Circuit/Equipment Specifications

Specifications

Every circuit or piece of equipment has certain characteristics or specifications that must be considered when connecting them together in a system. The most important of these are power consumption, gain/attenuation, input/output impedances, bandwidth/frequency response, and interface. Interfaces will be discussed later.

If circuits or different parts of the system are to work together, they must be compatible. To connect the output of one circuit to the input to another, the circuits must have matching impedance levels, frequency response, and other characteristics if the combined circuit is to perform as desired.

Furthermore, connecting one circuit to another has overall consequences on the combination. One circuit tends to modify the characteristics of another with the combination producing some overall effect.

Gain

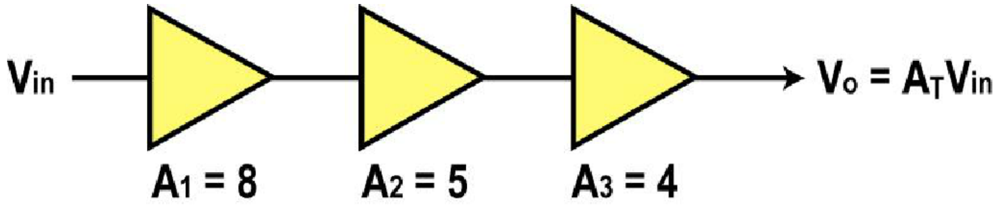
Gain is a factor that indicates how much the amplitude of a signal is increased by an amplifier or other circuit. It is usually expressed as the ratio of the output to the input. The two types of gain are voltage gain (A_g) and power gain (A_p).

$$A_v = V_o/V_{in} \text{ and } A_p = P_o/P_{in}$$

If a signal has a voltage gain of 100 then an input signal of 6 mV will be multiplied by 100 to produce an output of 600 mV or 0.6 volt.

$$V_o = A_v \times V_{in} = 100 \times (6 \times 10^{-3}) = 0.6 \text{ volts}$$

Overall Gain



$A_T = A_1 \ A_2 \ A_3$

$A_T = (8)\ (5)\ (4) = 160$

When circuits are cascade, the overall gain of the combination is the product of the individual circuit gains. For example, it the gains are 8, 5, and 4 as shown, the total gain is

$$A_t = A_1 \times A_2 \times A_3 = 8 \times 5 \times 4 = 160$$

Gain in Decibels

When very large and very small signals are encountered and the gains are very large, gain is often expressed in decibels (dB). The gain in dB is calculated as follows:

Voltage gain: $A_v = 20 \log (V_o/V_{in})$

Power gain: $A_p = 10 \log (P_o/P_{in})$

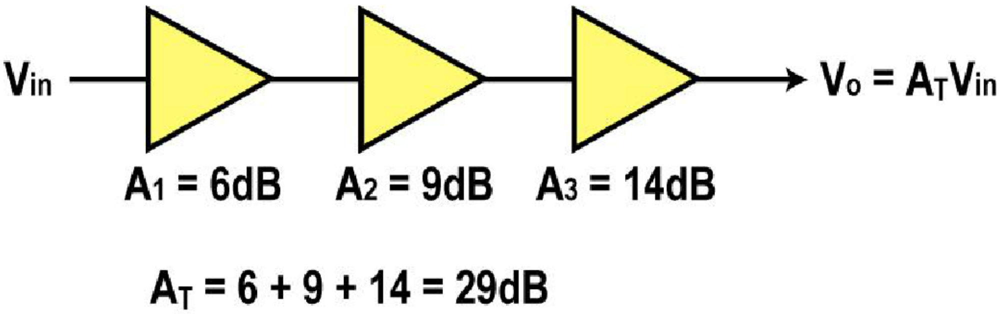
For example the voltage gain of the circuit in the previous frame is:

$$A_v = 20 \log (160) = 20 (2.2) = 44 \text{ dB}$$

If an audio power amplifier has an input of 70 mW and an output of 5 watts, the gain is:

$$A_p = 10 \log (5/0.07) = 10 (1.854) = 18.54 \text{ dB}$$

Cascade Gain in dB



Amplifier gains are often stated in dB. When such amplifiers are cascaded, the total gain is simply the sum of the individual amplifier dB gains.

In the figure, the overall gain is simply:

$$A_t = 6 + 9 + 14 = 29 \text{ dB}$$

Calculating Input or Output Values

When dB is used for gain, it is often necessary to calculate either the input or output value if the gain in dB and the other value is known. This can be done by algebraically rearranging the basic dB formulas.

Power: dB = 10 log (Po/Pin) then:

P_o/P_i = antilog (dB/10) or $\log^{-1}$ (dB/10) or $10^{dB/10}$

Voltage: dB = 20 log (V_o/V_{in})

V_o/V_{in} = antilog (dB/20) or $\log^{-1}$ (dB/20) or $10^{dB/20}$

Example: What is the input power if an amplifier with a gain of 22 dB produces an output of 50 watts?

$50/P_{in} = 10^{22/10} = 10^{2.2} = 158.5$

$P_{in} = P_o/158.5 = 50/158.5 = 0.3155$ or 31.55 mW

Attenuation

Many circuits actually attenuate the signal, that is, make it smaller. This may be done deliberately to prevent overload in another circuit or it just may be the natural effect of some other process such as filtering or mixing.

One way to look at attenuation is simply as a gain of less than one.

$$\text{Attenuation} = V_o/V_{in} \text{ or } P_o/P_{in}$$

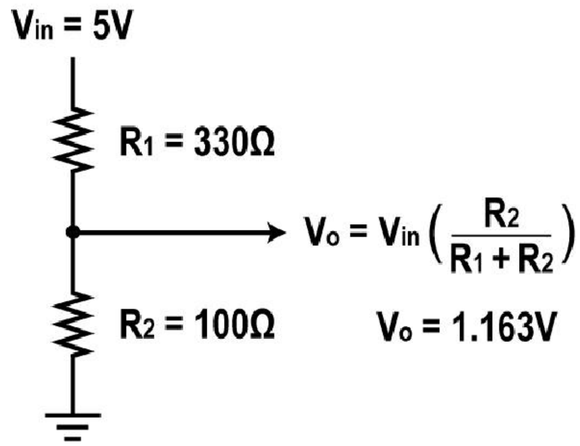
The output is less than the input.

Attenuation Example

In the simple voltage divider shown here, you can calculate the attenuation with the expression:

Attenuation = R2/(R1 + R2)
With the values shown the attenuation is 100/(100 + 330) = 100/430 = 0.233.

If the input is 5 volts, the voltage divider output is 5 (0.233) = 1.163 volts.



Attenuation in dB

Attenuation, like gain, can also be expressed in decibels using the same formulas for gain.

The attenuation of the voltage divider example in the previous frame is:

$$dB = 20 \log (0.233) = 20 (-0.633) = -12.65 \text{ dB}$$

Note that attenuation is shown by a negative value. The logarithm of a fraction is a negative value.

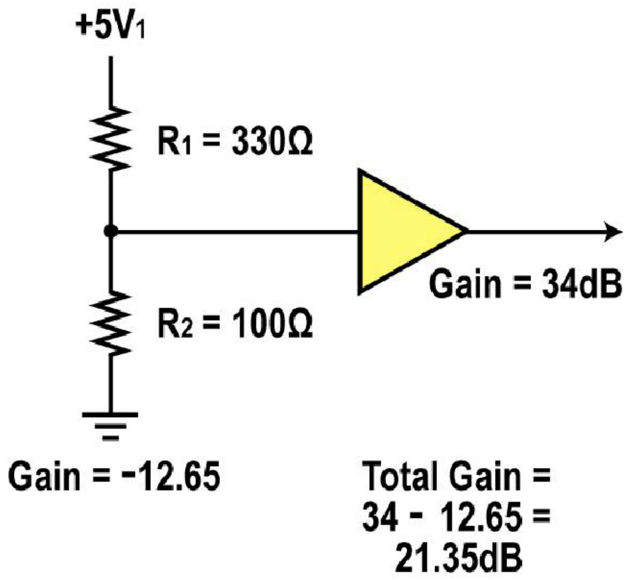
Attenuation in dB Example

In this example, an amplifier with a voltage gain of 34 dB is connected to the voltage divider.

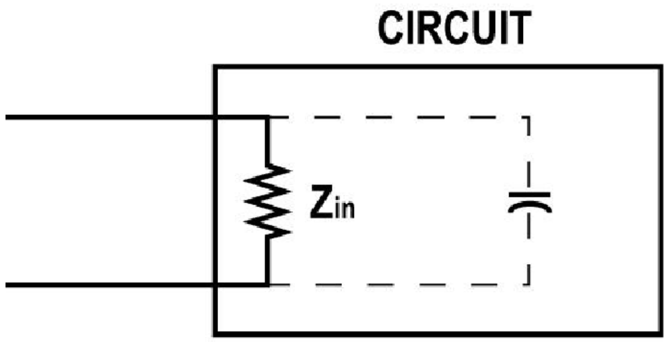
What is the overall gain of the combination?

Total gain = 34 + (-12.65) = 34 – 12.65 = 21.35 dB

The loss in the divider offsets some of the amplifier gain.



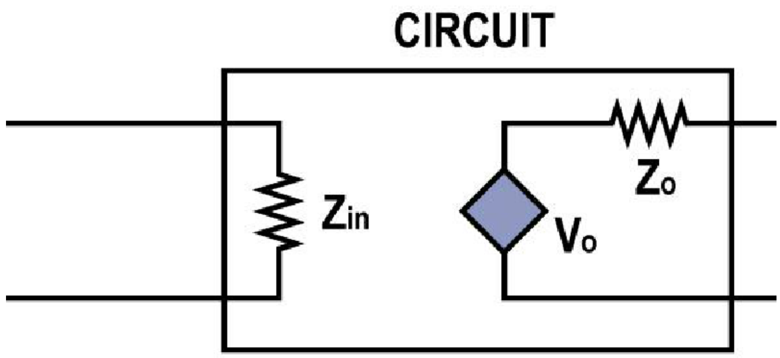
Input Impedance



Input Impedance

All circuits that process signals will have a certain amount of input and output impedance. The input impedance is that resistance (and reactance) that the circuit supplying the signal will see when connected to the input terminals. Usually the input impedance is resistive but there is usually some parallel capacitance as well that affects the circuit only at the higher frequencies.

Output Impedance



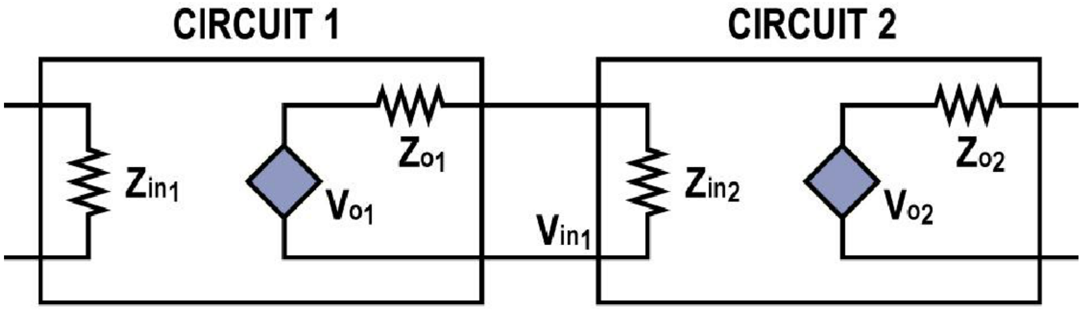
Output Impedance

The output impedance is the internal impedance of the circuit that effectively appears in series with the circuit output. The circuit develops an output voltage that will drive another circuit. The output impedance Z_o appears in series with this output voltage.

Input Impedance Example

The input impedance of a circuit can range from a few ohms to well over a megohm. In general, the higher the input impedance the better. If you are passing a signal voltage from one circuit to another in cascade, you want the input impedances to be as high as possible to avoid loss due to the voltage divider effect produced by the output put impedance of the driving circuit and the input impedance of the receiving circuit.

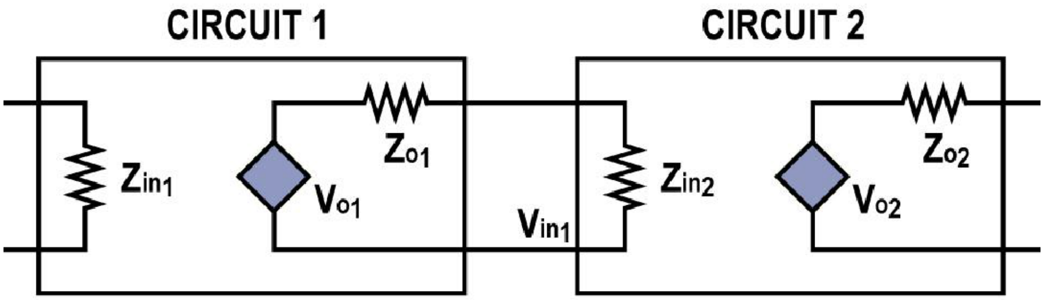
Impedance Example



$$V_{in1} = V_{o1}\left(\frac{Z_{in2}}{Z_{in2} + Z_{o1}}\right)$$

In the example shown in the figure above, circuit 1 has an output impedance that appears in series with the input impedance of the following stage. The two form a voltage divider. Ideally, you would like the output impedance to be zero and the input impedance to be infinite. With those conditions, all the voltage produced by one circuit is transferred to the other circuit.

The Voltage Divider Effect

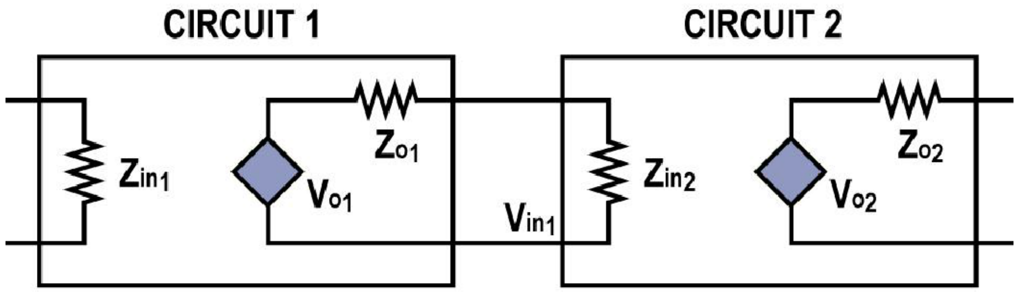


$$V_{in1} = V_{o1}\left(\frac{Z_{in2}}{Z_{in2} + Z_{o1}}\right)$$

In the figure above, you can see that because of the voltage divider that is formed with the output and input impedances the voltage reaching the input to the second circuit will be lower than the output voltage of the driving circuit. You can calculate the input voltage with the expression:

$V_{in1} = V_{o1}(Z_{in2})/(Z_{in2} + Z_{o1})$

Output Voltage



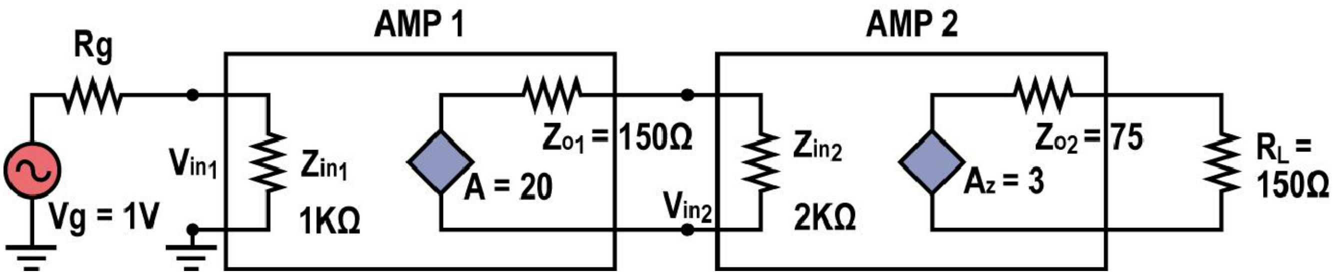
$$V_{in1} = V_{o1}\left(\frac{Z_{in2}}{Z_{in2} + Z_{o1}}\right)$$

Assume that the output voltage of circuit 1 is 3 volts with no load connected. This is V_{o1}. Also, assume that Z_{o1} of the driving circuit is 75 ohms and the input impedance to the next circuit is 120 ohms. The actual input voltage to circuit 2 then is:

$$V_{in1} = 3(120)/(75 + 120) = 360/195 = 1.846 \text{ volts}$$

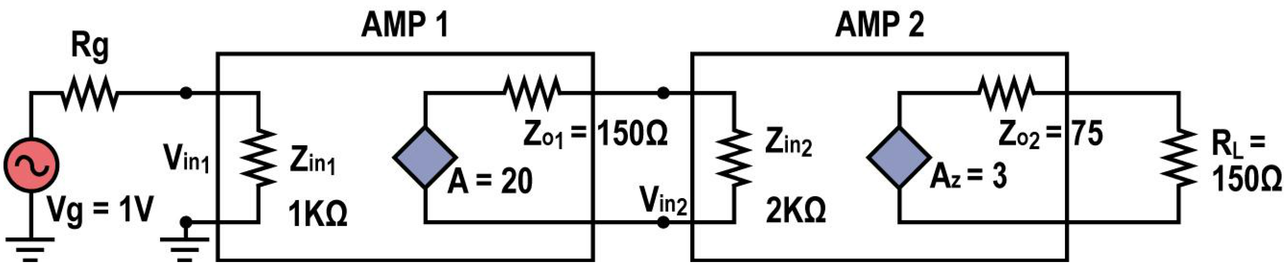
The entire 3 volts from circuit 1 does not reach circuit 2 because of the input and output impedances form a voltage divider. We say that circuit 2 loads circuit 1.

The Effect on Gain



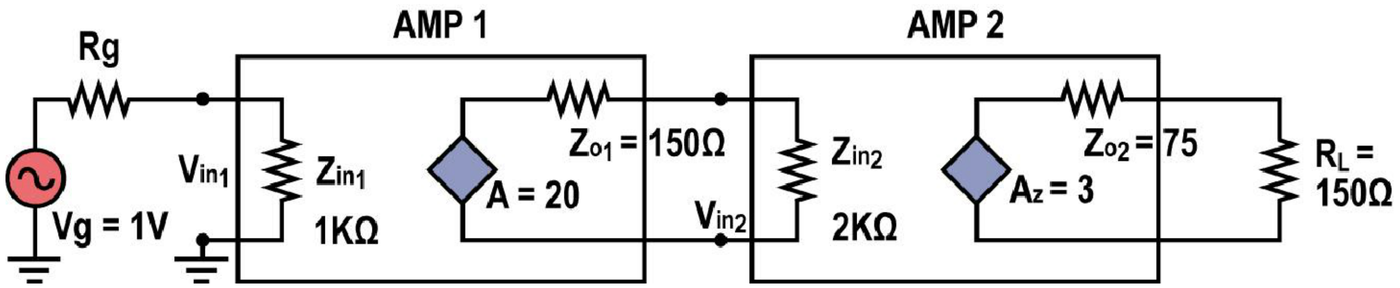
When amplifiers are cascaded, their gains multiply as described earlier in this module. This assumes that the effects of input and output impedances are ignored. But you can see that the voltage divider effect is going to lower the gain of any amplifier.

The Effect on Gain



In the figure, a signal generator with an output voltage (V_g) of 1 volt and an output impedance or generator impedance R_g of 50 ohms is driving Amplifier 1 with Z_{in} = 1K ohm. The output impedance of Amp 1 is 150 ohms and it has a gain of 20. Amplifier 1 drives Amplifier 2 with a Z_{in} of 2K ohms. If R_g and Z_o1 were zero and Z_{in}1 infinite, then the 1 volt from the generator would be amplified by 20 to produce 20 volts at the input to Amp 2.

The Effect on Gain: Input Voltage



However, what we really get is something less thanks to the voltage divider effects.

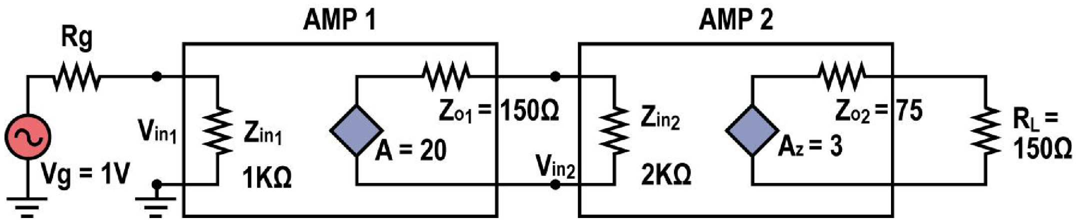
For example, the input voltage that Amp 1 sees is:

$V_{in1} = V_g(Z_{in1})/(R_g + Z_{in1}) =$

$1(1000)/(50 + 1000) = 1000/1050 = 0.952$ volts.

This input voltage is amplified by a gain of 20 to produce an output voltage of 0.952(20) = 19 volts.

The Effect on Gain: Loss



This voltage is then divided down by the effect of the output impedance of Amp 1 and the input impedance of Amp 2. The actual input to Amp 2 is:

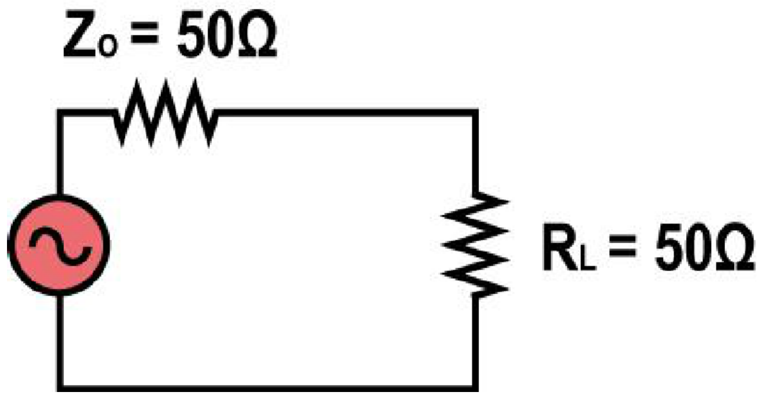
$V_{in2} = V_{o1}(Z_{in2})/(Z_{o1} + Z_{in2}) = 19(2000)/(150 + 2000) = 17.67$ volts.

As you can see, while Amp 1 can produce a gain of 20, we only get a total gain of 17.67 because we lose some voltage to the voltage divider effects of the input and output impedances. To get an overall true gain of 20 from this circuit, the gain of the amplifier must be increased so that it will overcome the voltage divider effects that are inherent in every practical circuit.

Maximum Power Transfer

In most applications, the goal is to transfer as much voltage from one circuit to another. Keeping the output impedances low and the input impedances high will minimize the voltage divider effects. However, in some applications the goal is to transfer maximum power rather than maximum voltage. In some audio applications and many RF or microwave circuits, maximum power transfer is desired. In this case, low Z_o and high Z_{in} is no longer appropriate.

Maximum Power Transfer Example



Maximum power transfer takes place when the load or input impedance matches the output impedance of the driving circuits. For example, in the circuit shown, the output impedance is 50 ohms and the load or input impedance is 50 ohms. Normally this will produce an output voltage that is one half of the input voltage. However, maximum power transfer will occur.

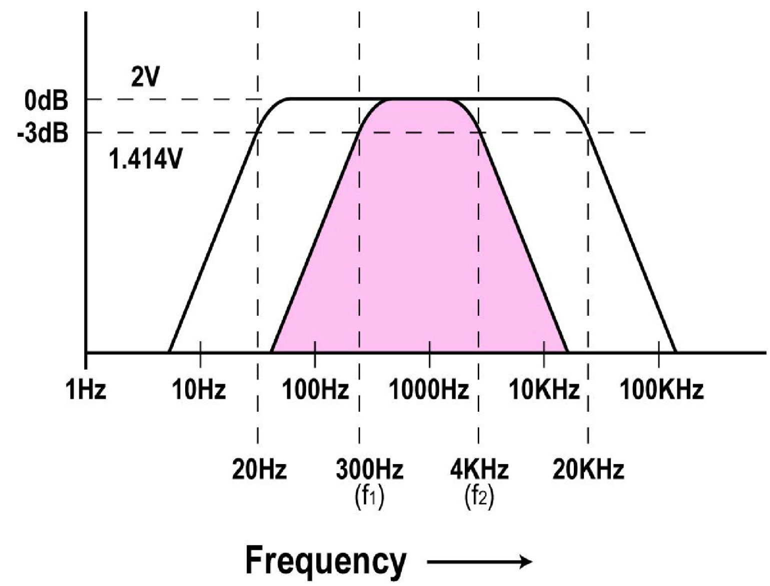
Frequency Response

Another basic specification is the frequency range over which a circuit will operate. We call that the frequency response of the circuit. Most circuits are only capable of operating over a relatively narrow range which is specified in their design. For example many audio and radio applications like telephones have a response of 300 to 4000 Hz, the normal voice range.

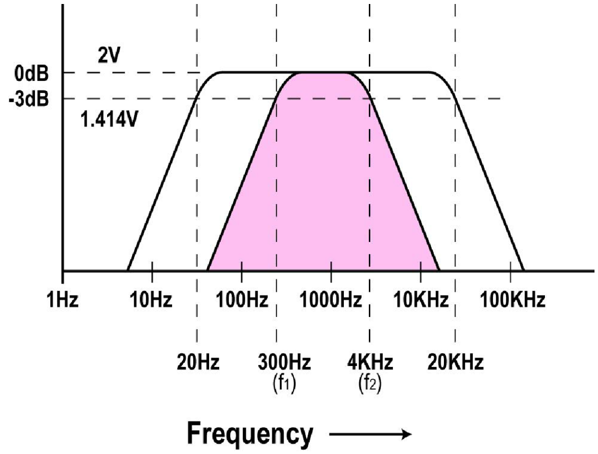
Frequency Response

The figure shows a basic frequency response curve showing the normal voice range, 300 to 4000 Hz.

Music audio systems usually operate over the 20 Hz to 20 kHz range, the maximum range of human hearing. RF circuits may only operate at frequencies from 100 MHz to 3 GHz. In any case, you must know this operating frequency range to be sure the circuit will handle the signal frequency range.

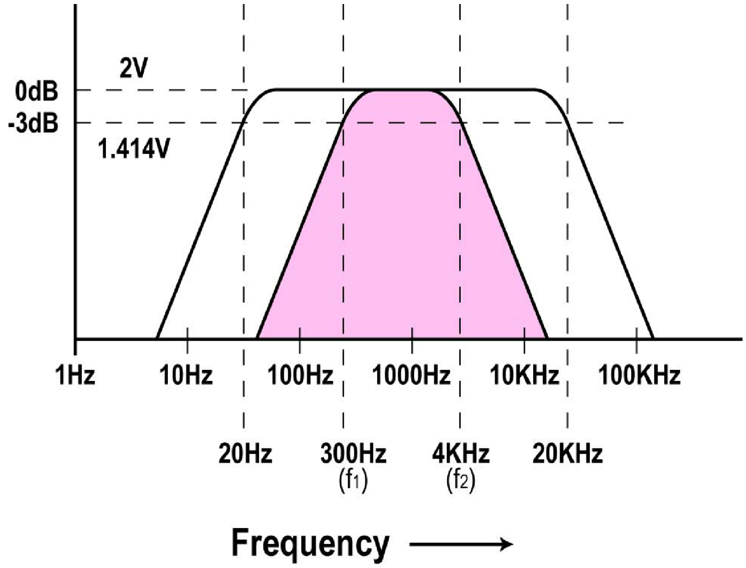


Cut-off Frequencies



The upper and lower frequencies defining the operating range are referred to as the cut-off points. These cut off points are those frequencies where the output voltage falls to the 70.7 % of the maximum output voltage. The maximum voltage is 2 volts. When the voltage rolls off to 2 x 0.707 = 1.414 volts, the cut-off point is defined. This cut-off point is also called the 3 dB down (-3 dB) point since the output at the cut-off frequencies is 3 dB less than that at the maximum output.

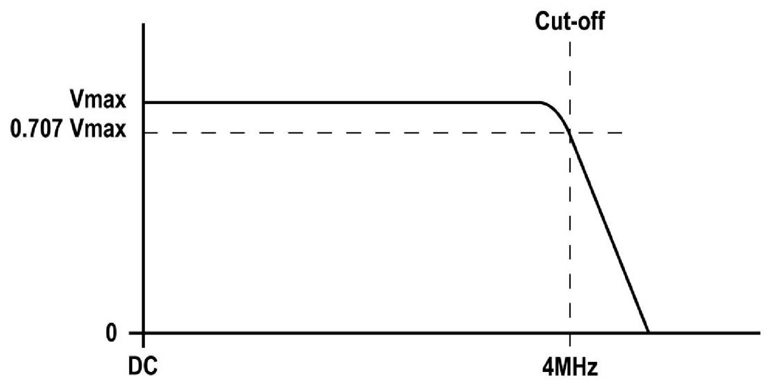
Bandwidth



Bandwidth is defined as the difference between the two cut-off frequencies. The lower cut-off frequency is f_1 and the upper cut-off frequency is f_2. The bandwidth (BW) is $(f_2 – f_1)$. In the case of the curve here, the bandwidth is

BW = 4000 – 300 = 3700 Hz

Bandwidth Response Curve



Many circuits have a lower cut-off of 0 Hz. This means that the circuit passes DC and any very low frequencies. The lower cut-off frequency is zero. An example is a DC amplifier like an op amp. It has an upper cut-off frequency. So the response curve looks like that in Figure 23. This is the response curve of a low pass filter. And since the lower cut off is zero, the bandwidth is simply the value of the upper cut-off frequency. In this case,

$$BW = f_2 - f_1 = 4 \text{ MHz} - 0 = 4 \text{ MHz}.$$

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