BIARC

Big Island Amateur Radio Club

# Decibels!

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# Objectives

- Introduce the concept and history of decibels (dB).
- Explain their uses and importance in radio communication.
- Cover practical applications, including:
    - Signal strength
    - Power ratios
    - Antenna gain
    - Path budgets
- Explore common "flavours" of decibels:
    - dBm
    - dBmv
    - dBi
    - dBd
    - dBc
    - dBfs
- Provide real-world examples.
    - Introducing: ET's easy mode decibel math!

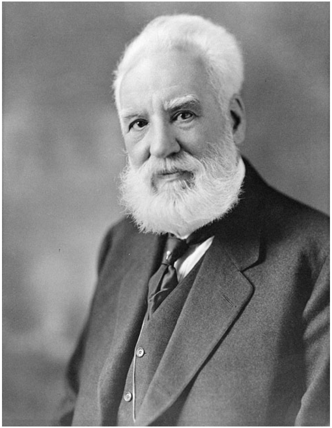
# What is a Decibel?

- A unit to compare two values, such as power or intensity.
- Simplifies working with very large or very small ratios.
- Developed at Bell Labs in the 1920s, named after Alexander Graham Bell.
    - The ”Bel” was introduced by engineers at Bell Labs in the 1920s as a logarithmic measure of power loss.
        - ⋆ Based on a single-wire, ground-return telephone system’s signal loss over 1 mile.
    - The Bel proved too large a unit for practical use, so they adopted the ”decibel” (1/10th of a Bel).
        - ⋆ Engineers do it in metric. ”Deci” means one tenth.

**Bell Laboratories**

# Why Do We Need Decibels?

- Makes large ratios easier to express.
    - To make big and small numbers easier to compare.
- Helps compare signal strength, gain, and losses, all using the same unit.
- Essential for RF work, including antenna theory, radio design, and troubleshooting.



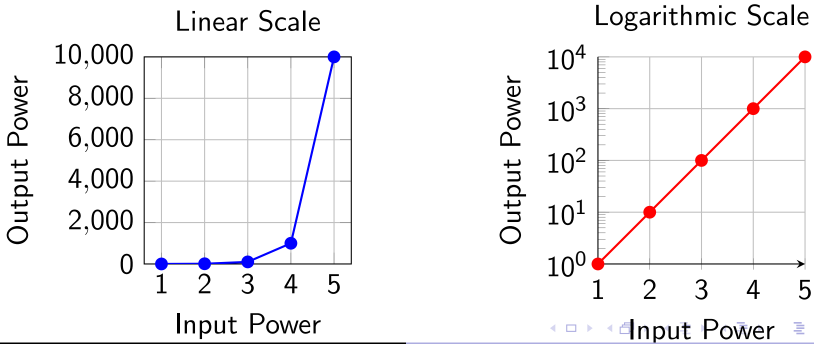
Alexander "Aleck" Graham Bell c. 1917

# Decibels: Simplifying Large Ratios

- A logarithm tells you how many times to multiply a number by itself.
  - Example:

$$\log_{10}(100) = 2 \quad \text{because} \quad 10 \times 10 = 100$$

- Why use logarithms?
  - Example: How many watts of drive does Roy need for his surplus broadcast amplifier to output exactly the legal limit?



# Large Ratios in RF Power

- **Why Handling Large Ratios Matters:**
    - RF power spans a huge range, from strong transmit signals to extremely weak received signals.
    - Linear scales (e.g., watts) make it difficult to compare values.
    - Logarithmic scales (e.g., dBm) simplify the comparison.

## Watts Scale

- **Legal Limit**: 1500 watts
- **Weak Signal**: 0.0000000000001 watts
- **Ratio**:

$$\frac{15}{0.0000000000000001}$$

- **Difference**: $1.5 \times 10^{17}$

## dBm Scale

- **Legal Limit**: 61.671 dBm
- **Weak Signal**: $-120$ dBm
- **Ratio**:

$$\frac{61.671}{-120}$$

- **Difference**: 181.671

# Why Use Decibels in RF?

- **Simplifies Calculations:**
  - Gains and losses in RF systems are often multiplicative.
  - Decibels turn these into simple addition/subtraction.
- **Practical Examples:**
  - **Signal Strength:**
    - Received Signal Level (RSL): $-120\,\text{dBm}$
    - Transmit Power: $61.671\,\text{dBm}$
  - **Antenna Gain:**
    - Adding gain: $+15\,\text{dBi}$
  - **Cable Loss:**
    - Subtracting loss: $-3\,\text{dB}$
- **Why It's Useful:**
  - Makes large ranges easier to compare.
  - Turns complex multiplications/divisions into simple addition/subtraction.

# Why Logarithms for Power?

- **Historical Context:**
    - The Bel was developed at Bell Labs in the 1920s to quantify power loss in telephone lines.
    - Early systems used a single-wire ground-return configuration.
    - Observation: A power loss over 1 mile was roughly an **order of magnitude** $(10 : 1)$.
- **Evolution to Decibels:**
    - $1$ Bel $= 10 : 1\,\text{ratio} =$ one order of magnitude $= 10\,\text{dB}$.
    - $10 \cdot \log_{10}$ naturally aligns to orders of magnitude in our ten finger based decimal number system.
    - Decibel (dB) became standard for practical use.

# Calculating Decibels

- **Decibel Formula:**
  - Power (dB):

$$P_{\text{dB}} = 10 \cdot \log_{10}\left(\frac{P_1}{P_2}\right)$$

  - Voltage (dB):

$$V_{\text{dB}} = 20 \cdot \log_{10}\left(\frac{V_1}{V_2}\right)$$

- **Key Concepts:**
  - Power ratios: $10 \cdot \log_{10}$, Because we are working with 1/10th steps of a Bel.
  - Voltage ratios: $20 \cdot \log_{10}$, because of its squared relationship to the power.
- **Examples:**
  - Power:

$$10 \cdot \log_{10}(1500) \approx 31.76\,\text{dB}.$$

  - Voltage:

$$20 \cdot \log_{10}(10) = 20\,\text{dB}.$$

# Decibel Rules of Thumb

- **Simple Decibel Rules:**
  - Doubling power adds $+3\,\mathrm{dB}$
  - Halving power subtracts $-3\,\mathrm{dB}$
  - $10 \times$ power $= +10\,\mathrm{dB}$.
- **Practical Examples:**
  - $100\,\mathrm{watts} \rightarrow 200\,\mathrm{watts}$ : $+3\,\mathrm{dB}$.
  - $100\,\mathrm{watts} \rightarrow 50\,\mathrm{watts}$ : $-3\,\mathrm{dB}$.
  - $100\,\mathrm{watts} \rightarrow 1000\,\mathrm{watts}$ : $+10\,\mathrm{dB}$.
- **Why It Matters:**
  - Simplifies power calculations in RF systems.
  - Saves time during design and troubleshooting.

# Understanding Relative dB Units

- **What Are Relative dB Units?**
  - dB is a **relative measurement**: compares two quantities to a reference.
  - Examples: Power, voltage, gain, signal strength.
- **Common Relative dB Units:**
  - **dBm**: Power relative to 1 mW.

$$P_{\text{dBm}} = 10 \cdot \log_{10}\left(\frac{P}{1\,\text{mW}}\right)$$

  - **dBi**: Antenna gain relative to an isotropic radiator.
  - **dBd**: Antenna gain relative to a dipole.
  - **dBc**: Relative to carrier power (e.g., spurious emissions, sideband noise).
  - **dBmV**: Voltage relative to 1 mV.
  - **dBFS**: Relative to **full scale**, used in digital systems.
- **Why Use Relative dB Units?**
  - Simplifies comparisons over large ranges.
  - If we choose the right ones, we can do apples to apples math. For instance, dBm and dBi to get EIRP.

# Antenna Gain: Focused Power

- **What is Antenna Gain?**
  - Gain measures how well an antenna focuses energy in a specific direction.
  - Relative to:
    - ⋆ *dBi*: Isotropic radiator.
    - ⋆ *dBd*: Dipole antenna ($0\,\text{dBd} = 2.15\,\text{dBi}$).
- **Why It's Important:**
  - Higher gain improves signal strength by focusing energy.
  - Example: Yagi antenna vs. dipole.
- **Quick Tips:**
  - Gain in $dBi$ = Gain in $dBd + 2.15$
  - Antenna salesmen will use dBi because the number is bigger and more inticing.

# What is an Isotropic Radiator?

- **Definition:**
  - A **theoretical antenna** that radiates power equally in all directions (a perfect sphere).
  - Serves as a **reference** for measuring antenna gain in dBi.
- **Why Is It Important?**
  - Provides a standard reference for antenna performance.
  - Gain in dBi: Compares how well an antenna focuses energy versus isotropic radiation.
- **Characteristics:**
  - Perfect spherical radiation pattern.
  - Impossible to construct physically, but useful for calculations.
- **Real-World Analogy:**
  - A **flare in the sky** radiates light uniformly in all directions, similar to an isotropic source.
  - A star, like our **sun**.

# Dipoles and Monopoles: Directional Radiation and Gain

- **Dipoles and Monopoles:**
  - **Dipole Antenna:** Two poles radiating energy in a **donut-shaped pattern**.
    - Real-world analogy: **Fluorescent tube**. The electrode caps create a null at each end.
  - **Monopole Antenna:** Single pole radiating energy in a **pattern akin to a sliced bagel**.
    - Real-world analogy: **Light bulb**. The base creates a null.
- **Radiation Patterns:**
  - Energy is concentrated in specific directions, by taking it from other directions, creating **nulls** where little or no radiation occurs.
- **Thermodynamics and Gain:**
  - Energy isn't "lost" in the nulls; it is **redirected** to focus more power in specific directions.
  - This directional focus creates **gain**:
    $Gain =$ power density compared to an isotropic radiator.
- **Why It Matters:** Higher gain antennas focus more energy in desired directions, improving efficiency and range.

# Visualizing Dipoles and Monopoles

- **Dipole Antenna:**
  - Radiation pattern resembles a **donut**.
  - Real-world analogy: **Fluorescent tube**.
- **Monopole Antenna:**
  - Radiation pattern resembles a **sliced bagel**.
  - Real-world analogy: **Light bulb**.

Dipole: Donut Radiation Pattern

Monopole: Sliced Bagel Radiation

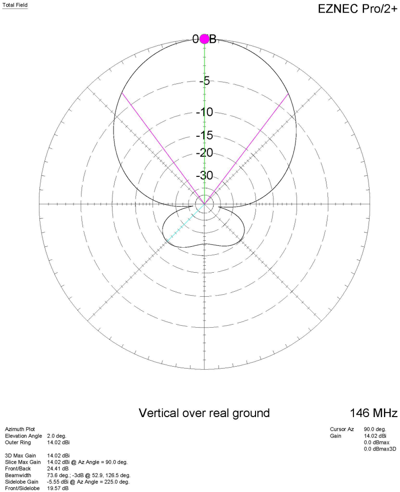
# Understanding Antenna Front-to-Back Ratios

- **What is the Front-to-Back Ratio (F/B)?**
  - A measure of an antenna's ability to focus energy in the desired direction (front) while minimizing radiation in the opposite direction (back).
- **Expressed as:**

$$\text{F/B Ratio (dB)} = 10 \cdot \log_{10}\left(\frac{\text{Power (front)}}{\text{Power (back)}}\right)$$

- **Typical Values:**
  - Omni-directional antennas: $0\,\text{dB}$ (equal radiation in all directions).
  - Yagi antennas: $10 - 20\,\text{dB}$ (good rejection of rear signals).
  - High-gain directional antennas: $30+$ dB (excellent rejection).
- **Why It Matters:**
  - Reduces interference from signals behind the antenna.
  - Improves reception of weak signals in the desired direction.
  - Essential for reducing noise and increasing signal-to-noise ratio (SNR).

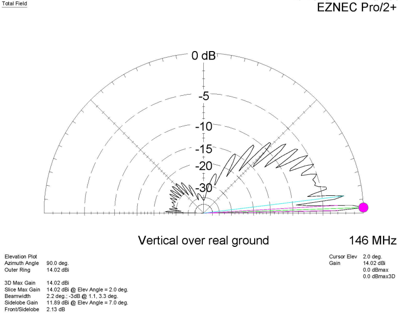
# Antenna Radiation Patterns



| | |
|---|---|
| Azimuth Plot | |
| Elevation Angle | 2.0 deg. |
| Outer Ring | 14.02 dBi |
| 3D Max Gain | 14.02 dBi |
| Slice Max Gain | 14.02 dBi @ Az Angle = 90.0 deg. |
| Front/Back | 24.41 dB |
| Beamwidth | 73.6 deg.; -3dB @ 52.9, 126.5 deg. |
| Sidelobe Gain | -5.55 dBi @ Az Angle = 225.0 deg. |
| Front/Sidelobe | 19.57 dB |

| | |
|---|---|
| Cursor Az | 90.0 deg. |
| Gain | 14.02 dBi<br>0.0 dBmax<br>0.0 dBmax3D |

Azimuth Radiation Pattern



| | |
|---|---|
| Elevation Plot | |
| Azimuth Angle | 90.0 deg. |
| Outer Ring | 14.02 dBi |
| 3D Max Gain | 14.02 dBi |
| Slice Max Gain | 14.02 dBi @ Elev Angle = 2.0 deg. |
| Beamwidth | 2.2 deg.; -3dB @ 1.1, 3.3 deg. |
| Sidelobe Gain | 11.89 dBi @ Elev Angle = 7.0 deg. |
| Front/Sidelobe | 2.13 dB |

| | |
|---|---|
| Cursor Elev | 2.0 deg. |
| Gain | 14.02 dBi<br>0.0 dBmax<br>0.0 dBmax3D |

Elevation Radiation Pattern

# Other Types of Gain: Amplifiers and LNAs

- **What is Gain?**
  - Gain increases the power or amplitude of a signal.
  - Measured in **positive dB** (e.g., $+10\,\mathrm{dB}$).
- **Common Types of Amplifiers:**
  - **Power Amplifiers (PAs):**
    - ⋆ Boost the transmitted signal to a higher power level.
    - ⋆ Example: $5\,\mathrm{W} \to 100\,\mathrm{W} = +13\,\mathrm{dB}$.
  - **Preamplifiers (Preamps):**
    - ⋆ Boost weak signals before processing.
    - ⋆ Example: Amplifying a faint RF signal for better reception.
  - **Low Noise Amplifiers (LNAs):**
    - ⋆ Amplify weak signals while adding minimal noise.
    - ⋆ Critical for satellite and weak-signal communications.
- **Why Gain Matters:**
  - Improves **signal-to-noise ratio (SNR)**:
    - ⋆ Makes weak signals easier to detect and process.
  - Enables communication over longer distances.
- **Quick Tip:**

$$\text{Total Gain (dB)} = G_{\text{PA}} + G_{\text{Preamp}} - L_{\text{Cable}} - L_{\text{Connectors}}$$

# Understanding Losses in RF Systems

- **What is Loss?**
  - Loss occurs when power is **dissipated or absorbed** rather than transmitted.
  - Measured in **negative dB** (e.g., $-3\,\text{dB}$).
- **Common Types of Loss:**
  - **Cable Loss:**
    - ⋆ Power dissipated as heat due to resistance in coaxial cables.
    - ⋆ Increases with the length of the cable and the frequency of the signal.
    - ⋆ Example: 100 ft of no name RG-8X at 144 MHz: $-4.5\,\text{dB}$
  - **Connector Loss:** Each connector introduces a small loss (usually $< -0.2$ dB).
  - **Atmospheric Loss:** Absorption of RF energy by the atmosphere, more significant at higher frequencies.
  - **Filters:** Duplexers and other filters can ass significant loss (sometimes $> 3$ dB.)
  - **Obstruction Loss:** Loss due to objects (e.g., buildings, trees, a Puu) blocking the signal. This can include the curvature of the earth!

# Decibels and Signal Strength

- **What is Signal Strength?**
  - Signal strength is the power level of a received signal, typically measured in **dBm**.
- **S-Meter Scale (Typical):**
  - S1 : Weak signal ( $-121\,\text{dBm}$).
  - S9 : Strong signal ( $-73\,\text{dBm}$).
- **Rule of Thumb:**
  - $+6\,\text{dB}$: Corresponds to **1 S-unit increase**.
  - **Example:** Going from S7 to S9 adds $12\,\text{dB}$ of signal strength.
- **Why It Matters:**
  - Helps quantify signal quality and communication effectiveness.
  - Guides antenna rotation, helps assess the noise level at Gary's house.

# S-Units vs. Decibels: A Historical Perspective

- **S-Units: The Early Days**
  - Developed as a **qualitative system** for radio operators to describe signal strength.
  - Pre-dates the formal adoption of decibels in radio communications, as a **quantitative system** of signal strength.
  - Original S-meters provided **approximate** signal strength readings without standardization.
- **The Hybrid System**
  - Decibels were incorporated into S-unit scales to **standardize** measurements.
  - Modern S-meters use:
    - **S1 to S9:** Approximately **6 dB per S-unit**.
    - **Above S9:** Signal strength expressed directly in decibels (e.g., S9+10 dB).

# Path Loss and Decibels

- **Free Space Path Loss Formula:**

$$L = 20 \cdot \log_{10}(d) + 20 \cdot \log_{10}(f) + 20 \cdot \log_{10}\left(\frac{4\pi}{c}\right)$$

  - $d$: Distance (meters).
  - $f$: Frequency (Hz).
  - $c$: Speed of light ($3 \times 10^8$ m/s).
- **Key Insights:**
  - Path loss increases with **distance** ($d$).
  - Path loss increases with **frequency** ($f$).
- **Practical Implication:**
  - Higher frequencies and longer distances mean higher losses.
  - Highlights the importance of high power, efficient antennas, and optimized frequencies.
- **Quick Example:**
  - $f = 2.4\,\text{GHz}, d = 1\,\text{km}$:

$$L = 20 \cdot \log_{10}(1000) + 20 \cdot \log_{10}(2.4 \times 10^9) - 147.55$$

  - Approximate loss: 100.04 dB.

# Maxwell's Equations and Path Loss

- **Wave Propagation:**
  - Maxwell's equations govern how electromagnetic waves propagate:
    - Changing magnetic fields create electric fields (**Faraday's Law**).
    - Changing electric fields and currents create magnetic fields (**Ampère's Law**).
- **Inverse Square Law:**
  - Radiated energy spreads spherically.
  - Intensity decreases with distance: Power Density $\propto \frac{1}{d^2}$
- **Why It Matters:**
  - Path loss arises from these fundamental principles:
    - Greater distances = weaker signals.
    - Higher frequencies = more loss.
- **Quick tip:** Double the distance = four times the loss (-6dB).

# Comparing Antenna and Cable Configurations

**Dipole with 100’ RG-58**

- **Transceiver Power:** 100 W (50 dBm)
- **Amplifier Gain:** +10 dB
- **Antenna Gain:** 2.15 dBi
- **Cable Loss:** −5.5 dB
- **EIRP:** 56.65 dBm

**Performance:**

- Amplifier mitigates cable loss, but overall efficiency is limited.
- Poor cable reduces usable power for both transmit and receive.

**Yagi with 50’ LMR-400**

- **Transceiver Power:** 100 W (50 dBm)
- **Antenna Gain:** 7.5 dBi
- **Cable Loss:** −0.75 dB
- **EIRP:** 56.75 dBm

**Performance:**

- Yagi’s gain improves both transmit range and received signal clarity.
- Lower cable loss ensures efficient power use and better SNR on reception.

# Putting It All Together: A Path Budget

- **What is a Path Budget?**
    - Combines **gains** and **losses** from transmitter to receiver.
- **Key Formula:**

$$\text{Received Power (dBm)} = \text{Transmitter Power (dBm)} + \text{Gains (dB)} - \text{Lo}$$

- **Example:**
    - **Transmitter Power:** 5 W (37 dBm).
    - **Amplifier Gain:** +10 dB.
    - **Cable Loss (Tx Side):** −5.5 dB.
    - **Free Space Path Loss (100 km at 144 MHz):** −115.61 dB.
    - **Cable Loss (Rx Side):** −0.75 dB.
    - **Antenna Gain (Rx):** +7 dBi.

# Path Budget: Calculation and Outcome

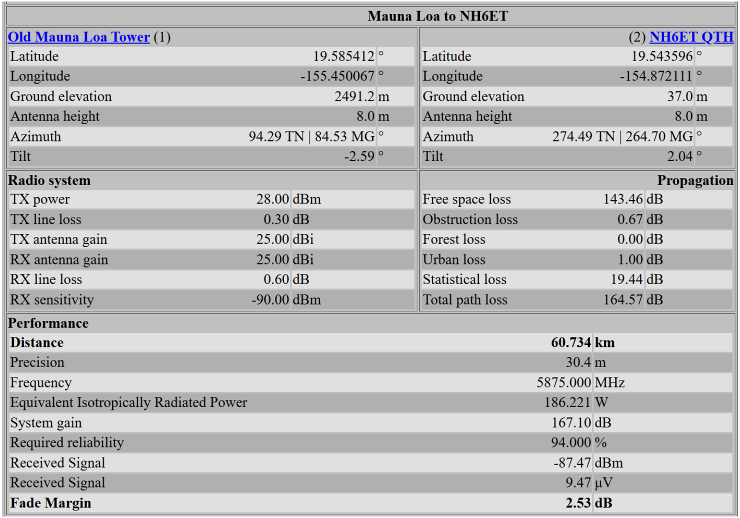
- **Path Budget Calculation:**

$$\text{Received Power (dBm)} = 37+10-5.5+2.15-115.61-0.75+7$$

$$\text{Received Power} = -65.71\,\text{dBm}$$

- **Outcome:**
  - The received signal ($-65.71\,\text{dBm}$) is **well above typical 2-meter receiver sensitivity** ($-120\,\text{dBm}$).
- **Fade Margin:**
  - **What is it?**
    - Additional signal strength above the receiver's sensitivity needed to account for signal fading due to environmental factors.
    - Typical fade margin values range from 10 dB (clear line of sight) to 20 dB (urban or obstructed paths).
  - **This Example:**
    - Received power ($-65.71\,\text{dBm}$) provides a fade margin of approximately 54.29 dB.

# Path Budget Example: Radio Mobile



**Mauna Loa to NH6ET**

| Old Mauna Loa Tower (1) | | | (2) NH6ET QTH | | |
|---|---|---|---|---|---|
| Latitude | 19.585412 | ° | Latitude | 19.543596 | ° |
| Longitude | -155.450067 | ° | Longitude | -154.872111 | ° |
| Ground elevation | 2491.2 | m | Ground elevation | 37.0 | m |
| Antenna height | 8.0 | m | Antenna height | 8.0 | m |
| Azimuth | 94.29 TN \| 84.53 MG | ° | Azimuth | 274.49 TN \| 264.70 MG | ° |
| Tilt | -2.59 | ° | Tilt | 2.04 | ° |

| **Radio system** | | | **Propagation** | | |
|---|---|---|---|---|---|
| TX power | 28.00 | dBm | Free space loss | 143.46 | dB |
| TX line loss | 0.30 | dB | Obstruction loss | 0.67 | dB |
| TX antenna gain | 25.00 | dBi | Forest loss | 0.00 | dB |
| RX antenna gain | 25.00 | dBi | Urban loss | 1.00 | dB |
| RX line loss | 0.60 | dB | Statistical loss | 19.44 | dB |
| RX sensitivity | -90.00 | dBm | Total path loss | 164.57 | dB |

| **Performance** | | |
|---|---|---|
| **Distance** | **60.734** | **km** |
| Precision | 30.4 | m |
| Frequency | 5875.000 | MHz |
| Equivalent Isotropically Radiated Power | 186.221 | W |
| System gain | 167.10 | dB |
| Required reliability | 94.000 | % |
| Received Signal | -87.47 | dBm |
| Received Signal | 9.47 | µV |
| **Fade Margin** | **2.53** | **dB** |

# ET's Easy Mode for Decibel Math

- **Step 1: Start with the Sign**
  - $+$: Move the decimal point to the **right**.
  - $-$: Move the decimal point to the **left**.
- **Step 2: Read the Tens**
  - Each 10 tells you how many places to move the decimal point.
- **Step 3: Handle the Ones**
  - Each $+3$ dB: Double the value.
  - Each $-3$ dB: Halve the value.
  - Each remaining $+1$ dB: Add 20
  - Each remaining $-1$ dB: Subtract 20
- **Why It Works:**
  - It's simple, quick, and close enough for RF work!

# Calculating Power in Watts: 27 dBm

- **Step 1: Recall the Formula**

$$P_{\text{watts}} = 10^{\frac{P_{\text{dBm}}-30}{10}}$$

- **Step 2: Plug in 27 dBm**

$$P_{\text{watts}} = 10^{\frac{27-30}{10}}$$

- **Step 3: Simplify the Exponent**

$$P_{\text{watts}} = 10^{\frac{-3}{10}} = 10^{-0.3}$$

- **Step 4: Approximate the Value**

$$P_{\text{watts}} \approx 0.501\,\text{W}$$

- **Result:**
  - $27\,\text{dBm} \approx 0.501\,\text{W}$
  - Half a watt is a common power level for low-power transmitters!

# Calculating Power in Watts: 27 dBm (ET's Easy Mode)

- Start with the sign: + means we're moving the decimal point to the **right**.
- Break it down:
    - Start with 1mw - because it's dBm, or dB relative to one milliwatt
    - 20 dBm = 0.1 W (move the decimal two places to the right).
    - Add +3 dB: Double it → 0.2 W.
    - Add another +3 dB: Double it again → 0.4 W.
    - Add the final +1 dB: Add 20% → $0.4 + 0.08 = 0.48$ W.
- Result: 27 dBm $\approx$ 0.48 W
- Close enough for RF work!