EUROPEAN UNION
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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Electrical quantities and units in electromagnetic compatibility

Study material with examples for the subject KEI/EMC2

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Content

1 Physical quantities and units in general 1

2 Electrical quantities and units 1

3 Electrical quantities and units in electromagnetic compatibility 4

3.1 Units conversion 5

References: 7

Author's note
The notation of physical (electrical) quantities, their values and units is relatively strictly determined by standards, which will be described later in the text. On the other hand, it is good to say that in electric engineering exists an established notation that may be in conflict with standards, but it is good to know them - it is more used than standard notation…

1 Physical quantities and units in general

The notation of a general equation is:

$$f = \{\mathrm{f}\} \cdot [\mathrm{f}],$$

where *f* represents an electrical quantity (the italic font is always used), {f} is number value and [f] is its unit (normal typeface). WARNING! Although it looks like that (see the equation), the unit is always without square brackets – the possibilities will be shown in the following text. The equation is normalized according to ČSN ISO 80000-1 [1].

Example: f = 100 kHz, where $\{\mathrm{f}\}_{\mathrm{kHz}}$ = 100 and [f] = kHz.

A non-breaking space (in MS Office CTRL + Shift + Space) is always use between the number value and the. There exist only two exceptions (in English) – the first one is percentage and the second one is degree and minutes [2].

Example: 12 ° represents 12 degree

NOTE: If the unit is written directly after the value (without space), then it represents an adjective. E.g. 12 ° means twelve-degree (beer), etc.

Units in tables and graphs should always be given below the polyline, in extreme cases in parentheses (). As written above, they should never be in square brackets – here is already encountered the established marking in electrical engineering, where especially in English written texts this is introduced (but in terms of standards is not correct).

Example:

Correct:	Permissible:	Wrong:
$\frac{f}{\mathrm{Hz}}$	*f* (Hz)	*f* [Hz]
50	50	50
…	…	…

2 Electrical quantities and units

The electrical circuit can be described by electrical quantities – by voltage and current at a given point in the circuit. The Ohm's law relates the circuit impedance. The letter marks used in electrical engineering are defined in ČSN EN IEC 60027-2 ed. 2, Část 2: Telekomunikace a elektronika [3],

logarithmic units are defined in the part 3 of this [4]. Especially the standardized form is usually very different from the established form…

The logarithmic units are often used in electrical measurement – then we talking about levels *L*, which can be relative (for example to another node of the circuit) or absolute (for example to the some voltage value).

Relative levels are described by equations:

- for power levels:

$$L_{\mathrm{r}} = 10 \cdot \log \frac{P}{P_0},$$

  where L_r is relative power level in dB, P is value of measured power and P_0 is power value in node 0,

- for voltage levels:

$$L_{\mathrm{rU}} = 20 \cdot \log \frac{U}{U_0},$$

  where L_r is relative voltage level in dB, U is value of measured voltage and U_0 is voltage value in node 0,

- for current levels:

$$L_{\mathrm{rI}} = 20 \cdot \log \frac{I}{I_0},$$

  where L_r is relative current level in dB, I is value of measured current and I_0 is current value in node 0.

Absolute levels are related to a given value, most often to the 1 mW or 1 µW for power levels, 1 V / 1 mV / 1 µV for voltage levels, etc. Then can be written:

- for power levels:

$$L_{\mathrm{P}}(\mathrm{re\ 1\ mW}) = 10 \cdot \log \frac{P}{1\ \mathrm{mW}},$$

  where L_P (re 1 mW) is absolute power level related to the 1 mW (decibel over the miliwatt for positive values, decibel under miliwatt for negative values), P is value of measured power P_0 ,

- for voltage levels:

$$L_{\mathrm{U}}(\mathrm{re\ 1\ \mu V}) = 20 \cdot \log \frac{U}{1\ \mu\mathrm{V}},$$

  where L_U (re 1 µV) is absolute voltage level related to the 1 µV (decibel over the microvolt for positive values, decibel under microvolt for negative values), U is value of measured voltage,

- for current levels:

$$L_{\mathrm{I}}(\mathrm{re}\ 1\ \mu\mathrm{A}) = 20 \cdot \log \frac{U}{1\ \mu\mathrm{A}},$$

where L_{I} (re 1 µA) is absolute current level related to the 1 µA (decibel over the microamp for positive values, decibel under microamp for negative values), I is value of measured current.

See the notation related to the level, e.g. L_{U} (re 1 µV). This is normalized notation and there follows: L_{U} (re 1 µV) = 6 dB.

The next normalized notation according to the standard is: $L_{\mathrm{U/1\ \mu V}}$ = 6 dB.

If the value of the level after "re" or a slash is equals to 1, then this one can be omitted.

Furthermore, the note of the standard states the notation for practical use: L_{U} = 6 dB (1 µV).

The units in the tables and graphs should again be shown below the curve.

Example:

Correct:	Permissible:	Wrong:
$\frac{L_{\mathrm{U}}\ (\mathrm{re}\ 1\ \mu\mathrm{V})}{\mathrm{dB}}$	L_{U} (dB (µV)) or $\frac{L_{\mathrm{U}}}{\mathrm{dB}\ (\mu\mathrm{V})}$	L_{U} [dBµV]
50	50	50
…	…	…

The established units in electrical engineering use simple form (and non-normalized…):

- dBm – power level related to the 1 mW,
- dBµV – voltage level related to the 1 µV,
- dB µA – current level related to the 1 µA,
- dBµV/m – E-field level related to the 1 µV/m,
- dBµA/m – H-field level related to the 1 µA/m, etc.

All levels are marked by *L*.

There can be find also gain G and losses A. The relationship between them is: G (dB) = -A (dB).

Example: measured level is equals to *L* = *G* = -34 dBm. Losses *A* then equals to *A* = -*G* = 34 dBm.

3 Electrical quantities and units in electromagnetic compatibility

Voltage / current / E or H-filed related units are most often used for measurements in electromagnetic compatibility, for example 1 µV, 1 µV/m, 1 µA, 1 µA/m. The established unit form will be used in the next text – dBµV (even though we know that dB (µV) is correct), etc. Usually we are not talking about levels, but about voltage, field strength, currents, magnetic field strength.

Then we can write:

- for measured voltage:

$$U = 20 \cdot \log \frac{U_{meas}}{1\ \mu\mathrm{V}} \quad (\mathrm{dB\mu V}),$$

- for measured current:

$$I = 20 \cdot \log \frac{I_{meas}}{1\ \mu\mathrm{A}} \quad (\mathrm{dB\mu A}),$$

- for measured E-field:

$$E = 20 \cdot \log \frac{E_{meas}}{1\ \mu\mathrm{V/m}} \quad (\mathrm{dB\mu V/m}),$$

- for measured H-field:

$$H = 20 \cdot \log \frac{H_{meas}}{1\ \mu\mathrm{A/m}} \quad (\mathrm{dB\mu A/m}),$$

- for measured power:

$$P = 10 \cdot \log \frac{P_{meas}}{1\ \mathrm{mW}} \quad (\mathrm{dBm}).$$

The measurement is always performed for the reference impedance Z = 50 Ω.

For measured values (for example dBm, realted to 1 mW) we can say that:

- if the measured value is positive, then the power is greater than 1 mW,
- if the measured value is negative, then the power is lower than 1 mW.

The power level -3 dB mean a decrease to the half power; 3 dB means double power respectively.

One half of the voltage corresponds to the level -6 dB; twice voltage to 6 dB. A corner frequency for filters is given by a decrease of 3 dB and then the voltage level is 0,707x U_0.

The conversion table can be found at the end of this document.

3.1 Units conversion

The spectrum analyser usually measure the level in dBm, the re-calculation to the different unit (dBμV) is often necessary.

We start from the general equation for power: $P = U \cdot I = \frac{U^2}{Z}$.

Example: Convert the power *P* = 0 dBm to voltage *U* (V) a *U* (dBμV).

Solution: The definition of reference impedance is the first step. The reference impedance is equals to 50 Ω for EMC measurement.

Then can be calculated: $0 = 10 \cdot \log \frac{P}{1\ \mathrm{mW}} \rightarrow P = 1\ \mathrm{mW}$,

$U = \sqrt{P \cdot Z} = \sqrt{1e-3 \cdot 50} = 0{,}22361\ \mathrm{V}$ a $U = 20 \cdot \log \frac{0{,}22361}{1\ \mu\mathrm{V}} = 106{,}9897\ \mathrm{dB\mu V}$.

i.e. 0 dBm ≈ 107 dBμV.

The general form for conversion is: U (dBμV) ≈ P (dBm) + 107

The conversion between voltage and current levels is the next important conversion in EMC (for measurement with current probe) – the limits in standards are usually defined for voltage level and then must be converted to the current.

Example: Convert the value of the limit 76 dBμV to value in dBμA.

Solution: Substitute into a known equation: $76 = 20 \cdot \log \frac{U_{meas}}{1\ \mu\mathrm{V}}$ and edit it: $\frac{76}{20} = \log \frac{U_{meas}}{1\ \mu\mathrm{V}}$ and edit it again: $10^{\frac{76}{20}} = \frac{U_{meas}}{1\ \mu\mathrm{V}} \rightarrow U_{meas} = 1\mu \cdot 10^{\frac{76}{20}} = 6{,}31\ \mathrm{mV}$

We know that $I = \frac{U}{Z} = \frac{6{,}31\ \mathrm{mV}}{50\ \Omega}$ = 126 mA and the current is:

$I = 20 \cdot \log \frac{126\ \mathrm{mA}}{1\ \mu\mathrm{A}} = 42{,}02\ \mathrm{dB\mu A}$.

i.e. 76 dBμV ≈ 42 dBμA.

In generally – 0 dBμV corresponds to the voltage 1 μV at the impedance 50 Ω and the current is: $I = \frac{U}{Z} = \frac{1\ \mu\mathrm{V}}{50\ \Omega} = 20\ \mathrm{nA}$. $I = 20 \cdot \log \frac{20\ \mathrm{nA}}{1\ \mu\mathrm{A}} = -33{,}979\ \mathrm{dB\mu A}$.

The general form for conversion is: I (dBμA) ≈ U (dBμV) – 34

Levels conversion table:

L (-)	L_P (dB)	$L_{V/I/E/H}$ (dB)
0,00001	-50	-100
0,0001	-40	-80
0,001	-30	-60
0,01	-20	-40
0,1	-10	-20
0,5	-3	-6
1	0	0
2	3	6
10	10	20
100	20	40
1000	30	60
10000	40	80
100000	50	100

References:

[1] ČSN ISO 80000-1: Veličiny a jednotky - Část 1: Obecně. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví. Praha, 2011.

[2] ČSN 01 6910: Úprava dokumentů zpracovaných textovými procesory. Úřad pro technickou normalizaci, metrologii a státní zkušebnictví, Praha, 2014.

[3] ČSN EN IEC 60027-2 ed. 2: Písmenné značky používané v elektrotechnice - Část 2: Telekomunikace a elektronika. Česká agentura peo standardizaci, Praha, 2019.

[4] ČSN EN IEC 60027-3: Písmenné značky používané v elektrotechnice - Část 3: Logaritmické a knim se vztahující veličiny a jejich hednotky. Český normalizační institut, Praha, 2004.