Chapter 9 Section A

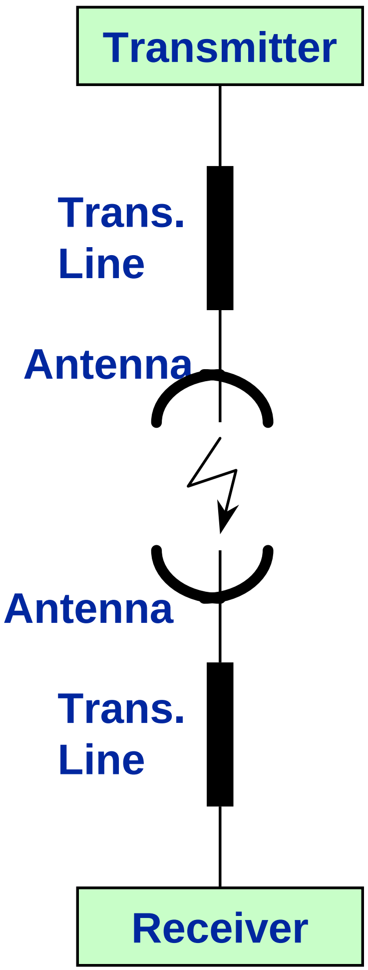
Background Material and Review Topics

Chapter 9 Section A

Working in Decibels

Example: A Tedious Tale of One Radio Link

Why Use Decibels? For convenience and speed.
Here's an example of why, then we'll see how.



- **Let's track the power flow from transmitter to receiver in the radio link we saw back in lesson 2. We're going to use real values that commonly occur in typical links.**

20 Watts TX output

x 0.50 line efficiency
= 10 watts to antenna

x 20 antenna gain
= 200 watts ERP

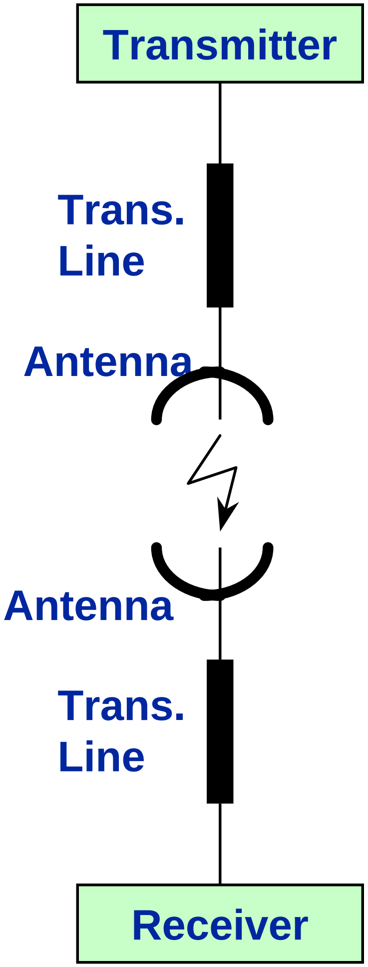
x 0.000,000,000,000,000,1585 path attenuation
= 0.000,000,000,000,031,7 watts if intercepted by dipole antenna

x 20 antenna gain
= 0.000,000,000,000,634 watts into line

x 0.50 line efficiency
= 0.000,000,000,000,317 watts to receiver

- **Did you enjoy that arithmetic? Let's go back and do it again, a better and less painful way.**

Example: A Much Less Tedious Tale
of that same Radio Link



Let's track the power flow again, using decibels.

+43	**dBm TX output**
-3	**dB line efficiency**
= +40	**dBm to antenna**
+13	**dB antenna gain**
= +53	**dBm ERP**
-158	**dB path attenuation**
= -105	**dBm** if intercepted by dipole antenna
+13	**dB antenna gain**
= -92	**dBm into line**
-3	**dB line efficiency**
= -95	**dBm to receiver**

- **Wasn't that better?! How to do it -- next.**

Using Decibels

- In manual calculation of RF power levels, unwieldy large and small numbers occur as a product of painful multiplication and division.
- It is popular and much easier to work in Decibels (dB).
  - rather than **multiply and divide** RF power ratios, in dB we can **just add & subtract**

Ratio to Decibels

$$db = 10 * Log (X)$$

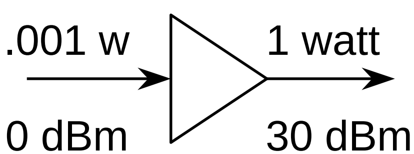
Decibels to Ratio

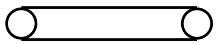
$$X = 10^{(db/10)}$$

Decibel Examples

Number N	dB
1,000,000,000	+90
100,000,000	+80
10,000,000	+70
1,000,000	+60
100,000	+50
10,000	+40
1,000	+30
100	+20
10	+10
4	+6
2	+3
1	0
0.5	-3
0.25	-6
0.1	-10
0.01	-20
0.001	-30
0.0001	-40
0.00001	-50
0.000001	-60
0.0000001	-70
0.00000001	-80
0.000000001	-90

Decibels - Relative and Absolute





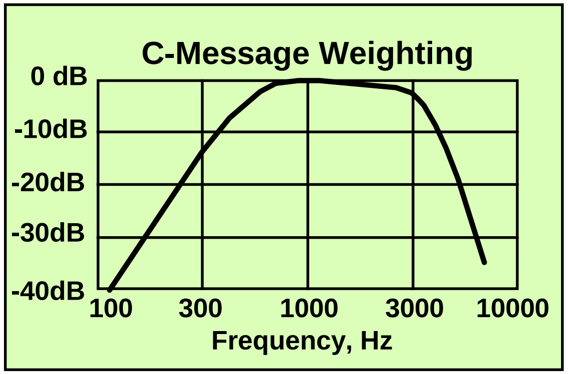
- Decibels normally refer to power ratios -- in other words, the numbers we represent in dB usually are a ratio of two powers. Examples:
  - A certain amplifier amplifies its input by a factor of 1,000. (P_{out}/P_{in} = 1,000). That amplifier has 30 dB gain.
  - A certain transmission line has an efficiency of only 10 percent. (P_{out}/P_{in} = 0.1) The transmission line has a loss of -10 dB.
- Often decibels are used to express an absolute number of watts, milliwatts, kilowatts, etc.... When used this way, we always append a letter (W, m, or K) after “db” to show the unit we’re using. For example,
  - 20 dBK = 50 dBW = 80 dBm = 100,000 watts
  - 0 dBm = 1 milliwatt

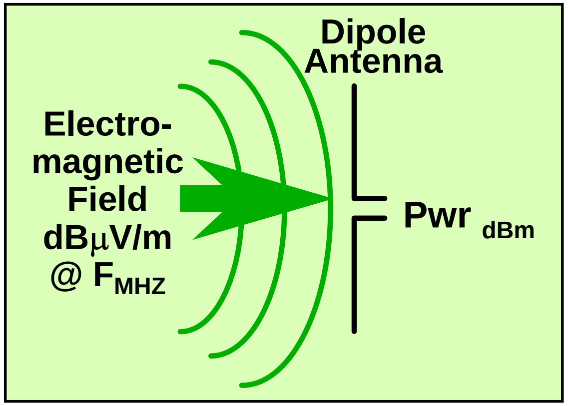
Decibels
Two Other Popular Absolute References

- **dBrnc**: a common <u>telephone noise</u> measurement
  - "db above reference noise, C-weighted"
  - "Reference Noise" is 1000 Hz. tone at -90 dBm
  - "C-weighting", an arbitrary frequency response, matches the response best suited for intelligible toll quality speech
  - this standard measures through a "C-message" filter
- **dBu**: a common <u>electric field strength</u> expression
  - dBu is "shorthand" for dBμV/m
  - "decibels above one microvolt per meter field strength"
  - often we must convert between E-field strength in dBu and the power recovered by a dipole antenna bathed in such a field strength:

$$FS_{dBu} = 20 * Log_{10}(F_{MHZ}) + 75 + Pwr_{DBM}$$

$$Pwr_{DBM} = FS_{dBu} - 20 * Log_{10}(F_{MHZ}) - 75$$





Decibels referring to Voltage or Current

- By convention, decibels are based on power ratios. However, decibels are occasionally used to express to voltage or current ratios. When doing this, be sure to use these alternate formulas:

  db = 20 x Log_{10} (V or I) **(V or I) = 10 ^ $^{(db/20)}$**

  - Example: a signal of 4 volts is 6 db. greater than a signal of 2 volts

    db = 20 x Log_{10} (4/2) = 20 x Log_{10} (2) = 20 x 0.3 = 6.0 db

Prefixes for Large and Small Units

Summary of Units

Number N	x10^y	Prefix
1,000,000,000,000	$x10^{12}$	Tera
1,000,000,000	$x10^{9}$	Giga-
1,000,000	$x10^{6}$	Mega-
1,000	$x10^{3}$	Kilo-
100	$x10^{2}$	hecto-
10	$x10^{1}$	deca-
1	$x10^{0}$	
0.1	$x10^{-1}$	deci-
0.01	$x10^{-2}$	centi-
0.001	$x10^{-3}$	milli-
0.000001	$x10^{-6}$	micro-
0.000000001	$x10^{-9}$	nano-
0.000000000001	$x10^{-12}$	pico-
0.000000000000001	$x10^{-15}$	femto-

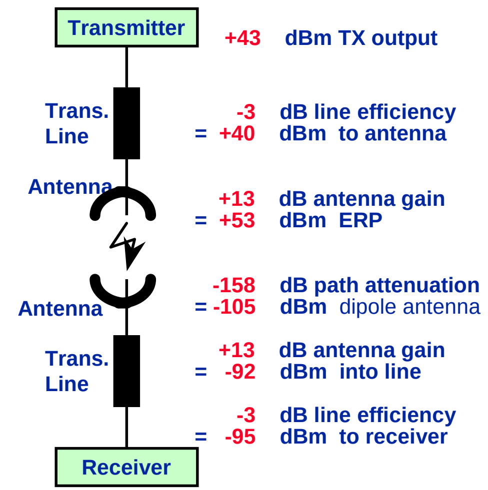
Large and small quantities pop up all over telecommunications and the world in general.

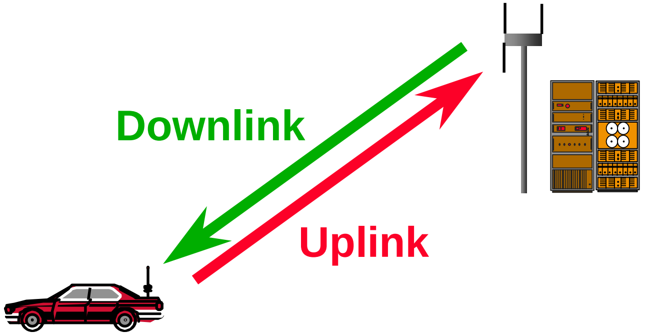
We like to work in units we can easily handle, both in math and in concept. So, when large or small numbers arise, we often use prefixes to scale them into something more comfortable:

- **Kilo**meters
- **Mega**hertz
- **Milli**watts
  - etc....

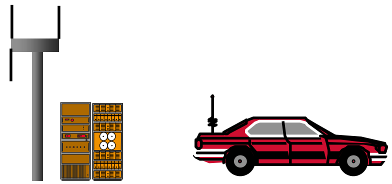
Link Budget Models

- Link Budgets trace power "expenditures" along path from transmitter to receiver
  - identify maximum allowable path loss
  - determine maximum feasible cell radius
- Two distinct cases: Uplink, Downlink
  - No advantage if link range in one direction exceeds the other
  - adjust cell power to achieve uplink/downlink balance
  - set power on both links as low as feasible, to reduce interference
- Link budget model can include appropriate assumptions for propagation, geography, other factors

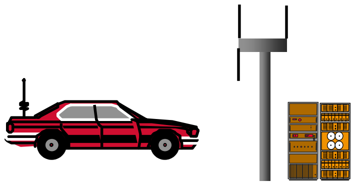




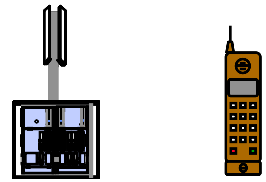
Cellular Link Budget Model Example



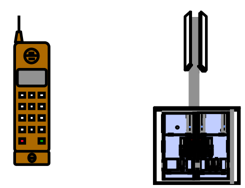
	Source:	FWD Path	REV Path	
Cell TX PO Watts	Spec:	45.00	3.00	MS TX PO Watts
Cell TX PO dBM	Calc:	46.53	34.77	MS TX PO dBm
Cell Combiner Loss dB	Input:	-3.00	0.00	MS Combiner Loss db
Cell Cable Loss db	Input:	-3.00	-2.00	MS Cable Loss db
Cell Antenna Gain dBd	Input:	10.00	5.00	MS Antenna Gain dBd
ERP Watts	*Calc:*	*113.03*	*5.99*	*ERP Watts*
ERP dBm	Calc:	50.53	37.77	ERP dBm
Max. FWD Path Loss, dB	Calc:	-169.53	-169.77	Max. REV Path Loss, dB
MS Antenna Gain dBd	Calc:	5.00	10.00	Cell Antenna Gain dBd
MS RX Cable Loss	Input:	-2.00	-3.00	Cell RX Cable Loss
MS Diversity Gain	Input:	0.00	4.00	Cell Diversity Gain
MS RX Sensitivity dBM	Spec.:	-116.00	-121.00	Cell RX Sensitivity dBM
Worst-Case Link Budget	Calc:	-169.77	0.24	Imbalance, dB



PCS-1900 GSM Link Budget Model Example



	Source:	FWD Path	REV Path	
Cell TX PO Watts	Spec:	16.00	1.00	MS TX PO Watts
Cell TX PO dBM	Calc:	42.04	30.00	MS TX PO dBm
Cell Combiner Loss dB	Input:	-2.00	0.00	MS Combiner Loss db
Cell Cable Loss db	Input:	-3.00	0.00	MS Cable Loss db
Cell Antenna Gain dBd	Input:	16.00	0.00	MS Antenna Gain dBd
ERP Watts	*Calc:*	*201.43*	*1.00*	*ERP Watts*
ERP dBm	Calc:	53.04	30.00	ERP dBm
Max. FWD Path Loss, dB	Calc:	-155.04	-154.00	Max. REV Path Loss, dB
MS Antenna Gain dBd	Calc:	0.00	16.00	Cell Antenna Gain dBd
MS RX Cable Loss	Input:	0.00	-3.00	Cell RX Cable Loss
MS Diversity Gain	Input:	0.00	4.00	Cell Diversity Gain
MS RX Sensitivity dBM	Spec.:	-102.00	-107.00	Cell RX Sensitivity dBM
Worst-Case Link Budget	Calc:	-155.04	-1.04	Imbalance, dB



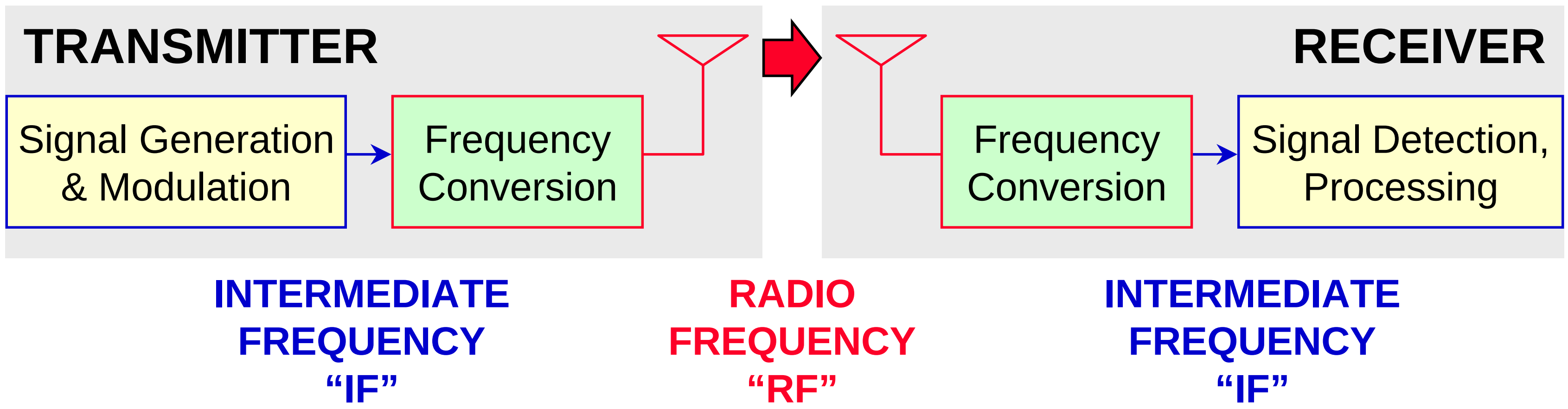
Chapter 9 Section B

Receiver and Transmitter Characteristics

RELEVANT EQUIPMENT CHARACTERISTICS

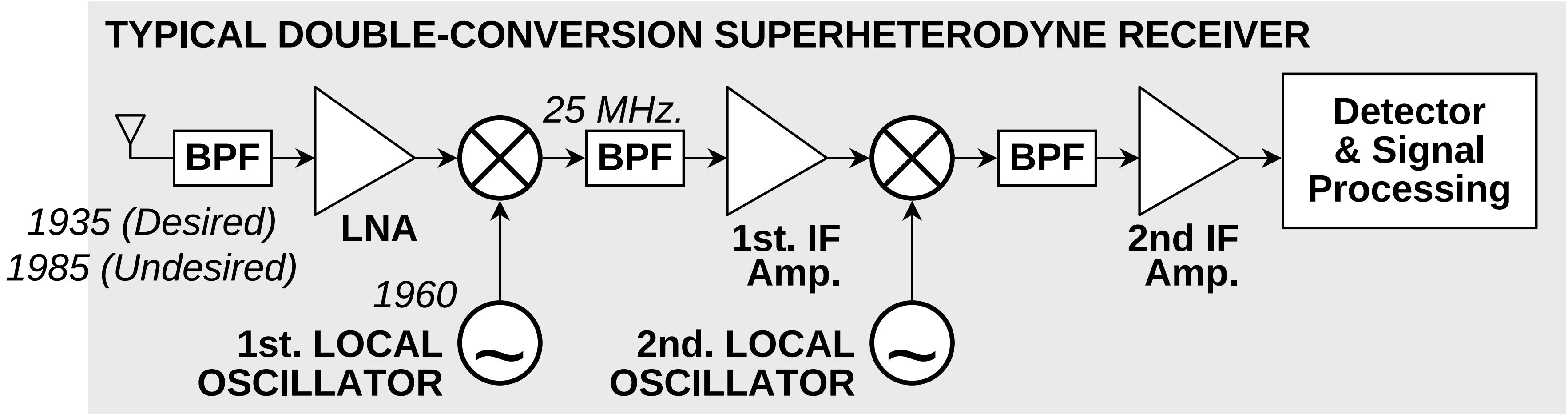
- Receiver Performance
  - Sensitivity
  - Selectivity
    - Adjacent Channel Rejection, IF & detection bandwidth
  - Dynamic Range
- Transmitter Performance
  - Power output & accuracy of regulation
  - Emitted noise spectrum
  - Modulation percentage, Deviation, Deviation Limiting
  - Frequency accuracy
  - SAT conditioning, ST production, QPSK phase accuracy

Superheterodyne Process



- The complex waveforms of popular wireless technologies are generated, detected, and filtered or processed most easily and precisely at relatively low frequencies
- Signals can be easily and arbitarily converted from low to high frequencies & vice-versa
- Most modern receivers and transmitters therefore perform frequency conversion to allow processing at lower "intermediate frequencies"
- This architecture is called "superheterodyne"

Superheterodyne Pitfall: Image Frequencies



Example: Desired signal is 1935 MHz. 1st. LO is 1960 MHz. 1st. IF operates on 25 MHz. Undesired signal on 1985 MHz. also mixes with 1960 MHz. to produce IF signal of 25 MHz., and becomes indistinguishable from desired signal.
Solution: Use a higher first IF frequency, and lower 1st. LO frequency.

- Although superheterodyne receivers give superior signal processing performance, they are vulnerable to image frequencies
  - frequencies of local oscillators and IF amplifiers must be carefully chosen so that unintended “image” frequencies will be excluded from processing
  - IF frequency and IF bandwidth must be chosen so that the undesired image is highly attenuated

Limitations of Radio Receivers

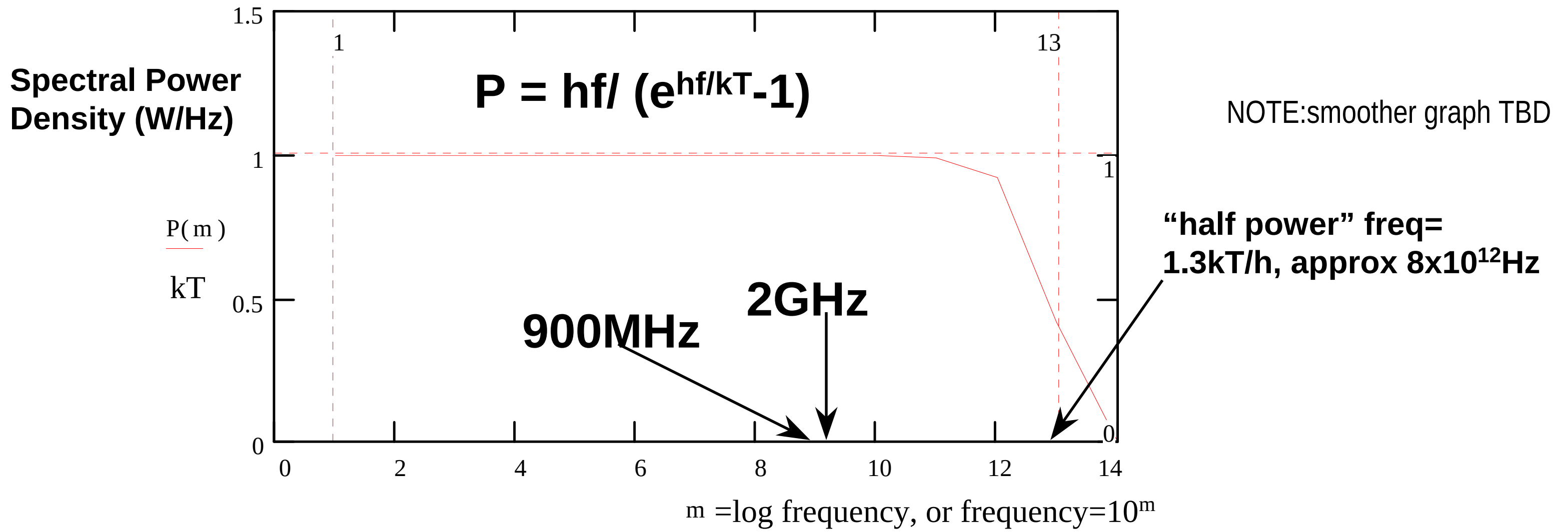
Noise Basics

- The weakest signal detectable is limited by presence of undesired “noise”:
  - Thermal (“white”) noise
  - Shot noise
  - Fluctuation, partition and other causes
- Characterization by a “Noise Figure”
  - Ratio of S/N out to S/N in
- Limitations of strongest signals, or presence of both weak and strong signals are due to non-linearities
  - Inter-modulation (IM), both inside and outside the receiver
- IM also produces noise; characterized by “Intercept Points”

Sensitivity Limitations of receivers:

- Thermal “white” noise is a manifestation of thermal equilibrium distribution of electromagnetic zero-point wave energy
  - electrical resistor (thermal agitation of electrons)
  - radio antenna coupled to empty space
- shot noise is a manifestation of movement of discrete electrons accelerating
  - What is the sound of a thousand hands clapping? (Zen and the art of cellular system design!!) Applause is an audio signal analogous to discrete electron noise.
- Fluctuation and partition noise result from random variation of electron streams which divide between several target electrodes

Quantum Limited Spectral Noise Power



- P is spectral power density in W/Hz. T is absolute Kelvin temperature (293=room temp, 20 Celsius). k is Boltzmann's constant 1.38×10^{-23} Ws/deg. h is Planck's constant 6.6×10^{-34} Ws^2.
- For frequencies below 10^{11}Hz, we can treat the spectral power density as a uniform value kT

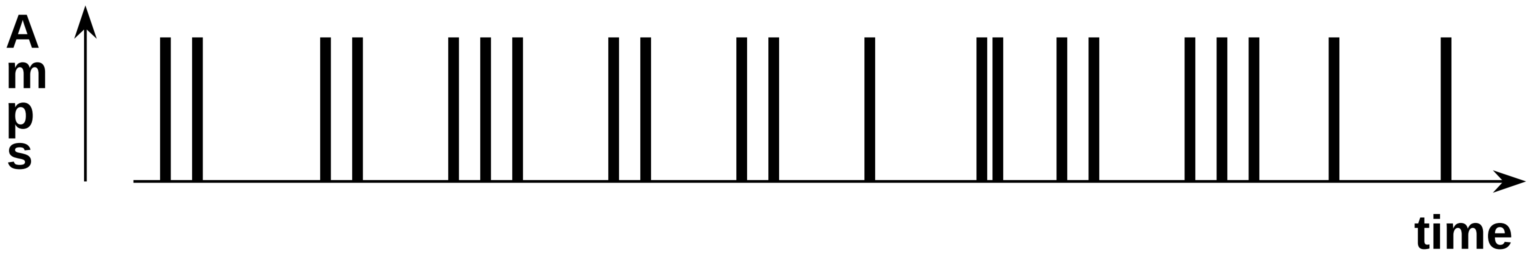
Ideal Uniform Spectrum Noise

- Theoretically, noise power is computed by integral of frequency power filter function with uniform kT, 4.14×10^{-21}watts/hertz density.
- For practical accuracy, compute thermal noise power as product of kT and bandwidth. Bandwidth may be derived from half-power points or other criteria.

System Names	BW(kHz)	Noise Power(W)	Noise Power(dBm)
TACS, SMR	25	1x10-19	-129.8
AMPS, TDMA	30	1.2x10-16	-129.05
GSM, DCS1900	200	8.3x10-16	-120.8
CDMA	1000	4.2x10-15	-113.8*

CDMA figure is broadband for entire composite signal without despreading gain. For individual user including effects of despreading, the equivalent bandwidth is taken as the bit rate of the vocoder (14,400 b/s in present-day IS-95 commercial applications). On this basis, noise power is -132.25 dBm for an individual user

Shot Noise



- Shot noise is due to granularity of current flow at weak signal lvels- - the distinguishable random impacts of individual electrons in active devices (diodes, transistors, etc.)
  - Many impacts in random time sequence produce uniform noise power spectrum, like applause or raindrops

$I_n^2 = qIG\Delta f$, where I_n is the standard deviation of the shot noise current, q is 1.6x10-19As, the charge of the electron, I is the dc signal current through an active junction, and G is a factor dependent on geometry of the structure. Δf is bandwidth. Note that I_n is *not* related to temperature.

Shot noise is a problem for the circuit designer, not the system designer. Its effect is included in the Noise Figure.

Noise Figure of Receiver

- The composite effect of all noise generated in the receiver is expressed by a figure of merit called Noise Figure (NF)
  - NF of an amplifier, or the entire pre-detection section of a receiver, is the ratio of Signal/Noise at the output divided by S/N at the input. Usually expressed in dB.
  - The input to a receiver is the antenna, and the assumed noise source there is the kT thermal noise of space.
- Example: A 30 kHz bandwidth receiver rated at 7dB NF has equivalent input noise level of -129+7=-122 dBm. Minimum analog received signal must be -122+18=-104 dBm for good noise-limited reception. (*not* -111dBm!)
  - Neglecting IM, interference or other undesired signals

Chapter 9 Section C

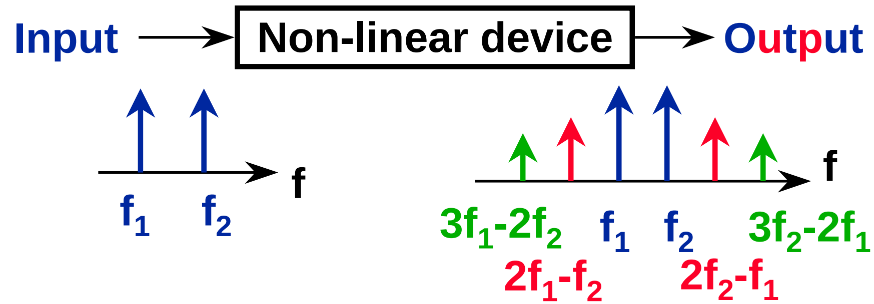
Intermodulation

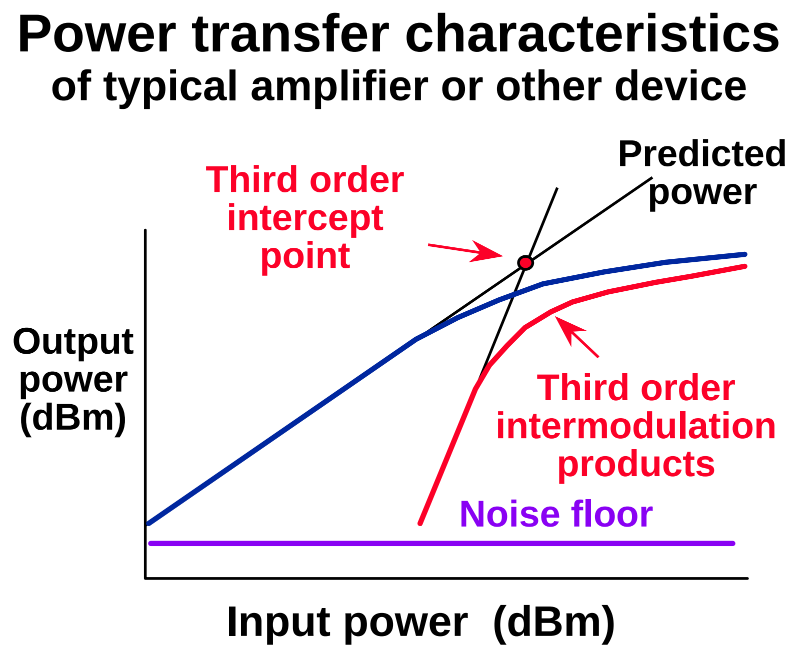
Intermodulation

- Intermodulation (IM) is an effect arising from very strong signals. It thus relates to the upper end of the dynamic range of signal power
- IM produces small signals at various frequencies which add to other sources of system noise and reduce the sensitivity of receivers. It thus relates to the lower end of the dynamic range of signal power as well.

Intermodulation

- Intermod theory
  - mixing
  - power amplifier transfer characteristics of active and passive devices
  - third-order intercept point
    - lab determination of 3rd-order points, two-tone testing
    - effective 3rd. order points in passive devices
  - higher-order intercept points
- Cellular and PCS channelization characteristics
  - where we can expect intermod to affect us
    - receive bands
    - transmit bands





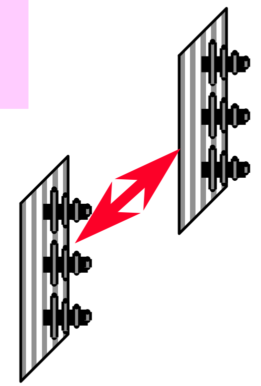
Intermodulation

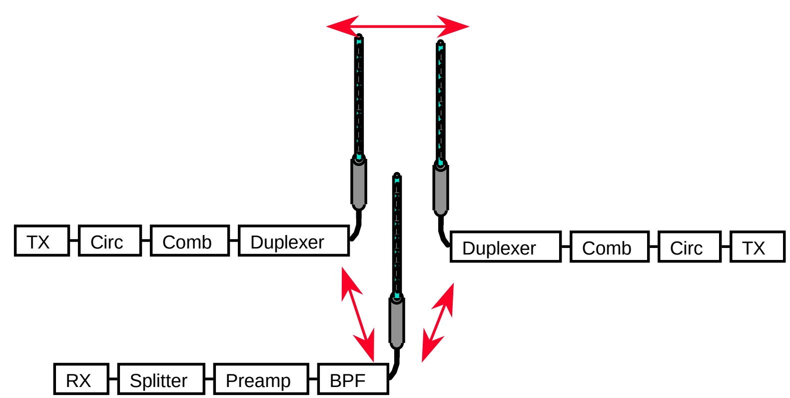
- Active intermod
  - production in transmitters and receivers
- Passive Intermod
  - antenna production
  - production in other points of rectification
- intermod forensics
  - finding intermod
  - eliminating intermod
  - available intermod prediction software

Equivalent Conversion Loss -6 dB.

Effective Intercept Point

Isolation





Non-linear Effects and Intermodulation

- Almost “everything” is slightly (or extremely) non-linear. Only free space is theoretically a true linear medium. Particularly non-linear are:
  - all active semiconductor devices
  - corroded electrical connections, etc.
- When high RF current levels are present in non-linear devices, waveform distortion occurs
  - A distorted (clipped, peaked, etc.) non-sinusoidal waveform is equivalent to a sum of sine waves of several different frequencies (Fourier series)
  - Product waveforms can also occur when two frequencies are “mixed” due to the non-linearity
  - if the nonlinear device characteristics are accurately known (intercept point, etc.), IM amplitudes can be accurately computed.
  - If nonlinear device characteristics are unknown, the worst-case intermod mechanism will have a conversion loss of at least 6 dB.

Modulation vs. Intermodulation

- When two signals are intentionally combined in a non-linear device we call the effect modulation
  - Amplitude modulator, or quad phase modulator
  - Mixer, down or up convertor in superheterodyne
- When two (or more) signals are *un*intentionally combined in a non-linear device, we call the effect *inter*modulation (a pejorative term)

An analogy: Botanists use soil to grow plants. But on your living room carpet, soil is just dirt.

- IM signals increase system noise, or cause distinctive recognizable interference signals

What to do about IM

- Try to prevent or reduce the amplitude of strong RF signals reaching receivers in wireless systems
  - Reduce or eliminate at the source, if feasible (spurious emissions from electric lamps, signs, elevator motors, etc.)
  - Shielding, enclosure, modification of antenna directionality to reduce the penetration of electromagnetic waves
  - Identify and eliminate secondary non-linear radiators: parallel metal joints with conductive connections, ground all parts of metal fences, rain gutters, etc. (also improves lightning protection)
  - Conducted RF from wires, etc. entering receiver can be reduced via low pass or band pass filters, ferrite beads, etc.
  - Notch filters to remove source RF, or specific harmonics or products

Chapter 9 Section D

RFI/EMI

Interactions between Wireless Sites and other Communication Systems

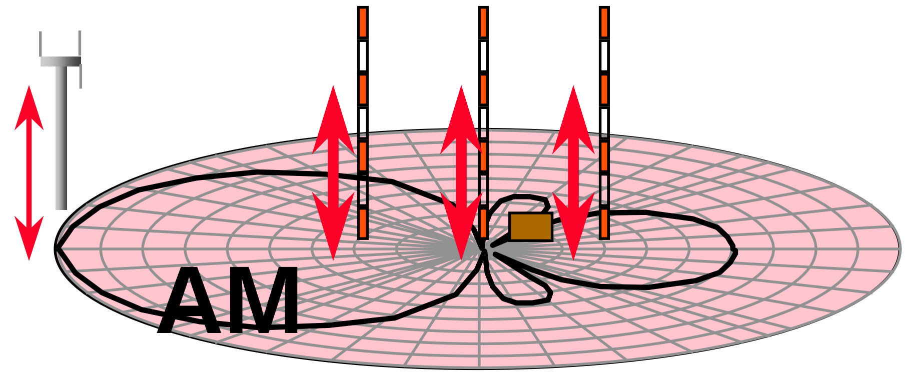
- Antenna Interactions
  - blocking or shadowing by closely-spaced antennas
  - pattern distortion due to induced currents & re-radiation
- EMI/RFI ElectroMagnetic Interference,
  Radio Frequency Interference
  - crosstalk induced in audio circuitry
  - erratic operation of T1s, data circuits
- Radio Interference
  - intermodulation products
    - externally generated due to high signal levels
    - generated by receiver overload
    - generated in unprotected transmitters
  - spurious products (noise, harmonics)
- RF Exposure Biological Hazards near other high power sites

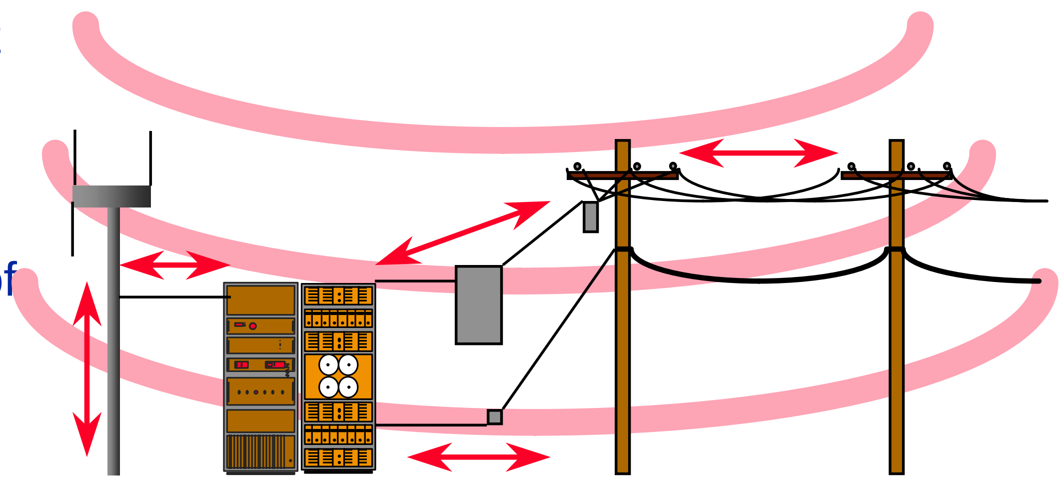
Key Parameters of Communication Systems

System	Frequencies	Wavelength	TX Power	ERP
AMPs Cellular Sites	**T 869-896 MHz** **R 824-841 MHz**	**13-14 in** ***33-36 cm***	**1-60 watts** per carrier	**1-300 watts** per carrier
PCS Sites	**T 1930-1990 MHz** **R 1850-1910 MHz**	**5.9-6.4 in** ***15-16 cm***	**1-45 watts** per carrier	**1-1000 watts** per carrier
AM Broadcast	**540-1600 kHz**	**615-1822 ft** ***187-556 m***	**250 watts** **to 50 kW.**	**250 watts** **to 500 kW.**
FM Broadcast	**88 - 108 MHz**	**9.1-11.2 ft.** ***2.8-3.4 m.***	**10 watts** **to 40 kW**	**10 watts** **to 100 kW**
VHF TV Broadcast **Channels 2-6**	**54 - 88 MHz**	**11.1-18 ft** ***3.4 - 5.6 m***	**10 watts** **to 50 kW**	**10 watts** **to 100 kW.**
VHF TV Broadcast **Channels 7-13**	**174 - 216 MHz**	**4.6-5.6 ft** ***1.4-1.7 m***	**10 watts** **to 100 kW.**	**10 watts** **to 316 kW.**
UHFTV Broadcast **Channels 14-69**	**490 - 800 MHz**	**1.2-2.1 ft** ***37-64 cm***	**100 watts** **to 220 kW.**	**10 watts** **to 5 MW**
Land Mobile, SMR, ESMR & Paging	**30 - 50 MHz** **152-174 MHz** **450-470 MHz** **800-900 MHz**	**1.2-2.1 ft** ***37-64 cm***	**1 watt** **to 1 kW.**	**10 watts** **to 10 kW.**

Interactions between Wireless Sites and AM Broadcast Stations

- **Broadcaster affected**
  - cellular tower may intercept and **reradiate** enough AM energy to alter the AM coverage pattern -- especially if broadcaster is already directional and has carefully-controlled pattern shape. FCC will require <u>cellular operator</u> to correct
- **Wireless system affected**
  - strong signal intercepted by cell site wiring can cause audible **crosstalk** of radio program on analog voice circuits, or erratic operation of T1 & data circuits

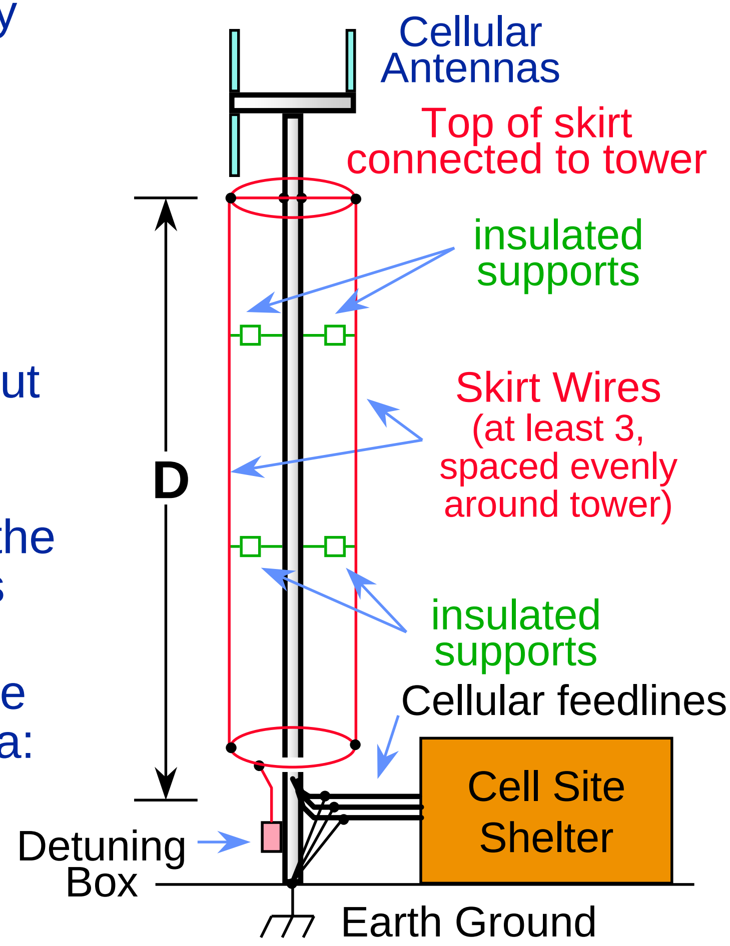




Neutralizing AM Broadcast Re-radiation by using a Detuning Skirt

- Best solution: avoid building in the vicinity of AM antennas
- Second-best solution:
  - If AM radial measurements show excessive reradiation, ***detune*** the cellular structure using a wire skirt
  - the skirt “cancels” the reradiation by carrying a current equal in strength but opposite in direction to the current naturally induced in the tower itself
  - adjustment of tuning components in the detuning box to obtain cancellation is very “touchy”
  - Skirt height is determined by available space on tower, or by D from formula:

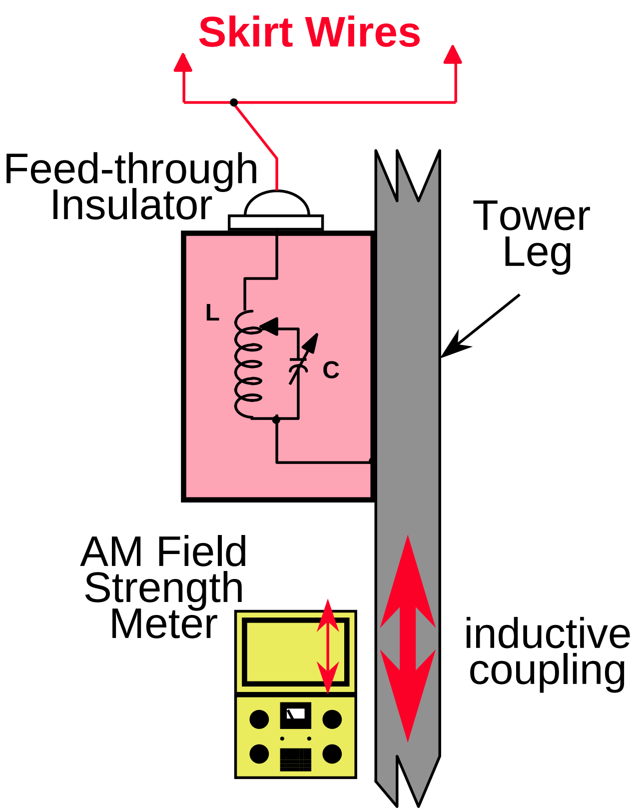
Optimum D in meters and feet:
D_{meters} = 60,000 / (AM Freq., kHz.)
D_{feet} = 200,000 / (AM Freq., kHz.)



Neutralizing AM Broadcast Re-radiation by using a Detuning Skirt

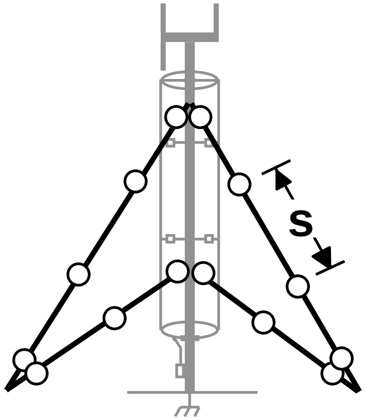
- **L** and **C** in box are chosen for resonance at AM frequency and tuned to set up proper current and phase in skirt
  - L = typically 25 -125 uH @ 6 amps
    - use non-corroding straps, not wire or braid, for all connections
    - make connections to L using clips to allow very sensitive adjustment
  - C = typically 1000 pF to 3000 pF
    - vacuum-variable best, but $$$; fixed mica OK - at least 6 kV, 5 A
- AM field strength meter measures residual current in tower leg to indicate degree of cancellation
  - L and C connections carefully adjusted to achieve resonance and then to minimize residual current

Detail of Tuning Box



Neutralizing AM Broadcast Re-radiation by using a Detuning Skirt

- Guy wires of the cellular tower can also re-radiate AM signal!
  - insulators must be used to break guy wires into sections too short to re-radiate
- Antenna feedlines on the the cellular tower must be electrically connected to the tower to avoid reradiation
  - at the top of their runs
  - at the point where they leave the tower
  - at intervals of not over 100 ft (30m) (ignore if inside monopole)
  - use grounding kits supplied by the cable manufacturer



Maximum non-radiating length S:
D_{meters} = 4,500 / (AM Freq., kHz.)
D_{feet} = 15,000 / (AM Freq., kHz.)

Other Detuning Resources

- Detuning structures to prevent AM re-radiation is quite different from ordinary cellular and PCS RF practices and can be complex
- Sometimes it is less expensive to turn to vendors and consultants in the broadcast industry to resolve difficult problems
  - advantage: ready availability of parts, materials, kits
  - advantage: familiarity with design and adjustment techniques

A few vendors and consultants are shown below. Check ads in broadcast trade and engineering magazines for others.

A Detuning hardware vendor:

Kintronic Laboratories
PO Box 845
Bristol, Tennessee 37615
(615) 878-3141
Fax (615) 878-4224

•Skirt kits & components
•Detuning network kits, parts

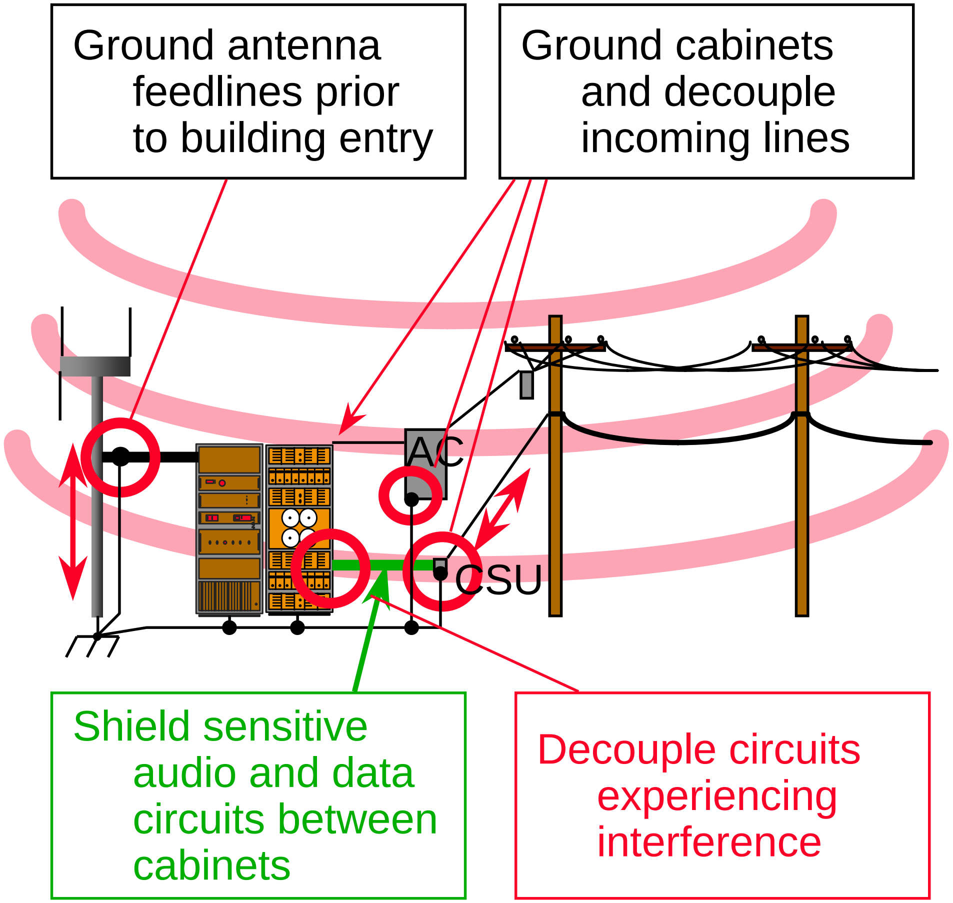
Consultants active in detuning work:

Biby Engineering Service
(Washington DC area)
(703) 558-0505 Fax (703) 558-0523

DuTreil, Lundin & Rackley (FL area)
(813) 366-2611 Fax (813) 366-5533

Eliminating Crosstalk due to AM Broadcasters

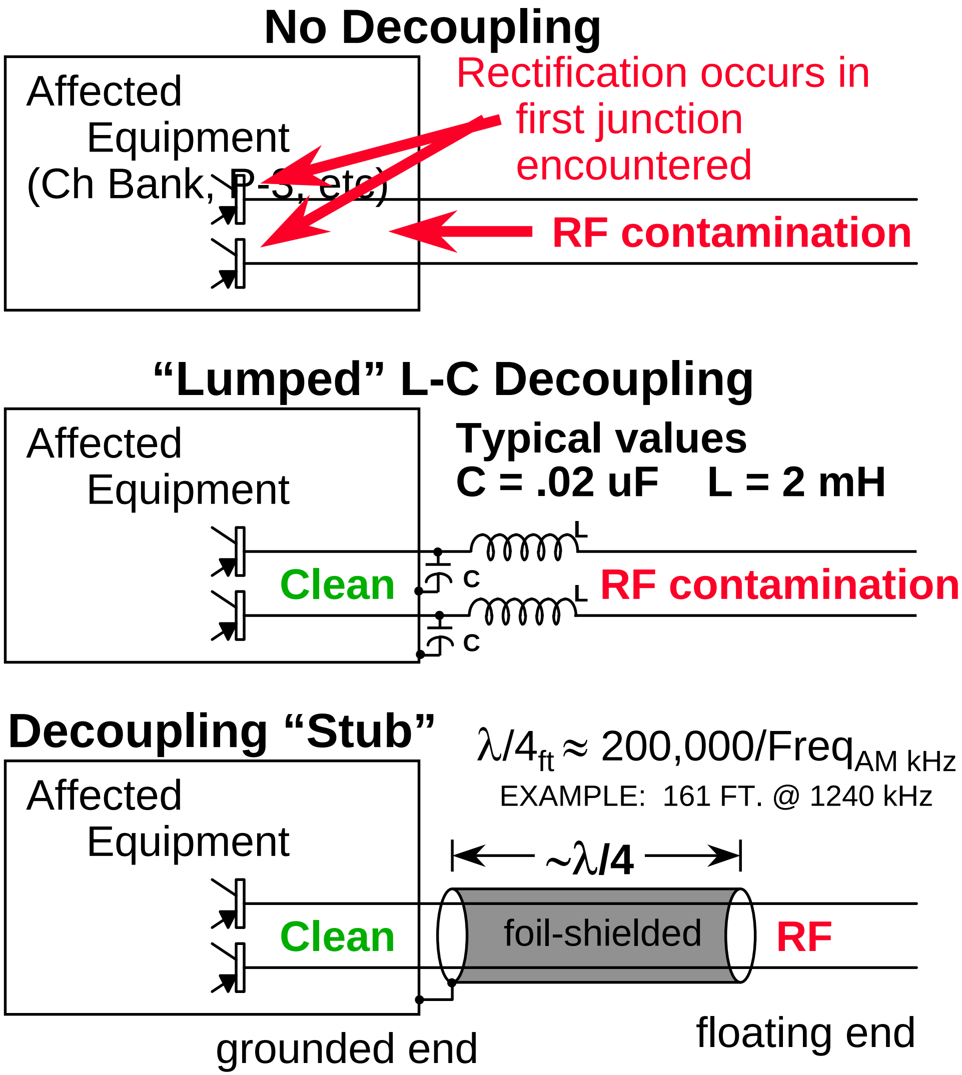
- Crosstalk occurs when high-level AM signal is rectified in sensitive audio circuits
- AM RF Pickup mechanism: every incoming wire is an AM receiving antenna
- Identify circuits where interference is present
  - Identify probable RF coupling mechanism
  - Decouple external lines using L-C networks or tuned stubs
  - Use shielded wiring for sensitive audio and data circuits between cabinets



Decoupling Methods for AM Crosstalk

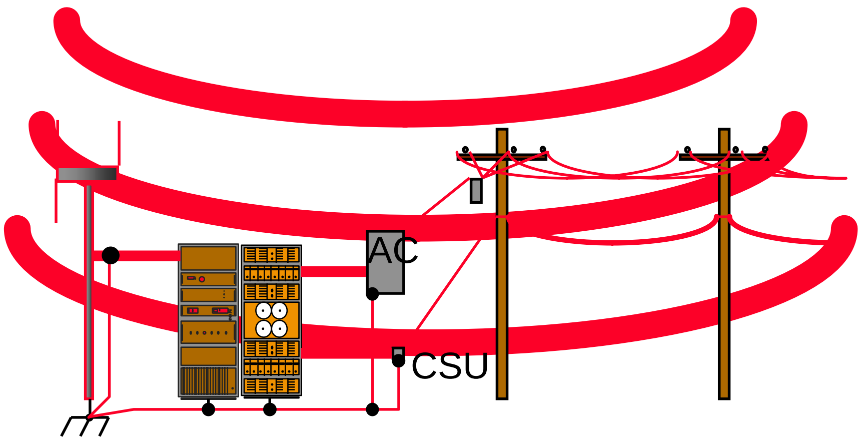
AM frequencies: 540-1600 kHz
Wavelengths: 600 - 1800 Feet

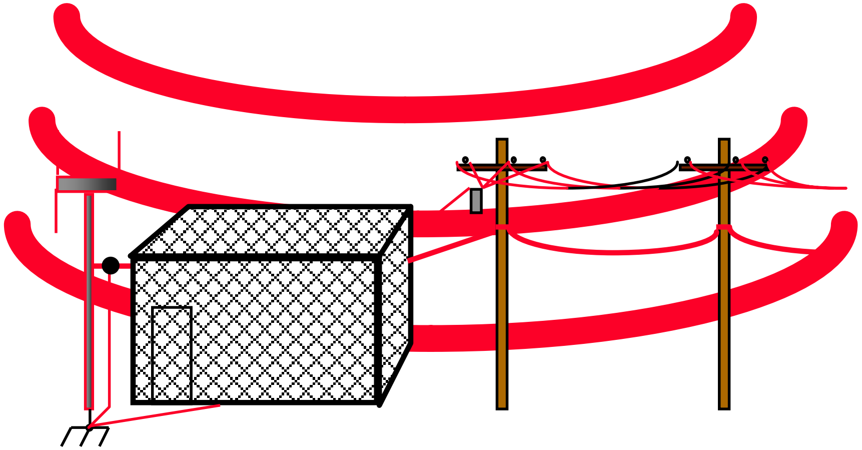
- Incoming circuits are contaminated with RF
  - rectification occurs in first solid-state junction(s) encountered
- "Lumped" L-C circuits
  - good technique for analog audio circuits (voice, modem)
  - watch out: can't directly decouple high-bandwidth circuits (T-1s, etc.)
- Decoupling stubs
  - less degradation of circuit bandwidth: OK for T-1s
  - ~λ/4 is long! OK to coil in a convenient location



AM Crosstalk
Additional Techniques for Severe Cases

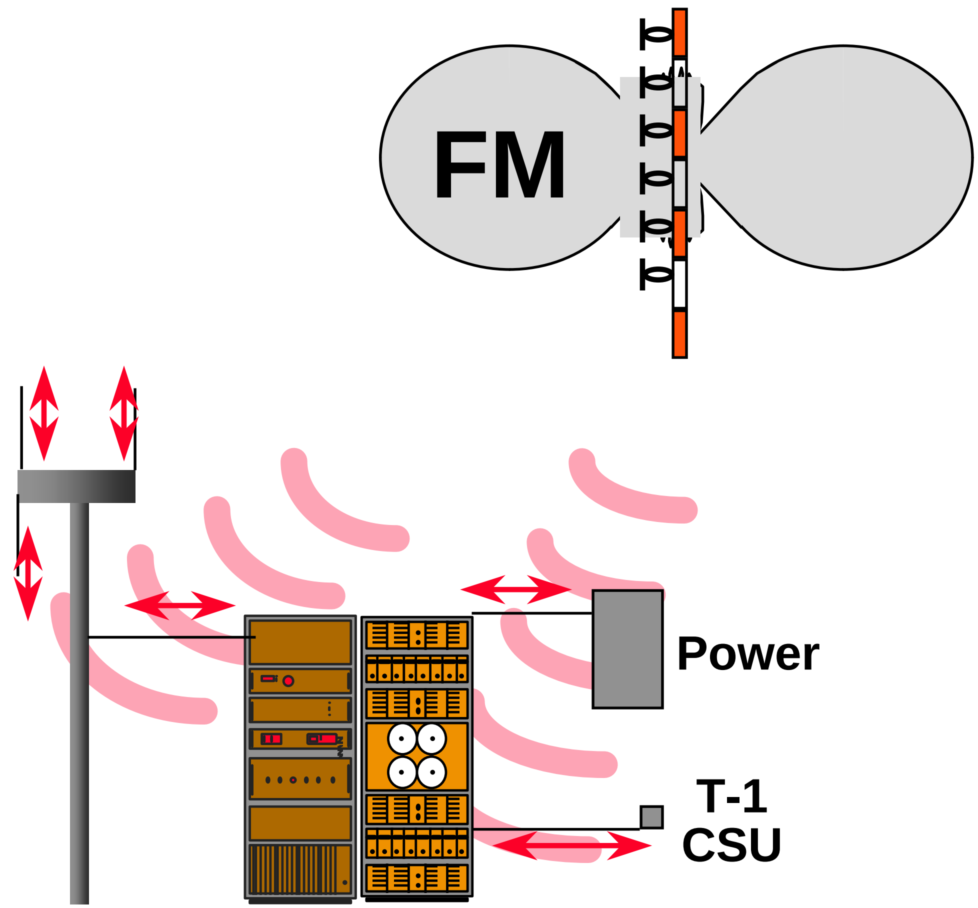
- If AM signal is extremely strong (>1000 mV/m), even ground wires and cables between cabinets become contaminated with RF
- Shield the entire cell site shelter using expanded mesh copper screen
  - connect all seams and corners; use metal door and ground with multiple flexible braids across hinges
  - this is best done during shelter manufacture
  - don't forget to ground or decouple ***every*** circuit coming in or out!!





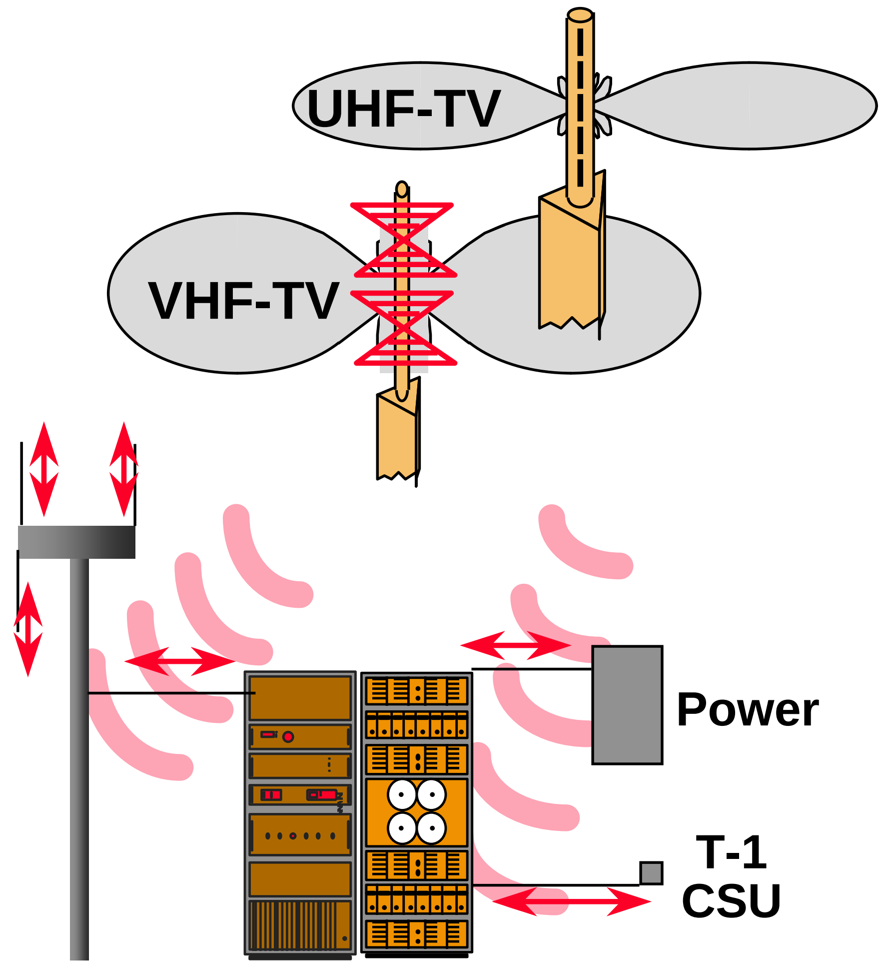
Interactions between Wireless Sites and FM Broadcast Stations

- **Wireless System Injured**
  - strong FM signal may overload cellular receivers, producing intermod
  - strong FM signal may create intermod products in nearby metal objects
  - strong FM signal intercepted by cell site wiring may cause white noise or audible crosstalk of radio programming into analog voice circuits, and erratic operation of T-1s & data circuits
  - possible long-term exposure hazard near high-power FM antennas



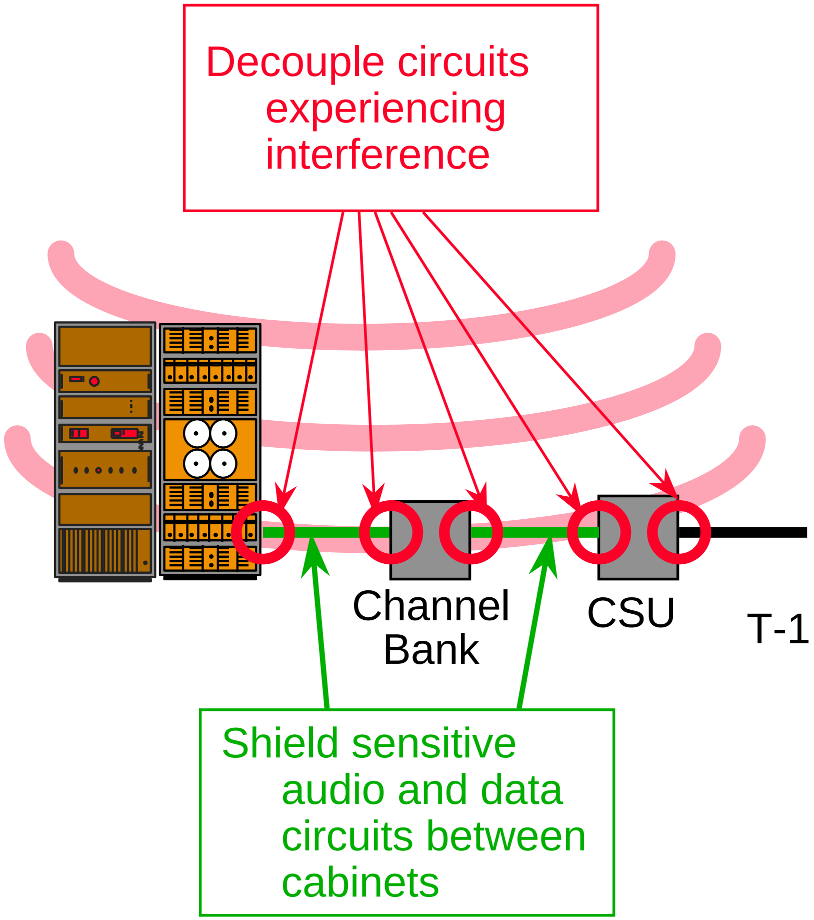
Interactions between Wireless Sites and TV Broadcast Stations

- **Wireless System Injured**
  - strong TV signal intercepted by cell site wiring may cause “sync buzz” in analog voice circuits, erratic operation of T-1s & data circuits
  - strong TV signal may create intermod products in nearby metal objects
  - strong TV signal may overload wireless receivers, producing intermod which causes “sync buzz” on specific wireless channels
  - possible long-term exposure hazard near high-power TV antennas



Eliminating Crosstalk due to FM and TV Broadcasters

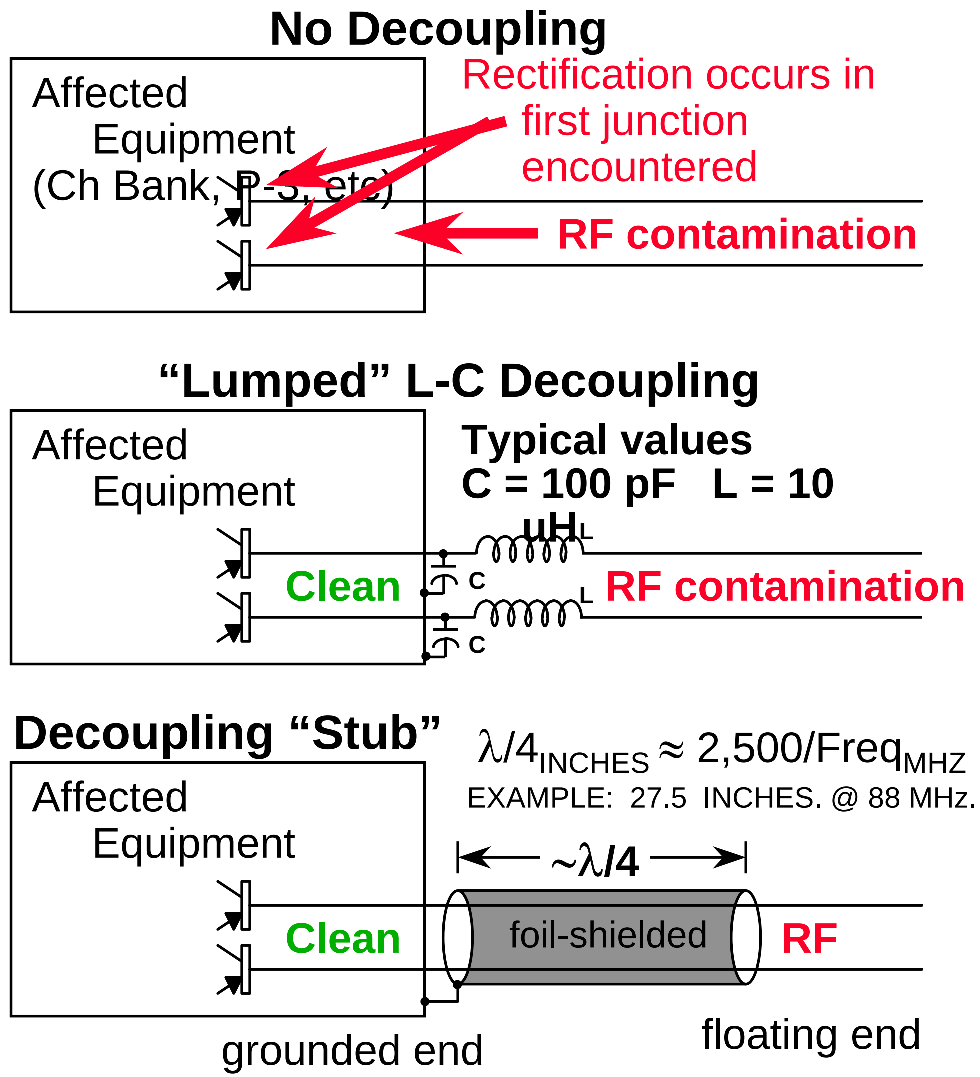
- Crosstalk occurs when strong FM or TV RF is rectified in sensitive circuits
- TV/FM RF Pickup mechanism: any short length of wire is a receiving antenna
  - "grounding" of cell cabinets, etc., has NOTHING to do with the problem -- a ground connection only 6 inches long is a very good antenna!!
- Identify circuits where interference is present
  - Decouple at the affected equipment, using L-C networks or tuned stubs
  - Use shielded wiring for sensitive audio and data circuits between cabinets



Decoupling FM and TV RF

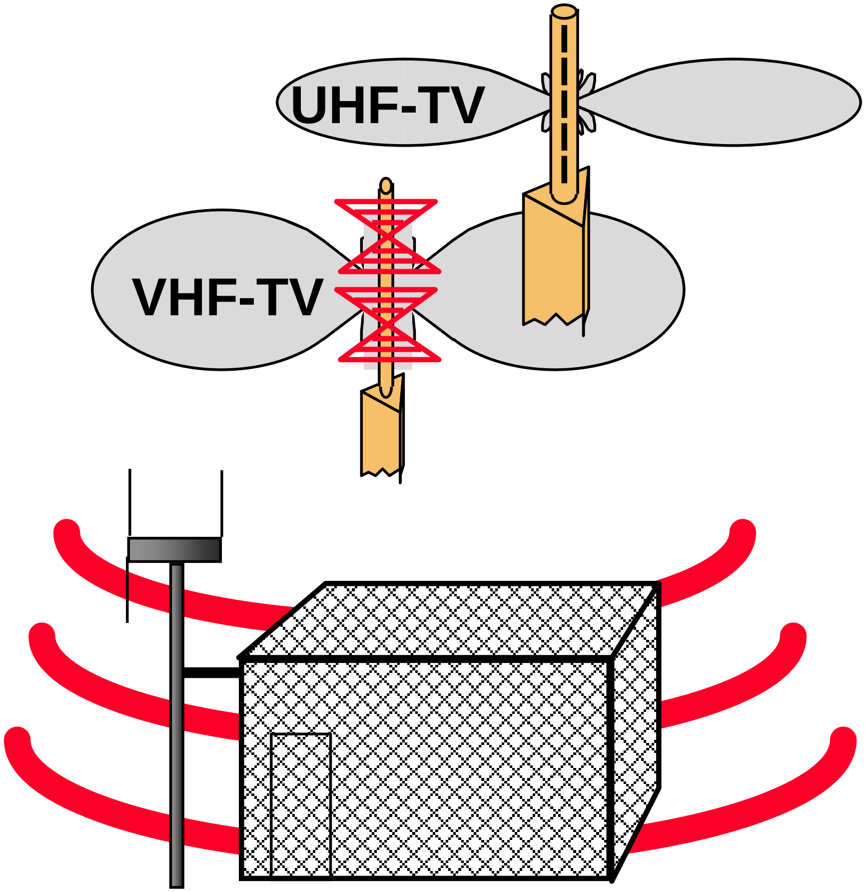
Frequencies: 54-806 MHz
Wavelengths: 1.2 - 18 feet

- How rectification occurs
  - every circuit contaminated
  - rectification occurs in first solid-state junction(s) encountered
- "Lumped" L-C circuits
  - parts are very small
  - apply **directly** at terminals of affected equipment -- do not allow even a few inches of exposed wire after decoupling!!
- Decoupling stubs
  - easier to apply than lumped L-C circuits



FM and TV Interference Crosstalk
Additional Techniques for Severe Cases

- If the FM/TV signals are extremely strong or numerous, shield the entire cell site shelter using expanded mesh copper screen
  - connect all seams and corners; use metal door and ground with finger stock against contacts on door
  - this is best installed during shelter manufacture
  - don't allow any openings larger than 1/8 wavelength!!
  - don't forget to ground or decouple ***every*** circuit coming in or out!!

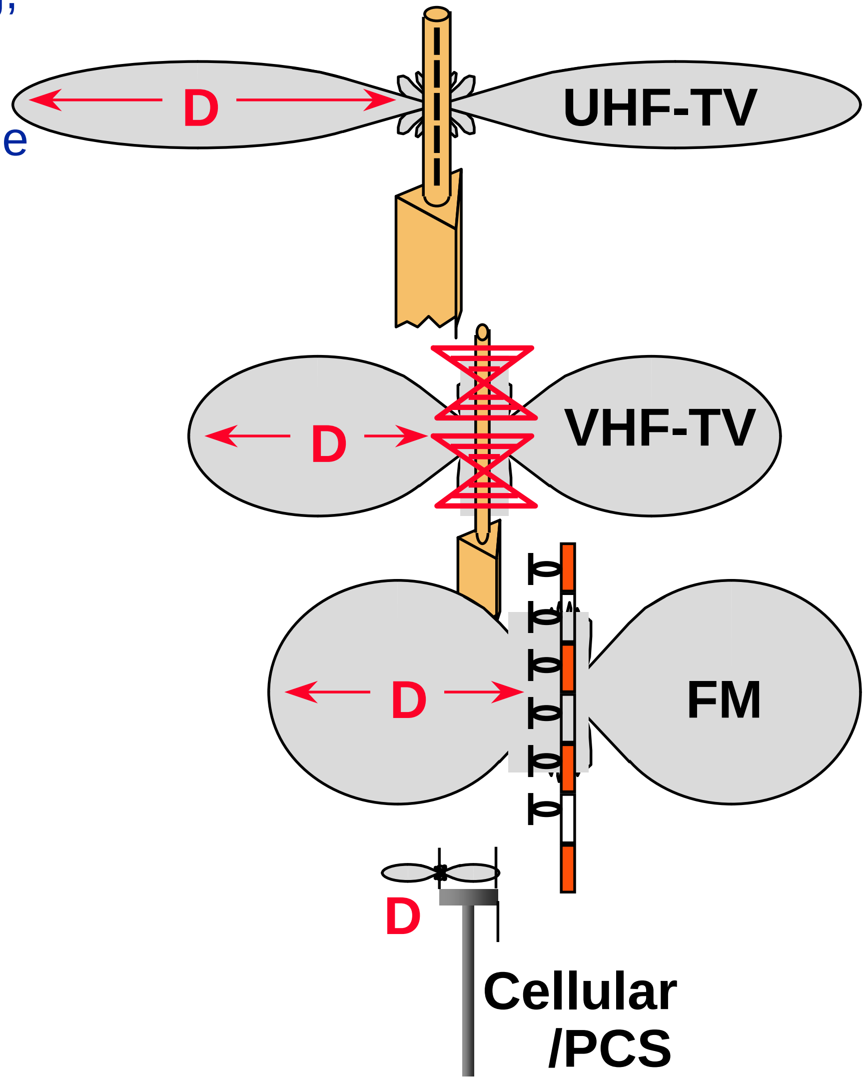


Chapter 9 Section E

RF Safety

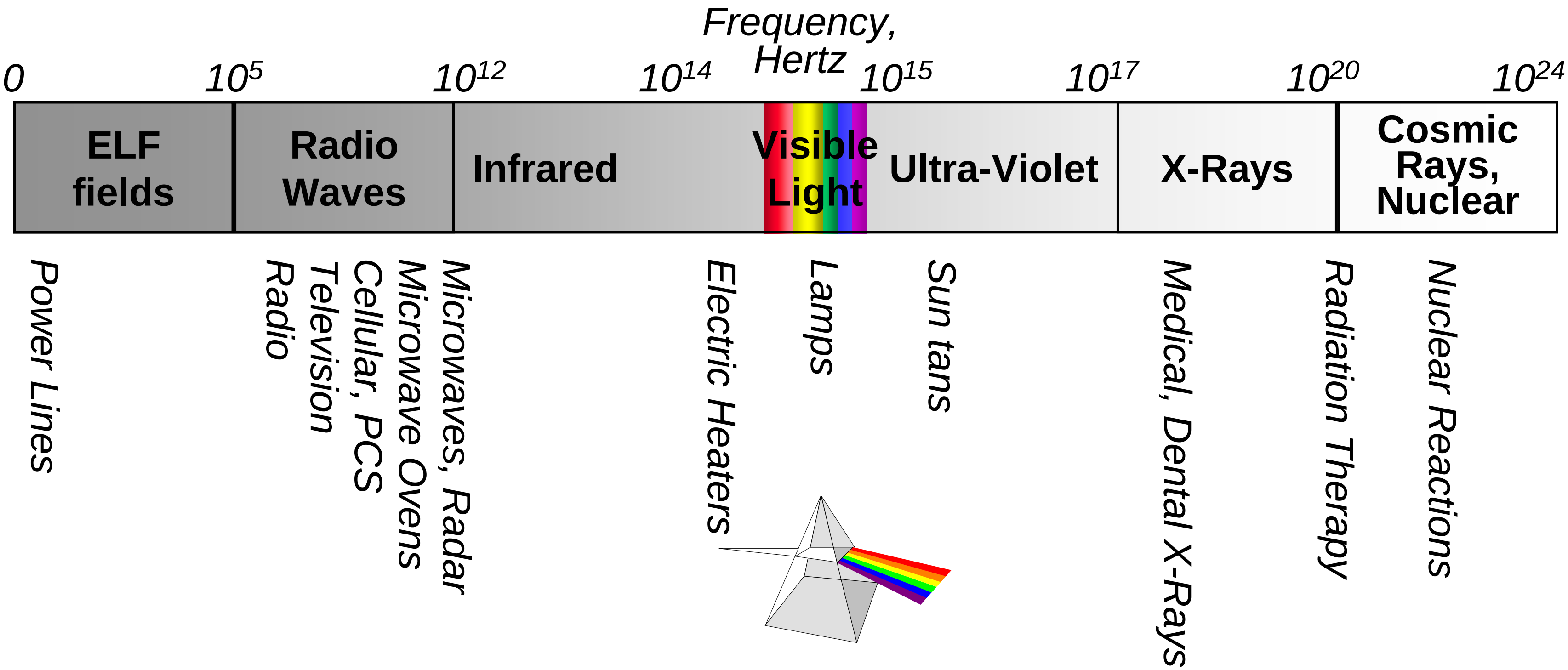
Observe RF Exposure Guidelines

- Although RF radiation is non-ionizing, and the epidemiological data is inconclusive, our medical understanding of RF and any possible effects is incomplete
- Avoid RF exposure in excess of appropriate guidelines
  - Typical distance to source, **D**:
    - **UHF-TV: 500 ft.+/-**
    - **VHF-TV: 200 ft. +/-**
    - **FM: 100 ft. +/-**
    - **Cellular/PCS: 5-15 ft.**
- Read and follow the progress of ongoing research in this field
- More information is available at the US website www.fcc.gov/oet/rfsafety

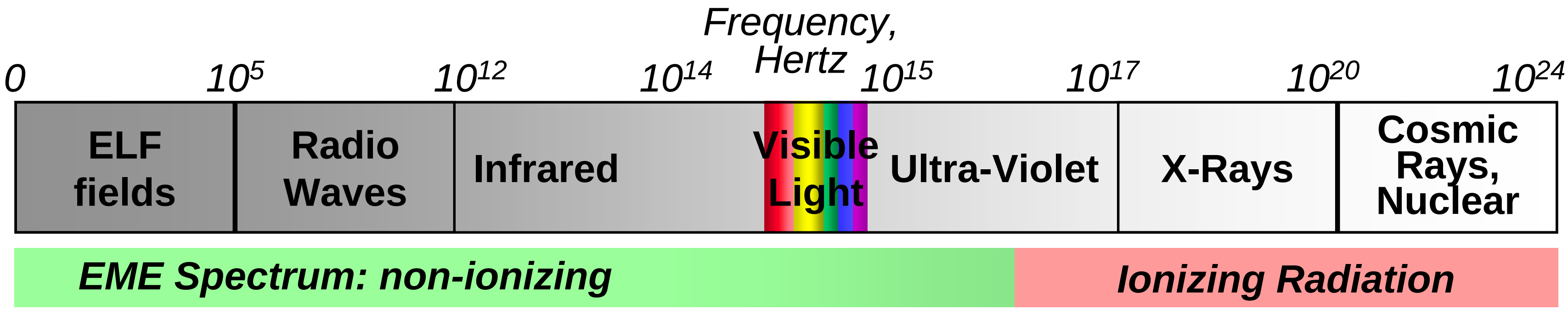


The Electromagnetic Spectrum

- Electrical Power, Radio waves for Communication, Microwaves, Heat, Visible Light, Ultraviolet light, X-rays, and Nuclear radiation are all part of the electromagnetic spectrum



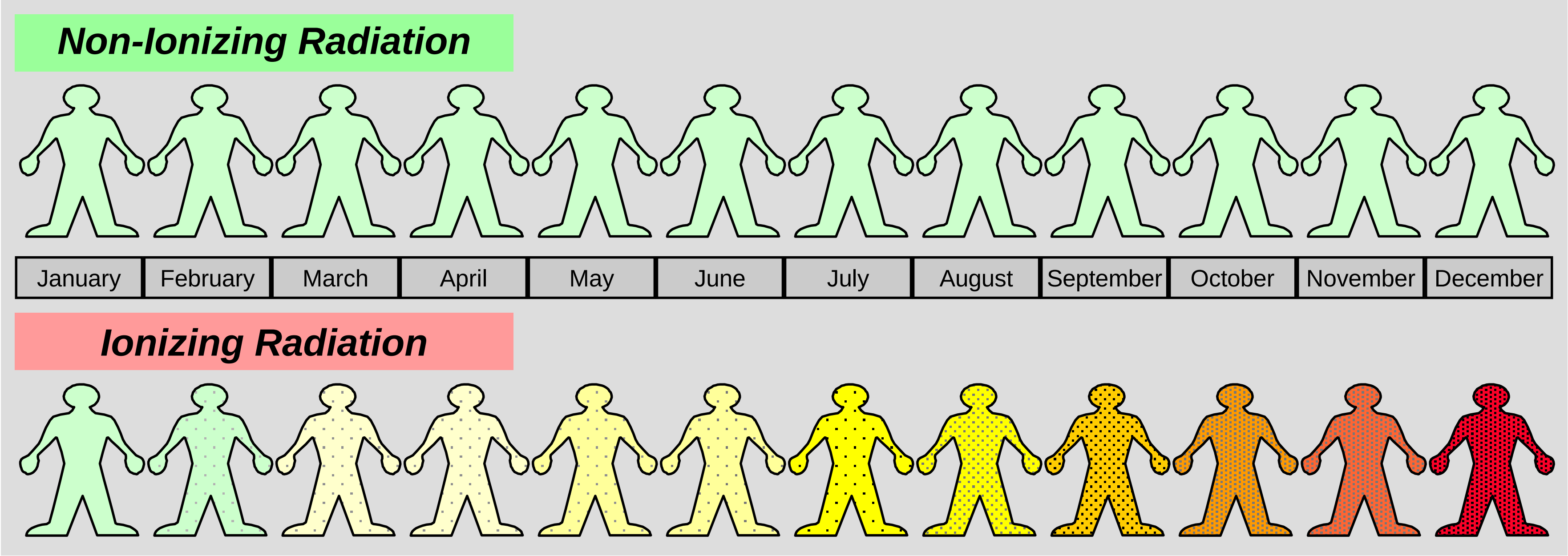
Non-Ionizing and Ionizing Radiation



- **Electromagnetic energy at frequencies below visible light is *"non-ionizing"***
  - the photons don't contain enough energy to knock electrons out of atoms or molecules, and no chemical changes are caused
  - the energy turns into heat if absorbed
  - the only known effects on living things come from this heat
  - at power levels defined in FCC standards, the heating is not physically perceptible -- less than from the light of a flashlight
  - research is continuing into other possible interaction mechanisms, but no conclusive links yet seen
- **Electromagnetic energy at frequencies above visible light is "*ionizing*"**
  - photons have enough energy to tear electrons from their atoms, creating ions
  - can cause chemical and biological changes (sun tans and more serious effects)

Cumulative and Non-Cumulative Radiation Effects

- **Effects of non-ionizing radiation are not cumulative**
  - heating is the only known mechanism causing effects
  - heating at allowed levels causes no changes in tissue
- **Effects of ionizing radiation are cumulative**
  - chemical changes: formation of ions which may eventually recombine, or may linger as free radicals with potential biological damage; cells die, and may possibly mutate



PRACTICAL RF HAZARDS

- RF energy will not "shock" or "electrocute" you. However, it is possible to get a nasty "RF Burn" by touching RF-energized metal surfaces. RF current only flows on the ***surface*** of a conductor.
- Most antennas have insulated radomes, so you won't get burns
  - but don't put your fingers in RF connectors or touch the metal surfaces of energized antennas
- Danger of falling, if surprised/startled by an unexpected RF burn
- DO NOT connect or disconnect RF connectors with power applied!
- If using Cardiac Pacemakers, Medical Monitoring Equipment, or other health-related electronic devices, consult your physician and/or site safety manager before entering any controlled area
- ***The standard is designed to protect YOU from these hazards!***
- Following these guidelines will ensure a safe working environment with RF exposures at safe levels, and avoid the potential for hazardous exposure.

Guidance on Acceptable RF Exposure

Read and be familiar with the following documents:

- OSHA Safety Manual
- RF safety chapter in your employee health and safety manual
- additional reference documentation should be available in the H&S manual or from your supervisor
- additional company-specific RF material
- many individual antenna locations have specific guidelines or procedures which must be followed

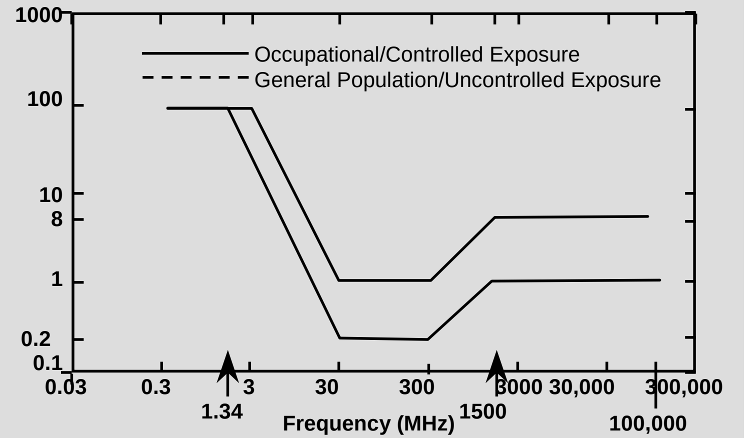
Maximum Permissible Exposure (MPE) Limits

(A) Limits for Occupational/Controlled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\lvert E \rvert^2$, $\lvert H \rvert^2$ or S (minutes)
0.3 - 3.0	614	1.63	(100)*	6
3.0 - 30	1842/f	4.89/f	$(900/f^2)$*	6
30 - 300	61.4	0.163	1.0	6
300 - 1500	--	--	f/300	6
1500 - 100,000	--	--	5	6

f = frequency in MHz. *Plane-wave equivalent power density

Figure 1. FCC Limits for Maximum Permissible Exposure (MPE)
Plane-wave Equivalent Power Density



(B) Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\lvert E \rvert^2$, $\lvert H \rvert^2$ or S (minutes)
0.3 - 1.34	614	1.63	(100)*	30
1.34 - 30	842/f	2.19/f	$(180/f^2)$*	30
30 - 300	27.5	0.073	0.2	30
300 - 1500	--	--	f/1500	30
1500 - 100,000	--	--	1.0	30

f = frequency in MHz. *Plane-wave equivalent power density

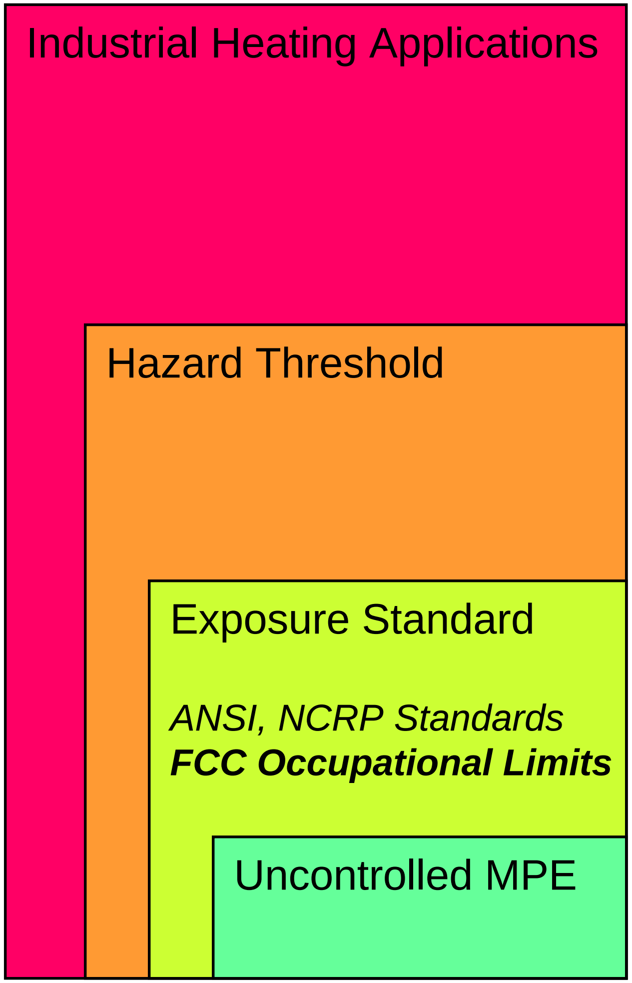
FCC OET Bulletin No. 65 gives these MPE limits for RF energy. Notice the two different sets of limits.

Occupational/Controlled Exposure limits apply to workers who know the details of the RF sources and can intelligently minimize their exposure by controlling their work practices.

General Population/Uncontrolled limits apply to the public at large, which will not be familiar with the RF sources and thus cannot take prudent steps to minimize their exposure. This group gets a larger measure of protection.

Relative EME Levels

- The EME MPE values set by the FCC have been determined after exhaustive research of all available data on possible ill effects of RF. They are very conservatively below all suspected thresholds of harm.
- Safety limits set are generally 10 to 100 times lower than conditions known to be potentially hazardous
  - common exposures can be controlled to fall well below safety limits
- Momentary exposure above standard thresholds is permitted by the standard, provided average exposure levels are below the threshold. RF exposure effects are not cumulative, so averaging is a valid way to monitor and control exposure.



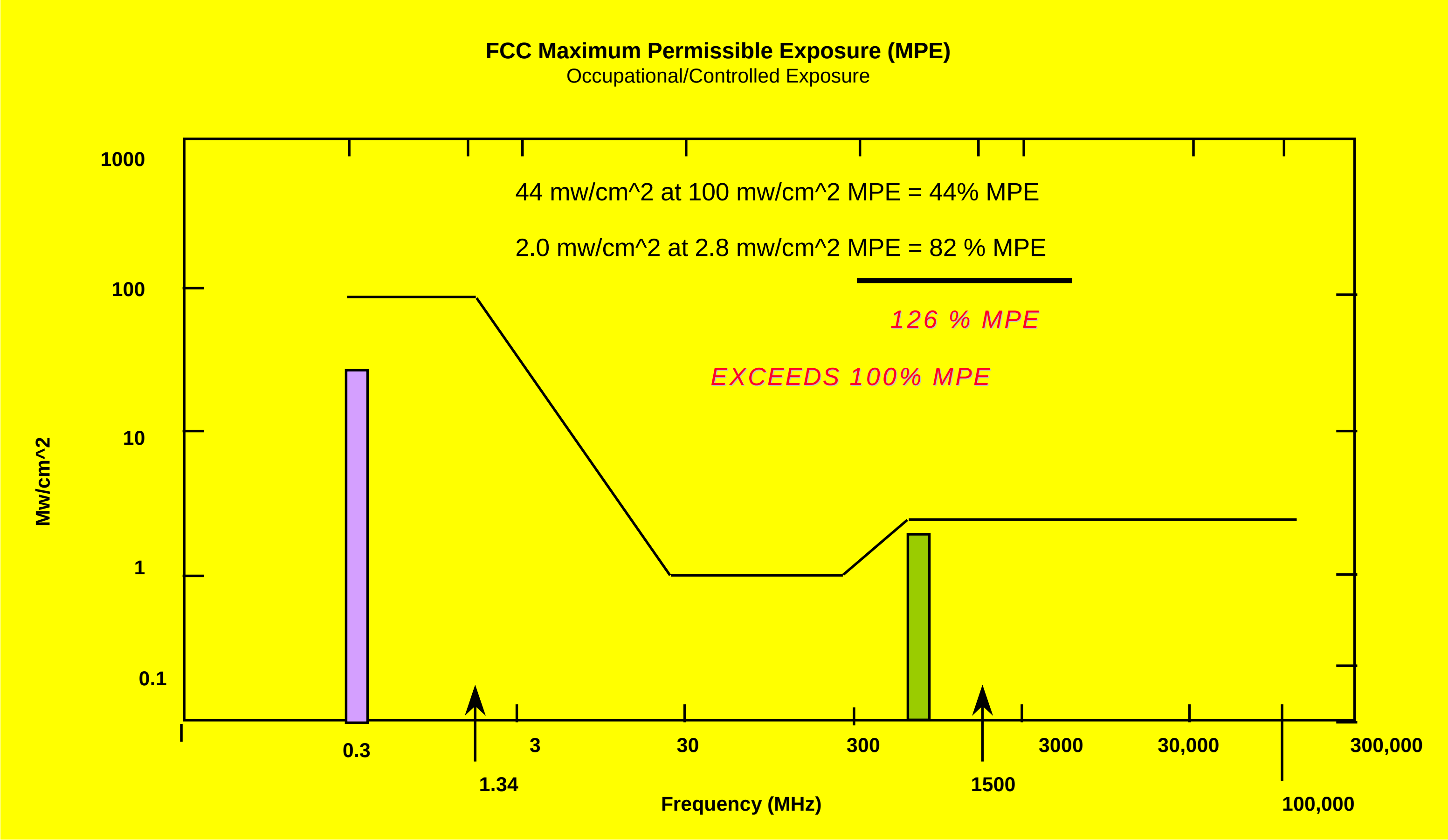
RF Exposure Surveys

- Perform on-site survey characterize area with multiple RF sources
- Need measurement equipment and probes which will
  - measure all frequencies used at site
    - Microwave to 28 or 38 GHz
    - Low Band Land Mobile to 30 MHz
    - AM Broadcast around 1.0 MHz
  - measures E field for higher frequencies, and M field for lower frequencies
  - passband response shaped to give proper MPE percentage of exposure directly

Site Survey to measure EME exposure as percentage of MPE

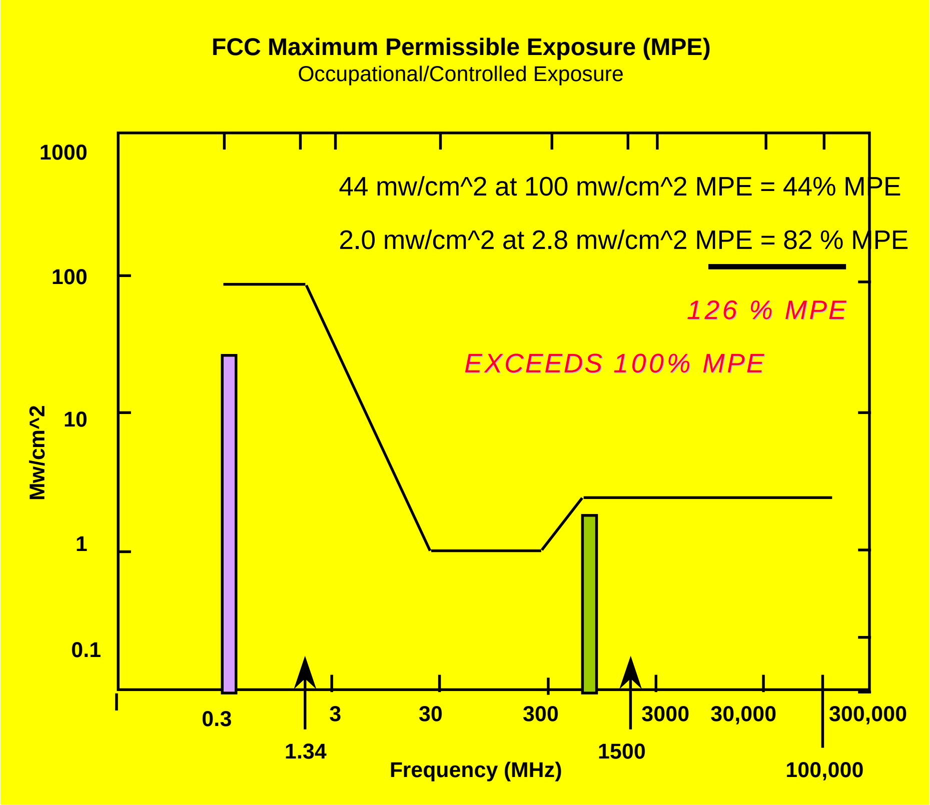
Exposure as Percentage of MPE

Each RF signal at a site must be considered; it contributes a percentage of your MPE limit. Refer to the MPE graph to determine the percentage it represents. *Your* **total** EME exposure **from *all* sources** must remain below the 100% MPE limit.

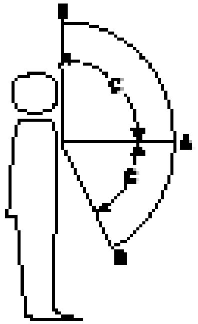


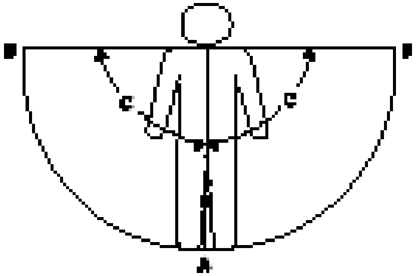
Exposure as Percentage of MPE

- examine EME exposure at a particular frequency
- compute percentage of MPE limit at that frequency
- add to percentages of all other operating frequencies at test location
- if total percentages > 100% = Problem
- if total percentages <= 100% = OK



Tips on Using Personal Safety Monitors

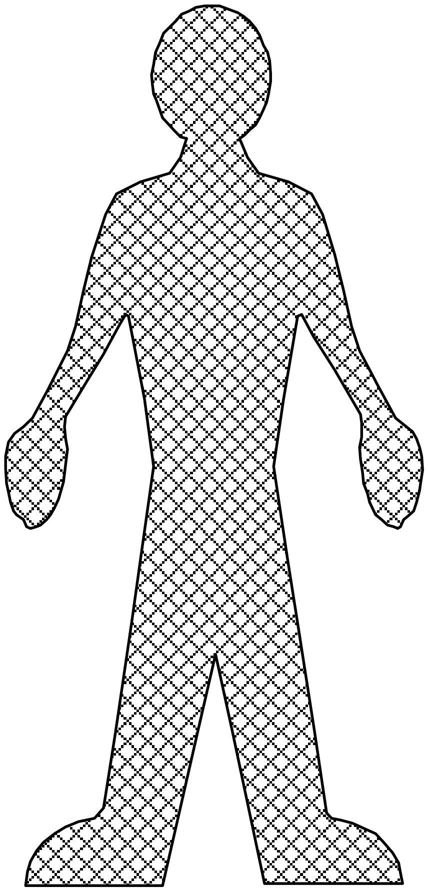




- Personal Safety Monitors sound an alarm when EME at their location exceeds MPE
  - small, can be worn or carried at all times when working in RF environment
  - accurately measure total EME level at a site, from all sources
  - Can be used as hand-held “probes” to locate and avoid hot spots
- Guidelines for using Personal Safety Monitors:
  - be sure it’s turned on and operating correctly while you work!
  - be sure to turn it off when you leave!
  - wear it on your front, at waist or shirt level
  - keep it between you and the RF sources
  - be sure you can hear it over local noises!

Tips on using RF Protective Suits

- RF Protective Suits are shielded garments which can reduce RF exposure by a factor of 10 to 100 or more
  - drawbacks: expensive, somewhat awkward to wear; easily torn or damaged; some are hot to wear in summer months
  - advantage: allows safe, routine work in otherwise excessive EME zones
- Wear your Personal Safety Monitor inside the suit to alarm when levels inside exceed the MPE
- Watch out for tears and damage to suits when working
- Inspect each suit at the beginning and end of each work session



3G Information Resources

Bibliography - Articles - Web Links

Bibliography, 3G Air Interface Technologies

<u>"3G Wireless Demystified"</u> by Lawrence Harte, Richard Levine, and Roman Kitka
488pp. Paperback, 2001 McGraw Hill, ISSBN 0-07-136301-7 $50. For both non-technical and technical readers. An excellent starting point for understanding all the major technologies and the whole 3G movement. Comfortable plain-language explanations of all the 2G and 3G air interfaces, yet including very succinct, complete, and rigorously correct technical details. You will still want to read books at a deeper technical level in your chosen technology, and may sometimes turn to the applicable standards for finer details, but *this* book will give you what you won't find elsewhere -- how everything relates in the big picture, and probably everything you care to know about technologies other than your own.

<u>"Wireless Network Evolution 2G to 3G"</u> by Vijay K. Garg. 764pp. 2002 Prentice-Hall, Inc. ISBN 0-13-028077-1. $80. Excellent technical tutorial and reference. The most complete and comprehensive technical detail seen in a single text on all these technologies: IS-95 2G CDMA, CDMA2000 3G CDMA, UMTS/WCDMA, Bluetooth, WLAN standards (802.11a, b, WILAN). Includes good foundation information on CDMA air interface traffic capacity, CDMA system design and optimization, and wireless IP operations. Excellent level of operational detail for IS-95 systems operating today as well as thorough explanations of 2.5G and 3G enhancements.

<u>"3G Wireless Networks"</u> by Clint Smith and Daniel Collins. 622pp. Paperback. 2002 McGraw-Hill, ISBN 0-07-136381-5. $60. An excellent overview of all 3G technologies coupled with good detail of network architectures, channel structures, and general operational details. Good treatment of both CDMA2000 and UMTS/WCDMA systems.

<u>"WCDMA: Towards IP Mobility and Mobile Internet"</u> by Tero Ojanpera and Ramjee Prasad. 476pp. 2001 Artech House, ISSBN 1-58053-180-6. $100. The most complete and definitive work on UMTS (excellent CDMA2000, too!). CDMA principles, Mobile Internet, RF Environment & Design, Air Interface, WCDMA FDD standard, WCDMA TDD, CDMA2000, Performance, Heirarchical Cell Structures, Implementation, Network Planning, Basic IP Principles, Network Architectures, Standardization, Future Directions. This is a MUST HAVE for a one-book library!

More Bibliography, 3G Air Interface Technologies

“The UMTS Network and Radio Access Technology” by Dr. Jonathan P. Castro, 354 pp. 2001 John Wiley, ISBN 0 471 81375 3, $120. An excellent, well-organized, and understandable exploration of UMTS. Includes radio interface, channel explanations, link budgets, network architecture, service types, ip network considerations, a masterful tour de force through the entire subject area. Very readable, too!

“WCDMA for UMTS” by Harri Holma and Antti Toskala, 322 pp. 2000 Wiley, ISBN 0 471 72051 8, $60. Very good overall treatment of UMTS. Excellent introduction to 3G and summary of standardization activities, every level of UMTS/UTRA. Good overview of CDMA-2000, too!

“The GSM Network - GPRS Evolution: One Step Towards UMTS” 2nd Edition by Joachim Tisal, 227pp. paperback, 2001 Wiley, ISBN 0 471 49816 5, $60. Readable but not overwhelming introduction to GSM in all its aspects (140pp), DECT (11pp), GPRS (6pp), UMTS (7pp), WAP (25pp), EDGE (10pp).

Bibliography, The IP Aspect of 3G

“Mobile IP: Design, Principles and Practices” by Charles E. Perkins, 275 pp., 200, 1998 Addison-Wesley, ISBN 0-201-63469-4. $60. Comprehensive view of Mobile IP including home and foreign agents, advertisement, discovery, registration, datagrams, tunneling, encapsulation, route optimization, handoffs, firewalls, IPv6, DHCP. Tour-de-force of mobile IP techniques.

“Mobile IP Technology for M-Business” by Mark Norris, 291 pp., 2001 Artech House, ISSBN 1-58053-301-9. $67. GPRS overview and background, Mobile IP, Addressing, Routing, M-business, future prospects, IPv4, IPv6, Bluetooth & IrDA summaries.

“TCP/IP Illustrated, Volume 1, The Protocols” by W. Richard Stevens, 1994 Addison-Wesley, ISBN-0-201-63346-9, 576pp., $66. Comprehensive, definitive, and authoritative exposition of each protocol in modern networking – IP, ARP, RARP, ICMP, IP, dynamic routing, UDP, Broadcasting & multicasting, IGMP, DNS, TFTP, BOOTP, TCP including sections on connection establishment and termination, interactive data flow, bulk data flow, timeout and retransmission, all its parameters; SNMP, Telnet, FTP, SMTP, NFS, and much, much more. Very highly recommended.

“TCP/IP Explained” by Phillip Miller, 1997 Digital Press, ISBN 1-55558-166-8, 518pp. $50. In-depth understanding of the Internet protocol suite, network access and link layers, addressing, subnetting, name/address resolution, routing, error reporting/recovery, network management.

“Cisco Networking Academy Program: First-Year Companion Guide” edited by Vito Amato, 1999 Cisco Press, ISBN 1-57870-126-0, 438pp. Textbook supporting a year-long course on networking technologies for aspiring LAN/WAN (and 3G) technicians and engineers. It covers every popular networking technology (including all its elements and devices) in deep and practical detail. Excellent real-world understanding of TCP/IP, as well as the nuts-and-bolts of everything from physical components to protocols to actual devices such as routers, switches, etc. You might even want to take the evening courses at a local community college near you.

Bibliography - General CDMA

"IS-95 CDMA and CDMA2000: Cellular/PCS Systems Implementation" by Vijay K. Garg. 422 pp. 2000 Prentice Hall, ISBN 0-13-087112-5, $90. IS-95 and CDMA2000 Access technologies, DSSS, IS-95 air interface, channels, call processing, power control, signaling, soft handoff, netw. planning, capacity, data. CDMA2000 layers, channels, coding, comparison w/ WCDMA.

"CDMA Systems Engineering Handbook" by Jhong Sam Lee and Leonard E. Miller, 1998 Artech House, ISBN 0-89006-990-5. Excellent treatment of CDMA basics and deeper theory, cell and system design principles, system performance optimization, capacity issues. Recommended.

"CDMA RF System Engineering" by Samuel C. Yang, 1998 Artech House, ISBN 0-89006-991-3. Good general treatment of CDMA capacity considerations from mathematical viewpoint.

"CDMA Internetworking: Deploying the Open A-Interface" by Low and Schneider. 616 pp. 2000 Prentice Hall, ISBN 0-13-088922-9, $75. A tour-de-force exposition of the networking between the CDMA BSC, BTS, and mobile, including messaging and protocols of IS-634. Chapters on SS7, Call Processing, Mobility Management, Supplementary Services, Authentication, Resource Management (both radio and terrestrial), 3G A-Interface details. One-of-a-kind work!

"CDMA: Principles of Spread Spectrum Communication" by Andrew J. **Viterbi**. 245 p. Addison-Wesley 1995. ISBN 0-201-63374-4, $65. Very deep CDMA Theory. Prestige collector's item.

Bibliography - General Wireless

“Mobile and Personal Communication Services and Systems” by Raj Pandya, 334 pp. 2000 IEEE Press, $60. IEEE order #PC5395, ISBN 0-7803-4708-0. Good technical overview of AMPS, TACS< NMT, NTT, GSM, IS-136, PDC, IS-95, CT2, DECT, PACS, PHS, mobile data, wireless LANs, mobile IP, WATM, IMT2000 initiatives by region, global mobile satellite systems, UPT, numbers and identities, performance benchmarks.

“Wireless Telecom FAQs” by Clint Smith, 2001 McGraw Hill, ISBN 0-07-134102-1. Succint, lucid explanations of telecom terms in both wireless and landline technologies. Includes cellular architecture, AMPS, GSM, TDMA, iDEN, CDMA. Very thorough coverage; an excellent reference for new technical people or anyone wishing for clear explanations of wireless terms.

"Mobile Communications Engineering" 2nd. Edition by William C. Y. Lee. 689 pp. McGraw Hill 1998 $65. ISBN 0-07-037103-2 Lee’s latest/greatest reference work on all of wireless; well done.

Bibliography

"Wireless Communications Principles & Practice" by Theodore S. Rappaport. 641 pp., 10 chapters, 7 appendices. Prentice-Hall PTR, 1996, ISBN 0-13-375536-3. If you can only buy one book, buy this one. Comprehensive summary of wireless technologies along with principles of real systems. Includes enough math for understanding and solving real problems. Good coverage of system design principles.

"The Mobile Communications Handbook" edited by Jerry D. Gibson. 577 pp., 35 chapters. CRC Press/ IEEE Press 1996, ISBN 0-8493-0573-3. $89 If you can buy only two books, buy this second. Solid foundation of modulation schemes, digital processing theory, noise, vocoding, forward error correction, excellent full-detailed expositions of every single wireless technology known today, RF propagation, cell design, traffic engineering. Each chapter is written by an expert, and well-edited for readability. Clear-language explanations for both engineers and technicians but also includes detailed mathematics for the research-inclined. Highly recommended.

"Digital Communications: Fundamentals and Applications" by Bernard Sklar. 771 pp., Prentice Hall, 1988. $74 ISBN# 0-13-211939-0 Excellent in depth treatment of modulation schemes, digital processing theory, noise.

"Communication Electronics" by Louis E. Frenzel, 2nd. Ed., list price $54.95. Glencoe/MacMillan McGraw Hill, April, 1994, 428 pages hardcover, ISBN 0028018427.

"Wireless Personal Communications Services" by Rajan Kuruppillai. 424 pp., 75 illus., McGraw-Hill # 036077-4, $55 Introduction to major PCS technical standards, system/RF design principles and process, good technical reference

"Voice and Data Communications Handbook" by Bates and Gregory 699 pp, 360 illus., McGraw-Hill # 05147-X, $65 Good authoritative reference on Wireless, Microwave, ATM, Sonet, ISDN, Video, Fax, LAN/WAN

Bibliography (concluded)

"Spread Spectrum Communications Handbook" by Simon, Omura, Scholtz, and Levitt. 1227 pp., 15 illus., McGraw-Hill # 057629-7, $99.50 Definitive technical reference on principles of Spread Spectrum including direct sequence as used in commercial IS-95/JStd008 CDMA. Heavy theory.

"Cellular Radio: Principles and Design" by Raymond C. V. Macario. 215 pp., 142 illus., 044301-7, $50 Good introduction to RF basics for AMPS and TDMA technologies; but no CDMA coverage.

"Applications of CDMA in Wireless/Personal Communications" by Garg, Smolik & Wilkes. 360 pp., Prentice Hall, 1997, ISBN 0-13-572157-1 $65. Probably the best CDMA-specific book we've seen. Excellent treatment of IS-95/JStd. 008 as well as W-CDMA. More than just theoretical text, includes chapters on IS-41 networking, radio engineering, and practical details of CDMA signalling, voice applications, and data applications.

"CDMA: Principles of Spread Spectrum Communication" by Andrew J. **Viterbi**. 245 p. Addison-Wesley 1995. ISBN 0-201-63374-4, $65. Definitive CDMA Theory. Valuable but dry reading for mere mortals. Much calculus.

"PCS Network Deployment" by John Tsakalakis. 350 pp, 70 illus., McGraw-Hill #0065342-9, $65 Tops-down view of the startup process in a PCS network. Includes good traffic section.

"CDPD: An Introduction" by John Agosta. 256 pp, 100 illus, McGraw-Hill # 000600-8, $50. Detailed reference on how CDPD works in Analog and TDMA systems.

"Cellular System Design & Optimization" by Clint Smith and Curt Gervelis. 448 pp, 110 illus., McG.-Hill #059273-X, $65 Optimization for conventional cellular systems; implications for PCS but not CDMA-specific.

"The ARRL Handbook for Radio Amateurs (1997)" published by the American Radio Relay League (phone 800-594-0200). 1100+ page softcopy ($44); useful exposure to nuts-and-bolts practical ideas for the RF-unfamiliar. Solid treatment of the practical side of theoretical principles such as Ohm's law, receiver and transmitter architecture and performance, basic antennas and transmission lines, and modern circuit devices. Covers applicable technologies from HF to high microwaves. If you haven't had much hands-on experience with real RF hardware, or haven't had a chance to see how the theory you learned in school fits with modern-day communications equipment, this is valuable exposure to real-world issues. Even includes some spread-spectrum information in case you're inclined to play and experiment at home. At the very least, this book will make dealing with hardware more comfortable. At best, it may motivate you to dig deeper into theory as you explore why things behave as they do.

Web Links and Downloadable Resources

Scott Baxter: http://www.howcdmaworks.com
Latest versions of all courses are downloadable.
Category - Username - Password
Intro - (none required) - (none required)
RF/CDMA/Performance - shannon - hertz
3G - generation - third
Grayson - telecom - allen
Agilent - nitro - viper

Dr. Ernest Simo's Space2000: http://www.cdmaonline.com/ *and* http://www.3Gonline.com/

CDG: http://www.cdg.org (check out the digivents multimedia viewable sessions)
The IS-95 and IS-2000 CDMA trade marketing webside, CDMA cheerleaders.

GSM: http://www.gsmworld.com
The GSM Association website. Worldwide GSM marketing cheerleaders but also includes some excellent GSM and GPRS technical overview whitepapers and documents; latest user figures.

UWCC: http://www.uwcc.com
The IS-136 TDMA trade marketing website, TDMA cheerleaders.

RCR News: http://www.rcrnews.com
Wireless Industry trade publication - regulatory, technical, business, marketing news.
Subscribers can access text archives of past articles; very handy in researching events.

Wireless Week: http://www.wirelessweek.com
Wireless Industry trade publication - regulatory, technical, business, marketing news.

More Web Links

3GPP: http://www.3gpp.org/
The operators' harmonization group concerned mainly with ETSI-related standards

3GPP2: http://www.3gpp2.org/
The operators' harmonization group concerned mainly with IS-95-derived CDMA standards

ITU: http://www.itu.int/imt/

ETSI: http://www.etsi.fr/

UMTS forum: http://www.umts-forum.org/

GSM MoU: http://www.gsmworld.com/

TIA: http://www.tiaonline.org/

T1: http://www.t1.org/

ARIB: http://www.arib.or.jp/arib/english/index.html

TTC: http://www.ttc.or.jp/

TTA: http://www.tta.or.kr/

ETRI: http://www.etri.re.kr/

RAST: http://www.rast.etsi.fi/

End of Chapter 9

End of Course