Summary

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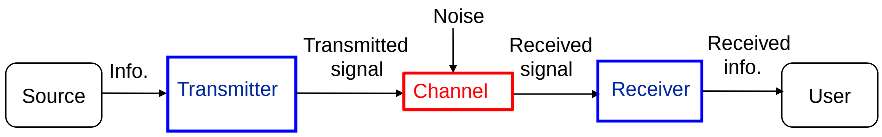
What matter we covered

- Antennas in a system
  - Friis' formula (transceiver-channel-receiver)
- Transceiver side : EIPR
- Channel : path loss
- Receiver side : G/T (includes antenna and reciever noise)

General wireless link



Received power:

Attenuation due to propagation

$$P_R = P_T G_T \frac{1}{\left(\frac{4\pi D}{\lambda}\right)^2} G_R = P_T G_T \frac{1}{\alpha_0} G_R$$

In decibel:

$$P_R|_{dBW} = P_T|_{dBW} + G_T|_{dB} - \alpha_0|_{dB} + G_R|_{dB}$$

$$= EIRP|_{dBW} - \alpha_0|_{dB} + G_R|_{dB}$$

EIRP (Equivalent Isotropic Radiated Power)

- Is the product (the sum in logarithmic units) of the transmitted power and the gain of the transmit antenna
- It is directly derived from the definition of the antenna gain
- It represents the power applied at the input of an isotropic radiator in order to obtain the same power density as that of the real case

Path loss

- Power of wireless transmission reduces with square of distance (due to surface area increase of sphere)
- Reduction also depends on wavelength
  - Long wave length (low frequency) has less loss
  - Short wave length (high frequency) has more loss

$$P_L = \left(\frac{4\pi D}{\lambda} \right)^2$$

Path loss exponent

Path loss

Different path loss exponents are used in different environments:

Free space	2
Urban area cellular	2.7 to 3.5
Shadowed urban cell	3 to 5
In building Line Of Sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

SIGNAL TO NOISE RATIO

- We often use, in order to evaluate power level relative to noise, the ratio:

$$\gamma = \frac{P_R}{N_0}$$

where: $P_R =$ Received power

$N_0 =$ Noise power spectral density

- Such a ratio is used for any modulation scheme, analog or digital

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- The ratio γ has the dimension of frequency; all together, for this expression one specifies a logarithmic unit (dBHz)

- The spectral density level N_0 equals:

$$N_0 = KT_{op}$$

where $K =$ Boltzmann's constant $= 1.38 \cdot 10^{-23}$

$T_{op} =$ Effective temperature of the receiver $(= T_A + T_R)$

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- Hence:

$$\gamma = \frac{P_R}{N_0} = \frac{P_R}{KT_{op}}$$

And in logarithmic units:

$$\gamma|_{dBHz} = P_R|_{dBW} - 10 \cdot \log_{10} K - 10 \cdot \log_{10} T_{op}$$

$$+228.6$$

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- Substituting the expression for $P_R|_{dBW}$

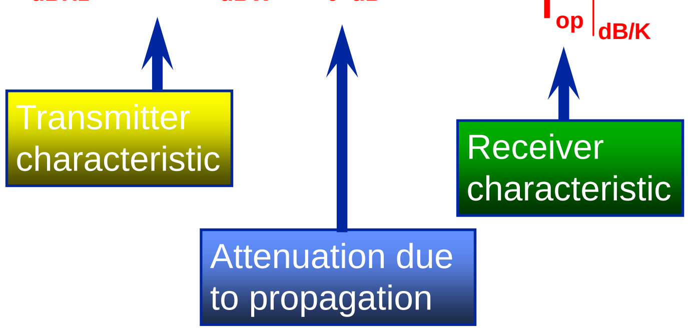
$$\gamma|_{dBHz} = EIRP|_{dBW} - \alpha_0|_{dB} + 228.6 + G_R|_{dB} - 10 \cdot \log_{10} T_{op}$$

$$10 \cdot \log_{10} \frac{G_R}{T_{op}} = \left.\frac{G_R}{T_{op}}\right|_{dB/K}$$

From which:

$$\gamma|_{dBHz} = EIRP|_{dBW} - \alpha_0|_{dB} + 228.6 + \left.\frac{G_R}{T_{op}}\right|_{dB/K}$$

$$\gamma|_{dBHz} = EIRP|_{dBW} - \alpha_0|_{dB} + 228.6 + \left.\frac{G_R}{T_{op}}\right|_{dB/K}$$



Antenna parameters

- Gain: G
- Directivity D
- efficiency: η
- effective aperture: A_e
- radiation pattern: $E(\theta,\varphi)$, $p(\theta,\varphi)$
- antenna input impedance: Z_a
- antenna input reflection coefficient: s_{11}
- polarization: linear, circular or elliptic

Antenna pattern

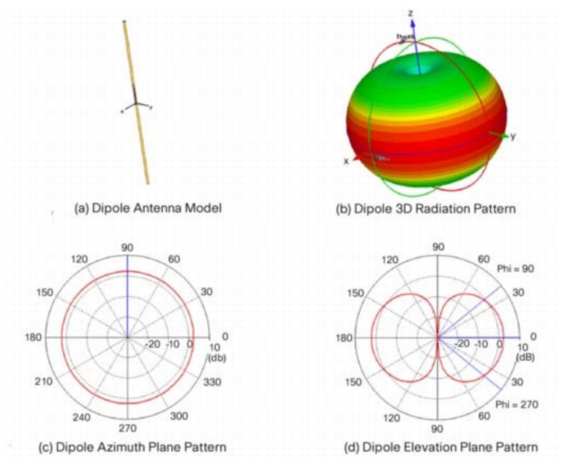


Image from: http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-antennas-accessories/prod_white_paper0900aecd806a1a3e.html

Antenna gain

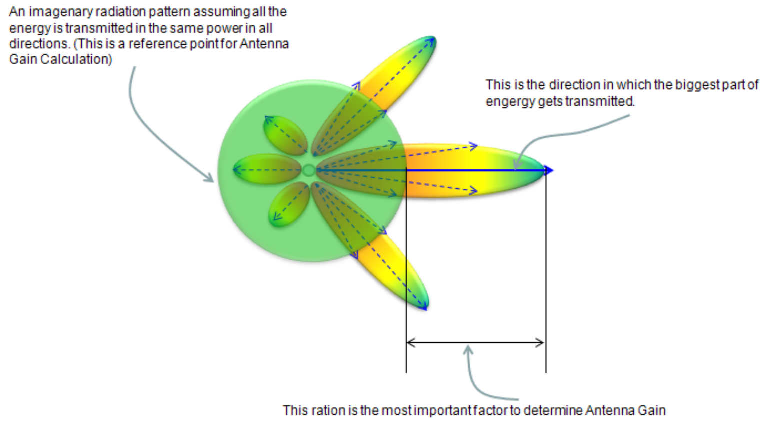


Image from : http://www.sharetechnote.com/html/Handbook_LTE_AntennaPerformance.html

Antenna parameters

$$G(\theta,\varphi) = \eta D(\theta,\varphi)$$

$$G(\theta,\varphi) = \frac{4\pi}{\lambda^2} A_e(\theta,\varphi)$$

$$s_{11} = \frac{Z_a - Z_{gen}}{Z_a + Z_{gen}}$$

Z_{gen} is the impedance of the generator (transmitter) or the load (reciever)

Friis formula (ideal)

In free space

$$P_r = P_{tr} g_r g_{tr} \left(\frac{\lambda}{4\pi R} \right)^2$$

in general

$$P_r = P_{tr} g_r g_{tr} \left(\frac{\lambda}{4\pi R} \right)^\alpha$$

Friis formula (real)

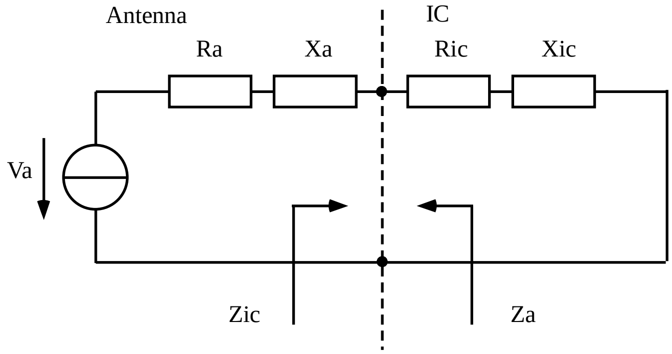
In free space $$P_r = P_{tr} g_r g_{tr} \left(1-\rho_r^2\right)\left(1-\rho_{tr}^2\right)\left(\frac{\lambda}{4\pi R} \right)^2 \left| \boldsymbol{pol}_{tr} \bullet \boldsymbol{pol}_r^* \right|^2$$

in general $$P_r = P_{tr} g_r g_{tr} \left(1-\rho_r^2\right)\left(1-\rho_{tr}^2\right)\left(\frac{\lambda}{4\pi R} \right)^\alpha \left| \boldsymbol{pol}_{tr} \bullet \boldsymbol{pol}_r^* \right|^2$$

depolarization factor $$\chi_{pol} = \left| \boldsymbol{pol}_{tr} \bullet \boldsymbol{pol}_r^* \right|^2$$

ρ_r: reflection cofficient of recieving antenna
ρ_{tr}: reflection coefficient of transmitting antenna
$\mathbf{pol}_r$: polarisation vector of recieving antenna
$\mathbf{pol}_{tr}$: polarisation vector of transmitting antenna

Antennas in RFID scenarii



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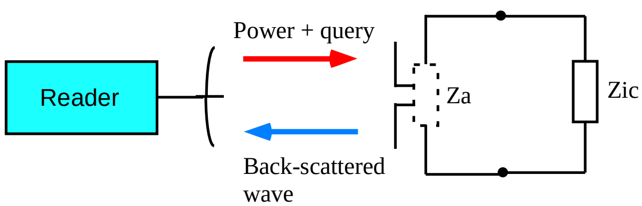
power scavenging and backscattering



$$P_{rload} = S_t(r,\theta,\varphi)A_{e,\max}\tau\chi_{pol} = S_t(r,\theta,\varphi)G_r(\theta,\varphi)\frac{\lambda^2}{4\pi}\left(1-\left|\Gamma^*\right|^2\right)\chi_{pol}$$

$$S_{scat} = \frac{P_{re-rad}G_r(\theta,\varphi)}{4\pi r^2} == S_{t,inc}(\theta_{inc},\varphi_{inc})\frac{\lambda^2}{(4\pi r)^2}G_r(\theta_{inc},\varphi_{inc})\left|\Gamma^*\right|^2 G_r(\theta,\varphi)\chi_{pol}$$

-A good match is needed for the power transfer
-A large mismatch is required for the backscattering

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figure of merit for RFIDs : max read range

$$r_{\max}(\theta,\varphi)=\frac{\lambda}{4\pi}\sqrt{\frac{G_{r,real}(\theta,\varphi)\chi_{pol}EIRP}{P_{ic,th}}}$$

Regulations and standarts

- Each country has its own regulations
- Based on IEEE standards, FCC (US), ICNIRP (Europe)
- Some rules can be contradictory
- They change over time with the advance of science

Antennas for W-BAN

- They radiate at least partially into lossy media
- Most classic antenna characteristic definitions do not apply anymore
- Radiation into lossy medium is not well known

Antennas in/on biological tissues

- The medium will absorb a large amount of the power
- In order to optimize the design, we try to control the near field, use a magnetic type antenna and have an appropriate polarization (e.g. orthogonal to the wearer for a wearable anenna). We also try to use a ground plane.

Measurment of W-BAN antennas

- Implantable and wearable antennas are usually electrically small
- Their port might be ill defined leading to cable currents when connected to measurement devices and thus wrong results
- Some tricks can be used to overcome this
  - baluns, aavoid contact of cable with lossy tissues, etc.
- But the only reliable measurements are system measurememnt with the antenna in their final setting.

Exam (antenna part)

- 1 exercise (same stile as during class exercises)
- 3 multiple choice questions, with justification of the answer
- Do not forget your pocket calculator !!!