Decibel & S-Readings

Serge Stroobandt, ON4AA

Base-10 logarithms: $\log_{10} x$

$\log_{10} x = \ldots$ means: *"To what power do I need to raise 10, in order to obtain x?"*

$$\log_{10} x = y \quad \Leftrightarrow \quad 10^y = x \tag{1}$$

dB as a power ratio

The decibel (dB) is a logarithmic unit used to express the ratio of two values of a physical quantity.[1] For power ratios the decibel unit is defined as follows:

$$L_{dB} = 10 \cdot \log_{10} \frac{P_{out}}{P_{in}} \tag{2}$$

dB as a field amplitude ratio

For intensity ratios the decibel unit is defined as follows:

$$G_{dB} = 20 \cdot \log_{10} \frac{A_{out}}{A_{in}} \tag{3}$$

Decibel conversion table

Table 1: Mnemonic decibel conversion table

dB	$\frac{P_{out}}{P_{in}}$	$\frac{A_{out}}{A_{in}}$
40	10000	100
30	1000	≈31.62
20	100	10
10	10	≈3.162
6	≈ 4	≈ 2
3	≈ 2	$\approx \sqrt{2} \approx 1.414$
1	≈ 1.25	≈ 1.125

dB	$\frac{P_{out}}{P_{in}}$	$\frac{A_{out}}{A_{in}}$
0	1	1
-1	≈0.8	≈0.9
-3	$\approx \frac{1}{2} = 0.5$	$\approx \frac{1}{\sqrt{2}} \approx 0.707$
-6	$\approx \frac{1}{4} = 0.25$	$\approx \frac{1}{2} = 0.5$
-10	0.1	≈0.3162
-20	0.01	0.1
-30	0.001	≈0.03162
-40	0.0001	0.01

dBm as a power level

dBm is a logarithmic unit of power level, expressed in decibel (dB) and referenced to a power level of one milliwatt (mW).[2]

Table 2: dBm as a power level

dBm	P_{out}	typical for
60	1kW	typical radiated RF power of a microwave oven
50	100W	typical maximum output RF power from a ham radio HF transceiver
40	10W	
37	≈ 5W	typical maximum output RF power from a handheld ham radio VHF/UHF transceiver
33	≈ 2W	maximum output from a GSM 850/900 mobile phone
30	1W	DCS or GSM 1 800/1 900 MHz mobile phone
20	100mW	EIRP for a IEEE 802.11b/g 20 MHz-wide channel in the 2.4 GHz ISM band (5 mW/MHz)
10	10mW	
0	1mW	Bluetooth class 3 radio with 1 m range
-10	100µW	IEEE 802.11 maximal signal strength
-60	1nW	power received per m^2 of a magnitude +3.5 star
-73	≈ 50pW	S9 signal strength on S-meter
-100	100fW	IEEE 802.11b/g minimal signal strength
-101	≈ 83fW	noise floor of a IEEE 802.11b/g 20 MHz channel at 300 K
-134	≈ 41aW	noise floor of a 10 kHz wide FM signal at 300 K
-140	≈ 12aW	noise floor of a 2.7 kHz wide SSB signal at 300 K

In this table, the term noise floor refers to the calculated thermal noise, also known as the Johnson–Nyquist noise.[3]

HF S-meter

Many amateur radio and shortwave broadcast receivers feature a signal strength meter (S-meter).[4] In 1981, the International Amateur Radio Union (IARU) Region 1 agreed on a technical recommendation for S-meter calibration of HF and VHF/UHF transceivers.[5,6]

IARU Region 1 Technical Recommendation R.1 defines S9 for the HF bands to be a receiver input power of -73 dBm. This is a level of 50 µV at the receiver's antenna input assuming the input impedance of the receiver is 50 Ω.

The recommendation defines a difference of one S-unit corresponds to a difference of 6 dB, equivalent to a voltage ratio of two, or a power ratio of four. Signals stronger than S9 are given with an additional dB rating, thus "S9 + 20 dB", or, verbally, "20 decibel over S9", or simply "20 over 9" or even the simpler "20 over."

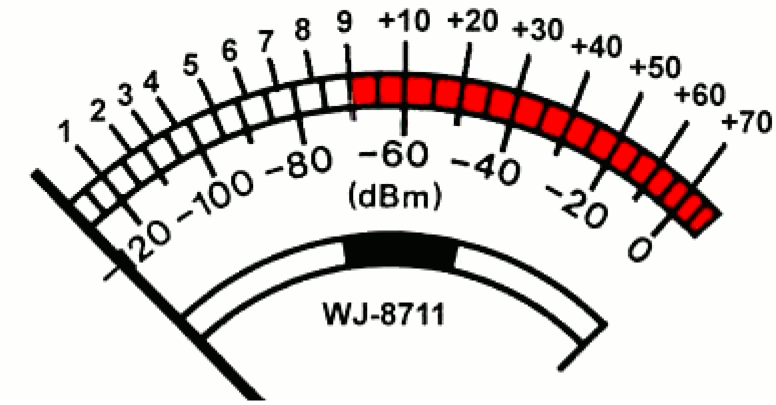

Figure 1: Well-designed S-meter on the DRS WJ-8711A HF transceiver. *Source:* N9EWO

Table 3: Conversion between power and HF S-units

S-reading	P_{out} @50Ω	V_{out} @50Ω	$\frac{V_{out}}{[1\,\mu V]}$ @50Ω
S9 + 40 dB	-33 dBm	5.0 mV	74 dBμV
S9 + 30 dB	-43 dBm	1.6 mV	64 dBμV
S9 + 20 dB	-53 dBm	0.50 mV	54 dBμV
S9 + 10 dB	-63 dBm	0.16 mV	44 dBμV
S9	-73 dBm	50 μV	34 dBμV
S8	-79 dBm	25 μV	28 dBμV
S7	-85 dBm	12.6 μV	22 dBμV
S6	-91 dBm	6.3 μV	16 dBμV
S5	-97 dBm	3.2 μV	10 dBμV
S4	-103 dBm	1.6 μV	4 dBμV
S3	-109 dBm	800 nV	-2 dBμV
S2	-115 dBm	400 nV	-8 dBμV
S1	-121 dBm	200 nV	-14 dBμV

The noise floor for a $B = 2700$ Hz wide SSB signal at $T = 300$ K is:[3]

$$P = k_B \cdot T \cdot B = k_B \cdot 300 \cdot 2700 = 11.8 \cdot 10^{-18}\,\mathrm{W} = 11.8\mathrm{aW} = -139.5\,\mathrm{dBm}$$

where $k_B = 1.3806488 \cdot 10^{-23}\,\mathrm{J/K}$ is Boltzmann's constant.

VHF/UHF S-meter

The same IARU Region 1 recommendation defines S9 for VHF/UHF to be a receiver input power of -93 dBm. This is the equivalent of 5 μV in 50 Ω. Again, one S-unit corresponds to a difference of 6 dB, equivalent to a voltage ratio of two, or a power ratio of four.

Table 4: Conversion between power and VHF/UHF S-units

S-reading	P_{out} @50Ω	V_{out} @50Ω	$\frac{V_{out}}{[1\,\mu V]}$ @50Ω
S9 + 40 dB	-53 dBm	0.50 mV	54 dBµV
S9 + 30 dB	-63 dBm	0.16 mV	44 dBµV
S9 + 20 dB	-73 dBm	50 µV	34 dBµV
S9 + 10 dB	-83 dBm	16 µV	24 dBµV
S9	-93 dBm	5.0 µV	14 dBµV
S8	-99 dBm	2.5 µV	8 dBµV
S7	-105 dBm	1.26 µV	2 dBµV
S6	-111 dBm	630 nV	-4 dBµV
S5	-117 dBm	320 nV	-10 dBµV
S4	-123 dBm	160 nV	-16 dBµV
S3	-129 dBm	80 nV	-22 dBµV
S2	-135 dBm	40 nV	-28 dBµV
S1	-141 dBm	20 nV	-34 dBµV

The noise floor for a 10 kHz wide FM signal at 300 K is:[3]

$$P = k_B \cdot T \cdot B = k_B \cdot 300 \cdot 10^4 = 41 \cdot 10^{-18}\,\mathrm{W} = 41\mathrm{aW} = -134\,\mathrm{dBm}$$

where $k_B = 1.3806488 \cdot 10^{-23}\,\mathrm{J/K}$ is Boltzmann's constant.

References

1. Wikipedia. Decibel. https://en.wikipedia.org/wiki/Decibel

2. Wikipedia. dBm. https://en.wikipedia.org/wiki/dBm

3. Wikipedia. Johnson–Nyquist noise. https://en.wikipedia.org/wiki/Johnson–Nyquist_noise

4. Wikipedia. S meter. https://en.wikipedia.org/wiki/S_meter

5. *IARU Region 1 Technical Recommendation R.1*. International Amateur Radio Union Region I; 1981. http://hamwaves.com/decibel/doc/iaru.region.1.s-meter.pdf

6. Ulrich Mueller, DK4VW. *IARU Region 1 HF Manager Handbook v8.1*. IARU; 1994. http://www.iaru-r1.org/index.php/downloads/Documents/HF/IARU-Region-1-HF-Manager-Handbook-V.8.1/