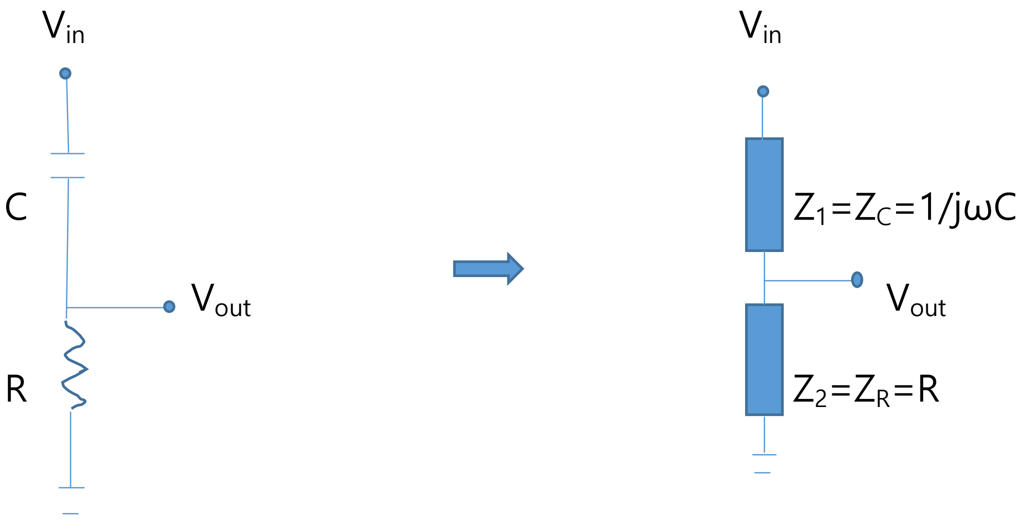
Lecture 6-HPF (High Pass Filter)

<u>HPF (High Pass Filters)</u>

: To pass high frequency component, or

To filter out the low frequency noise from the signal



The left RC circuit can be changed as the right circuit of voltage divider,

considering that $Z_R=R$ and $Z_C=1/j\omega C$

Transfer function$=V_{out}/V_{in}=Z_2/(Z_1+Z_2)=R/(R+1/j\omega C)$

$=j\omega RC/(1+j\omega RC)$;

This is the complex number, thus magnitude, phase are of interest.

Magnitude$=|H|=|V_{out}/V_{in}|=\omega RC/\sqrt{1+(\omega RC)^2}$

Phase$=\angle H=\angle V_{out}/V_{in}=\angle(j\omega RC) - \angle(1+j\omega RC)=90^\circ - \tan^{-1}(\omega RC)$

where ω=angular velocity of signal [rad/sec]$=2\pi f$

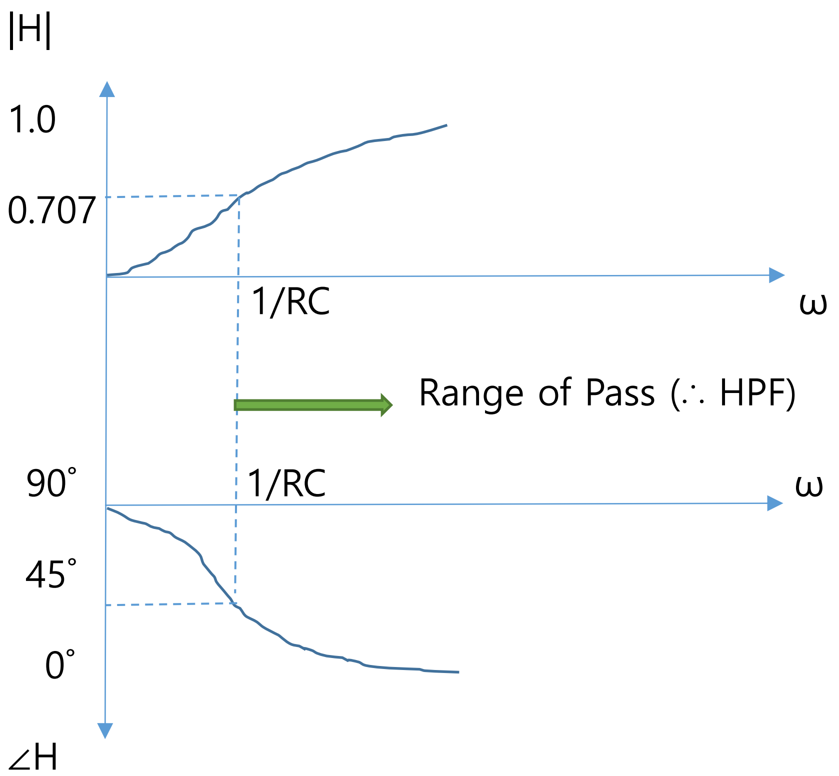
and f=frequency of signal [Hz]

Let's plot the magnitude and phase in the ω domain;

If $\omega<1/RC$ then $|H|\fallingdotseq 0$ and $\angle H\fallingdotseq 90^\circ$

If $\omega=1/RC$ then $|H|=1/\sqrt{2}=0.707$ and $\angle H=45^\circ$

If $\omega>1/RC$; then $|H|\fallingdotseq 1$ and $\angle H\fallingdotseq 0^\circ$ (or $[0^\circ, 45^\circ]$)



If $\omega\geq 1/RC$ then $|H|\geq 0.707$ and $|\angle H|\leq 45^\circ$, and they are acceptable for many engineering application. Thus this circuit effectively can pass the signal of frequency range over 1/RC. Thus it is HPF, High Pass Filter.

At $\omega=1/RC$, $dB\equiv -20Log|H|=-20Log(1/\sqrt{2})\fallingdotseq 3$, thus 1/RC is called as ω_{3dB} which is very important for application. At $\omega=\omega_{3dB}$, 70% amplitude of signal is delivered, while 30% of signal is attenuated, which is quite acceptable for many engineering application.

This HPF is also a very useful tool for signal conditioning, or removing the low frequency noise from the high frequency signal.

5 Design Procedures or 5 Steps for HPF

1) Frequency identification of signal

   Measured signal can be analyzed by oscilloscope or frequency spectrum analysis. Then identify f_{signal} and f_{noise}

2) Choose f_{3dB}

   You can assign f_{3dB} at your design target, and f_{signal} can be conveniently chosen as the f_{3dB}

3) Choose R, C such that $1/RC=\omega_{3dB} =2\pi f_{3dB}$ among commercially available components

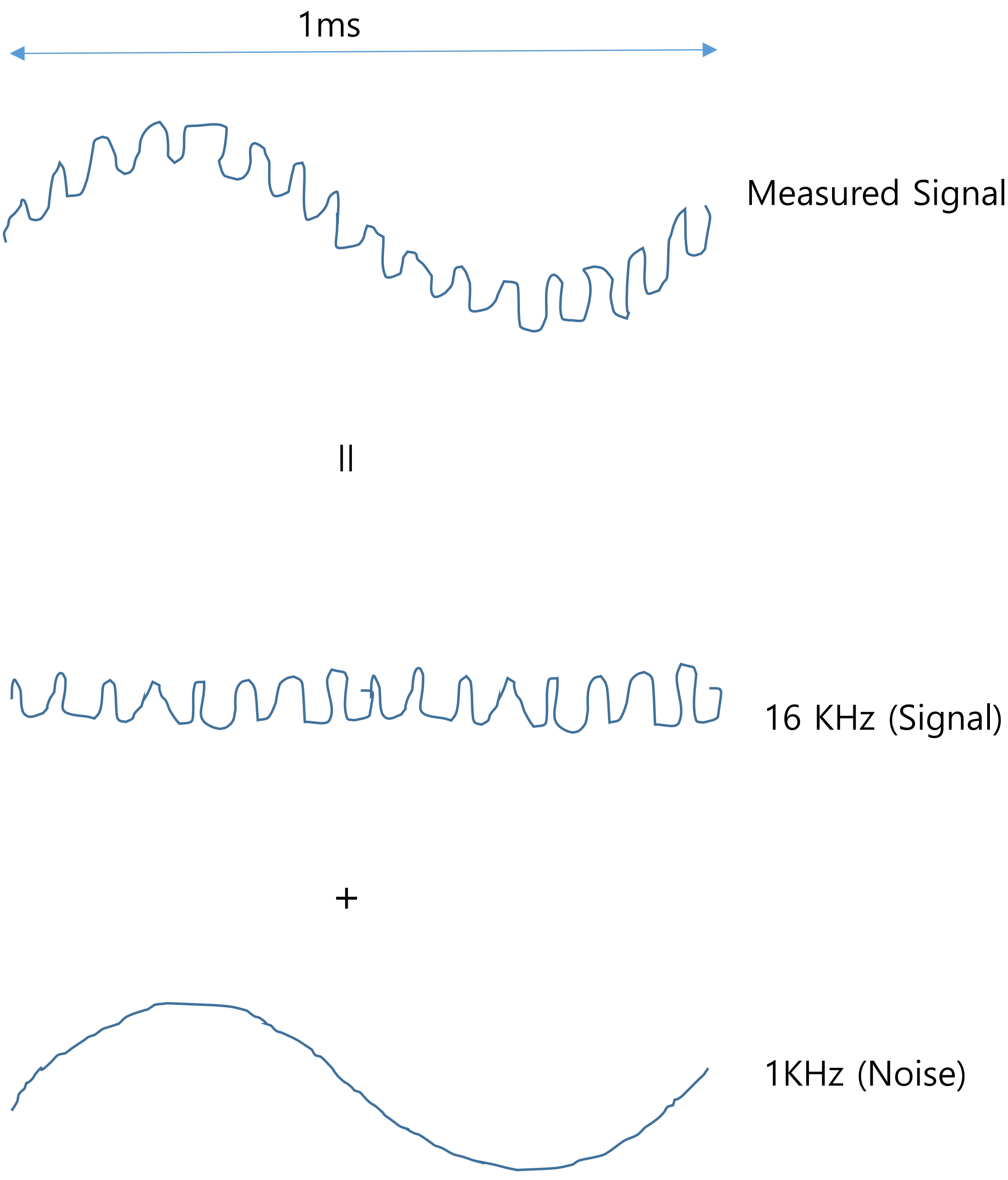
4) Use 10X rule for choosing components if necessary

5) Performance Verification by using Signal to Noise ratio, or S/N ratio, etc

Ex) HPF design

Design a HPF to remove the low frequency noise from the signal. This HPF will be connected to A/D converter of 100KΩ input impedance.

Oscilloscope shows the measured signal as follows;



1)Frequency identification

f_{signal}=16 KHz, f_{noise}=1KHz by oscilloscope or spectrum analysis

2)Choose f_{3dB}

$f_{3dB}=f_{signal}$=16 KHz

(Q: What happen if we chose f_{3dB} as 1KHz?)

3)Choose R,C from $\omega_{3dB}=1/RC$

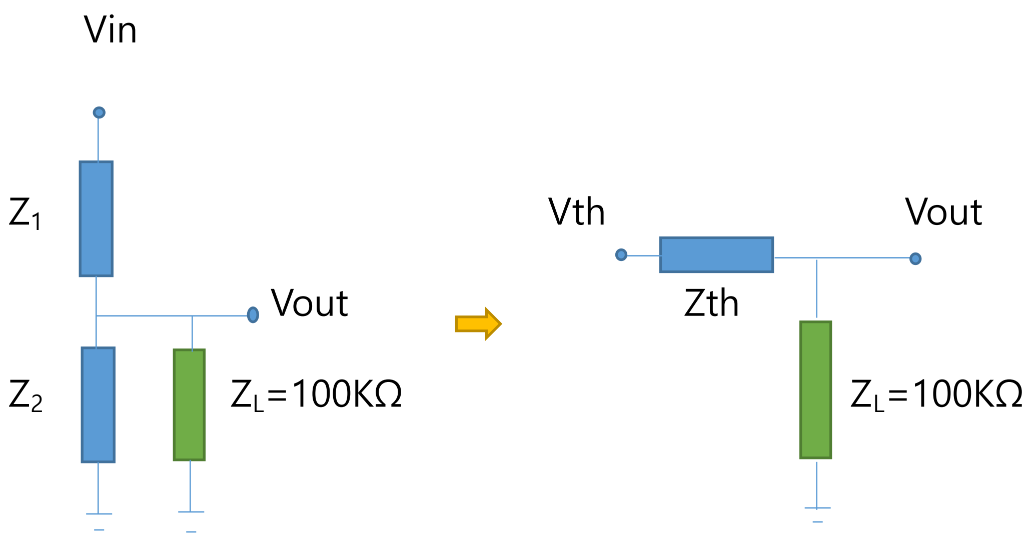
Thus $1/RC=\omega_{3dB}=2\pi f_{3dB}$ =100,480[rad/sec]

There are so many combinations to satisfy, thus we need more information from the 10X rule

4) 10X rule

This HPF is to drive the ADC of 100KΩ input impedance as follows;

And it can be transformed to Thevenin's equivalent circuit



$Zth = Z_1 \parallel Z_2 = Z_1Z_2/(Z_1+Z_2) = (R/j\omega C)/(R+1/j\omega C) = R/(1+j\omega RC)$

Magnitude of Zth, $|Zth| = R/\sqrt{1+(\omega RC)^2} \leq R$

Thus maximum of Zth is R, and Zth is to drive the Z_L ; therefore it is quite reasonable to choose R as one tenth of Z_L(=100KΩ) by the 10X rule such as $Z_{out} \leq Z_{in}/10$ in general application of voltage circuit.

Thus R =10KΩ, and C≒100pF from commercial availability.

5) Verification

For 16KHz signal, or $\omega = 2\pi(16000)$ rad/sec

$|H| = |V_{out}/V_{in}| = \omega RC/\sqrt{1+(\omega RC)^2} \fallingdotseq 0.707$

$\angle H = 90^\circ - \tan^{-1}(\omega RC) \fallingdotseq 45^\circ$

For 1 KHz noise, or $\omega = 2\pi(1000)$ rad/sec

$|H| = |V_{out}/V_{in}| = \omega RC/\sqrt{1+(\omega RC)^2} \fallingdotseq 0.0628$ (6.28%)

$\angle H = 90^\circ - \tan^{-1}(\omega RC) \fallingdotseq 86.4^\circ$

Before HPF application, given S=1, N=1, then S/N=1

After HPF application, S = 0.707, N=0.0628,

then S/N=0.707/0.0628≒11.3

Thus S/N ratio changes from 1 to 11.3, which is more than 10 times improvement!

It is wonderful result for S/N ratio improvement by the HPF application.

Q: What happen if only Z_L is changed to 10KΩ, while others are unchanged? Hint -> $H = V_{out}/V_{in} = j\omega RC/\{1+R/R_L+j\omega RC\}$

HW3)

1. Design a LPF to filter out the noise of 20KHz from the signal of 2KHz, which is to drive an amplifier of input impedance of 200KΩ.
2. Design a HPF to filter out the noise of 2KHz from the signal of 20KHz, which is to drive an amplifier of input impedance of 200KΩ.
3. Only the input impedance of the amplifier is changed to 10KΩ, while others are unchanged. Discuss the performance of the above filters, respectively, in the changed case.