Units of Measure; dB, dBd, dBi, dBm, dBW and dB/μV

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Picture of a 7-band Log-Periodic, with a 10 dBd forward gain on 20 Meters

Decibel ('dB')

Manufacturers use the decibel (dB) and other power units, in their advertisements. It is thus necessary to understand what they represent. **There is a fundamental difference between 'dB' and 'dBm'.** *These two units are used when a RF Engineer reviews,*

1. An antenna.
2. The receiver portion of a transceiver (its dynamic range (DR), 3d-order IMD, etc).
3. Propagation charts for a specific circuit.

As it suggests, the decibel (dB) is a tenth of a Bel (In honor of Alexander Graham Bell). Where does it come from? We use this unit because of the nature of the human ear which shows a logarithm response to sound power variations. The wave pressure that the human ear is able to detect or tolerate, ranges between a level of 2 x 10^{-5} mbar (weakest) and 2 mbar (loudest), and forgets the other units like dynes, psi or Pa. The ratio between both signals reaches 10 million or a factor of 7 equates to 7 Bel. This is thus a large unit and in Radio Electronics we usually work with values ten times (deci) below the level of a Bel, hence the use of the decibel (dB). For example, if you increase the power of your speaker by a factor of 10, you will only feel a doubling of the sound power.

The 'dB always expresses the logarithmic measurement of a power ratio. It thus has a meaning only if a reference level is set.' For example, 'a received signal is 20 dB over S9 on a

Transceivers Signal Strength Meter'. **In this example, the starting power is set, indicated by S9, which is the power transferred by a 50µV (-73 dBm) signal to a 50Ω load.** '20 dB (-53 dBm) over S9' thus means a power that is 100 times greater than the starting power, because 20 dB means a power ratio of 100.

The decibel is:

A power ratio: dB = 10 Log P_2/P_1

A voltage ratio: dB = 20 Log V_2/V_1

If an amplification stage offers a voltage gain of 30, followed with another stage having a voltage gain of 10.

1st formula: 30 x 10 = 300 dB

2nd formula: 29.5 + 20 = 49.5 dB

dB and Transceiver S-Meter S-Units

What does '1' S-Unit represent in dB? Each S-Unit corresponds to a current or voltage ratio of 2 and a power ratio of 4. '1' S-unit represents thus a power ratio of 6 dB (and rather 4 dB on average in some Japanese transceivers in the lower part of the meter).

From a meter reading of S6 to S7 there is a 6 dB change and increases 1/2 an S-Unit or a +3 dB each time you double the power output. A 100 Watt signal received with a reading on the S-Meter of S6 would require a 200 Watt transmitted signal to read S6.5 (+3dB), a 400 Watt transmitted signal to read S7 (+3dB), a 800 Watt transmitted signal to read S7.5 (+3dB) and a 1600 Watt transmitted signal to read S8 (+3dB), for a total of +12dB increase from S6 to S8.

In the same way a signal strength reduction of 6 dB is equivalent to a power loss of 75% (2 x 3 dB or 2 x 50% less in this case). **6 dB is also a power ratio of 4 times knowing that 3 dB = 2x, 6 dB = 4x, 9 dB = 8x, 10 dB = 10x, 20 dB = 100x.**

'Log' with an uppercase 'L' used here means in base 10, to not confuse with 'log', in lowercases, that uses the natural logarithm, in base 'e' (~2.72).

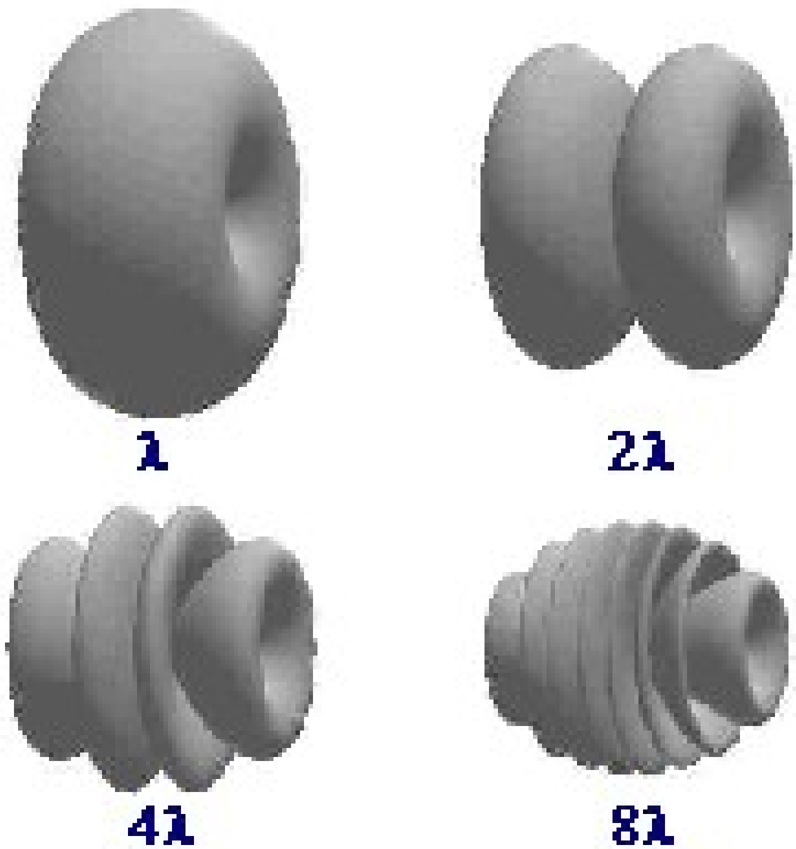
Decibel over a 'dipole' ('dBd') versus Decibel over an 'isotropic radiator' ('dBi')

To get comparable numbers in measuring the gain of antennas, an isotropic radiator (a theoretical radiator) must be defined as one with zero gain (which is unity gain), that we write '0 dBi'. The radiation pattern of this antenna is circular and even like a sphere centered on the antenna viewed in space. But such a pattern does not exist on earth, as there are numerous objects and obstacles that alter this theoretical pattern. **In practice comparison is normally made in measuring the field strength produced by a 'Hertz' antenna,** (the name 'Hertz' is used in honor of Heinrich Rudolf Hertz, the Scientist who developed it). **A Hertz is also called a 'Dipole', 'Doublet', 'Halfwave' or 'Ungrounded'.** It is placed at the same height and used in the same polarization as the antenna under test.

With this comparison model we can accurately measure the gain of any antenna. Let's begin with the simplest case of a dipole. What is it's the gain of a dipole? From various measurements we can estimate it at 2.14 dBi (gain over an isotropic antenna). In fact we should say 2.14 dBd, thus comparing the dipole to itself instead of speaking in dBi, which is never met, excepting in simulation programs. In this context it is not impossible to find a dipole offering a 6 dBd gain placed over saltwater (or 8.14 dBi). Each frame of reference is thus valid, as long as it is used consistently and clearly, which is furthest from what is used.

Some people, including manufacturers, will say that their antenna has a 5 dB gain. Compared to what reference? Stating the gain of an antenna without a reference is meaningless. It should be stated as the antenna offers a 5 dB gain over an isotropic radiator (5 dBi). In this case the antenna has a gain of 2.86 dB gain over a dipole (5 dBi – 2.14 dBi = 2.86 dBd). A gain below 3 dB is not much and the improvement is not very appreciable, but using a real life Antenna in the field a 0.5 dB can mean hearing or not hearing a station. So we have to put this value in context and translate it to actual field applications to understand what advertisers write. Some will say that their antenna offers a 10 dBi gain. Well, fine! But what does it mean? In the field this antenna has really a 7.86 dBd (10 dBi - 2.14 dBi = 7.86 dBd) compared to the dipole. This is not a very high gain, especially if the new antenna is expensive! All manufacturers do not compare their antennas to the same reference antenna; some measure them against a dipole reference (in dBd) but some measure them against a isotropic reference (in dBi). Both figures are completely different.

So instead of using gain figures, advertisers would be smarter working with decibels. Knowing then that when doubling your output power you improve your signal by 3 dB, it is easy to understand that a fine tuned antenna system can sometimes exceed the theoretical performances of a so-called high-gain antenna.



Evolution with frequency of the radiation patterns of a ‘Dipole. Each time we double the frequency, new lobes appear, modifying the way the antenna spreads power into space. This pattern is also affected by the proximity of ground and its properties.

But even if you transmit with a power twice as powerful as the previous, although your transmitting power has increased, your receive range will stay unchanged as long as you use the same antenna! In other words DX stations can now hear you but you cannot always hear them! So do you really need a high-gain antenna?

To notice a difference in what you hear you must make a big jump in increasing the performances of your antenna system installation. Begin by improving the receiving sensitivity of your antenna by installing a more directional one, and for other stations to hear a difference in your signal begin by doubling your transmitting output power in place of replacing your antenna as that can already improve your signal strength by 3 dB! This being said, it is obvious that concentrating 100 Watts into a high-gain beam directed toward the receiving station is by far preferable than dissipating 1 kilowatt in an omnidirectional antenna!

Decibel over a milliwatt ('dBm')

Contrarily to dB, dBm is a measurement of absolute power, not a power ratio. For convenience, the 'm' in 'dBm' refers to 'milliwatt', and by convention, *'0' dBm equals* the power dissipated by a power of *1 mW* into a *50Ω load*. This reference is important because '0' dBm into 50Ω is not equivalent to '0' dBm into 75Ω. The dBm relation is next, P being the power:

$$\text{dBm}_{(mW)} = 10 \text{ Log } P \quad \text{and} \quad P_{(mW)} = 10^{(\text{dBm}/10)}$$

For example 100 Watts is 50 dBm into 50Ω, and 10 Watts is 40 dBm into 50Ω. A value of +10 dBm thus means 10 times that power, +20 dBm means 100 times that power, etc. The dBm is very interesting because we can calculate the output power of a transceiver in dBm after removing losses and adding the antenna gain to estimate for example the signal strength at a target location like propagation programs. For example, a 12 dBm signal amplified by a system offering a 20 dB gain, becomes a signal that is +32 dBm stronger or a little more than 1 watt. Of course we could also use directly the S-meter but the signal strength expressed in power is more accurate because it is also equivalent to a voltage developed at the load (antenna).

S-point	Microvolt	dBm
S9+10	= 160.00 µV =	- 63 dBm
S9	= 50.15 µV =	- 73 dBm
S8	= 25.13 µV =	- 79 dBm
S7	= 12.60 µV =	- 85 dBm
S6	= 6.31 µV =	- 91 dBm
S5	= 3.16 µV =	- 97 dBm
S4	= 1.59 µV =	- 103 dBm
S3	= 0.79 µV =	- 109 dBm
S2	= 0.40 µV =	- 115 dBm
S1	= 0.20 µV =	- 121 dBm

S-meter standard readings as defined by IARU. One S-unit is equal to a signal difference of 6 dB. The value in microvolts is given into 50Ω. On frequencies below 30 MHz, a S-9 signal is equivalent to a power of -73 dBm [continuous wave (CW) on receive].

Japanese "SG"	American "SG"
–6dB	0.25μV
0dB	0.5μV
6dB	1μV
12dB	2μV
24dB	8μV
30dB	15.8μV
40dB	50μV
50dB	158μV
60dB	500μV
70dB	1.58mV
80dB	5mV
90dB	15.8mV
100dB	50mV
120dB	0.5V

A signal level of +12 dBm for example is 12 dB greater than a milliwatt, or about 13 mW. In this case the gain does not indicate the 'power' of an antenna but rather the increase in power compared to another antenna. An antenna does not amplify signals by re-distributing the energy or improving the modulation! Except active antennas, all antennas radiate passively.

Calculations of gains and losses must always be expressed in dB instead of dBm. The dBm is used in all circuits offering different impedances; the calculation of the power expressed in dBm remains constant while RF voltages and impedances change.

IARU Region 2 Technical Recommendation defined that on frequencies below 30 MHz, a S-9 signal is equivalent to a power of -73 dBm (continuous wave on receive). Note that on frequencies higher than 30 MHz a S-9 signal is equivalent to a power of -93 dBm (continuous wave on receive). The 20 dB difference between HF and VHF is due to the less noise temperature as frequencies increase and the use of transverters in front of HF transceivers calibrated for S9 = - 73 dBm showing usually a gain over 20 dB.

We will also see below that there is of course a relation between the antenna voltage (dBm) and the field strength (dB>μV). The correct interpretation on these measurements is another thing that we must tackle now.

Decibel below a Watt ('dBW') or ('SDBW')

Among the other scales often used, there is the signal strength or noise level estimation, also known as the 'dB below a Watt' (dBW or SDBW). It uses the same principle as dBm except that the power is expressed over the watt. The dBW relation is next, P being the power:

$$dBW_{(W)} = 10 \text{ Log } P \quad \text{and} \quad P_{(W)} = 10^{(dBW/10)}$$

100 Watts is 20 dBW into 50Ω.

Knowing the power in dBm (see above), it is easy to get its équivalence in dBW, knowing that 30 dB is a power ratio of 1000. For example a signal at -73 dB or S9 is also -103 dBW.

Field Strength ('dB/µV' or 'dB>µV')

At last the power can also qualify the field strength, using the 'dB over microvolt' better known as 'dB over µV/m' (dB/µV). As a given field strength generates different voltage in the antenna at different frequencies, we generally use approximations between common values set by IARU and what you might read on an S-meter, knowing that each S-point is 6 dB:

dBW	dB>µV
- 93 ~ S9+10	44 = S9+10
- 103 ~ S9 = 50 µV	32 = S9
- 109 ~ S8	27 = S8
- 115 ~ S7	21 = S7
- 121 ~ S6	15 = S6
- 127 ~ S5	8 = S5
- 133 ~ S4	2 = S4
- 139 ~ S3	- 3 = S3
- 145 ~ S2	- 8 = S2
- 151 ~ S1	-14 = S1

At left the equivalence between S-points and signal power at receiver (SDBW or dBW) as defined by IARU. At right the field strength scale or 'dB over µV/m', often displayed using the abbreviation 'dB/µV', valid below 30 MHz. It displays the field strength generated by your signal if greater than 1 mV into 50 ohms. For example +32 dB/µV is S9 below 30 MHz or 50 µV, or equivalent to -103 dBW. These units are also commonly used in propagation programs.

These values are often used in propagation programs to provide an easier reading of signal or field strength displayed in prediction charts and other map predicting ionospheric conditions.

There are thus some relations between the antenna voltage (dBm), the field strength (dB/µV) and the wavelength (Ω) to name:

- The antenna voltage: $U_{ant} = 0.132\ E\lambda\ \sqrt{G_{rx}}$

- The receive antenna gain: $G_{rx} = U^2_{ant} / (0.132\ E\lambda)^2$

- The power density: $S = EH = E^2/Z_o$ with $Z_o = 377\Omega$

- The receiving antenna's area: $A = 1.64\ (\lambda^2/4\pi)\ G_{rx}$

Antenna Voltage ('U_{ant}')

One of the most used units is the antenna voltage U_{ant} converted in dBm:

$$U_{ant}/dBm = 45 - 20 \log f\ (Hz) + E/(dB{>}\mu V)$$

This relation is a function of the frequency and the related S-unit and field strength (dB/μV) change thus consequently as follows:

S-Unit	1	3	5	7	9
dBm	-121.0	-109.0	-97.0	-85.0	-73.0
3.5 MHz	-35.1	-23.1	-11.1	0.9	+12.9
7 MHz	-29.1	-17.1	-5.1	6.9	18.9
14 MHz	-23.1	-11.1	0.9	12.9	24.9
21 MHz	-20.6	-8.6	4.4	16.4	28.4
28 MHz	-17.1	-5.1	6.9	18.9	30.9

In addition, the field strength expressed in dB/μV for a receive antenna that yields '0' dBd gain = 2.14 dBi. Noise plays an important role in propagation forecasts. For example, if field strength reaches S9 on 7 MHz, it is 18.9 dB/μV. But if we use an isotropic antenna (gain '0' dBi), this value must be increased by 2.14 dB.