dB Or Not dB?
All About The Decibel

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Agenda

1. Definition of the Decibel
2. Usages of the Decibel
3. Standard Measures using Decibel
4. Summary
5. Q&A

Definition of the Decibel

Definition of a Decibel

- A unit used to measure the intensity of a sound or the power level of an electrical signal by comparing it with a given level on a logarithmic scale.
- The decibel represents the ratio of two values of a power or a root-power quantity on a logarithmic scale.
- The important parts of this definition are:
  - ***Ratio*** *of two values on a logarithmic scale*
  - *Power Quantity*
  - *Root-Power Quantity*

What's a Logarithm?

- A logarithm **is the exponent by which another fixed value, the base, must be raised** to produce that number.

  $\log_b(b^x) = x$, where b is the base

- Any value can be used as a base, however:
  - **Common** logarithms use a base **10**
  - **Natural** logarithms use a base ***e*** **(Euler's number)**, approximately 2.718.
- X = log (10^x)
  - In calculator terms – the value, log, equals provides X
  - Likewise, in calculator terms – X, 10^x, equals provides the value

Power Quantity

- Power
  - An amount of energy transferred or converted over time
- Energy Density
  - The quotient between an amount of energy stored and the volume
- Acoustical Intensity
  - The power carried by sound waves per unit area in a direction perpendicular to that area
- Luminous Intensity
  - The measure of wavelength weighted power emitted in a particular direction per unit of field of view (solid angle)

Root-Power Quantity (aka Amplitude)

- A quantity, when squared, is proportional to power in a linear system
- This includes voltage, current, sound pressure, electric field strength and more
- *Root-Power Quantity* refers to the square root that relates these values to power.
- For example, Watt's and Ohms's Laws – W = E * I, E = I * R or I= E / R
  1. W = E * I
  2. W = E * E / R, W = E^2 / R
  3. W * R = E^2
  4. E^2 = W * R

Quantity, squared

Power (equals sign denotes proportionality)

Definition of Decibel Recap

- The decibel represents the ratio of two values of a power or a root-power quantity on a logarithmic scale
- The logarithmic scale is based on the common logarithm
- Power quantities are watts, typically
- Root-power quantities are volts or amperes, typically

Rule of Thumb – if quantity measures contain watts, joules or candela then you are dealing with power quantities, otherwise it's root-power quantities.

Usages of the Decibel

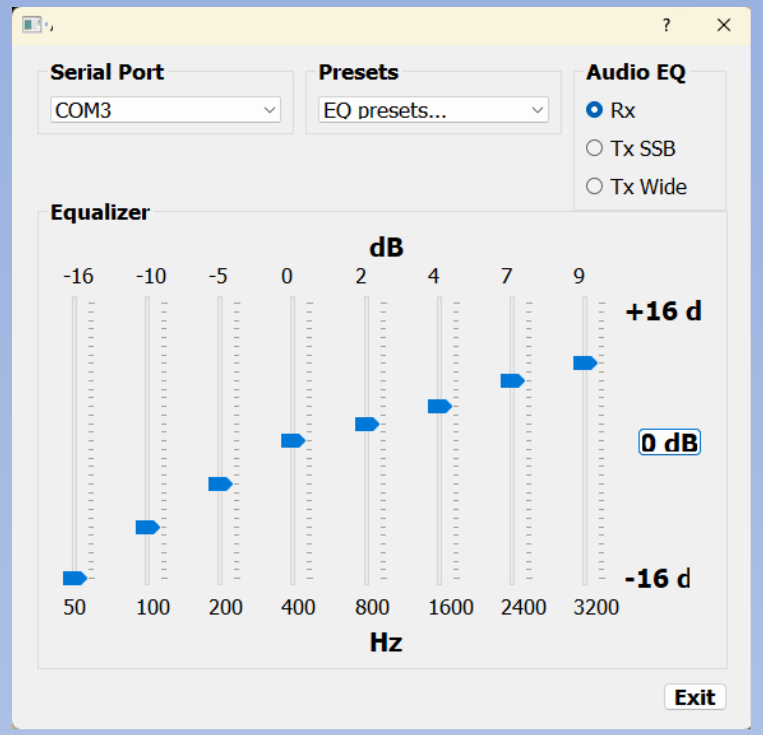
Let’s Look at a Radio Shack

An imaginary “Typical” Shack

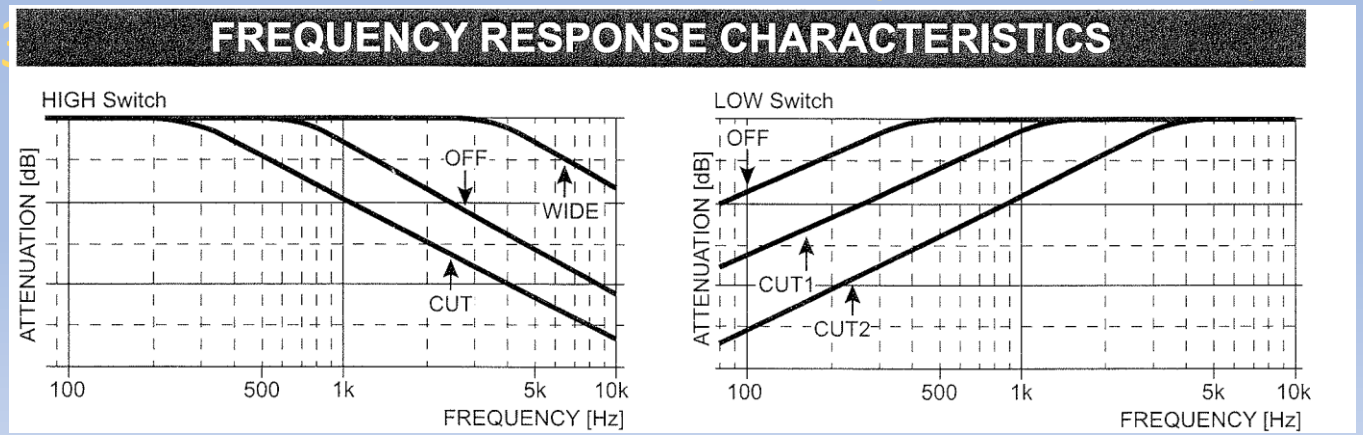
- HF Transceiver
- Getting to the Antenna from the Transceiver
  - Transmission Line
  - Polyphaser protection
  - Bandpass Filter
- Antenna

Transceiver – Audio Perspective

- Elecraft K3S
  - From the Menu I can “equalize” the audio for phone transmission and reception

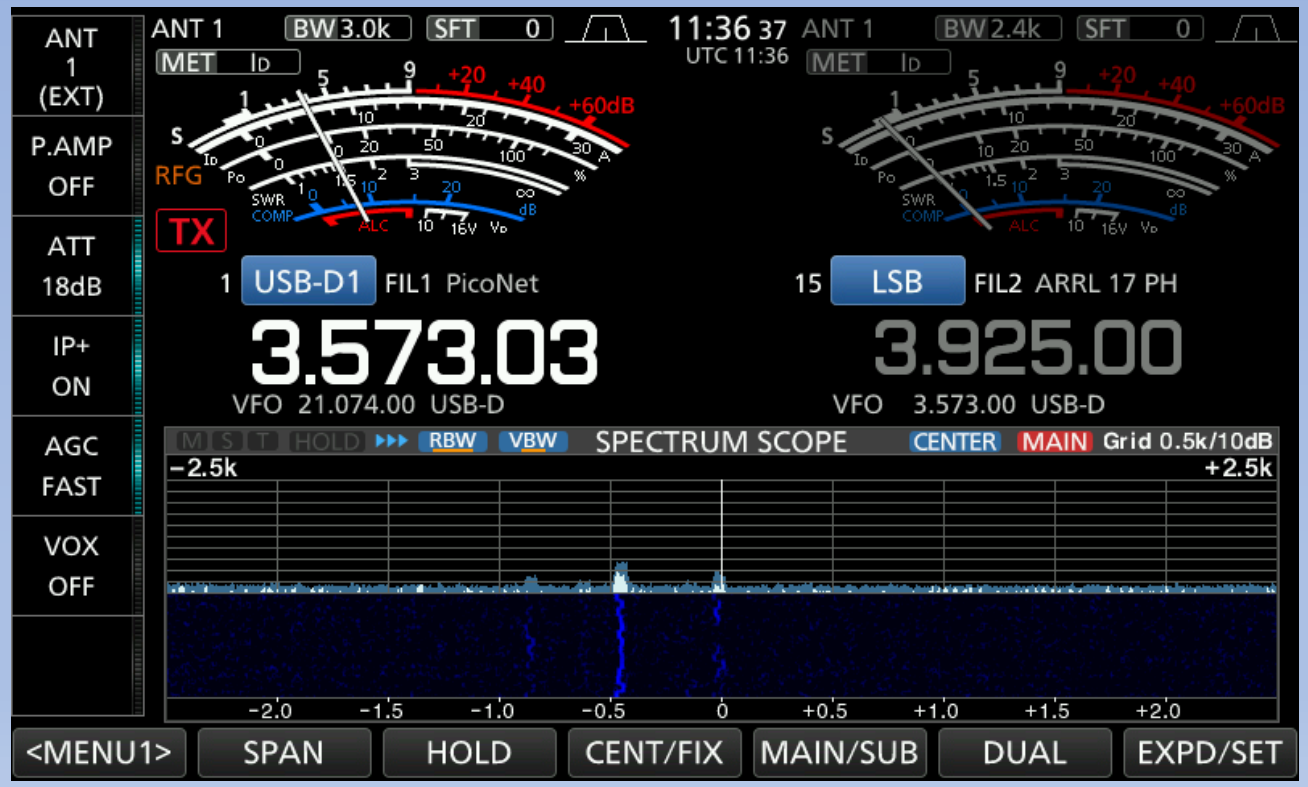


- An Icom SP-41 is shared between an IC-7610 and K3S with switches to shape audio response.



Transceiver – Signal Reception

- S-Meter, assuming properly calibrated
  - S-9 represents -73dBm or approximately 50 pW or 50µV@50Ω
  - Each S-unit represents 6dB
- Waterfall Display
  - Depending on setup, each division may be 10dB



Getting to the antenna

- The Coax is LMR-240, which has an attenuation of 1.3dB/100 ft at 30MHz.
- Polyphasers are used for lightning protection, and these are rated at 0.1dB insertion loss.
- The bandpass filter has less than 0.25dB insertion loss in the pass band, and 55dB plus in the stop band.
- Assuming 100ft of transmission line, the overall loss is 1.65dB (1.3+0.1+0.25) between the antenna and transceiver.

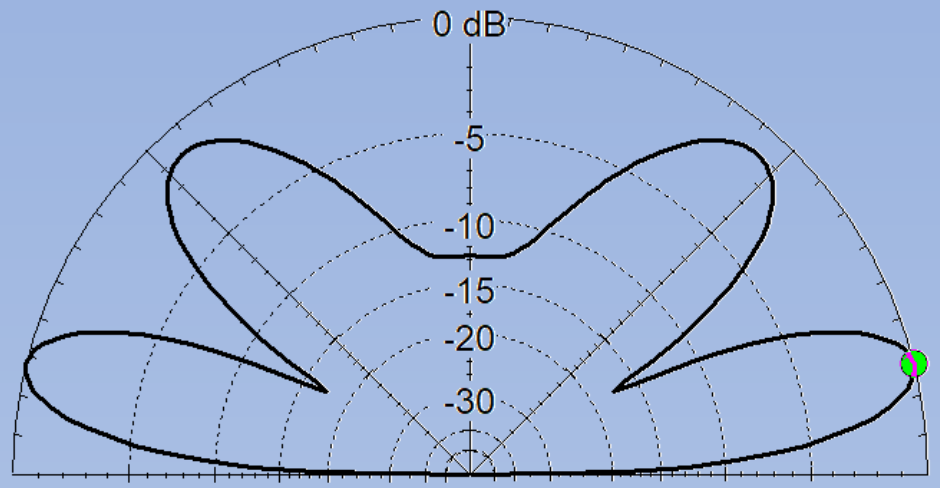
The Antenna

- Theoretical Antennas
  - The isotropic antenna radiates equally in all directions.
  - A dipole in free space concentrates radiation broadside to the dipole with 2.15dBi gain.
- Real Antennas
  - Antenna gain comparison is based on dBi (the isotropic antenna) or dBd (the dipole).
  - Antenna measures, such as front-to-back are measured in dB alone.
- Can we overcome a 1.65dB loss?

Dipole Antenna at 1λ over “medium” ground

Total Field

EZNEC Pro/2+



Elevation Plot
Azimuth Angle 0.0 deg.
Outer Ring 7.64 dBi

Slice Max Gain 7.64 dBi @ Elev Angle = 14.0 deg.
Beamwidth 14.8 deg.; -3dB @ 6.9, 21.7 deg.
Sidelobe Gain 7.64 dBi @ Elev Angle = 166.0 deg.
Front/Sidelobe 0.0 dB

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Cursor Elev 14.0 deg.
Gain 7.64 dBi
0.0 dBmax

Usages of the Decibel

- In a typical radio shack we'll find
  - Accessories (or the transceiver itself) that shape audio frequencies using dB to describe the gain
  - Speakers that have audio filtering, with the characteristics expressed as dB
  - The transmission line and all the "stuff" along the transmission line that may have loss (transmission line, insertion loss) or gain (such as a pre-amplifier) all measured in dB, and in some cases qualified by frequency.
  - The antenna, having a characteristic gain compared to the theoretical isotropic antenna expressed as dBi, or dipole expressed as dBd.

Note dBd = 2.15 + dBi

Standard Measures Using Decibel

Rule of Thumb

If quantity measures contain watts, joules or candela then you are dealing with power quantities, otherwise it’s root-power quantities.

Common Power Quantities

- dBm [aka dB(mW)] relative to 1 milliwatt, **however there are two different contexts to consider.**
  - In RF terms, the reference load of 50 ohms, with a resultant voltage of 0.224 volts.
  - In audio or telephony, the reference load of 600 ohms, with a resultant voltage of 0.775 millivolts.
- dBc [not dB(C)] enables measures of noise or sideband power relative to the carrier.
- dBSWL is sound intensity level (NOT sound pressure), relative to 1 picowatt.

RF Power Quantities in dBm

dBm	Power	Comment
62	1500W	Max Amateur Radio PEP
60	1000W	Typical Max RF Power of Microwave
50	100W	Typical RF output of Amateur Radio Transceiver
40	10W	
37	~5W	Typical QRP / Handheld Amatuer Radio Transceiver
33	~2W	Max Output from GSM 850/900 Mobile Phone
30	1W	DCS or GSM 1800/1900 MHz Mobile Phone
20	100mW	EIRP for an IEEE 802.11b/g 20MHz-wide channel in 2.4GHz ISM Band
10	10mW	
-73		S9; 50µV at 50 ohms; not adhered to in most transceivers
-79		S8; 25µV at 50 ohms; not adhered to in most transceivers
-85		S7; 12.5µV at 50 ohms; not adhered to in most transceivers
-91		S6; 6.3µV at 50 ohms; not adhered to in most transceivers
-97		S5; 3.16µV at 50 ohms; not adhered to in most transceivers
-100	100fW	IEEE 802.11b/g minimum signal strength
-101	~83fW	noise floor IEEE 802.11b/g 20MHz channel at 300K
-103		S4; 1.58µV at 50 ohms; not adhered to in most transceivers
-109		S3; 0.8µV at 50 ohms; not adhered to in most transceivers
-115		S2; 0.4µV at 50 ohms; not adhered to in most transceivers
-121		S1; 0.2µV at 50 ohms; not adhered to in most transceivers
-127		S0; 0.2µV at 50 ohms; not adhered to in most transceivers
-134	~41aW	noise floor of 10kHz wide FM signal at 300K
-140	~12aW	noise floor of 2.7kHz wide SSB signal at 300K

Root-Power Quantities

- dbV or dB(V_{RMS}) is voltage relative to 1 volt regardless of impedance
- dBµV or dBuV is voltage relative to 1 microvolt – where load is typically 50 or 75 ohms
- dBu or dBv is voltage relative to the RMS voltage that would dissipate 0 dBm (1 milliwatt) into a 600 ohm load.
- dBµV/m, dBuV/m or dBµ is electrical field strength relative to 1 microvolt per meter
- dBSPL is sound pressure level relative to 20 micropascals (µPA) – 0dBSPL is approximately the quietest sound a human can hear.

Sound Root-Power Quantities

- Jet takeoff is at 150 dB – may cause eardrum rupture
- Live rock music 108-114dB – 110 is average pain threshold
- Vacuum cleaner 70 dB
- Conversation in restaurant 60dB
- Conversation at home 50dB

Antenna Measures

- **dB** is used to describe front-to-back ratio on an antenna
- **dBi** is used to compare antenna gain to an isotropic antenna
- dBd is used to compare antenna gain to a dipole antenna
  - dBd = dBi + 2.15
  - A 3 dBd antenna has the same gain as a 5 dBi antenna
- dBq – the gain compared to a ¼ wave whip, used in marketing

Some Idea of Scale

dB	Power Ratio	Root-Power (Amplitude) Ratio	dBm	Power	Comment	dB	Power Ratio	Root-Power (Amplitude) Ratio	dBm	Power	Comment
150	1000000000000000	31622776.602				-30	0.00100000000000	0.03162278			
140	100000000000000	10000000.000				-40	0.00010000000000	0.01000000			
130	10000000000000	3162277.660				-50	0.00001000000000	0.00316228			
120	1000000000000	1000000.000				-60	0.00000100000000	0.00100000			
110	100000000000	316227.766				-70	0.00000010000000	0.00031623			
100	10000000000	100000.000				-73	0.00000005011872	0.00022387	-73		S9; 50µV at 50 ohms; not adhered to in most transceivers
90	1000000000	31622.777				-79	0.00000001258925	0.00011220	-79		S8; 25µV at 50 ohms; not adhered to in most transceivers
80	100000000	10000.000				-80	0.00000001000000	0.00010000			
70	10000000	3162.278				-85	0.00000000316228	0.00005623	-85		S7; 12.5µV at 50 ohms; not adhered to in most transceivers
62	1584893	1258.925	62	1500W	Max Amateur Radio PEP	-90	0.00000000100000	0.00003162			
60	1000000	1000.000	60	1000W	Typical Max RF Power of Microwave	-91	0.00000000079433	0.00002818	-91		S6; 6.3µV at 50 ohms; not adhered to in most transceivers
50	100000	316.228	50	100W	Typical RF output of Amateur Radio Transceiver	-97	0.00000000019953	0.00001413	-97		S5; 3.16µV at 50 ohms; not adhered to in most transceivers
40	10000	100.000	40	10W		-100	0.00000000010000	0.00001000	-100	100fW	IEEE 802.11b/g minimum signal strength
37	5012	70.795	37	~5W	Typical QRP / Handheld Amatuer Radio Transceiver	-101	0.00000000007943	0.00000891	-101	~83fW	noise floor IEEE 802.11b/g 20MHz channel at 300K
33	1995	44.668	33	~2W	Max Output from GSM 850/900 Mobile Phone	-103	0.00000000005012	0.00000708	-103		S4; 1.58µV at 50 ohms; not adhered to in most transceivers
30	1000	31.623	30	1W	DCS or GSM 1800/1900 MHz Mobile Phone	-109	0.00000000001259	0.00000355	-109		S3; 0.8µV at 50 ohms; not adhered to in most transceivers
20	100	10.000	20	100mW	EIRP for an IEEE 802.11b/g 20MHz-wide channel in 2.4GHz ISM	-110	0.00000000001000	0.00000316			
10	10	3.16227766	10	10mW		-115	0.00000000000316	0.00000178	-115		S2; 0.4µV at 50 ohms; not adhered to in most transceivers
6	3.981	1.99526231				-120	0.00000000000100	0.00000100			
3	1.995	1.41253754				-121	0.00000000000079	0.00000089	-121		S1; 0.2µV at 50 ohms; not adhered to in most transceivers
1	1.259	1.12201845				-127	0.00000000000020	0.00000045	-127		S0; 0.2µV at 50 ohms; not adhered to in most transceivers
0	1.000	1.00000000	0	1mW	Bluetooth Class 3 Radio with 1 m Range	-130	0.00000000000010	0.00000032			
0	1.000	1.00000000	0	1mW	Bluetooth Class 3 Radio with 1 m Range	-134	0.00000000000004	0.00000020	-134	~41aW	noise floor of 10kHz wide FM signal at 300K
-10	0.10000000000000	0.31622777	-10	100µW		-140	0.00000000000001	0.00000010	-140	~12aW	noise floor of 2.7kHz wide SSB signal at 300K
-20	0.01000000000000	0.10000000				-150	0.000000000000001	0.00000003			

Some Idea of Scale

- Factor of 2 (Double/Halve)
  - 3dB for Power Quantity
  - 6dB for Root-Power Quantity
- Factor of 10
  - 10dB for Power Quantity
  - 20dB for Root-Power Quantity

dB	Power Ratio	Root-Power (Amplitude) Ratio
30	1000	31.6227766
20	100	10
10	10	3.16227766
6	3.981071706	1.995262315
3	1.995262315	1.412537545
1	1.258925412	1.122018454
0	1	1

How to Calculate Power Quantity Decibels

Let's say you measure 100 watts of forward power and 5 watts of reflected power. What is the relative measure, in dB of reflected power to forward power?

- In your calculator enter 5/100 equals 0.05 – this is the ratio of two power quantities.
- Press the Log function, then multiply by **10**. this gives you -13.01dB.

Note: the factor of 10 is used in Power (e.g. watts) Quantities.

How to Calculate Root-Power Quantity Decibels

Let's say you measure $4V_{RMS}$ in and $75V_{RMS}$ out. What is the relative measure, in dB, of output to input voltage?

- In your calculator enter 75/4 equals 18.75 – this is the ratio of two root-power quantities.
- Press the Log function, then multiply by **20**. This gives you 25.46dB.

Note: the factor of 20 is used for Root-Power (e.g. volts, amperes) quantities.

Summary

All About the Decibel

Definition

The decibel represents the ratio of two values of a power or a root-power quantity on a logarithmic scale.

- Power quantities have watts or candela as part of the unit of measure.
- Root-power quantities do NOT have watts or candela as part of unit of measure.

Summary

Usages

We took a trip into a ham shack and explored the places the decibel was used. We saw usage in audio (for shaping voice audio), uses in the S-Meter, waterfall displays, and potentially the speakers used. We saw usage in the context of transmission line loss, insertion loss for filters and lightning protection, and we saw usage in the description of antennas.

Standard Measures

We reviewed power using dBm, root-power using dBSPL for sound and dBµV/m for field strength. We also reviewed specific relative measures for antennas. We then did practical calculations of dB for power quantities in watts and root-power quantities in volts.

Key Points to Remember

- Power quantities have watts or candela as part of the unit of measure.
- Root-power quantities do NOT have watts or candela as part of unit of measure.
- Increase by a factor of 2 (Doubling)
  - Increase of 3dB for power
  - Increase of 6dB for root-power (aka amplitude)
- Increase by a factor of 10
  - Increase of 10dB for power
  - Increase of 20dB for root-power (aka amplitude)
- Quantities in watts (power) – 10 log (W1 $_{5}$/W2 $_{100}$)
- Quantities in volts, amps (root-power) – 20 log (V1 $_{75}$/V2 $_{4}$)
- For antenna gain, dBd = dBi + 2.15

Note: Values in Red

Q&A

Exercise – 1.65dB insertion loss

- What power is at the antenna feed point with 1.65dB insertion and coax loss assuming 100 watts at the transceiver?
- Power uses dB = 10 log (W_1/W_2)
  1. -1.65 = 10 log (?/100)
  2. -.165 = log (?/100)
  3. $10^{-.165}$ = ? /100
  4. 100 * $10^{-.165}$ = ?
  5. 100 * .6839 = ?
- 68.39 watts at the antenna feed point

Thank You!