Wireless Telecommunications

Enrichment Material

1. The RF Spectrum
2. Propagation
3. Antenna Basics
4. Transmitters and Receivers
5. Broadcasting: Video, Audio and Data
6. Fixed and Land Mobile Services
7. Radar Systems
8. RF Regulation
9. EMC and RFI
10. RF Human Hazards

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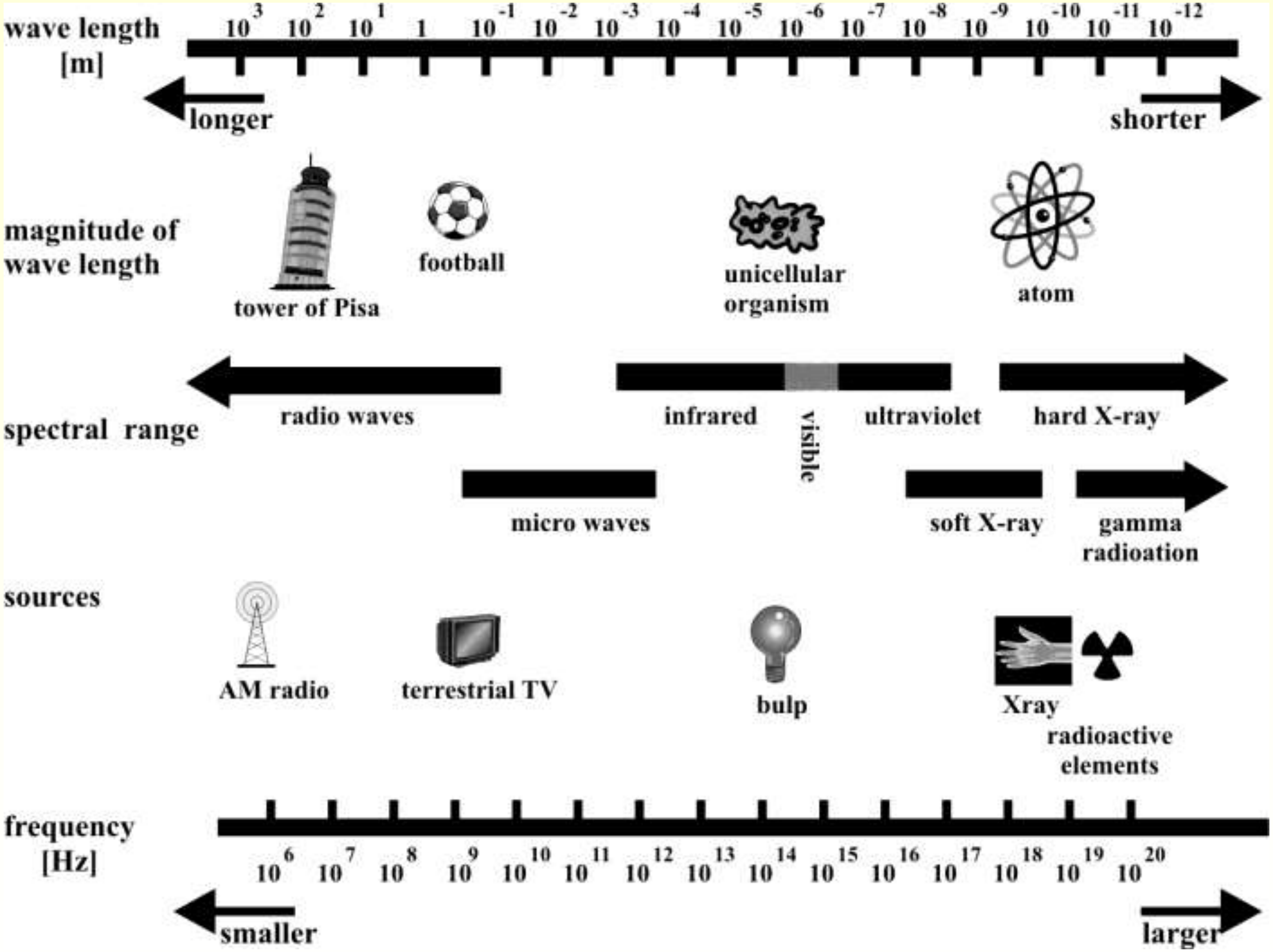
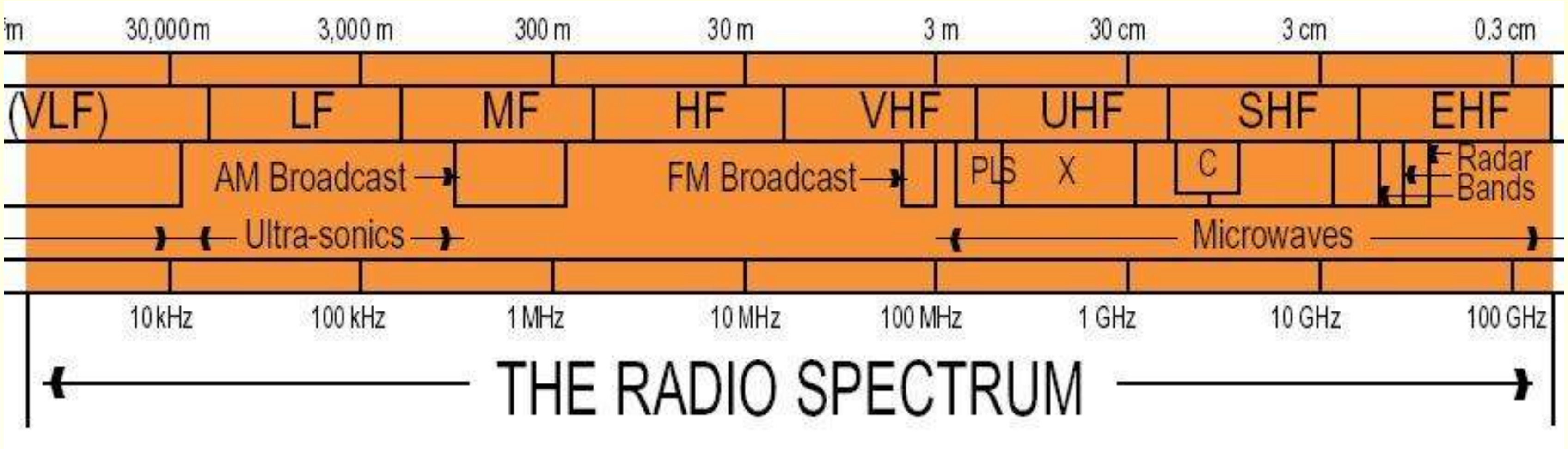
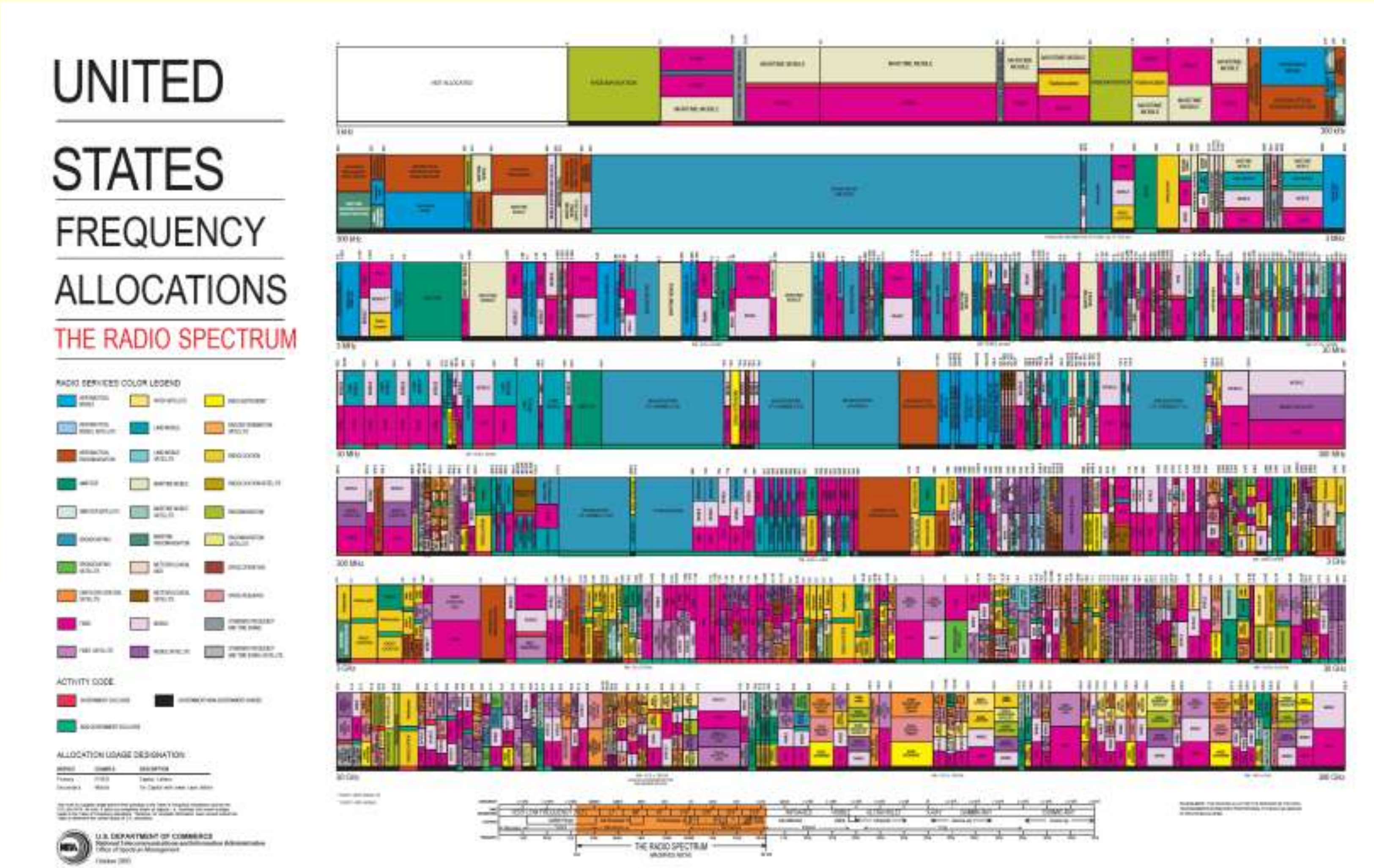
The RF Spectrum



The RF Spectrum: including ITU symbols

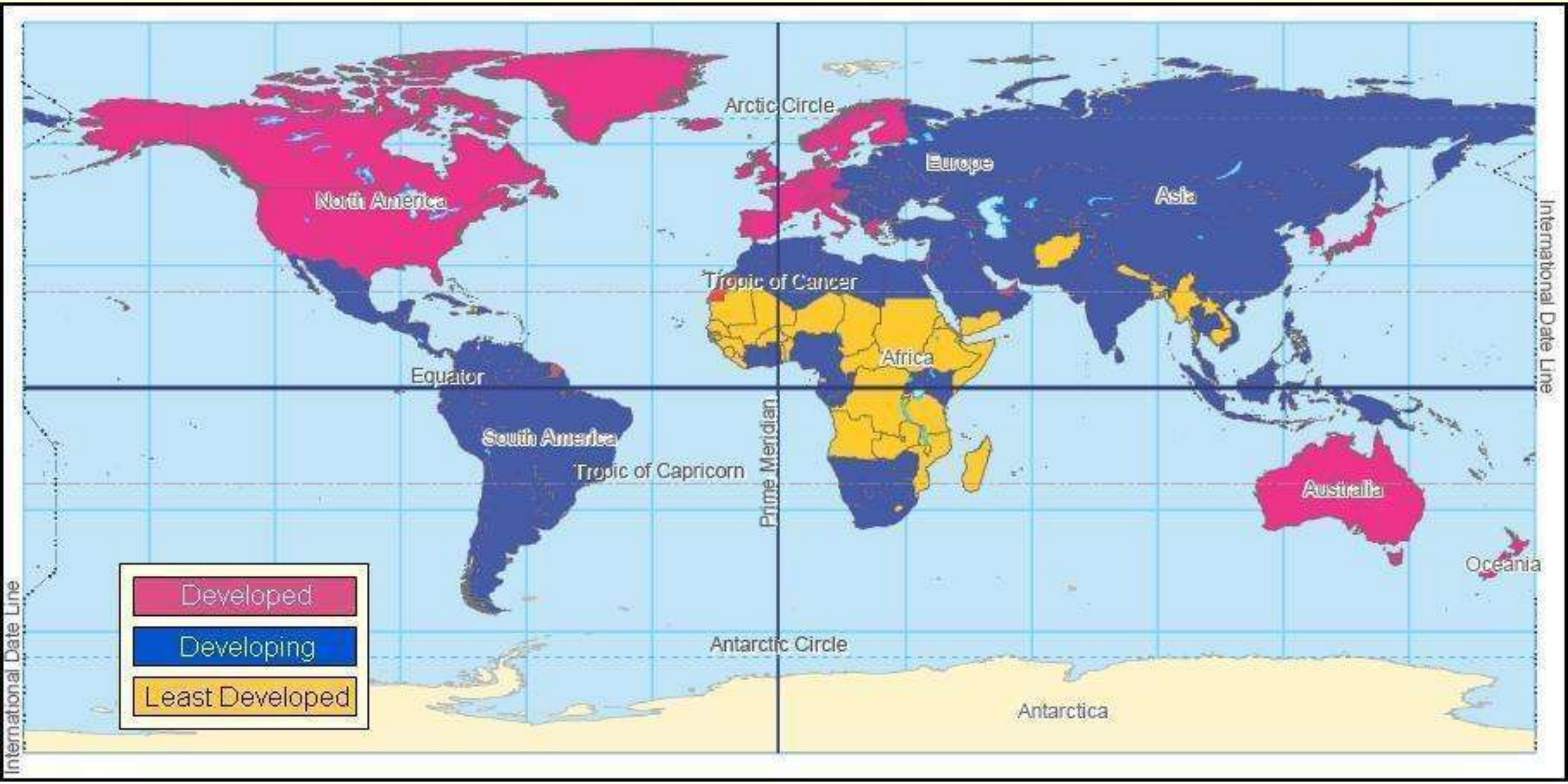


US RF Allocations, 2003

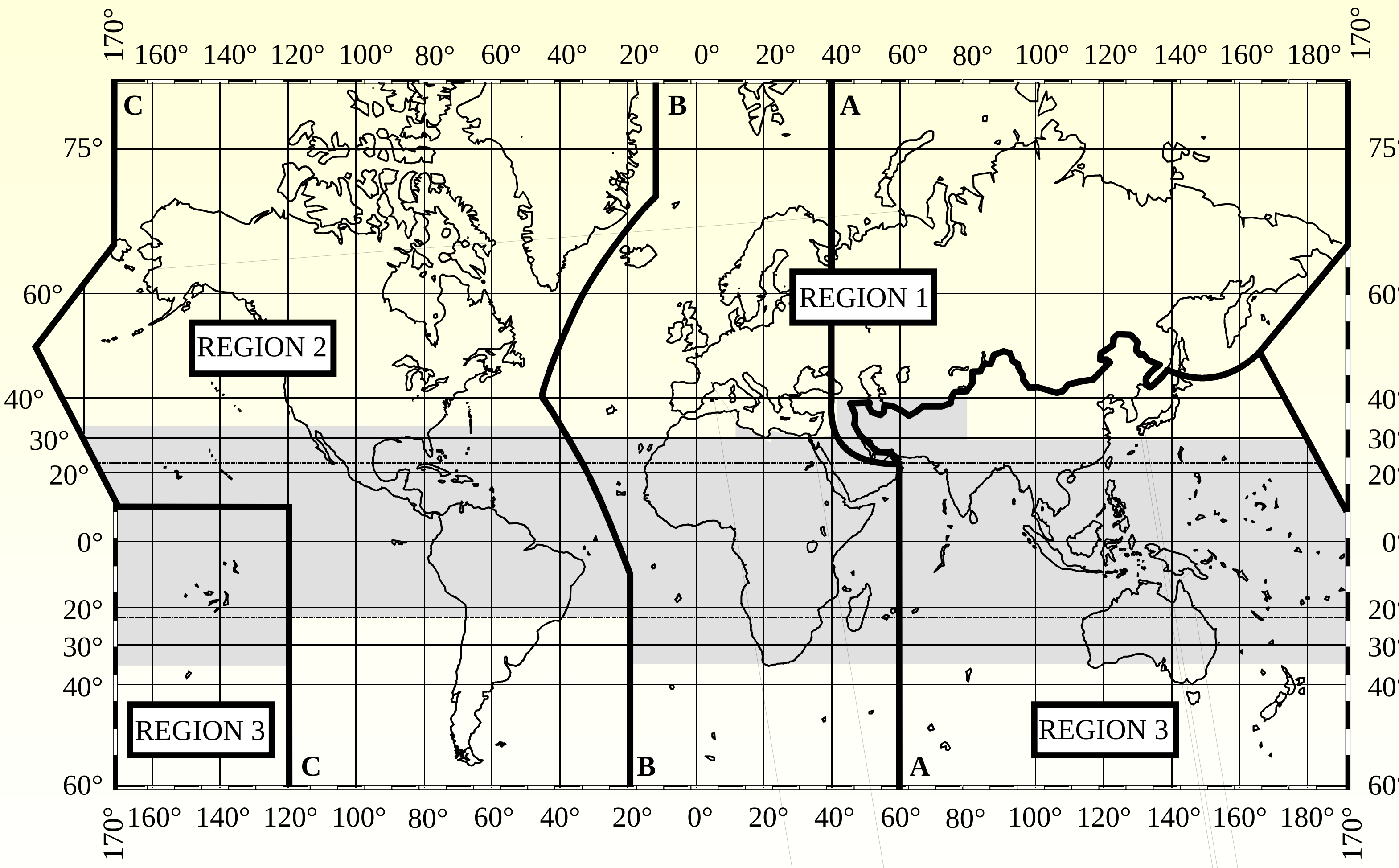



Structure
ITU
Plenipotentiary Conferences
Council
World Conferences on International Telecommunications
World/Regional Radiocommunication Conferences
Radiocommunication Assemblies
Radio Regulations Board
Advisory Group
Study Groups
World Telecommunication Standardization Assemblies
Advisory Group
Study Groups
World/Regional Telecommunication Development Conferences
Advisory Group
Study Groups
General Secretariat
Secretary-General
Deputy Secretary-General
Director
Director
Director
Radiocommunication Bureau
Telecommunication Standardization Bureau
Telecommunication Development Bureau
Radiocommunication Sector
Telecommunication Standardization Sector
Telecommunication Development Sector

Countries: Developed, Developing and LDCs



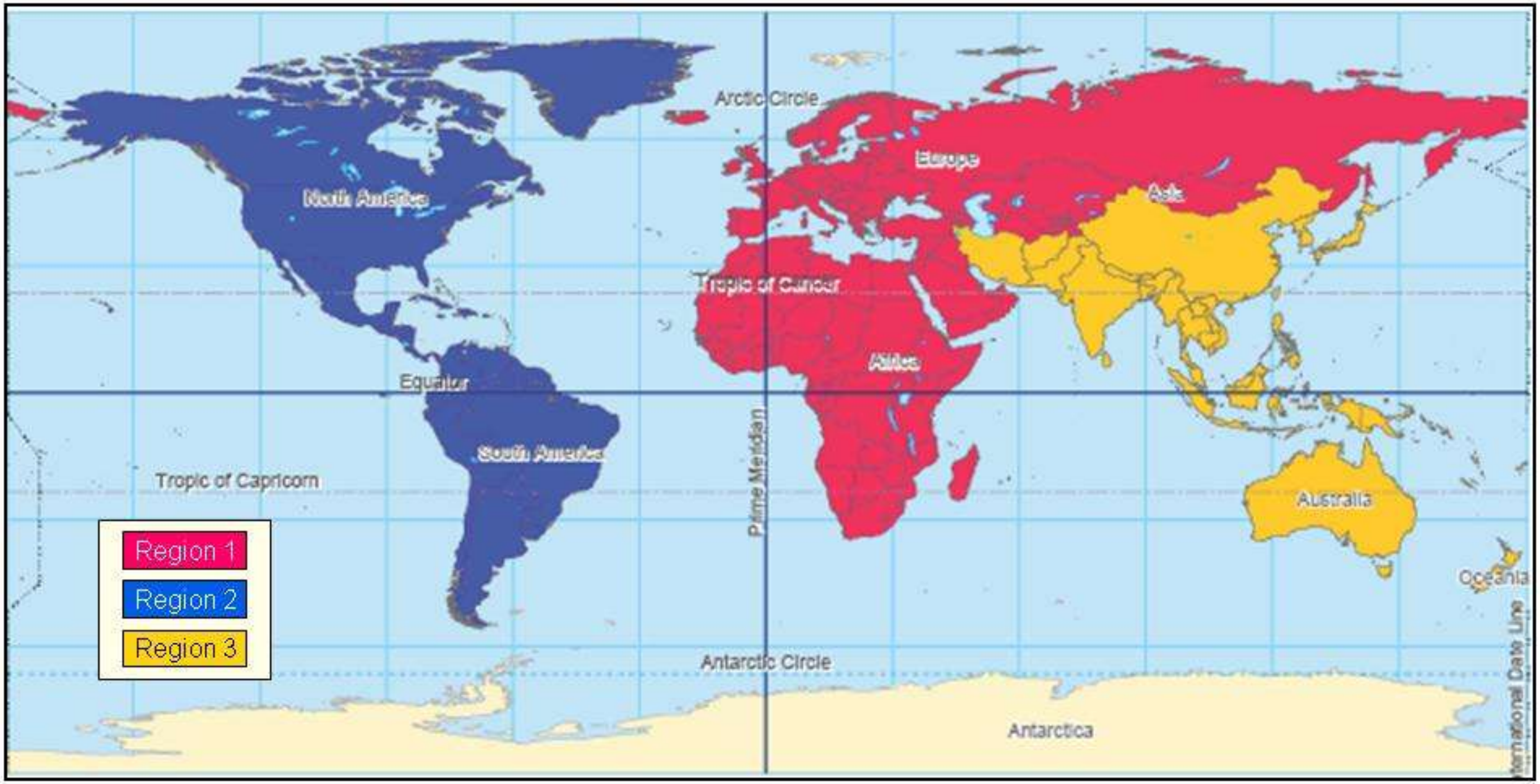
Three ITU-R Regions



The shaded part represents the Tropical Zones as defined in Nos. **S5.16** to **S5.20** and **S5.21.**

S5-01

ITU Regions



Arctic Circle
Europe
Asia
North America
Tropic of Cancer
Africa
Equator
South America
Prime Meridian
Tropic of Capricorn
Australia
Oceania
Region 1
Region 2
Region 3
Antarctic Circle
Antarctica
International Date Line

Allocation, Allotment and Assignment

RR 5.1

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

Wireless Telecommunications

Enrichment Material

Propagation

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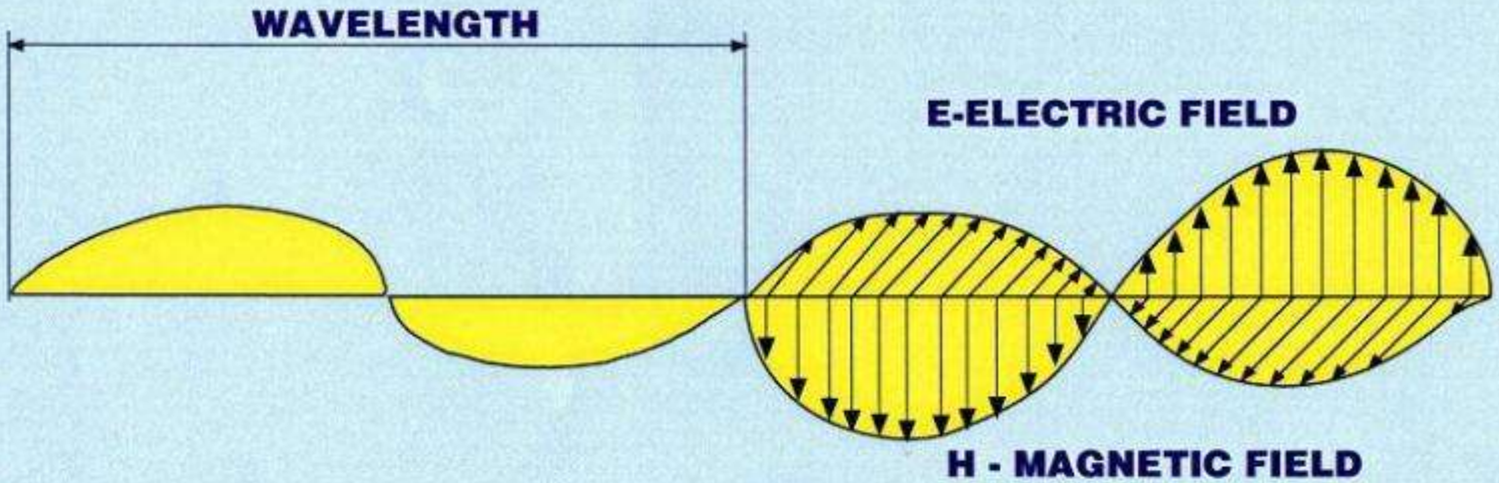
Propagation Theory

EM WAVE PROPERTIES



LIGHT VELOCITY = 300,000Km/ sec

ELECTRIC FIELD UNITS - V/m

MAGNETIC FIELD UNITS - A/m

POINTING VECTOR UNITS - W/ m^2 [P = E·H]

$$f = (MHz) = \frac{300}{\lambda (m)}$$

Elements Influencing Propagation Loss (ITU-R P.1812)

- *line-of-sight*
- *diffraction* (embracing smooth-Earth, irregular terrain and sub-path cases)
- *tropospheric scatter*
- *anomalous propagation* (ducting and layer reflection/refraction)
- *height-gain variation in clutter*
- *location variability*
- *building entry losses*
- *Earth Radius* =6,371 *k*m

Free Space loss, power

PL=PropagationLoss; P_t=T_xPower, P_r=R_xPower; d=distance, λ=wavelength, A_e =Effective ant. area

Assuming g_r & g_t = 1, at d, power density = $\dfrac{P_t}{4\pi d^2}$

$$A_e = \frac{g_r \lambda^2}{4\pi}$$

$$PL = \frac{P_t}{P_r} = \frac{P_t}{\left[(P_t \div 4\pi d^2) \bullet \frac{\lambda^2}{4\pi}\right]} = \left(\frac{4\pi d}{\lambda}\right)^2$$

$$PL(dB) = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$PL(dB) = 20\log(d_{kM} / \lambda_m) + 82 = 82 + 20\log d_{kM} - 20\log \lambda_m$$

$$PL(dB) = 20\log d_{kM} f_{MHz} + 32.44 = 32.44 + 20\log d_{kM} + 20\log f_{MHz}$$

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Free Space loss, Field Strength

P_t=T_xPower, g= antenna gain d=distance, P_t xg- EiRP E=field strength H=magnetic field

$$PoyntingVector = \frac{P_t g}{4\pi d^2} = (\vec{E} x \vec{H}) = \frac{1}{\mu_0}(\vec{E} \times \vec{B}) = \frac{E_O^2}{Zo}$$

The impedance, Z_0 in ohms, 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.

$$c_0 \equiv \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \quad Z_0 \equiv \mu_0 c_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{1}{\varepsilon_0 c_0} = 120\pi \approx 377$$

$$E_0 = \frac{\sqrt{30 \cdot P_t \cdot g}}{d} = \frac{\sqrt{30 \cdot EiRP}}{d}$$

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Free Space loss, Field Strength

Based on ITU-R P. 525 Field strength for a given isotropically transmitted power:

$$E = Pt - 20 \log d + 74.8 \quad (7)$$

Isotropically received power for a given field strength:

$$Pr = E - 20 \log f - 167.2 \quad (8)$$

Free-space basic transmission loss for a given isotropically transmitted power and field strength:

$$Lbf = Pt - E + 20 \log f + 167.2 \quad (9)$$

Power flux-density for a given field strength:

$$S = E - 145.8 \quad (10)$$

Pt : isotropically transmitted power (dB(W))
Pr : isotropically received power (dB(W))
E : electric field strength (dB(μV/m))
f : frequency (GHz)
d : radio path length (km)
Lbf :free-space basic transmission loss (dB)
S : power flux-density (dB(W/m^2)).

The free-space field strength relative to a half-wave dipole for 1 kW e.r.p. is given by:

$E = 106.9 – 20 \log d$
E: free-space field strength (dB(μV/m))
d: distance (km) between transmitting and receiving antenna.

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Voltage or current ratio	Power ratio	Decibels	Voltage or current ratio	Power ratio
1.00	1·000	0	1.000	1.000
0·989	0.977	0.1	1.012	1.022
0.977	0.955	0.2	1.023	1.047
0.966	0.933	0.3	1.035	1.072
0.955	0.912	0.4	1.047	1.096
0.944	0.891	0.5	1.059	1.122
0.933	0.871	0.6	1.072	1.148
0.912	0.832	0.8	1.096	1.202
0·891	0.794	1.0	1.122	1.259
0.841	0.708	1.5	1·189	1.413
0.794	0.631	2.0	1.259	1.585
0.750	0.562	2.5	1.334	1.778
0.708	0.501	3.0	1.413	1.995
0.668	0.447	3.5	1.496	2.239
0.631	0.398	4.0	1.585	2.512
0.596	0.355	4.5	1.679	2.818
0.562	0.316	5.0	1.778	3.162
0.501	0.251	6.0	1.995	3.981
0.447	0.200	7.0	2.239	5.012
0.398	0.159	8.0	2.512	6.310
0.355	0.126	9.0	2.818	7.943
0.316	0.100	10	3.162	10.00
0.282	0.0794	11	3.55	12.6
0.251	0.0631	12	3.98	15.9
0.224	0.0501	13	4.47	20.0
0.200	0.0398	14	5.01	25.1
0.178	0.316	15	5.62	31.6
0.159	0.0251	16	6.31	39.8
0.126	0.0159	18	7.94	63.1
0.100	0.0100	20	10.00	100.0
3.16×10^{-2}	10^{-3}	30	3.16×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.16×10^{-3}	10^{-5}	50	3.16×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.16×10^{-4}	10^{-7}	70	3.16×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.16×10^{-5}	10^{-9}	90	3.16×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}
3.16×10^{-6}	10^{-11}	110	3.16×10^{5}	10^{11}
10^{-6}	10^{-12}	120	10^{6}	10^{12}

Correspondence e.i.r.p., e.r.p., field strength, *E*, and pfd

e.i.r.p. (dBm)	e.i.r.p. (nW)	e.i.r.p. (dB(pW))	e.i.r.p. (dBW)	e.r.p. (dBm)	*E* field free space (dB(μV/m)) at 10 m	E_{max} OATS (dB(μV/m)) at 10 m	pfd free space (dB(W/m^2)) at 10 m	pfd maximum OATS (dB(W/m^2)) at 10 m
–90	0.001	0	–120	–92.15	–5.2	–1.2	–151.0	–147.0
–80	0.01	10	–110	–82.15	4.8	8.8	–141.0	–137.0
–70	0.1	20	–100	–72.15	14.8	18.8	–131.0	–127.0
–60	1	30	–90	–62.15	24.8	28.8	–121.0	–117.0
–50	10	40	–80	–52.15	34.8	38.8	–111.0	–107.0
–40	100	50	–70	–42.15	44.8	48.8	–101.0	–97.0
–30	1 000	60	–60	–32.15	54.8	58.8	–91.0	–87.0
–20	10 000	70	–50	–22.15	64.8	68.8	–81.0	–77.0
–10	100 000	80	–40	–12.15	74.8	78.8	–71.0	–67.0
0	1 000 000	90	–30	–2.15	84.8	88.8	–61.0	–57.0

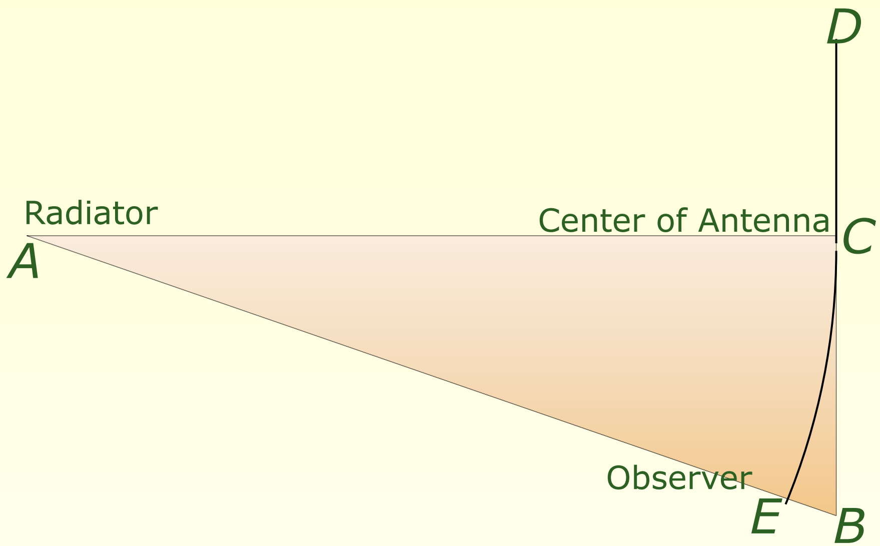
Open Area Test Site (OATS)

Far-Field, Near-Field

- Near-field region:
  - Angular distribution of energy depends on distance from the antenna; Reactive field components dominate (L, C)
  - In the reactive near-field (very close to the antenna), the relationship between the strengths of the E and H fields is often too complex to predict
  - The energy in the radiative near-field is all radiant energy, although its mixture of magnetic and electric components are still different from the far field
- Far-field region:
  - Angular distribution of energy is independent on distance
  - Radiating field component dominates (R)

Far-Field, Near-Field

The Fraunhofer distance is the value of: 2 $\mathbf{D}^2/\lambda$, where **D** is the largest dimension of the radiator (or the cross-sectional diametre of the antenna and λ is the wavelength of the radio wave. Phase variation over the ant. Aperture is less than π/8 radians



AB = Tx/Rx distance

AC = X, limit far/near field

BD = **D**, largest dimension of Ant

BC = **D**/2

AE = *AC*; *EB*= λ/16

λ = wavelength of the radio wave

Phase difference 2∏ is equivalent to λ; phase diff ∏/8 equivalent to λ/16.

$X^2 + (\mathbf{D}/2)^2 = (X + \lambda/16)^2 = X^2 + X\lambda/8 + (\lambda/16)^2$

$(\lambda/16)^2$ is relatively small to $X\lambda/8$ (as $X >> \lambda/32$), so $X^2 + (\mathbf{D}/2)^2 \approx X^2 + X\lambda/8$ and $(D/2)^2 \approx X\lambda/8$, $D^2 \approx X\lambda/2$ and $\mathbf{X \approx 2D^2/\lambda}$ *QED*

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

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

For non directive antenna, far field is beyond 3 λ

Fresnel Zones

- The Fresnel zone is the ellipsoid that stretches between the two antennas; locus of points such that the difference between the direct path $\overline{AB}$ and the indirect path $\overline{ACB}$ is half the wavelength. λ = The wavelength of the transmitted signal F_n is the n^{th} Fresnel zone radius d ($\overline{AB}$)= d_1 ($\overline{PA}$)+ d_2 ($\overline{PB}$), F gets the same unit as λ, d_1 and d_2 (e.g. meter). Units: d_1 , d_2 , λ in metres

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \qquad F_n = F_1\sqrt{n}$$

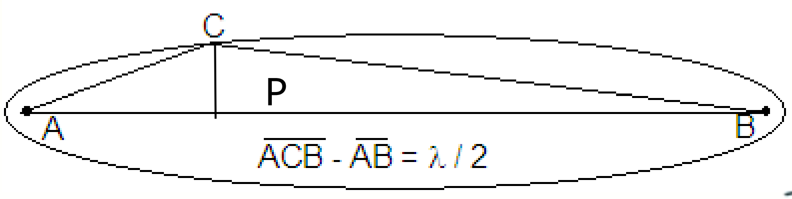
- the max value of F_n , ***b***, equals

$$b = \sqrt{\frac{n\lambda d}{4}}$$

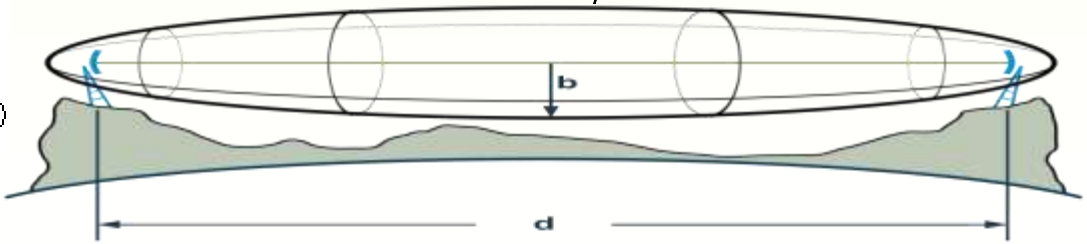
- For *f* : frequency (GHz); *d* , d_1, d_2: path lengths (km) F_1 is the radius of the first Fresnel ellipsoid, in metres F_3 is the radius of the third Fresnel ellipsoid, in metres

$$F_1 = 17.3\sqrt{\frac{d_1\, d_2}{fd}} \qquad F_3 = 30\sqrt{\frac{d_1\, d_2}{fd}}$$

The First Fresnel zone



The Fresnel Ellipsoid



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Effective Radius of the Earth (P. 310)

- ***Effective radius of the Earth: a*** Radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths are along straight lines, the heights and ground distances being the same as for the actual Earth in an atmosphere with a constant vertical gradient of refractivity. *Note* – For an atmosphere having a standard refractivity gradient, the effective radius of the Earth is about **4/3 t**hat of the actual radius, which corresponds to approximately **8 500 km**
- ***Refractive index n*** *Ratio of the speed of radio waves in vacuo to the speed in the medium under consideration*
- ***Refractivity; N*** One million times the amount by which the refractive index *n* in the atmosphere exceeds unity: $N = (n - 1)10^6$
- **Effective Earth-radius factor, k** Ratio of the effective radius of the Earth to the actual Earth radius. Note 1 – This factor k is related to the vertical gradient dn/dh of the refractive index n and to the actual Earth radius a by the equation:

$$\mathrm{k} = \frac{1}{1 + a\dfrac{dn}{dh}}$$

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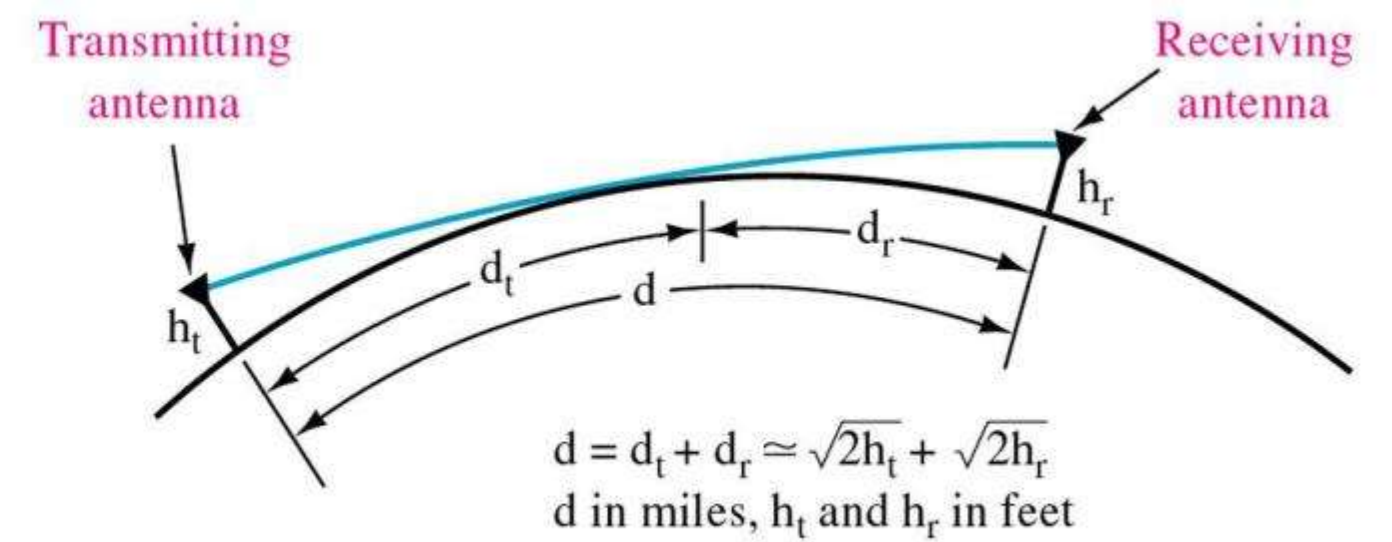
Radio horizon Tx & Rx Antennas



$(a+h_1)^2 = a^2 + 2h_1a + h_1^2 = x^2 + a^2$; $2h_1a + h_1^2 = x^2$

$(a+h_2)^2 = a^2 + 2h_2a + h_2^2 = x^2 + a^2$; $2h_2a + h_2^2 = x^2$

$$x = \sqrt{2h_1a + h_1^{\,2}} + \sqrt{2h_2a + h_2^{\,2}} \approx \sqrt{2h_1a} + \sqrt{2h_2a}$$

$$x = \sqrt{2h_1a} + \sqrt{2h_2a} \quad \text{when } x \ll a$$

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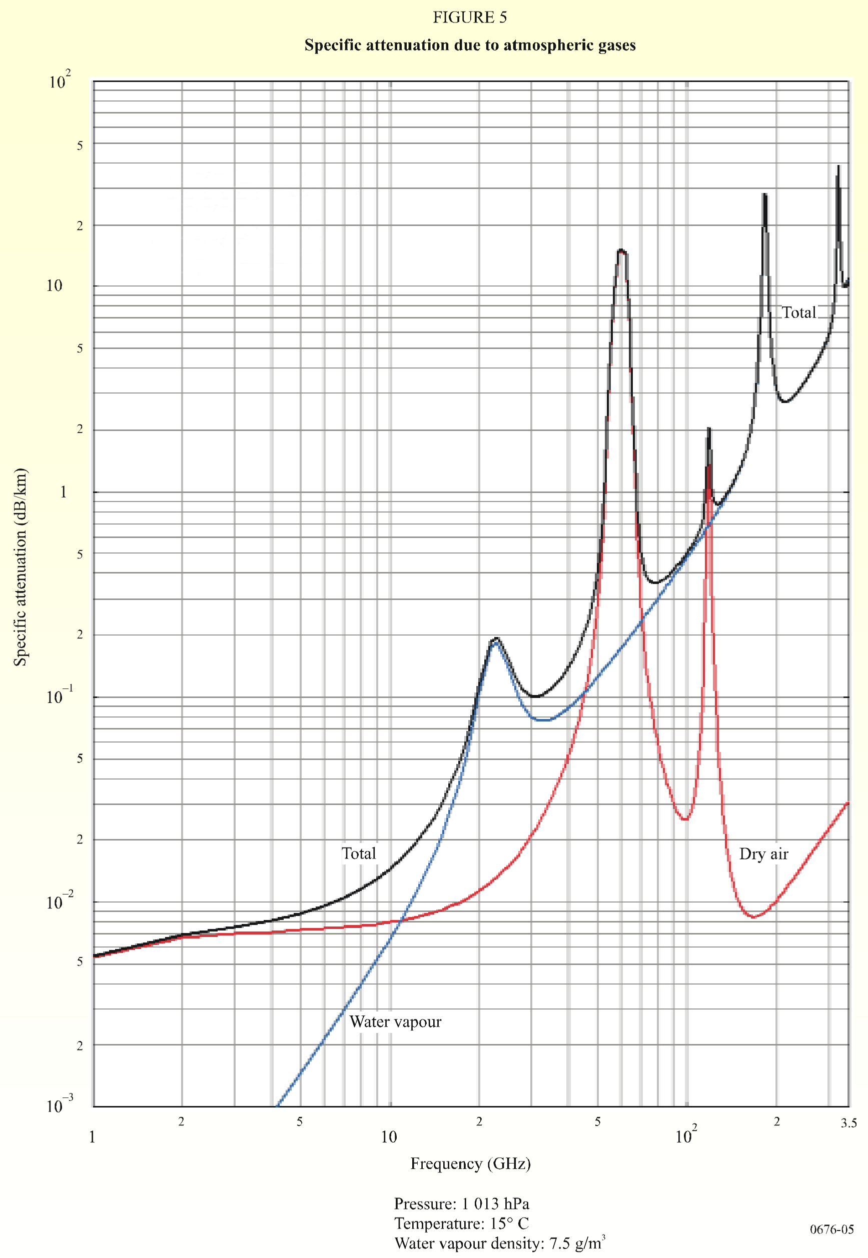
Attenuation due to atmospheric gases; P.676



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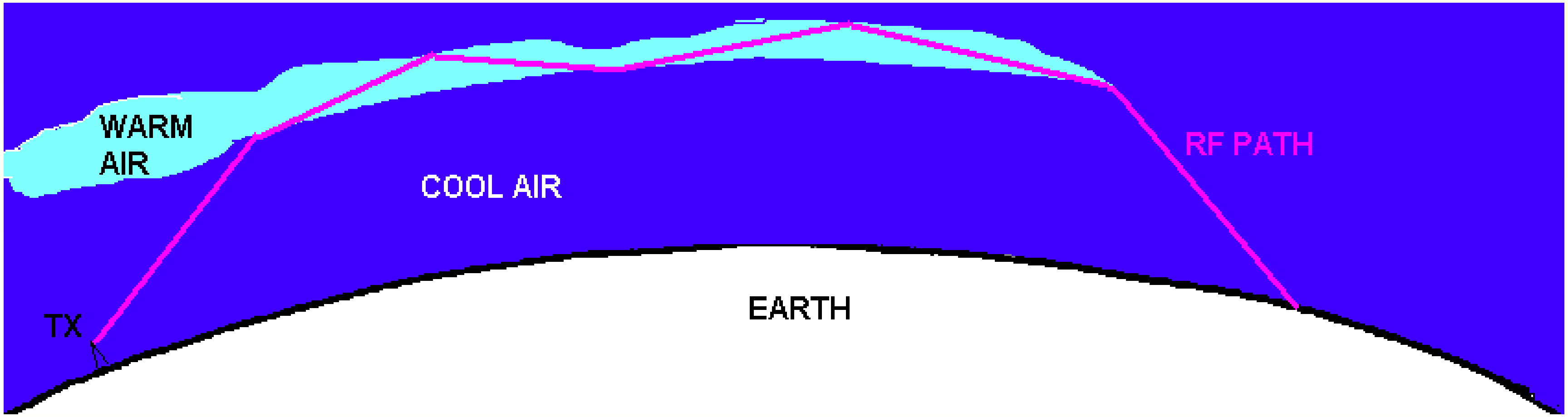
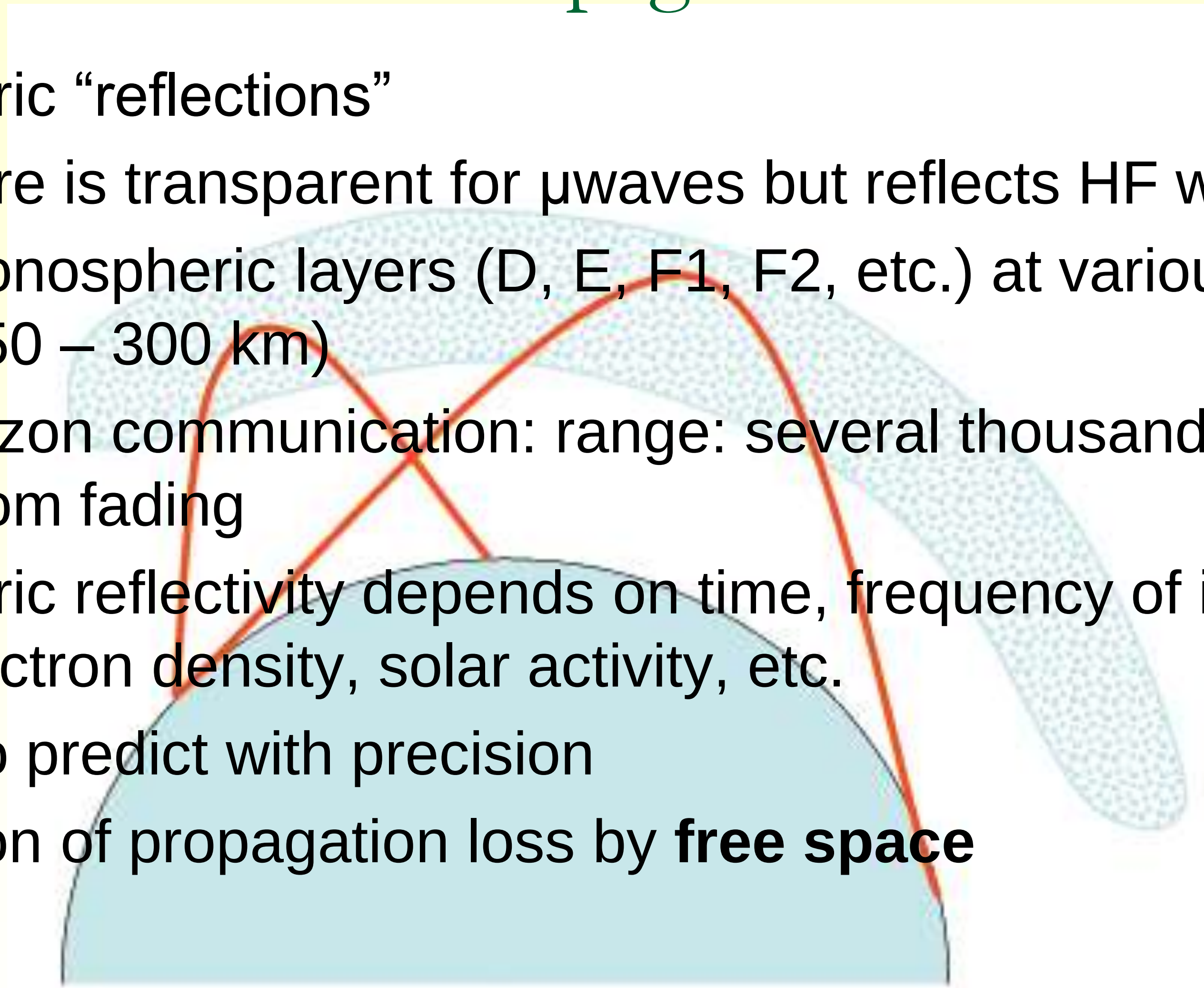
Duct: Temperature Inversion / Troposphere Ducting

1. **Certain weather conditions** produce a layer of air in the Troposphere that will be at a higher temperature than the layers of air above & below it.
2. Such a layer **will provide a "duct"** creating a path through the warmer layer of air
3. These ducts occur over relatively long distances and at varying heights from almost ground level to several hundred meters above the earth
4. This propagation takes place when hot days are followed by rapid cooling at night. Signals can propagate hundreds of kM up to about 2,000 kM



HF Propagation

- 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**



Propagation Loss HF (P. 533)

$$\text{PL(dB)} = 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad PL(dB) = 32.44 + 20\log d_{kM} + 20\log f_{MHz}$$

P. 533 5.2.2 Field strength determination

the median field strength is given by:

$E_w = 136.6 + P_t + G_t + \mathbf{20\log f} - L_b$ dB (μV/m) (17)

where:

f : transmitting frequency (MHz)

P_t : transmitter power (dB(1 kW))

G_t : Tx ant gain at the required azimuth & elevation angles relative to an isotropic ant (dB)

L_b : ray path basic transmission loss for the mode under consideration given by:

$L_b = 32.45 + \mathbf{20\log f} + 20\log p' + L_i + L_m + L_g + L_h + L_z$ (18)

P' : virtual slant range (km)

L_i : absorption loss (dB) for an *n*-hop mode given by

L_m: "above-the-MUF" loss.

L_g: summed ground-reflection loss at intermediate reflection points

L_h: factor to allow for auroral and other signal losses

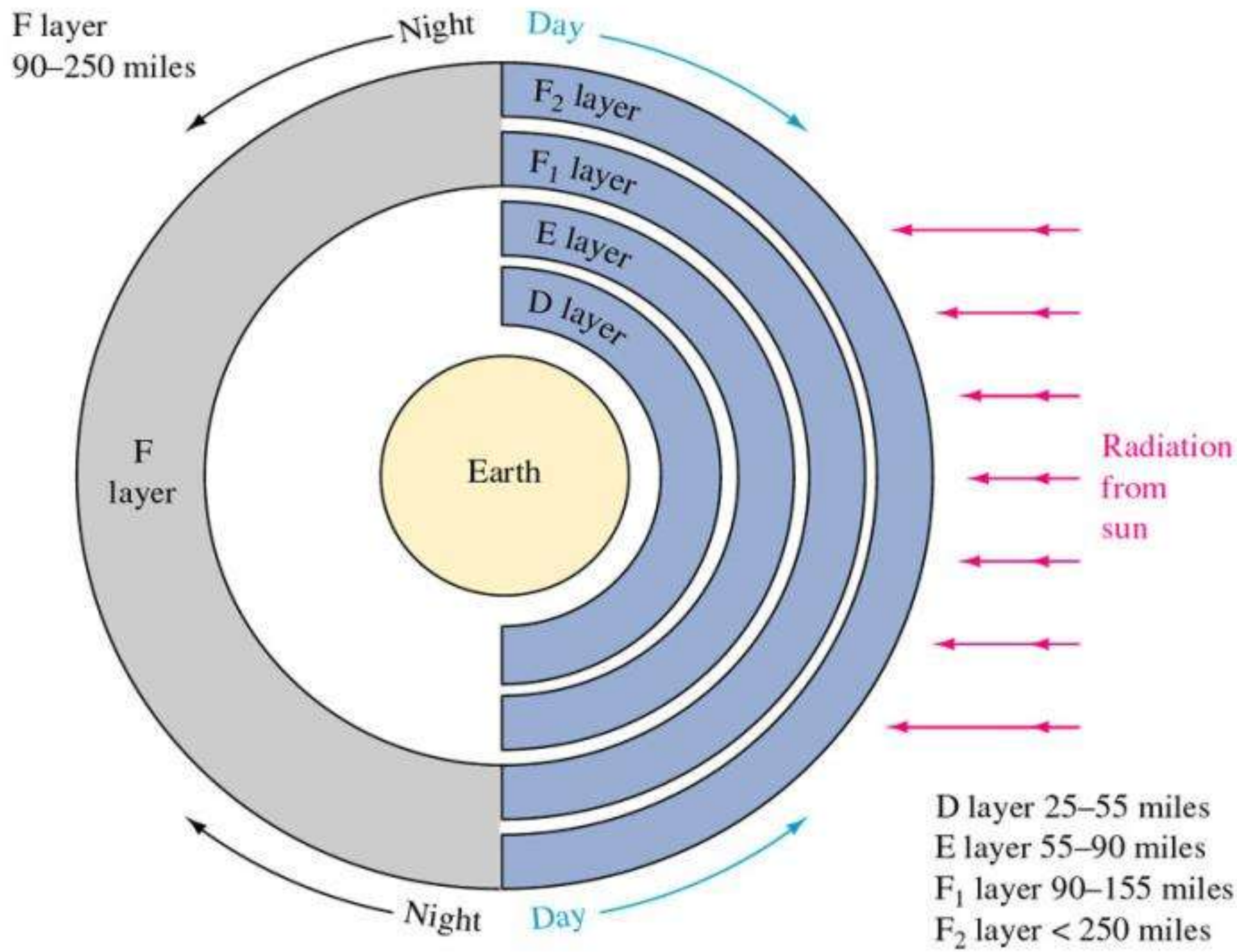
L_z: term containing those effects in sky-wave propagation

Note: **20 log *f*** of E_w is subtracted by **20 log *f*** at L_b

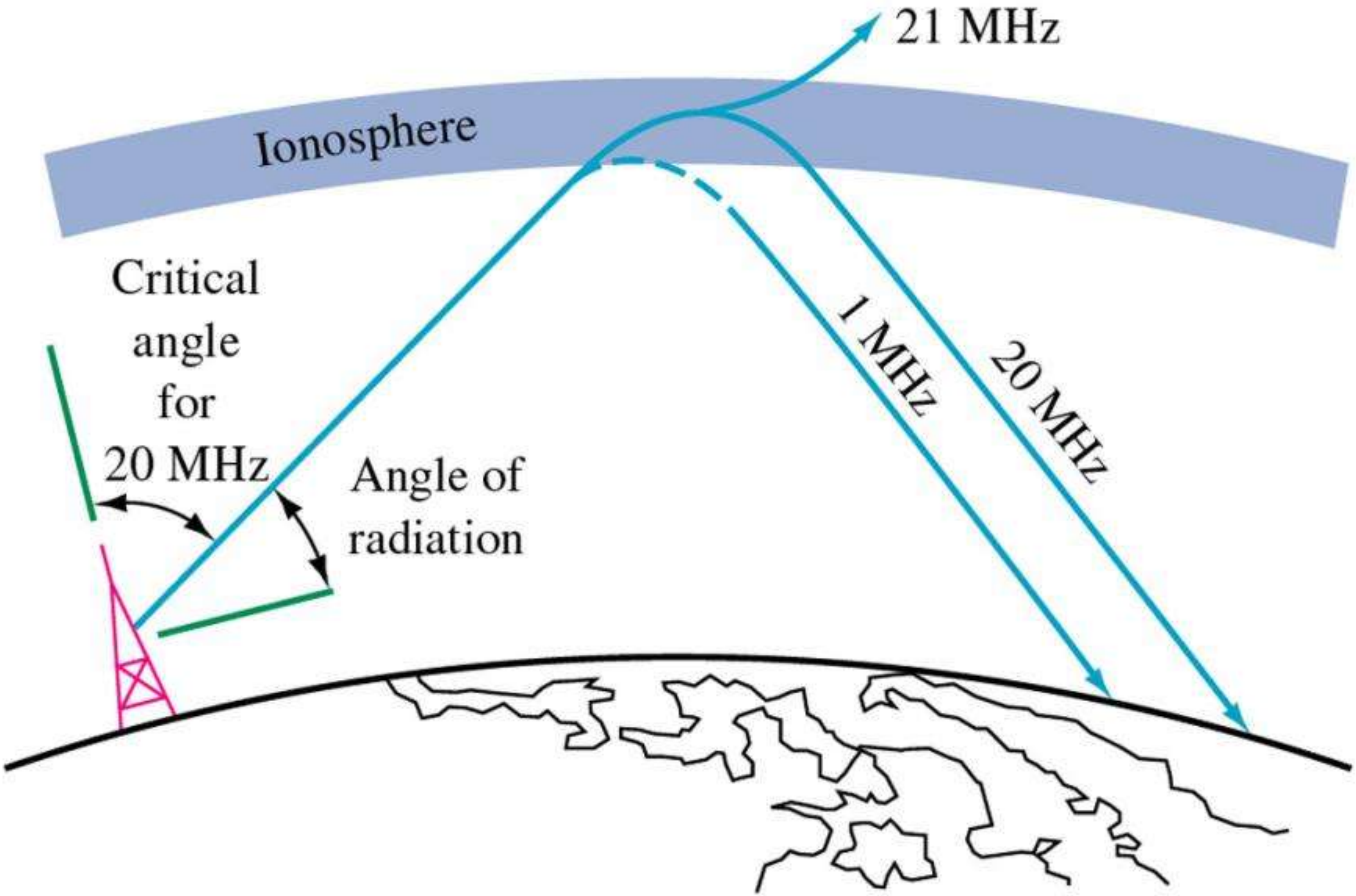
HF Propagation; Definitions

1. *basic MUF* is the highest frequency by which a radiowave can propagate between given terminals, on a specified occasion, by ionospheric refraction alone
2. *Optimum working frequency (OWF)*: the lower decile of the daily values of operational MUF at a given time over a specified period, usually a month. That is, it is the frequency that is exceeded by the operational MUF during 90% of the specified period
3. *Highest probable frequency (HPF)*: the upper decile of the daily values of operational MUF at a given time over a specified period, usually a month. That is, it is the frequency that is exceeded by the operational MUF during 10% of the specified period
4. *Lowest usable frequency (LUF)*: the lowest frequency that would permit acceptable performance of a radio circuit by signal propagation via the ionosphere between given terminals at a given time under specified working conditions

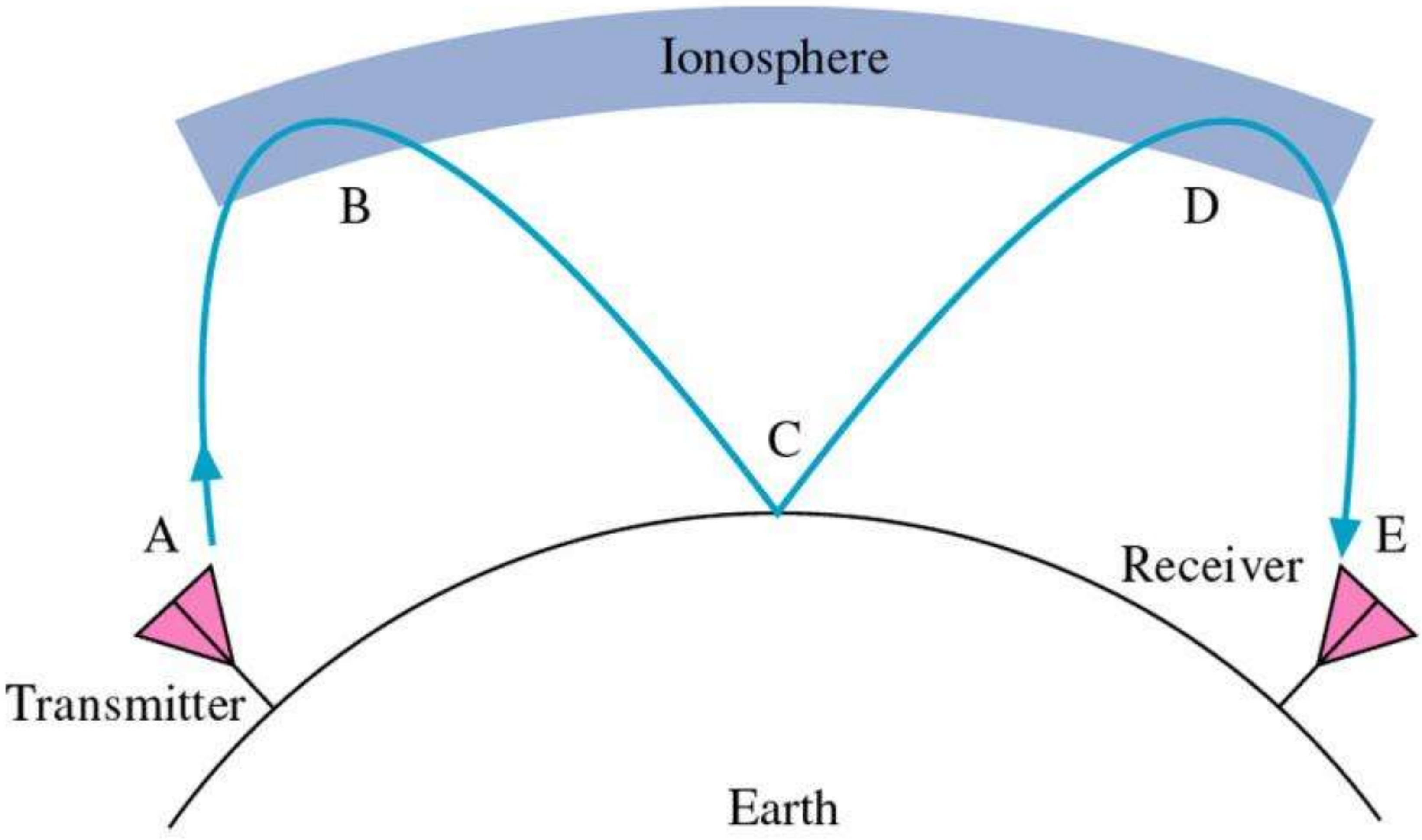
Ionospheric Layers



Ionospheric Layers (cont'd)



HF Hops



Wireless Telecommunications

Gain, Beamwidths, Patterns and VSWR

http://people.itu.int/~mazar/

Definitions

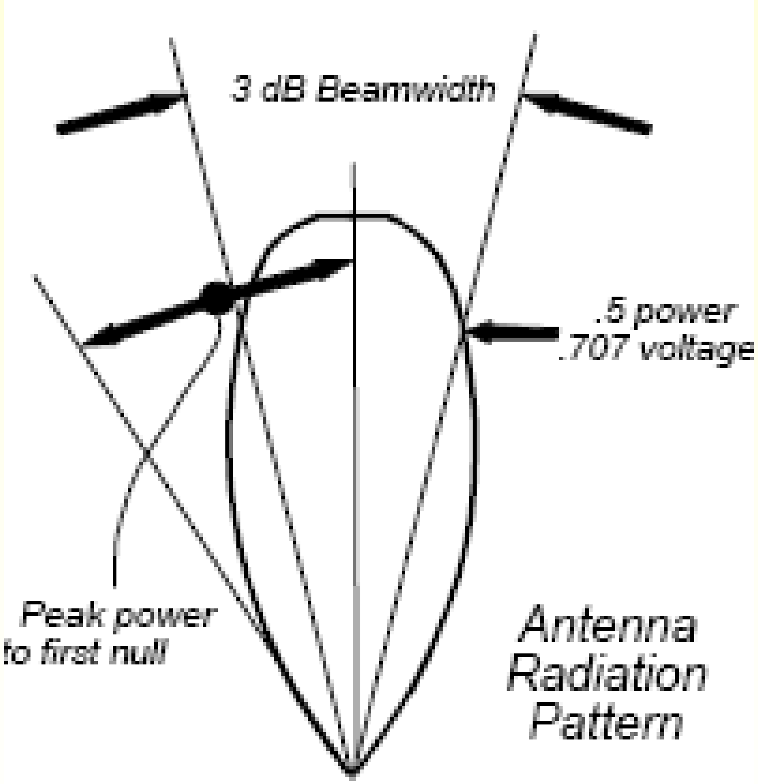
Isotropic, Omni and Directional

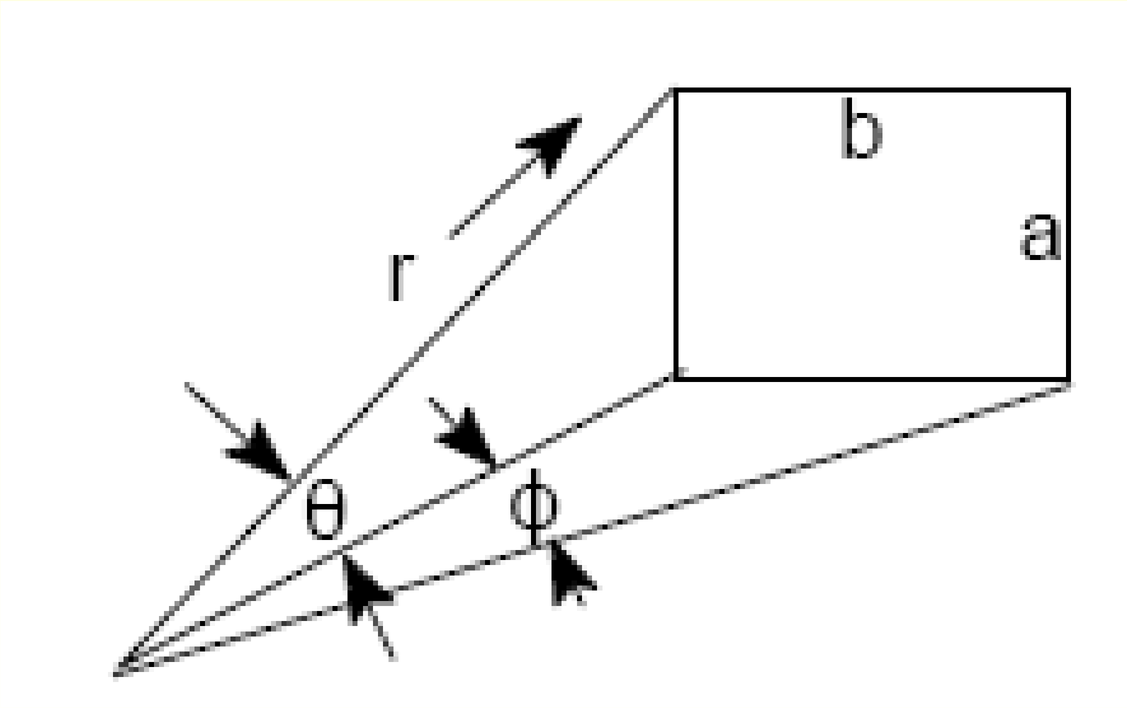
- Isotropic = equal radiation in all angles (4π steradian)
- Omni Directional = equal radiation in one plane
- Directional = the radiation goes to a narrow sector

Antenna RF Bandwidth

Bandwidth is the relative RF band BW = $f_{max}-f_{min}/f_{mean}$

Antenna Aperture and Beamwidths (Paul Wade)





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Effective Capture Area

For η = Aperture efficiency; *A* = Physical aperture area, A_e = Effective aperture area; g= Ant Gain , G= Ant Gain (dBi), Gd =Gi-2.15; λ= wavelength, BW= Ant beamwidth, θ= BW_{elv} φ= BW_{az}

$$\eta = \frac{P_{rad}}{P_{input}} = \frac{A_e}{A}$$

φ= λ/a, θ = λ/b, also from Fraunhofer theory of diffraction, $G = \eta\,(4\pi/\lambda^2)\,A$

$$g = \frac{4\pi}{\Omega(steradians)} = \frac{4\pi}{\varphi\theta(radians)} = \frac{4\pi a_{az} b_{el}}{\lambda^2} = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi\eta A}{\lambda^2}$$

$$\mathrm{A} = \frac{g\lambda^2}{\eta 4\pi} \quad \mathrm{A_e} = \frac{g\lambda^2}{4\pi}$$

Equation to calculate the gain of a passive reflector

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Practical Formulas, for Ant. Gain

For η = 0.7

$$g = \eta \frac{4\pi}{\varphi\theta(radians)} = \eta \frac{4\pi}{\varphi\theta(^0)}\left(\frac{360}{2\pi}\frac{360}{2\pi}\right) = \eta \frac{41,253}{\varphi\theta(^0)} = \eta \frac{41,253}{\varphi\theta(^0)} \approx \frac{28,800}{\varphi\theta(^0)}$$

$G = 44.6$ dBi $-10\log\theta^0 - 10\log\varphi^0$; for circular Ant, $G = 44.6$ dBi $-20\log\theta$

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Rec F699 Patterns for 1 GHz to about 70 GHz, where D/λ <100

D= Ant length or diameter; these formulas apply for circular reflectors

$G(\varphi)$: gain relative to an isotropic antenna; φ : off-axis angle (degrees)

D : antenna diameter
λ : wavelength
} expressed in the same units

G_1 : gain of the first side-lobe $= 2 + 15 \log D/\lambda$

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \quad \text{degrees}$$

$$G(\varphi) = G_{max} - 2.5\times10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for} \quad 0^\circ < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for} \quad \varphi_m \le \varphi < 100\frac{\lambda}{D}$$

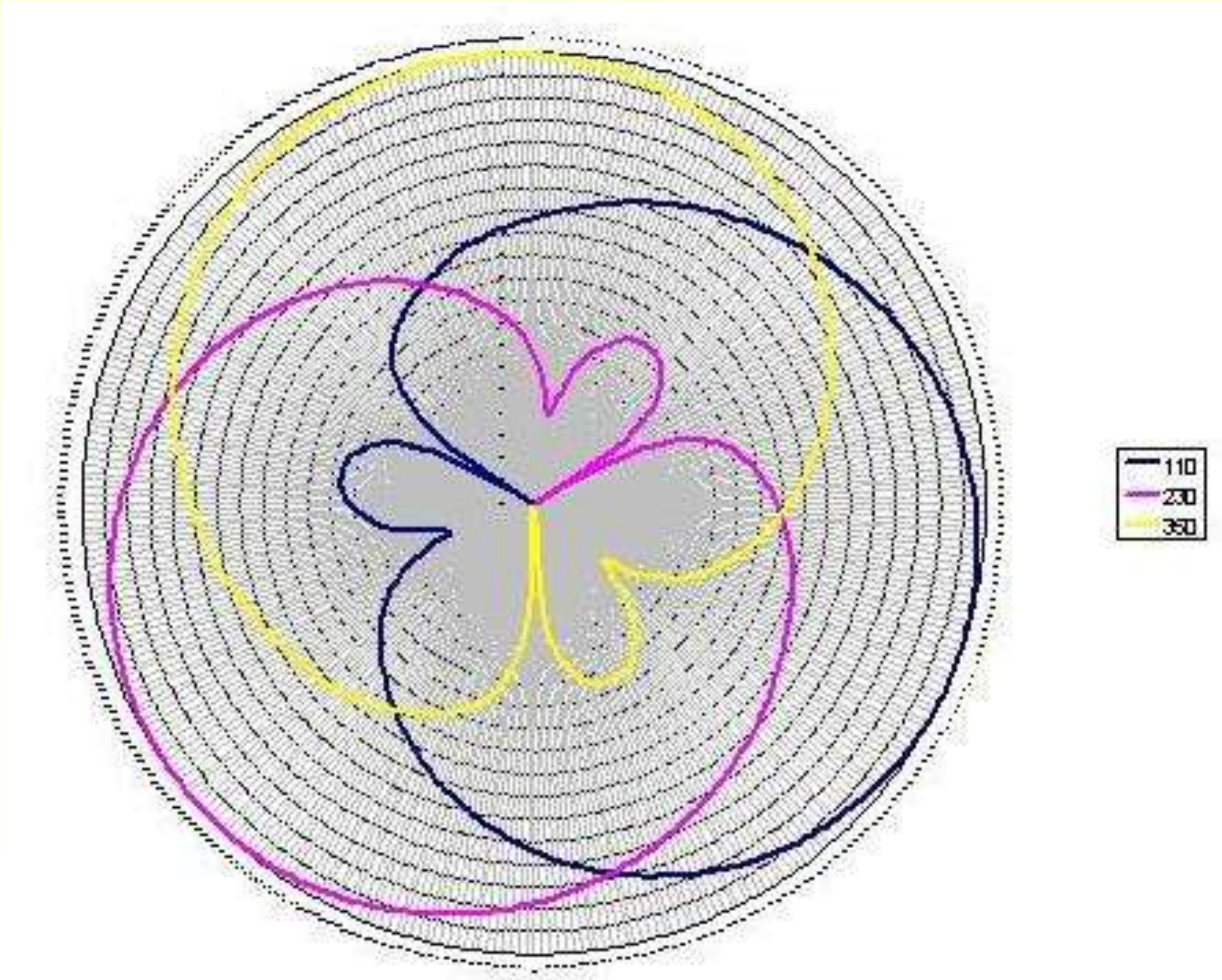
$$G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi \quad \text{for} \quad 100\frac{\lambda}{D} \le \varphi < 48^\circ$$

$$G(\varphi) = 10 - 10\log\frac{D}{\lambda} \quad \text{for} \quad 48^\circ \le \varphi \le 180^\circ$$

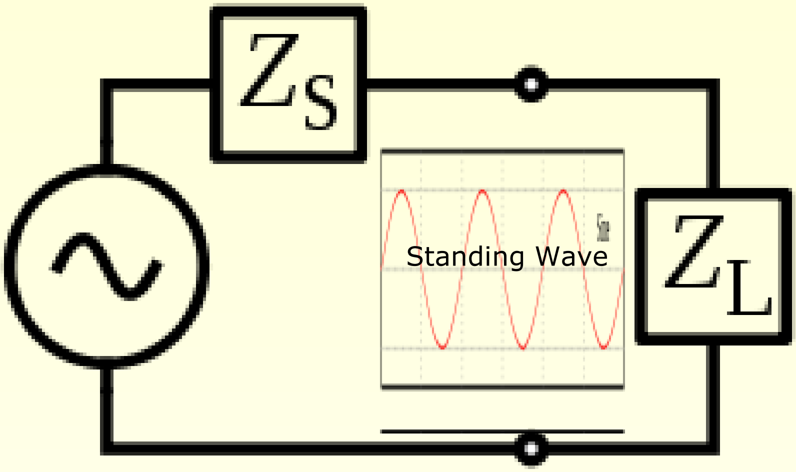
$$20\log\frac{D}{\lambda} \approx G_{max} - 7.7 \qquad D/\lambda \approx 70/\theta \qquad G_{max}(\text{dBi}) \approx 44.5 - 20\log\theta$$

For η = 0.7 (not at 699)

Photo and Horiz Pattern of a Typical Cellular Antenna



Impedance, Return Loss and VSWR



Z_S represents the Tx and Z_L the ant impedance, a complex number.

$Z = R + jX = |Z|e^{j\theta}$ $\quad Z_L = Z_a = R_{losses} + R_{radiation} + j X_L$

At resonance $Z_a = R_r$ (Radiation Resistance).

The ant impedance can be viewed as a load connected to a transmission line with characteristic impedance of Z_0

The reflection coefficient Γ is the ratio of reflected voltage to incident voltage waves at the ant terminals

Γ is related to the impedances at resonance by: $\Gamma=(R_r-Z_0)/(R_r+Z_0)$

The returned power from the ant to the generator is the Power Loss (PL) or Return Loss

$PL=RL= |\Gamma|^2=\rho^2$

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VSWR: Voltage Standing Wave Ratio

The voltage component of a standing wave consists of the forward wave (with amplitude V_f) superimposed on the reflected wave (with amplitude V_r).

The voltage reflection coefficient $\Gamma \equiv V_r / V_f$ $\rho \equiv |\Gamma|$ Return Loss $\equiv \rho^2$

$V_{max} = V_f + V_r = V_f + \rho V_f = V_f (1+\rho)$ $V_{min} = V_f - V_r = V_f - \rho V_f = V_f (1-\rho)$

$$\text{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1+\rho}{1-\rho} \qquad \rho = \frac{VSWR-1}{VSWR+1}$$

ρ always falls in the range [0,1], so the VSWR is always ≥ +1
SWR is also defined as the ratio of the maximum amplitude of the electric field to its minimum amplitude E_{max} / E_{min}

$$\text{SWR} = \frac{E_{max}}{E_{min}} = \frac{1+\rho}{1-\rho}$$

return loss Vs. VSWR

table of return loss vs. voltage standing wave ratio

$RL=20\log\rho=20\log(VSWR-1)-20\log(VSWR-1)$

RETURN LOSS (dB)	VSWR	RETURN LOSS (dB)	VSWR	RETURN LOSS (dB)	VSWR	RETURN LOSS (dB)	VSWR	RETURN LOSS (dB)	VSWR
46.064	1.01	13.842	1.51	9.485	2.01	7.327	2.51	5.999	3.01
40.086	1.02	13.708	1.52	9.428	2.02	7.294	2.52	5.970	3.02
36.607	1.03	13.577	1.53	9.372	2.03	7.262	2.53	5.956	3.03
34.151	1.04	13.449	1.54	9.317	2.04	7.230	2.54	5.935	3.04
32.256	1.05	13.324	1.55	9.262	2.05	7.198	2.55	5.914	3.05
30.714	1.06	13.201	1.56	9.208	2.06	7.167	2.56	5.893	3.06
29.417	1.07	13.081	1.57	9.155	2.07	7.135	2.57	5.872	3.07
28.299	1.08	12.964	1.58	9.103	2.08	7.105	2.58	5.852	3.08
27.318	1.09	12.849	1.59	9.051	2.09	7.074	2.59	5.832	3.09
26.444	1.10	12.736	1.60	8.999	2.10	7.044	2.60	5.811	3.10
25.658	1.11	12.625	1.61	8.949	2.11	7.014	2.61	5.791	3.11
24.943	1.12	12.518	1.62	8.899	2.12	6.984	2.62	5.771	3.12
24.289	1.13	12.412	1.63	8.849	2.13	6.954	2.63	5.751	3.13
23.686	1.14	12.308	1.64	8.800	2.14	6.925	2.64	5.732	3.14
23.127	1.15	12.207	1.65	8.752	2.15	6.896	2.65	5.712	3.15
22.607	1.16	12.107	1.66	8.705	2.16	6.867	2.66	5.693	3.16
22.120	1.17	12.009	1.67	8.657	2.17	6.839	2.67	5.674	3.17
21.664	1.18	11.913	1.68	8.611	2.18	6.811	2.68	5.654	3.18
21.234	1.19	11.818	1.69	8.565	2.19	6.783	2.69	5.635	3.19
20.828	1.20	11.725	1.70	8.519	2.20	6.755	2.70	5.617	3.20
20.443	1.21	11.634	1.71	8.474	2.21	6.728	2.71	5.598	3.21
20.079	1.22	11.545	1.72	8.430	2.22	6.700	2.72	5.579	3.22
19.732	1.23	11.457	1.73	8.386	2.23	6.673	2.73	5.561	3.23
19.401	1.24	11.370	1.74	8.342	2.24	6.646	2.74	5.542	3.24
19.085	1.25	11.285	1.75	8.299	2.25	6.620	2.75	5.524	3.25
18.783	1.26	11.202	1.76	8.257	2.26	6.594	2.76	5.506	3.26
18.493	1.27	11.120	1.77	8.215	2.27	6.567	2.77	5.488	3.27
18.216	1.28	11.039	1.78	8.173	2.28	6.541	2.78	5.470	3.28
17.949	1.29	10.960	1.79	8.138	2.29	6.516	2.79	5.452	3.29
17.690	1.30	10.881	1.80	8.091	2.30	6.490	2.80	5.435	3.30
17.445	1.31	10.804	1.81	8.051	2.31	6.465	2.81	5.417	3.31
17.207	1.32	10.729	1.82	8.011	2.32	6.440	2.82	5.400	3.32
16.977	1.33	10.654	1.83	7.972	2.33	6.415	2.83	5.383	3.33
16.755	1.34	10.581	1.84	7.933	2.34	6.390	2.84	5.365	3.34
16.540	1.35	10.509	1.85	7.894	2.35	6.366	2.85	5.348	3.35
16.332	1.36	10.437	1.86	7.856	2.36	6.341	2.86	5.331	3.36
16.131	1.37	10.367	1.87	7.818	2.37	6.317	2.87	5.315	3.37
15.936	1.38	10.298	1.88	7.781	2.38	6.293	2.88	5.298	3.38
15.747	1.39	10.230	1.89	7.744	2.39	6.270	2.89	5.281	3.39
15.563	1.40	10.163	1.90	7.707	2.40	6.246	2.90	5.265	3.40
15.385	1.41	10.097	1.91	7.671	2.41	6.223	2.91	5.248	3.41
15.211	1.42	10.032	1.92	7.635	2.42	6.200	2.92	5.232	3.42
15.043	1.43	9.968	1.93	7.599	2.43	6.177	2.93	5.216	3.43
14.879	1.44	9.904	1.94	7.564	2.44	6.154	2.94	5.200	3.44
14.719	1.45	9.842	1.95	7.529	2.45	6.131	2.95	5.184	3.45
14.564	1.46	9.780	1.96	7.494	2.46	6.109	2.96	5.168	3.46
14.412	1.47	9.720	1.97	7.460	2.47	6.086	2.97	5.152	3.47
14.264	1.48	9.660	1.98	7.426	2.48	6.064	2.98	5.137	3.48
14.120	1.49	9.601	1.99	7.393	2.49	6.042	2.99	5.121	3.49
13.979	1.50	9.542	2.00	7.360	2.50	6.021	3.00	5.105	3.50

020710

Transmitters and Receivers

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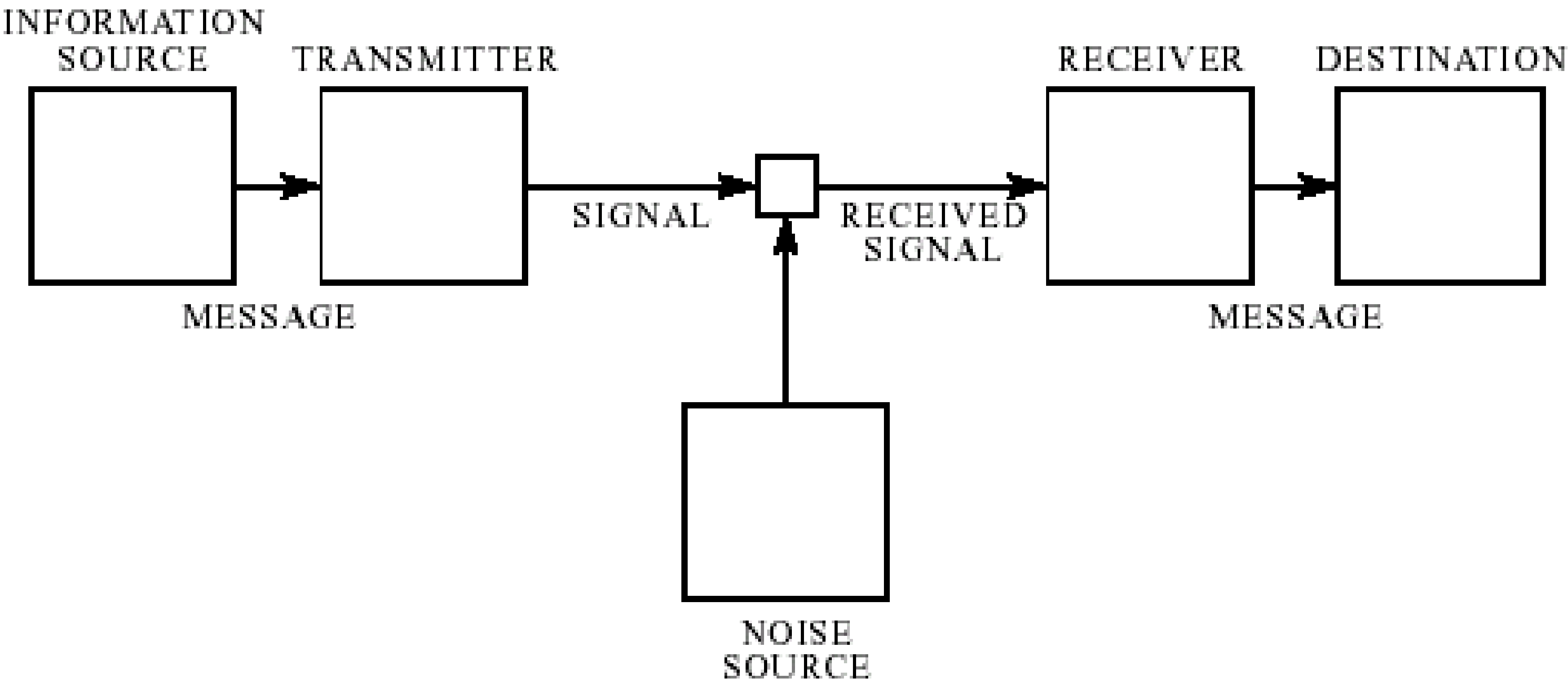
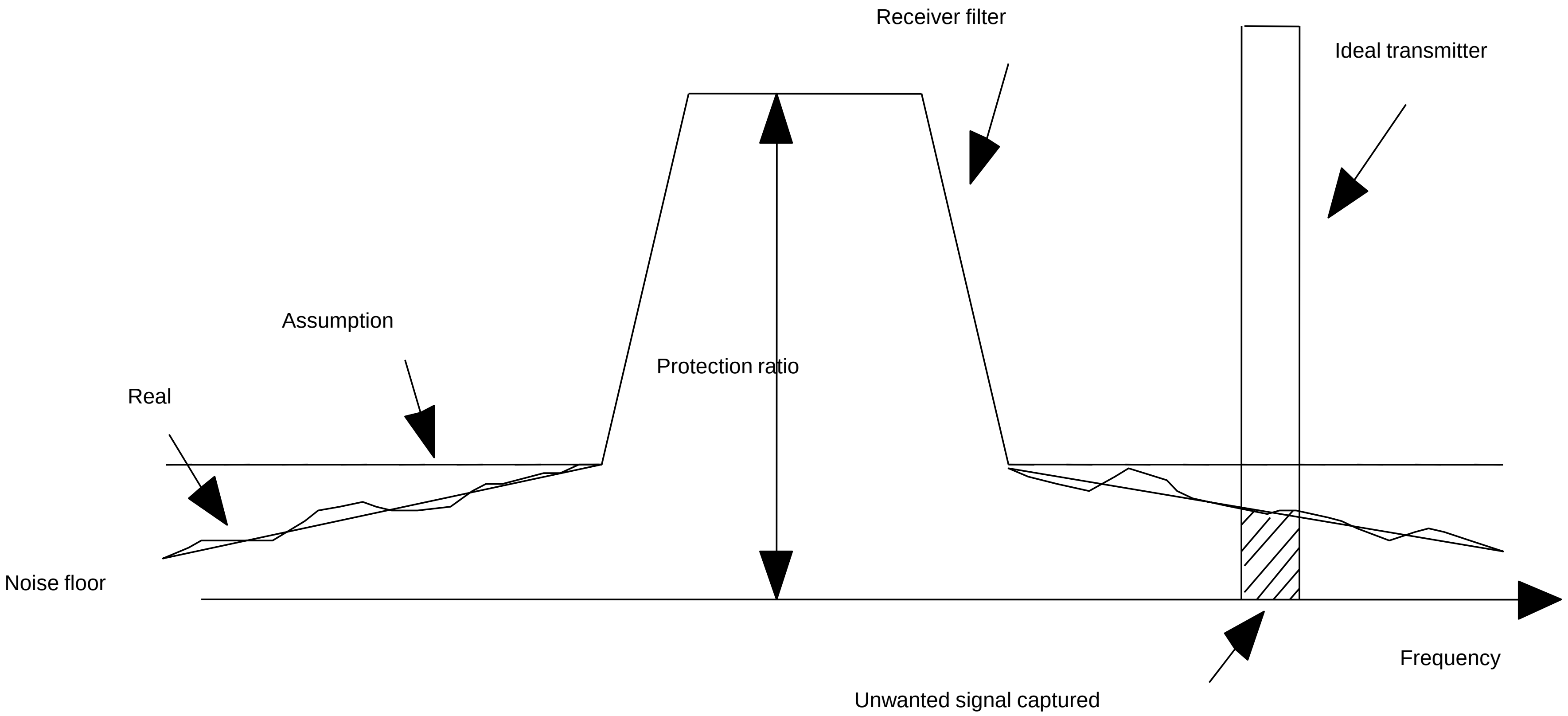
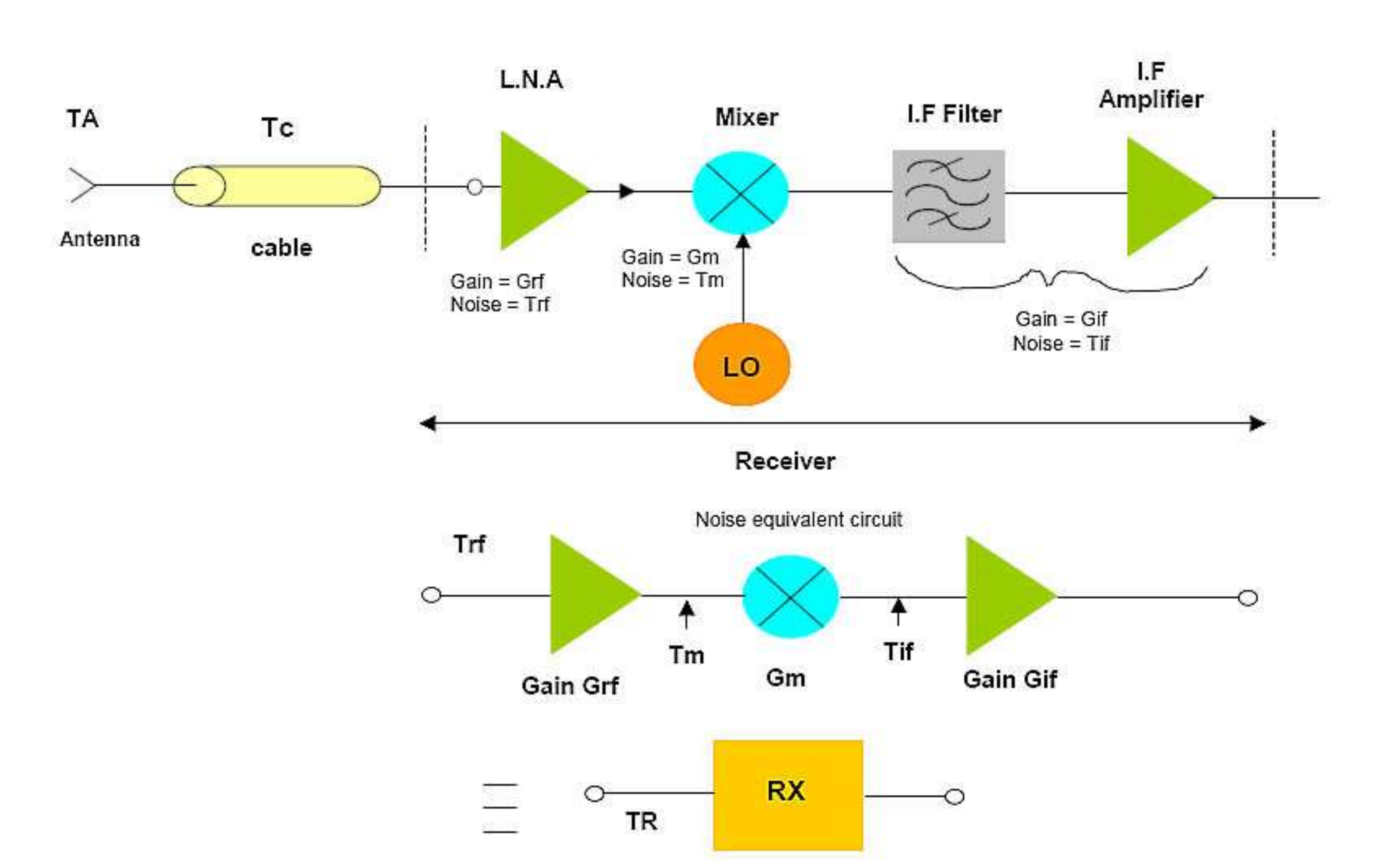
Schematic Diagram of a General Communication (Shannon &Weaver 1949)



Receiving Conditions



Typical Rx Schematics (Rami Neuderfer)



Noise Figure and Terms to specify noise intensity and inter-relationship

Noise Figure (and Noise Factor) is defined as the ratio of the output noise power to the portion attributed to thermal noise in the input termination at standard noise temperature t_c (usually 290 K)

$$f = \frac{SNR_{in}}{SNR_{out}}$$

If devices are cascaded use with Friis' Formula: where Fn is the noise factor for the n-th device and Gn is the power gain (linear, not in dB) of the n-th device.

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \cdots + \frac{F_n - 1}{G_1 G_2 G_3 \cdots G_{n-1}},$$

In a well designed receive chain, only the noise factor of the first amplifier is significant.

Noise Figure and Terms to specify noise intensity… (cont'd)

f_a : the external noise factor is defined as

$$f_a = \frac{p_n}{k\, t_0\, b}$$

p_n: available noise power from an equivalent lossless ant

Logarithm $F_a = 10 \log f_a$ dB

$$\boldsymbol{f = f_a - 1 + f_c\, f_t\, f_r}$$

Given $t_c = t_t = t_0$

t_o : reference temperature (K) taken as 290 K

t_c: actual temperature (K) of the antenna and nearby ground

t_t: actual temperature (K) of the transmission line

k : Boltzmann's constant = 1.38×10^{-23} J/K

b : noise power bandwidth of the receiving system (Hz)

f_r : noise factor of the receiver

Noise Figure (cont'd)

k : Boltzmann's constant = 1.38 x 10^{-23} J/K

b : noise power bandwidth of the receiving system (Hz)

f_r : noise factor of the receiver

$$f_a = \frac{p_n}{k\, t_0\, b} \qquad\qquad f_a = \frac{t_a}{t_0}$$

external noise factor can be expressed as a temp t_a, where, by definition of f_a:

t_a is the effective antenna temperature due to external noise

p_n from f_a in dB: $P_n = F_a + B - 204$ dBW

Pn = 10 log p_n available power (W)

B = 10 log b

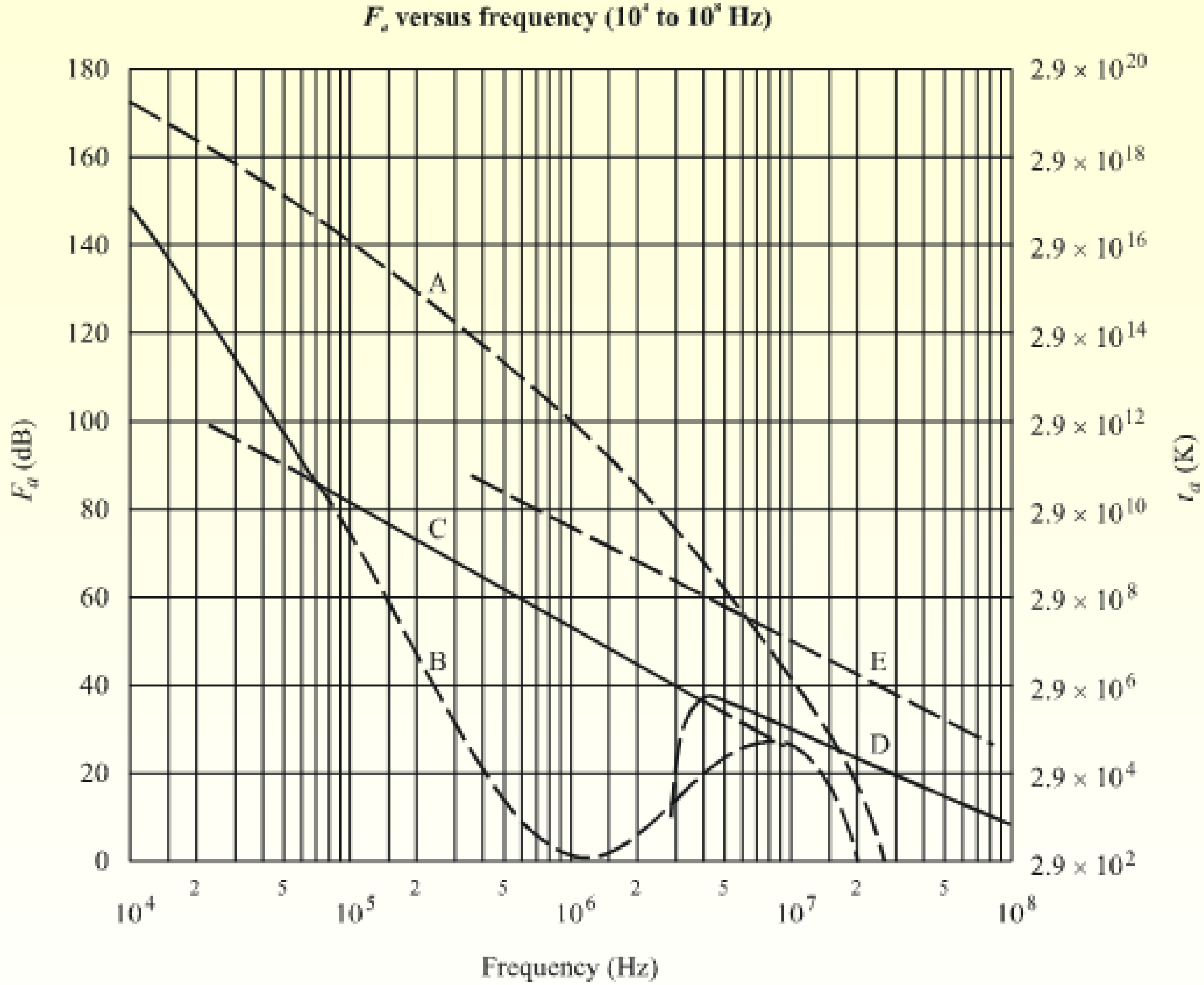
–204 =10 log k t_o (1.38 x 290 = 400.2)

for a half-wave dipole in free space:

$$P_r = \frac{E^2\, G\lambda^2}{Z_0 4\pi} = \frac{E^2 G c^2}{480\pi^2 f^2}$$

En = Fa + 20 log f(MHz) + B (MHz) – 98.9 dB(μ V/m)

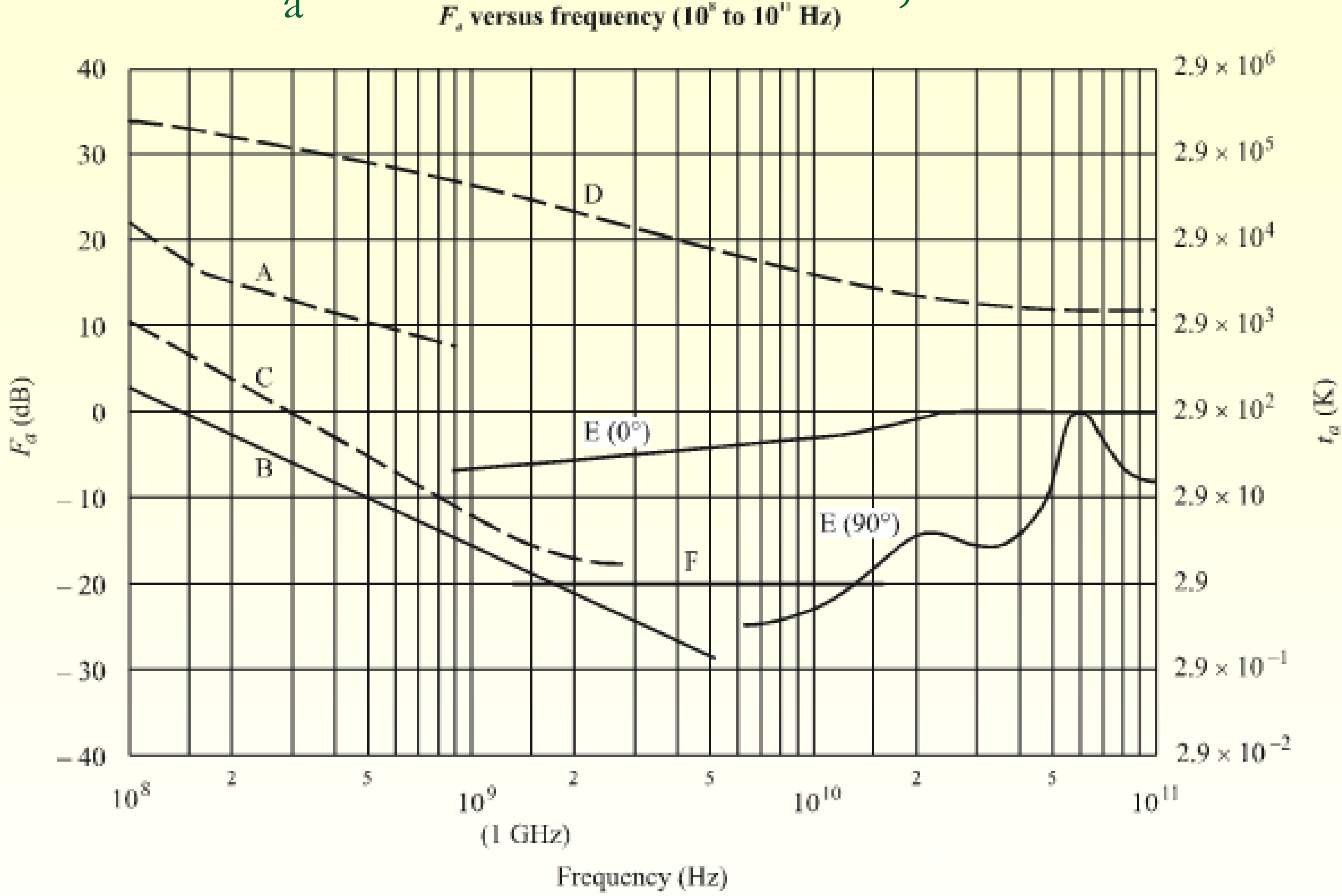
Radio Noise: F_a vs RF ITU-R P. 372 ; 10 kHz to 100 MHz



A : atmospheric noise, value exceeded 0.5% of time
B : atmospheric noise, value exceeded 99.5% of time
C : man-made noise, quiet receiving site
D : galactic noise
E : median city area man-made noise
——— minimum noise level expected

0372-02

Radio Noise: F_a vs RF ITU-R P. 372 ; 100 MHz to 100 GHz



A: estimated median city area man-made noise
B: galactic noise
C: galactic noise (toward galactic centre with infinitely narrow beamwidth)
D: quiet Sun (½° beamwidth directed at Sun)
E: sky noise due to oxygen and water vapour (very narrow beam antenna); upper curve, 0° elevation angle; lower curve, 90° elevation angle
F: black body (cosmic background), 2.7 K

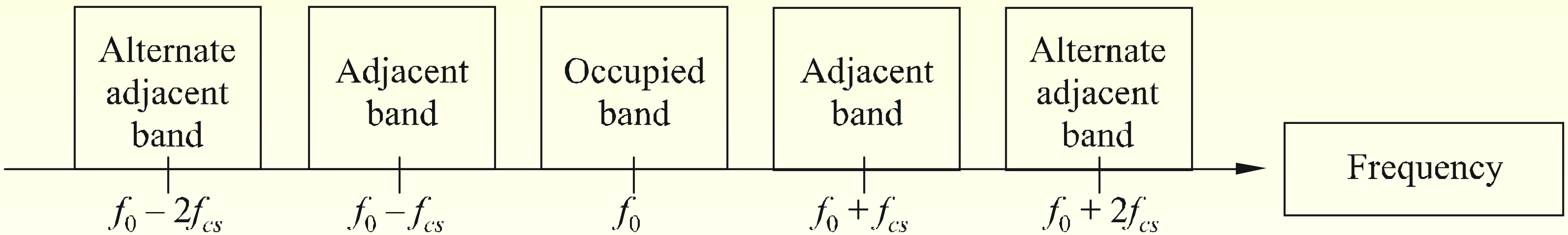
——— minimum noise level expected

0372-03

Unwanted Masks, Rec SM 1541

FIGURE 3

Power measurement bands



f_{cs}: spacing between assigned frequencies

1541-03

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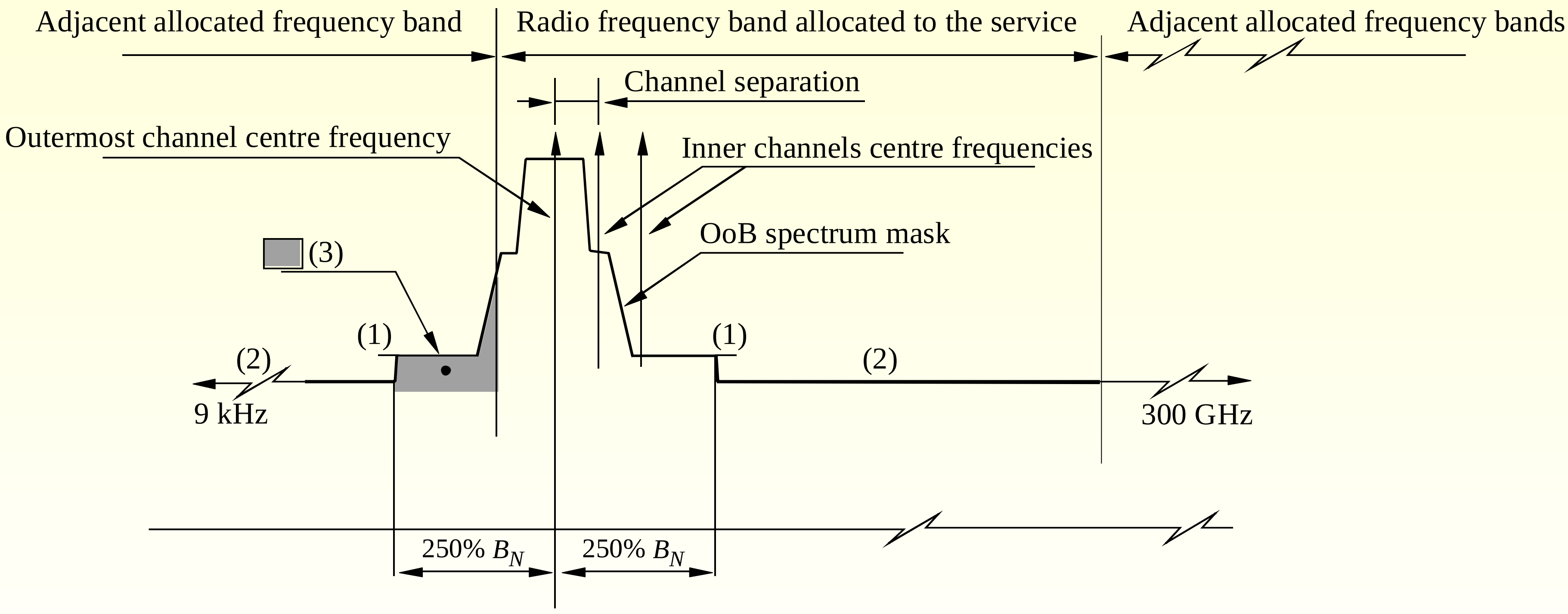
Unwanted Emissions (Rec SM.1540)



(1) Actual OoB mask for the system under consideration
(2) Spurious limit defined by RR Appendix 3 or Recommendation ITU-R SM.329
(3) Unwanted emissions in the OoB domain falling in the adjacent allocated frequency band

1540-01

Wireless Telecommunications

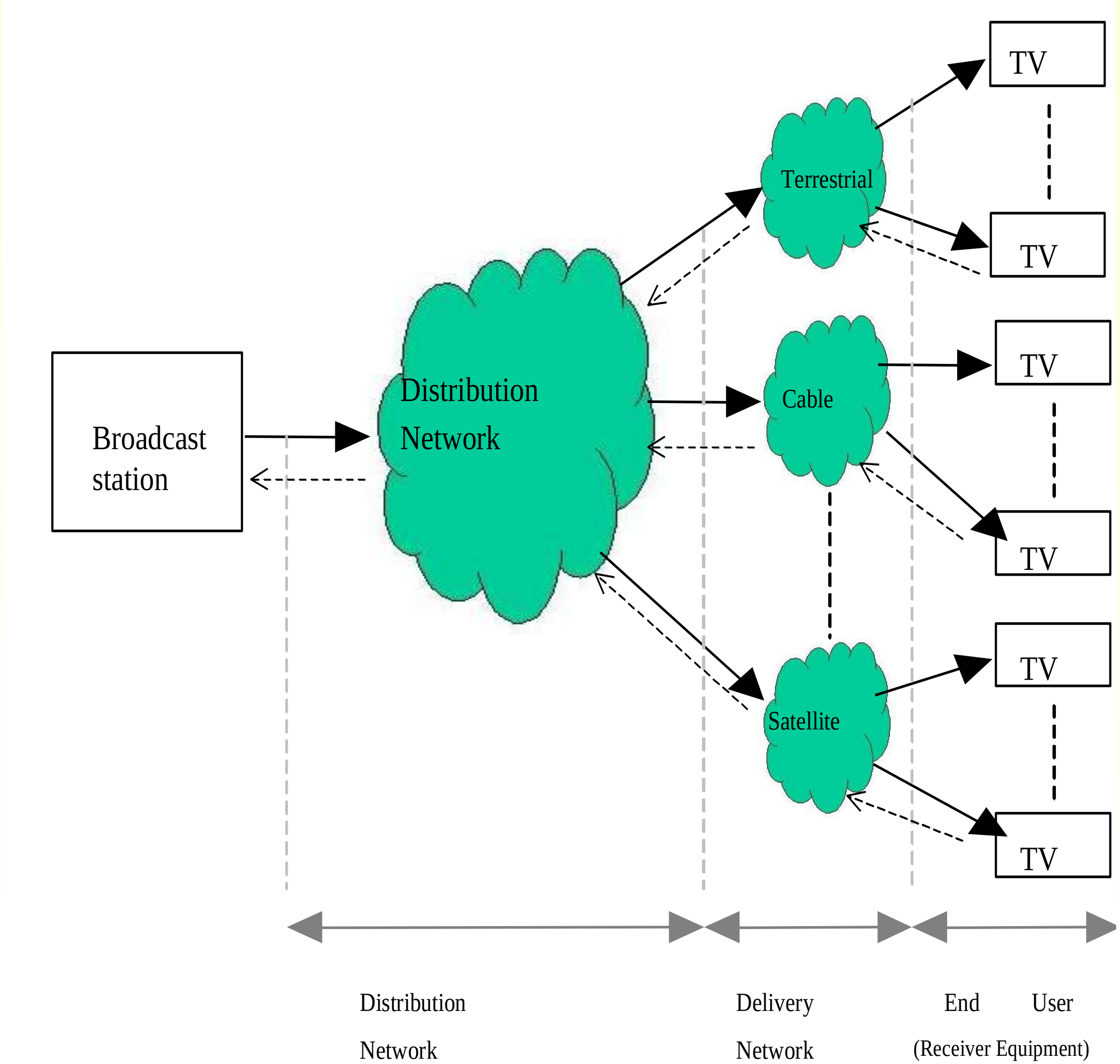
Enrichment Material

Broadcasting: Video, Audio and Data

http://people.itu.int/~mazar/

Broadcasting Network Henten A., Samarajiva R., Melody WH. 2003

Cable and Satellite communications are also good alternatives



Technical Parameters of the TV systems

The three Analogue (or Analog) TV standards

	Lines per frame (visible lines)	Fields per second	Line Frequency (Hz)	Video Bandwidth (MHz)	Colour subcarrier (MHz)	Subcarrier Modulation	Year implemented
NTSC	525 (480)	59.94	15,734.264	4.2	3.58	Quadrature Amplitude (QAM)	1954
PAL	625 (576)	50	15,625. Only for PAL-M 15,734.264	5; 5.5; 6	4.43; PAL-M 3.58, PAL-N 3.58		1967
SECAM						Frequency (FM)	

median field strength

Band	**I**	**III**	**IV**	**V**
dB(μV/m)	+48	+55	+65	+70

The Three Digital TV Standards (Aware Channel Separation)

	Reception speed	Scanning Lines	Image size Pixels	Modulation
ATSC	Portable	1125	1920x1080	Single 8-VSB carrier codes
DVB-T	< 90 km/h, for 8k carriers; <180 km/h, 2k	Flexible		OFDM
ISDB-T				

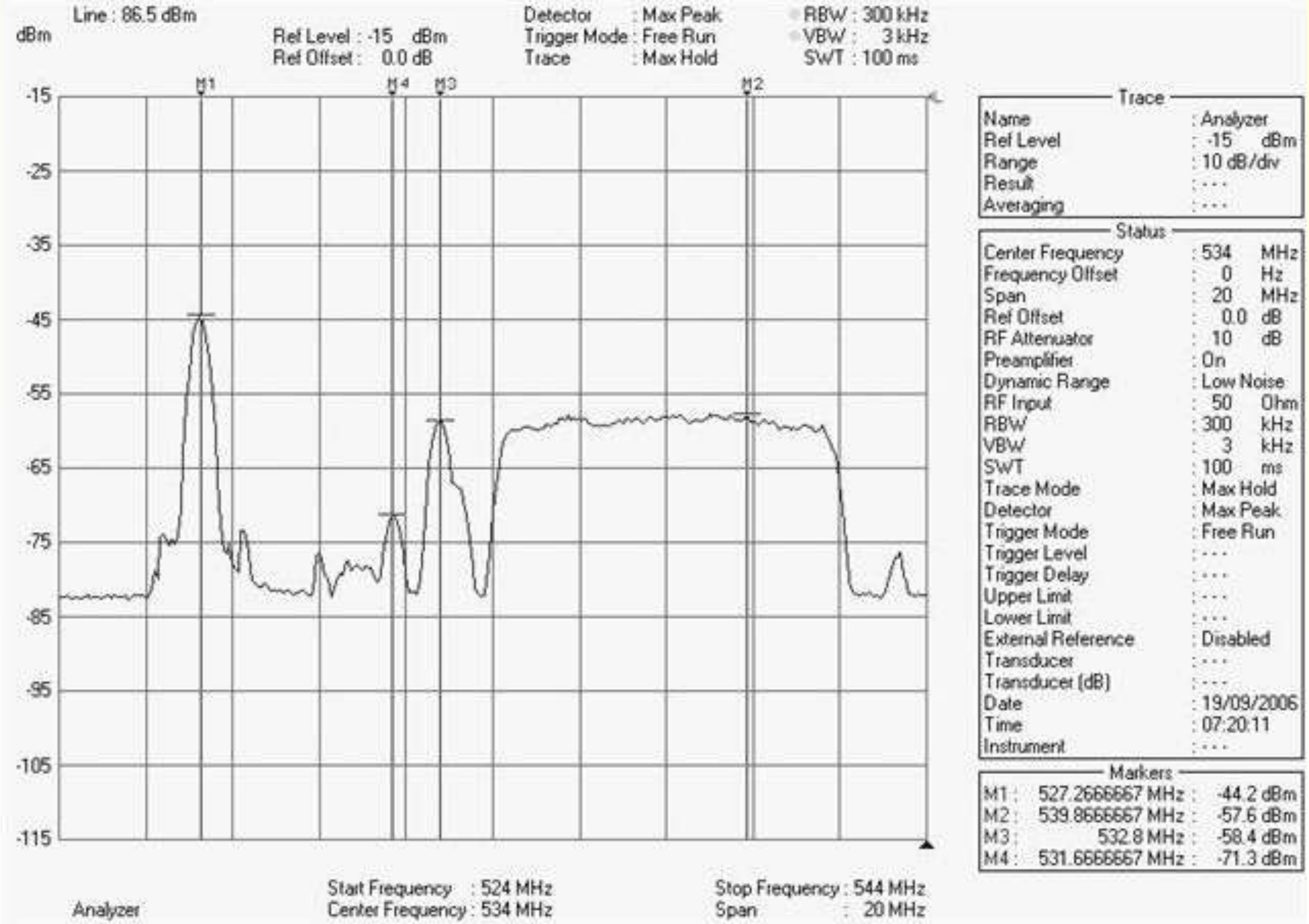
See author's PhD thesis at http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 20

TV Standards; ITU report –Digital TV

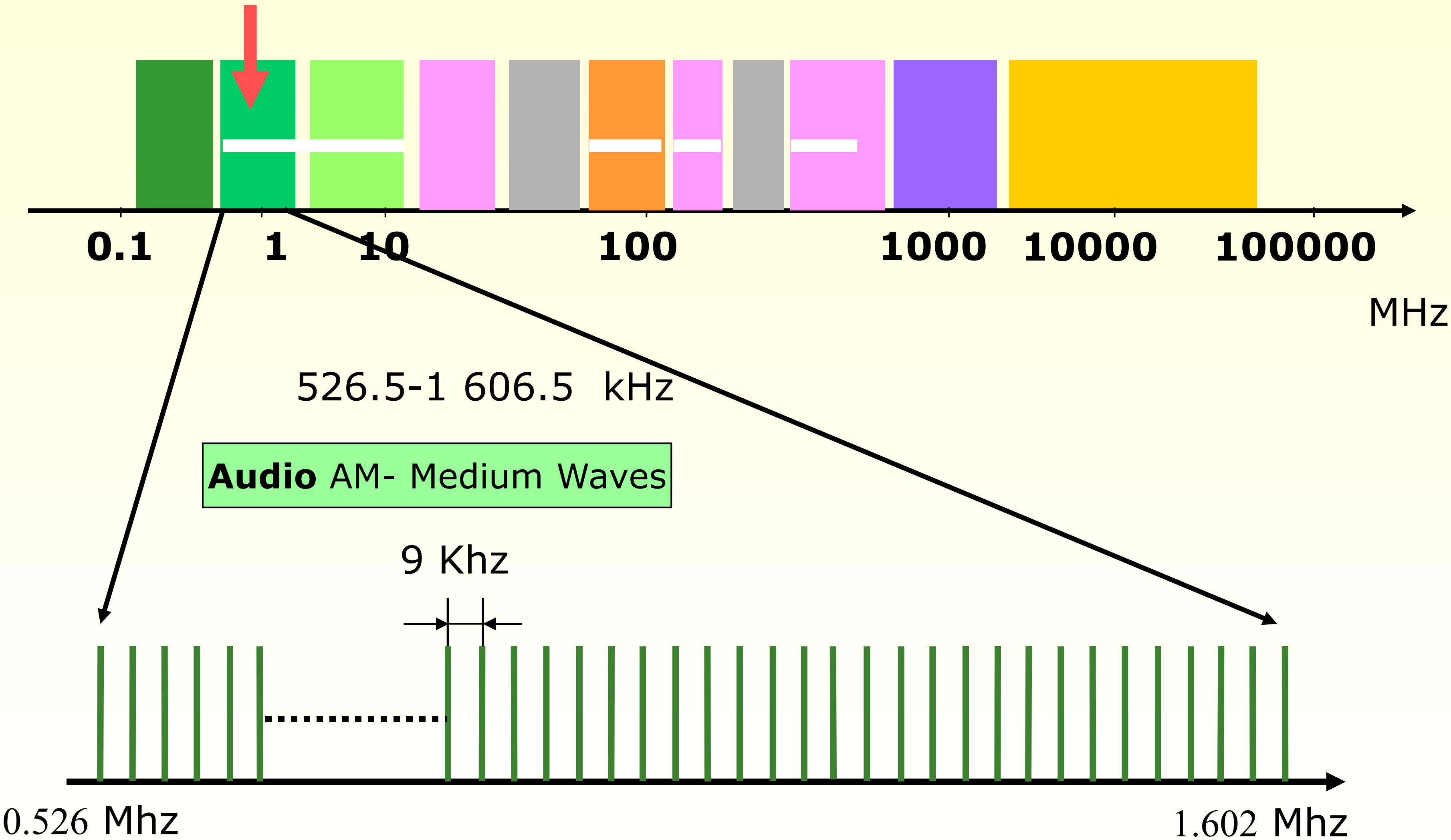
Standard	**Channels**	**Band**	**Modulation**	**Applicable standards**
ATSC	6 MHz	UHF/VHF	8-VSB	A/52,A/53, A/65, A/153
ChinaDTV	8 MHz	UHF/VHF	OFDM	GB 20600-2006
DVB-T	6, 7 and 8 MHz	UHF/VHF	OFDM	EN 300 744
DVB-H	5, 6, 7 and 8 MHz	UHF/VHF	OFDM	EN 302 304
ISDB-T	6, 7 and 8 MHz	UHF/VHF	Segmented OFDM	ARIB STD-B31
T-DMB	1.75 MHz	VHF/1.5GHz	OFDM	ETSI TS 102 427 and ETSI TS 102 428
FLO	5, 6, 7 and 8 MHz	UHF/VHF	OFDM	TIA 1099
ISDB-T_{SB}	0.43, 0.50, 0.57 MHz 1.29, 1.50, 1.71 MHz	UHF/VHF	Segmented OFDM	ARIB STD-B29

TV Analog ch. 28 (526-534 MHz) adjacent to Digital ch. 29 (534-542 MHz)

19/09/06; measured by author; M1-an.Video,M4-an.synch,M3-an.sound, M2- dig. OFDM



Radio Frequency



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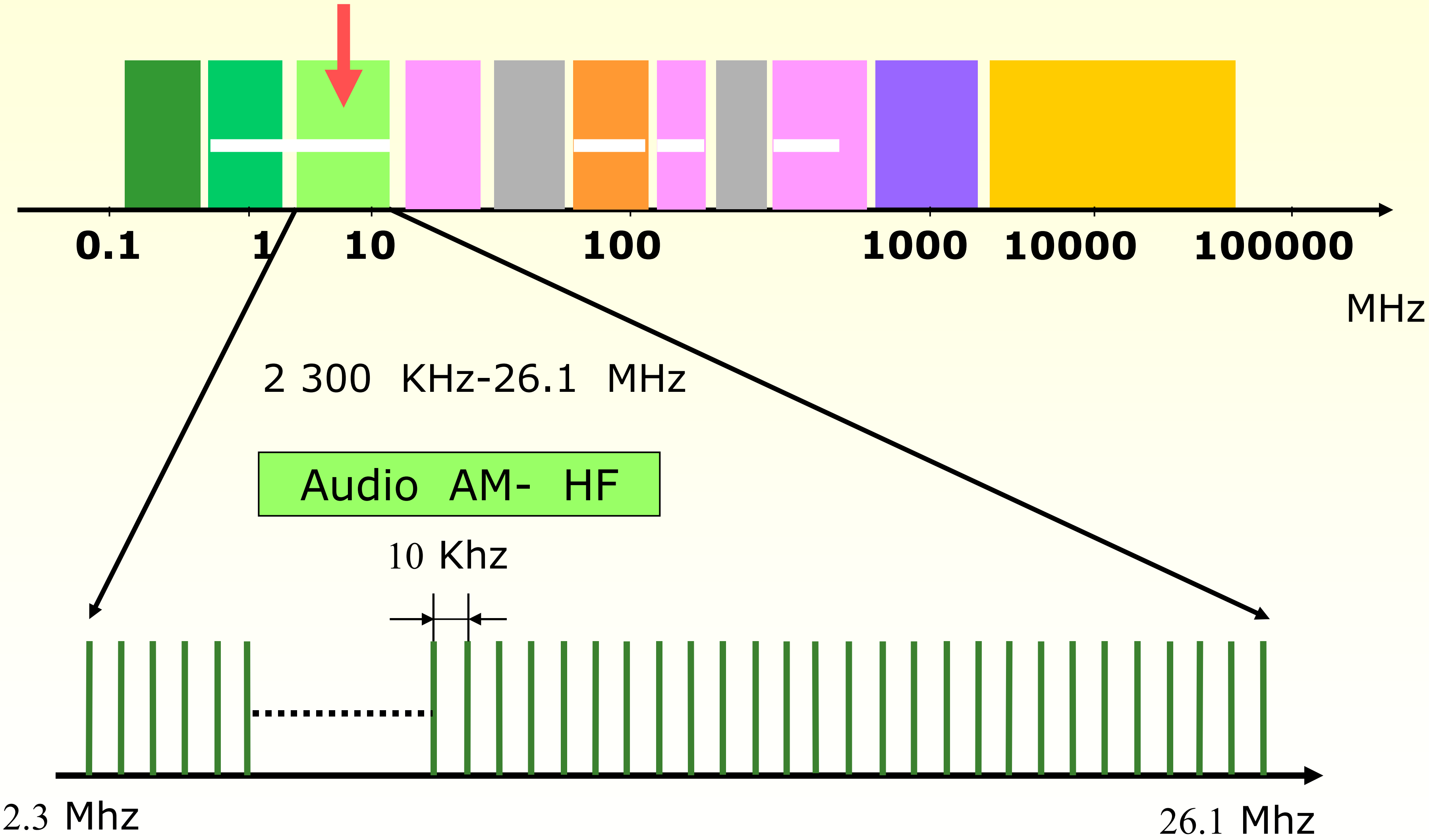
Radio Frequency



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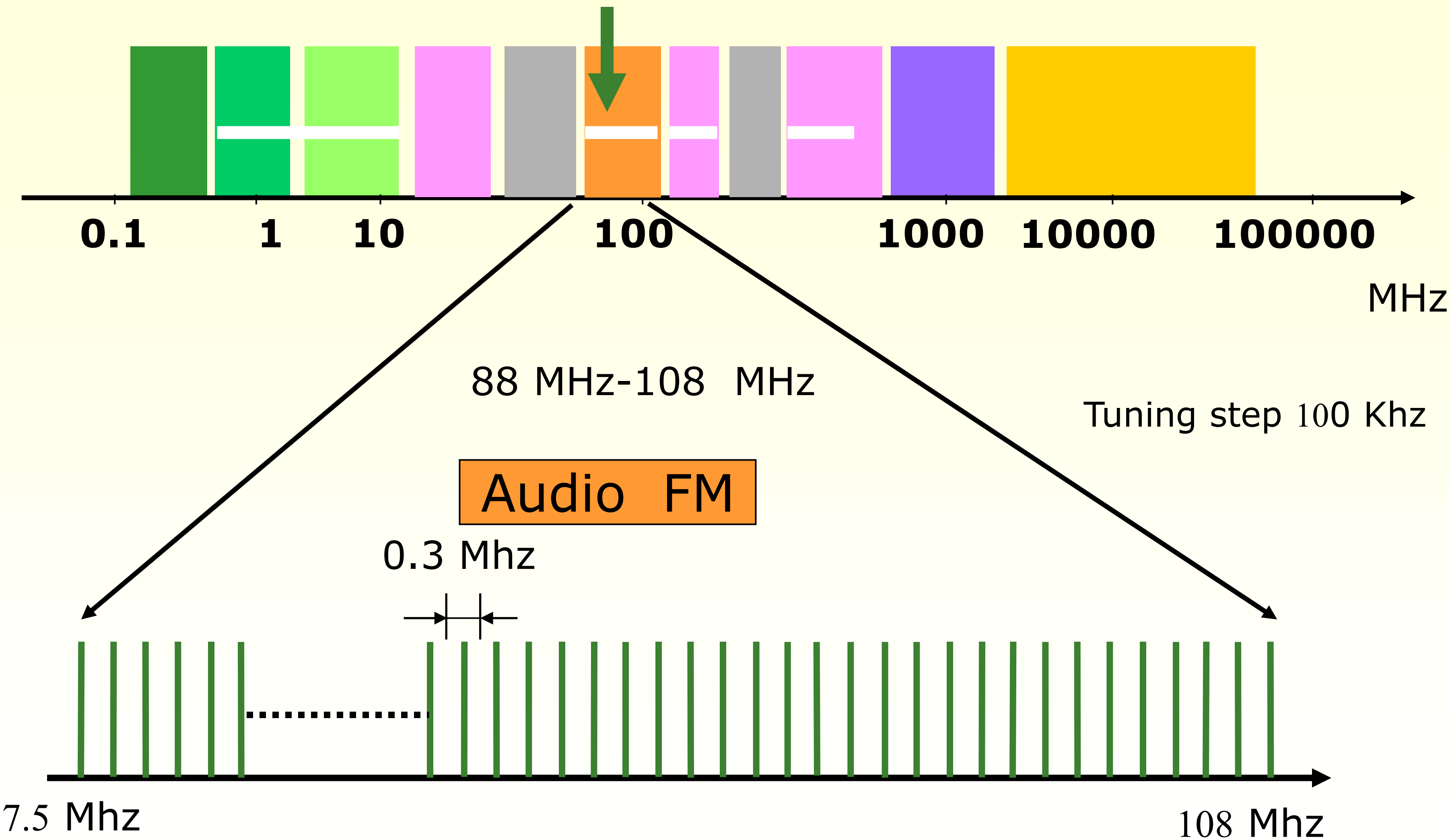
Radio Frequency



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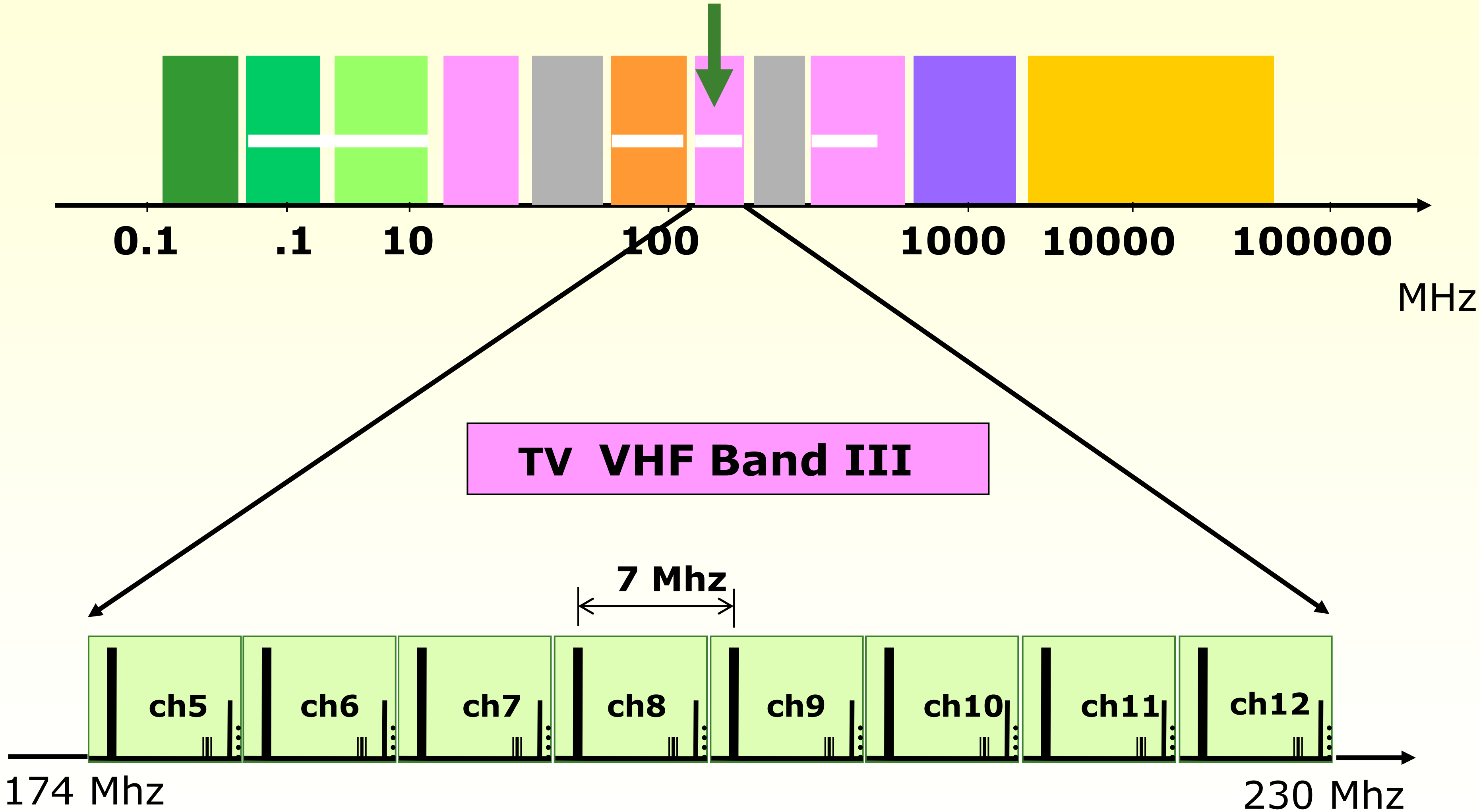
Radio Frequency



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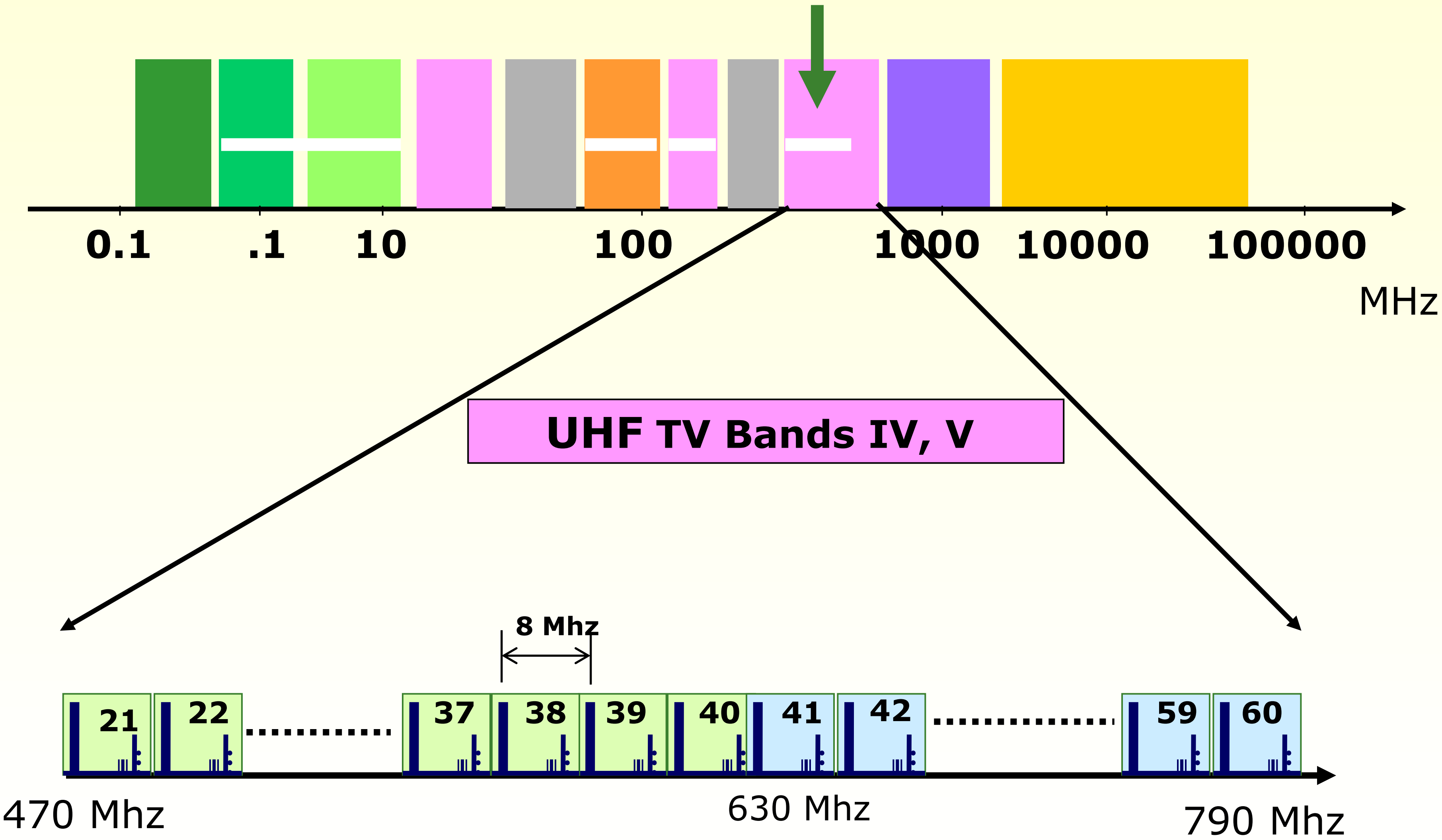
Radio Frequency



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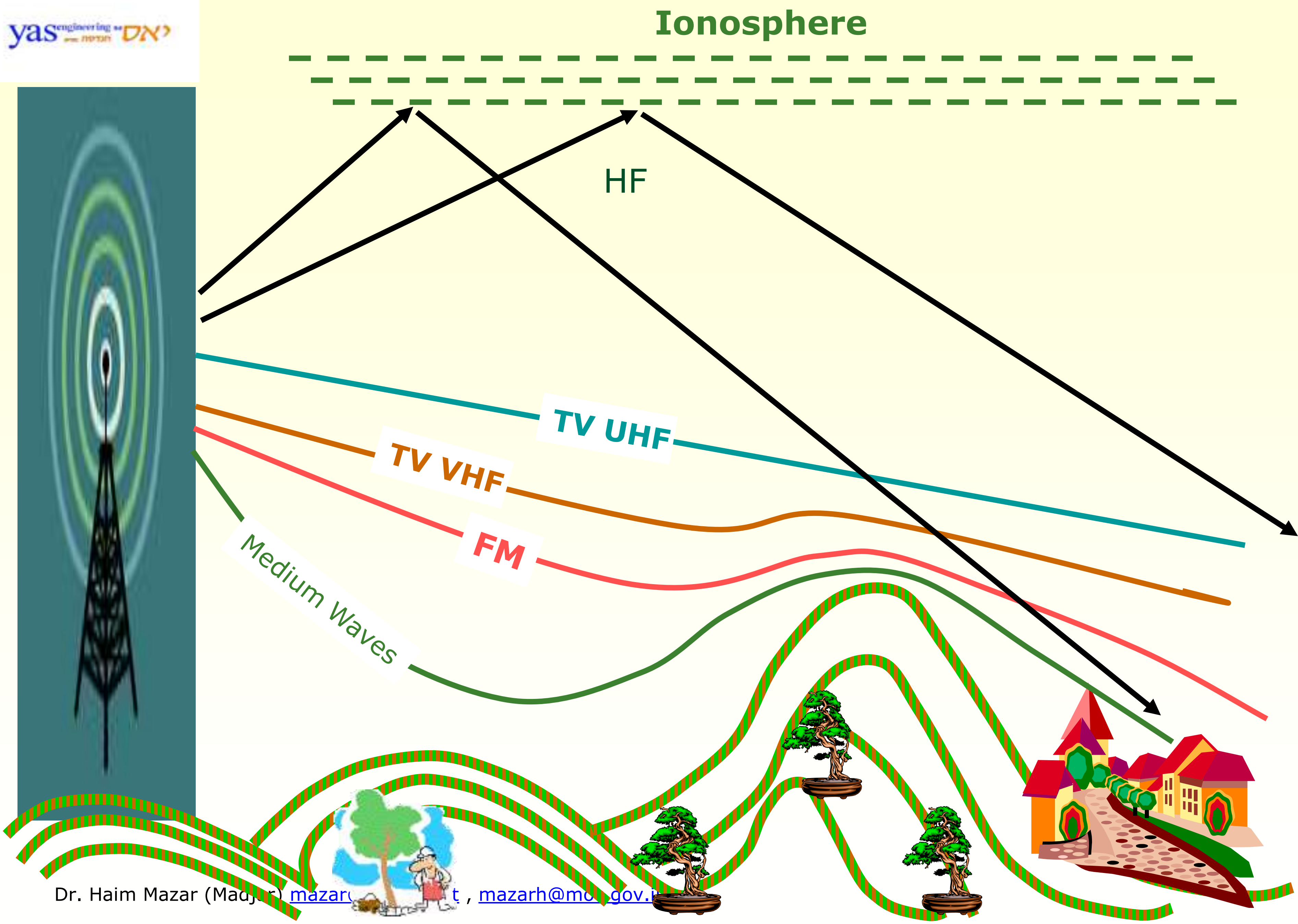
Band I and Band II TV Channel separation

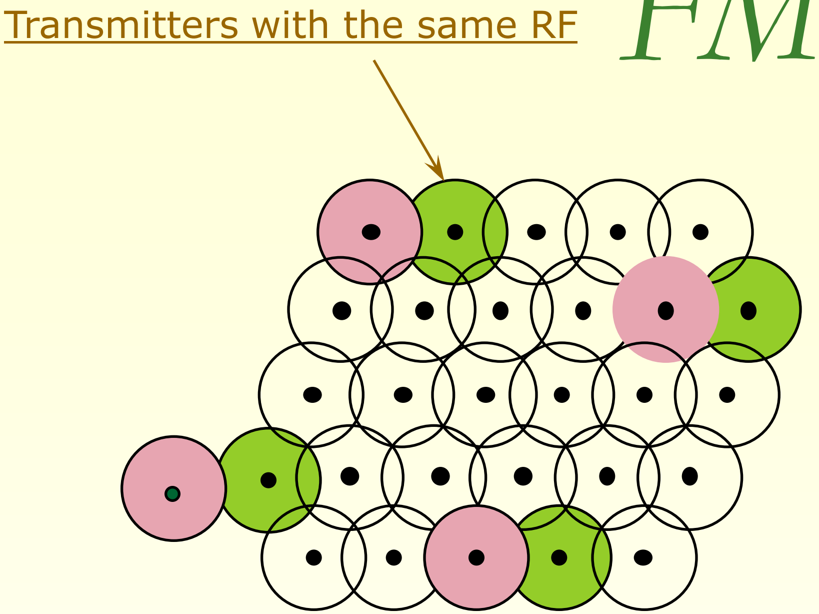
Channel number	*Channel Limits (7 MHz channel spacing)*
2	47 – 54
3	54 – 61
4	61 – 68
5	174 – 181
6	181-188
7	188 – 195
8	195 – 202
9	202 – 209
10	209 – 216
11	216 – 223
12	223 – 230

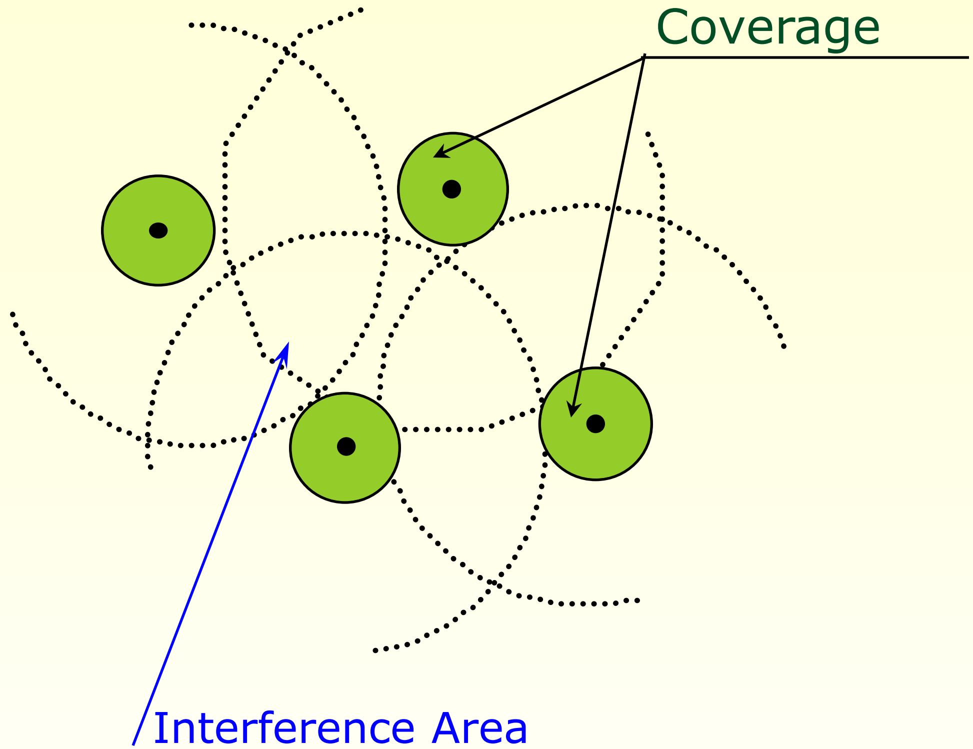
Ch. numbering in Band IV (ch. 21-34) & in Band V (ch. 35- 69)

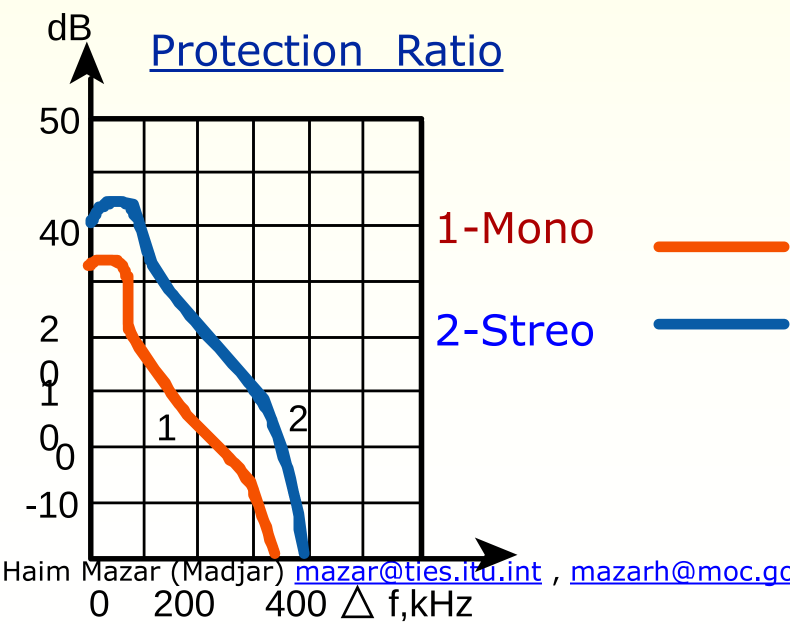
Channel number	*Channel limits*	*Channel number*	*Channel limits*
21	470 - 478	51	710 - 718
22	478 - 486	52	718 - 726
23	486 - 494	53	726 - 734
24	494 - 502	54	734 - 742
25	502 - 510	55	742 - 750
26	510 - 518	56	750 - 758
27	518 - 526	57	758 - 766
28	526 - 534	58	766 - 774
29	534 - 542	59	774 - 782
30	542 - 550	60	782 - 790
31	550 - 558	61	790 - 798
32	558 - 566	62	798 - 806
33	566 - 574	63	806 - 814
34	574 - 582	64	814 - 822
		65	822 - 830
35	582 - 590	66	830 - 838
36	590 - 598	67	838 - 846
37	598 - 606	68	846 - 854
38	606 - 614	69	854 - 862
39	614 - 622		
40	622 - 630		
41	630 - 638		
42	638 - 646		
43	646 - 654		
44	654 - 662		
45	662 - 670		
46	670 - 678		
47	678 - 686		
48	686 - 694		


Ionosphere
HF
TV UHF
TV VHF
FM
Medium Waves

FM Network







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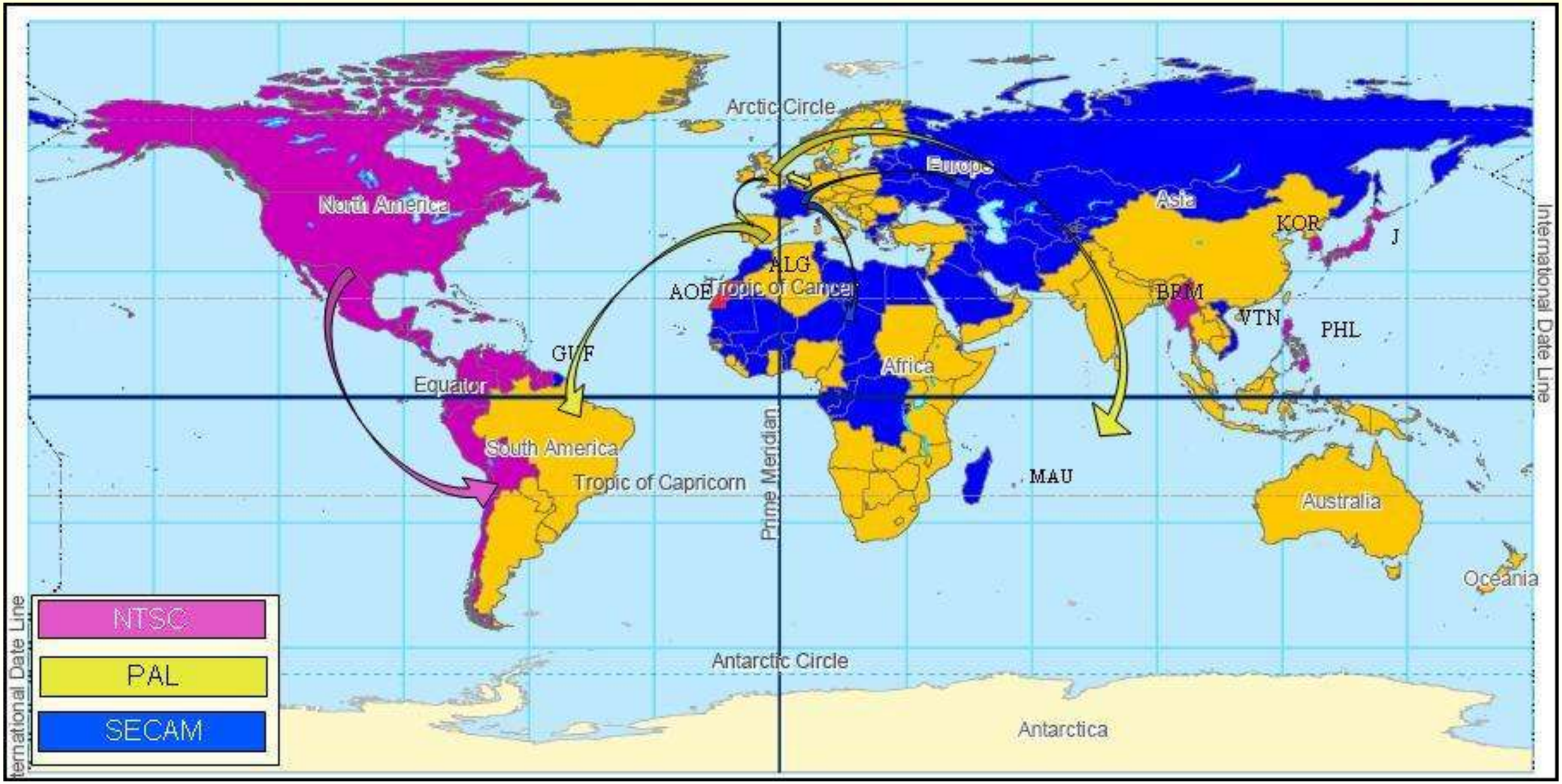
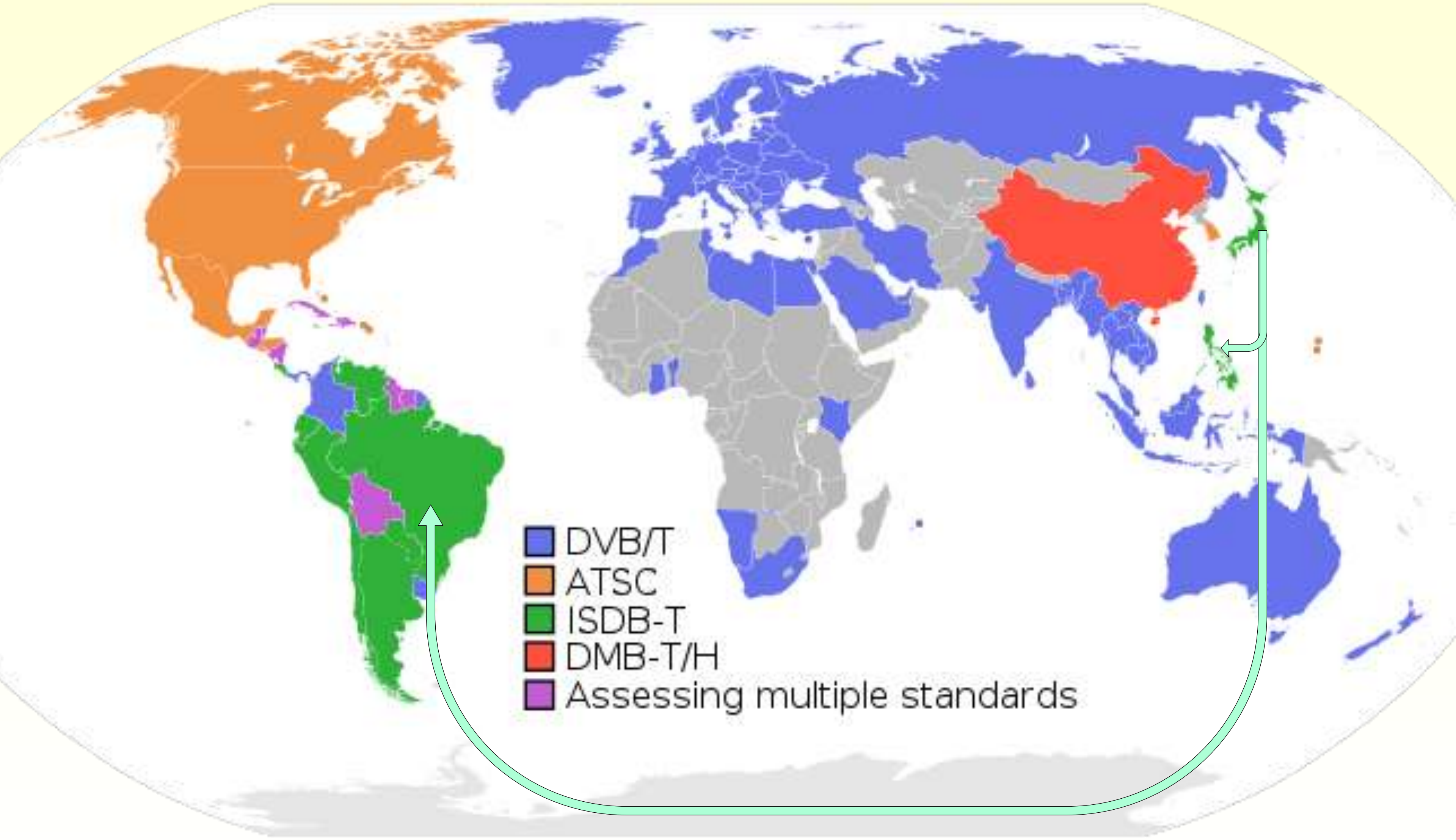
TV colours; analogue TV around the world

Influence of language (English or French) and colonialism



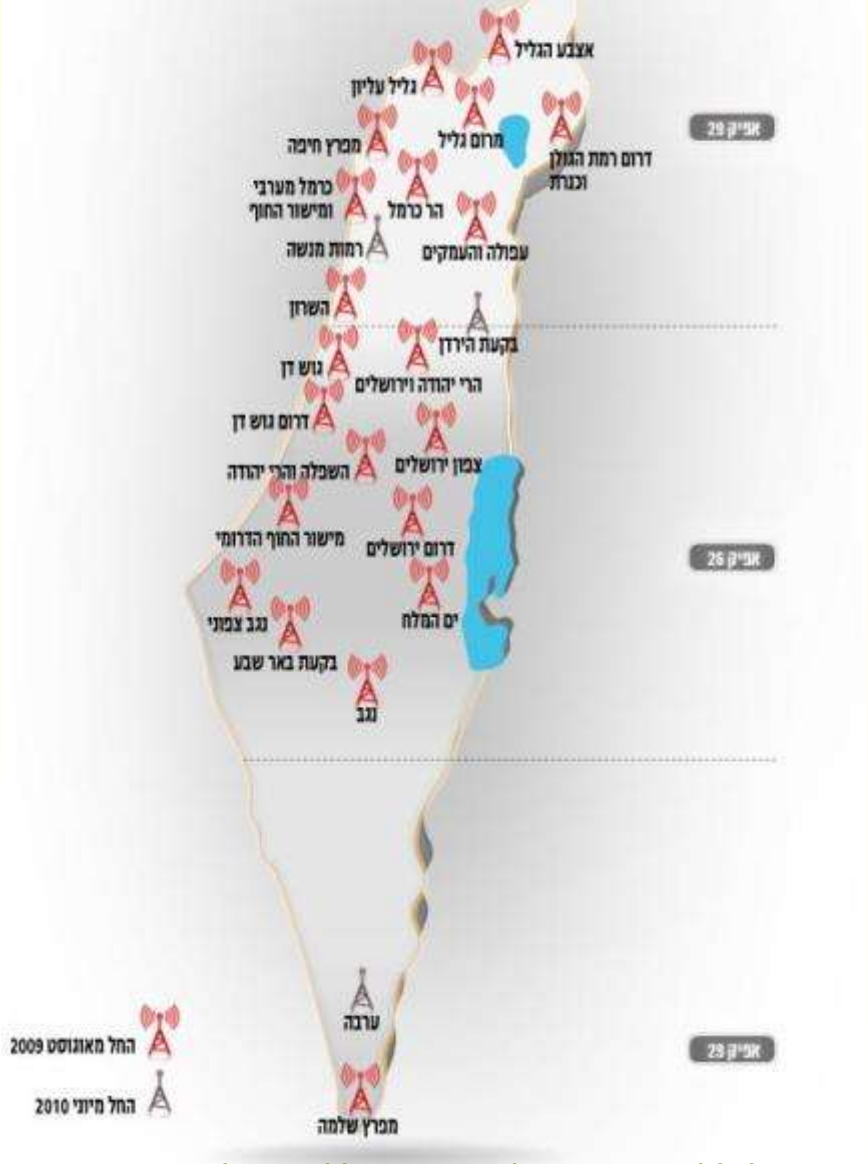
See http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 184

Digital Terrestrial Television (DTT) broadcasting systems by country



See http://en.wikipedia.org/wiki/File:Digital_broadcast_standards.svg 2 July 2010

2 digital 8 MHz UHF channels cover all Israel



Channel 29

Channel 26

Channel 29

See http://www.rashut2.org.il/idan_map.asp 9 January 11

Digital Switchover and Dividend

1. Digital switchover saves RF spectrum
2. Digital TV multiplexes don’t need all the VHF and UHF bands allocated today to the analog TV, for the same transmissions
3. Switchover requires homes to upgrade their aerials and their direction
4. The free RF spectrum is very useful for the land-mobile service
5. International http://www.itu.int/dms_pub/itu-d/opb/hdb/D-HDB-GUIDELINES.01-2010-R1-PDF-E.pdf and Regional activities

Questions to be Asked

1. Except competition to satellites and cable, do we really need over-the-air terrestrial TV?
2. Which Standard: DVB-T, ISDB-T? ATSC? DMB-T? (check Channel Separation)
3. Free view or paid? Will HD be free also? HD or Ultra HD, 3D?
4. How many programs to transmit? Subsidise set-top box?
5. Business model of DVB-H? Cellular Operators or Broadcasters transmit the DVB-H? Which Regulator?

LTE parameters in 800 MHz

ETSI and3GPP band plan for Band Class 20

3GPP bandplan for class 20	Downlink (DL) operating band BS transmit UE receive			Uplink (UL) operating band BS receive UE transmit			Duplex Mode
	F_{DL_low}	–	F_{DL_high}	F_{UL_low}	–	F_{UL_high}	
20	791 MHz	–	821 MHz	832 MHz	–	862 MHz	FDD

3GPP bandplan for class 20	TX - RX carrier centre frequency separation
20	41 MHz

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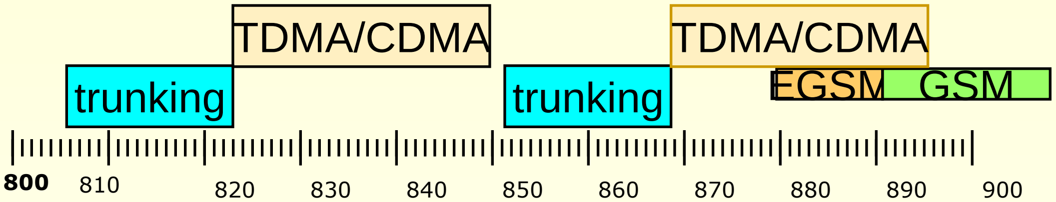
Digital Dividend 790-862 MHz: Present 800/900 MHz Cellular, Trunking & TV allocations

04 July 2010

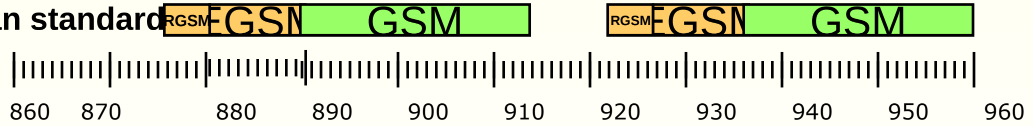
European and American RF allocations

US
System standard



EUROPEEN
UHF TV standard

System European standard



European Radio Telephones RDT 201

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Planning, Protection of land mobile and fixed systems from terrestrial digital video and audio broadcasting systems

1. PP2%20Tables TV\REC-M1767TV_M.pdf
2. PP2%20Tables TV\REC-F1670TV_FIX.pdf

Wireless Telecommunications

Enrichment Material

Fixed and Land Mobile Services

http://people.itu.int/~mazar/

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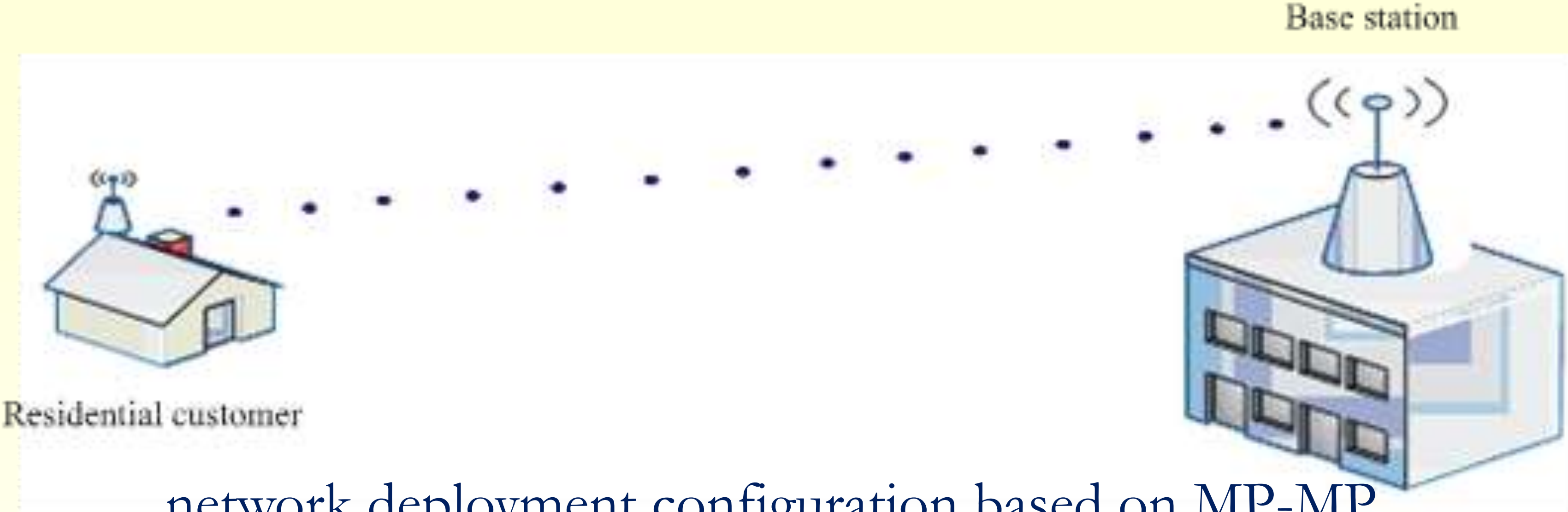
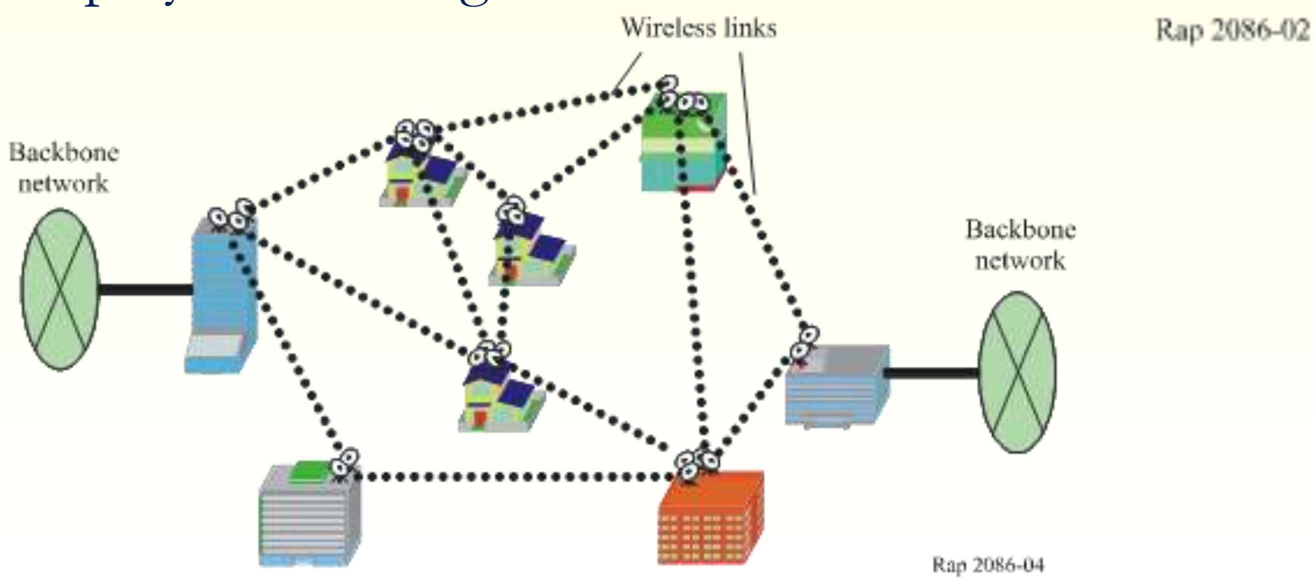
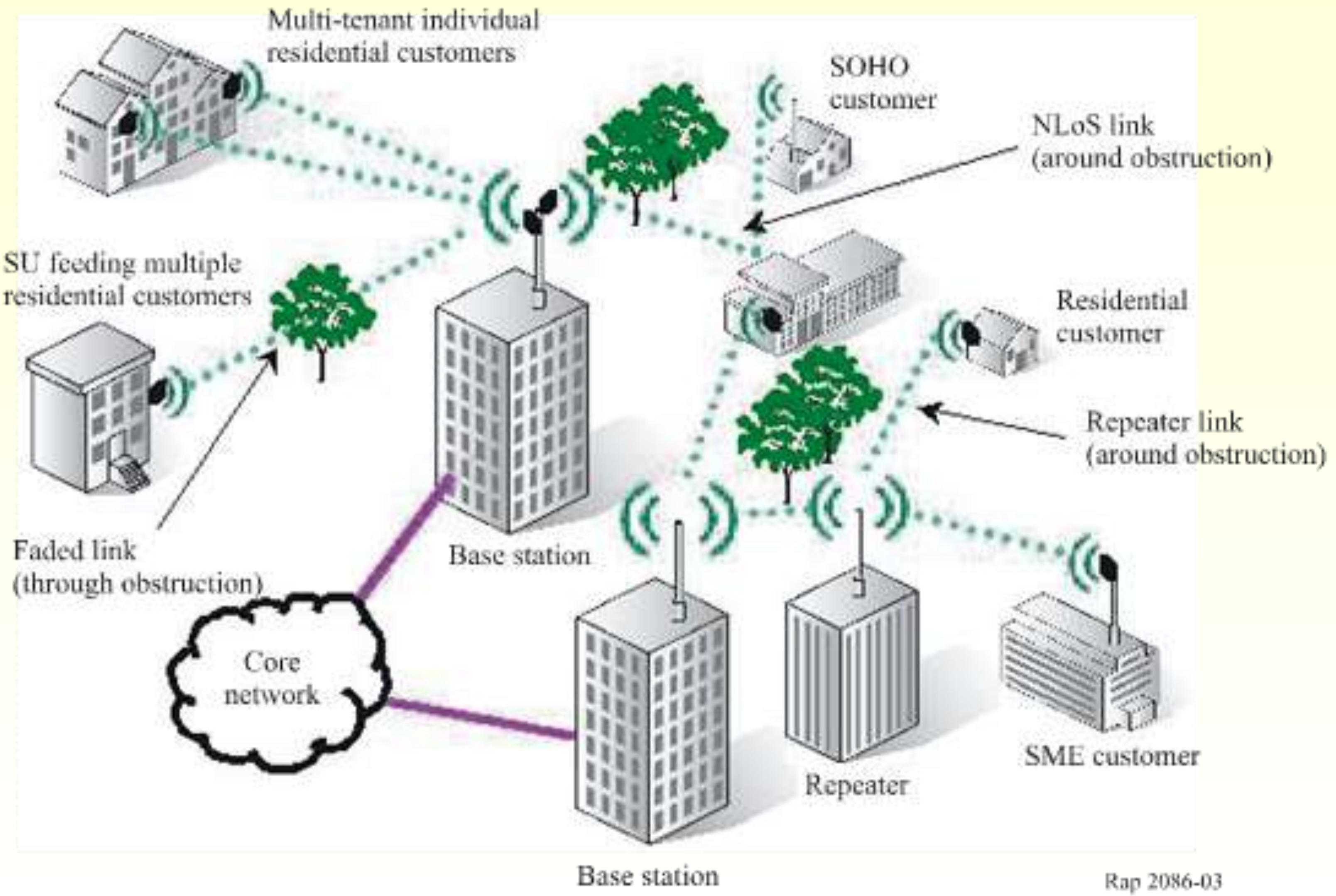
Illustrating network deployment configuration based on P-P configuration



network deployment configuration based on MP-MP



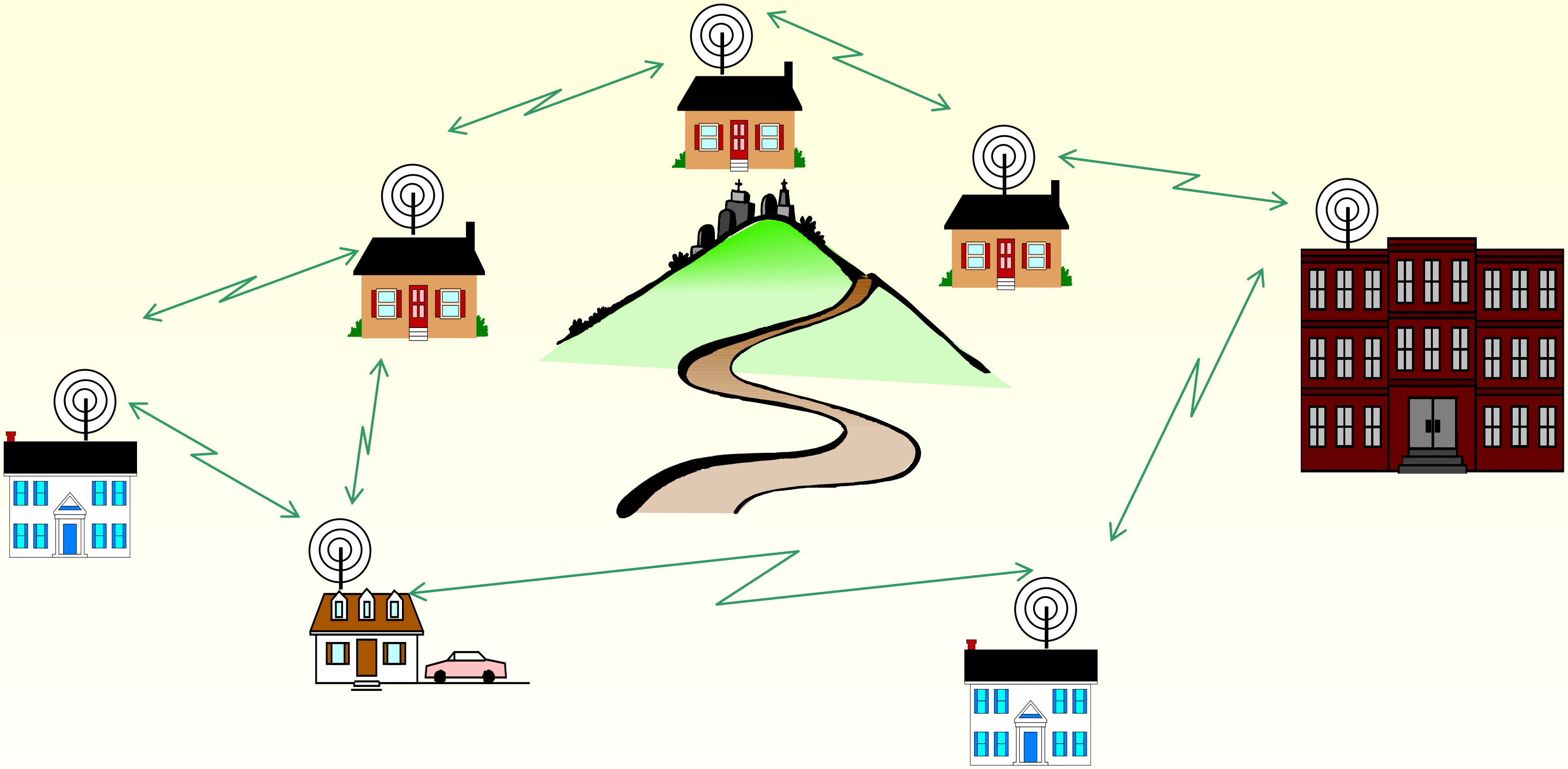
Illustrating network deployment configuration based on P-MP configuration



Acronyms and Abbreviations

BRAN	Broadband radio access network (ETSI)
BS	Base station
BWA	Broadband wireless access
CDMA	Code division multiple access
FDD	Frequency division duplex
FWA	Fixed wireless access
ISP	Internet service providers
LAN	Local area network
LoS	Line-of-sight
MIMO	Multiple input multiple output
MPEG4	Moving Picture Experts Group 4
MP-MP	Multipoint-to-multipoint
NLOS	Non-line-of-sight
P-P	Point-to-point
P-MP	Point-to-multipoint
QoS	Quality of service
RLAN	Radio local area network
SDH	Synchronous digital hierarchy
SME	Small medium enterprise
SOHO	Small office home office
ST	Subscriber terminal
SU	Subscriber unit
TCP/IP	Transmission control protocol/Internet protocol
TDD	Time division duplex
VoIP	Voice over Internet protocol
WAN	Wide area network
WAS	Wireless access systems

Mesh Network; Mobile & RLAN, ITU-R LMHB



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Point-to-Point Link Budget

Link budget (dB) = Tx power (dBm)

- \+ Transmitting antenna gain (dBi)
- \+ Receive antenna gain (dBi)
- – Receive Sensitivity (–dBm)
- – Antenna cable losses
- – RF fade margin
- – Interference margin

Fade Margin

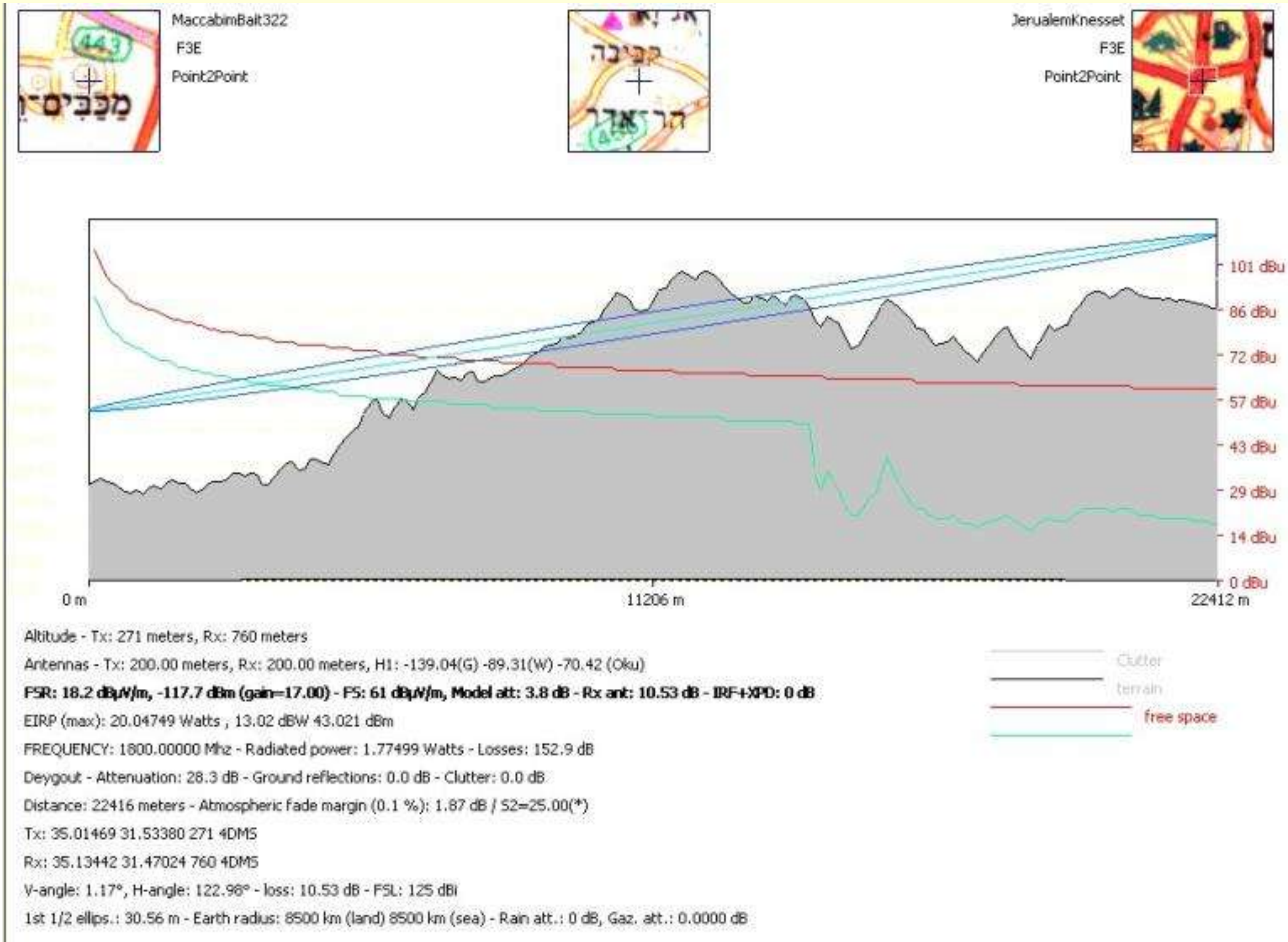
$$FM = P_r - P_{r,min}$$

or:

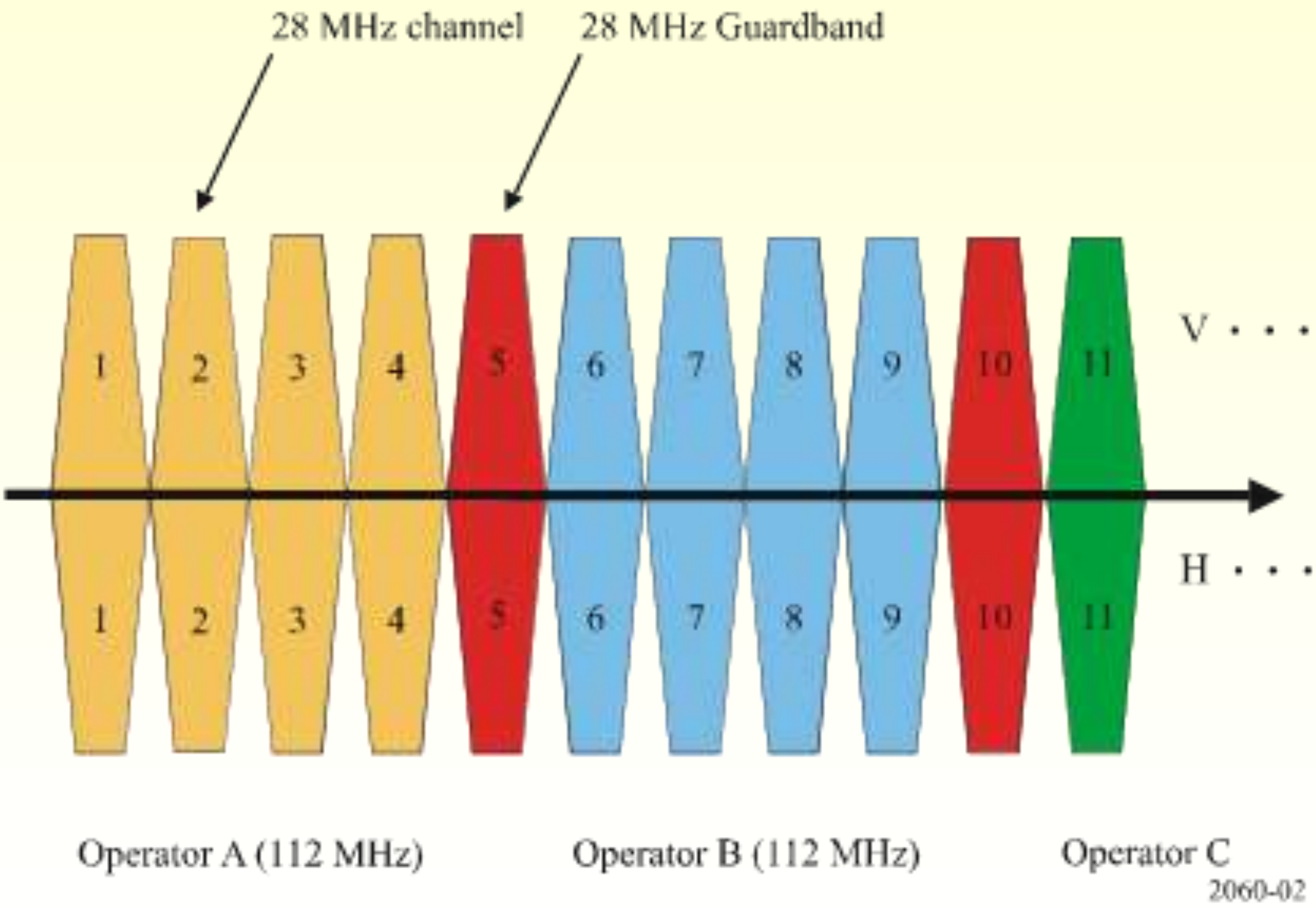
- $$FM = G_e + G_r + P_e - L_T(p) - FL - P_{r,min}$$
- *FM*: fade margin
- P_e: input power at the emission (transmitter power) (dBm)
- $L_T(p)$: total loss (rain at p%, gas, diffraction) (dB)
- *FL*: feeder loss (total: at the emission and reception) (dB)
- $P_{r,min}$: min. level at the reception (usually for BER of 10^{-6}) (dBm)
- G_e: antenna gain at the emission (transmitter) (dBi)
- G_r: antenna gain at the reception (receiver) (dBi).

If only P-P FS systems are considered, in the following calculation usually $G_e = G_r = G$.

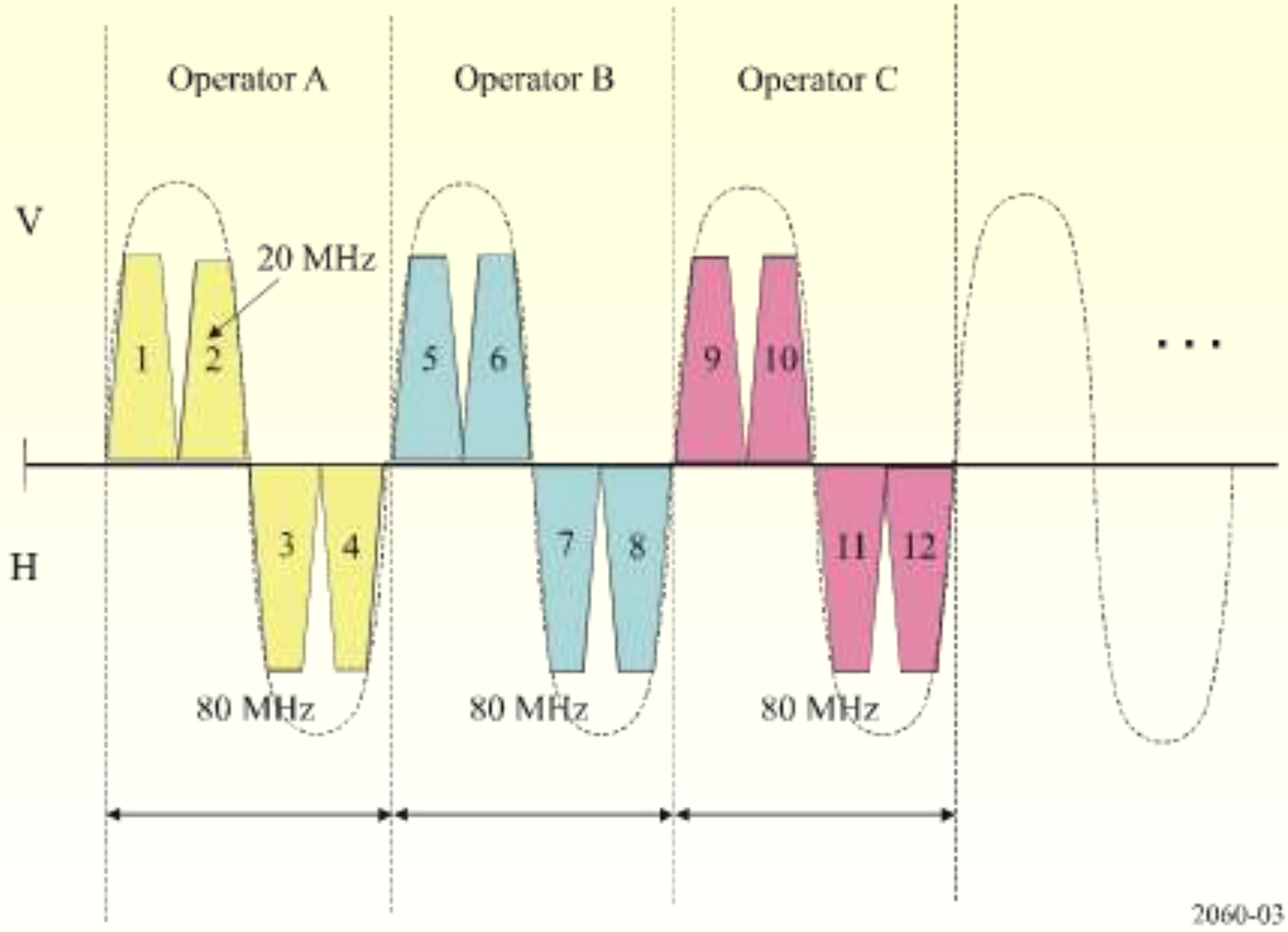
Profile P2P Maccabim-Jerusalem



Example of block and guardband assignment

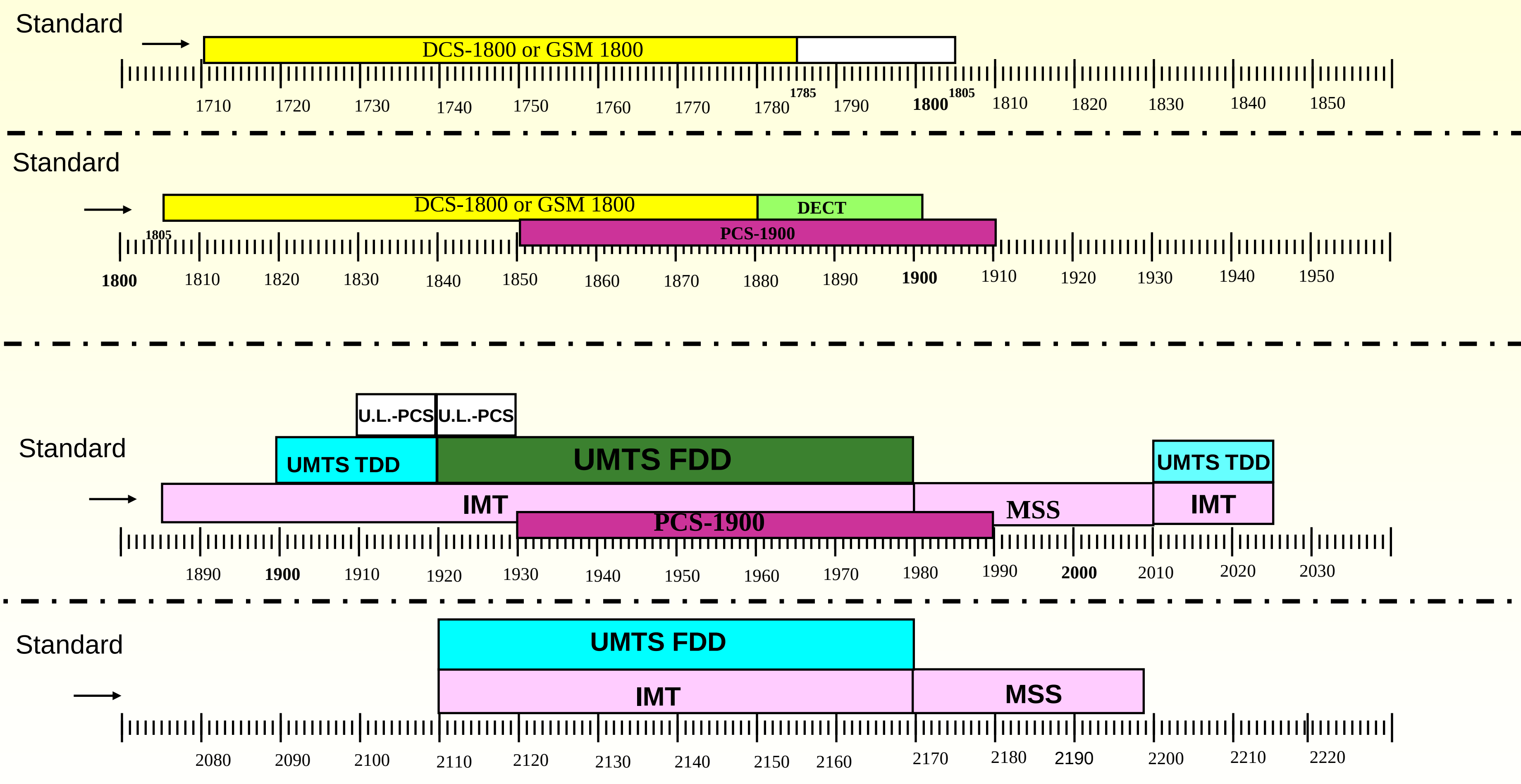


Interleaved assignment without guardband



LAND Mobile Standards 1700-2200 MHz

15 October 2008



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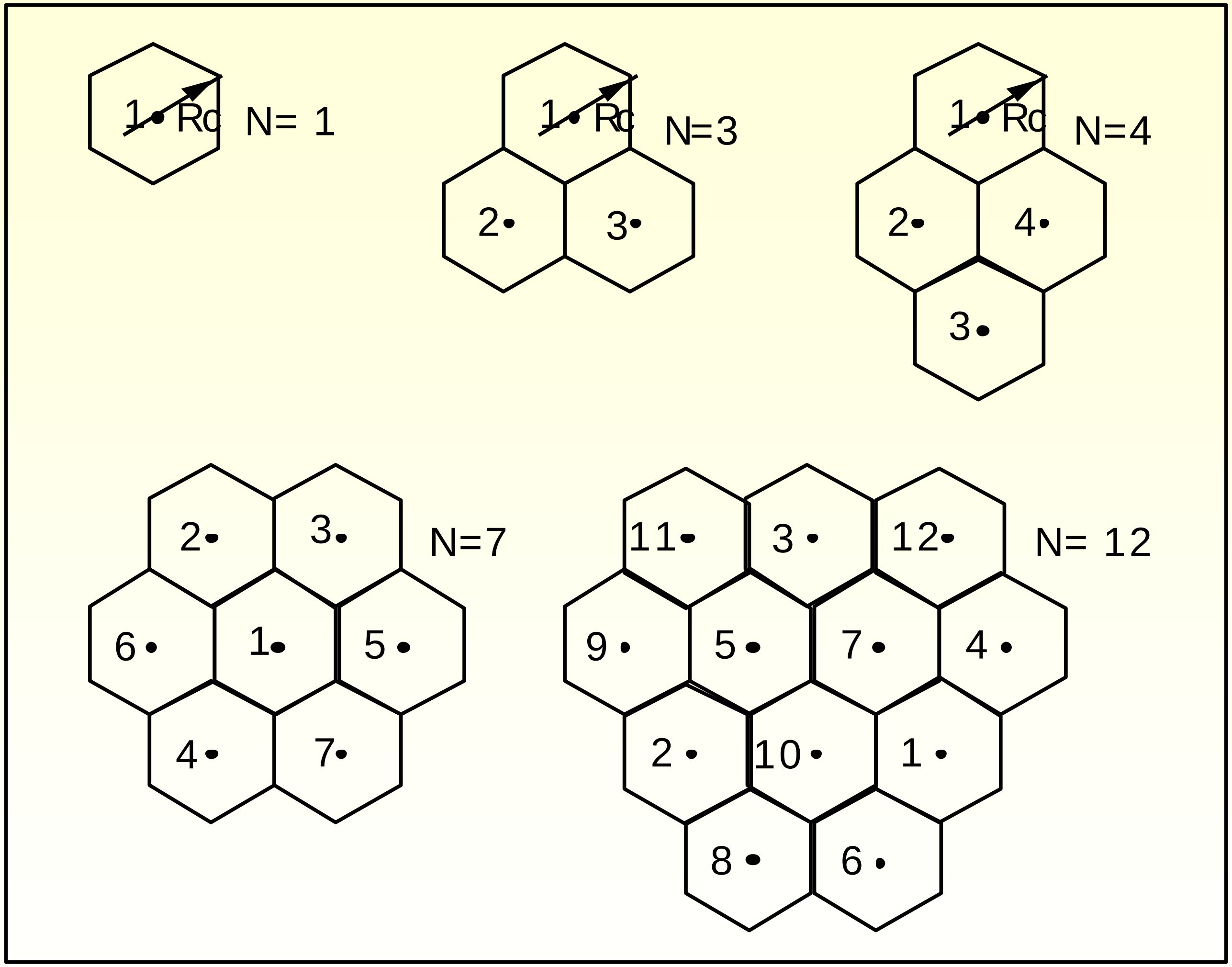
Typical cell clusters and re-use



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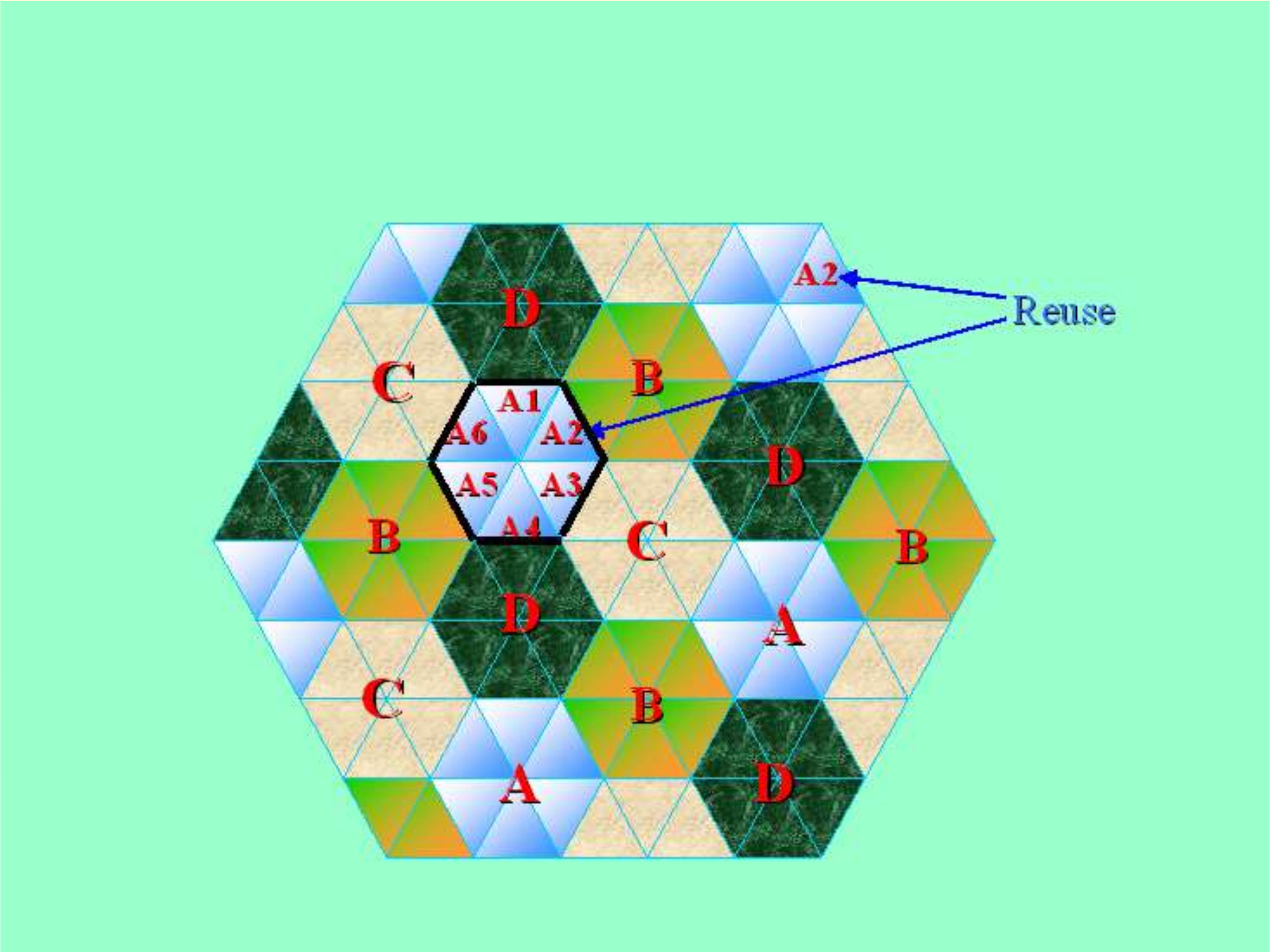
Land Mobile- Reuse



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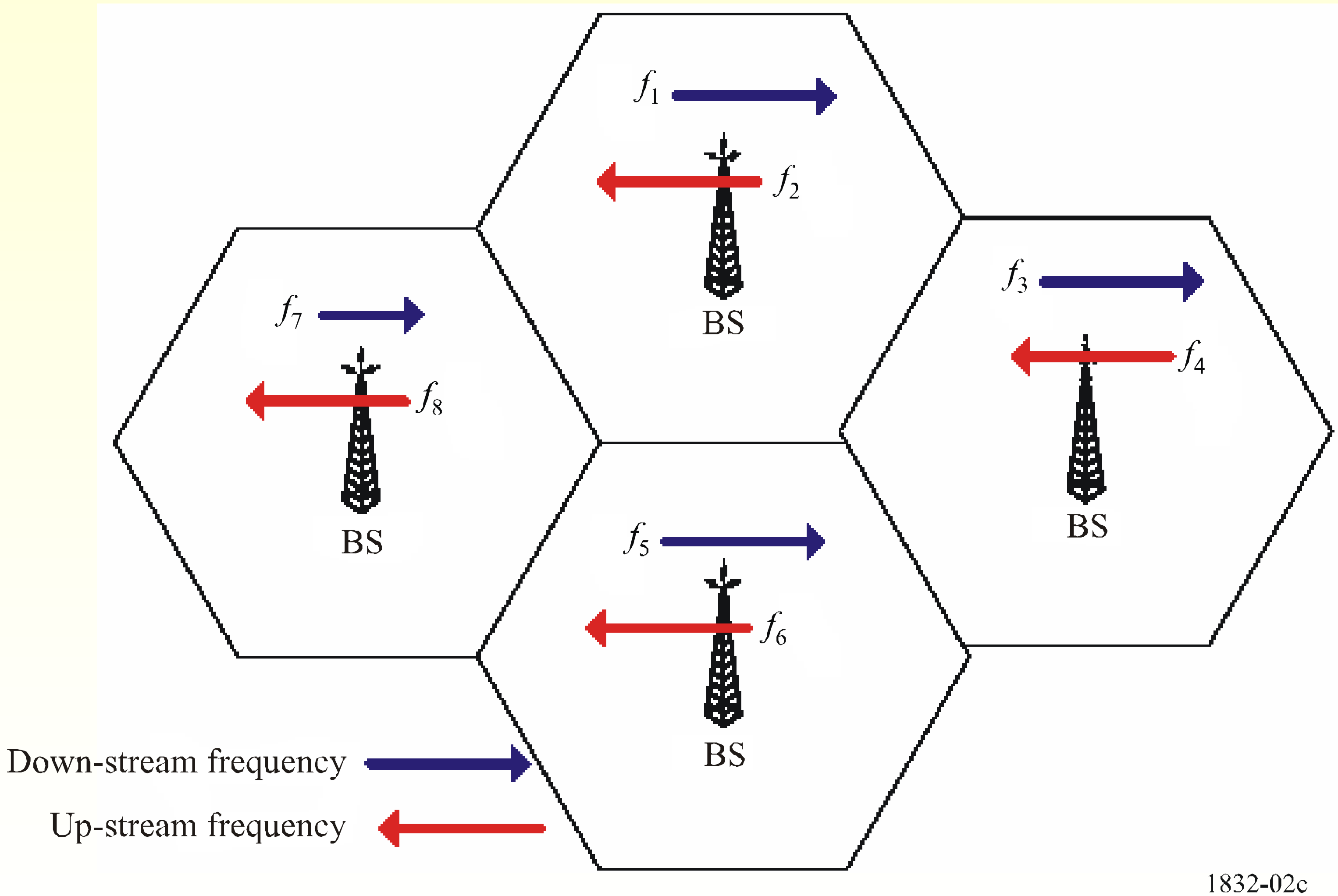
Land Mobile- Up and Down Links



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Wireless Telecommunications

Enrichment Material

Radar Systems

http://people.itu.int/~mazar/

Radar (Radio Detection And Ranging)

1. **Radar** is an object-detection system which uses mainly radio waves to determine the range, altitude, direction, or speed of both moving and fixed objects
2. **Civil Applications**: Air Traffic Control (including altimetry and flight-control); Nautical Radars(landmarks and other ships); a/c and cars anti-collision; ocean-surveillance; outer-space surveillance and rendezvous ; meteorology; ground-penetrating radar (geological observations, coins), astronomy
3. **Military Applications**: air-defense and fire control - Acquisition (bistatic, monostatic) (phased array antennas), tracking (conical scan, monopulse), illumination, detonation; antimissile; protection (a/c, tanks, fence)

Radar Free Space Basic Transmission Loss

σ: radar target cross-section *d*: distance from the radar to the target λ: wave length

$$P_{TARGET} = PFD \cdot A_e = \left(\frac{g_T P_T}{4\pi d^2}\right) \times \sigma$$

$$P_{received} = \left(\frac{g_T P_T}{4\pi d^2}\right) \times \sigma \times \left(\frac{1}{4\pi d^2}\right) \times \left(\frac{g_T \lambda^2}{4\pi}\right) = P_{Transmit} g^2 \times \sigma \times \left(\frac{\lambda}{4\pi d^2}\right)^2 \frac{1}{4\pi}$$

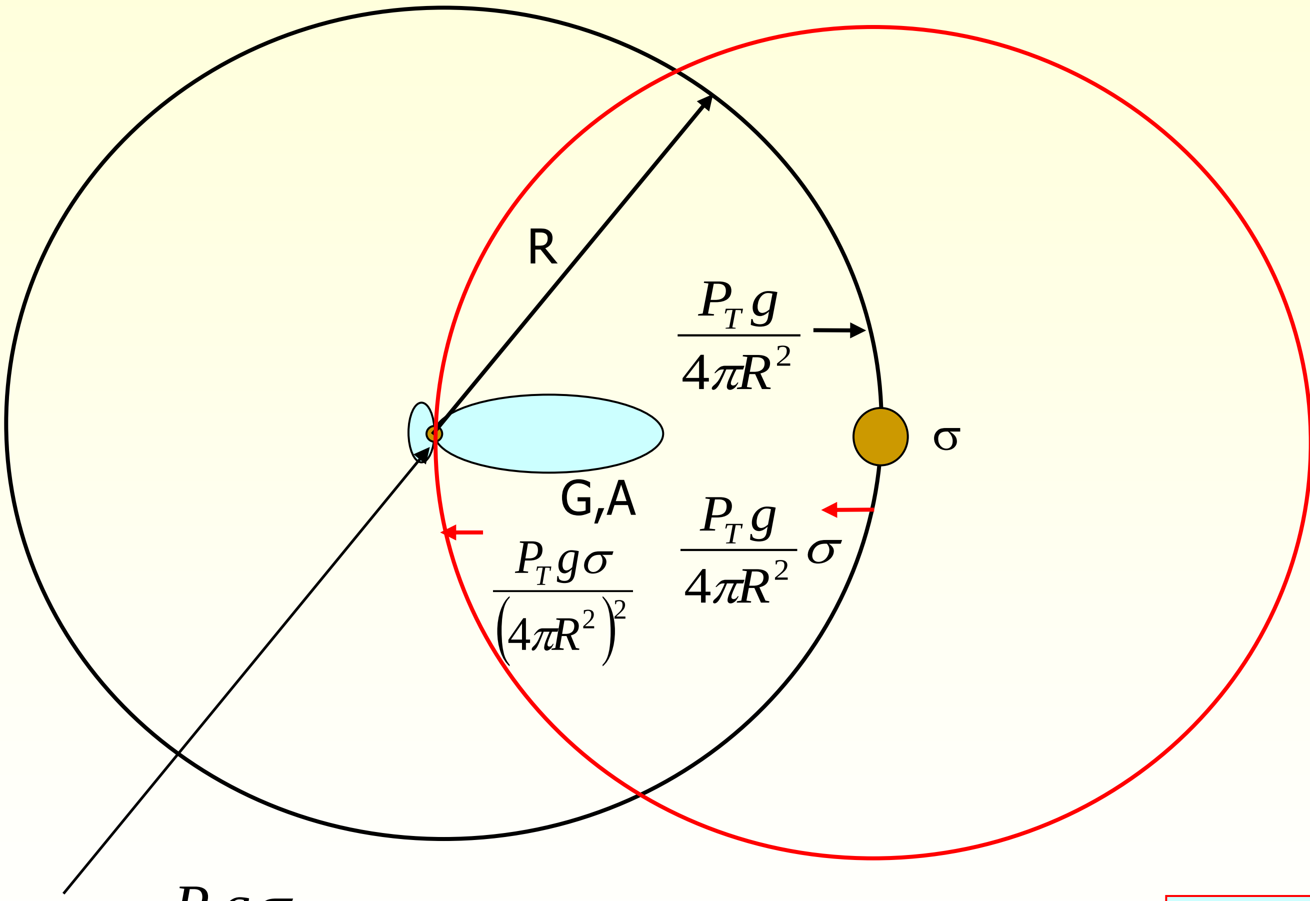
$$P_{received} = P_{Transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 d^4}$$

P minimal discernable signal= KTBFS/N. For pulse radar B≈ $\frac{1}{\tau}$

Exercise*: prove that for* pulse width t_o and *B= 1/* t_o the max detection range depends on Transmitted Energy and not only Transmitted Power

$$d_{max}{}^4 = P_{Transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 P_{min}} = P_{Transmit} g^2 \sigma \frac{\lambda^2 \tau}{(4\pi)^3 KTF} = Energy_{Transmit} g^2 \sigma \frac{\lambda^2}{(4\pi)^3 KTF}$$

The RADAR Equation



$$P_R = \frac{P_T g \sigma}{\left(4\pi R^2\right)^2} A$$

$$A = \frac{G\lambda^2}{4\pi}$$

$$P_R = \frac{P_T g^2 \lambda^2}{\left(4\pi\right)^3 R^4}\sigma$$

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Range ⇔ Delay

$$R = \frac{1}{2} C_p \tau$$

Range

2-way

Velocity of propagation

Delay

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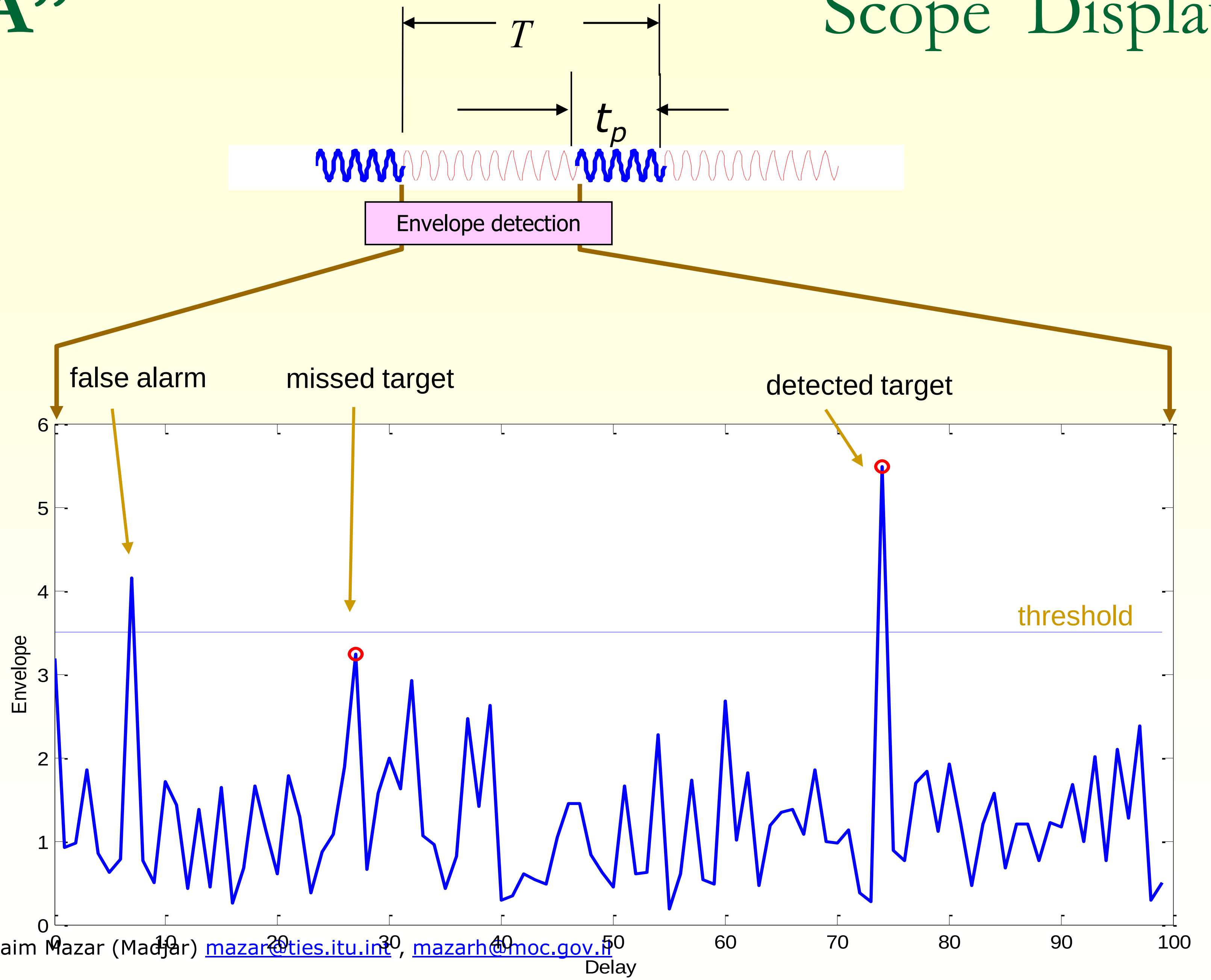
"A" Scope Display



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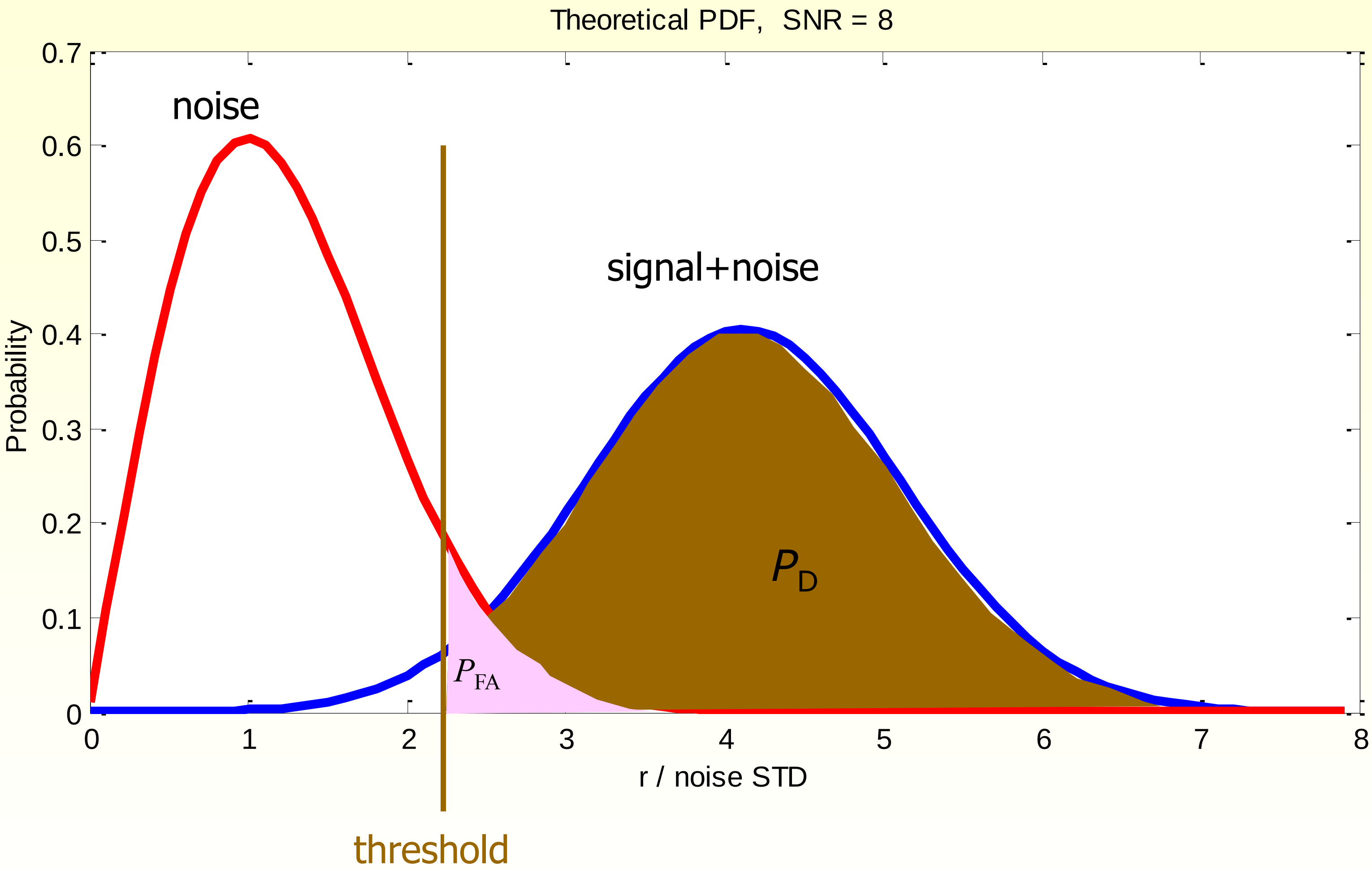
Pulse Detection Probability



Single pulse non-fluctuating

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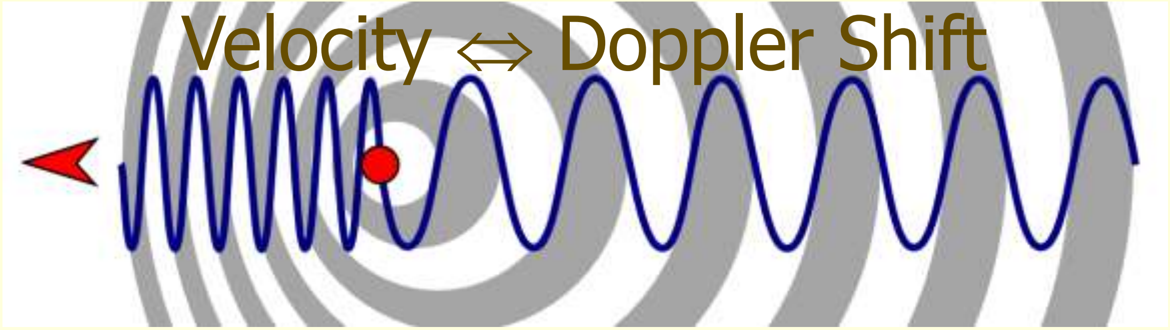
Velocity ⇔ Doppler Shift



$$f_D \approx -2\frac{\dot{R}}{\lambda}$$

Range rate

Wavelength

2-way

Doppler shift

Velocity of propagation

$$\lambda = \frac{C_p}{f_0}$$

Carrier frequency

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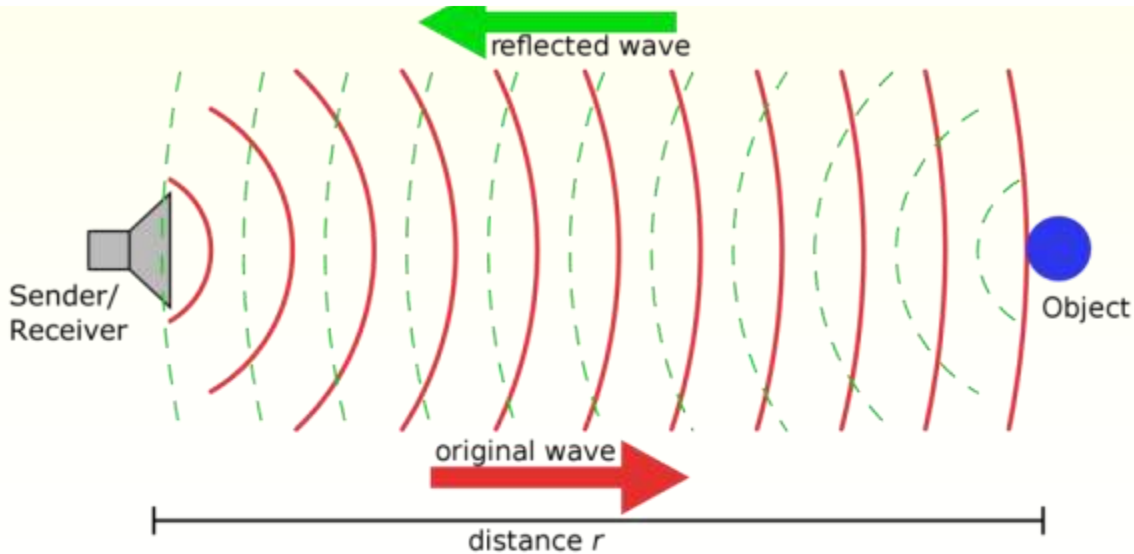
Values of Doppler Shift

From M.A. Richards, Georgia Tech

Band	Frequency (GHz)	Doppler shift (Hz) for v = 1 m/s
L	1	6.67
C	6	40.0
X	10	66.7
K_a	35	233
W	95	633



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Radar Frequency Bands $c=\lambda f$

From M.A. Richards, Georgia Tech

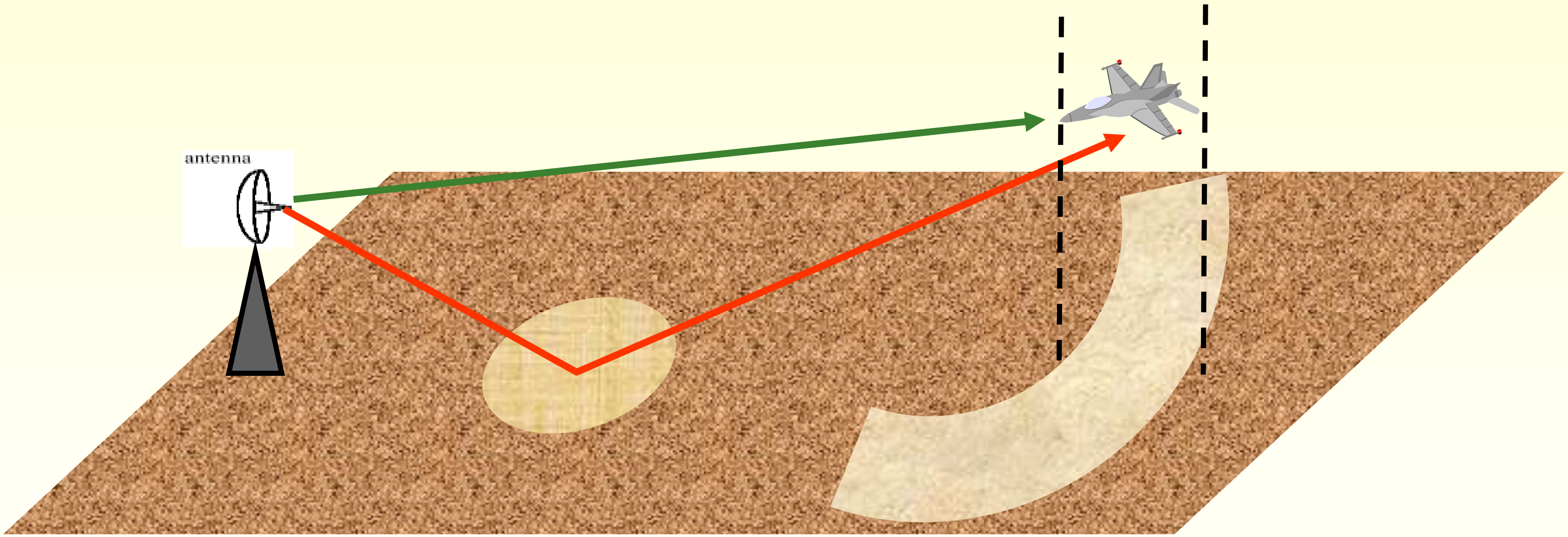
Band	*Frequencies*	*Wavelengths*
HF	3 - 30 MHz	100 m - 10 m
VHF	30 - 300 MHz	10 m - 1 m
UHF	300 MHz - 1 GHz	1 m - 30 cm
L	1 - 2 GHz	30 cm - 15 cm
S	2 - 4 GHz	15 cm - 7.5 cm
C	4 - 8 GHz	7.5 cm - 3.75 cm
X	8 - 12 GHz	3.75 cm - 2.5 cm
K_u	12 - 18 GHz	2.5 cm - 1.67 cm
K	18 - 27 GHz	1.67 cm - 1.11 cm
K_a	27 - 40 GHz	1.11 cm - 7.5 mm
mm	40 - 300 GHz	7.5 mm - 1 mm

Measured antenna Plot (M1851)

Typical Pulse search Radar Parameters

- Transmitter power ………………………….. 1 MW
- Pulse width ………………………….. 1 μsec
- Mainbeam antenna gain…………. 43 dBi
- scan all directions (all sectors)
- Frequency range ………………. 3300-3500 MHz
- First sidelobe antenna gain ………. 20 dBi
- Backlobe antenna gain……………. 0 dBi
- 2nd harmonic output ……………. 73 dB down
- 3rd and higher harmonics ………. >80 dB down
- Receiver sensitivity ………………. -90 dBm

Ground Effects - Multipath and Clutter



Area contributing
to multipath

Area contributing
clutter at target's range

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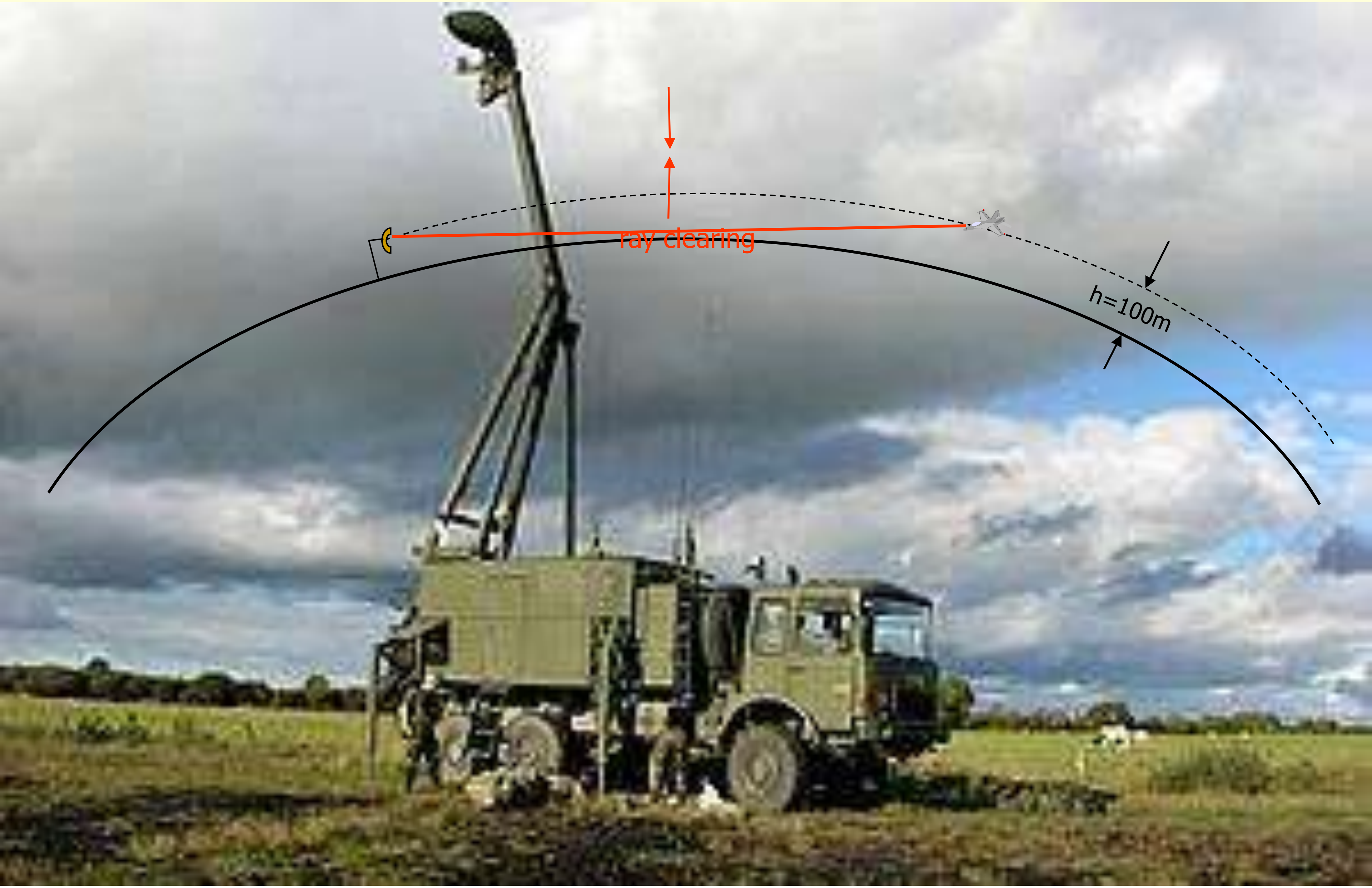
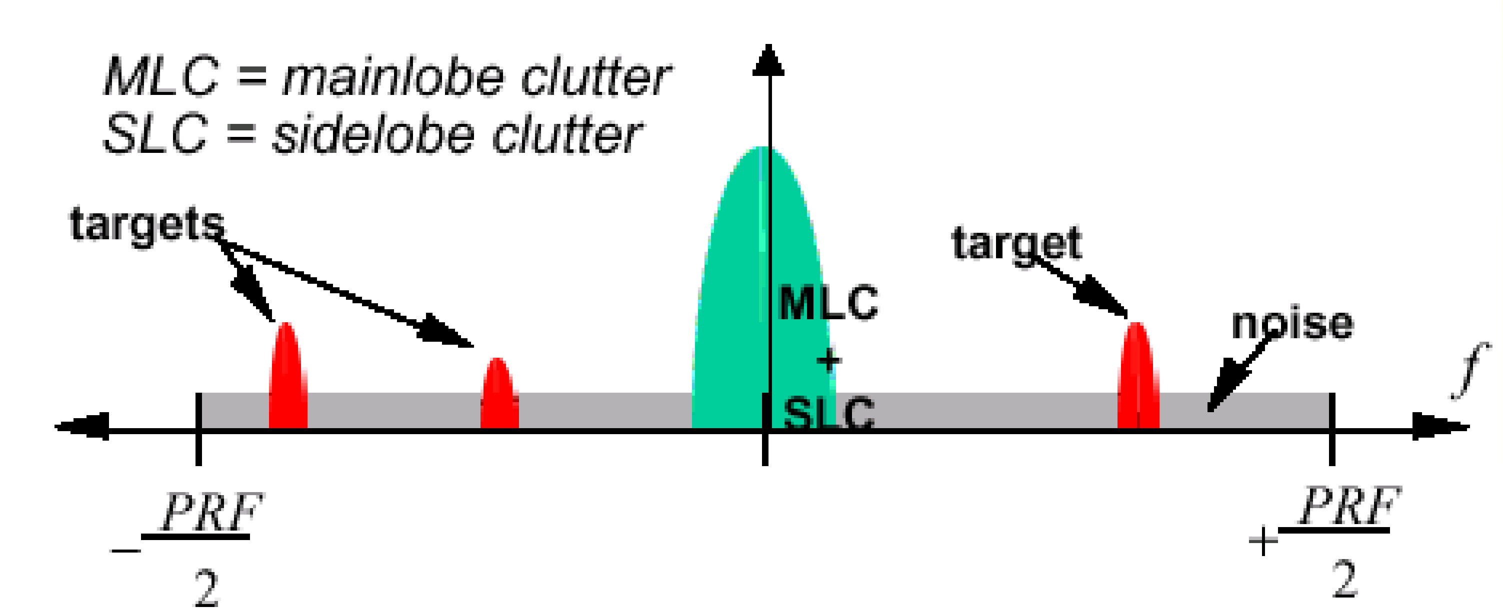
Line of Sight and Detecting Low Flying A/C



From M.A. Richards, Georgia Tech

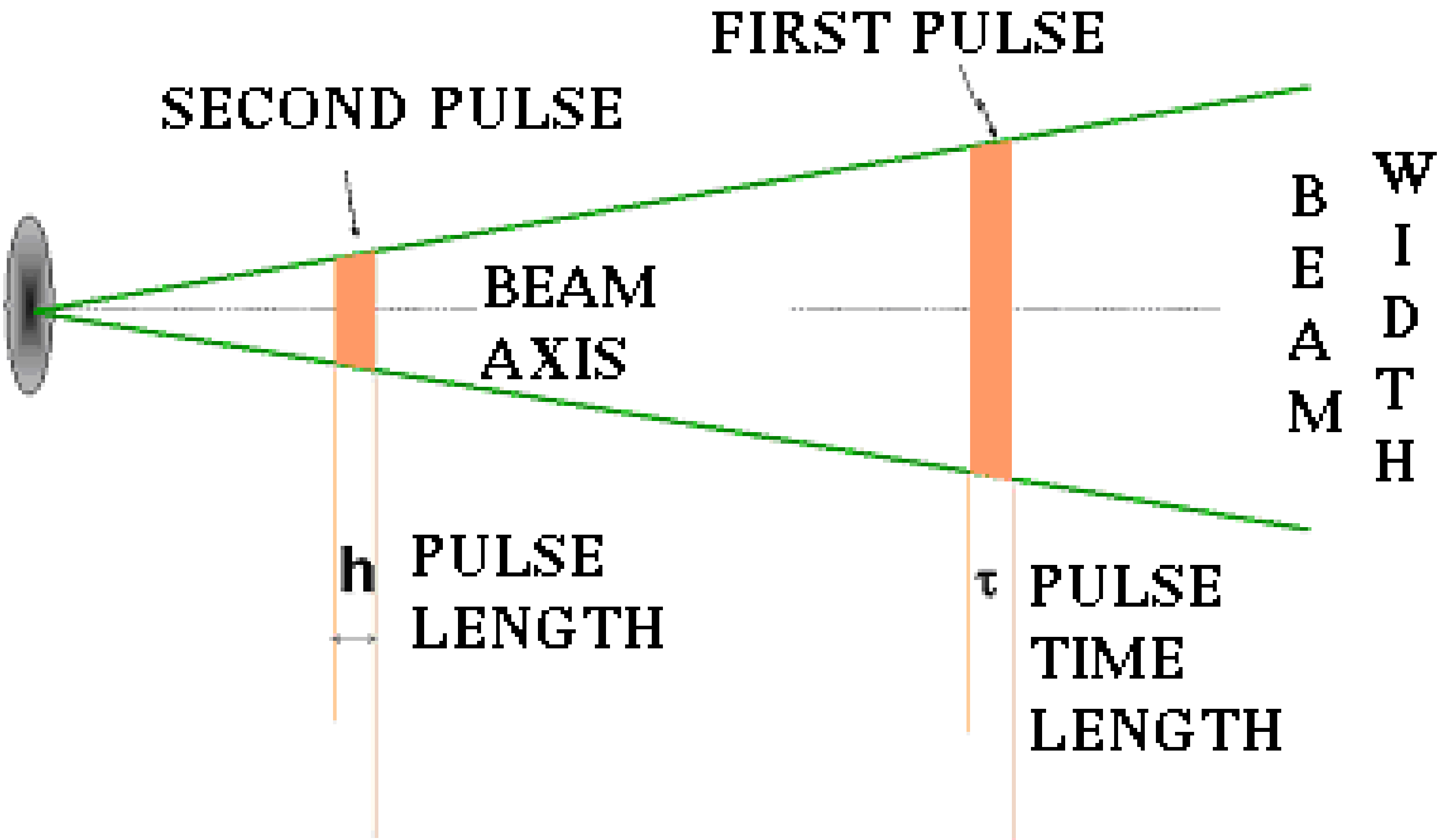
MOVING TARGET INDICATOR (MTI) or DOPPLER PROCESSING

- Involves coherent processing of a pulse train (plain or compressed)
- Purposes: Separate weak returns of moving targets from large clutter returns
- Two basic approaches:
  - Bank of filters (usually DFT)
  - Pulse cancelers



Dr.

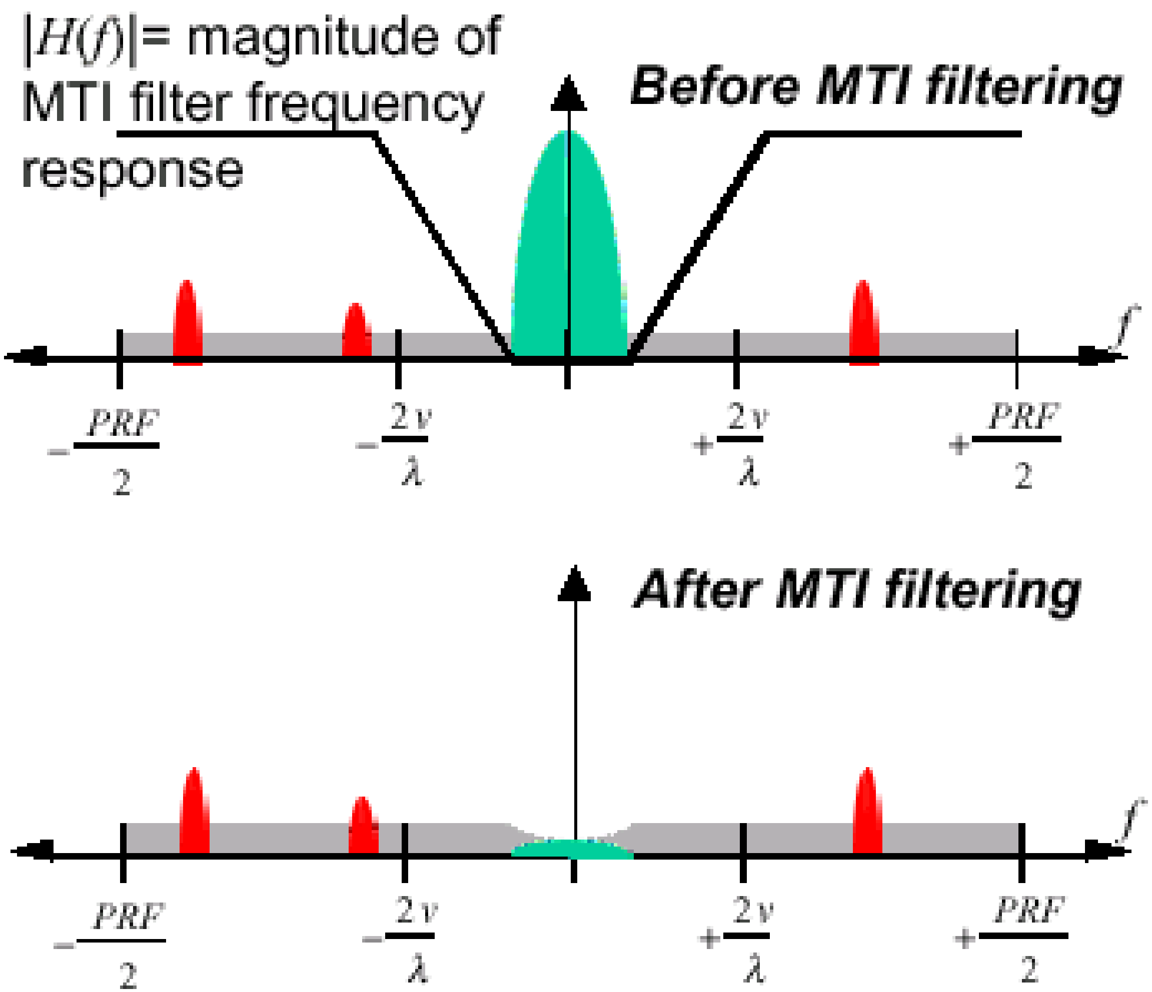
Unambiguous Range



The Concept of Moving Target Indication (MTI)

From M.A. Richards, Georgia Tech

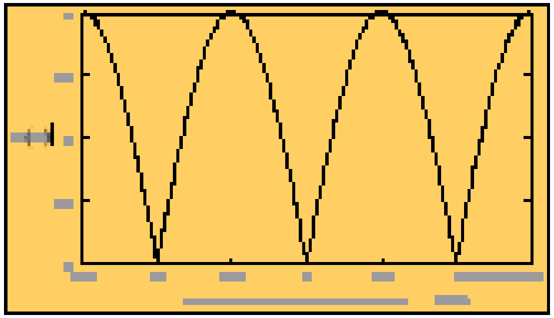
- MTI filtering applies a high-pass filter to the data in each slow-time row
- Filter output retains noise, moving target(s), but has reduced clutter
  - goes to detector next



Blind Speeds

From M.A. Richards, Georgia Tech

- MTI filters are digital filters, so frequency response is periodic
  - Nulls at multiples of PRF Hz
  - "Blind" to targets at corresponding radial velocity:
  - Could fix by raising PRF
- Unambiguous range is inversely proportional to PRF:
- Tradeoff in PRF choice required



$$v_{blind} = \frac{\lambda\, PRF}{2} = \frac{c\, PRF}{2 f_0}$$

$$R_{ua} = \frac{c}{2\, PRF}$$

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Unambiguous Range vs. Blind Speeds

From M.A. Richards, Georgia Tech

$$R_{UA} = \frac{C}{2} PRI = \frac{C}{2\,PRF}$$

$$PRF = \frac{C}{2R_{UA}}$$

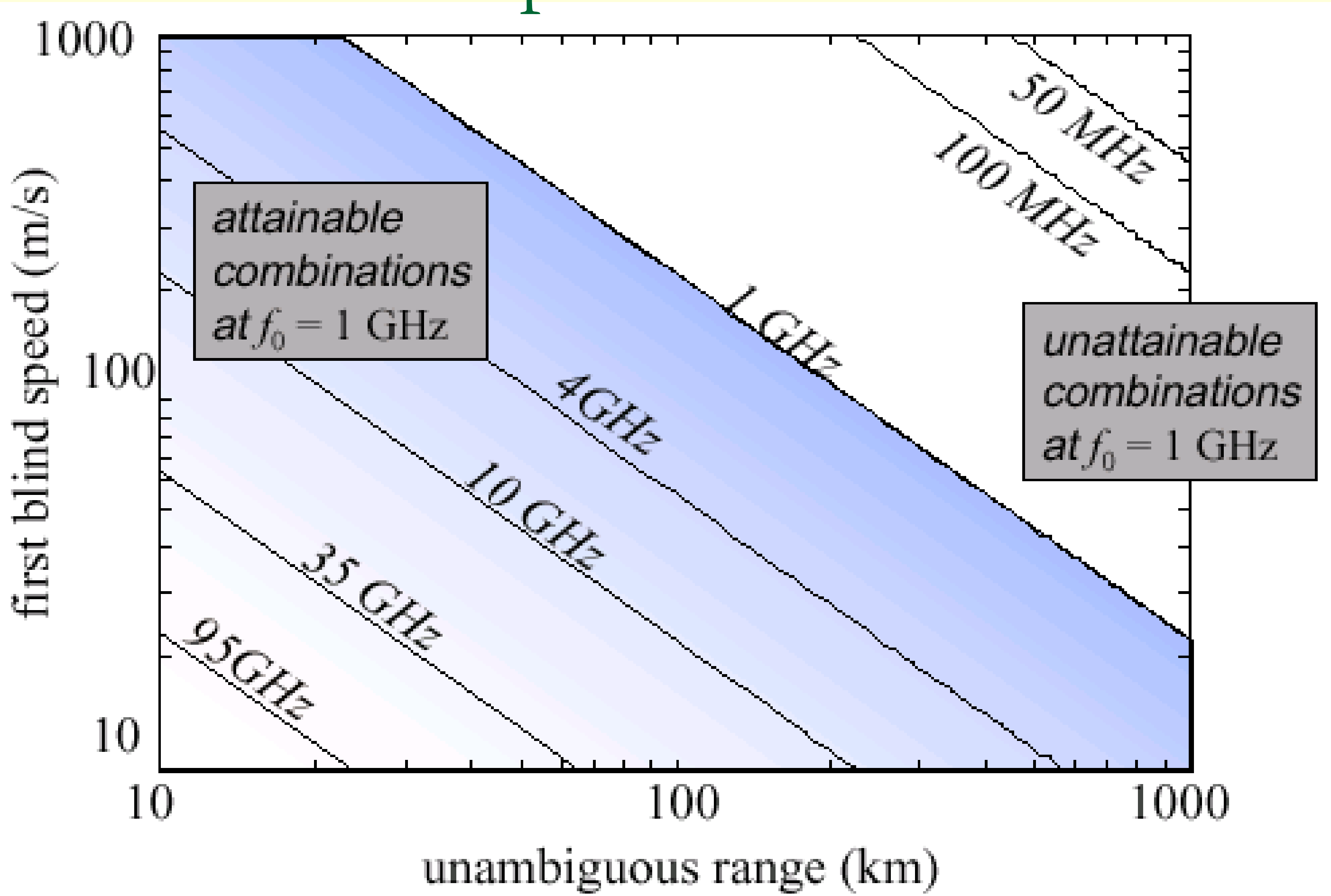
$$Doppler_{BS} = \frac{C}{2R_{UA}} = \frac{2V_{BS} f_c}{C}$$

$$PRF = \frac{2V_{BS}}{\lambda} = \frac{2V_{BS} f_c}{C}$$

$$V_{BS} R_{UA} = \frac{C^2}{4 f_c}$$

Blind Speeds vs. RF

From M.A. Richards, Georgia Tech



$$V_{\mathrm{BS}}\,[\mathrm{m/s}]\,R_{\mathrm{UA}}\,[\mathrm{km}] = \frac{22500}{f_c\,[\mathrm{GHz}]}$$

, mazarh@moc.gov.il

Staggered PRFs

From M.A. Richards, Georgia Tech

- A way to raise blind speed without significant effect on unambiguous range
- Concept: combine data from multiple PRFs
  - target is not simultaneously blind on all of them
- Two basic varieties:
  - pulse-to-pulse
  - block-to-block

Wireless Telecommunications

Enrichment Material

RF Regulation (exclusive views of the author)

http://people.itu.int/~mazar/

Spectrum Control (see ITU-R HB)

MONITORING

- **Predicted Data**
- **Reference data base: Users, Sites, Equipment**
- **Tasks & Priorities according to importance (safety of life), decision makers policy & Interference Complaints**

- **Measurements**
- **Eyes & Ears : Frequency, Occupancy, Power, Bandwidth, Direction, Polarization, Modulation.**
- **Infringements : Discrepancies, Illegal stations, Comparison to licenses.**

- **Common Display** : Visualisation of Monitoring results and Licence Data
- **Records, Reports, Statistical data & Analysis**
- **Broadcasting – Video,Audio & data, Fixed, Mobile…**
- **Coverage & Quality**
- **Interference** : Complaints, Investigation, Identification,
- **Enforcement and Clearance**

MANAGEMENT

Items which need to be regulated

1. RF allocations to radio services
2. Assignment of licence and RF to Tx Stations
3. Type approval of equipment; not in CE countries
4. Fee collection
5. Notifying ITU to the Main International Frequency Register (MIFR)
6. Coordination with neighbour countries (no borders to the electromagnetic waves)
7. External relations: toward regional commissions (CEPT) for European Countries) and International (ITU)

Aims of the National Spectrum Management

- Protect the licensed channels
- Solve & avoid interference
- Design long and short range RF spectrum
- Support Engineering: Propagation, DTM
- Assist in solving Near-field, Co-site, Co-ship, Co-a/c
- Exercise and simulate for dense RF environment
- Advance new RF technologies; Participate in R&D of new RF systems
- Coordinate with other Administrations
- Consult all stake holders and interest organisations

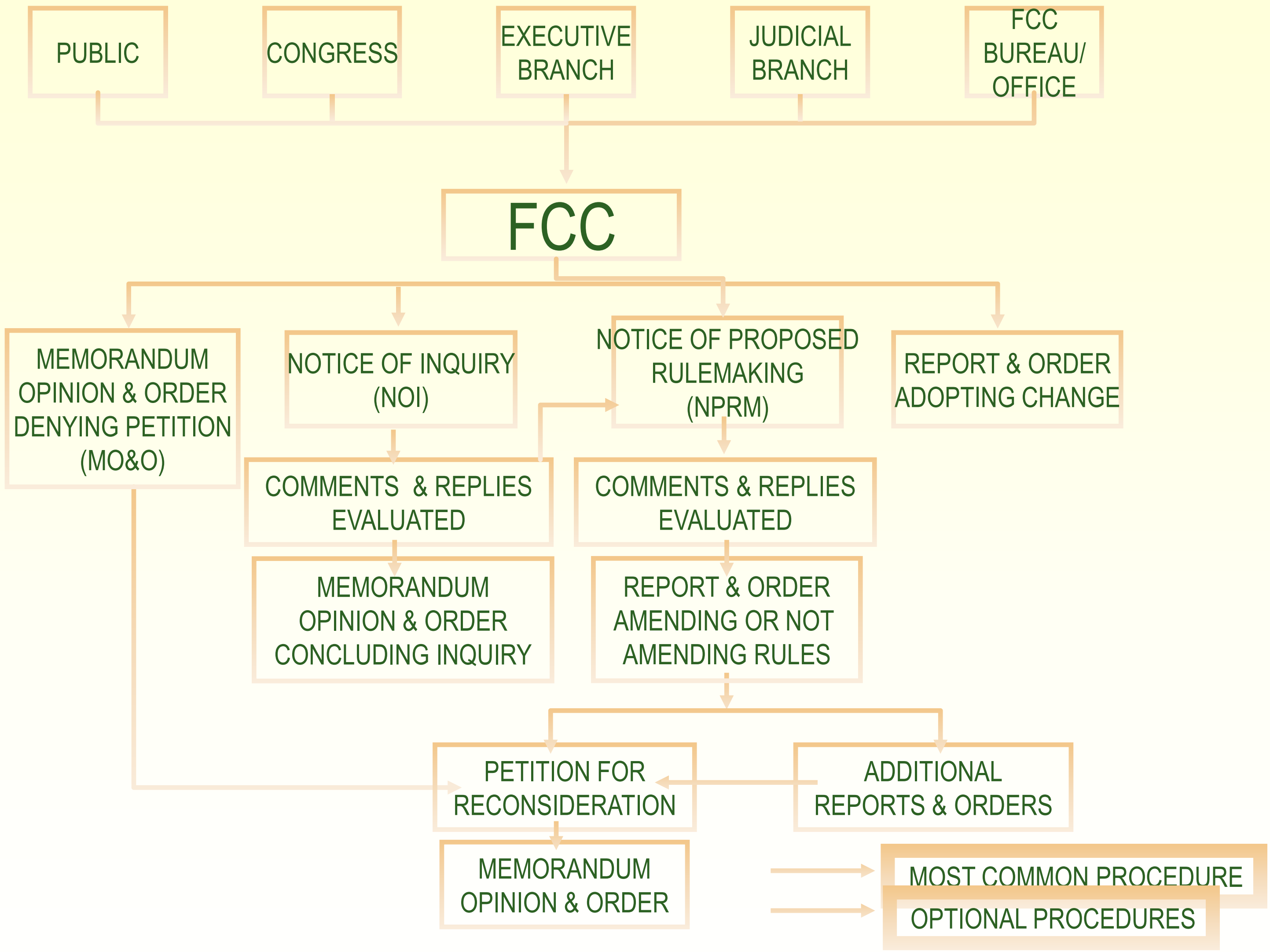
RF Spectrum Management in Developed Countries

- Wealthy countries are similar *All happy families are alike (so begins Leo Tolstoy's Anna Karenina)*
- 'Government of the people, by the people, for the people' *A. Lincoln 'Gettysburg Address' (19.11.1863)*
- Optimal use of RF
- Fair, Objective, Transparent, Nondiscriminatory, Proportionate
- Flexible, Dynamic
- Privatisation, Liberalisation, **Competition**
- Deregulation; Minimum Intervention (learn from Internet non-regulation); Light Touch
- Neutral Technology
- More RF Spectrum and more RF power for Unlicensed (unprotected devices)
- Exempt Receivers from any licensing
- Take reasonable risks
- All RF operators may pay fees for the RF spectrum

FCC and NTIA differences (Bill Luther)

- FCC is an independent regulatory agency, but the U.S. Congress has oversight and controls the FCC budget
- The U.S. president delegates government spectrum management (SM) responsibilities to NTIA, which acts as telecom advisor to the president
- FCC and NTIA serve different interests
  - Federal laws such as the Communications Act and Administrative Procedure Act (APA) govern the FCC interaction with the public and the management of public resources (RF Spectrum)
  - NTIA only governs federal government operations and is not held to the same laws as the FCC
  - Changes to SM policy in government are not subject to rule making (APA); no notice to private industry is required
  - Private industry can meet with NTIA without filing *Ex Parte* notices

How FCC rules are made (Bill Luther)



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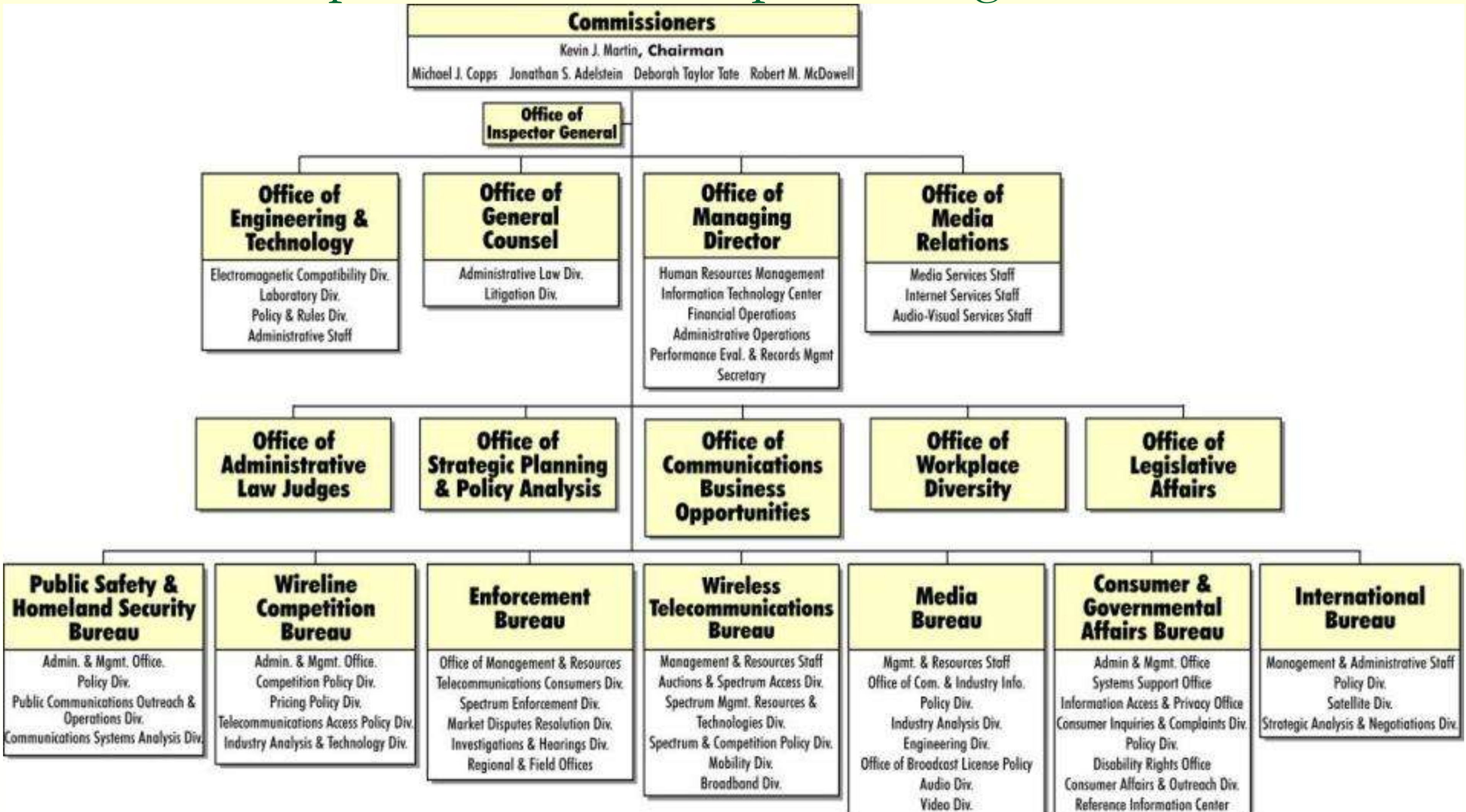
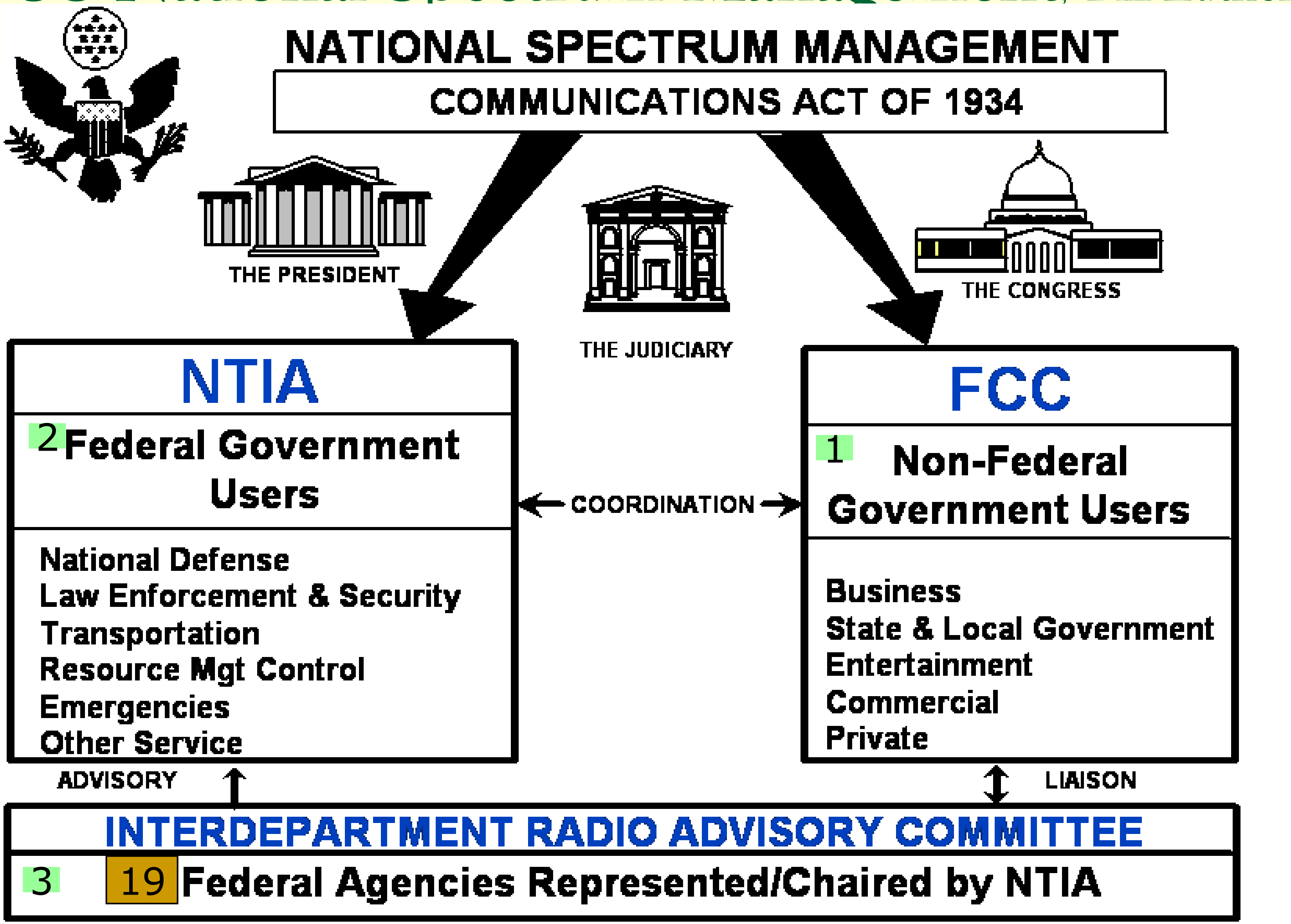
FCC Organizational Chart

All spectrum users except federal government



US National Spectrum Management; Bill Luther



CFR 47, the Code of Federal Regulations

National Archives and Records Administration

Federal Communications Commission

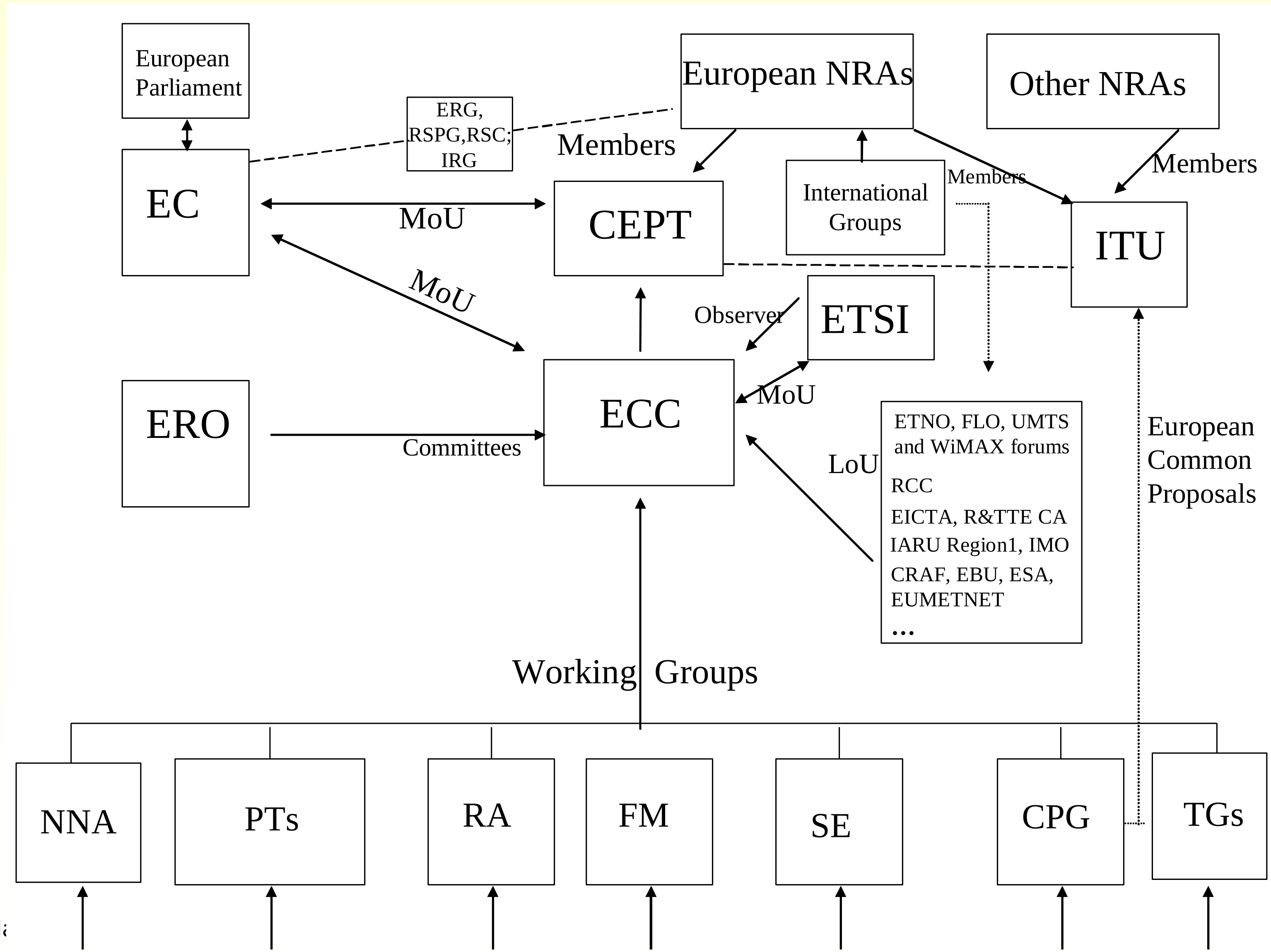
1. Rules and Regulations
2. Title 47: Telecommunication
3. Public Mobile Services
4. PART 15— Radio Frequency Devices

NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management (Redbook)

National Telecommunications & Information Administration (NTIA)

http://www.ntia.doc.gov/osmhome/redbook/redbook.html

The Main Players in European RF Regulation



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.

The European table of frequency allocations and utilisations in the frequency range 9 kHz to 3000 GHz

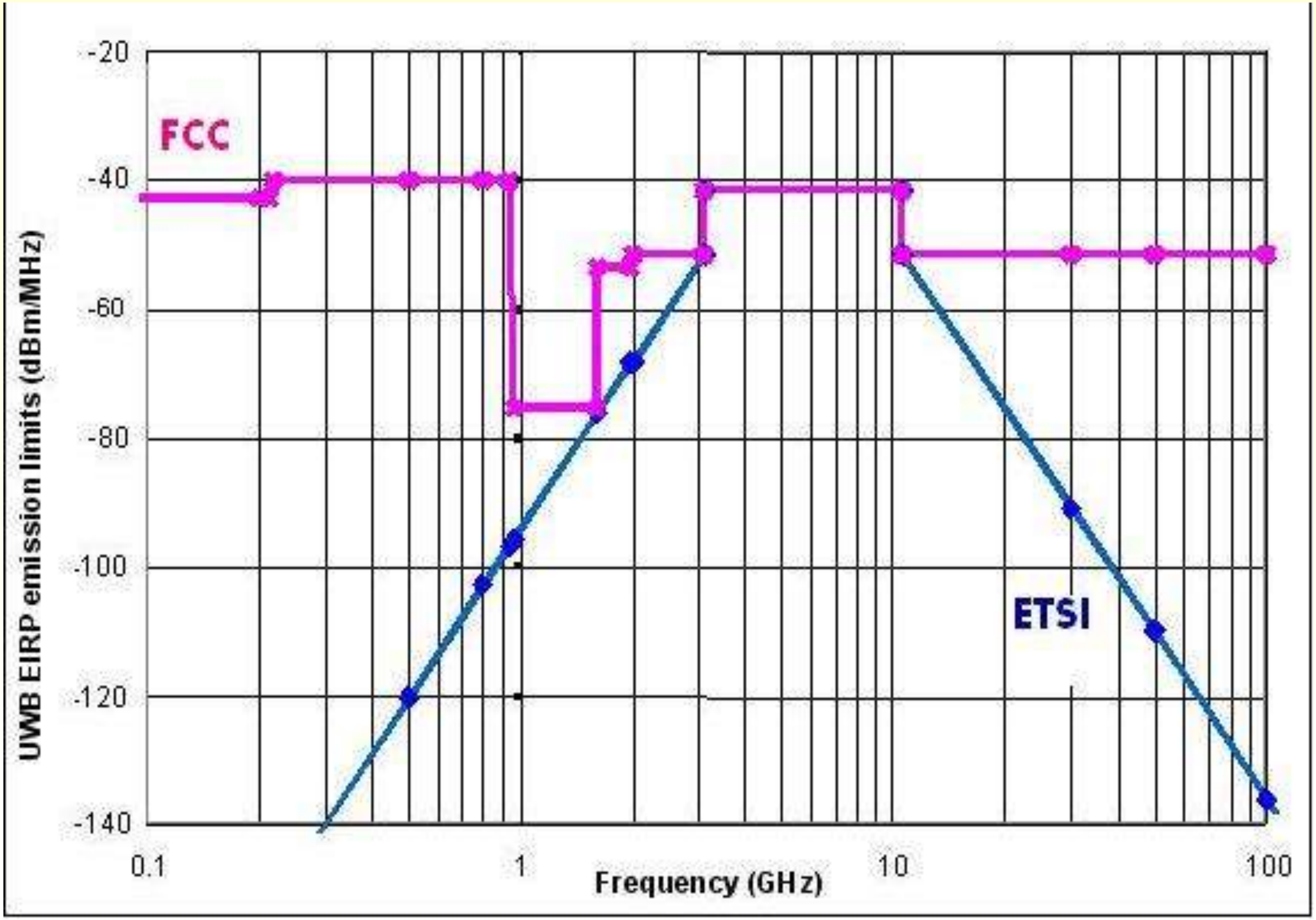
ERC Recommendation 70-03
Relating to the Use of Short Range Devices (SRD)

1. http://www.erodocdb.dk/Docs/doc98/official/pdf/ERCREP025.PDF
2. http://www.erodocdb.dk/Docs/doc98/official/pdf/REC7003E.PDF

Standards, Thresholds, Regulatory Framework: Europe-N.America

Standard	TV			Cellular standardised	Main Power and TV frames/s	*Spurious Emissions*	*Human Hazards*	
	Analog	Digital	Bandwidth				Base Stations	Handsets
Europe	PAL-SECAM	DVB-T	7-8 MHz	UMTS/ TETRA	50 Hz	Stringent		Flexible
North America	NTSC	ATSC	6 MHz	CDMA2000	60 Hz	Flexible		Stringent

UWB emissions masks ETSI-FCC



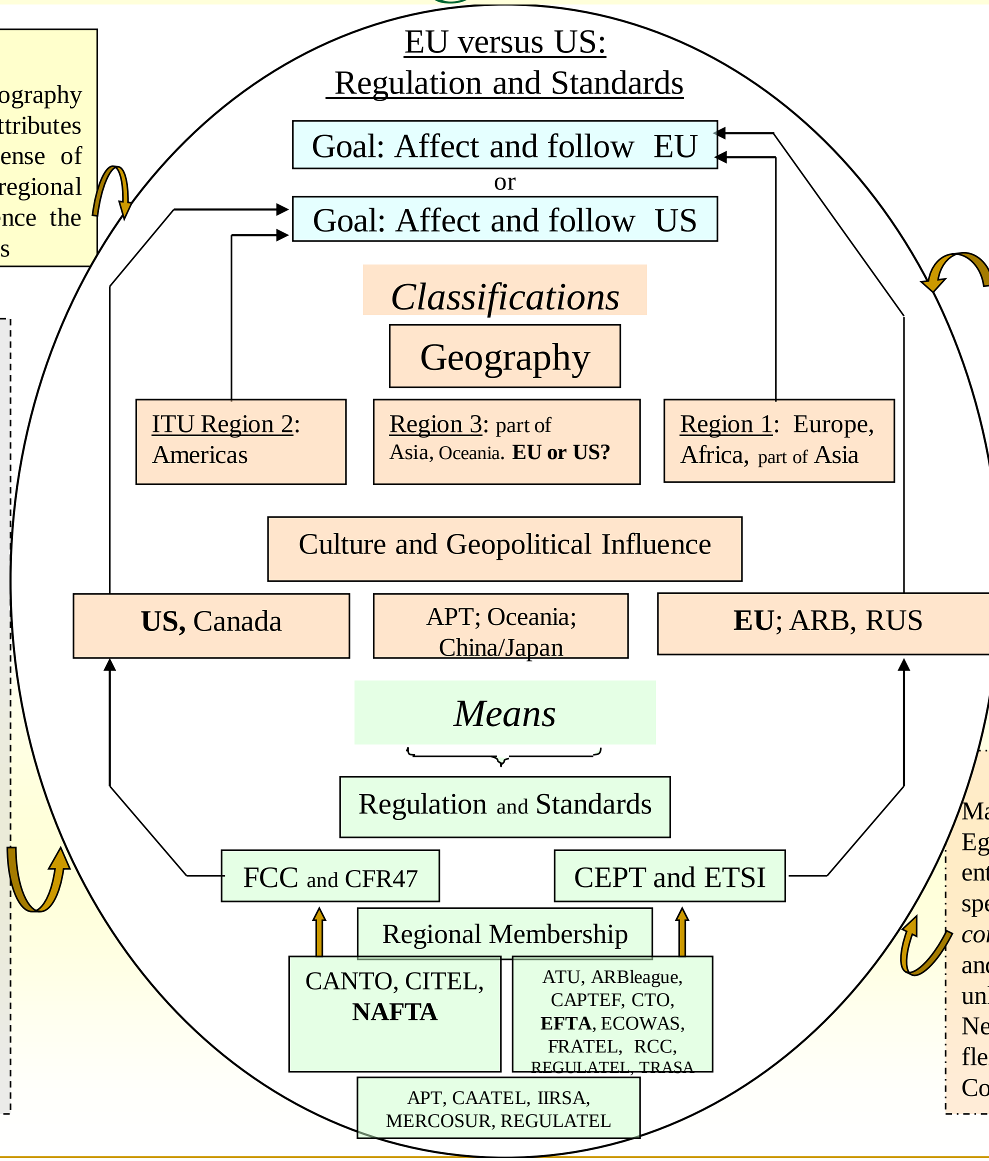
EU versus US; Regulation& Standards

Strategies

US and EU suspend geography and national cultural attributes (language, tradition, sense of belonging) and regional organisations to influence the regulation and standards

Instincts

Follow countries that you feel belonging to. Vagueness? Sympathy vs. distrust. Decision making itself is a source of controversy. EU and US: to sell wireless equipment and networked services, e.g. UMTS, SECAM, PAL, DVB-T, or CDMA2000, NTSC and ATSC. Distrust to US leads to EU standards. US $ vs EU Francophone countries follow France; left driving countries follow UK. 110V/60 Hz mains, 01 country code, transfer of power to the US and US Dollar as official currency reveal the US influence.



Values

Independent solutions or 'climb atop the shoulders of giants'. dependence vs. sovereignty, national RF allocation & standards. To belong; *common understanding* and *knowledge, collective unconscious and constructs;* language, legal origin and colonial heritage; state politics. Subregion and neighbours

Values EU

Central planning. Harmonisation; *civil law.* Solidarity. Stringent limits for *spurious emissions;* worst-case scenarios, precaution. Self Conformity by manufacturers.

Values US

Market-based solutions. Ego-oriented; individual entrepreneurs. English speaking, Protestantism, *common law.* More power and bandwidth to unlicensed RF bands. Neutral technology; flexibility; property; trust. Competition and Efficiency

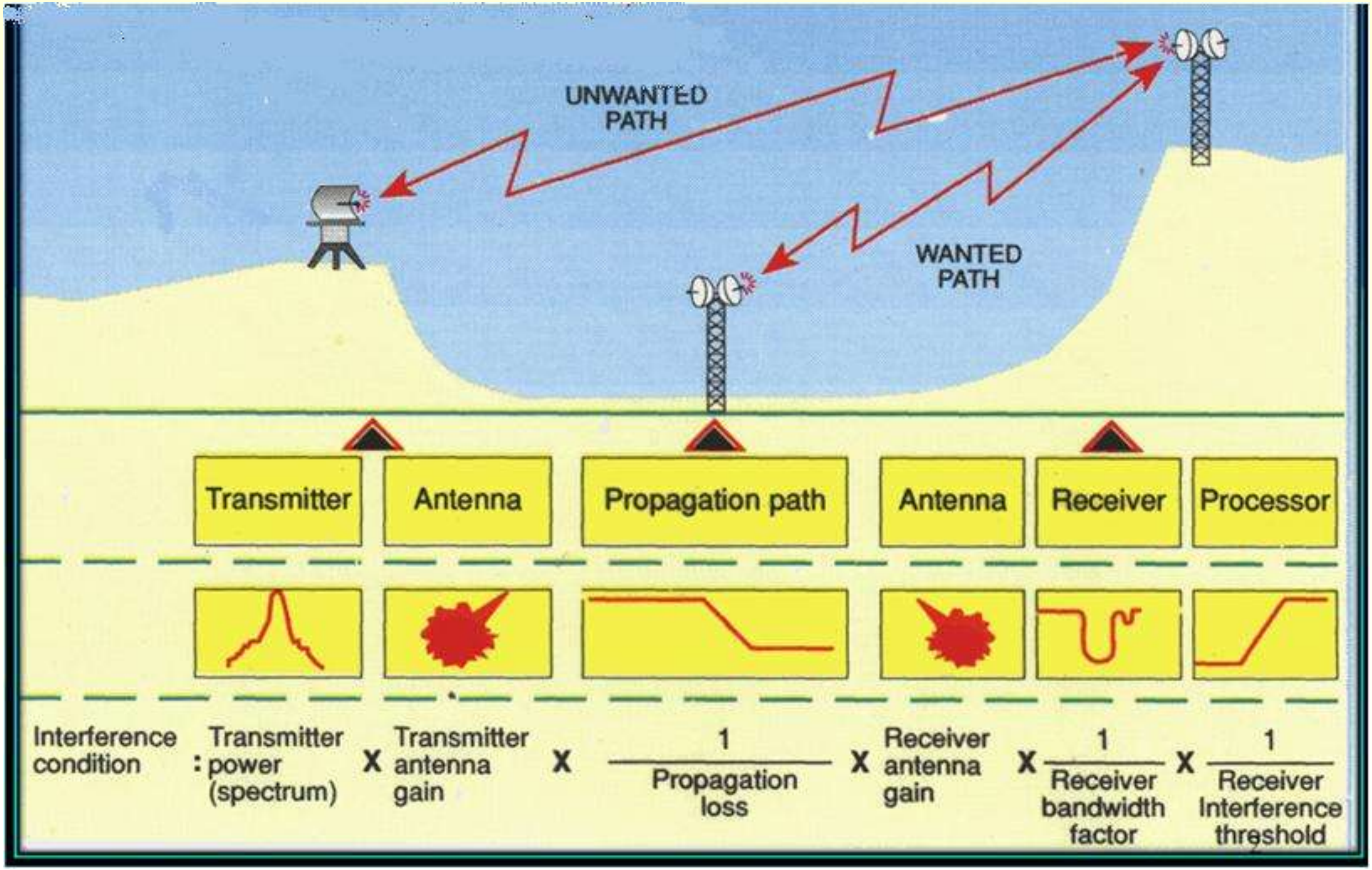
Wireless Telecommunications

Enrichment Material

EMC and RFI (some of the material from Moshe Netzer)

http://people.itu.int/~mazar/

Antenna to Antenna Coupling, RFI



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Interference Types and Modes

Linear Interference

- Co-Channel
- Adjacent Channel

Non-linear Interference

- Desensitization
- Cross-Modulation
- Intermodulation

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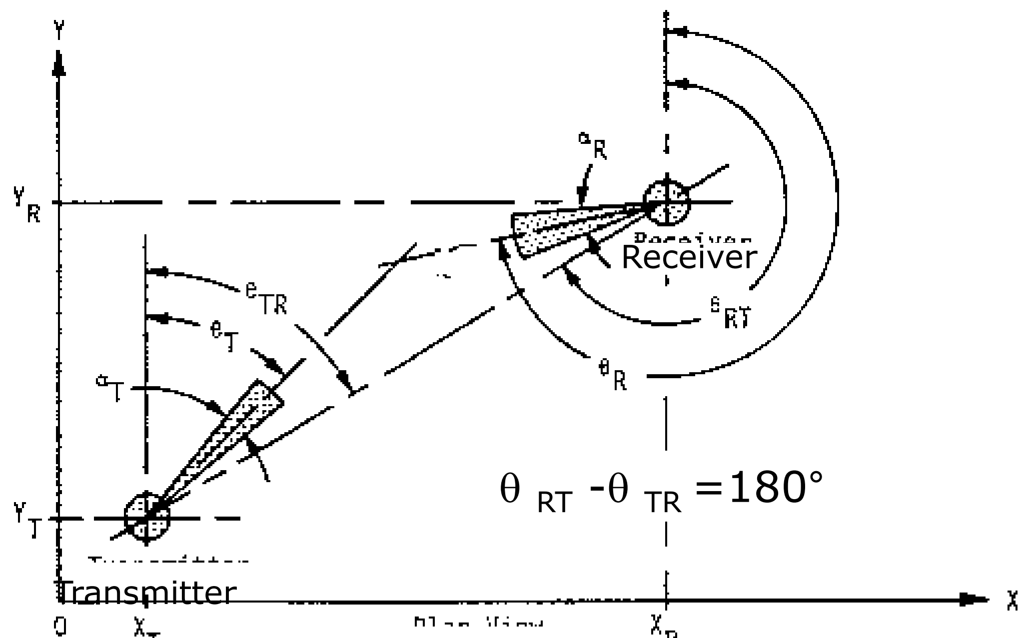
Antenna Coexistence - Freedom of Measures

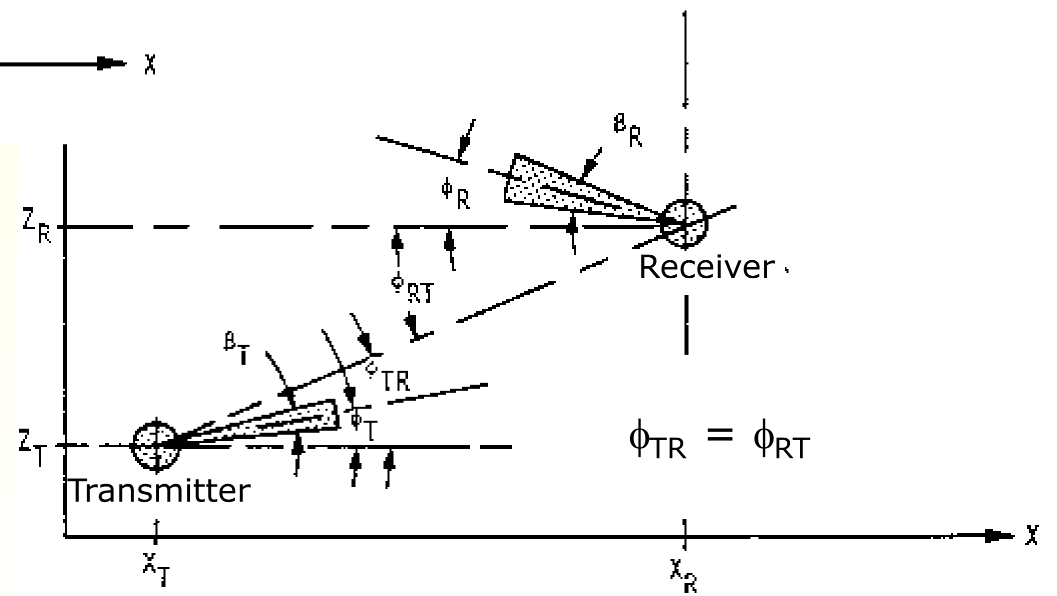
- Amplitude *(Power, Sensitivity, Distance & Ant. Orientation)*
- Frequency *(Assignment, Filtering, Bandwidth Reduction)*
- Time *(Time Sharing, Blanking, Peeping)*
- Coding *(Modulation, Spread Spectrum, Matched Filter)*

Antenna to Antenna Coupling



Plan view

Transmitter- Receiver Deployment Used to Determine Applicable Ant Pattern Region



Elevation view

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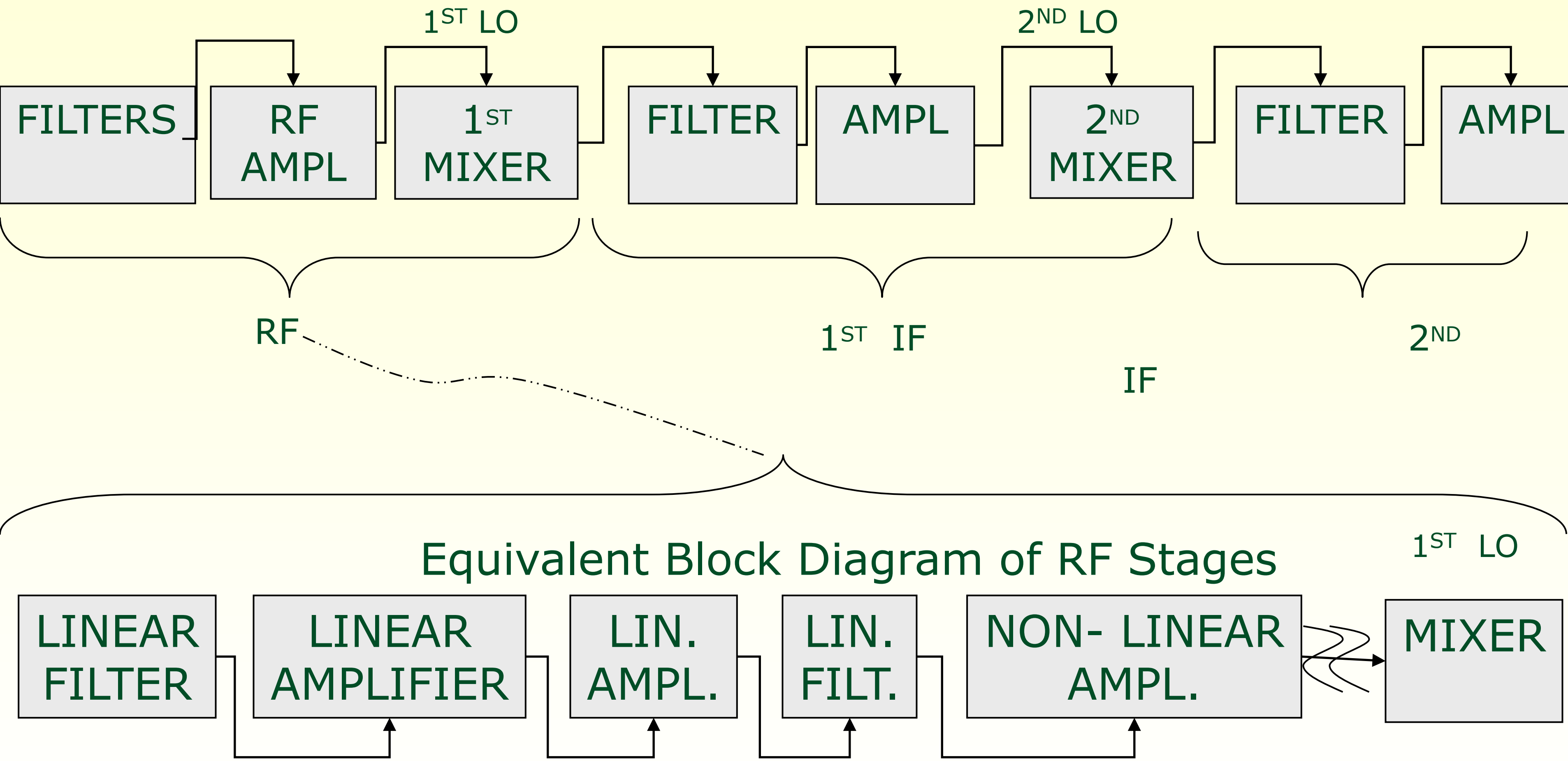
Super- Heterodyne Receiver Susceptibility



General Pre- detection
Representation for Super Heterodyne Receiver

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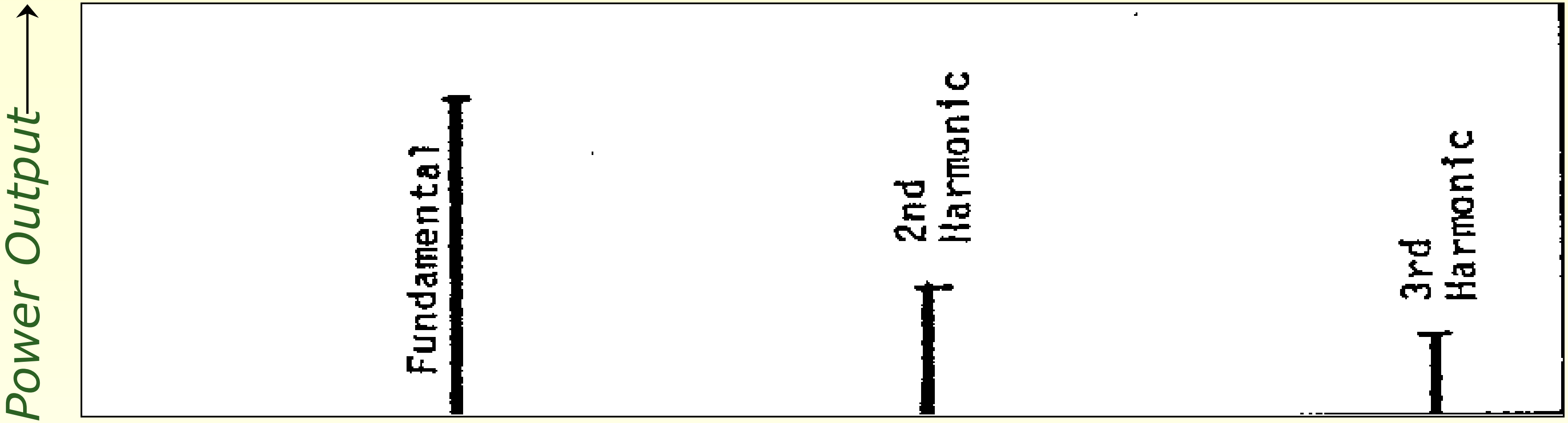
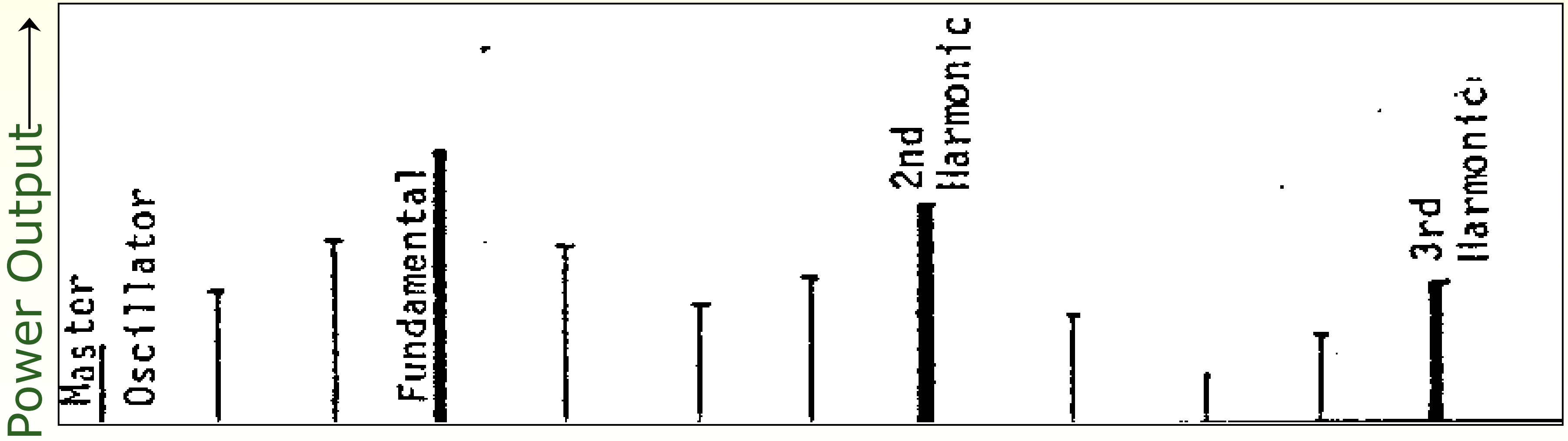
Transmitter Emissions



(a) Fundamental and harmonic Emissions *Frequency*



(b) Master Oscillator, Fundamental & Harmonics - Related Emissions

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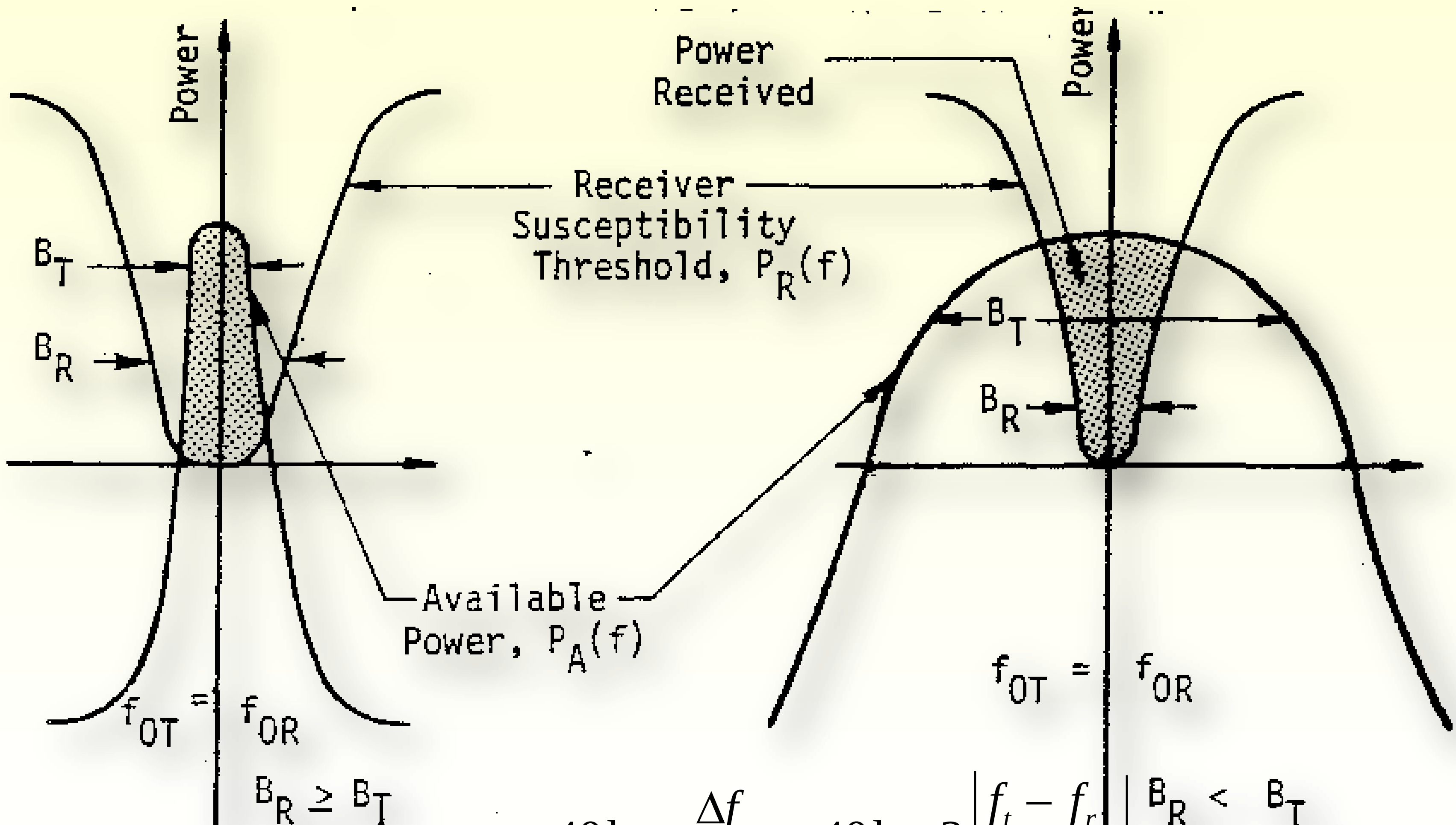
TX - RX CO – Tune Case Channel Coupling

Case Left Power received = Power Available *Case Right* Power Received < Power Available
A need of Co-Channel Alignment Correction When $BW_R < BW_T$
Receiver 3dB Bandwidth - BWR Transmitter 3dB Bandwidth - BWT
Transmitter fo - FT Receiver fo - FR



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

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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 x 232 – 229.75 = 234.25 MHz

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

Passive Intermod (PIM) for different TxRx 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 and time

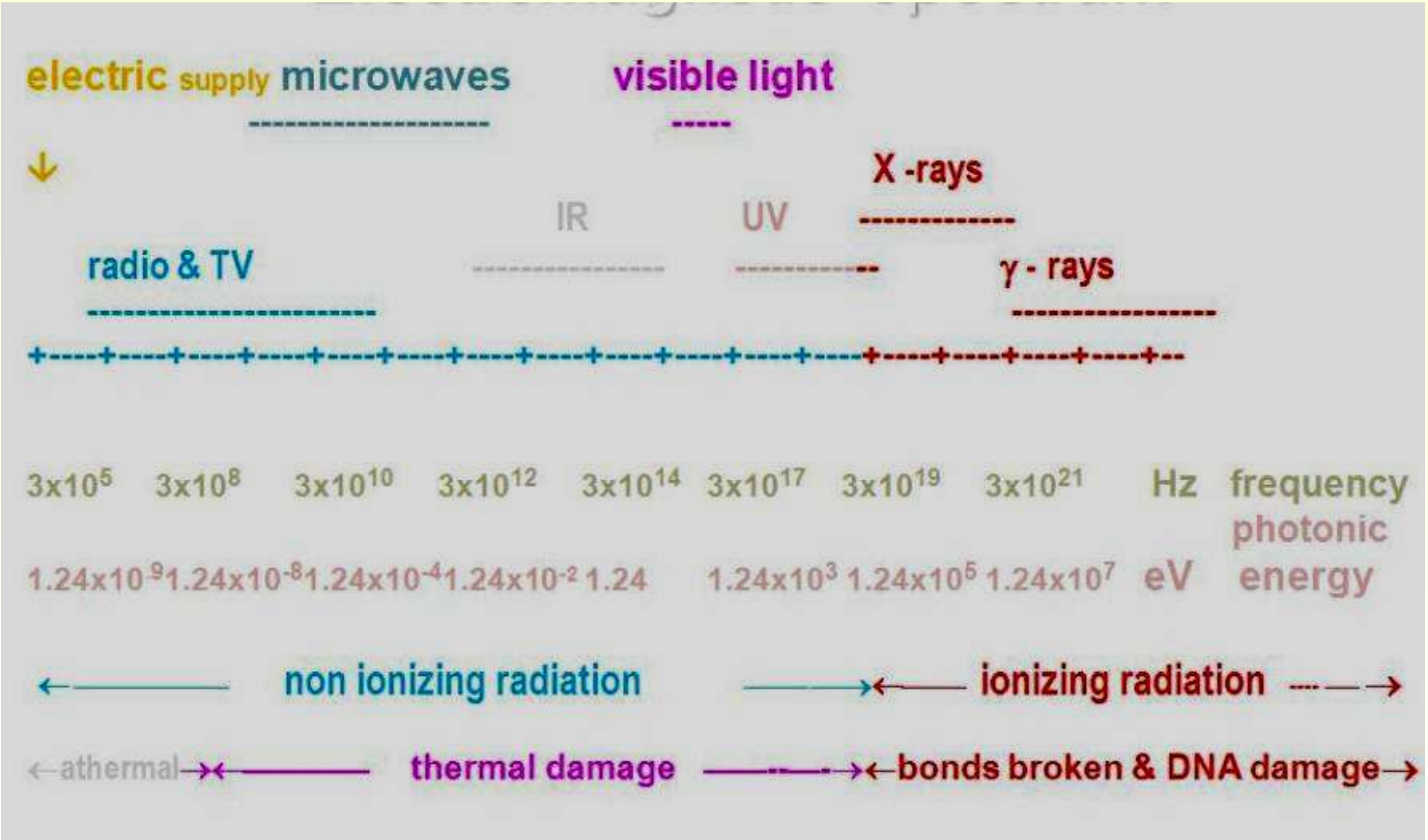
Wireless Telecommunications

Enrichment Material

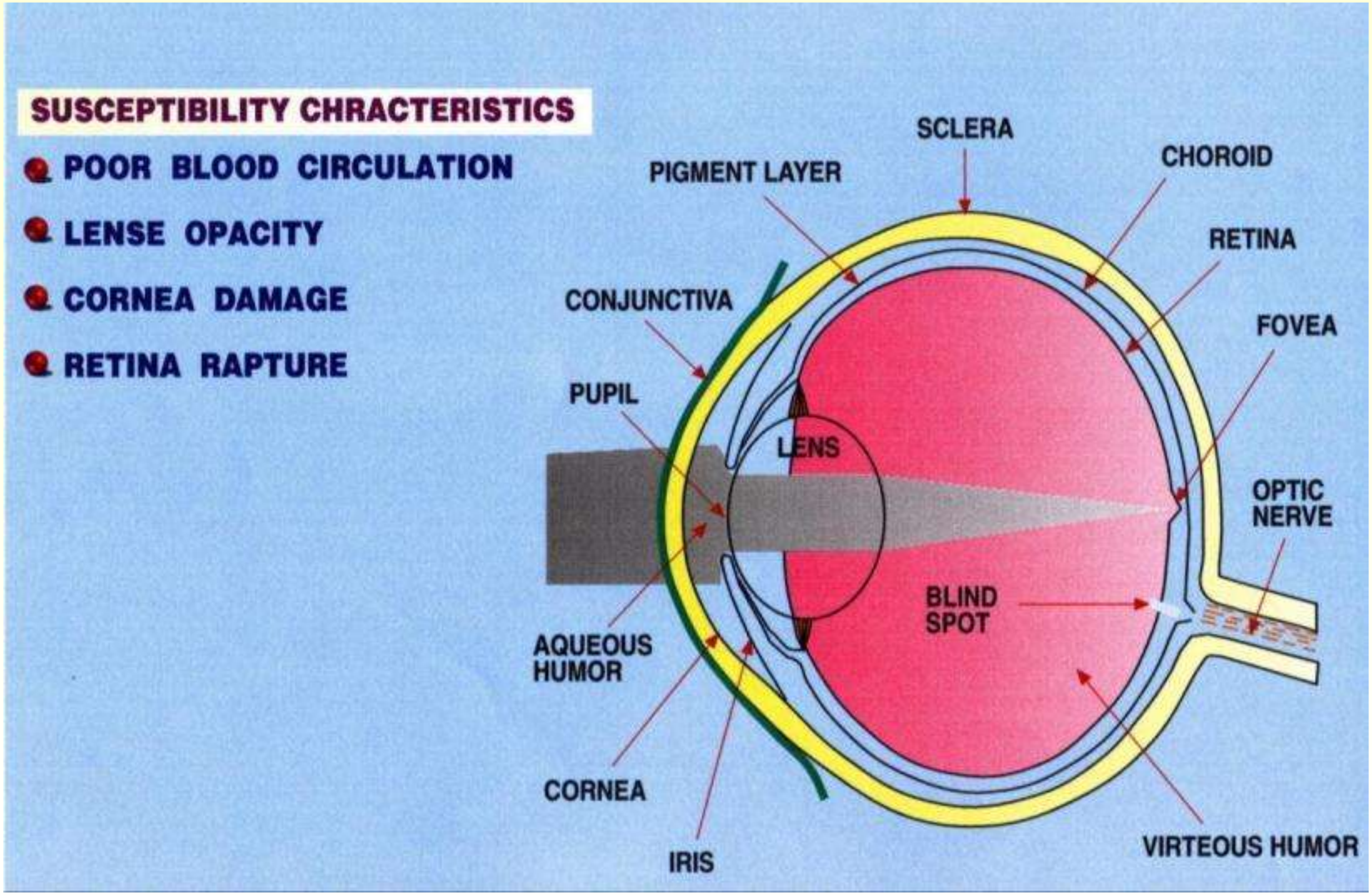
RF Human Hazards (exclusive views of the author)

http://people.itu.int/~mazar/

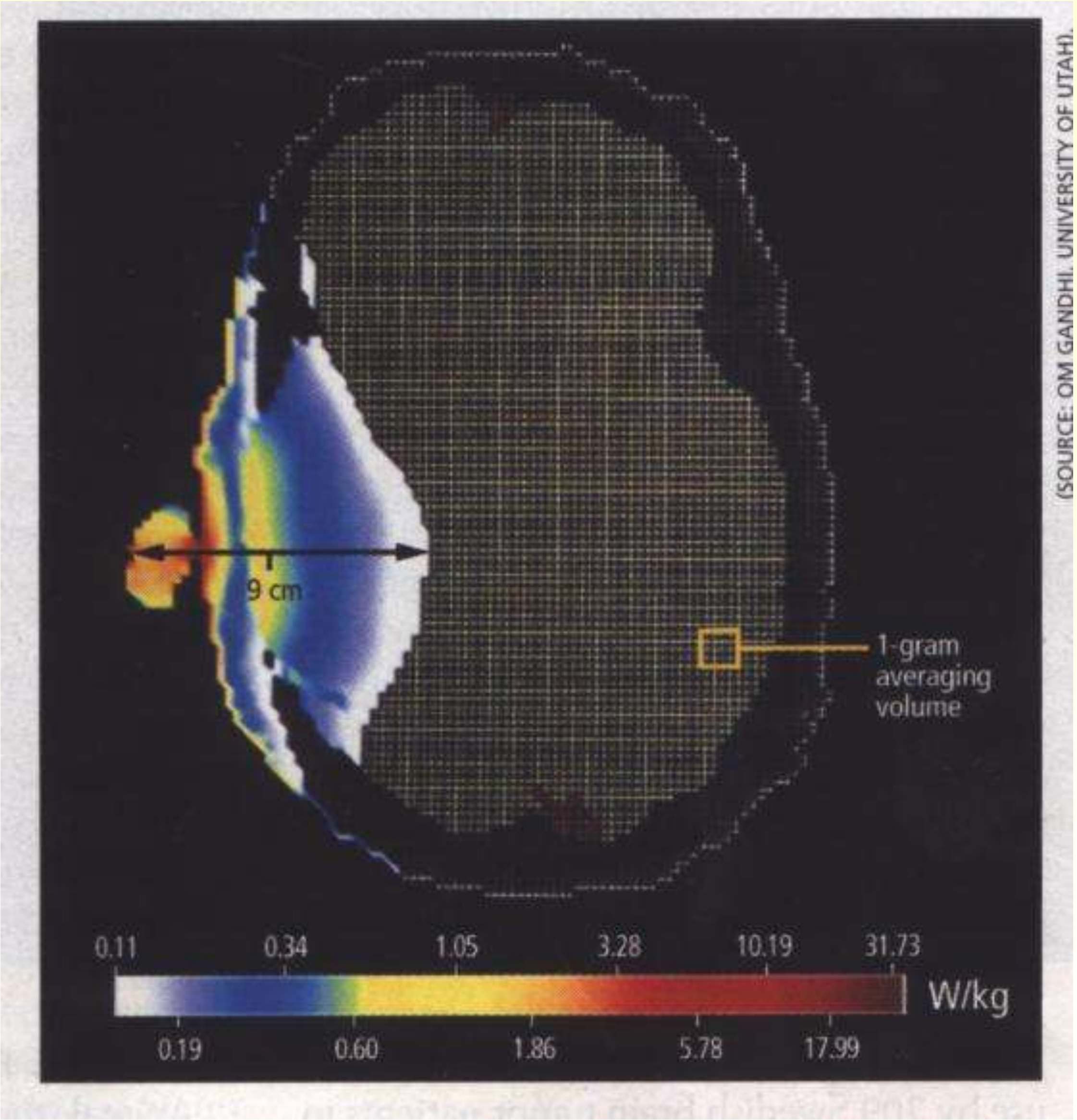
Electro-Magnetic Spectrum



The Human Eye (Moshe Netzer)



Typical SAR from a Cell Phone (Moshe Netzer)



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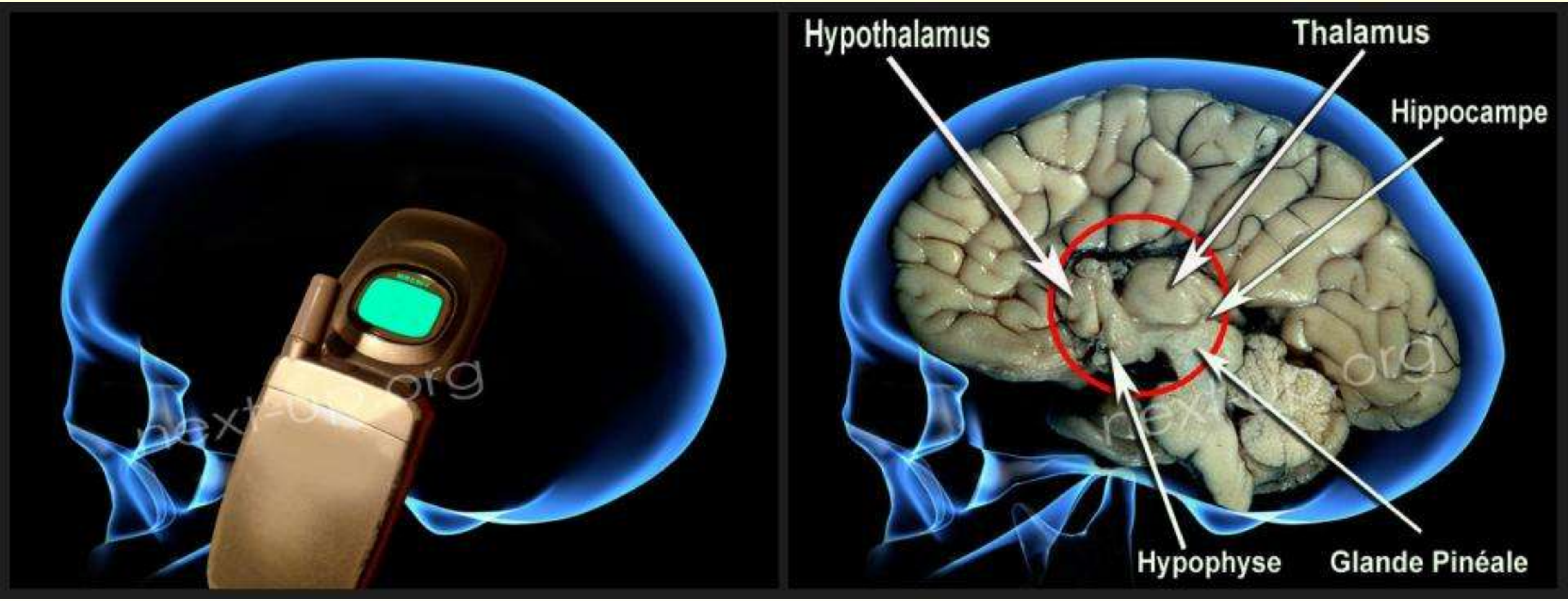
Brain is Near the Cellphone (Photo, Dr. Shalita)



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

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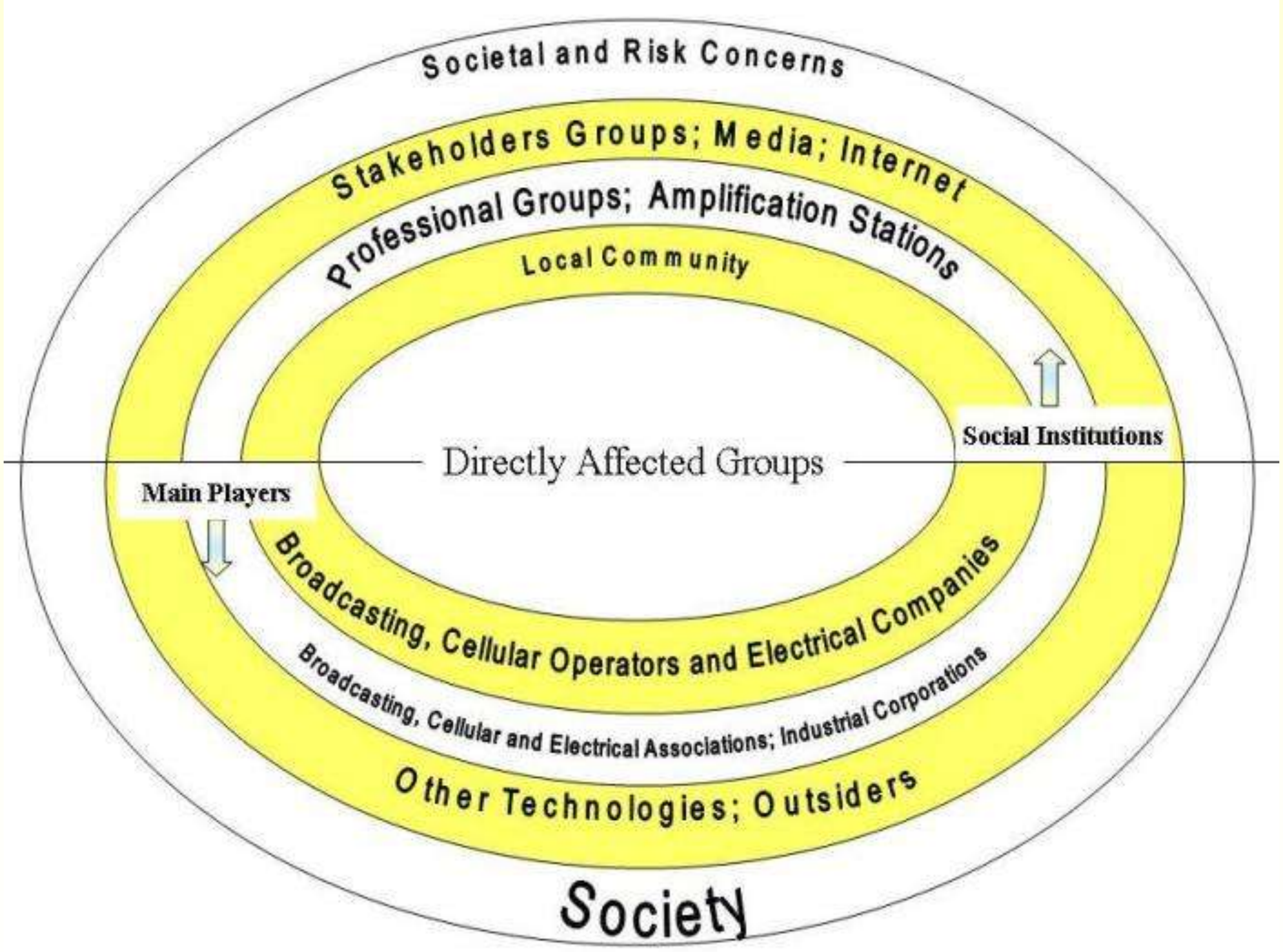
Ripple effects amplifying the Risk (Mazar Thesis)

http://www.moc.gov.il/new/documents/frequences/MazarThesisOct08.pdf

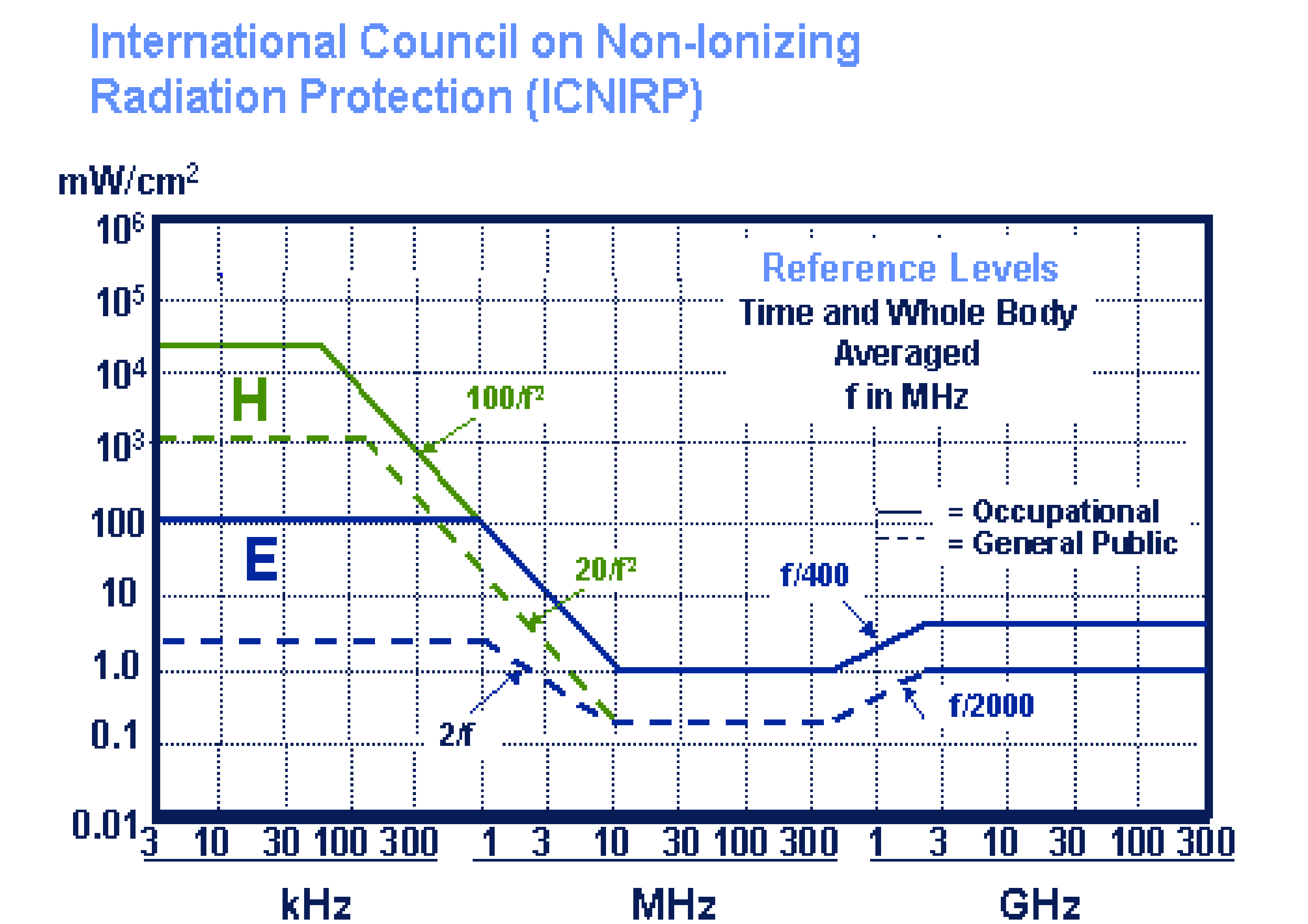


Base Station Antenna Pattern: Azimuth and Elevation
(Dr. Zamir Shalita)

ICNIRP 1998 Table 7: Reference Levels for General Public Exposure

Frequency range	E-field strength ($V\,m^{-1}$)	H-field strength ($A\,m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\,m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Basic limits and reference levels RF workers: 0.4 W/kg , general public 0.08 W/kg



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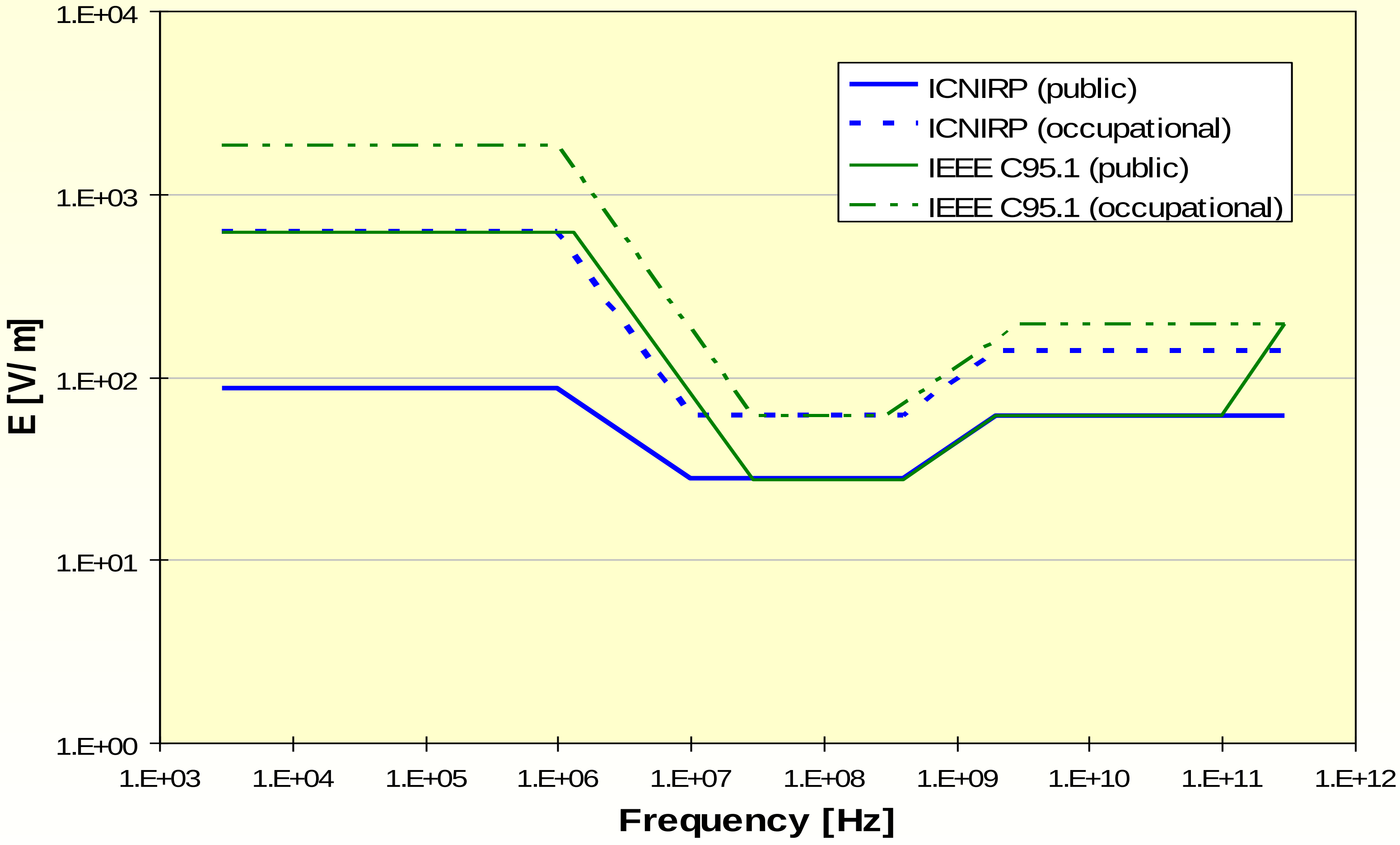
ICNIRP vs. IEEE-field limits (C_K_Chou_i)



Physical Quantities and Units (Mazar Thesis)

http://www.moc.gov.il/new/documents/frequences/MazarThesisOct08.pdf

Quantity	Symbol	Unit	Symbol
Frequency	f	Hertz	Hz
Electric field strength	E	Volt per metre	V/m
Magnetic field strength	H	Ampere per metre	A/m
Magnetic flux density	B	Tesla	T
		Gauss	G
Power	P	Watts	W
Specific Absorption Rate	SAR	Watt per kilogram or milliWatt per gram	W/kg or mW/g
Power density or power flux density	S	Watt per square metre	W/m²
		mWatt per square cm	mW/cm²

Magnetic flux density is commonly measured in units of microtesla (μT) or milligauss (mG); 1 μT = 10 mG.

ICNIRP/EC, FCC, IEEE reference levels for general public exposure (Mazar Thesis)

http://www.moc.gov.il/new/documents/frequences/MazarThesisOct08.pdf

ICNIRP http://www.icnirp.de/documents/emfgdl.pdf and EC reference levels for exposure

Frequency range	Electric field strength (V/m)	Magnetic field strength (A/m)	Equivalent plane wave power density S_{eq} (W/m^2)	Magnetic Flux Density (μT), B
25-800 Hz	250/f	4/f	-	5,000/f
400-2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	f/200	$0.0046 f^{½}$
2-300 GHz	61	0.16	10	0.2

FCC exposure limits (FCC 2001:67)

Frequency Range MHz	Electric Field (E) (V/m)	Magnetic Field H (A/m)	Power Density (S) (mW/cm^2)
30-300	27.5	0.073	0.2
300-1500	--	--	f/1500
1500-100,000	--	--	1

The new IEEE permissible exposure (IEEE Std C95.1-2005:25, table 9)

Frequency Range MHz	Electric Field (E) (V/m)	Magnetic Field H (A/m)	RMS power density (S) (W/m^2)
100-400	27.5	0.073	2
400-2000	--	--	f/200
2000-5000	--	--	10

Not Thesis: *Shalita: guidelines of 0.1μW/cm2 are used in Salzbourg Austria (since1998) and in France (since 09).*

For 2000 MHz ICNIRP is 10 W/m^2 =1 mW/cm^2 =1000 $μW/cm^2$;Israel 1 W/m^2=0.1 mW/cm^2 =100 $μW/cm^2$

For 2000 MHz ICNIRP is 4.5 W/m^2 =0.45 mW/cm^2 =450 $μW/cm^2$;Israel 0.45 W/m^2.=0.045 mW/cm^2 =45 $μW/cm^2$

Comparing the Genaeral Public Exposure Levels (Mazar Thesis)

http://www.moc.gov.il/new/documents/frequences/MazarThesisOct08.pdf

Derived levels, power density (W/m²): WHO (International), UK, USA

Frequency range	ICNIRP	Old NRPB (UK)	ANSI (USA)
	General Public	Adults and Children	General Public
400 - 1,550 MHz	f /200	$41 \times 10^{-6} f^2$	f /150
1,550 - 2,000 MHz	f /200	100	f /150

Maximal power from handsets: Specific Absorption Rate, SAR (W/kg)

ICNIRP	European Community	FCC- USA
10 MHz–10 GHz; Localised SAR (Head and Trunk)		Portable Devices; General Population/ Uncontrolled
2.0; averaged over 10 g tissue		1.6; averaged over 1g tissue

Countries less tolerant of magnetic risk, with more stringent magnetic thresholds

Country	Magnetic Flux Density relative to ICNIRP
Switzerland	0.01
Italy	0.03 (daily mean, for more than 4 hours); 0.1 (for designed lines)
Slovenia	0.1 (for new installations)
Israel	0.1 (proposed in occupational)
Russia	0.1 (Indoor); 0.5 (Outdoor)
Poland	0.75
Greece	0.8

Averaging time of 6 min

At 2 GHz the ICNIRP Power density level is 10 W/m² ; equivalent to 0.08 (W/kg) Whole-body-average SAR; 4 (W/kg) Localized SAR for head and trunk (100 kHz-10 GHz)

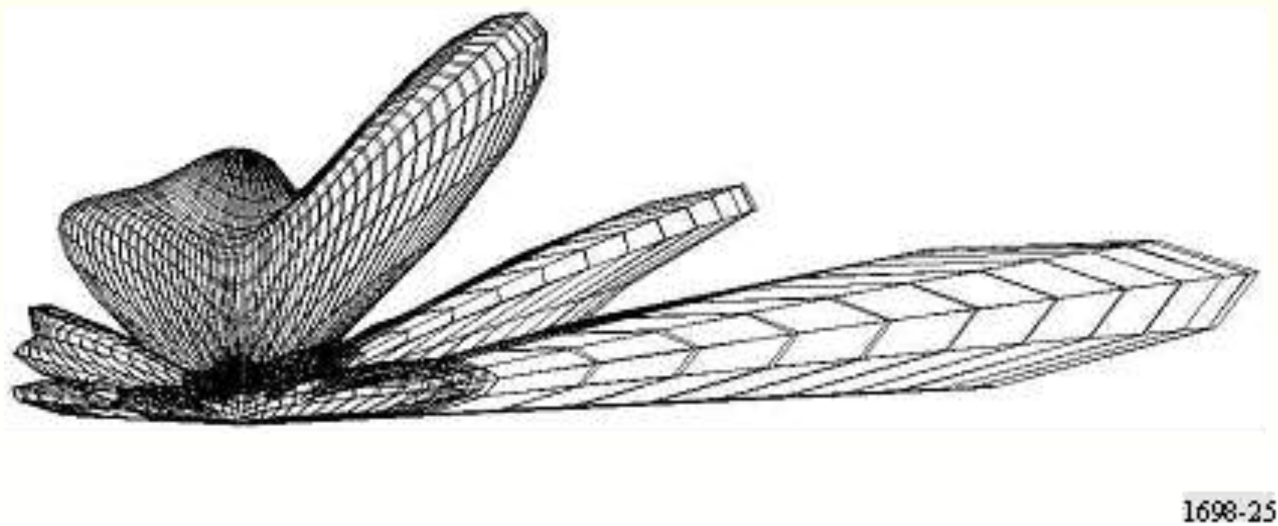
Specific Absorption Rate (SAR) limits for portable wireless devices.

- 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

Radiation Diagram, Vertical



ICNIRP- Established Effects of EMF (Paolo_Vecchia)

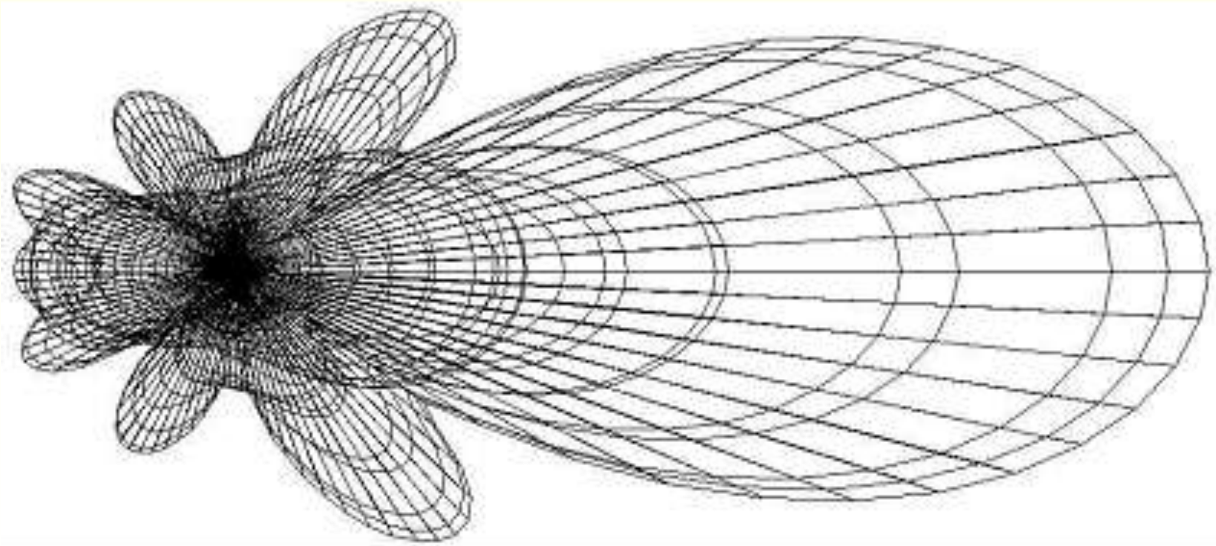
- All effects of EMF that have been established so far are acute in nature

- ELF
- Stimulation of electrically excitable tissues

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

Such acute effects occur above given exposure thresholds

Radiation Diagram, Horizontal



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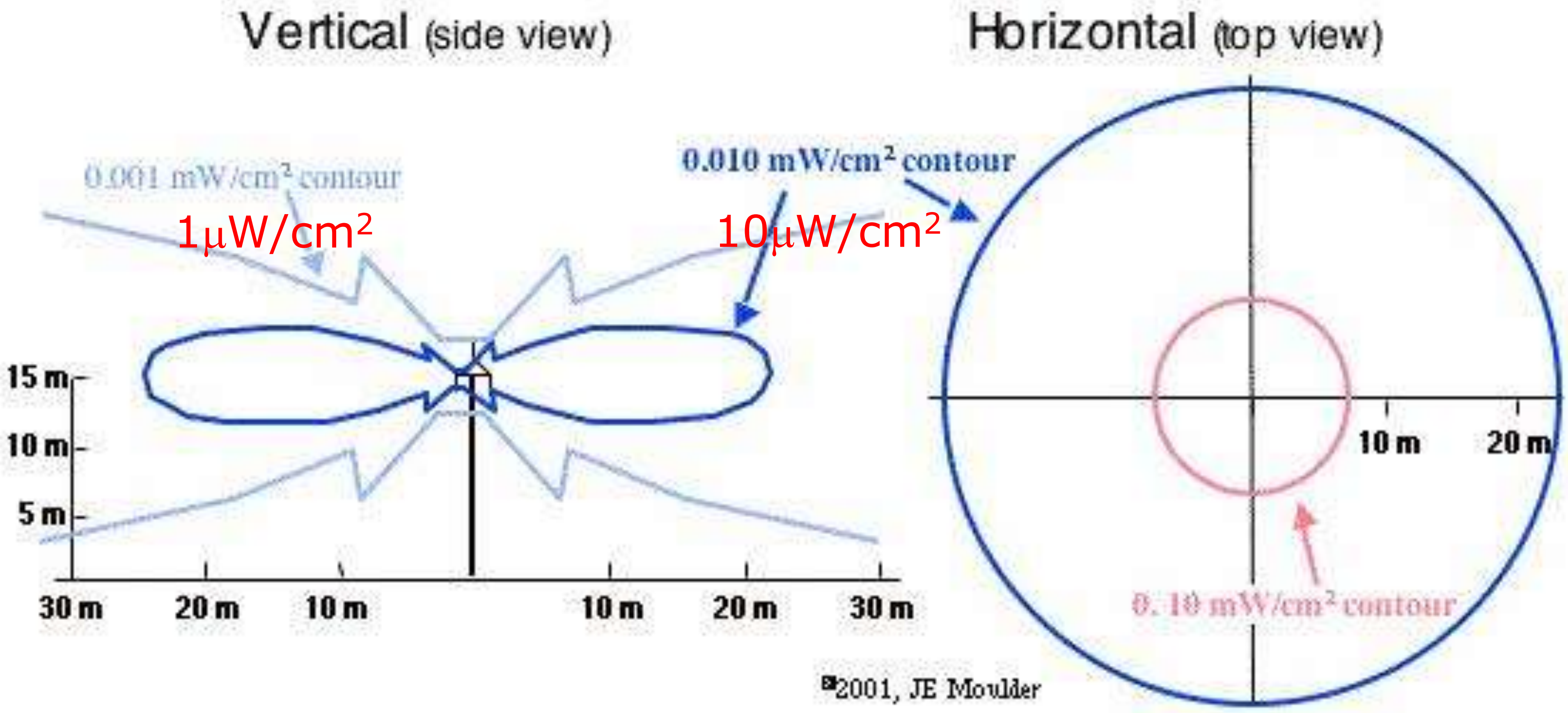
Main beam – Power densities (Dr. Zamir Shalita)

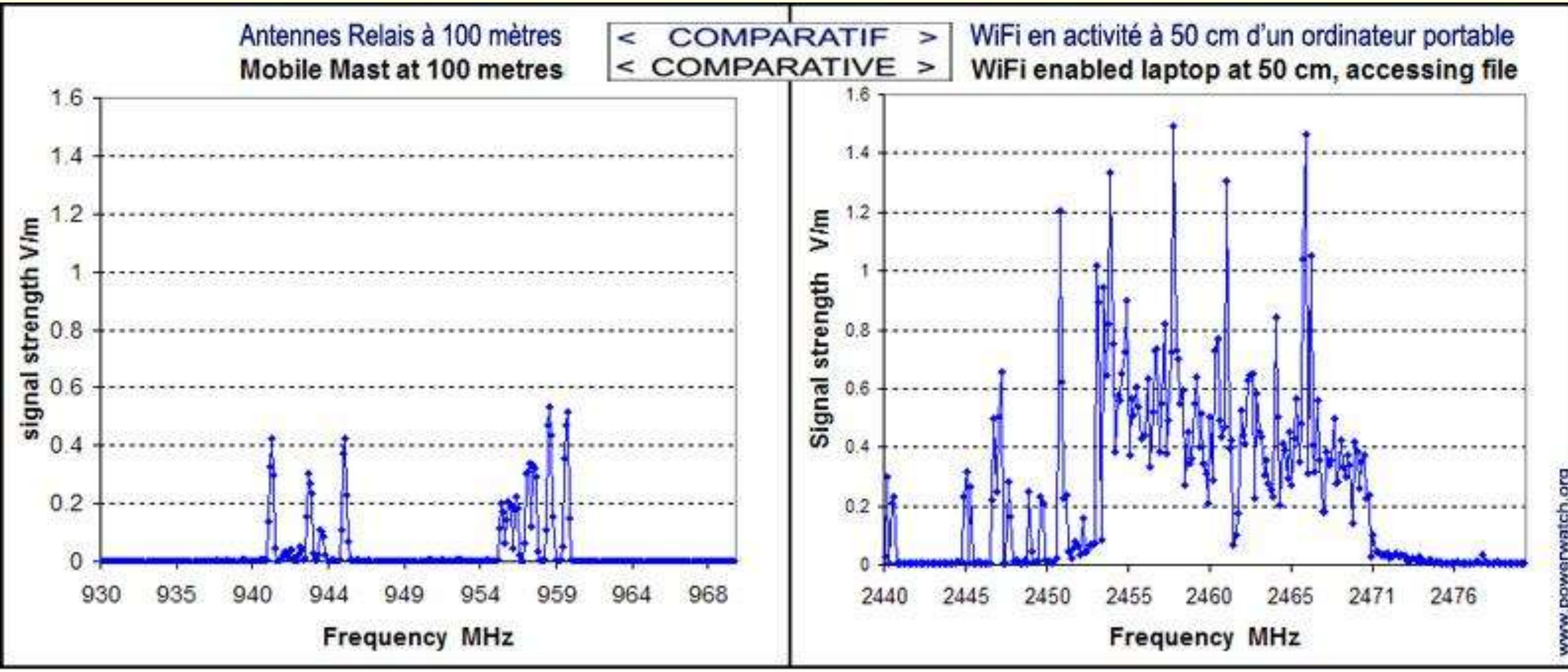


- Radiation units

μW/m²	W/m²	mW/m²	mW/cm²	μW/cm²	V / m
10,000,000	10	10,000	1	1,000	61.4

Portable WiFi emissions (Oberfeld 2005)

Mobile mast at 100m WiFi enabled Laptop 50



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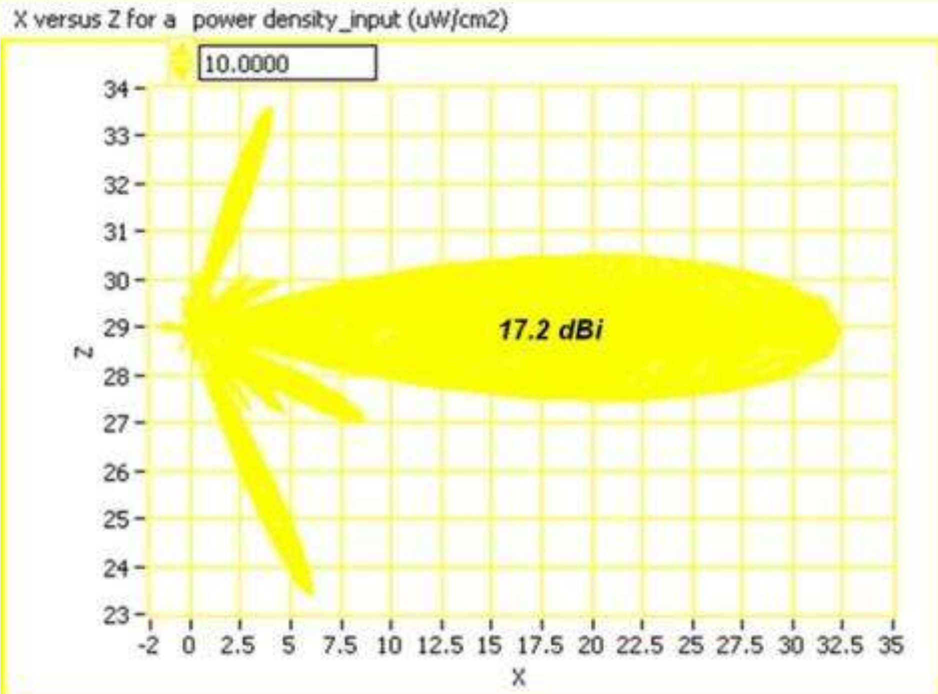
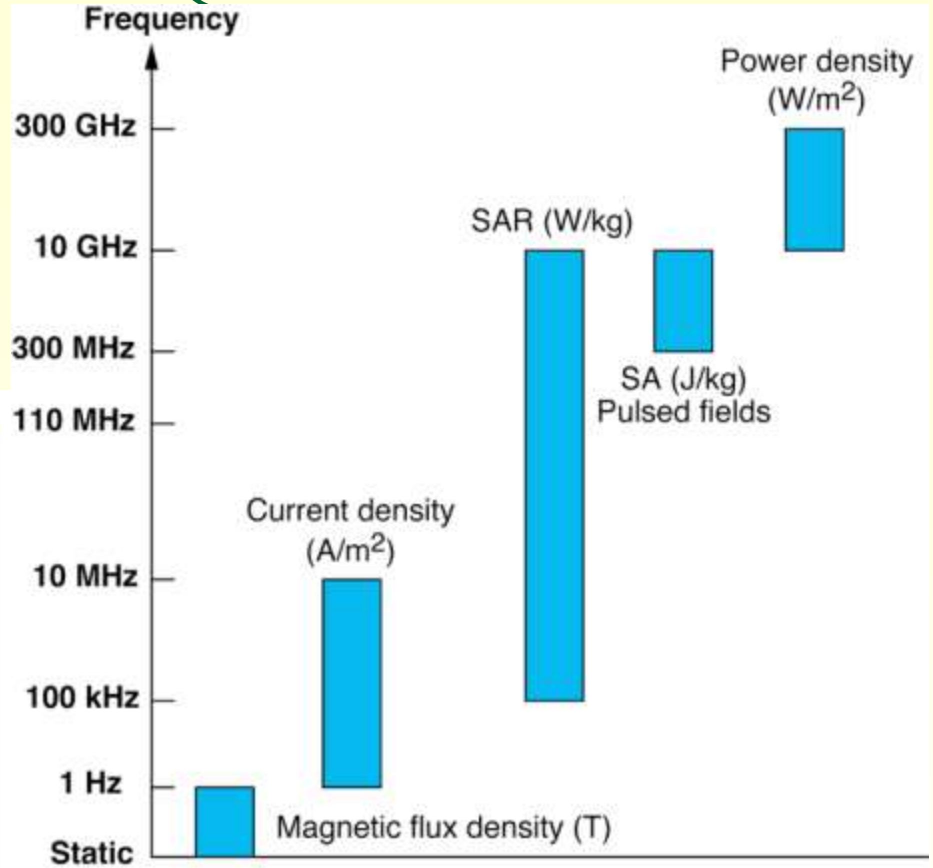
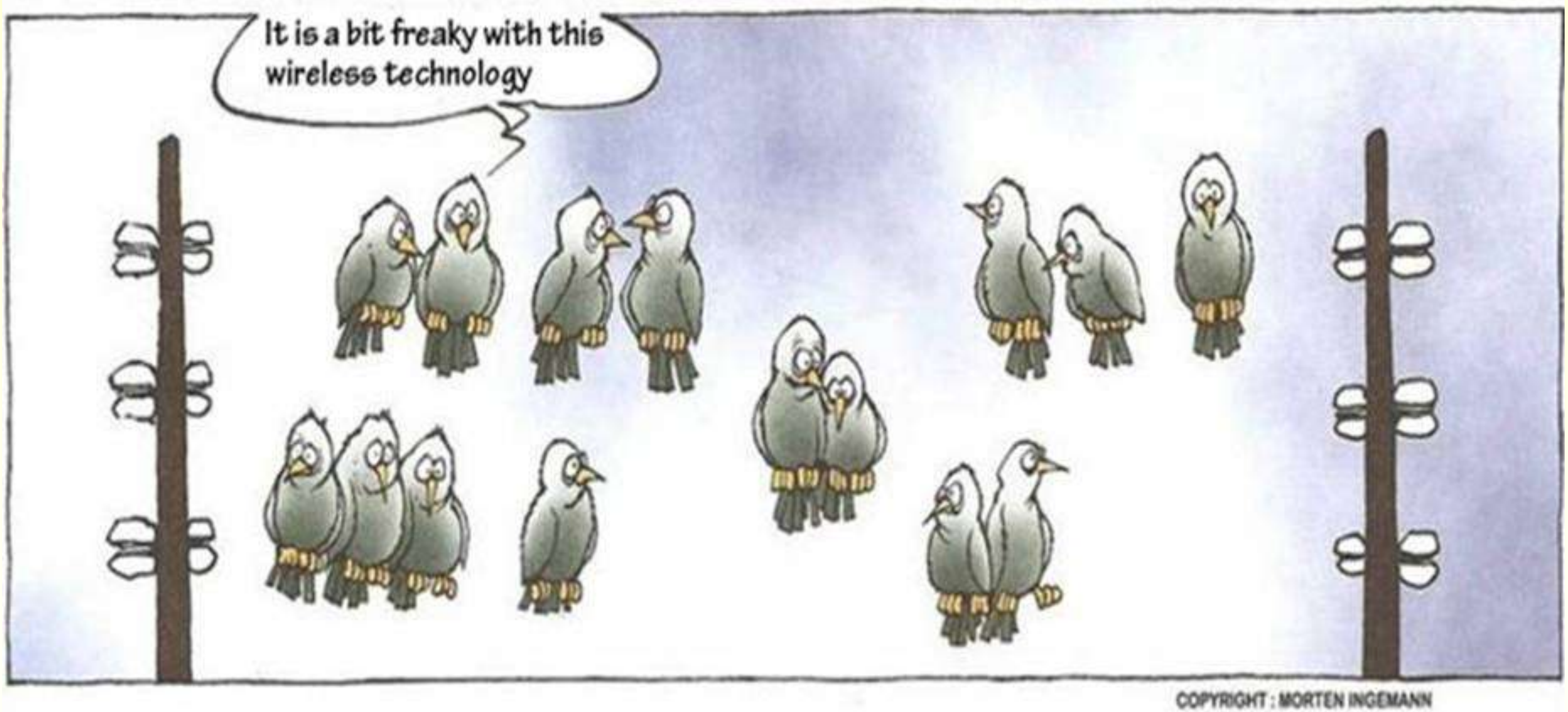
Biologically Effective Quantities





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

Hope that the material is enriching helpful



See also enclosed: Useful Equations

http://people.itu.int/~mazar/

Wireless Telecommunications Systems: Useful Equations

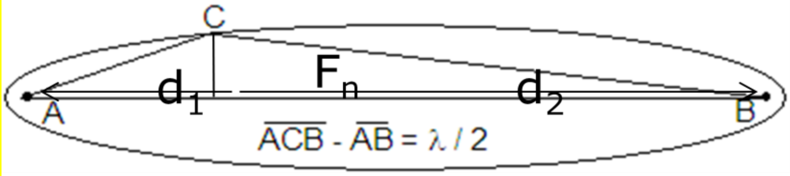
(when no units are mentioned- MKS or identical units)

	Free Space Propagation Loss (PL): Power
1)	$\mathrm{PL}(ratio) = \left(\frac{4\pi d}{\lambda}\right)^2$
2)	$\mathrm{PL}(dB) = 82 + 20\log d_{kM} - 20\log \lambda_m$
3)	$\mathrm{PL}(dB) = 32.44 + 20\log d_{kM} + 20\log f_{MHz}$
4)	EiRP= Transmitted Power (P_t) x gain Power Density $S_{eq} = \frac{EiRP}{4\pi d^2}$
	Free Space Propagation Loss: Field Strength
5)	$E_0 = \frac{\sqrt{30 \cdot P_t \cdot g}}{d} = \frac{\sqrt{30 \cdot EiRP}}{d}$
6)	$E = Pt + G - 20\log d + 14.8$
7)	20 log E_0 (dB μV/m) = EiRP (dBW) -20 log d (km) +74.8
	Poynting Vector
8)	$PoyntingVector = \frac{P_t g}{4\pi d^2} = (\vec{E} x \vec{H}) = \frac{1}{\mu_0}(\vec{E} \times \vec{B}) = \frac{E_O^2}{Zo} = \frac{E_O^2}{120\pi}$
9)	$c_0 \equiv \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \quad Z_0 \equiv \mu_0 c_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{1}{\varepsilon_0 c_0} = 120\pi \approx 377$
	Power ↔ Field-Strength
10)	$P_r = \frac{E^2 g \lambda^2}{Z_0 4\pi} = \frac{E^2 g c^2}{480\pi^2 f^2}$
11)	P(dbm)= E(dBμV/m) - 77.21- 20Log F(MHz) + G
	Power ↔ Voltage
12)	Given Rx input impedance 50 Ω Pr (dBm)= Vr (dB μV) – 107
	Power Density ↔ Field-Strength

13) ■ Radiation units

μW/m²	W/m²	mW/m²	mW/cm²	μW/cm²	V / m
10,000,000	10	10,000	1	1,000	61.4

Fresnel Zones



14) $F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} = \sqrt{\frac{n\lambda d_1 (d - d_1)}{d}}$

15)	Max Fresnel zone b $b=\sqrt{\frac{n\lambda d}{4}}$
16)	$F_1=17.3\sqrt{\frac{d_1 d_2}{fd}}$ f (GHz); d , d_1, d_2: (km) F_1 first Fresnel ellipsoid (metres)
	Antennas
17)	$\eta\equiv\frac{P_{rad}}{P_{input}}=\frac{A_e}{A}$
18)	$g=\frac{4\pi}{\Omega(steradians)}=\frac{4\pi}{\varphi\theta(radians)}=\frac{4\pi a_{az}b_{el}}{\lambda^2}=\frac{4\pi A_e}{\lambda^2}=\frac{4\pi\eta A}{\lambda^2}$
19)	$A=\frac{g\lambda^2}{\eta 4\pi}$ $A_e=\frac{g\lambda^2}{4\pi}$
20)	$g=\eta\frac{4\pi}{\varphi\theta(radians)}=\eta\frac{4\pi}{\varphi^0\theta^0}\left(\frac{360}{2\pi}\frac{360}{2\pi}\right)=\eta\frac{41,253}{\varphi^0\theta^0}=\eta\frac{41,253}{\varphi^0\theta^0}$
	Practical approximations, for $\eta\approx 0.7$
21)	$g\approx\frac{28,800}{\varphi^0\theta^0}$
22)	$G\approx 44.6$ dBi $-10\log\theta^0 - 10\log\varphi^0$; for circular Ant, $G\approx 44.6$ dBi $-20\log\theta^0$
23)	$\theta^0\approx\frac{70\lambda}{b}$ $\varphi^0\approx\frac{70\lambda}{a}$
	Receiver Sensitivity
24)	f noise factor of the receiver $f\equiv\frac{SNR_{in}}{SNR_{out}}$ $f\equiv\frac{p_n}{k\,t_0\,b}$ 10 log $f\equiv$ NF (dB)
25)	k : Boltzmann's constant $\equiv 1.38\times10^{-23}$ J/K
26)	–204 (dBW/Hz)=10 log ($k\,t_0$) $1.38\times10^{-23}\times290=400.2\times10^{-23}$
27)	$P_{thermal\ noise}\equiv$ ktbf B=10 log b
28)	$P_{thermal\ noise}$ (dBm)= 10 log ($k\,t_0 bf$) $\approx$-114(dBm)+ B (MHz)+ NF(dB)
	Point to Point
29)	Pr = Pt + Gt - PL + Gr ; Pr (dBm)= Pt (dBm) + Gt(dBi) - PL(dB) + Gr(dBi)

	Radar Equation (for free space)
30)	$P_{received} = P_{Transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 d^4}$
31)	$d_{\max}{}^4 = P_{Transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 P_{\min}}$
	Far-Near Fields Separation (x)
32)	$x \approx 2D^2/\lambda$
	Standing Waves
33)	$\text{VSWR} = \frac{V_{\max}}{V_{\min}} = \frac{1+\rho}{1-\rho}$
34)	$\rho = \frac{VSWR-1}{VSWR+1}$
35)	$\lvert\Gamma\rvert^2 = \rho^2$
36)	RL(Return Loss)=20 log ρ=20log(VSWR-1)-20 log(VSWR-1)
37)	Optical and RF Horizons (x)
38)	Earth Radius (a) =6,371 km 4/3 that of the actual radius, which corresponds to approximately 8 500 km
39)	$x \approx \sqrt{2h_t a} + \sqrt{2h_r a}$ _ when $x << a$
40)	feet≡0.3048 meter 1,852 m= 1Nautical Mile $for\, h = 28{,}000(feet)$ $x \approx 381{,}015(meters)/1{,}852 = 206.7(NM)$
41)	$x_{optical}(NM) \approx \sqrt{height(feet)}$
42)	$x_{electromagnetic}(meters) \approx 2{,}277\sqrt{h(feet)}$
43)	$x_{electromagnetic}$ (NM)≈1.23 $\sqrt{h(feet)}$
	General
44)	$\lambda = \frac{c}{f}$ λ= 1 meter for f = 300 MHz
45)	Doppler Shift $f_D \approx -2\frac{\dot{R}}{\lambda}$

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