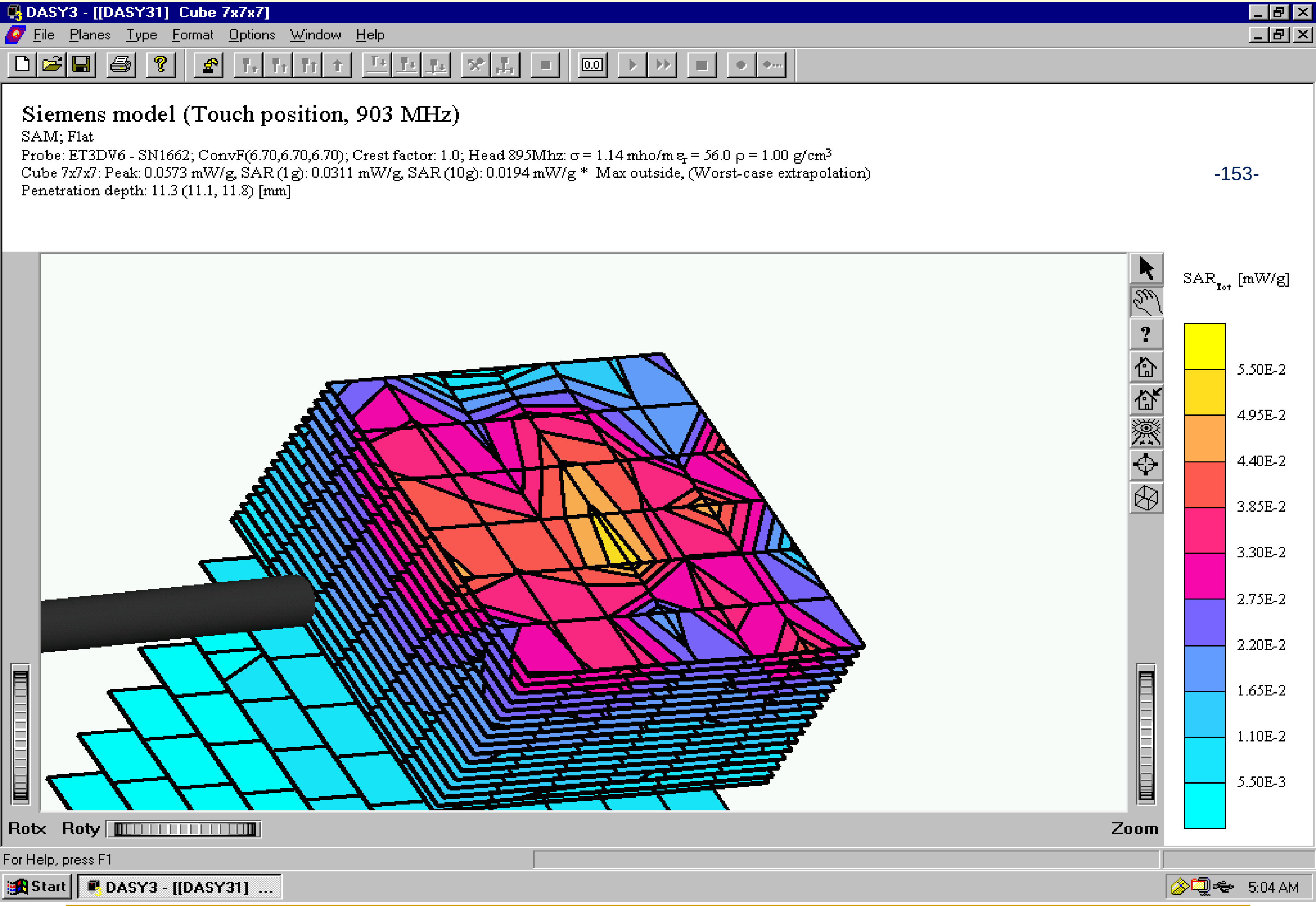
SAR phantom simulation (Stefan Chulski & Stav Revich from HIT)



Clamp to range: (Min: 0/ Max: 1)

Type	SAR (rms)
Monitor	SAR (f=0.9) [1] (Point)
Plane at z	763.944
Maximum-2D	8.02639 W/kg at -71.7044 / -14.0005 / 763.944
Frequency	0.9

Measurements of SAR (Pr. Moti Haridim from HIT)



Siemens model (Touch position, 903 MHz)

SAM; Flat

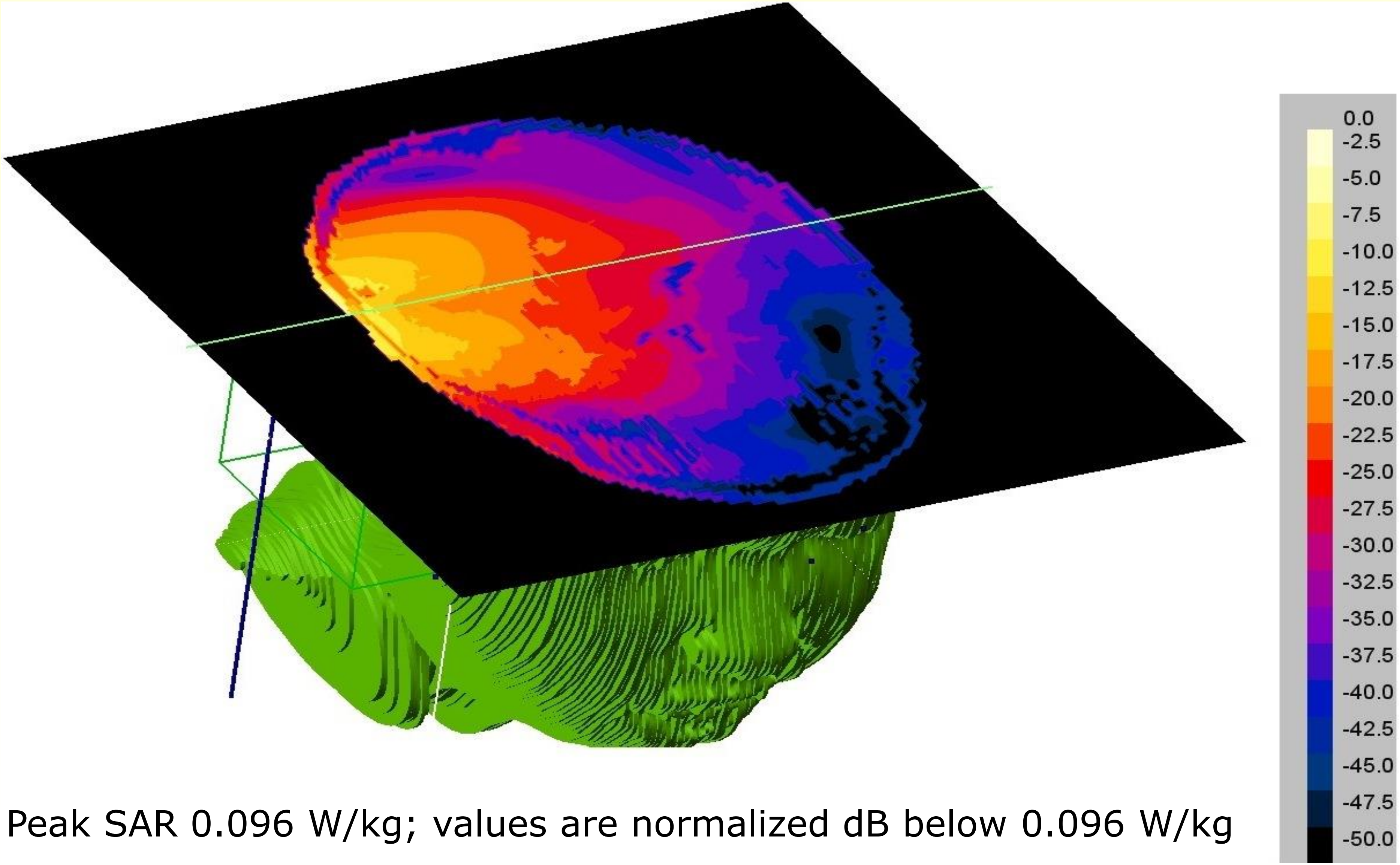
Probe: ET3DV6 - SN1662; ConvF(6.70,6.70,6.70); Crest factor: 1.0; Head 895Mhz: $\sigma = 1.14$ mho/m $\varepsilon_r = 56.0$ $\rho = 1.00$ g/cm^3

Cube 7x7x7: Peak: 0.0573 mW/g, SAR (1g): 0.0311 mW/g, SAR (10g): 0.0194 mW/g * Max outside, (Worst-case extrapolation)

Penetration depth: 11.3 (11.1, 11.8) [mm]

Numerical simulation of SAR; for a three years child

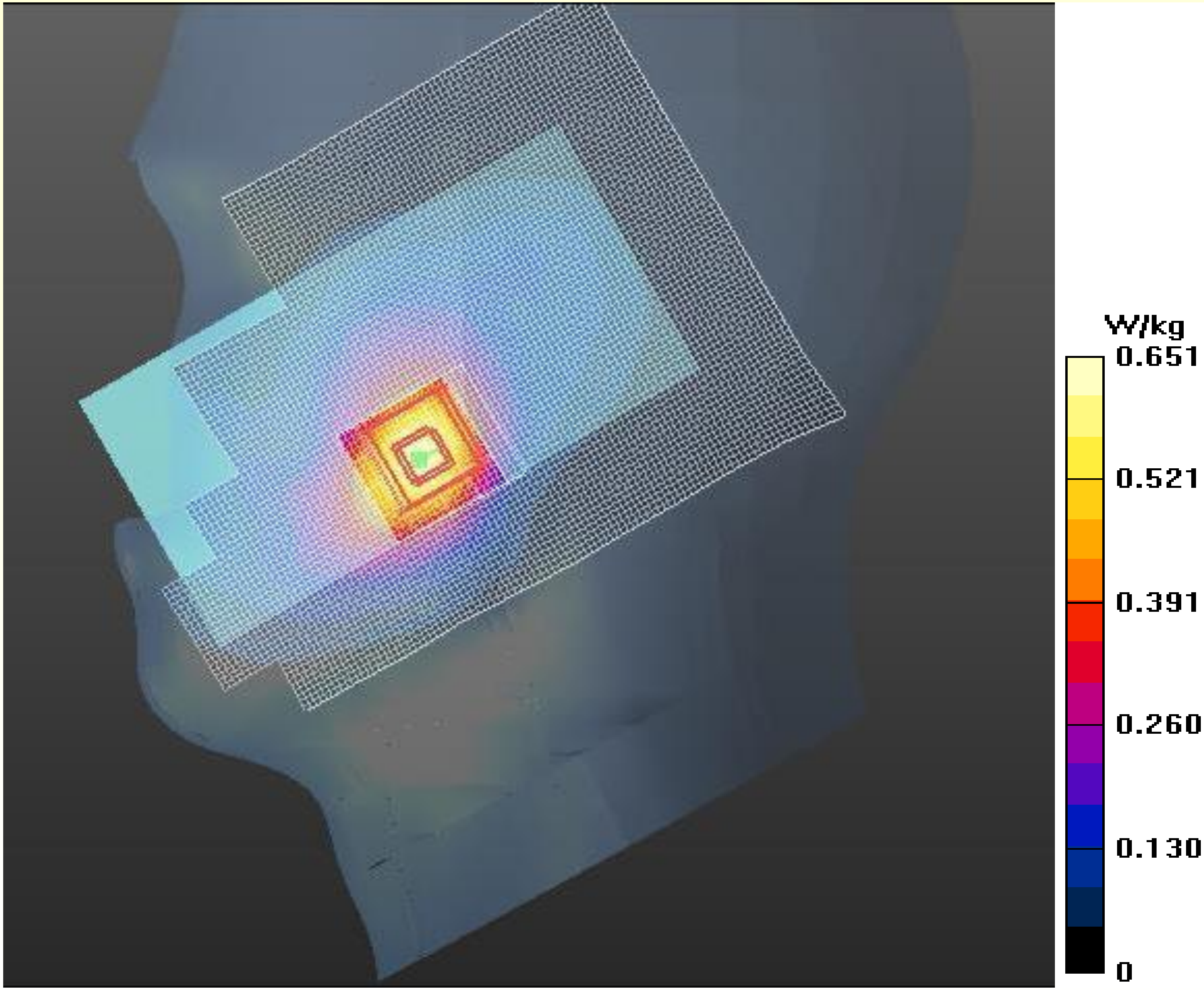
Source: Dr. Jafar Keshvari, Bio-electromagnetics
Aalto University, Helsinki-Finland



Peak SAR 0.096 W/kg; values are normalized dB below 0.096 W/kg

SAR real measurement for a commercial mobile phone

Source: Dr. Jafar Keshvari, Bio-electromagnetics Aalto University, Helsinki-Finland



FCC 2020 Limits for Maximum Permissible Exposure (MPE)

Reassessment of RF Exposure Limits & Policies, and Proposed Changes in the Rules Regarding Human Exposure to RF Fields

Frequency range (MHz)	*electric field strength (V/m)*	*magnetic field strength (A/m)*	*power density (mW/cm^2)*	*averaging time (minutes)*
(A) limits for occupational/controlled exposure				
0.3 – 3.0	614	1.63	100 *	6
3.0 – 30	1,842/*f*	4.89/*f*	$900/f^2$ *	6
30 – 300	61.4	0.163	1.0	6
300 – 1,500	–	–	*f*/300	6
1,500 – 100,000	–	–	5	6
(B) limits for general population/uncontrolled exposure				
0.3 – 1.34	614	1.63	100 *	30
1.34 – 30	824/*f*	2.19/*f*	$180/f^2$ *	30
30 – 300	27.5	0.073	0.2	30
300 – 1,500	–	–	*f*/1,500	30
1,500 – 100,000	–	–	1.0	30

[1] FCC uses different units than ICNIRP 1998 for power density: mW/cm^2 and not W/m^2; $W/m^2 = 0.1\ mW/cm^2$

ICNIRP vs. N. America and Japan reference levels; click for Mazar paper 2016

ICNIRP 1998, EC (1999/519) and IEEE reference levels for public

Frequency range	**electric field strength (V/m)**	**equivalent plane wave power density S_{eq}(W/m^2)**
10–400 MHz	28	**2**
400-2000 MHz	$1.375f^{1/2}$	***f*/200**
2-300 GHz	**61**	**10**

USA and Japan Maximum Permissible Exposure for general

RF (MHz)	**electric Field (*E*) (V/m)**	**power Density (*S*) (mW/cm^2)**
30-300	27.5	**0.2**
300-1500	--	***f*/1,500**
1,500-100,000	**--**	**1**

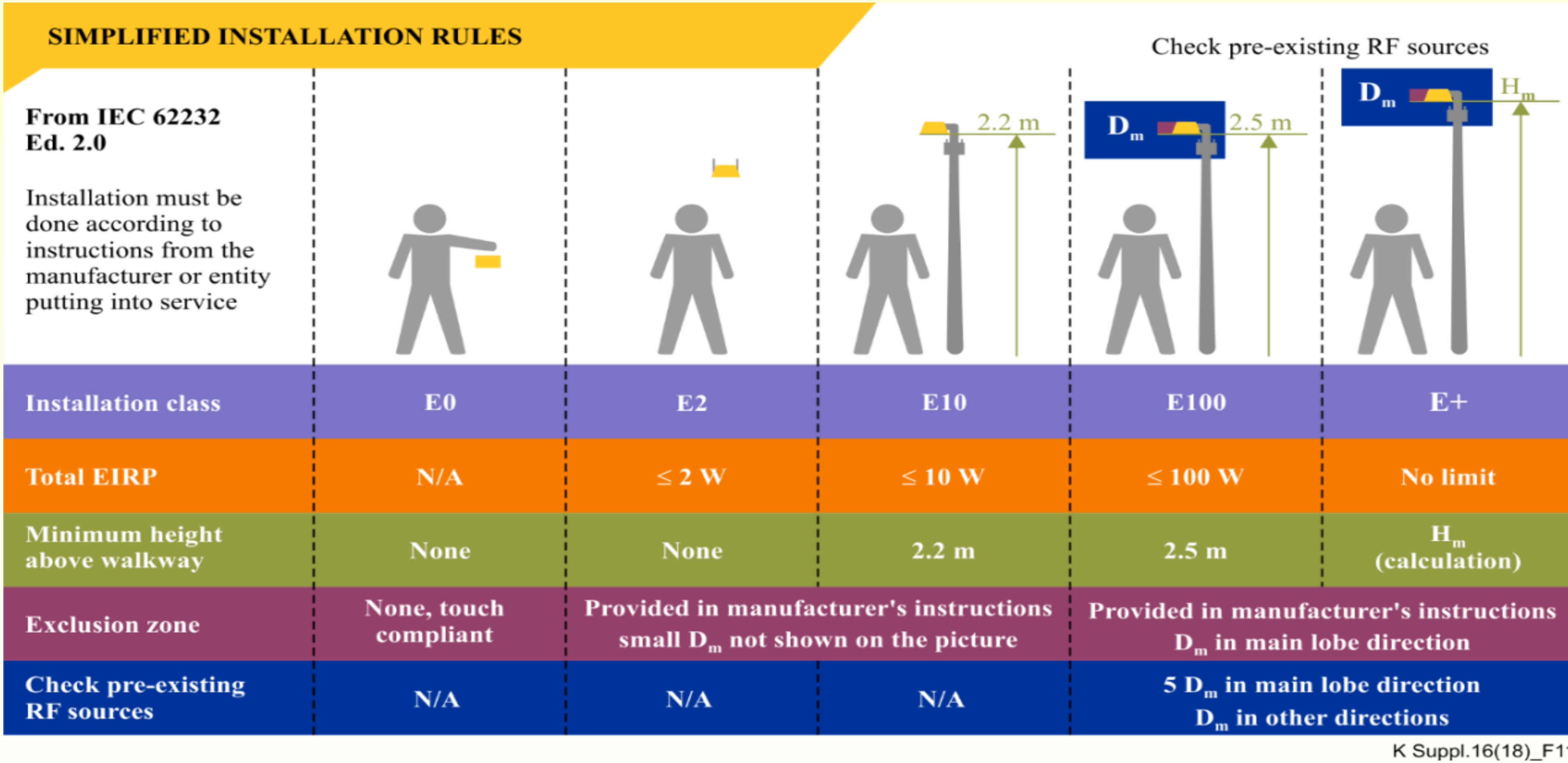
---

[1] FCC uses different units than ICNIRP for power density: mW/cm^2 and not W/m^2; W/m^2 = 0.1 mW/cm^2

ICNIRP 1998, FCC §1.1310 and Canada Safety Code SC6 (W/m^2)

Frequency	ICNIRP 1998	FCC §1.1310	SC6
300 MHz	2	2	1.291
1,500 MHz	*f*/200=1500/200=7.5	10	0.02619x $f^{0.6834}$ =3.88
3,000 MHz	10 W/m^2		0.02619x $f^{0.6834}$ =6.23
6,000 MHz	10 W/m^2		

Compliance: simplified installation rules



SIMPLIFIED INSTALLATION RULES

Check pre-existing RF sources

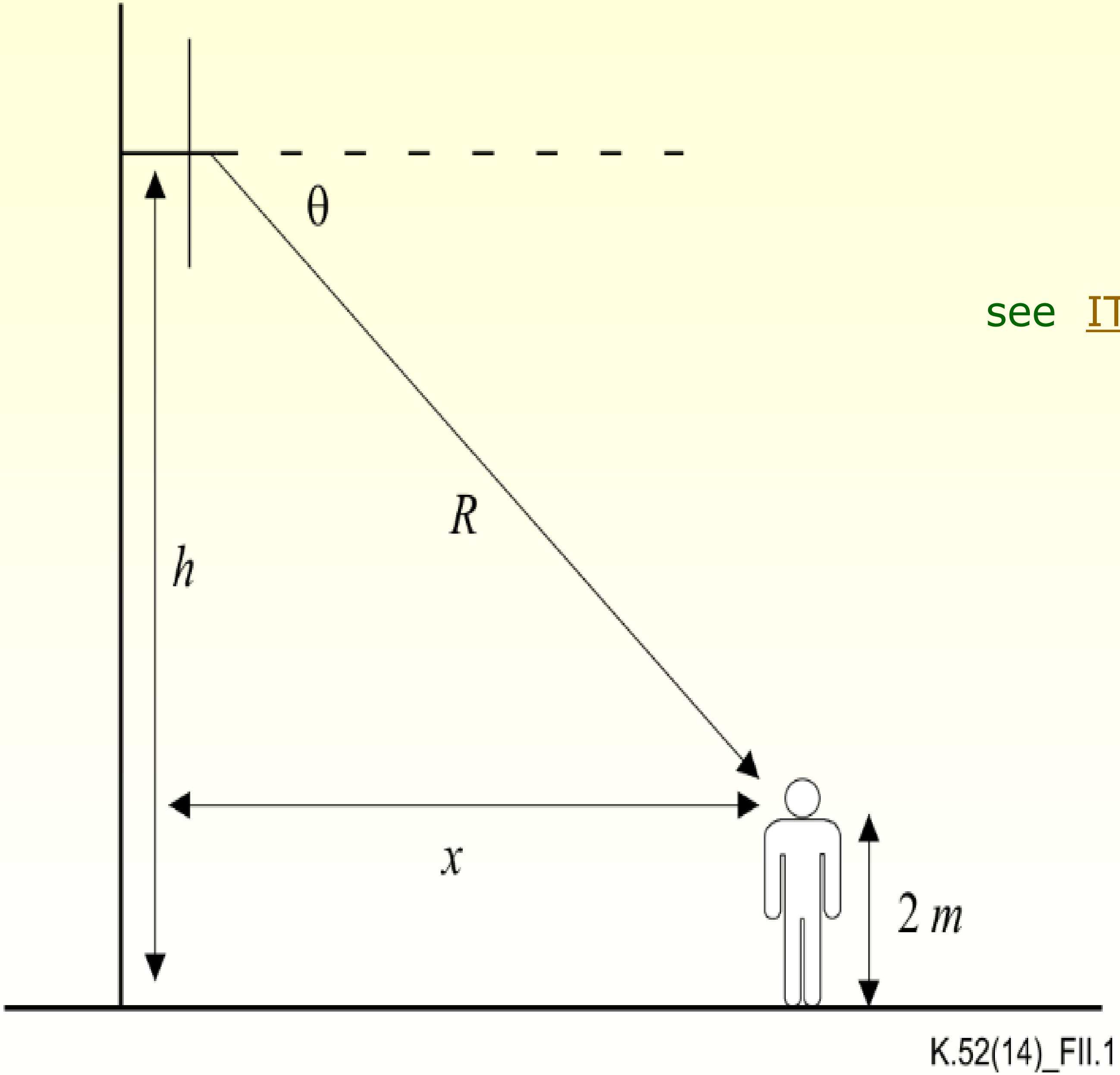
From IEC 62232 Ed. 2.0

Installation must be done according to instructions from the manufacturer or entity putting into service

Installation class	E0	E2	E10	E100	E+
Total EIRP	N/A	≤ 2 W	≤ 10 W	≤ 100 W	No limit
Minimum height above walkway	None	None	2.2 m	2.5 m	H_m (calculation)
Exclusion zone	None, touch compliant	Provided in manufacturer's instructions small D_m not shown on the picture		Provided in manufacturer's instructions D_m in main lobe direction	
Check pre-existing RF sources	N/A	N/A	N/A	5 D_m in main lobe direction D_m in other directions	

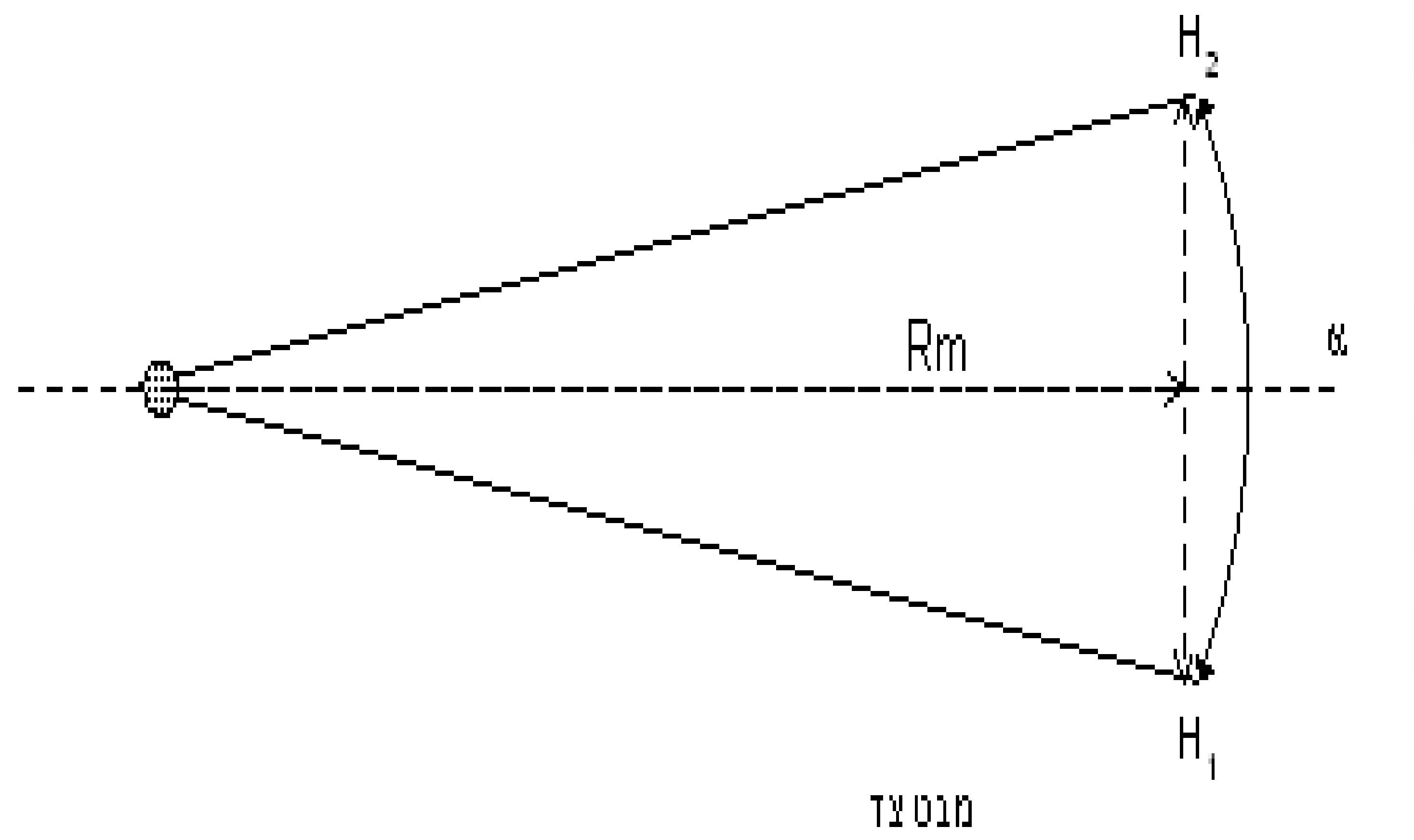
Source:Emf compliance assessments for 5G wireless networks ITU-T K Suppl 13 05/2019

Configuration for calculating exposure at ground level



see ITU-T 2018 K.52 Fig II.1

Vertical and Horizontal safety distances



Free Space loss, **Electric** Field-Strength

(see next slides)

p_t=t_x power, *g*= antenna gain *d*=distance (radiation contour); *p_t* x g- *e.i.r.p.*
Field-strength exposure limits: *e*=electric field strength, *h*=magnetic field-strength

$$PoyntingVector = \frac{p_t g_t}{4\pi d^2} = (\vec{e} \times \vec{h}) = \frac{e_o^2}{z_o}$$

Where *e* (V/m), *h* (A/m), the impedance the impedance Z_0 (Ω) relates the magnitudes of electric and magnetic fields travelling through free space. $Z_0 \equiv |E|/|H|$. From the plane wave solution to Maxwell’s equations , the impedance of free space equals the product of the vacuum permeability (or magnetic constant) μ_0 and the speed of light c_0 in a free space. The numerical equivalent isotropically radiated power is *e.i.r.p.* (W) and logarithmic *E.I.R.P.* (dBW)

$$z_0 \equiv \mu_0 c_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{1}{\varepsilon_0 c_0} \approx 120\pi \approx 376.730\,313\,461 \approx 377 Ohm$$

$$c_0 \equiv \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

$$\vec{e} = \frac{\sqrt{30 \times p_t \times g_t}}{d} = \frac{\sqrt{30 \times e.i.r.p.}}{d}$$

$$d = \frac{\sqrt{30 \times e.i.r.p.}}{\vec{e}}$$

$$e.i.r.p. = \frac{e^2 \times d^2}{30}$$

Free Space loss, Magnetic Field-Strength

p_t=t_x power, *g*= antenna gain *d*=distance (radiation contour); p_t x g- *e.i.r.p.*
Field-strength exposure limits: *e*=electric field strength, *h*=magnetic field-strength

$$PoyntingVector = \frac{p_t g_t}{4\pi d^2} = \frac{e.i.r.p.}{4\pi d^2} = (\vec{e} \times \vec{h}) = \frac{e^2}{z_o} = h^2 \times z_o = h^2 \times 120\pi$$

As the impedance Z_0 (Ω) relates the magnitudes of electric and magnetic fields travelling through free space. $Z_0 \equiv |E|/|H| ≈ 120п ≈ 377$ Ohm

$$\frac{e.i.r.p.}{4\pi d^2} = h^2 \times 120\pi$$

$$e.i.r.p. = h^2 \times 120\pi \times 4\pi d^2$$

$$h^2 = \frac{e.i.r.p.}{480\pi^2 d^2}$$

$$|\vec{h}| = \sqrt{\frac{e.i.r.p.}{480\pi^2 d^2}} = \frac{\sqrt{e.i.r.p.}}{\sqrt{480} \times \pi d}$$

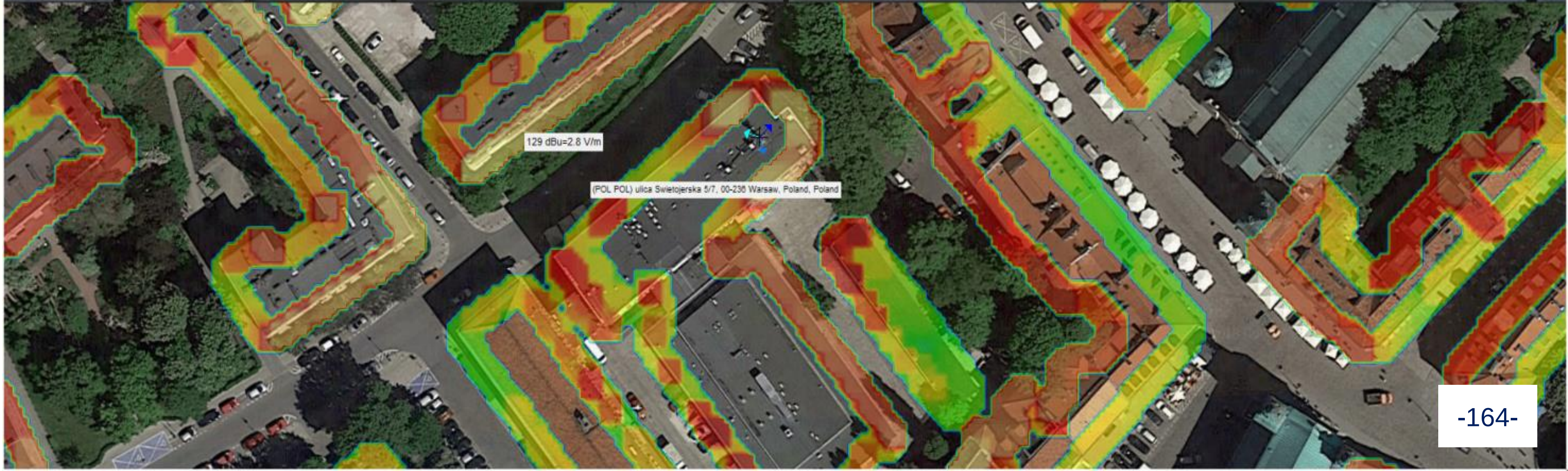
or

$$\boxed{|\vec{h}| = \frac{e}{120\pi} = \frac{\sqrt{30 \times e.i.r.p.}}{120\pi \times d} = \frac{\sqrt{e.i.r.p.}}{\sqrt{480}\pi \times d}}$$

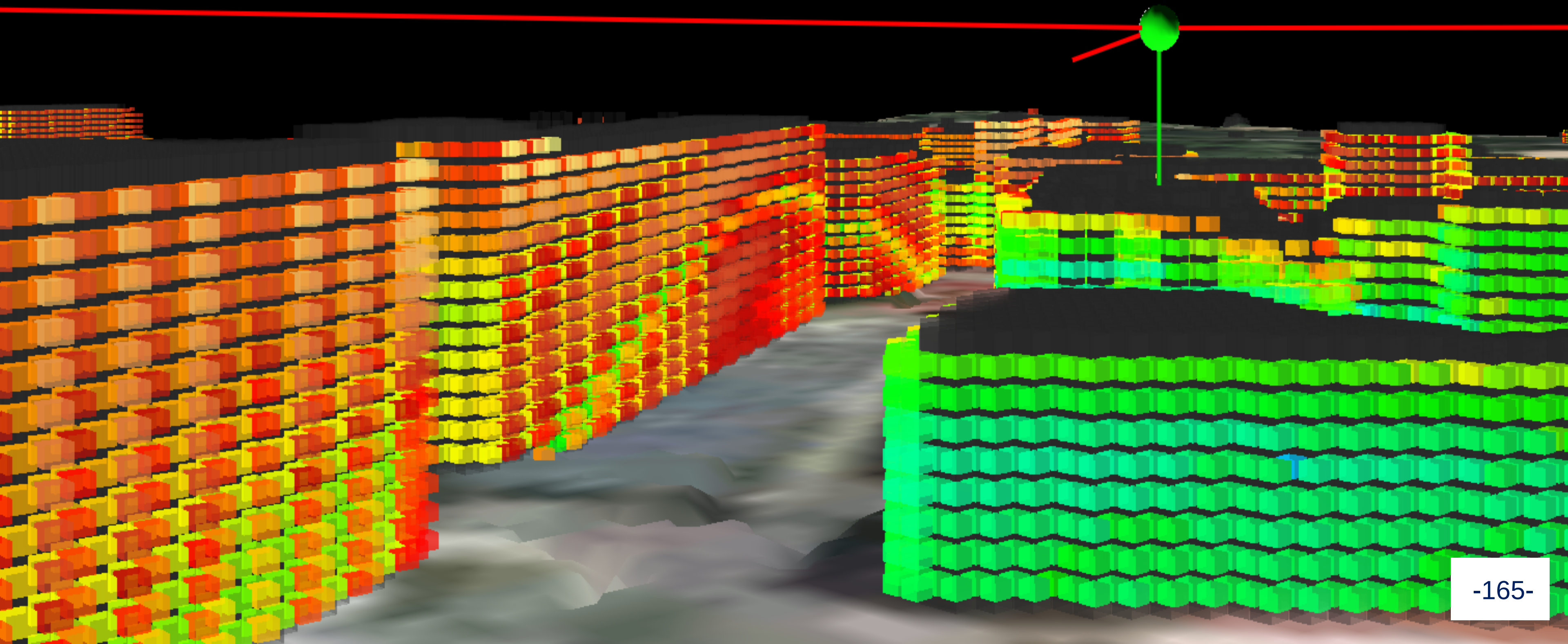
and

$$\boxed{e.i.r.p. = 480\pi^2 \times h^2 \times d^2}$$

ATDI 3D coverage analysis, to find max exposure locations

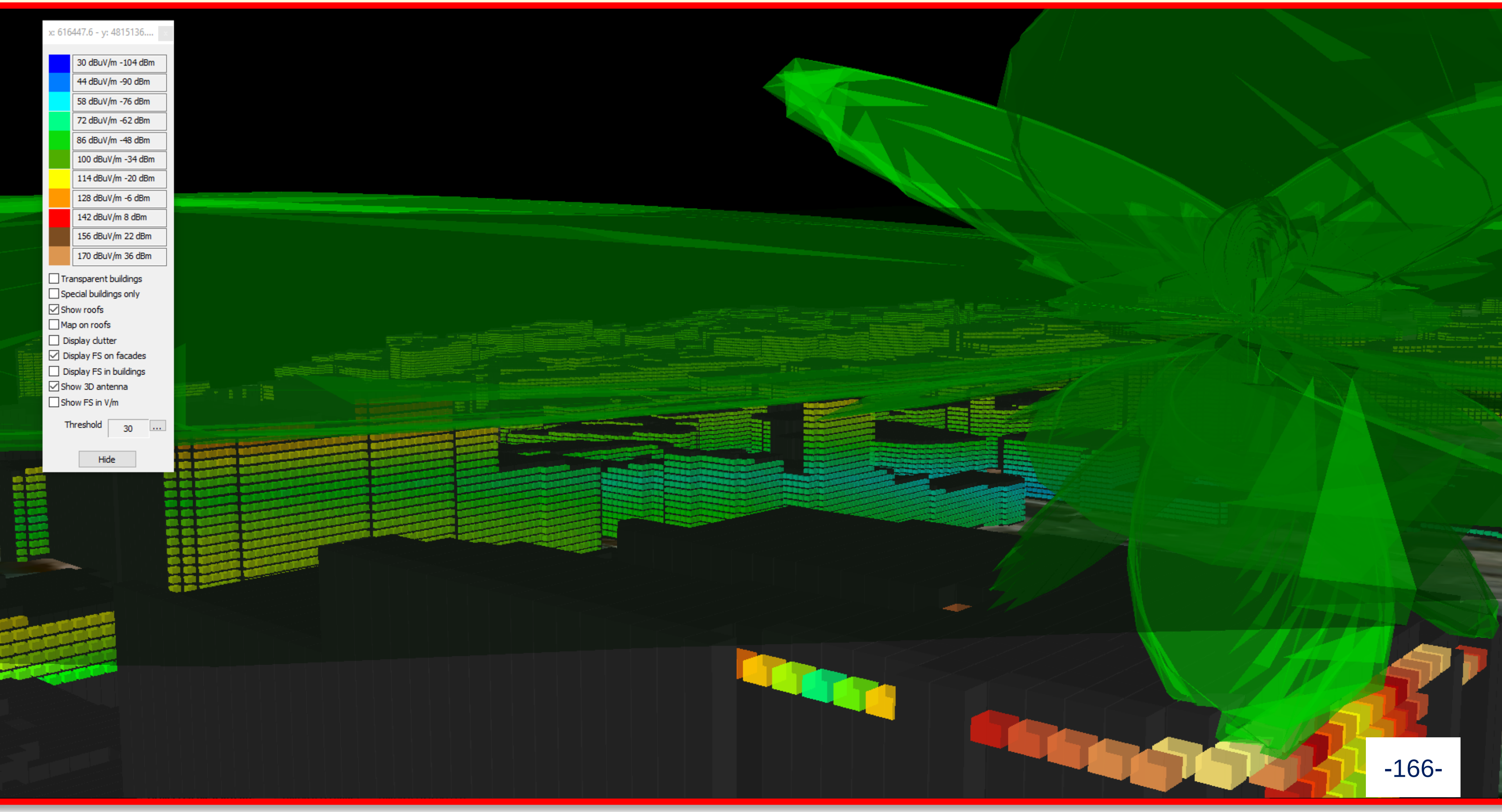


3D coverage calculation on building facades (1 m resolution X,Y,Z)



Calculating far-field safety-distances around base stations using elevation ant. pattern

Ant. tilt 0 degrees; also in azimuth antenna pattern is analysed; typically in 3 sectors 5G, there is azimuth overlap: 6dB attenuation in ±60^0 & 3dB ±45^0, around mainbeam

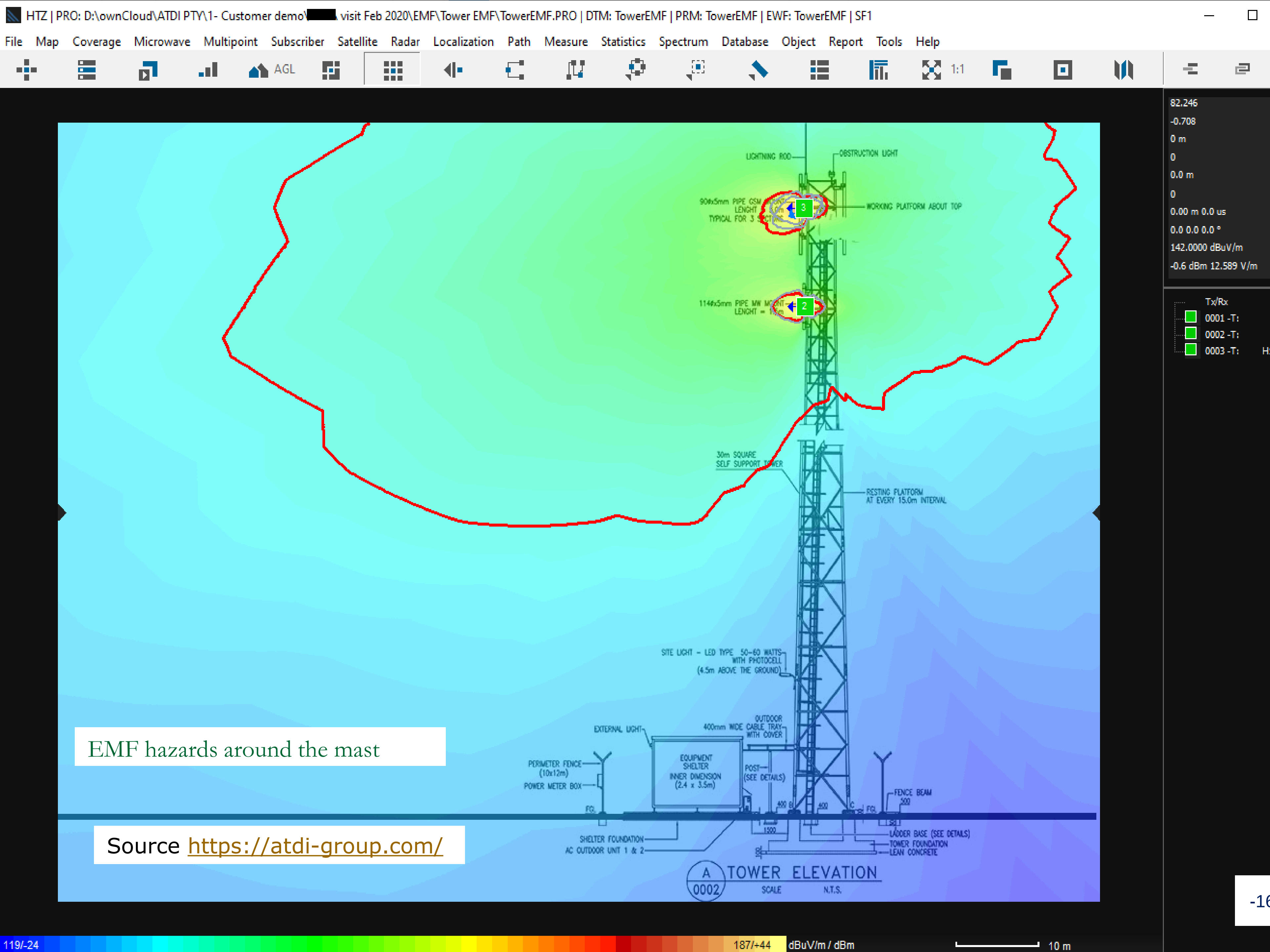


x: 616447.6 - y: 4815136....

🟦	30 dBuV/m -104 dBm
🟦	44 dBuV/m -90 dBm
🟦	58 dBuV/m -76 dBm
🟩	72 dBuV/m -62 dBm
🟩	86 dBuV/m -48 dBm
🟩	100 dBuV/m -34 dBm
🟨	114 dBuV/m -20 dBm
🟧	128 dBuV/m -6 dBm
🟥	142 dBuV/m 8 dBm
🟫	156 dBuV/m 22 dBm
🟧	170 dBuV/m 36 dBm

☐ Transparent buildings
☐ Special buildings only
☑ Show roofs
☐ Map on roofs
☐ Display clutter
☑ Display FS on facades
☐ Display FS in buildings
☑ Show 3D antenna
☐ Show FS in V/m

Threshold 30



HTZ | PRO: D:\ownCloud\ATDI PTY\1- Customer demo\[redacted] visit Feb 2020\EMF\Tower EMF\TowerEMF.PRO | DTM: TowerEMF | PRM: TowerEMF | EWF: TowerEMF | SF1

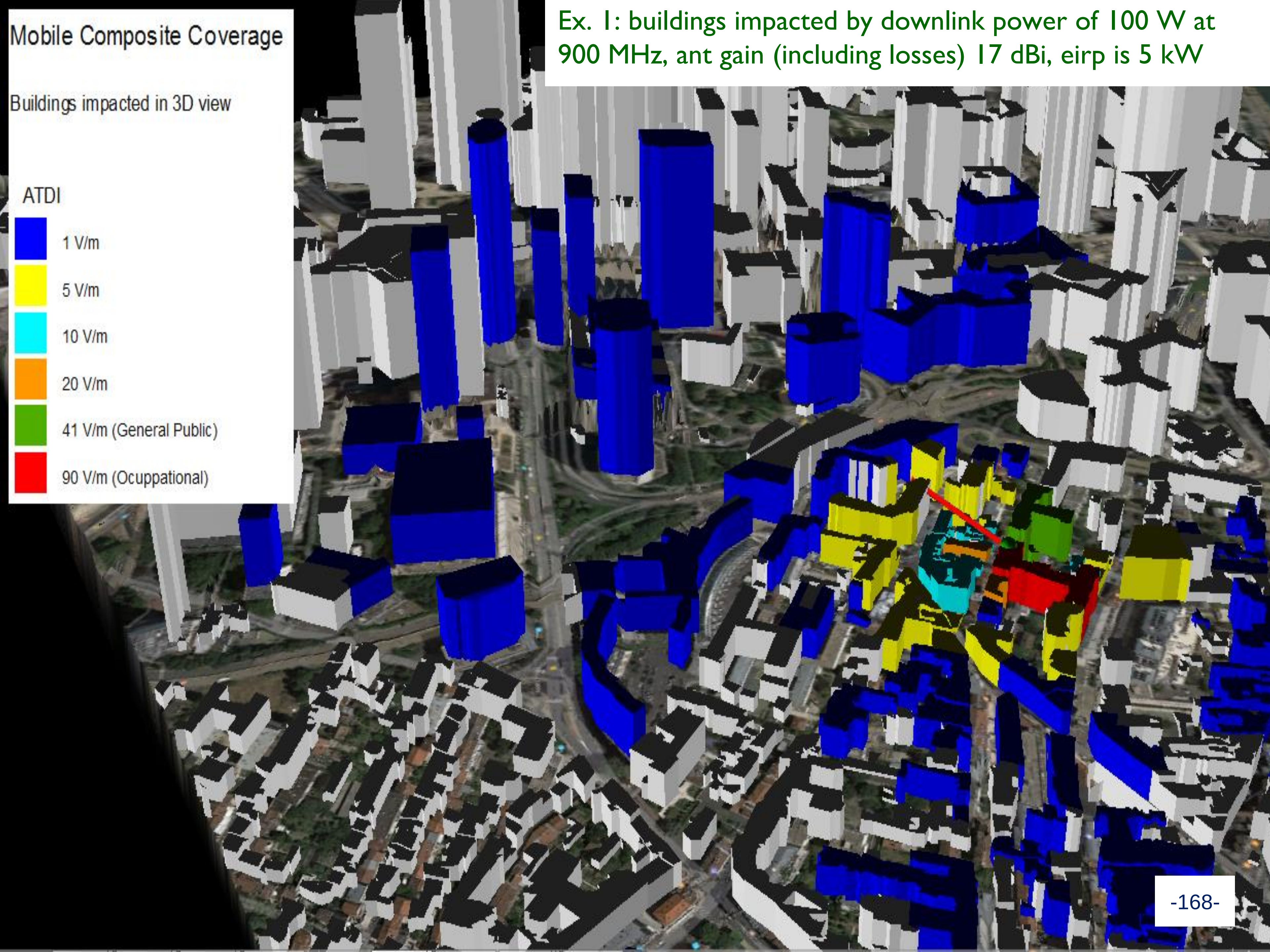
```
82.246
-0.708
0 m
0
0.0 m
0
0.00 m 0.0 us
0.0 0.0 0.0 °
142.0000 dBuV/m
-0.6 dBm 12.589 V/m
```

Tx/Rx
- 🟩 0001 -T:
- 🟩 0002 -T:
- 🟩 0003 -T:

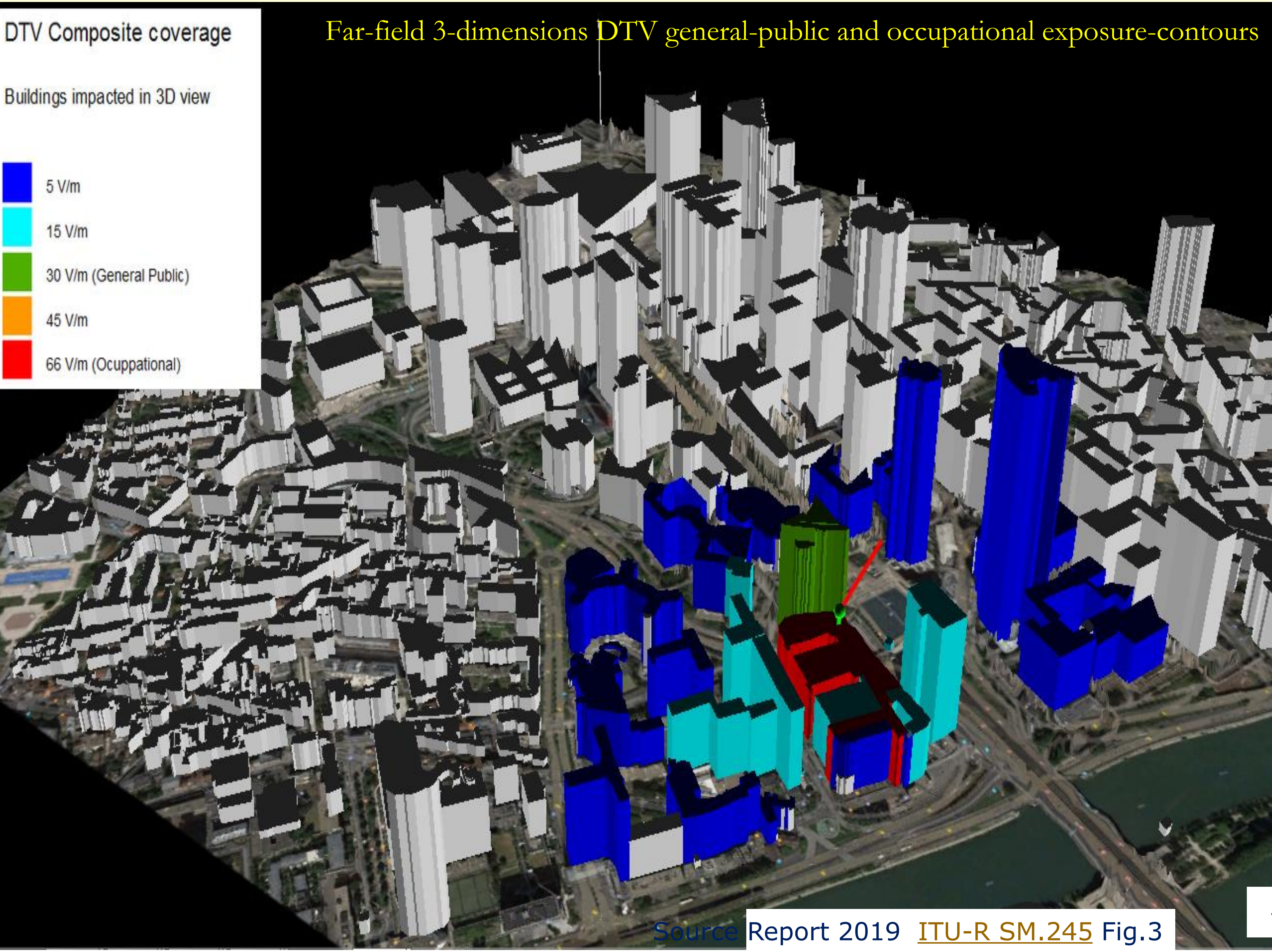
EMF hazards around the mast

Source https://atdi-group.com/

Ex. 1: buildings impacted by downlink power of 100 W at 900 MHz, ant gain (including losses) 17 dBi, eirp is 5 kW

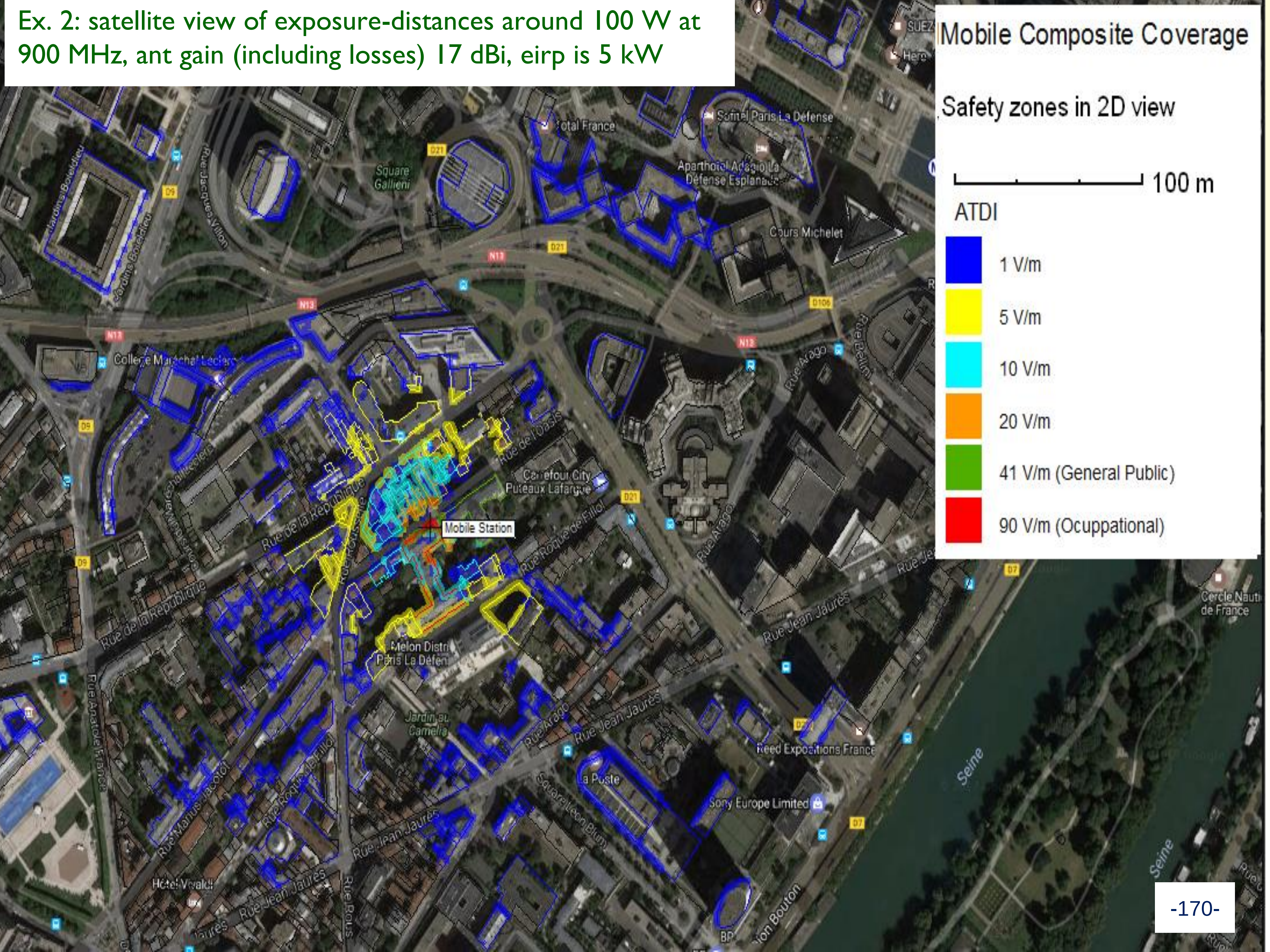


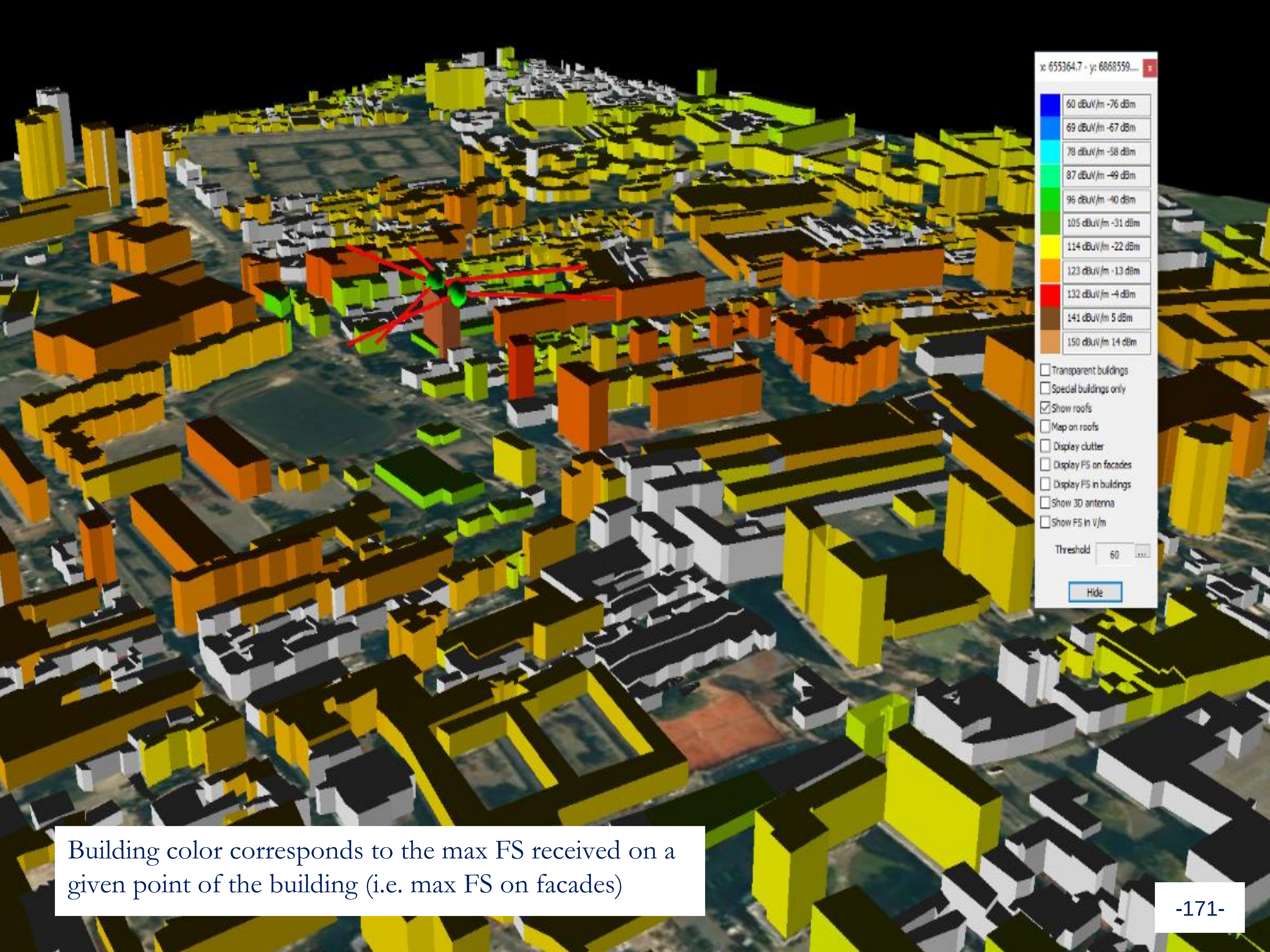
Far-field 3-dimensions DTV general-public and occupational exposure-contours



Source Report 2019 ITU-R SM.245 Fig.3

Ex. 2: satellite view of exposure-distances around 100 W at 900 MHz, ant gain (including losses) 17 dBi, eirp is 5 kW





x: 655364.7 - y: 6868559....

🟦	60 dBuV/m -76 dBm
🟦	69 dBuV/m -67 dBm
🟦	78 dBuV/m -58 dBm
🟩	87 dBuV/m -49 dBm
🟩	96 dBuV/m -40 dBm
🟩	105 dBuV/m -31 dBm
🟨	114 dBuV/m -22 dBm
🟧	123 dBuV/m -13 dBm
🟥	132 dBuV/m -4 dBm
🟫	141 dBuV/m 5 dBm
🟫	150 dBuV/m 14 dBm

☐ Transparent buildings
☐ Special buildings only
☑ Show roofs
☐ Map on roofs
☐ Display clutter
☐ Display FS on facades
☐ Display FS in buildings
☐ Show 3D antenna
☐ Show FS in V/m

Threshold 60

Building color corresponds to the max FS received on a given point of the building (i.e. max FS on facades)

Far-field free-space propagation loss

$$s=\frac{p_{\mathrm{t}}g_{\mathrm{t}}}{4\pi d^2}=\frac{eirp}{4\pi d^2};d=\sqrt{\frac{eirp}{4\pi s}}$$

$$\vec{s}=\vec{e}\times\vec{h}=\frac{eirp}{4\pi d^2}\qquad \vec{h}=\frac{\vec{e}}{z_o}\qquad z_0\equiv\mu_0\times c_0=\mu_0\times\sqrt{\frac{1}{\varepsilon_0\times\mu_0}}=\sqrt{\frac{\mu_0}{\varepsilon_0}}=\frac{1}{\varepsilon_0\times c_0}=120\pi$$

$$\vec{s}=\vec{e}\times\vec{h}=\frac{eirp}{4\pi d^2}=\frac{\vec{e}\times\vec{e}}{120\pi}\qquad |\vec{s}|=\frac{e^2}{z_o}=\frac{e^2}{120\pi}\qquad e=\frac{\sqrt{30\,eirp}}{d};d=\frac{\sqrt{30\,eirp}}{e}$$

where:

p_{t}: transmitter power (watts)

g_{t} : transmitter antenna gain (numeric)

eirp: equivalent isotropically radiated power (watts)

s: power density (watts/m^2) (limit)

d: distance (m)

e : electric field strength (V/m) (limit)

z_0 : impedance of free-space, 120π (Ohms)

μ_0: vacuum permeability (or magnetic constant)

ε_0 : vacuum permittivity (or electric constant)

c_0 : speed of light in vacuum

Multiple-antenna emissions from the same site & **same frequency**

at a frequency range whose limits are frequency independent (like 30–400 MHz & 2–300 GHz), the power-density limits are equal for all transmitters emitting at the same frequency range, i.e. $s_{l1}= s_{l2}=\ldots =s_l$. The equivalent cumulative *eirp* is the power scalar sum of all the emitters; equivalent *eirp* is used to calculate the safety-distance based on ICNIRP 1998 Tables 6 & 7, or ICNIRP 2020 Tables 5 & 6

$$eirp_{eq} = \sum eirp_i \qquad d_{eq} = \sqrt{\frac{eirp_{\mathrm{eq}}}{4\pi s_l}} = \sqrt{\frac{\sum eirp_{\mathrm{i}}}{4\pi s_l}}$$

the total field strength exposure ration w_t should be smaller than 1

$$w_t = \sum_i \left(\frac{e_i}{e_l}\right)^2 = \frac{\sum_i (e_i)^2}{(e_l)^2} \leq 1$$

Where

$eirp_{\mathrm{i}}$:	for each emitter	(watts)	
$eirp_{\mathrm{eq}}$:	equivalent cumulative *eirp*	(watts)	
d_{i}:	safety-distance from each emitter	(m)	
d_{eq}:	equivalent cumulative safety-distance	(m)	
s_{i} :	power density from each emitter	(W/m²)	index i
s_{li} :	power density **l**imit from each emitter	(W/m²)	index i
e_{i} :	electric field strength from each emitter	(V/m)	index i
e_{li} :	electric field strength **l**imit from each emitter	(V/m)	index i

Emissions from same site: multiple-antenna installation; **different frequencies**

- ICNIRP 1998 & ICNIRP 2020 limits are **RF dependent**; the equivalent cumulative safety-distance d_{eq}

$$d_{eq} = \sqrt{\sum_i d_i^{\,2}} \qquad d_i = \sqrt{\frac{eirp_{\mathrm{i}}}{4\pi s_i}}$$

- *eirp* is weighted by the inverse of its power density limit s_{li}

$$d_{eq} = \sqrt{\sum_i d_i^{\,2}} = \sqrt{\sum_i \frac{eirp_i}{4\pi s_{li}}} = \sqrt{\frac{eirp_1}{4\pi s_{l1}} + \frac{eirp_2}{4\pi s_{l2}} + \ldots + \frac{eirp_{\mathrm{n}}}{4\pi s_{\mathrm{ln}}}}$$

- check the limit compliance at each frequency band relative to the threshold s_{l} (or e_{l}); total exposure quotient (or cumulative exposure ratio) based on total cumulative weighted PD s_t

$$s_t = \sum_{i=1}^{n} \frac{s_i}{s_{li}} = \frac{s_1}{s_{l1}} + \frac{s_2}{s_{l2}} + \ldots + \frac{s_n}{s_{\mathrm{ln}}} \leq 1$$

- total cumulative weighted field strength exposure ration w_{t}

See table in next slide

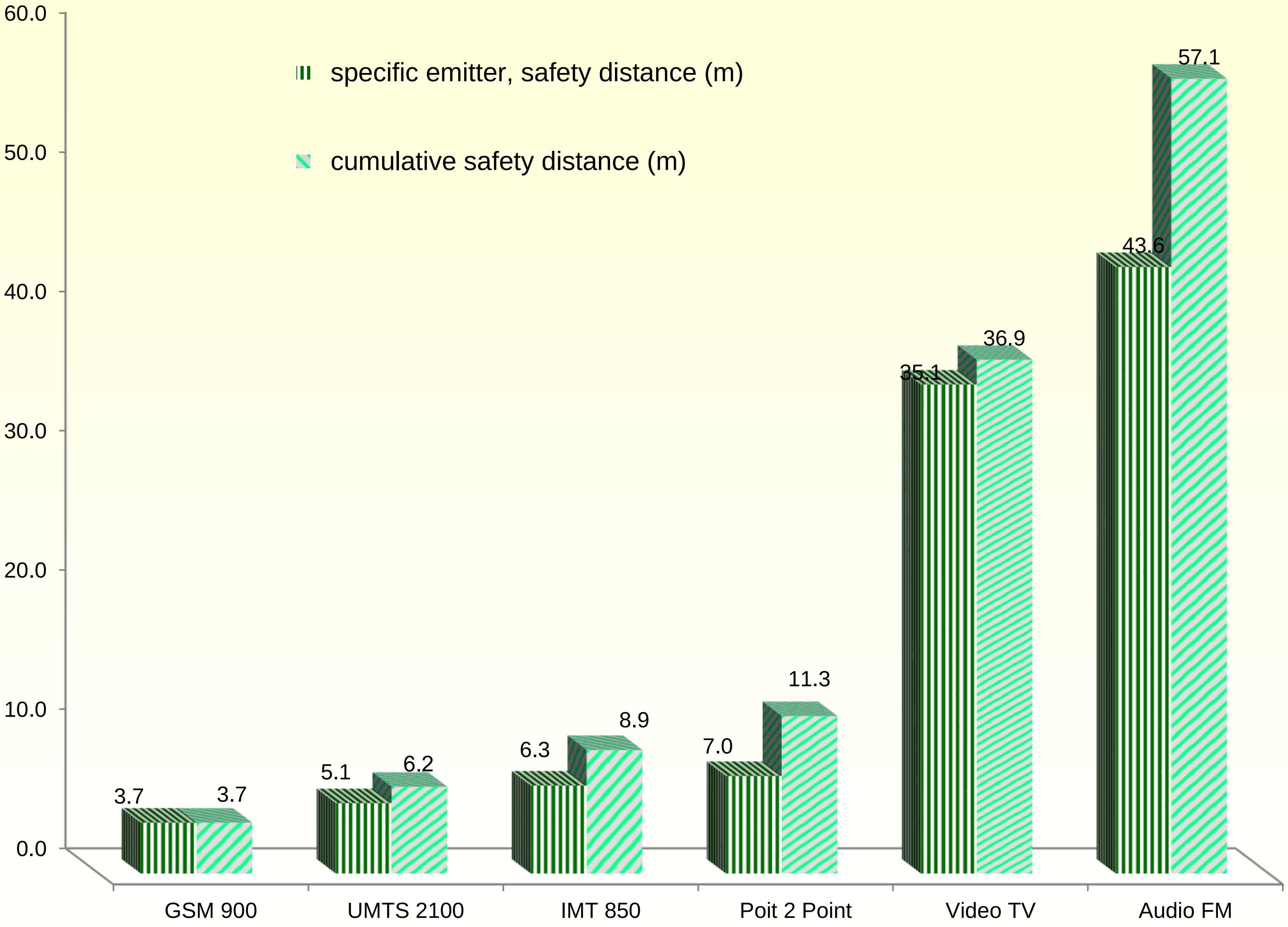
$$\boxed{w_t = \sum_i \left(\frac{e_i}{e_{li}}\right)^2 \leq 1}$$

Worst-case horizontal safety-distances & cumulative exposure; co-located site

Transmission System	GSM 900	UMTS 2100	IMT 850	point-to-point	Video TV	Audio FM
Frequency (MHz)	891	2100	800	514	514	100
ICNIRP limit, power density (W/m2)	4.75	10.00	4.00	2.57	2.57	2.00
Antenna Gain (dBi)	16	18	18	23	17	10
Antenna elevation model or real pattern	742 265	TBXLHA	80010302 _0824	ITU-R F.1336	ITU-R F.699	ITU-R F.699
Ant. Altitude above ground level (m)	32	45	15	25	60	60
Cable Loss (dB)	0	1	1	1	1	1
Power (Watt)	20	64	40	10	1,000	6,000
EIRP (Watt)	800	3,210	2,000	1,580	39,810	47,660
Specific safety distance (m)	3.7	5.1	6.3	7.0	35.1	43.6
Cumulative safety distance (m)	3.7	6.3	8.9	11.3	36.9	57.1
ICNIRP limit, field strength (V/m)	41.30	61.00	38.89	31.17	31.17	28.00
Specific field strength at 50m, ICNIRP ratio	0.08	0.10	0.13	0.14	0.70	0.85
Cumulative field strength ratio	0.08	0.13	0.18	0.23	0.74	1.13

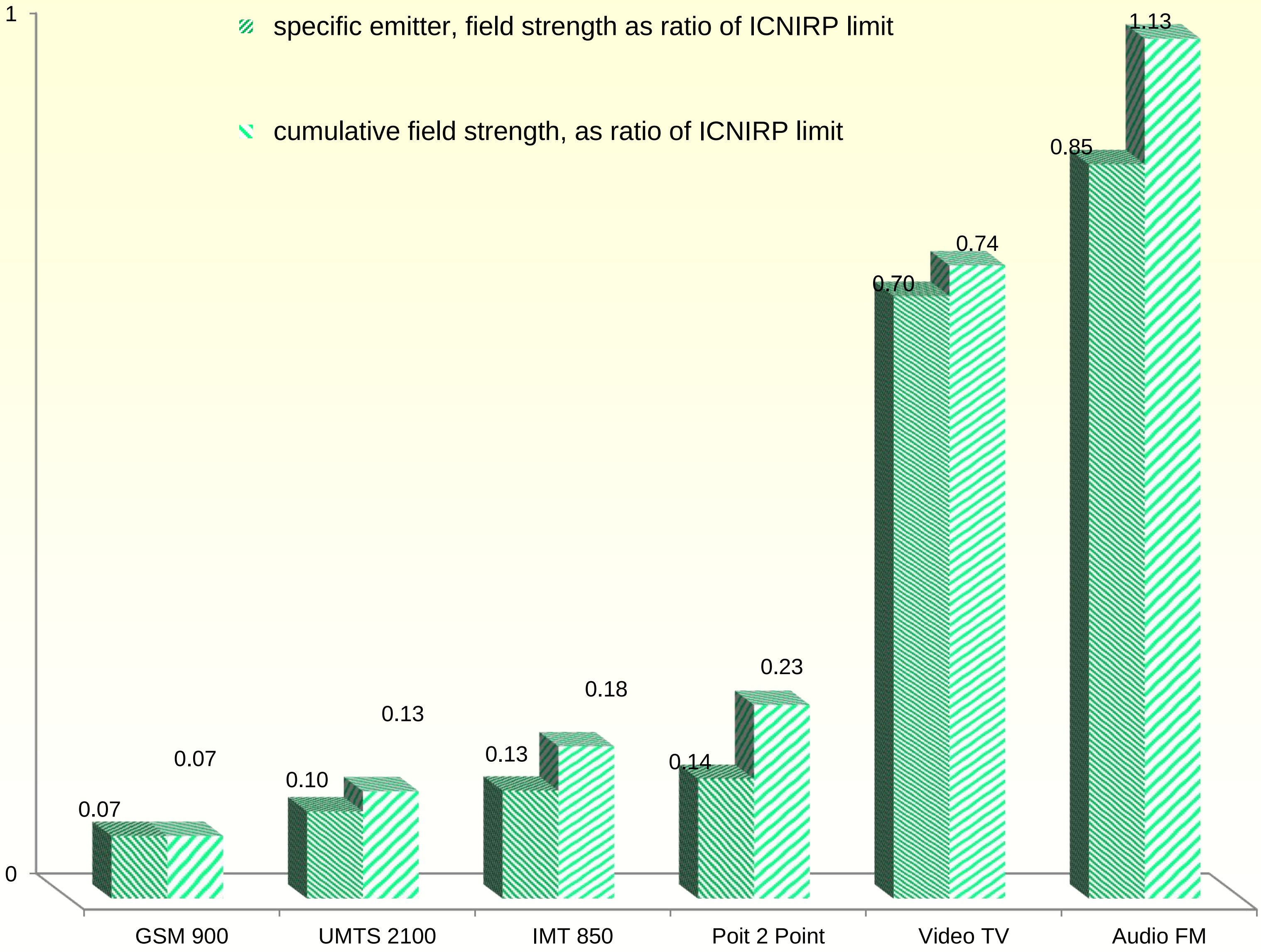
calculated by author

Cumulative horizontal safety-distance, co-located site; y axis (m)



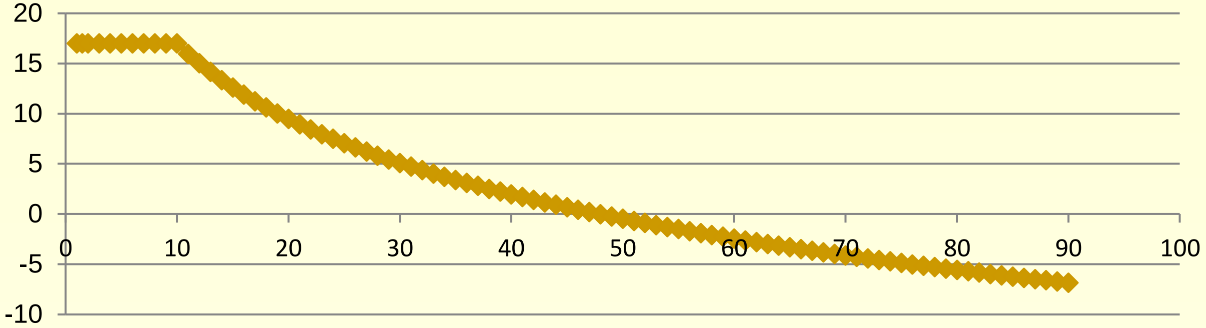
calculated by author

Cumulative field strength exposure ratio , co-located site; point of investigation at 50 meter

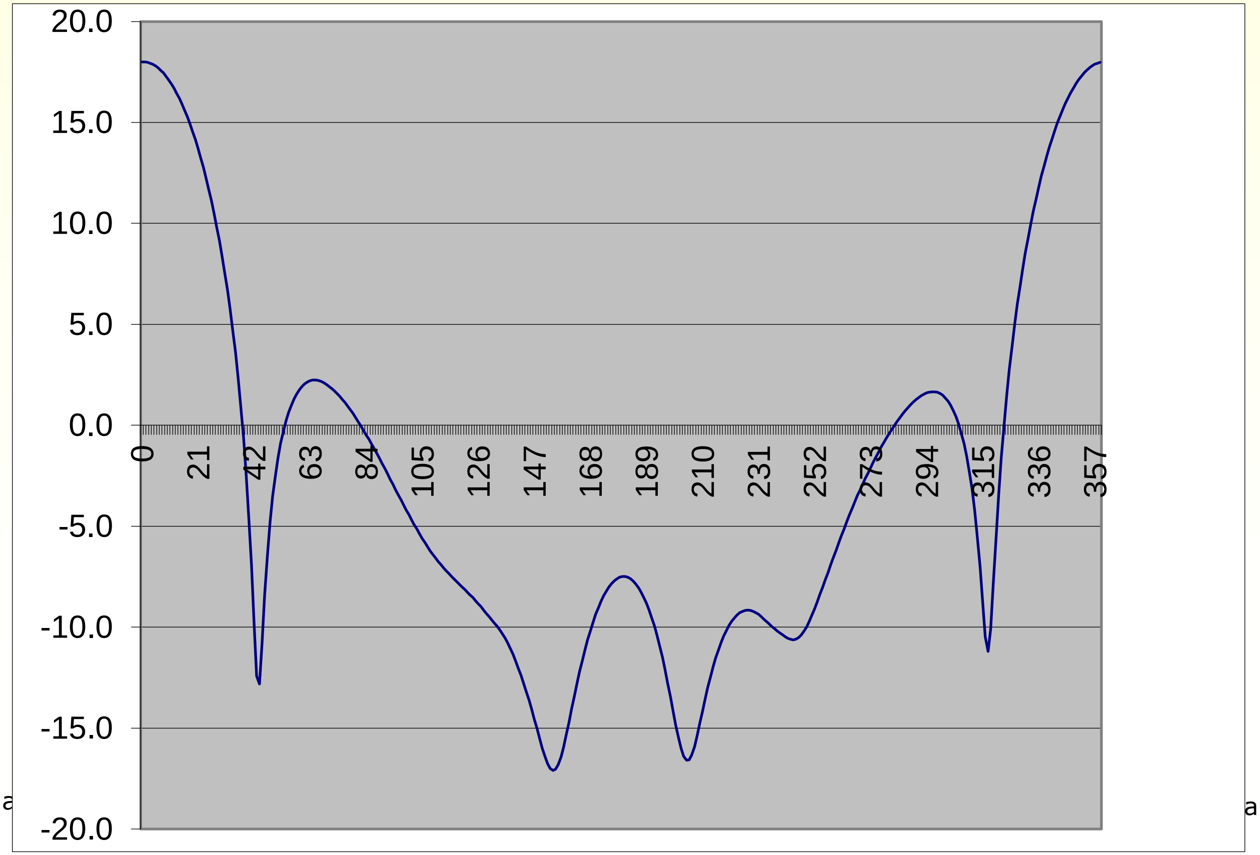


calculated by author

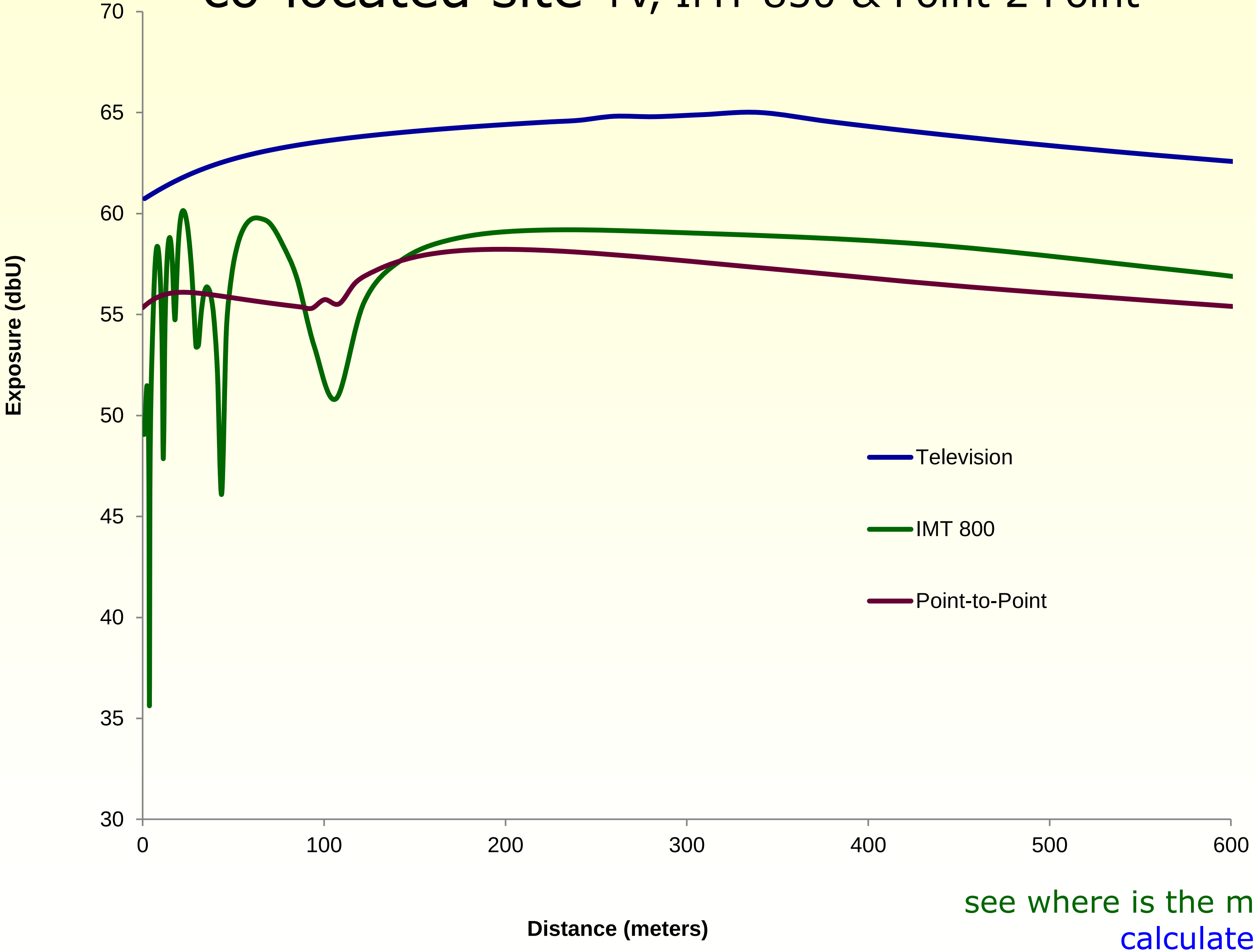
Vertical pattern of TV antenna 17 dBi calculated by ITU-R Rec. F.699



Vertical pattern of 80010302_0824_X_CO_M45_00T; Anatel

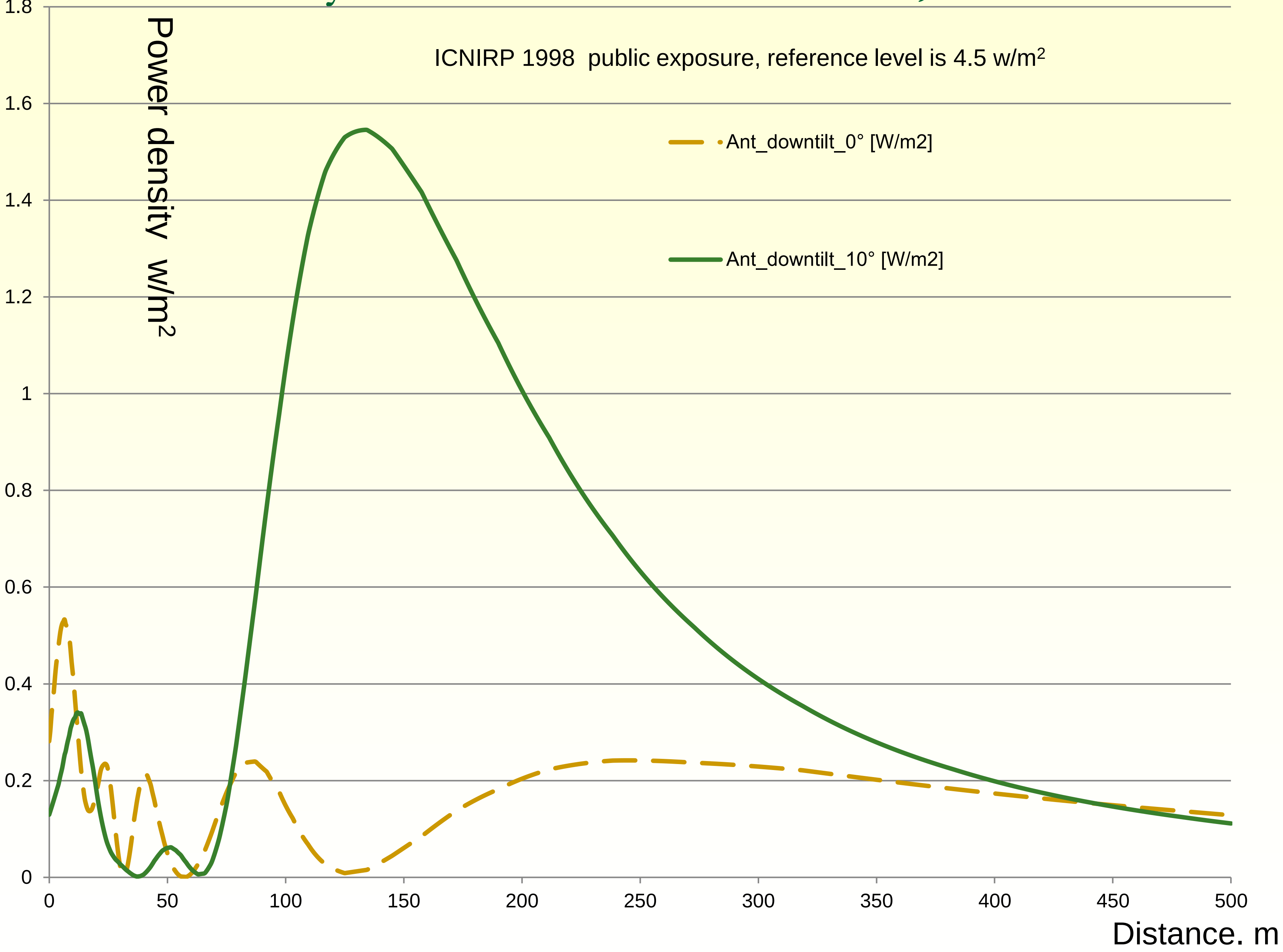


Field Strength (dBμV/m) vs. distance (m), co-located site TV, IMT 850 & Point 2 Point

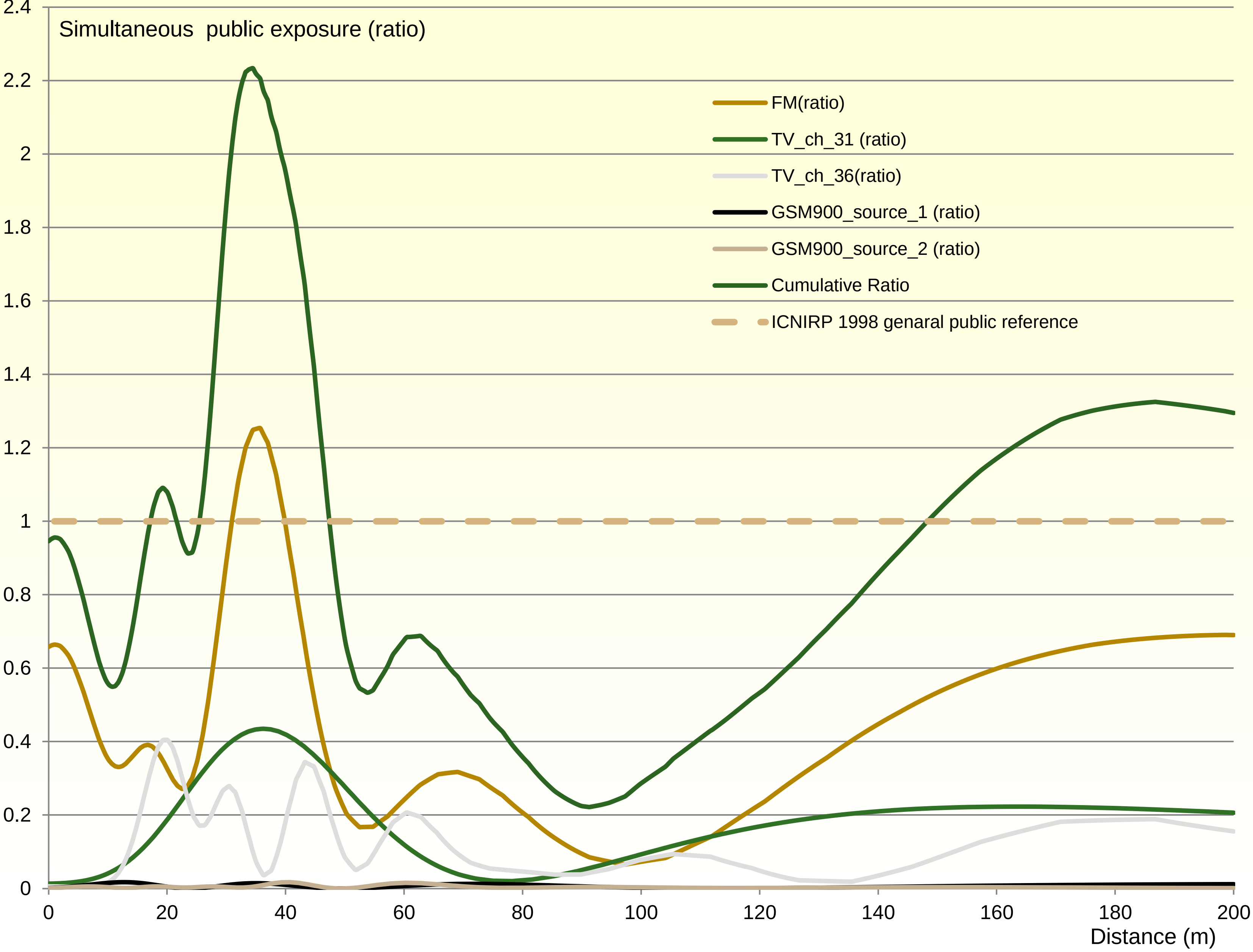


see where is the max exposure
calculated by author

Power density vs. horizontal distance, for 2 down-tilts

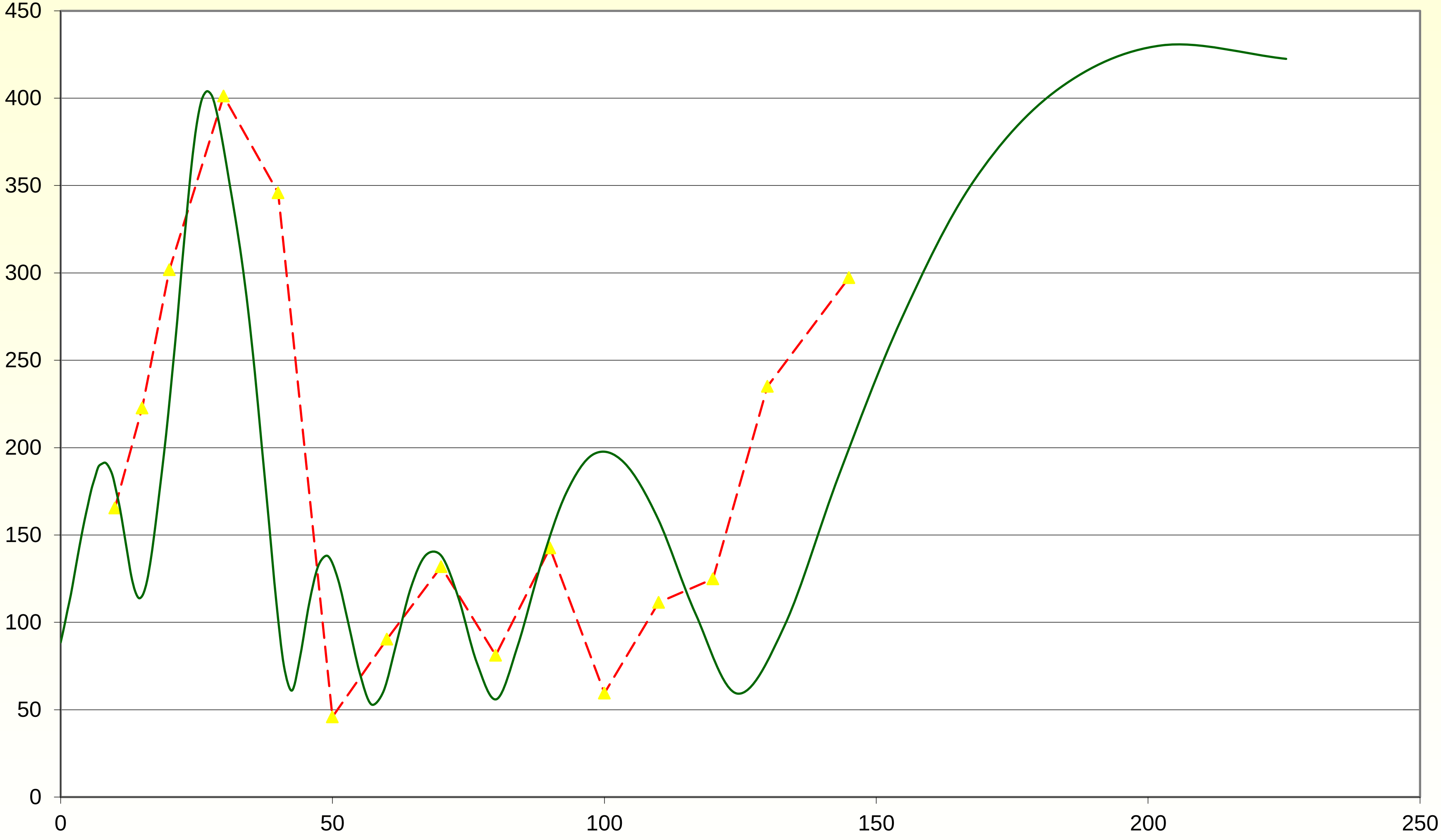


Coefficient W_t vs. distance for co-located site with FM, TV & GSM 900



Field Strength (mV/m) vs. distance (m)

RF = 1875.8 MHz; red- measured, green- calculated



Measured and calculated by ANATEL 2012, Eng . Agostinho Linhares de Souza Filho

RF Hazards limits & their impact on network planning

Excessive exposure limits affect network planning

- Co-location and MIMO increase the safety distance and restrict mast construction near buildings
- Countries (e.g. Switzerland) reduce by 100 (and Salzburg by 9,000) the power density level and restrict the cellular BTS planning and location
- Lower RF exposure limits enforce to decrease the EIRP (in order to reduce the power density and field strength near the station) or to extend the distance of the mast from the public
- Handling low exposure thresholds by additional cellular antennas or RF Spectrum

Mitigation techniques to decrease the radiation level (1)

1. Don’t use terrestrial TV, as the Tx & Rx are fixed, and cable TV and satellites provide TV coverage
2. Maximize RF to operators in order to decrease number of sites
3. Maximize sharing, including active frequencies sharing among cellular operators
4. Close the WI-FI access point when not in use

Mitigation techniques to decrease the radiation level (2)

- **Restrict access** to areas where the exposure limits are exceeded. Physical barriers, lockout procedures and adequate signs are essential; workers can use protective clothing (ITU-T 2004 K.52 p.19)
- **Increase the antenna height**. The distances to all points of investigation are increased and the radiation level is reduced. Moreover, additional attenuation to the radiation is achieved due to the increase of elevation angle and decrease of transmitting antenna sidelobe (ITU-T 2007 K.70 p.22)
- **Increase the antenna gain** (mainly by reducing the elevation beam width), and consequently decrease the radiation in the direction accessible to people. The vertical beam width may be used to reduce the radiation level in close proximity to the antenna. Moreover, the same value of the EIRP can be achieved by a low power transmitter feeding high gain antenna or by high power transmitter feeding low gain antenna. As far as the protection against radiation is concerned, a much better choice is to use the low power transmitter feeding the high gain antenna. (ITU-T 2007 K.70 p.22)
- **Minimize exposure to the min. needed** to maintain the quality of the service, as quality criterion. Decrease the Tx power & consequently decrease linearly the power density in all the observation points. As it reduces the coverage area, it is used only if other methods cannot be applied (2007 K.70 p.22)

Low exposure thresholds (?) by additional cellular antennas or RF Spectrum

Simplistic equations; see Mazar Wiley book 2016 section 9.6.3

For a given network (technology, number of sites, RF spectrum, quality of service), better coverage is achieved by transmitting at higher effective power (for both downlink and uplink channels), installing base stations at higher altitude above ground level (less signal attenuation) and using lower radio frequency.

Max. channel capacity for each communications link in a given network is derived from Shannon Hartley monumental paper (**Shannon 1948 p.43, theorem 17**), relating capacity (bit/s), RF bandwidth (Hz) and the signal to noise (dimensionless) ratio

$$\boxed{c = b \times log_2 \left(1 + s/n\right)}$$

Moreover, in urban scenario *s/n* is small. LTE RSRQ (Reference Signal Received Quality) quantifies the capacity; UE measures this parameter as reference signal. Values higher than −9dB guarantee the best subscriber experience; the range between −9 and −12dB can be seen as neutral with a slight degradation of Quality of Service. So for *s/n* very small relative to 1:

$$c = b \times log_2 \left(1 + s/n\right) \approx b \times \frac{s/n}{\ln 2} \approx 1.44 \times b \times s/n$$

Therefore, staying with the same *capacity* c- less base-stations (BS) (reduced s) can be compensated by more frequency *band* (b). The capacity is limited by power *s* & noise density n_o.

Cellular capacity is limited by power & noise; **adding RF to base stations decreases the number of BSs.** More RF for specific site doesn't necessarily increase EMF around BS. Around active RF shared BSs the EMF increases! This file doesn't analyse the total EMF derived from active sharing, as it depends on technologies and based on the cellular planning.

ITU workshop on modern policies, guidelines, regulations and assessments of human exposure to RF-EMF

ITU, Geneva 10 Oct. 18

See workshop presentations at
https://www.itu.int/en/ITU-D/Study-Groups/2018-2021/Pages/meetings/session-Q7-2-oct18.aspx

ITU-T Recommendations on EMF assessment

ITU-T SG5 (Environment, climate change and circular economy) has been particularly active in developing recommendations for the protection from and measurement/computation of RF fields. Enclosed the EMF ITU-T Recommendations (Standards). All of them include "related supplements":

1. K.52: Guidance on complying with limits for human exposure to electromagnetic fields
2. K.61: Guidance on measurement and numerical prediction of EMF for compliance with human exposure limits for telecommunication installations
3. K.70: Mitigation techniques to limit human exposure to EMFs in the vicinity of radio stations
4. K.83: Monitoring of electromagnetic field levels
5. K.90: Evaluation techniques and working procedures for compliance with exposure limits of network operator personnel to power-frequency EMF
6. K.91: Guidance for assessment, evaluation and monitoring of human exposure to RF-EMF
7. K.100: Measurement of RF-EMF to determine compliance with human exposure limits when a base station is put into service
8. K.113: Generation of RF-EMF level maps
9. K.121: Guidance on the environmental management for compliance with RF-EMF limits for radiocommunication base stations
10. K.122: Exposure levels in close proximity of radiocommunication antennas

New Supplements ITU-T K on EMF

1. Suppl. 9: 5G technology and human exposure to RF EMF
2. Suppl.10: Analysis of EMF compatibility aspects and definition of requirements for 5G mobile systems
3. K.Suppl.13: RF-EMF exposure levels from mobile and portable devices during different conditions of use
4. K.Suppl.14: Impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment
5. K. Suppl. 16: EMF compliance assessments for 5G wireless networks
6. K. Suppl. 19: EMF strength inside underground railway trains
7. K.70 Appendix I – Software: EMF-estimator

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4. ICNIRP 1998 ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHZ)
5. ICNIRP 2010 ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic fields (1HZ – 100 kHz)
6. ICNIRP 2020 ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)
7. IEC 62232 2017 ‘Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure’
8. IEC 62669 Case studies supporting IEC 62232 - Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure …
9. IEEE Std C95.6- 2002 IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz
10. IEEE Std C95.1-2005 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
11. IEEE C95.1-2019 Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz
12. Inskip et al., 2010 Brain cancer incidence trends in relation to cellular telephone use in the United States; Neuro-Oncology, Oxford University Press, ITU-R HB 2011 ITU Handbook on Spectrum Monitoring, Chapter 5.6
13. ITU-T FGTR, 2014 EMF considerations in smart sustainable cities; Focus Group Technical Report
14. ITU-R SM.2452 2022, Report SM.2452 ‘Electromagnetic field measurements to assess human exposure
15. Mazar H. 2009 An analysis of regulatory frameworks for wireless communications, societal concerns and risk: the case of radio frequency (RF) allocation and licensing
16. Mazar H. 2016 Radio Spectrum Management: Policies, Regulations and Techniques; Chapter 9, 2019 on EMF is public-domain
17. Rowley & Joyner 2012 Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations; *Journal of Exposure Science & Environmental Epidemiology* **volume 22**, pages304–315(2012)
18. Rowley J. 2019 RF-EMF presentation at WRC-19, 8 Nov. 2019
19. Sagar et al. 2017 Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: A systematic literature review Journal of Exposure Science and Environmental Epidemiology

Additional publications of the Author on EMF

- ITU Conferences and workshops on EMF
  1) A Comparison Between European and North American Wireless Regulations, presentation at the 'Technical Symposium at ITU Telecom World 2011' www.itu.int/worl2011; the slides presentation, 27 October 2011
  2) 2016 ITU R-D-T 'Intersectoral activities on human exposure to EMF'; Bangkok, 26 April 2016
  3) 2017 ITU Workshop '5G, EMF & Health'; Warsaw, Poland, 5 December 2017
  4) 2018 ITU workshop 'modern policies, guidelines, regulations and assessments of human exposure to RF-EMF'; Geneva, Switzerland, 10 October 2018 ; see slide
  5) PRIDA Track 1 (T1) On-line English workshop 20thApril–1stMay2020. First_week_slides_v2; see pp. 237–296, EMF presentation 24 April 2020
  6) PRIDA Track 1 (T1) Atelier de renforcement des capacités sur la gestion moderne du spectre 11-22 mai 2020. First_week_slides_v2; see pp. 224–278, EMF présentation 15 mai 2020
  7) ITU mission 26146 October 2020 'Implementing 5G for Good: Does EMF Matter?'
- Papers and Presentations
  1) Updated Chapter 9 on EMF exposure of my Wiley book on Spectrum Management
  2) Human RF Exposure Limits: Reference Levels in Europe, USA, Canada, China, Japan and Korea EMC Europe 2016; Wroclaw, Poland, 9 Sept. 2016
  3) Regulation of RF Human Hazards Lusaka, Zambia; 13 January 2017
  4) EMF Concerns and Perceptions Modiin, Israel; 25 March 2019
  5) EMF, New ICNIRP Guidelines and IEEE C95.1-2019 Standard: Differences and Similarities; Warsaw, Poland; 3 Dec 2019
  6) Module on EMF to the ITU Spectrum Training; April 2020
  7) EMF_HumanHazardsPresentation_MaccabimMazar9June2020.pdf
  8) 2020 IEEE Israel Conference on Electromagnetic Compatibility (EMC), 15 Oct. 2020; Updated Human Exposure Standards IEEE 2019 and ICNIRP 2020, towards 5G applications
  9) Academic_Course_Wireless_Communications_Mazar3_Regulation_EMC_**HumanHazards**_2020.pdf
  10) Policies, guidelines, regulations and assessments of human exposure to radio-frequency electromagnetic fields, ITU-D Study period 2018-2021
  11) ITU's Perspective on Compliance with the new 2020 RF Guidelines, ICNIRP Mini-Symposium 19 June 2022, 14.00-18.00 JST Nagoya, Japan and Online. Streaming of presentation, see minutes between 28:40 and 39:23

Abbreviations and Acronyms

3D	Three Dimensional
3G	3rd Generation mobile technology
4G	4th Generation mobile technology
5G	5th Generation mobile
BR	Basic Restriction
BS	Base Station
CENELEC	European Committee for Electrotechnical Standardization
DRL	Dosimetry Reference Limit
DVB-T	Digital Video Broadcasting - Terrestrial
EHS	Electromagnetic HyperSensitivity
EIRP	Equivalent Isotropic Radiated Power
EMC	ElectroMagnetic Compatibility
EMF	ElectroMagnetic Field
EMR	ElectroMagnetic Radiation
ERL	Exposure Reference Level
ERP	Effective Radiated Power
FCC	Federal Communications Commission
Gbit/s	Giga bits per second
GPS	Global Positioning System
HF	High Frequency
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICT	Information and Communication Technology
ICES (IEEE/ICES)	International Committee on Electromagnetic Safety
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ITU	International Telecommunication Union
LAN	Local Area Network
LTE	Long-Term Evolution
M2M	Machine-to-Machine
Mbit/s	Megabits per second
MPE	Maximum Permissible Exposure
NCD	Non-Communicable Diseases
NIR	Non-ionizing Radiation (NIR)
PFD	Power Flux Density
RAN	Radio Access Network
RF	Radio Frequency
SASB	Standards Association Standards Board (IEEE-SASB)
SAR	Specific Absorption Rate
SI	International System of Units
SRD	Short Range Devices
TTT	Transport and Traffic Telematics
UHF	Ultra High Frequency
VHF	Very High Frequency
WAN	Wide Area Network
WHO	World Health Organization
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
xDSL	x-type Digital Subscriber Line

First & second files of the course are found at

- Academic_Course_Advanced_Wireless_Communications_Mazar1_Engineering_2020.pdf
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Dr. Haim Mazar (Madjar) h.mazar@atdi-group.com

More info in my Wiley book 2016 'Radio Spectrum Management: Policies, Regulations, Standards and Techniques' :
policies, regulations, standards and techniques'

Additional links are found at

- http://mazar.atwebpages.com/Downloads

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