The decibel (dB)

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INTRODUCTION

It is quite common to make mistakes when using values in decibels (*dB*). Even you can see some data sheet using dB when it should have used dBu, dBV… and vice versa. The purpose of this White Paper is introduce in a useful way, the concept and use of the well-known dB to people who is forced to use it, both academic and professional life.

THE DECIBEL (dB)

In the telecommunication world the dB is a very useful and basic measurement unit. It was created in 1928 as a result of telephone companies' various attempts at quantifying the unit of attenuation in telephone lines.

The **Decibel** comes of one-tenth of **Bel** (name comes from *Alexander Graham Bell*).

The decibel (dB) is a logarithmic ratio between two numbers, i.e., it compares a value with other reference value. Decibels are based in relationships thus it is a relative scale. Depending on with which they are related there are: **dB *without suffixes* (dB)** and **dB *with suffixes*** *(dBu, dBV, dBm…)*:

- If it compares output level with input level (which it would be the Equipment Gain) we use **dB without suffixes**.
- If it compares values of volts, watts…with other standardized reference values, we use **dB with suffixes** like: **dBV, dBm, dBu…**These values mean specific values (for example + 4dBu are 1.228 V).

People use the decibel scale more than the linear scale due to its relative ease of expression. In Acoustics, the use of the decibel offers the benefit of approaching to the perception of human ear, which is logarithmic.

THE dB WITHOUT SUFFIXES

The **dB without suffixes** is used when you compare output level related to input level of a device. This relationship is known as **Gain of a device (G)** and is calculated:

$$G_{dB} = 20 \times \log_{10}\left(\frac{Output\ Level}{Input\ Level}\right)$$

- When we have **0dB** we have **unit gain** (the input – output ratio is 1), it's mean we have same output and input value. **The device doesn't modify the signal level.**
- If we have a **negative value in dB**, we know that output level is lower than the level we have at input. **If the result is < 0 the device attenuates the signal.**
- If we have a **positive value in dB,** we know that output level is higher than the level we have at input. **If the result is > 0 the device amplifies the signal.**

THE dB WITH SUFFIXES

We can find dB derivatives like: ***dBu, dBV, dBm, dBW…*** in these cases we are relating a certain amount of volts, watts, etc., with a fixed reference unit. It is used to give specific values of voltage, power…

We have the following formulas:

For change from linear to decibel unit:	For change from decibel to linear unit:	
$dB_{suffix} = 20 \times \log_{10}\left(\frac{Value}{Reference\ Value}\right)$	$0.001 \times 10^{(Valor\ en\ decibelios/20)}$	→ (*) Formula for voltage values or acoustic dB
$dB_{suffix} = 10 \times \log_{10}\left(\frac{Value}{Reference\ Value}\right)$	$0.001 \times 10^{(Valor\ en\ decibelios/10)}$	→ (*) Formula for power levels

It is very important using correctly **10**×$\log_{10}$ and **20**×$\log_{10}$ according to (*). Double is 6 dB when we speak about voltage and 3 dB when we speak about power.

Example with **dBu**, whose reference value is **0.775 V**:

- When we have **0dBu** we have a value which is equal to the reference value, i.e.: **0.775 V.**
- If we have a **negative value in dBu**, we know that the value is **lower than reference value of dBu: < 0.775 V.**
- If we have a **positive value in dBu we know that the value is higher than reference value of dBu: > 0.775 V.**

It applies to all dB with suffixes with their respective reference values.

Below it defines the main derivatives of dB:

dBV	The **dBV** is a measure unit of voltage with a **1 V** reference value. The dBV is commonly used in connection with unbalanced high impedance consumer electronics whose nominal value is -10 dBV.
dBu	It is a measure unit of voltage which has been taken with no concern for circuit impedance but is being referenced to **0.775 V** as though the circuit were 600 Ω (which may or may not be the case). Because the circuit impedance is unknown the actual power is not defined and the measurement is, strictly speaking, not a true dB measurement. It is however very useful.
dBm (z)	It is a measure unit of power referenced to **1 mW**. While the 'z' (often omitted), is the impedance of the circuit measured. When 'z' is omitted it is assumed to be 600 Ω. If 0 dBm is measured across a 600 Ω load (denoted most clearly as "dBm (600 Ω)") we know that 0.001 W is consumed. Then consider: $P = V \times I = \frac{V^2}{R}$

	$$0.001 = \frac{V^2}{600}$$ $$V = \sqrt{0.001 \times 600} = 0.775\ V = 0\ dBu$$ Therefore when 0.775 V is measured in a 600Ω circuit, we have a power of 0 dBm. The dBm can be related to dBV by: dBm = dBV – 2.21
dBW	It is a measure unit of power like dBm but referenced to **1W**. The dBW is generally too large a measure for microphone and line level audio but may be used to quantify the output of a power amplifier. The dBW is related with dBm by: dBW = dBm – 30
dB_{SPL}	It is a measure unit of acoustic sound pressure. Acoustic sound pressure levels (SPL's) measured in dB are commonly referenced to a level of **20×10^{-6} Pa** (Pascal) o **20 µPa**. This is the sound level of the threshold of human hearing. The SPL in decibels is the number of decibels above this threshold. Examples: A **conversation** at 1m distance → **60 dBSPL**, Rock **concert** → **110 dBSPL** y jet **takeoff** at 450 m → **120 dBSPL.** The **minimum threshold** of human hearing is in **0 dBSPL** y **maximum threshold** of pain level is in **130 -140 dBSPL**.
$dB_{A,B,C}$	This logarithmic unit is a **measure of a test signal** which has been passed through (weighted by) a **well-defined filter** prior to the measurement. Unlike the other suffixes the A, B o C does not imply a reference level, only filtering. It is used in acoustic measurements, such as those taken with a sound level meter; the reference level is that of the dB SPL (showed above). The dBA is popular as it approximates the ear's sensitivity to the different octave bands and hence yields a number which represents the approximate human response to the signal. This fact is true at moderate SPL levels; it becomes progressively less applicable as the level increases. The A-weighting filter attenuates signals below 1000 Hz and above 6 KHz. The filters B and C are less common.
dBuv	It is a unit referenced to **1µV** (microvolt).This measure is commonly used to measure receiving antenna RF signals, where it may be shortened to dBu. This may lead to confusion, as dBu in audio signal measurement is referenced to 0.775 V, not 1 µV.

TRANSFORMATIONS OF DECIBELS WITH SUFFIXES

The following table is shown both **formulas** to change from standard unit values to dB and from dB to standard unit value and **one example** of each.

Decibel	Formula	Example:	
dBm → W	[1] **$0.001 \times 10^{(\text{Value in decibels}/10)}$**	Para + 1 dBm	$0.001 \times 10^{(+1/10)} = 1.259 \cdot 10^{-3}$ W
W → dBm	**$10 \times \log_{10}\left(\frac{Value\ in\ watts}{10^{-3} V}\right)$**	Para 0.2 W	$10 \times \log_{10}\left(\frac{0.2\ W}{0.001 W}\right) = 23\ dBm$
dBu → V	[1] **$0.775 \times 10^{(\text{Value in decibels}/20)}$**	Para + 4 dBu	$0.775 \times 10^{(+4/20)} = 1.228$ V
V → dBu	**$20 \times \log_{10}\left(\frac{Value\ in\ volts}{0.775\ V}\right)$**	Para 2 V	$20 \times \log_{10}\left(\frac{2\ V}{0.775\ V}\right) = 8.23\ dBu$
dBV → V	[1] **$1 \times 10^{(\text{Value in decibels}/20)}$**	Para - 10 dBV	$1 \times 10^{(-10/20)} = 0.316$ V
V → dBV	**$20 \times \log_{10}\left(\frac{Value\ in\ volts}{1\ V}\right)$**	Para 5 V	$20 \times \log_{10}\left(\frac{5\ V}{1\ V}\right) = 13.97\ dBV$
dBW → W	[1] **$1 \times 10^{(\text{Value in decibels}/10)}$**	Para - 3 dBW	$1 \times 10^{(-3/10)} = 0.5$ W
W → dBW	**$10 \times \log_{10}\left(\frac{Value\ in\ watts}{1W}\right)$**	Para 3 W	$10 \times \log_{10}\left(\frac{3W}{1W}\right) = 4.77\ dBW$
dBuv → V	[1] **$1 \cdot 10^{-6} \times 10^{(\text{Value in decibels}/20)}$**	Para +2 dBuv	$1 \cdot 10^{-6} \times 10^{(+2/20)} = 1.26 \cdot 10^{-6}$ V
V → dBuv	**$20 \times \log_{10}\left(\frac{Value\ in\ volts}{10^{-6} V}\right)$**	Para $2 \cdot 10^{-6}$ V	$20 \times \log_{10}\left(\frac{0.000002\ V}{0.000001\ V}\right) = 6\ dBuv$
dBSPL → Pa	[1] **$20 \cdot 10^{-6} \times 10^{(\text{Value in decibels}/20)}$**	Para 0 dBSPL	$20 \cdot 10^{-6} \times 10^{(0/20)} = 20$ µPa
Pa → dBSPL	**$20 \times \log_{10}\left(\frac{Value\ in\ Pascals}{20 \cdot 10^{-6}\ Pa}\right)$**	Para 50 µPa	$20 \times \log_{10}\left(\frac{0.00005\ Pa}{0.00002\ Pa}\right) = 7.95\ dB\ SPL$

[1] NOTA:

$\log_{10} a = b \rightarrow 10^b = a$

BASIC OPERATIONS WITH DECIBELS

As it is said before, we can obtain the **device gain using dB** $_{\textbf{without suffixes}}$:

Input Level = 5 V Output Level = 10 V

$$\mathbf{G} = 20 \times \log_{10}\left(\frac{Output\ Level}{Input\ Level}\right) = 20 \times \log_{10}\left(\frac{10\ V}{5\ V}\right) = \mathbf{6.02\ dB}$$

We can see the ratio between output level and level we have in the input. It gives us an idea (positive value) of how this level **has increased.**

If the **level is attenuated** instead of amplified:

Input Level = 10 V Output Level = 5 V

$$\mathbf{G} = 20 \times \log_{10}\left(\frac{Output\ Level}{Input\ Level}\right) = 20 \times \log_{10}\left(\frac{5\ V}{10\ V}\right) = \mathbf{-6.02\ dB}$$

The value is negative, thus the **device attenuates** the input signal.

If instead of lineal units are logarithmic units **using dB** $_{\textbf{with suffixes}}$, calculations are different:

Output Level = +4 dBu Input Level = + 2 dBu

G = Output Level – Input Level = +4 dBu – 2 dBu = **2 dB**

If we know the gain value G = + 3 dB and Input Level = + 5 dBu but we want to know the **output level**:

G = +3 dB Input Level = + 5 dBu

Output Level = Input Level + G = 5dBu + 3 dB = **+ 8 dBu**

You can calculate **input-output ratio** of a device with **'no dB'**:

$$\text{Ratio} = \frac{Voutput\ (V)}{Vinput\ (V)} = \frac{5\ V}{2\ V} = \mathbf{2.5} \left[\frac{V}{V}\right]$$

Or you can calculate in logarithmic units **'dB'**:

Ratio (dB) = V output (dBu) **–** V input (dBu) = **16.2 dBu** [(3)] – **8.23 dBu** [(4)] = **7.9 dB**

[(3)] 16.2 dBu are 5 V converted to dBu (see how is made on page 6).
[(4)] 8.23 dBu are 2 V converted to dBu (see how is made on page 6).

When you divide with 'no dB' you subtract in "dB". In the same way, when you multiply with 'no dB' you add in "dB".

Now if we transform 7.9 dB to 'no dB' it has to give us the same as before:

$$\text{Ratio} = 10^{7.9/20\,(1)} = \mathbf{2.5} \left[\frac{V}{V}\right]$$

[(1)] NOTE:
$\log_{10} a = b \rightarrow 10^b = a$
$dB = 20 \times \log_{10}(\text{ratio}) \rightarrow \frac{dB}{20} = \log_{10}(\text{ratio})$
Ratio = $10^{dB/20}$ (dimensionless)

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