

Analog Circuits

For

EC / EE / IN

By



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Syllabus for Analog Circuits

Small Signal Equivalent Circuits of Diodes, BJTs, MOSFETs and Analog CMOS. Simple Diode Circuits, Clipping, Clamping, Rectifier. BIASING and Bias Stability of Transistor and FET Amplifiers. Amplifiers, Single-and Multi-Stage, Differential and Operational, Feedback, and Power. Frequency Response of Amplifiers. Simple Op-Amp Circuits. Filters. Sinusoidal Oscillators, Criterion for Oscillation, Single-Transistor and Op-Amp Configurations. Function Generators and Wave-Shaping Circuits, 555 Timers. Power Supplies.

Previous Year GATE Papers and Analysis

GATE Papers with answer key

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Subject wise Weightage Analysis

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Contents

Chapters	Page No.
#1. Diode Circuits-Anaylsis & Application	1 – 20
• Wave Shaping Circuit	1
• Linear Wave Shaping Circuits	1 – 9
• Non Linear Wave Shaping Circuits	9 – 13
• Rectifiers and Power Supplies	14 – 17
• Zener Voltage Regulator	18
• Solved Examples	18 – 20
#2. AC & DC Biasing-BJT's & FET	21 – 44
• Introduction	21 – 22
• Operating Point	22 – 27
• BIAS Stabilization	27 – 35
• Compensation Techniques	35 – 44
#3. Small Signal Modeling Of BJT & FET	45 – 69
• Introduction	45
• BJT Transistor Modeling	45 – 51
• The Hybrid Equivalent Model	51 – 55
• Characteristics of Amplifiers	55 – 61
• FET Small Signal Model	61 – 63
• Solved Examples	63 – 69
#4. BJT & JFET Frequency Response	70 – 86
• Introduction	70 – 72
• Low Frequency Response –BJT Amplifier	72 – 75
• Low frequency Response –FET Amplifier	76 – 80
• High Frequency Response –BJT Applfier	80 – 82
• High Frequency Response -FET Amplifier	82 – 86
#5. Feedback & Oscillator Circuits	87 – 108
• Classification of Amplifier	87 – 89
• Feedback Amplifiers	89
• Feedback Connection Types	89 – 93
• Various Types of Oscillators	93 – 97
• Tuned Oscillator Circuit	97 – 103

• Solved Examples	104 – 108
#6. Operational Amplifiers & Its Applications	109 – 157
• Differential Amplifiers	109 – 110
• Analysis of Differential Amplifier	110 – 111
• Common Mode Rejection Ratio (CMRR)	111 – 119
• Practical Op-Amp Circuits	119 – 135
• Astable Multivibrator (Square Wave Generator)	135 – 138
• Zero-Crossing Detector	138 – 148
• The 555 Timer	148 – 153
• Solved Examples	153 – 157
#7. Power Amplifiers	158 – 171
• Introduction	158 – 160
• Series –Fed Class Amplifier	160
• DC Bias Operation	161
• AC Operation	161 – 164
• Transformer Coupled Amplifier	164 – 165
• Push Pull Amplifier	165 – 166
• Transformer Coupled Push Pull Circuit	166 – 167
• Complementary –Symmetry Circuit	167 – 170
• Total Harmonic Distrtion	170 – 171
Reference Books	172

Diode Circuits - Analysis and Application

Learning Objectives

After reading this chapter, you will know

1. Wave Shaping Circuit
2. Clippers and Changers
3. Rectifiers and Power Supplies
4. Efficiency, Regulation, Ripple Frequency, Form Factor, Ripple Factor

Wave Shaping Circuits

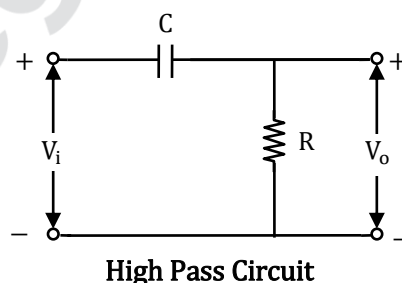
Wave shaping circuits are of two types

- (A) Linear wave shaping circuits
- (B) Non linear wave shaping circuits

Linear Wave Shaping Circuits

The process by which the wave form of non-sinusoidal signal is altered by passing it through the linear network is called the linear wave shaping.

High Pass Circuit



This circuit is called the high pass filter because it passes the high frequency components and attenuates the low frequency components.

For low frequency, the reactance of the capacitance is large.

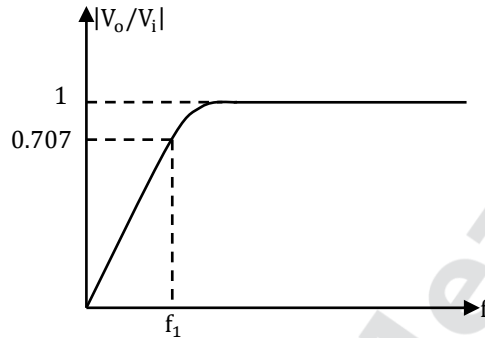
(a) Sinusoidal Input:

$$\frac{V_o}{V_i} = \frac{R}{R + 1/j\omega C} = \frac{1}{1 - j\frac{1}{\omega RC}}$$

$$\frac{V_o}{V_i} = \frac{1}{1 - j\left(\frac{f_1}{f}\right)}$$

Where, $f_1 = \frac{1}{2\pi RC}$

$$\left|\frac{V_o}{V_i}\right| = \frac{1}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}}, \angle \frac{V_o}{V_i} = -\tan^{-1}\left(-\frac{f_1}{f}\right) = \tan^{-1}\left(\frac{f_1}{f}\right)$$



Gain-Frequency Plot of High Pass Circuit

(b) **Step Input:**



Step Input

$$V_i(t) = V_c(t) + V_o(t), \dots\dots\dots (1)$$

$$V_i(t) = 1/C \int i dt + V_o(t) = iR, \dots\dots\dots (2)$$

$$\text{So } V_i(t) = 1/RC \int V_o(t) dt + V_o(t) = V u(t) \dots\dots\dots (3)$$

For step input $V_i(t) = \begin{cases} V & \text{for } t \geq 0 \\ 0 & \text{other wise} \end{cases}$

It is a single time constant circuit and a first order equation is obtained.

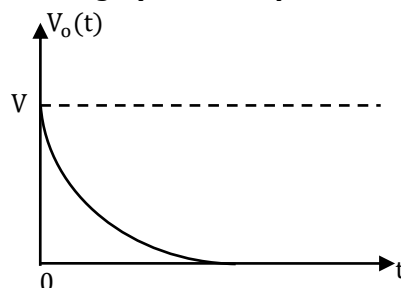
The general solution of any single time constant circuit can be written as,

$$V_o(t) = V_f + (V_i - V_f)e^{-t/\tau}, \dots\dots\dots (4)$$

Here, $V_f = 0$; $V_i = V$, $V_o(t) = Ve^{-t/\tau}$

Where $\tau = 1/RC$

For the circuit in high pass circuit fig, $V_f = 0$ and $V_i = V$ substituting in E.q., (4), we have

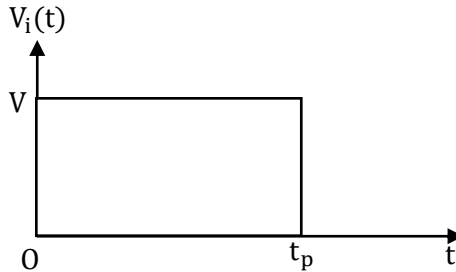


Output Voltage of High Pass Circuit When Input is a Step Voltage

(c) Pulse Input:

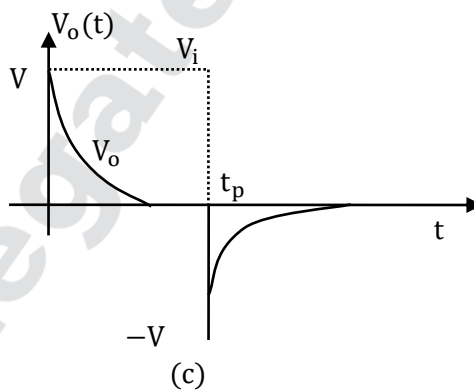
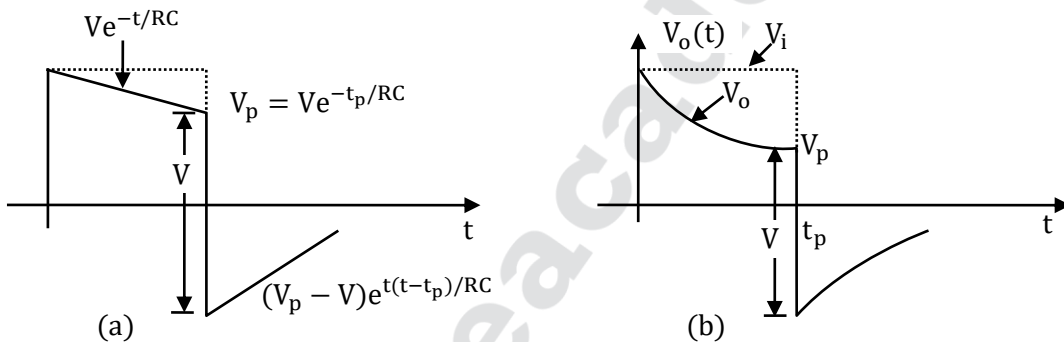
$$V_i(t) = V[u(t) - u(t - t_p)]$$

1. $V_o = Ve^{-t/\tau}, V_p = Ve^{-t_p/\tau}$
2. $V_o = V_2e^{-(t-t_p)/\tau}, V_2 = V_p - V$



Pulse Input Signal

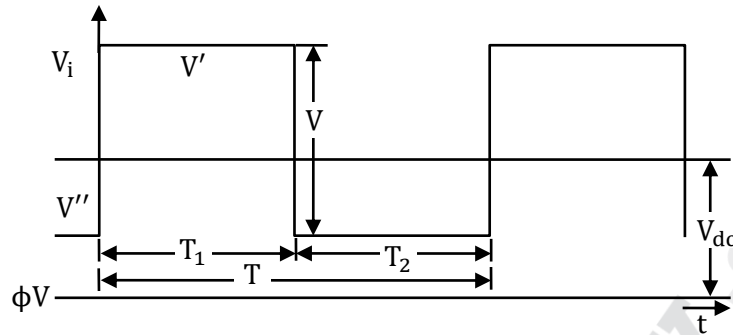
τ large \Rightarrow Slow response and
 τ small \Rightarrow Fast response



Output of High Pass Filter, When Input is a Pulse

For a low time constant the peak - to - peak amplitudes will be double. The process of converting pulses into spikes by means of a low time constant is called peaking. In high pass RC circuit, the average level of the output is always zero. The area above the zero axis should be equal to the area below the zero axis, $A_1 = A_2$.

(d) Square Wave Input:

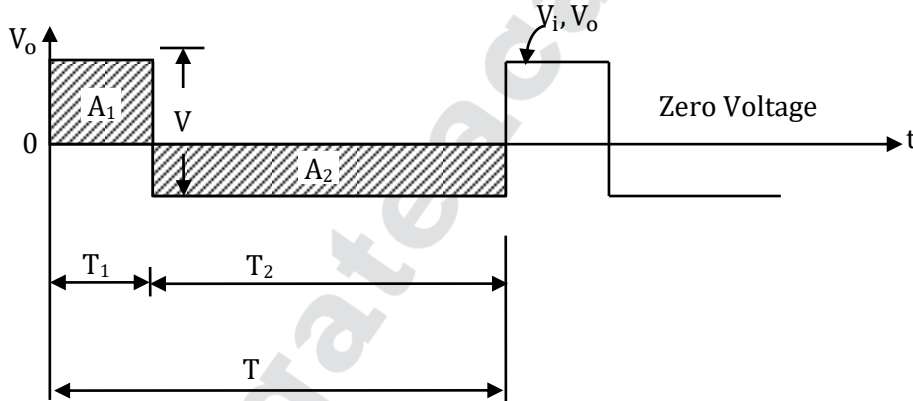


(a) Square Wave Input

A square wave is a waveform as shown in fig (a) which is periodic with time period T such that it maintains a level V' for time T_1 and V'' for time T_2 where $T = T_1 + T_2$.

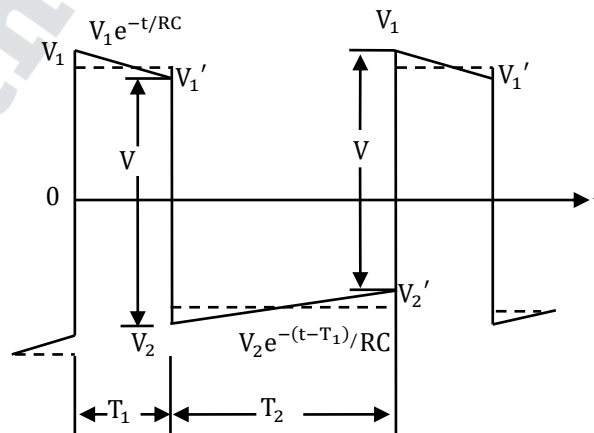
Figure (b) (c) (d) and (e) show output wave forms of the high pass RC circuit under steady-state conditions for the cases (i) $RC \gg T$ (ii) $RC > T$ (iii) $RC = T$ and (iv) $RC \ll T$

Case (i): For arbitrarily large time constant value, the output is same as that of input but with zero dc level.



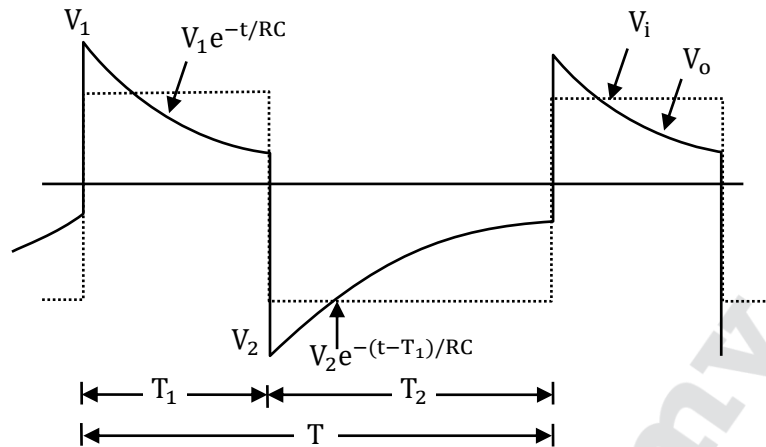
(b) Output When RC is Very Large

Case (ii): When $RC > T$, the output is in the form of a tilt.



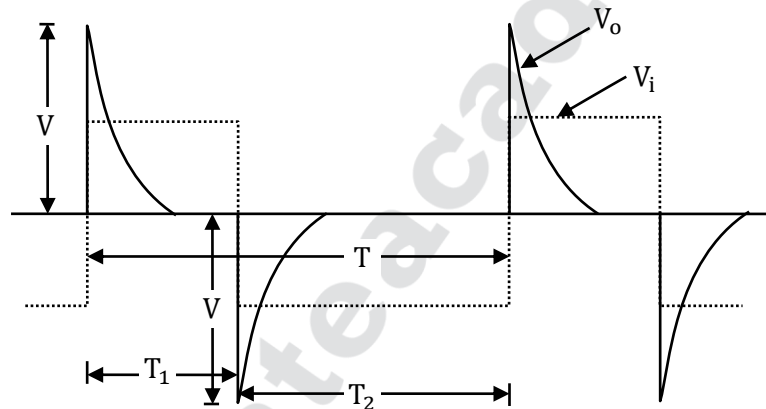
(c) Output When $RC > T$

Case (iii): When RC is comparable to T , the output rises and falls exponentially.



(d) Output When RC is Comparable to T

Case (iv): When $RC \ll T$, the output consists of alternative positive and negative spikes.



(e) Output When $RC \ll T$

More generally the response to a square wave must have the appearance shown below:

The four levels V_1, V_1', V_2, V_2' can be determined from (refer below figure)

$$V_1' = V_1 e^{-T_1/\tau}, V_1' - V_2 = V$$

$$V_2' = V_2 e^{-T_2/\tau}, V_1 - V_2' = V$$

For symmetrical square wave

$$T_1 = T_2 = T/2$$

$V_1 = -V_2, V_1' = -V_2'$ and the response is shown below in Fig. (b)

Percentage tilt 'P' is defined by

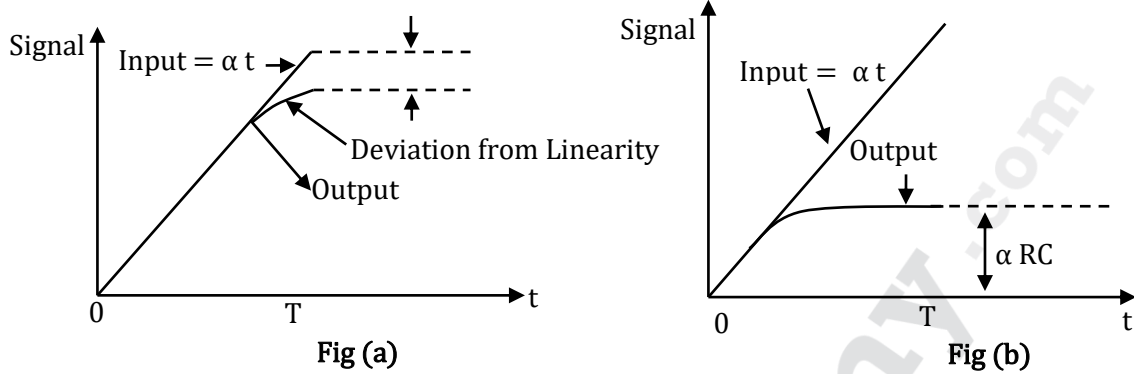
$$P = \frac{V_1 - V_1'}{V/2} \times 100 \approx \frac{T}{2\tau} \times 100 \%$$

$$= \frac{\pi f_1}{f} \times 100 \%$$

Where $f_1 = \frac{1}{2\pi\tau}$ and $f = \frac{1}{T}$

(e) Ramp Input

$V_i(t) = \alpha t u(t)$ and $V_o(t) = \alpha \tau (1 - e^{-t/\tau})$, are shown below,

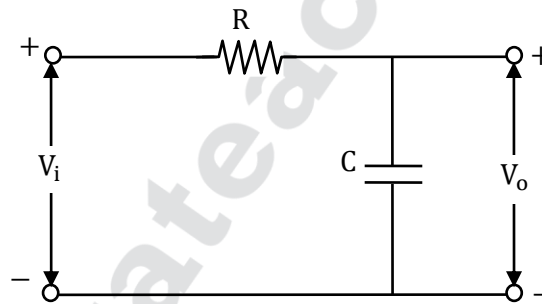


(a) Response of a High Pass RC Circuit to a Ramp Voltage for $RC/T \gg 1$;
(b) Response to a Ramp Voltage for $RC / T \ll 1$

For $t \ll \tau$, as a measure of departure from linearity, transmission error, e_t is defined as

$$e_t = \frac{V_i - V_o}{V_i}, \text{ At } t = T, e_t \approx \frac{T}{2\tau} = \pi f_1 T$$

Low Pass Filter



Low Pass Circuit

This circuit allows the low frequency components and attenuates the high frequency components.

$$X_c = \frac{1}{j\omega c} = \frac{1}{j2\pi f c}$$

At low frequency ($f \rightarrow 0$); $X_c \rightarrow \infty$

At high frequency ($f \rightarrow \infty$); $X_c \rightarrow 0$

So at low frequency capacitor behaves like open circuit so low frequency component passes to o/p

(a) Sinusoidal Input

$$\left| \frac{V_o}{V_i} \right| = \frac{1}{\sqrt{1 + (f/f_2)^2}}$$

$$\angle V_o / V_i = -\tan^{-1} \left(\frac{f}{f_2} \right), \text{ where } f_2 = 1/(2\pi RC)$$