Tech Note - Theory - 14 Ding Dong Bel

What is a dB (decibel)? It is one tenth(1/10) of a Bel. It is not an absolute value, but a ratio of two values of sound, power, voltage, or current.

The number of decibels (dB's) is expressed as ten times the logarithm (to the base ten), of the power ratio. It is commonly used for expressing transmission gains or losses and levels.

Mathematically it is expressed as: $\text{Bel} = \text{Log}_{10}\frac{P_1}{P_2}$ or $\text{Bel} = 2\ \text{Log}_{10}\frac{E_1}{E_2}$

It is a non linear function and is the same as the non linear response of the human ear. Since the decibel is 1/10 of a Bel the formula now becomes

$\text{dB} = 10\ \text{Log}_{10}\frac{P_1}{P_2}$ or $\text{dB} = 20\ \text{Log}_{10}\frac{E_1}{E_2}$.

The human ear is very ingenious in that it resembles a variable amplifier to some extent. It is more sensitive to soft sounds of air escaping through a slow leak in an automobile tire while at the same time limit the terrific roar of a jet engine, to a tolerable limit. Nature enabled the human ear to hear sound intensities at a logarithmic rate and thus ensure our survival and protection. Just imagine our ancestors creeping around in the tall grass trying to get within spear range of that buck. They had no problem hearing the herd move about but it was also vital that they could detect the soft padding of the Lion that may also have been lurking in the tall grass looking for a quick meal!

The louder the sound gets the less sensitive is the human ear to that sound. The variation in sound intensity between the dropping of a pin and the car out in the street honking the horn is many millions of times. If suddenly the human ear were to respond linearly or in exact proportion to the sound of the horn it is very doubtful the human ear could survive the blast.

Electrical energy can be expressed and measured in several ways, such as watts or volts. The volt is the unit of electrical pressure and the watt the unit of electrical power. However in communications and amateur radio we use microphones, speakers, headphones etc., and the microphone converts the sound energy to electrical energy (it is a transducer) the intensity of the sound waves is expressed in dB's.

This is proportionate to the logarithm of a voltage or power ratio, which represents the acoustic properties of our hearing ability.

The Unit is the Bel and it is named in honor of Mr. Alexander Graham Bell, who pioneered the discovery about the previously described peculiarity of the human ear. Before he became a great inventor, for which he is best remembered, he was a renowned teach of the deaf.

The audible range of sound is so great we can more conveniently express ourselves with a smaller measuring scale. Thus we use the decibel(dB) scale the correct spelling of the abbreviation is dB, no period. The dB, or one tenth of a Bel, is a relative value (ratio). You are comparing one level with another level and it is not an absolute value like voltage or watts.

Because of the mathematics involved, this is probably the most misunderstood and misused term, after VSWR in amateur radio or hamdom.

This points out the need for a definition. The "Bel" is the international transmission unit used in Landline cable, Studio Recording, Sound Anti Noise Bylaws, Industrial noise level regulations etc. The Bel is much too large a unit for radio communications, so we use the dB which is 1/10 of a Bel.

The power equation is $\text{Bel} = 1\ \text{Log}_{10}\frac{P_1}{P_2}$. Since Power is $\frac{E^2}{R}$, we can rewrite this as $\text{Bel} = \text{Log}_{10}\frac{\frac{E_1^2}{R_1}}{\frac{E_2^2}{R_2}}$.

However, since R_1=R_2, this can now be stated as $\text{Bel} = \text{Log}_{10}\frac{E_1^2}{E_2^2}$ which is the same as

$\text{Bel} = \text{Log}_{10}\left(\frac{E_1}{E_2}\right)^2$ which can be stated as $\text{Bel} = 2\text{Log}_{10}\frac{E_1}{E_2}$

$\therefore\ \text{dB} = 20\text{Log}_{10}\frac{E_1}{E_2}$.

The previous is a short mathematical explanation of the difference between the formulas for power and voltage.

Unfortunately we must have an understanding of the formulas used in determining dB levels before we can take full advantage of the short cuts included in this Tech note.

$\text{Bel} = \text{Log}_{10}\frac{P_1}{P_2}$ converts to $\text{dB} = 10\text{Log}_{10}\frac{P_1}{P_2}$ applies to sound levels and power levels.

Also, $\text{Bel} = 2\text{Log}_{10}\frac{E_1}{E_2}$ or $\text{Bel} = 2\text{Log}_{10}\frac{I_1}{I_2}$. So why the difference with voltage and current as opposed to power? Please stand by and we will walk you through basic ohms law again by having you study Appendix A at the end of the tech note.

The average amateur can learn to do calculations without resorting to pencil and paper or calculator by using four simple rules of thumb that were developed from careful study of the decibel tables.

POWER RATIOS

1	The point at which the human ear detects a change of sound either an increase or decrease is the one dB point. Note that this is not an absolute value, it may vary from person to person or ear to ear, however the ratio is still one dB. And this amounts to a change of 25% for an increase or minus 20% for a decrease. Remember the change is logarithmic not linear.
2	The point at which there is a 100% increase or decrease. Multiplied or divided by 2 is the 3dB point
3	The point at which there is a tenfold increase or decrease. Multiplied or divided by 10 is the 10 dB point.
4	The point at which there is a fourfold increase or decrease. Multiplied or diviede by 4 is the 6 dB point.

Here are three examples.

Example #1: A: increase 20 watts by 1dB (20 times 1.25=25 watts), B: increase 20 watts by 3dB (20 times 2=40 watts), and C: increase 20 watts by 10 dB (20 times 10=200 watts).

Example #2: reduce 200 watts by 10 dB or 200 divided by 10=20 watts. Lets do it the long way just to prove rule #2 and #1:

Decrease 3 dB, 200 divided by 2=100 watts
Decrease 3 dB, 100 divided by 2=50 watts
Decrease 3 dB, 50 divided by 2=25 watts
Decrease 1 dB, 25 multiplied by 0.8=20 watts
Total 10 dB, loss

Lets play with the 1 dB rule #1 and increase 10 watts by 3 dB

Increase 1 dB, 10 multiplied by 1.25=12.5 watts
Increase 1 dB, 12.5 multiplied by 1.25=15.625 watts
Increase 1 dB, 15.625 multiplied by 1.25=19.53 watts
Total 3 dB, increase or 19.53 watts (close enough to call 20 watts).

Example #3: Now for a practical example. Suppose, we already own a two metre hand held radio, but would like to have a base station with some punch. Investigating we find the prices are prohibitive for our budget, but at a flea market we come across an amplifier going for peanuts. The seller says you can drive it with your handheld (which has 5 watts output) and the amplifier has 16 dB gain. We very quickly determine this is going to give us the punch we are after. How? Well using rule #3, we arrive at 50 watts and using rule #2 twice we arrive at a total of 16 dB for an output of 200 watts. Great now we have to find a 25 amp. power supply to go with the amplifier. A little knowledge can be dangerous.

Another practical example: again at a flea market we purchase a 2 metre beam which is rated at 12 dB forward gain. We do this because at our home station we are using cable with a fairly long run and we know it has a loss of 5 dB. To buy a length of hardline to replace it would be too much, so here we go. Subtracting the loss of 5dB in the cable from the antenna 12 dB gain we are still left with a system gain of 7 dB. What is this going to do for our 25 watt base station? Now lets get into Rule #4.

Rule #4: says a 6 dB change will provide you with an increase factor of 4 or a decrease by 400%. That is to say if we loose 6dB we will be left with ¼ of our original level.

Now, applying this to our situation, 25 watts increased by a factor of 4 (4 times 25) is 100 watts. Don't you just love these dB's? Now we apply rule #1 to get the 7 dB increase and we end up with an ERP of 125 watts.

This same antenna is rated with a front to back ratio of 23 dB, how much power is going to be radiated off the back of the antenna?

10 dB, loss at 25 watts=2.5 watts
10 dB, loss at 2.5 watts=0.25 watts
3 dB, loss at 0.25 watts=0.125 watts
Total 23 dB, loss resulting in a radiation off the back of the antenna of 125 milliwatts.

We have a 100 foot length of RG8X cable which has an attenuation of 4 dB on the 2 metre band. What power ratio does this represent?

Example: We have a Yagi antenna with 10 dB of forward gain, we are using cable with two pieces of cable spliced together with a PL258 series connector. This gives a total of 4 PL259 connectors in the line. The cable loss is 4 dB and the connector losses are 0.5 dB each. What is the system gain and what will the ERP be with the 25 watt base station?

A typical ham station is made up of a 100 watt transceiver with a sixty foot tower from which is supported a multi band inverted V antenna. The owner of this station would like to up grade its performance and he has two routes to reach his goal.

A.) He can purchase a Linear amplifier which has 600 watts output and costs **$2000**

B.) He can purchase a Tri-band Yagi Antenna which has 7dB forward gain and 27 dB front to back ratio for a cost of **$600**.

Lets examine this situation closely from the dB point of view and see if we can help Mr. Ham come to a conclusion. First what is the gain of the amplifier? Second, what is the dollars per watt figure. Next, What will the ERP from this Yagi antenna be with Mr. Ham's 100 watt transceiver? What will the dollars per watt figure be? Lastly what will things look like off the back of the antenna?

Now that you are an expert in solving dB problems in transmitters and cables we are going to introduce you to a new ball game called voltage levels. This is where we make use of the formula, $dB = 20 Log_{10} \frac{E_1}{E_2}$. Here, also, three simple rules of thumb were developed. While the average ham won't be dealing with voltage levels as often as he does with power and cable loss etc. None the less, he should be familiar with the process so as to be able to evaluate the performance of his receiver, preamps,VSWR meter, microphones or any other device that is voltage sensitive.

VOLTAGE & CURRENT RATIOS

1	the one dB point will produce an increase of 13% or a decrease of 11%. Typically we use 10% in both directions for this rule because the error introduced is negligible and the simplification is worth it.
2	the 6 dB point will produce a doubling or halving of the voltage level, +dB or - dB, respectively
3	the 20 dB point results in a factor of 10, multiplied or divided by 10, +dB or -dB, respectively
4	the 3 dB point results in a factor of 3, multiplied or divided by 3, +dB or -dB, respectively

These three rules of thumb are to be used with voltage and current levels only! Do not confuse them with those used for power.

Since practice makes perfect, lets run through a few examples and become semi-expert in the application of dB's with respect to voltage levels!

Example #1: The typical HF transceiver or receiver has what is known as an "S meter". This is what is used to determine and give signal reports to other hams. The standard that is used throughout the communications industry for HF is "S 9 is equal to 50 micro volts,(v.)" and each "S" unit below that is equivalent to minus 6 dB. The questions are what is each "S" unit's equivalent micro volt level and what is each 20 dB over "S" nine equivalent in micro volts?

Example #2: When a 100 watt transmitter is loaded into a dipole antenna that is resonant, we will find 80 volts of RF present in the dipole every time we hold down the key. Your friend in Moncton has just given you a signal report of S 9 + 10 dB . How many volts does that represent in his antenna and how many dB's was the signal attenuated in reaching his antenna?

Time for Rule #4 (regarding voltages and currents): a 10 dB increase or decrease results in a factor of three or +10 dB is 3 times as great and minus 10 dB is 1/3 as great.

Example #3: A preamp. for a VHF receiver has a gain of 12 dB. To what level will this improve your receiver if it already has a 12 dB sinad of 0.5 micro volts? This preamp. has a noise figure of 0.5 db and cost **$90**. At another table there is one for sale for **$40** and it has a gain of 20 dB and a noise figure of 4 dB. Which is the better preamp. and why?

Example #4: Your receiver has a sensitivity of 0.5 microvolts for a 12 dB sinad rating. If you attach it to an antenna that has a forward gain of 12 dB what will be the 12 dB sinad rating in microvolts with that antenna attached?

The above examples should indicate how dB's apply to voltage levels and how to use them. It will not take much practice to become quite good at determining the results using the simple rules of thumb, and in the process appear to be a mathematical genius to the uninitiated.

Appendix A - Voltage & Current Bel Equation Derivations

A. Derivation of the "BEL" equation for "VOLTAGE" from the "BEL" equation for "POWER".

1. "POWER" equation
   $BEL=1 \, LOG \, P_1 / P_2$ (1)
2. Since "POWER" equals E^2 / R, equation (1) can be written
   $BEL=1 \, LOG \, (E_1^2 / R_1) / (E_2^2 / R_2)$ (2)
3. Since R_1 equals R_2, equation (2) can be written
   $BEL=1 \, LOG \, E_1^2 / E_2^2$ (3)
4. By the laws of mathematics, equation (3) is equal to
   $BEL=1 \, LOG \, (E_1 / E_2)^2$ (4)
5. Also, by the laws of mathematics, equation 4 is equal to
   $BEL=2 \, LOG \, E_1 / E_2$
   which is the equation for "VOLTAGE" when the input and output impedances are equal.

B. Derivation of the "BEL" equation for "CURRENT" from the "BEL" equation for "POWER".

1. "POWER" equation:
   $BEL=1 \, LOG \, P_1 / P_2$ (1)
2. Since "POWER" equals E^2 / R and $E^2=(I R)^2$, equation (1) can be written:
   $BEL=1 \, LOG \, ((I_1 R_1)^2 / R_1) / ((I_2 R_2)^2 / R_2)$ (2)
3. Since R_1 equalsR_2, equation (2) can be written:
   $BEL=1 \, LOG \, I_1^2 / I_2^2$ (3)
4. By the laws of mathematics, equation (3) is equal to:
   $BEL=1 \, LOG \, (I_1 / I_2)^2$ (4)
5. Also, by the laws of mathematics, equation (4) is equal to:
   $BEL=2 \, LOG \, I_1 / I_2$
   which is the equation for "CURRENT" when the input and output impedances are equal.

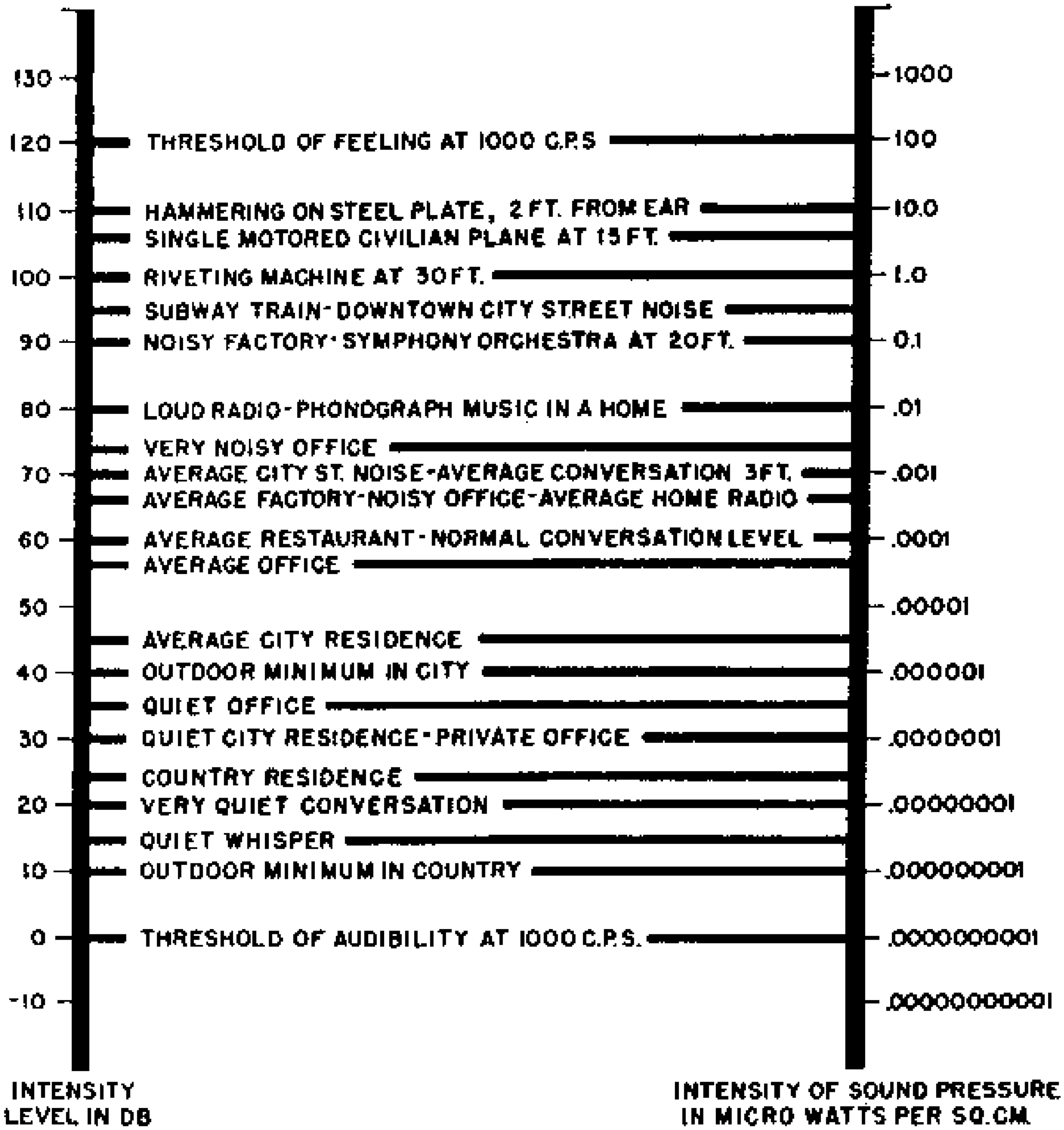
Appendix B - Table of Decibel equivalents to E, I, and P ratios

Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio	Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio
1.0000	1.0000	0.0	1.000	1.000	0.4898	0.2399	6.2	2.042	4.169
0.9886	0.9772	0.1	1.012	1.023	0.4842	0.2344	6.3	2.065	4.266
0.9772	0.9550	0.2	1.023	1.047	0.4786	0.2291	6.4	2.089	4.365

Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio	Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio
0.9661	0.9333	0.3	1.035	1.072	0.4732	0.2239	6.5	2.113	4.467
0.9550	0.9120	0.4	1.047	1.096	0.4677	0.2188	6.6	2.138	4.571
0.9441	0.8913	0.5	1.059	1.122	0.4624	0.2138	6.7	2.163	4.677
0.9333	0.8710	0.6	1.072	1.148	0.4571	0.2089	6.8	2.188	4.786
0.9226	0.8511	0.7	1.084	1.175	0.4519	0.2042	6.9	2.213	4.898
0.9120	0.8318	0.8	1.096	1.202	0.4467	0.1995	7.0	2.239	5.012
0.9016	0.8128	0.9	1.109	1.230	0.4416	0.1950	7.1	2.265	5.129
0.8913	0.7943	1.0	1.122	1.259	0.4365	0.1905	7.2	2.291	5.248
0.8810	0.7762	1.1	1.135	1.288	0.4315	0.1862	7.3	2.317	5.370
0.8710	0.7586	1.2	1.148	1.318	0.4266	0.1820	7.4	2.344	5.495
0.8610	0.7413	1.3	1.161	1.349	0.4217	0.1778	7.5	2.371	5.623
0.8511	0.7244	1.4	1.175	1.380	0.4169	0.1738	7.6	2.399	5.754
0.8414	0.7079	1.5	1.189	1.413	0.4121	0.1698	7.7	2.427	5.888
0.8318	0.6918	1.6	1.202	1.445	0.4074	0.1660	7.8	2.455	6.026
0.8222	0.6761	1.7	1.216	1.479	0.4027	0.1622	7.9	2.483	6.166
0.8128	0.6607	1.8	1.230	1.514	0.3981	0.1585	8.0	2.512	6.310
0.8035	0.6457	1.9	1.245	1.549	0.3936	0.1549	8.1	2.541	6.457
0.7943	0.6310	2.0	1.259	1.585	0.3890	0.1514	8.2	2.570	6.607
0.7852	0.6166	2.1	1.274	1.622	0.3846	0.1479	8.3	2.600	6.761
0.7762	0.6026	2.2	1.288	1.660	0.3802	0.1445	8.4	2.630	6.918
0.7674	0.5888	2.3	1.303	1.698	0.3758	0.1413	8.5	2.661	7.079
0.7586	0.5754	2.4	1.318	1.738	0.3715	0.1380	8.6	2.692	7.244
0.7499	0.5623	2.5	1.334	1.778	0.3673	0.1349	8.7	2.723	7.413
0.7413	0.5495	2.6	1.349	1.820	0.3631	0.1318	8.8	2.754	7.586
0.7328	0.5370	2.7	1.365	1.862	0.3589	0.1288	8.9	2.786	7.762
0.7244	0.5248	2.8	1.380	1.905	0.3548	0.1259	9.0	2.818	7.943
0.7161	0.5129	2.9	1.396	1.950	0.3508	0.1230	9.1	2.851	8.128
0.7079	0.5012	3.0	1.413	1.995	0.3467	0.1202	9.2	2.884	8.318
0.6998	0.4898	3.1	1.429	2.042	0.3428	0.1175	9.3	2.917	8.511
0.6918	0.4786	3.2	1.445	2.089	0.3388	0.1148	9.4	2.951	8.710
0.6839	0.4677	3.3	1.462	2.138	0.3350	0.1122	9.5	2.985	8.913
0.6761	0.4571	3.4	1.479	2.188	0.3311	0.1096	9.6	3.020	9.120
0.6683	0.4467	3.5	1.496	2.239	0.3273	0.1072	9.7	3.055	9.333
0.6607	0.4365	3.6	1.514	2.291	0.3236	0.1047	9.8	3.090	9.550
0.6531	0.4266	3.7	1.531	2.344	0.3199	0.1023	9.9	3.126	9.772
0.6457	0.4169	3.8	1.549	2.399	0.3162	0.1000	10.0	3.162	10.000
0.6383	0.4074	3.9	1.567	2.455	0.2985	0.08913	10.5	3.350	11.22
0.6310	0.3981	4.0	1.585	2.512	0.2818	0.07943	11.0	3.548	12.59
0.6237	0.3890	4.1	1.603	2.570	0.2661	0.07079	11.5	3.758	14.13
0.6166	0.3802	4.2	1.622	2.630	0.2512	0.06310	12.0	3.981	15.85
0.6095	0.3715	4.3	1.641	2.692	0.2371	0.05623	12.5	4.217	17.78
0.6026	0.3631	4.4	1.660	2.754	0.2239	0.05012	13.0	4.467	19.95
0.5957	0.3548	4.5	1.679	2.818	0.2113	0.04467	13.5	4.732	22.39

Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio	Voltage Current Ratio	- Power Ratio	Db	Voltage Current Ratio	+ Power Ratio
0.5888	0.3467	4.6	1.698	2.884	0.1995	0.03981	14.0	5.012	25.12
0.5821	0.3388	4.7	1.718	2.951	0.1884	0.03548	14.5	5.309	28.18
0.5754	0.3311	4.8	1.738	3.020	0.1778	0.03162	15.0	5.623	31.62
0.5689	0.3236	4.9	1.758	3.090	0.1585	0.02512	16.0	6.310	39.81
0.5623	0.3162	5.0	1.778	3.162	0.1413	0.01995	17.0	7.079	50.12
0.5559	0.3090	5.1	1.799	3.236	0.1259	0.01585	18.0	7.943	63.10
0.5495	0.3020	5.2	1.820	3.311	0.1122	0.01259	19.0	8.913	79.43
0.5433	0.2951	5.3	1.841	3.388	0.1000	0.01000	20.0	10.000	100.00
0.5370	0.2884	5.4	1.862	3.467	0.03162	0.00100	30.0	31.620	1,000.00
0.5309	0.2818	5.5	1.884	3.548	0.01	0.00010	40.0	100.00	10,000.00
0.5248	0.2754	5.6	1.905	3.631	0.003162	0.00001	50.0	316.20	10^{5}
0.5188	0.2692	5.7	1.928	3.715	0.001	10^{-6}	60.0	1,000.00	10^{6}
0.5129	0.2630	5.8	1.950	3.802	0.0003162	10^{-7}	70.0	3,162.00	10^{7}
0.5070	0.2570	5.9	1.972	3.890	0.0001	10^{-8}	80.0	10,000.00	10^{8}
0.5012	0.2512	6.0	1.995	3.931	0.00003162	10^{-9}	90.0	31,620.00	10^{9}
0.4955	0.2455	6.1	2.018	4.074	10^{-5}	10^{-10}	100.0	10^{5}	10^{10}

Appendix C - Levels of Sound Intensity


130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
THRESHOLD OF FEELING AT 1000 C.P.S
HAMMERING ON STEEL PLATE, 2 FT. FROM EAR
SINGLE MOTORED CIVILIAN PLANE AT 15 FT.
RIVETING MACHINE AT 30 FT.
SUBWAY TRAIN-DOWNTOWN CITY STREET NOISE
NOISY FACTORY-SYMPHONY ORCHESTRA AT 20 FT.
LOUD RADIO-PHONOGRAPH MUSIC IN A HOME
VERY NOISY OFFICE
AVERAGE CITY ST. NOISE-AVERAGE CONVERSATION 3 FT.
AVERAGE FACTORY-NOISY OFFICE-AVERAGE HOME RADIO
AVERAGE RESTAURANT-NORMAL CONVERSATION LEVEL
AVERAGE OFFICE
AVERAGE CITY RESIDENCE
OUTDOOR MINIMUM IN CITY
QUIET OFFICE
QUIET CITY RESIDENCE-PRIVATE OFFICE
COUNTRY RESIDENCE
VERY QUIET CONVERSATION
QUIET WHISPER
OUTDOOR MINIMUM IN COUNTRY
THRESHOLD OF AUDIBILITY AT 1000 C.P.S.
1000
100
10.0
1.0
0.1
.01
.001
.0001
.00001
.000001
.0000001
.00000001
.000000001
.0000000001
.00000000001
INTENSITY
LEVEL IN DB
INTENSITY OF SOUND PRESSURE
IN MICRO WATTS PER SQ.CM.