Free/unregulated/license-exempt spectrum

- Not subject to license
- Has rules for products (eg *power limitation*)
- More frequencies are being released as license-exempt
- Some current license-exempt frequencies
  - 900 MHz
  - 2.4 GHz ISM band (WiFi, Microwave etc.)
  - 5.2/5.3/5.8 GHz (WiFi, Cordless phone etc.)
  - Can you identify more?

Decibel

- Tx_power for practical mobile systems vary by many orders of magnitude
  - 100kW or kilowatt (FM radio station)
  - 500mW or milliwatt (cellular phone tx power)
  - 2.5mW (Bluetooth with ~10m range)
  - 100pW or picowatt (typical WiFi rx threshold)
  - Femto watt? (nanosensor communication)
  - 1 W = 10^3 mW = 10^6 μW = 10^9 nW = 10^{12} pW
- Decibel is a more convenient (logarithmic scale) unit to compare these powers, which are many orders of magnitude apart
- Also path loss (attenuation) can be many orders of magnitude
  - Path loss therefore is usually expressed in decibels

Decibel (dB) Formula

- In Honour of Graham Bell
- The number of decibels is ten times the logarithm to base 10 of the ratio of two power quantities ($dB = 10\log_{10}(P_1/P_2)$)
  - The quantity "Bel" would be $\log_{10}(P_1/P_2)$, but not used
- Decibel can be used for different purposes
  1. Path Loss: To express path loss or attenuation: [P_1 = transmit power; P_2 = receive power]
  2. SNR: To express signal (P_1) to noise (P_2) ratio at the receiver
  3. Signal Power: To express signal power (P_1), which can be either transmit or receive power, to a reference power (P_2)

Decibel Examples for Path Loss

- **Example 1**: P_t = 10 mW, P_r= 5 mW (power reduced by half)
  Attenuation (path loss) = 10 log $_{10}$ (10/5) = 10 log $_{10}$ 2 = 3 dB
- **Example 2**: P_t = 100 mW, P_r= 1 mW (power reduced by a factor of 100)
  Attenuation = 10 log $_{10}$ (100/1) = 10 log $_{10}$ 100 = 20 dB

Power Ratio	dB
10,000,000,000 (ten billion times)	100 (10 x 10)
1,000,000 (1 million times)	60 (10 x 6)
10 (ten times)	10 (10 x 1)
0.001 (10^{-3})	-30 (10 x -3)
0.0001 (10^{-4})	-40 (10 x -4)

Decibel Examples for Signal-to-Noise Ratio

- **Example 1**: P_{signal} = 1 mW (received signal strength), P_{noise}= 100 μW

  SNR = 10 log $_{10}$ (1000/100) = 10 log $_{10}$ 10 = 10 dB
- **Example 2**: Received signal strength is measured at 10 mW. What is the noise power if SNR = 10 dB?

  SNR = 10 dB = 10 log $_{10}$ (10mW/P_{noise})

P_{noise} = 1 mW

Expressing Power in dBm

- dBm is in reference to 1 milliwatt
- First, express power in milliwatt
- Then apply the following formula to obtain dBm

Power in dBm = 10 log (power in milliwatt)

Conversion to dBW

- dBW is in reference to 1 watt
- First express power in watt
- Then apply the following formula to obtain dBW

Power in dBW = 10 log (power in watt)

Relationship between dBm & dBW

- Note that 1 W = 1000 mW
- This gives us following relationship
  - Note log(axb) = log(a)+log(b)

dBm = dBW + 30

If you've calculated a power in dBW, you can simply derive the equivalent dBm by adding 30 to dBW, and vice versa.

Examples for converting Watt to dBm/dBW

- Example 1: Express 1 mW power in units of dBm

10 log (1) = 10x0 = 0 dBm

So, ZERO dBm does not mean there is no power !