Electronics
Operational Amplifier Dynamic Characteristics

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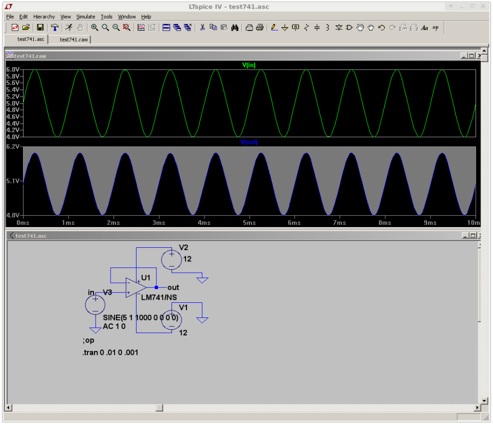
- The **open loop gain** is the gain without feedback.
- Open loop gain is constant at low frequencies,
  but then starts to decrease at higher frequencies.

6V

4V
6V

4V

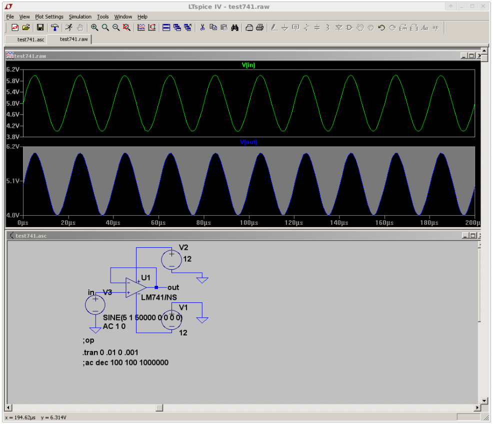


Here's a voltage follower with a 1 kHz input.

6V

4V
6V

4V

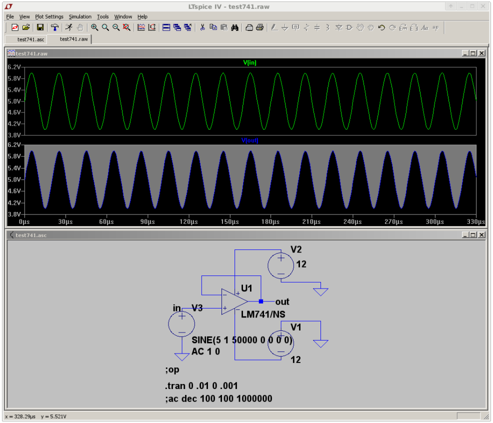


With a 50 kHz input, the output still matches pretty closely.

6V

4V
6V

4V



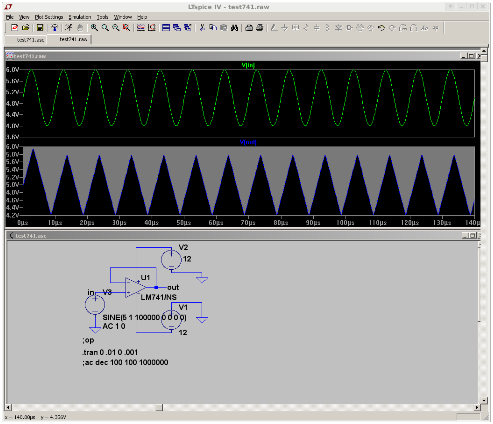
Here it is on the same scale.

6V

4V

5.8V

4.2V

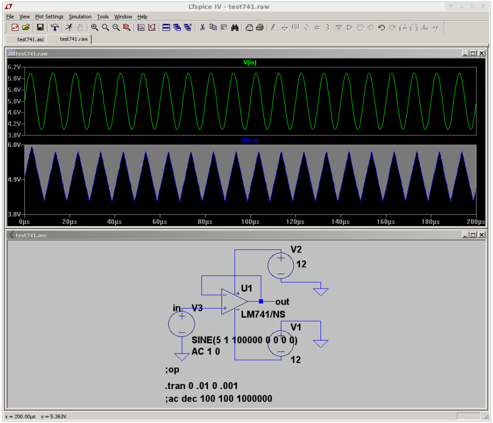


By 100kHz, the output is starting to diverge from the input.

6V

4V
6V

4V



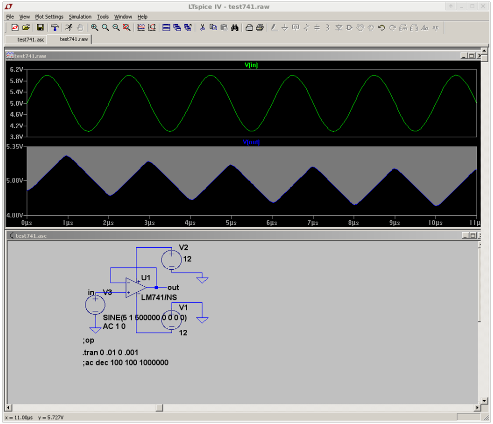
It's more obvious if the scales are the same.

6V

4V

5.4V

4.8V



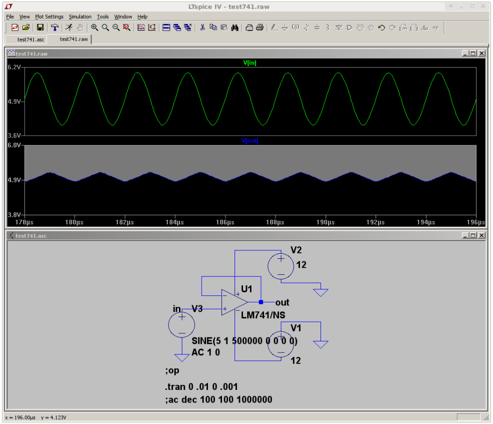
With a 500kHz input, the output change is very clear.

6V

4V

6V

4V

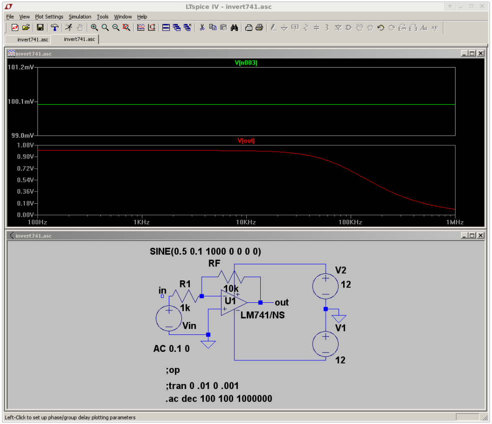


On the same scale, it's obvious.

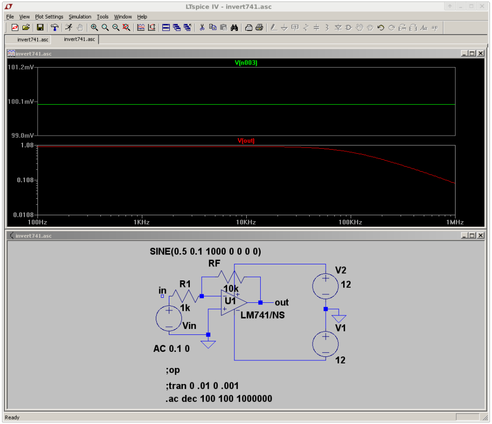
The **rolloff** can be seen in the next figures.

100mV

1V

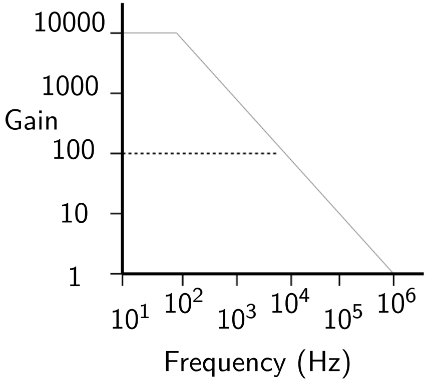


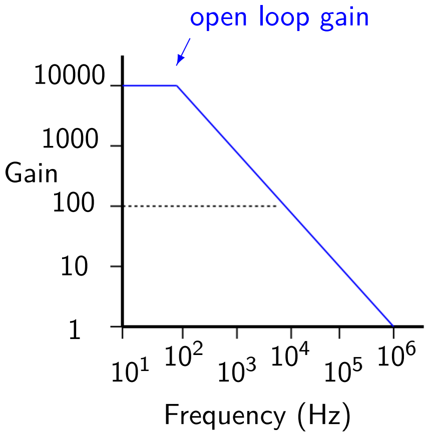
Here's what an AC analysis shows for a gain of 10.

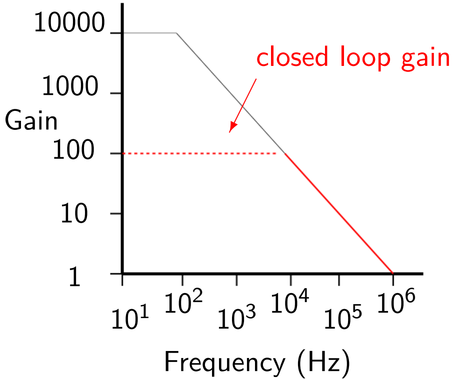


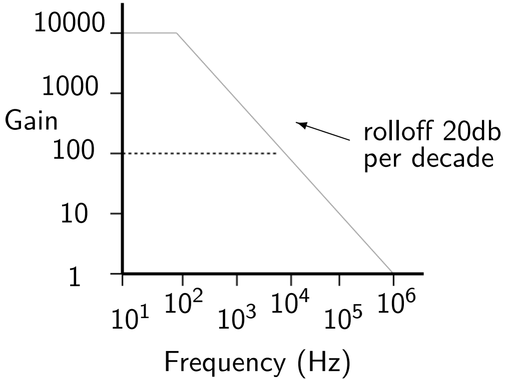
A logarithmic scale is helpful sometimes.

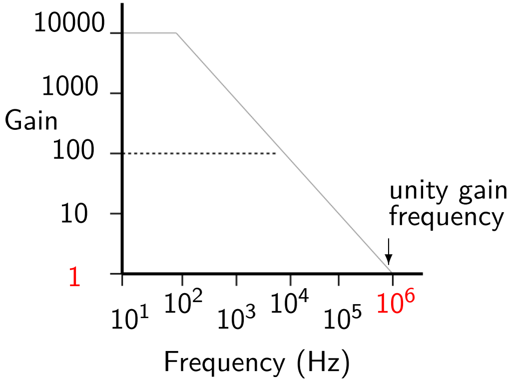
The **rolloff** affects both open-loop and closed-loop gain.

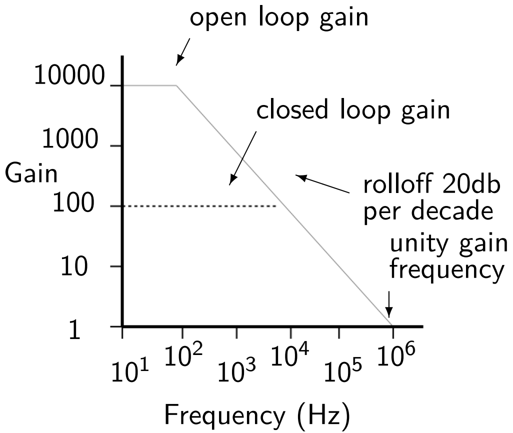

10000
1000
Gain
100
10
1
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (Hz)


open loop gain
10000
1000
Gain
100
10
1
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (Hz)


10000
1000
Gain
100
10
1
closed loop gain
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (Hz)


10000
1000
Gain
100
10
1
10^1 10^2 10^3 10^4 10^5 10^6
Frequency (Hz)
rolloff 20db
per decade


10000
1000
Gain
100
10
1
unity gain
frequency
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (Hz)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- A **decade** is a factor of 10, so rolloff of 20 db/decade represents a *decrease* in $\left(\frac{V_o}{V_i}\right)$ of a factor of 10 as the frequency *increases* by a factor of 10.

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- The **gain-bandwidth product** (GBW) is

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- The **unity-gain frequency** $\rightarrow$ frequency at which $\left(\frac{V_o}{V_i}\right) = 1$.
- (I will use the term A to refer to $\left(\frac{V_o}{V_i}\right)$ and G to denote the gain in decibels, as described above. This convention is common, but not universal, so when consulting information on the subject be sure to pay attention to how gain is expressed.)

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- *Thus the unity-gain frequency for an op amp circuit is the same, regardless of the mid-band gain.*

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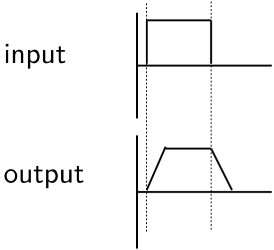

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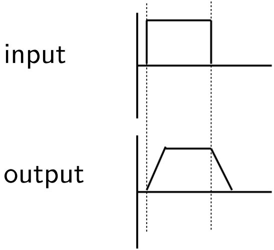

The *rate* of possible change of the output voltage is referred to as the **slew rate**.

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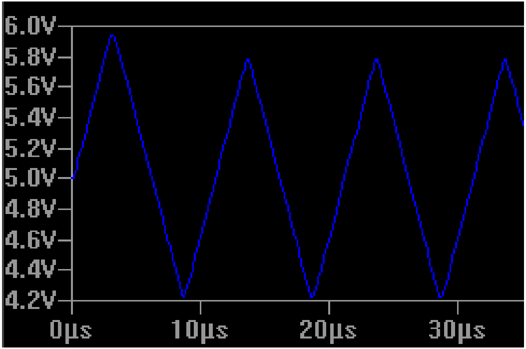

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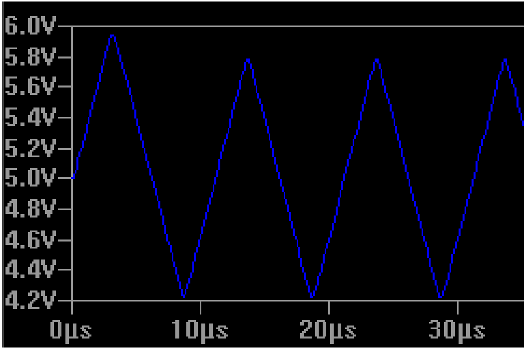

The rise (or fall) is about 1.6 volts in 5 μS, or about 0.3 V/μS.

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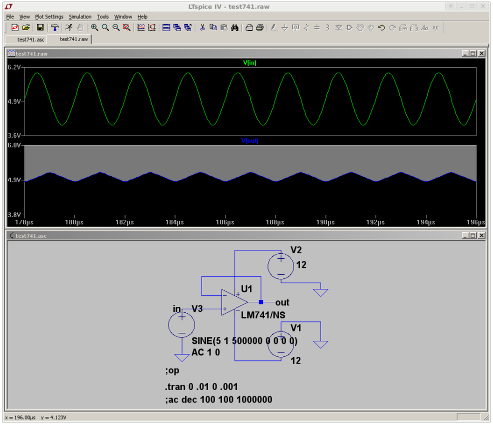
  Sine waves will be the *least* distorted of any waveform.

6V

4V
6V

4V



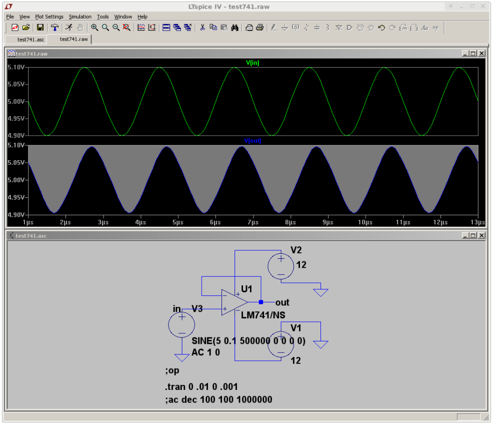
Here's a previous circuit; 1V, 500kHz into a voltage follower.

5.1V

4.9V

5.1V

4.9V



Reducing the input to 0.1V makes the output much closer.

Active filters

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- These are called **active filters**.

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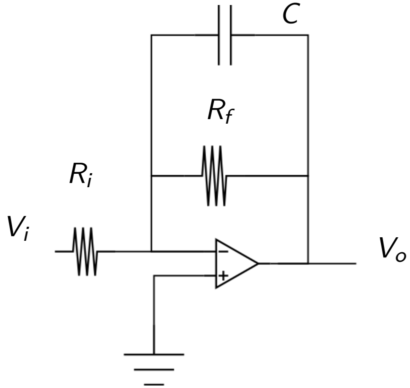
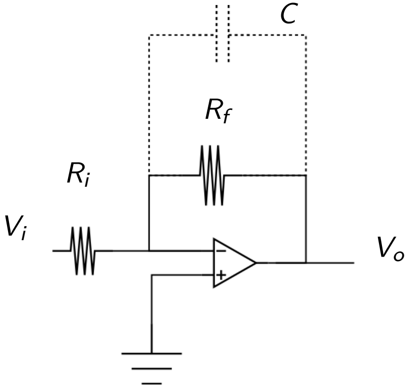
- (Note: there are numerous designs for filters; the ones shown here are simple to analyze.)

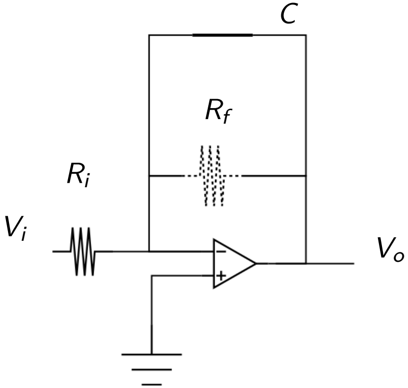
Low pass filter



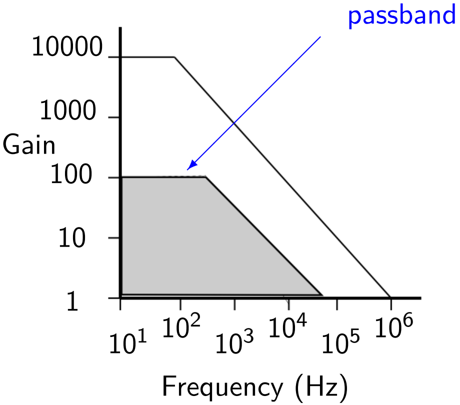
Low pass filter at *low* frequencies



Low pass filter at *high* frequencies



Low pass filter Bode plot



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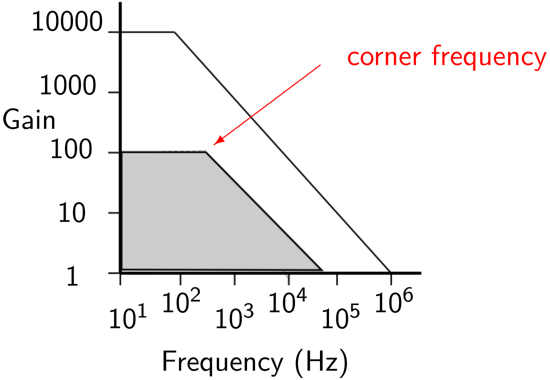

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$$Z \propto \frac{1}{f}$$

since $X_c < R_f$.

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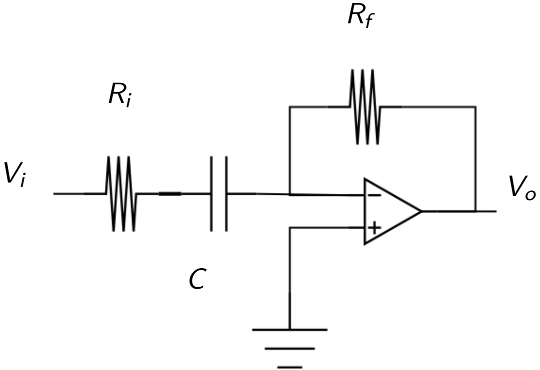
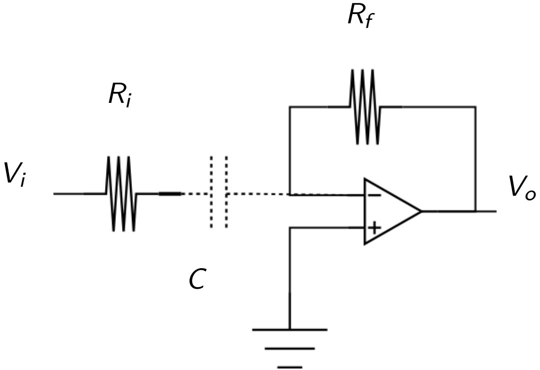


High pass filter at *low* frequencies



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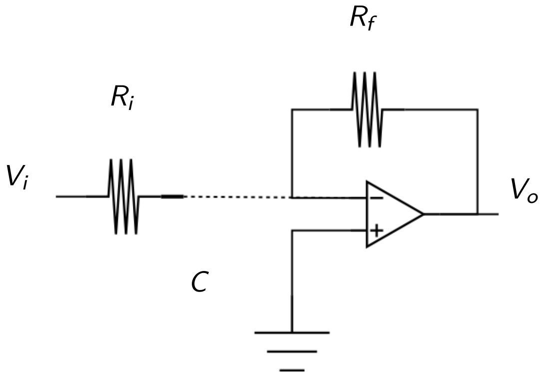

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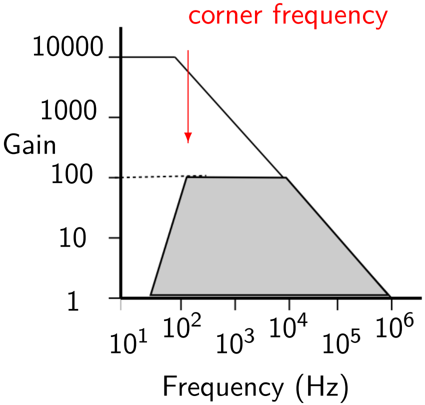

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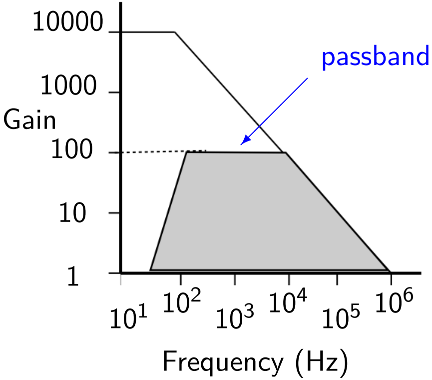

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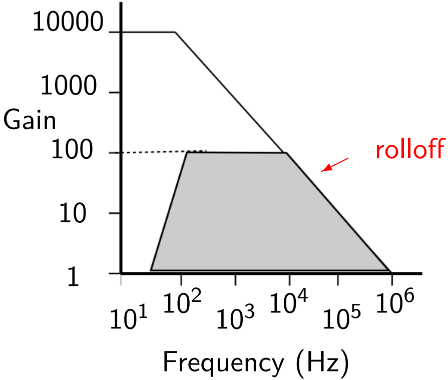

In the input part of the circuit, at high frequencies $X_c \approx 0$ and so the gain is that of a normal inverting amplifier. As the frequency decreases, at a **corner frequency** $X_c = R_i$. Below this frequency,

$$Z \propto \frac{1}{f}$$

since $X_c > R_i$.

A **band pass filter** combines a low pass and a high pass filter to allows frequencies *between* two corner frequencies, f_{c1} and f_{c2} to pass, and attenuates those *outside* that range. The next figure shows the Bode plot for a band pass filter.

Bandpass filter Bode plot