

EE334  
Gain and Decibels Worksheet

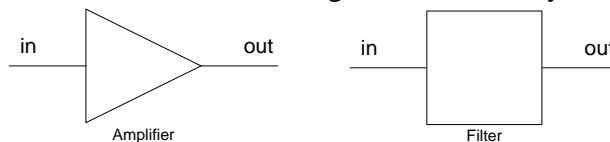
In electrical engineering one often finds situations where one is interested in either amplifying (making larger) or attenuating (making smaller) values such as voltage, current, and power. It is also very useful to have a standardized method to compare two different values in a circuit or system. For example, if we are interested in a power amplifier, we would want to compare the output power of the system to the input power. Electrical engineers and technicians use the term “Gain” to refer to the amount that something is amplified in a circuit or electrical system. Decibels are the most common way that ratios, including gain, are typically expressed, but we will come back to that concept after introducing gain. You will need to be comfortable with these terms because you will almost always find them necessary in order to communicate with anyone working in the field of electronics and communication.

- Gain is a generic term in electronics that relates to how much a signal (voltage, current, or power) grows or shrinks as it passes through different circuits. It is therefore a comparison of the output of a particular component to its corresponding input. It is very important to specify what the gain refers to, e.g., “voltage gain” or “power gain.” *They are not the same.*
- Gain can be expressed as a scalar ratio of the output to the input, in which case it is a *unitless* number, e.g., if you divide output voltage by input voltage, the voltage units cancel). This concept is relatively easy. If the voltage doubles, we would say the voltage gain is “2.” If the Gain is greater than unity (1), then we have “amplification,” and conversely if the gain is less than unity, then we instead have “attenuation.” Gain ratios can never be negative.
- There is no standard, *per se*, but the letter “A” is most often used to represent gain expressed as a ratio. To differentiate voltage and power gain, we often add a subscript, e.g.,  $A_V$  or  $A_P$ . Note that the following ratios are all dimensionless and are not equal to each other.

$$A = \text{Gain} = \frac{\text{output}}{\text{input}}$$

$$A_{\text{power}} = \frac{P_{\text{out}}}{P_{\text{in}}} \quad A_{\text{voltage}} = \frac{V_{\text{out}}}{V_{\text{in}}} \quad A_{\text{current}} = \frac{I_{\text{out}}}{I_{\text{in}}}$$

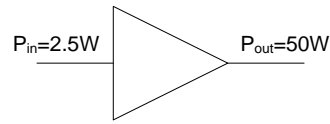
- An amplifier is a device designed to amplify signals. A filter is a device that we use to attenuate signals. The circuit symbol for an amplifier is a triangle, which often will be used generically for both amplification and attenuation. However, a square is also used to specifically represent a filter. We will be using both extensively this semester.



- For cascaded amplifiers, gain as a ratio is multiplicative. That is, the overall gain (as a ratio) that a signal experiences is the product of the individual gains of the sub-circuits or devices through which the signal passes.

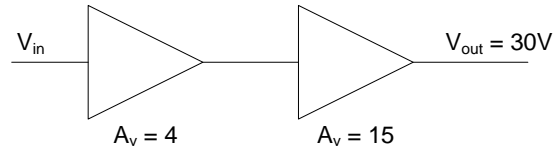
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1. What is the power gain for the simple amplifier circuit shown below?



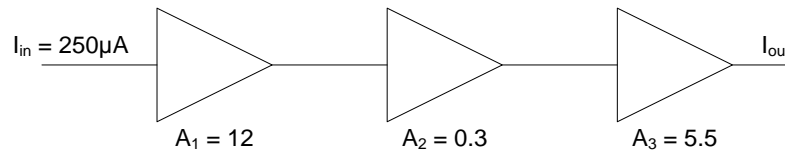
Answer: 20

2. What is the input voltage for the circuit of cascaded voltage amplifiers shown below?



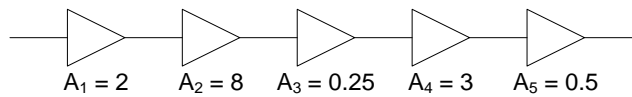
Answer: 0.5 V

3. What is the output current for the circuit of cascaded current amplifiers shown below?



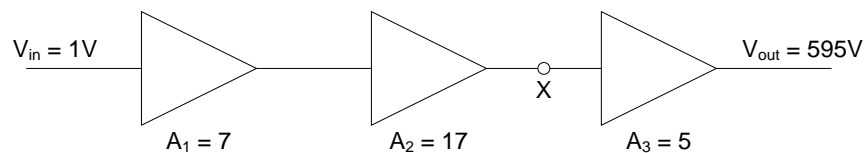
Answer: 4.95 mA

4. What is the overall gain of the multistage amplifier circuit below? In this case, we have not specified whether these are power or amplitude gains. The answer would apply to either case.



Answer: 6

5. What is the value of the voltage at point X in the circuit below? Assume voltage amplifiers.



Answer: 119 V

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For many reasons of history and practicality that your instructor can elaborate on, engineers usually use a *dimensionless* logarithmic unit called the decibel (dB) to express almost every ratio in an electrical circuit. In fact, it is quite unusual for engineers ever to use units other than dB. Engineering specifications and designs and day-to-day technical conversation with engineers and technicians will require that you use the language of decibels.

- There is no standard, per se, but the letter G is often used as the symbol for Gain expressed in decibels. Sometimes, to be explicit, it is written as  $G_{dB}$ . But, you will see A used, too.
- To express *power* gain in decibels (dB),  $G = 10 \log_{10} (A_{power})$
- To express *amplitude* (e.g., voltage or current) gain in decibels (dB),  $G = 20 \log_{10} (A_{voltage})$
- Of particular note, *these two answers come out to be the same*, so it is not necessary to differentiate between voltage and power gain when expressed in decibels (assuming impedances are matched). Your instructor will show you the proof. However, the trick is that you *must* recognize whether you are converting from/to an amplitude (voltage or current) ratio or a power ratio.
- If there is amplification, therefore, Gain will be a *positive* value when expressed in dB.
- If there is attenuation, Gain will be a *negative* value when expressed in dB.
- That means that a *unity* Gain (the output equals the input) will result in a Gain of 0 dB.
- For cascaded amplifiers, gain in dB is *additive*, whereas with ratios they were multiplicative. That is, the overall gain (in dB) that a signal experiences is the sum of the individual gains (in dB) of the sub-circuits or devices through which the signal passes. This is a major reason that dB's are so often used– they are easier.

6. A power amplifier has an output of 10 W and a gain of 36 dB. What is the power into the amplifier,  $P_{in}$ ?

*Answer: 2.5 mW*

7. A filter circuit reduces an input voltage from 5 V down to 3.3V. What is the voltage gain of the filter in decibels?

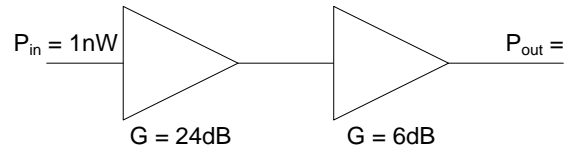
*Answer: -3.6 dB*

8. A stereo amplifier with a gain of 30 dB has a  $1\mu\text{V}$  input voltage. What is the voltage out of the amplifier?

*Answer: 31.6  $\mu\text{V}$*

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9. What is the overall power gain of the following multi-stage amplifier circuit?



*Answer: 30 dB*

10. What is the power at the output of the last stage,  $P_{out}$ ?

*Answer: 1  $\mu\text{W}$*

11. Redo #9 and #10, but use ratios instead of decibels.

Decibels are so useful that engineers actually use them to express almost every imaginable ratio of any two values. For example, we will find later that we will use them to express the relationship between “signal” and “noise” within a circuit. We also find it useful to convert units we are used to, such as Watts, milli-Watts, and Volts into decibel ratios as well. We do this simply by comparing them to a reference value and converting to decibels as before, and we add another symbol to the end of “dB” to differentiate. We will use dBm to illustrate.

- dBm (pronounced “dee-bee-m”) is a reference notation for expressing milli-Watts in a decibel notation.
- A dBm is simply a dB referenced to a milli-Watt. Whereas a value in dB is a dimensionless logarithmic representation of a ratio, a dBm is that same ratio related to a reference value, in this case a milli-Watt. Example: 3dB means some output is roughly twice some input power. 3dBm, however, means that output is exactly twice one milli-Watt = 2 mW.
- The equation for dBm is:

$$\text{power in dBm} = 10 \log \left( \frac{P}{0.001 \text{ W}} \right)$$

- Thus, 1 mW = 0 dBm
- Using this method, we can now work an entire problem from start to finish using only decibels and *addition* instead of multiplication. We first convert the input power to dBm instead of milli-Watts, then add the Gains of the stages up to the output. The answer will be in dBm, which we can either leave as-is or convert back to milli-Watts:

$$P_{\text{in}}(\text{dBm}) + \text{Gain}_{\text{dB}} = P_{\text{out}}(\text{dBm})$$

- A similar equation can be used to represent power in units of dBW, where the reference power is 1W:

$$\text{power in dBW} = 10 \log \left( \frac{P}{1 \text{ W}} \right)$$

- A similar equation can be used to represent voltage in units of dBV, where the reference voltage is 1V, but *we must multiply by 20 instead of 10*:

$$\text{voltage in dBV} = 20 \log \left( \frac{V}{1 \text{ V}} \right)$$

12. Assume a cell phone antenna output power is 0.25 Watts. What is the power in dBm?

*Answer: 24 dBm*

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13. Convert the following numbers into a decibel notation (i.e., dBm, dBW, or dBV).

- a. 25 Watts = \_\_\_\_\_ dBm = \_\_\_\_\_ dBW
- b. 3 Volts = \_\_\_\_\_ dBV
- c. 800,000 Volts = \_\_\_\_\_ dBV
- d. 1500 Watts = \_\_\_\_\_ dBW = \_\_\_\_\_ dBm

*Answers: 44 dBm = 14 dBW  
9.5 dBV  
118 dBV  
31.76 dBW = 61.76 dBm*

14. Convert the following numbers from decibel notation to actual voltage (V) or power (W).

- a. 32 dBV = \_\_\_\_\_ V
- b. -0.17dBW = \_\_\_\_\_ W
- c. -11 dBV = \_\_\_\_\_ V
- d. 15dBm = \_\_\_\_\_ W

*Answers: 39.8 V  
962 mW  
282 mV  
32 mW = 0.032 W*

## EE334: Gain and Decibels Worksheet

10 decibel rules to live by:

1. Always know whether you are converting from/to power or amplitude ratios and apply the correct factor (10/20).
2. Never mix ratios and decibels algebraically. Either convert everything to decibels first and work the problem that way, or convert everything to ratios and work the problem that way. Never attempt to mix the two.
3. Never attempt to multiply decibels. They can only be added and subtracted.
4. A few decibel values should be committed to memory as power ratios:
  - a. 0 dB = 1
  - b. 3 dB = 2 (approximate)
  - c. -3 dB =  $\frac{1}{2}$  (approximate)
  - d. 10 dB = 10
  - e. -10 dB =  $\frac{1}{10}$

Using these values, one can estimate almost any dB value.

For example,  $7 \text{ dB} = 10 \text{ dB} - 3 \text{ dB} = (10)(\frac{1}{2}) = 5$

And  $4 \text{ dB} = 7 \text{ dB} - 3 \text{ dB} = (5)(\frac{1}{2}) = 2.5$

5. Subtracting reference value dB's, e.g., dBm or dBW yields an answer in dB. This is equivalent to dividing power by power, which would yield a unitless ratio answer (gain). One should never sum two reference value dB's – this would be like multiplying power times power, which makes no sense.
6. There is no limit to the number of times I can add or subtract dB values together; the answer is still in dB.
7. When adding or subtracting dBm and dB, however, the answer will be in dBm (or whatever reference value I'm using, e.g., dBW or dBV) This would be just like multiplying mW times a ratio, so it makes sense that the answer would be in mW.
8. In terms of power ratios, 30 dB is very useful. The difference between the engineering units pW, nW,  $\mu$ W, mW, W, kW, MW, GW, etc. is 30 dB. Example: 1 Watt is 30dB more than a milli-Watt. Or,  $0 \text{ dBW} = 30 \text{ dBm}$ .
9. In terms of power ratios, every “decade” in dB (meaning every 10 dB) is like adding another zero to the power ratio. Example,  $10 \text{ dB} = 10$ ,  $20 \text{ dB} = 100$ ,  $30 \text{ dB} = 1000$ ,  $40 \text{ dB} = 10000$ , etc.
10. There are some applications where dB's cannot be used due to algebra (such as calculating noise in cascaded amplifier stages).