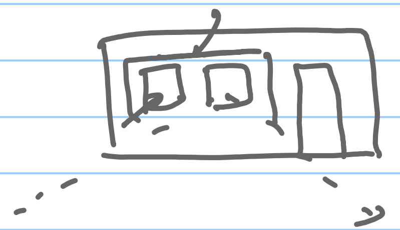
EE3007 Jan-Apr, 2022

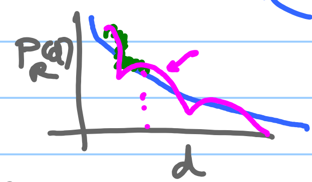
Lesson #5 (C1 -- Feb.16, 2022)

Note Title XXXXXXXX

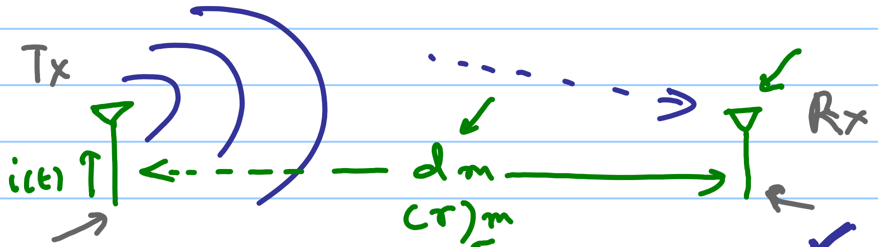


Wireless Link Budget

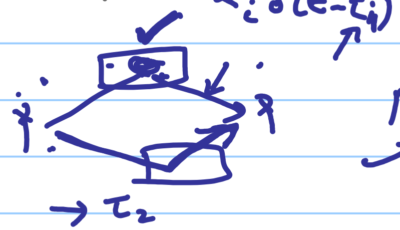
- EM wave Propagation
- Path Loss Model
- Rx Sensitivity
- Noise-limited ✓ / Interference-limited



(*)



- → conduction ✓
- → induction ✓
- → radiation ← ✓



3-basic propagation mechanisms

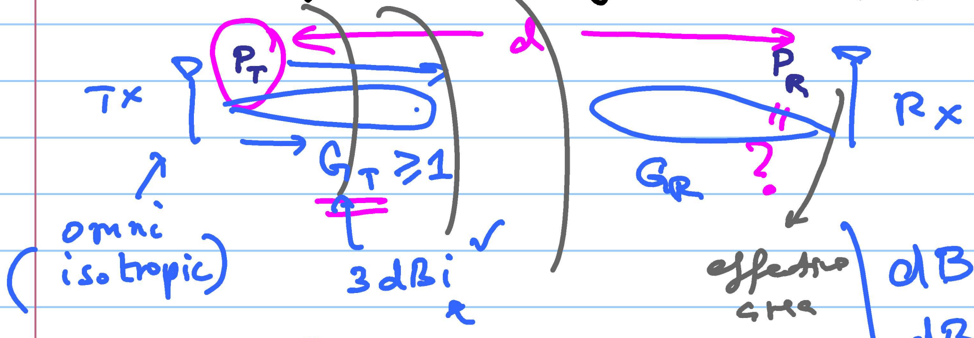
- Reflection ✓
- Diffraction ✓ (Huygens)
- Scattering ✓ ✓

shadow loss ✓

--- short-term fading

→ long-term path loss ✓

(*) Free-space Propagation ← no reflections, no shadowing



dB ✓
dBm ✓
dBi ✓

$4\pi d^2$

$$P_R(d) = \left(\frac{P_T \cdot G_T}{(4\pi d^2)} \right) \cdot A_R$$

P_R: watts (dBm); P_T: dBm; G_T: dBi; $(4\pi d^2)$: m^2; A_R: m^2 — effective Rx Area

P_T, P_R → Watts …. milli – μ – η – p (10^{-12})
Kilowatts

1 mWatt → 0 dBm
1 Watt → 0 dBW

P_T → $10 \log_{10}\left(\frac{1 \text{ watts}}{1 \text{ mwatt}}\right)$ → 30 dBm

100 milliwatts → 20 dBm
200 " → 23 dBm
(3dB)

$$P_R = P_T + G_T - PL + A_R$$

pp. 684- 687

Effective Area at the Rx :

$$A_R = \frac{G_R}{(4\pi/\lambda^2)} \; m^2$$

Directivity

Greene's Thm.

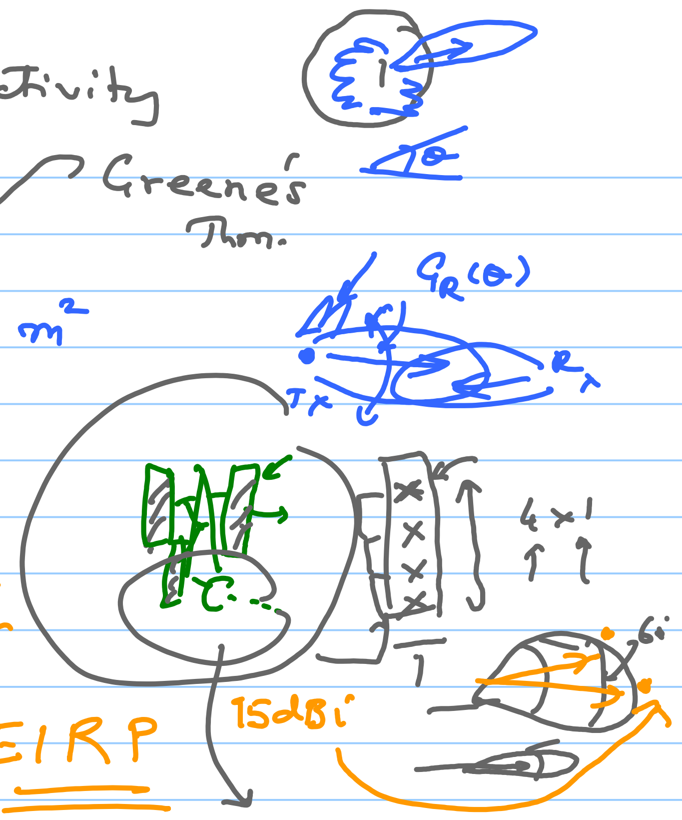
$f_c \rightarrow \lambda \rightarrow$ wavelength of operation

450MHz $\leftrightarrow$ 6GHz

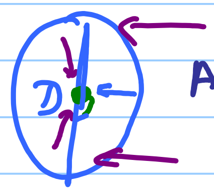
27

EIRP

15dBi



Example : Parabolic dish



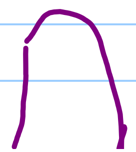
$$A_R = \frac{\pi D^2}{4} \cdot \eta$$

D → Diameter

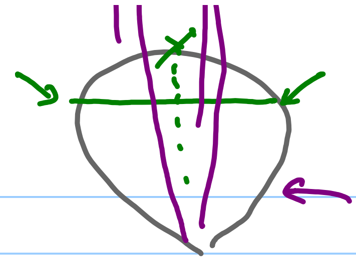
η ← illumination efficiency.

$0.5 < \eta < 0.6$

$$G_R = \eta \left(\frac{\pi D}{\lambda}\right)^2$$



Aside : 3-dB beam width → Parabolic Dish



$$\theta = \frac{70\lambda}{D} \text{ degrees}$$

∴ For free-space propogation $(n = 2)$ — path loss exponent

$$P_R(d) = \frac{P_T \cdot G_T \cdot G_R}{(4\pi d/\lambda)^2} \text{ Watts} \qquad n=2$$

$$P_R(d) = \frac{P_T \, G_T \, G_R}{(4\pi/\lambda)^2 \cdot d^n} \quad (1)$$

$2 \leq n \leq 6$

1.5?

-60dBm

-80 dBm

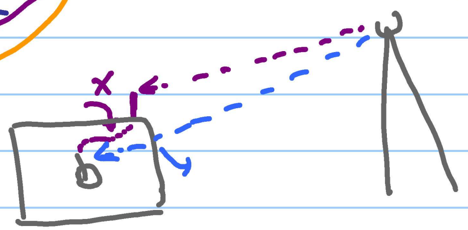
$$P_R(d) = P_T + G_T + G_R - 20\log_{10}\left(\frac{4\pi}{\lambda}\right) - n \cdot 10\log_{10}(d) - L_{margin}$$

$P_R(d)$: dBm; P_T: dBm; G_T: dBi; G_R: dBi; 1-m Loss: dB; "Path-loss": dB; L_{margin}: dB (20dB) — Link Margin

500 MHz → 5 GHz. (20dB)

d = 1m

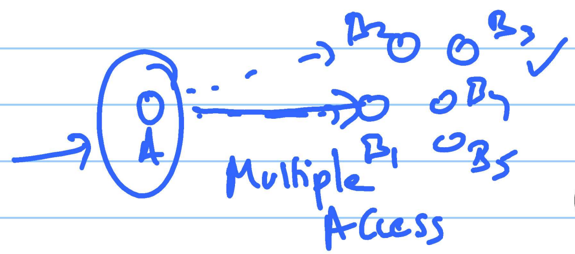
fixed wireless



Rate / Power — Margin

5 GHz.

-80dBm is min. P_R required. How much P_R is adequate? Rx NF



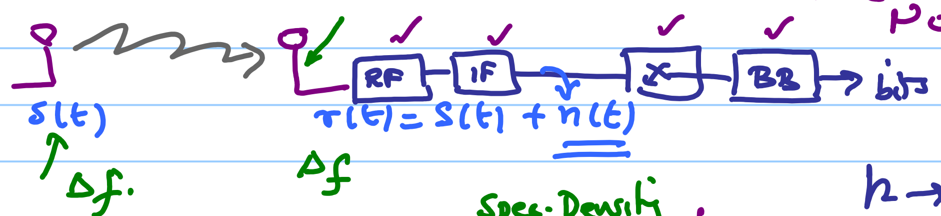
QoS (link)
- Bit Rate bits/s
- Bit Error Rate (BER) / Packet Error Rate (PER) ← coded bits
- Latency, Jitter (?)

Lesson #5 (C3 -- Feb.22, 2022)

Rx Sensitivity → Minimum Detectable Signal (MDS) strength.

* Rx → "Noise Figure" → Additional noise power added by all the elements in a TX-Rx chain

"white noise" ↳ Thermal Noise ||



Noise Power (per Hz) → kT (Spec. Density)

↗ PSD

k → Boltzmann's const. 1.38×10^{-23} Joules/K

T → Ambient temp. 300° K

kT ↳ Joules

Noise Power → $kT\Delta f$ ← Hz → Joules/sec → Watts

Δf → BW of operation.

Noise Power (per Hz) → −174 dBm → noise PSD (Watts/Hz)

(*) Example :

BW = 1 MHz (Δf) ;

QPSK Modulation → 10^{-3} BER → SNR = 9.7 dB → 10 dB

E_b/N_0 = 6.7 dB

Rx NF = 5 dB ;

Link margin 20 dB

−79 dBm → Rx sensitivity

−99 dBm → Rx Sensitivity = −79 dBm

SNR = 10 dB : 10 dB

−109 dBm

NF = 5 dB : 5 dB

−114 dBm

Δf = 1 MHz : 60 dB

−174 dBm (1 Hz) ← noise floor

10 dB

10 MHz

2G → 3G → 4G

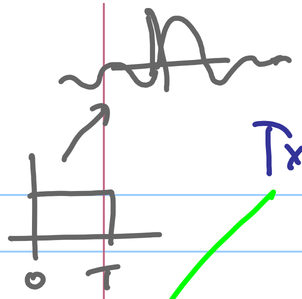
200 KHz → 5 MHz → 20 MHz

4 MHz

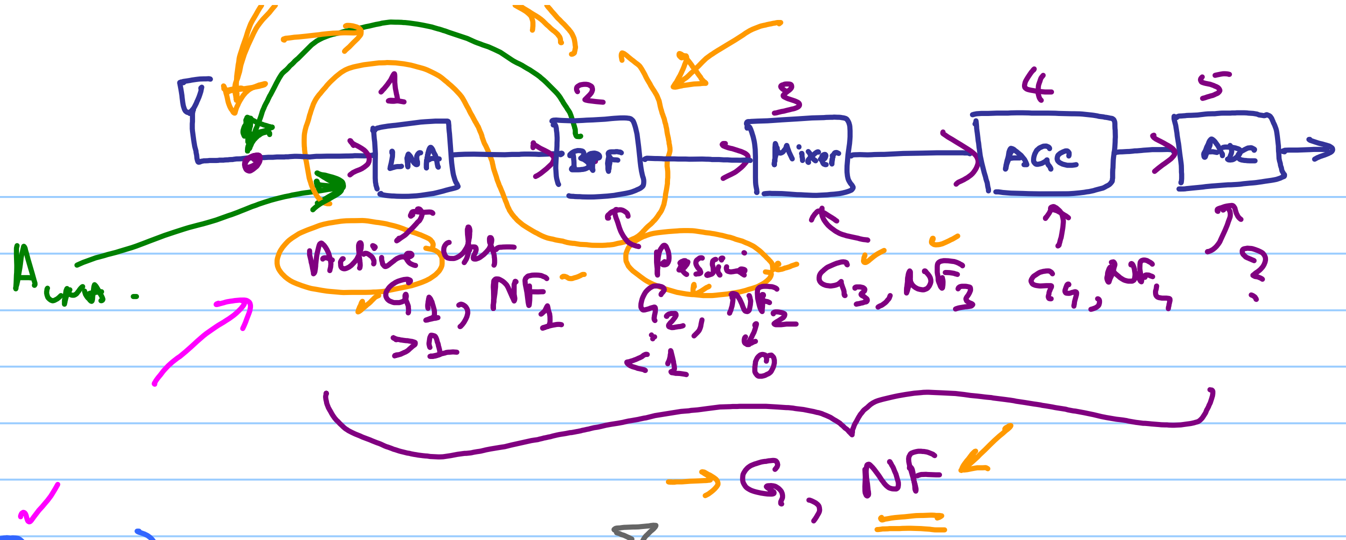
3 GHz

5G

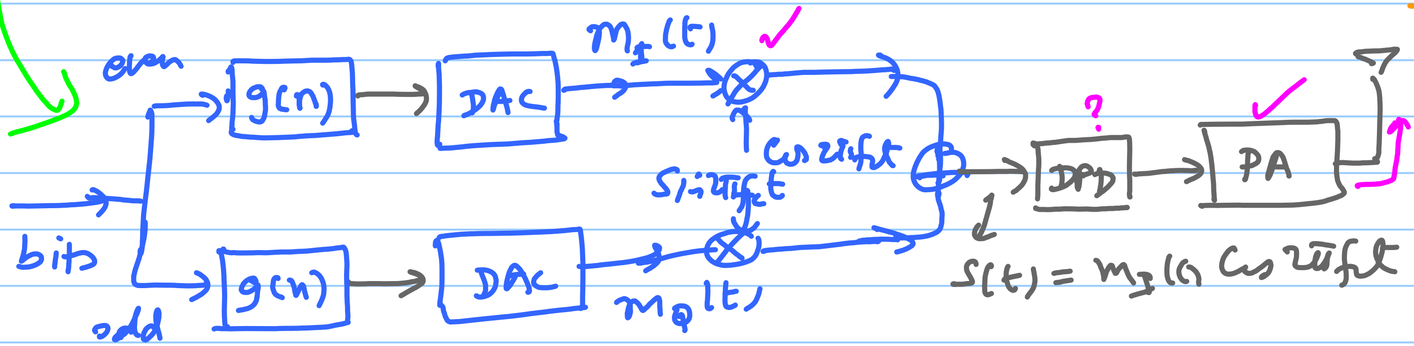
800 MHz ← 100 MHz



Tx-Rx Noise figure ?



QCM



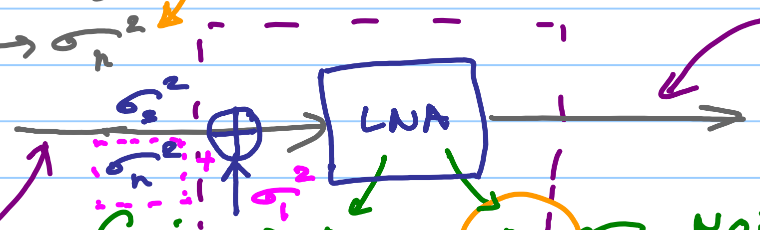
Lesson #5 (C4 -- Feb.25, 2022)

Overall Noise figure of an RF Chain (Cascade)

$\sigma_n^2 = (kT \cdot (BW))$ — only the basic thermal noise

signal $\rightarrow \sigma_s^2$

noise $\rightarrow \sigma_n^2$



Gain (power) $\rightarrow A_1$

Noise figure $\rightarrow N_1$

$\sigma_1^2 = (N_1 - 1) \cdot \sigma_n^2$

I/p SNR $= \dfrac{\sigma_s^2}{\sigma_n^2}$; (A)

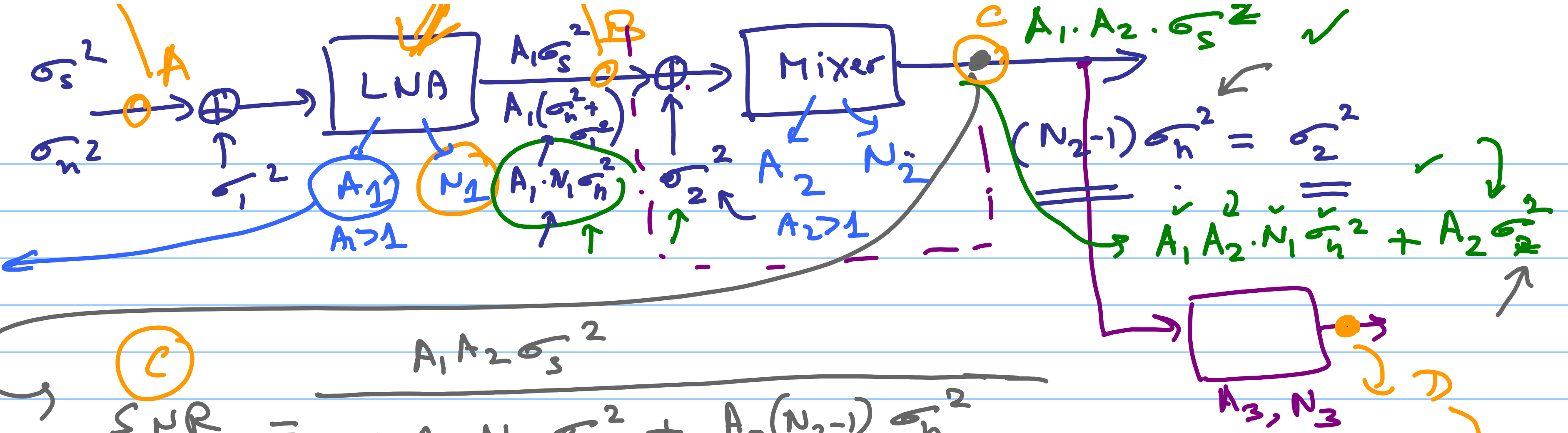
O/p SNR $= \dfrac{A_1 \cdot \sigma_s^2}{A_1 (\sigma_n^2 + \sigma_1^2)}$, where $\sigma_1^2 = (N_1 - 1)\sigma_n^2$

$= \dfrac{\sigma_s^2}{N_1 \cdot \sigma_n^2}$ (B)

$A_i > 1$

$N_1 > 1$ (Active ckt)

$N_1 = 1$ (Passive, $A_i < 1$)



$\gg 1$

$$SNR = \frac{A_1 A_2 \sigma_s^2}{A_1 A_2 N_1 \sigma_n^2 + A_2 (N_2 - 1)\sigma_n^2}$$

$$SNR = \frac{\sigma_s^2}{N_1 \sigma_n^2 + \frac{(N_2-1)}{A_1} \cdot \sigma_n^2 + \frac{(N_3-1)}{A_1 A_2}\sigma_n^2}$$

$NF_1 \leftarrow N_1$

$NF_2 \leftarrow N_2$

$NF_3 \leftarrow N_3$

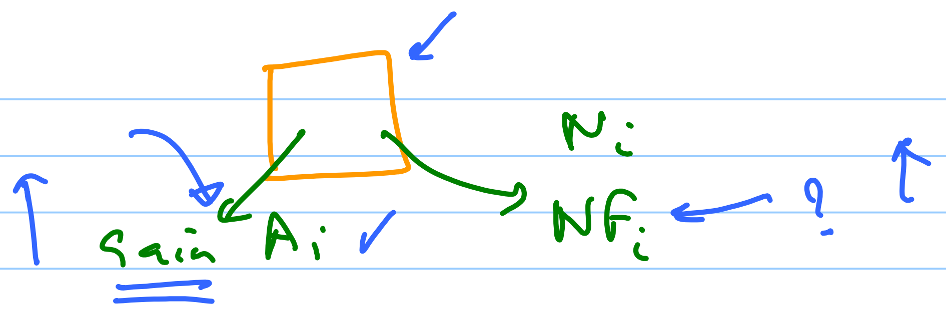
$\rightarrow A_1 \gg 1 \leftarrow$ High gain

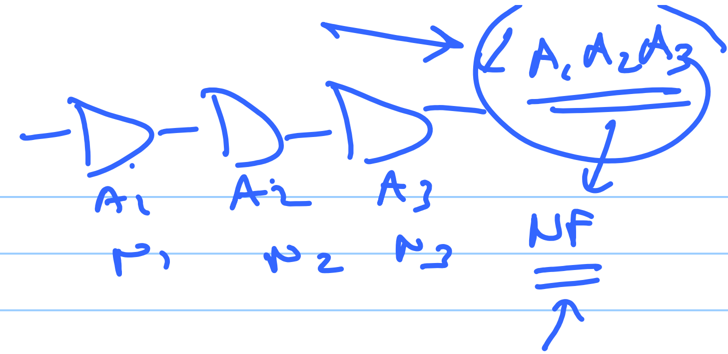
< 1

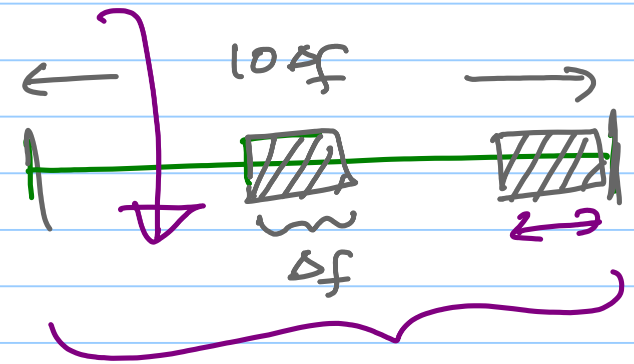
$\ll 1$

Overall noise figure

$$NF = \left(N_1 + \frac{(N_2-1)}{A_1} + \frac{(N_3-1)}{A_1 A_2}\right)$$


gain
A_i
N_i
NF_i
?


A_1 A_2 A_3
N_1 N_2 N_3
$A_1A_2A_3$
NF


$10\Delta f$
Δf