\[ f = \frac{1}{T} \]

\[ \lambda = \frac{V}{F} \]

Wavelength \( \lambda = \frac{V}{F} \)

Where \( V = 3 \times 10^8 \) m/s

And \( F = \text{Hz} \)
**Fig. 2-72** A square wave is made up of a fundamental sine wave and an infinite number of odd harmonics.
Time domain (Oscilloscope)
Pure of 1 kHz square-wave

Frequency domain
(Spectrum Analyzer)
Picture of 1 kHz square-wave
A 1 kHz square wave
500 milliV/Div
200 usec/Div
On the oscilloscope

A 1 kHz square wave
100 milliV/Div
That shows on the spectrum analyzer
Filters are circuits that are capable of passing signals with certain selected frequencies while rejecting signals with other frequencies. This property is called selectivity.

Active filters use transistors or op-amps combined with passive RC, RL or RCL circuits. The active devices provide voltage gain, and the passive circuits provide frequency selectivity. The four basic categories of active filters are: low pass filter, high pass filter, band pass filter, band stop filter (Notch filter).

1. LOW PASS FILTER

![Ideal Response Diagram](image)

- **Ideal Response**: $\text{Av(dB)} = \frac{V_o}{V_i}$
  - $0 \text{ dB}$
  - $-3 \text{ dB}$
  - $BW = \text{Band Width}$

![Practical Response Diagram](image)

- **Practical Response**: $\text{Av(dB)} = \frac{V_o}{V_i}$
  - $0 \text{ dB}$
  - $-3 \text{ dB}$
  - $BW = \text{Band Width}$
  - Slope = $-20 \text{ dB/decade}$
  - $f_c$ to $10f_c$
• One pole Low Pass Filter (LPF) (one resistor, one capacitor)

• LPF only allows low frequency signals from 0 hertz to its cut-off frequency fc point to pass while blocking those any higher

• cut-off frequency or corner frequency or critical frequency is calculated by the following formula: \[ f_c = \frac{1}{2\pi RC} \]

Where f= Hz, R=Ohm, C=farad.

• at cut-off frequency the Gain(AV) is down -3dB or the output going down to 70.7% (same as 0.707) of its maximum values.

• after fc output decreases at a constant rate a the frequency increases. That is, when the frequency is increased tenfold (one decade) the voltage gain is divided by 10, in other words, the gain decreased 20dB\(=20\log_{10}10\) each time the frequency is increases by 10.

• One pole LPF (one R, one C) roll-off rate -20dB/Decade or 0.1

• Two pole LPF (two R, two C) roll-off rate -40dB/decade or 0.01

• Three pole LPF (three R, three C) roll-off rate -60dB/decade or 0.001
The following shows the response for LPF with different poles

- 0 dB
- -20 dB/decade (1pole LPF)
- -40 dB/decade (2pole LPF)
- -60 dB/decade (3pole LPF)

**EXAMPLE 01**

For the LPF circuit shown, \( R=1\,k\Omega \), \( C=0.1\,\mu F \), \( \text{Vin}=10\text{Vrms} \). Calculate:

1. Gain \( \text{AV} = \) __1__ NA
2. cut-off frequency \( fc=\) __1.59__ kHz
3. \( V_{out} \) at \( fc = \) ________7.07________ Vrms
4. \( V_{out} \) at 10\( fc=\) ____1_______ Vrms
5. \( V_{out} \) at 500Hz = ___10________ Vrms
**EXAMPLE 02**

For the LPF circuit shown, Given $V_{in} = 2.5 \text{ Vrms}$. Calculate:

1. Gain $AV = (1 + \frac{R2}{R1})$ \(10\)
2. cut-off frequency $f_c = 159$ Hz
3. $V_{out \ max} = \underline{25} \text{ Vrms}$
4. $V_{out} \ at \ f_c = \underline{17.67} \text{ Vrms}$
5. $V_{out} \ at \ 10f_c = \underline{2.5} \text{ Vrms}$
2. ACTIVE HIGH PASS FILTER (HPF)

- Pass any frequencies higher than cut-off frequency (fc)
- Cut-off frequency formula is the same as LPF: $fc = \frac{1}{2\pi RC}$

**EXAMPLE 03**

For the HPF circuit shown, Given $Vin = 2.0V_{rms}$, $R = 910\Omega$, $C = 0.1\mu F$.
Calculate:

1. Gain $AV = 1$
2. cut-off frequency $fc = 1.748$ kHz
3. Vout at $fc = 1.414$ Vrms
4. Vout at $fc/10 = 0.2$ Vrms
3. ACTIVE HIGH PASS FILTER (HPF) using Inverting Amplifier

**EXAMPLE 04**

For the HPF circuit shown, Given \( \text{Vin} = 1.5\text{Vrms}, \ R_1 = 1\, \text{k}\Omega, \ R_2 = 2.7\, \text{k}\Omega, \ C = 10\, \text{nF} \). Calculate:

1. Gain \( AV = -2.7 \)
2. cut-off frequency \( f_c = 15.9 \, \text{kHz} \)
3. \( V_{\text{out max}} = -4.05 \) \( \text{Vrms} \)
4. \( V_{\text{out at fc}} = -2.86 \) \( \text{Vrms} \)
5. \( V_{\text{out at 1.59kHz}} = -0.286 \) \( \text{Vrms} \)
4. Two Poles ACTIVE HIGH PASS FILTER (HPF)

- 2 resistors R3, R4 and two capacitors C1, C2
- If R3=R4 and C1=C2 then cut-off frequency is $f_C = \frac{1}{2\pi RC}$
5. BAND PASS FILTER (BPF)

![BPF Diagram]

- High Pass Filter Stage
- Amplification
- Low Pass Filter Stage

**Band Pass**

\[
\text{Band Pass} = \text{High Pass} + \text{Low Pass}
\]

- \( f_L \)
- \( f_H \)
5. **BAND PASS FILTER RESPONSE**

- Pass frequencies higher \( f_L \) and less than \( f_H \)
- \( BW \) (bandwidth) = \( f_H - f_L \)
- \( f_{\text{center}} = \sqrt{f_1 f_2} \)
- The quality \( Q = f_{\text{center}} / BW \)
- Quality \( Q \) controls the roll-off rate and the bandwidth of the filter
Inverting Band Pass Filter Circuit

Voltage Gain = \(-\frac{R_2}{R_1}\), \(fC_1 = \frac{1}{2\pi R_1 C_1}\), \(fC_2 = \frac{1}{2\pi R_2 C_2}\)
6. BAND STOP (Notch) FILTER RESPONSE

- Pass frequencies less than $f_L$ and higher than $f_H$
**Fig. 2-43** How cascading filter sections narrow the bandwidth and improve selectivity.
**Fig. 2-46** Butterworth, elliptical, Bessel, and Chebyshev response curves.
• **SUMMARY**

• **Active Low-Pass-Filter (LPF)**
  - Pass low frequency
  - One R and one C: One pole means down 20 dB/decade
  - Two R and 2 DC: Two pole means down -40 dB/decade
  - Three R and 3 DC: Three pole down -60 dB/decade
  - At cutoff frequency down – 3 dB or 70.7% Vout Maximum
  - Can be built as Unity Amp, Inverting Amp or Non-inverting Amp
• SUMMARY

• Active High-Pass-Filter (HPF)

- Pass high frequency
- One R and one C: One pole means down 20 dB/decade
- Two R and 2 DC: Two pole means down -40 dB/decade
- Three R and 3 DC: Three pole down -60 dB/decade
- At cutoff frequency down – 3 dB or 70.7% Vout Maximum
• **SUMMARY**

• **Band-Pass-Filter (BPF)**

- BPF pass all frequencies bounded by a lower-frequency limit and an upper-frequency limit, and reject all other lying outside this specified band.

Note:
- Q>10 Narrow band
- Q<10 Wide band
• SUMMARY
• Band-Stop-Filter (Notch Filter)