

Solid State Relays & Its Applications

Presented By

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Course Objectives

- Know new techniques in relay industries.
- Understand the types of static relays and its components.
- Understand Digital relay fundamentals
- apply the different types of digital relays

Course contents

- Type of relay system
- General overview of static relays.
- Static Relay elements and design
- Computer applications to protective relaying.
- Digital relay fundamentals
- Mathematical Background of digital relay.
- Applications of Digital relay
- Advanced topics in relaying system


Course outcomes


- Based on NARS (National Accreditation reference Standard) the course should cover some intended learning outcomes

1- Knowledge and Understanding 

2- skills

– 1-Intellectual Skills 

– 2- Practical Skills 

– 3- General Skills 

Knowledge and understanding

- Understand electromechanical relays verses static and digital relay.
- Know recent developments in the area of microprocessor relays and protection systems.
- Demonstrate the utilization and various applications of digital relays in integrated apparatus protection.
- Know how to integrate protection and control in substations.
- Distinguish between different mathematical tools used in digital relay



Intellectual skills

- Determine the relay function and classify the relay types
- Determine the relay components
- Select the suitable mathematical tools to build digital relay algorithm
- Demonstrate the hardware and software of digital relay
- Report the main differences between digital and static relay
- Apply digital relay for different electric equipments



Practical (Professional) Skills

- Design a complete static relay
- Select the hardware that is suitable for use in digital relays effectively.
- Design a digital relay for different electric equipment.
- Differentiate between the suitable relay algorithm for a specified relay function
- Manipulate the measured signal numerically
- Performing laboratory experiments to get familiar with different types of protective relays



General skills

- Communicate effectively with colleagues and professional engineers to interchange knowledge and information in the power engineering field of practice.
- Prepare effective and informative technical reports and present results on electrical power engineering.
- Using information technology (IT) to follow the continuous advancement in electrical power innovations and technological applications.
- Practice digital relay operation and tuning

Lecture 1: Introduction

- Introduction to relaying system
- Multi-layer structure of power system
- Elements of protection system
- Type of protection devices
- Type of relaying system

Protective Relaying

- Power system is an essential and the main stem of modern industrial society, therefore increasing availability, safety and quality of power system is mandatory .
- The power system is always subject to almost un-measurable and unpredictable disturbances created by different abnormal reasons such as:
 - random load changes
 - Equipment and operator failure
 - Faults due to natural causes

Protective Relaying

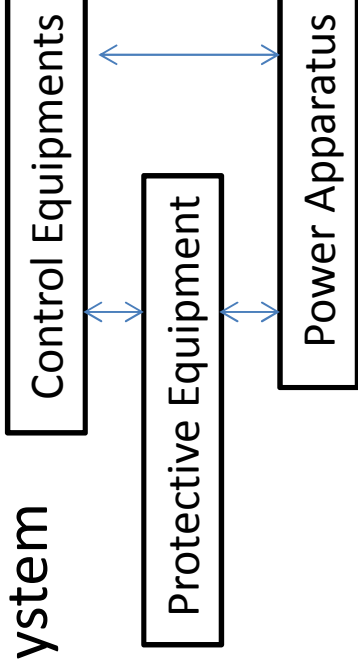
- The function of protective relaying is to promptly remove from service any element from the power system that starts to operate in an abnormal manner.
- The purpose is
 - Limit further damage of equipment
 - Minimize danger to people
 - Reduce stress on other equipments
 - Maintain integrity and stability

- Protective relaying is a device that detects abnormal power system conditions and initiates a corrective action as fast as possible in order to return the power system to its normal state . The response must be automatic, quick and cause minimum a mount of disruption of power system
- Main requirements of protective system
 - Quick response
 - Correct diagnosis of trouble
 - Minimum disturbance to power system
 - Absolute discrimination
 - Sensitive and accurate
 - Reliable
 - Stable

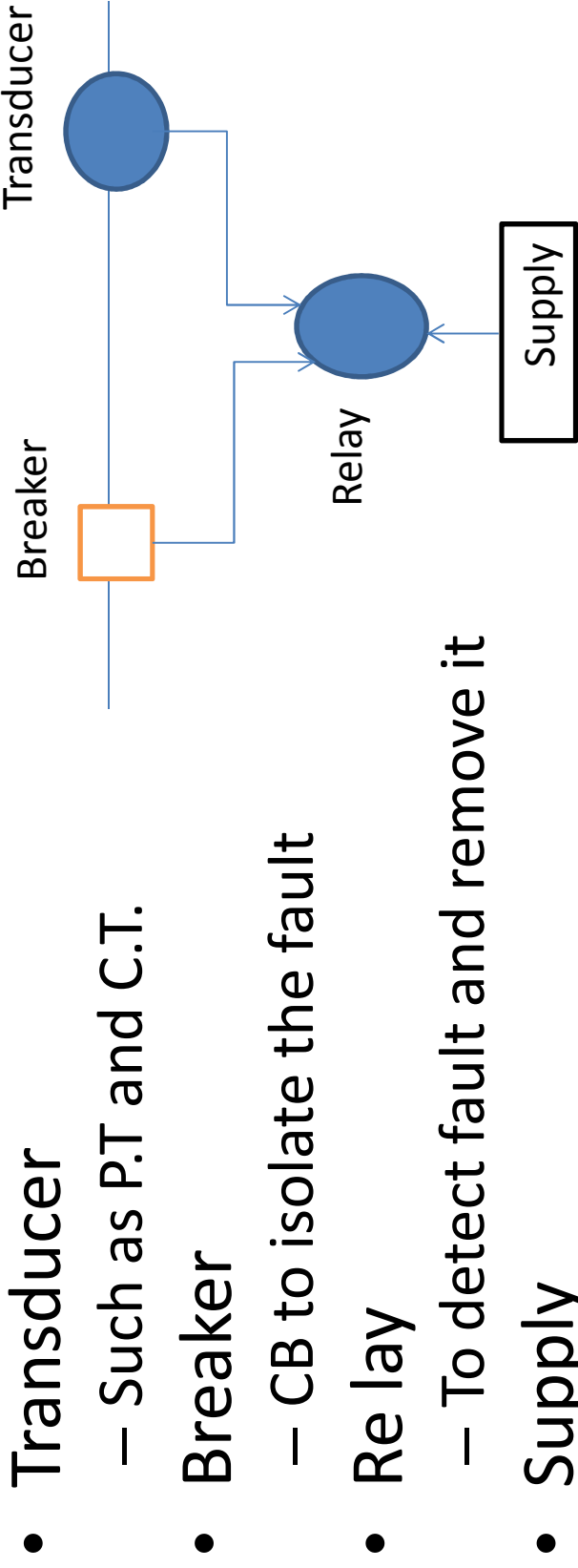
Therefore expensive and sophisticated equipment is needed to accomplish these tasks.

Multi-layer structure of power system

- Three layered structure of power system
 - Apparatus such as (generator, Transformer, etc.)
 - Control Eq. which control voltage, frequency, power, optimal economic and security in interconnected network
 - Relay: more fast than control and it acts to open and close Circuit Breaker (CB), which leads to changing structure of power system. While control acts continuously adjust system variations.



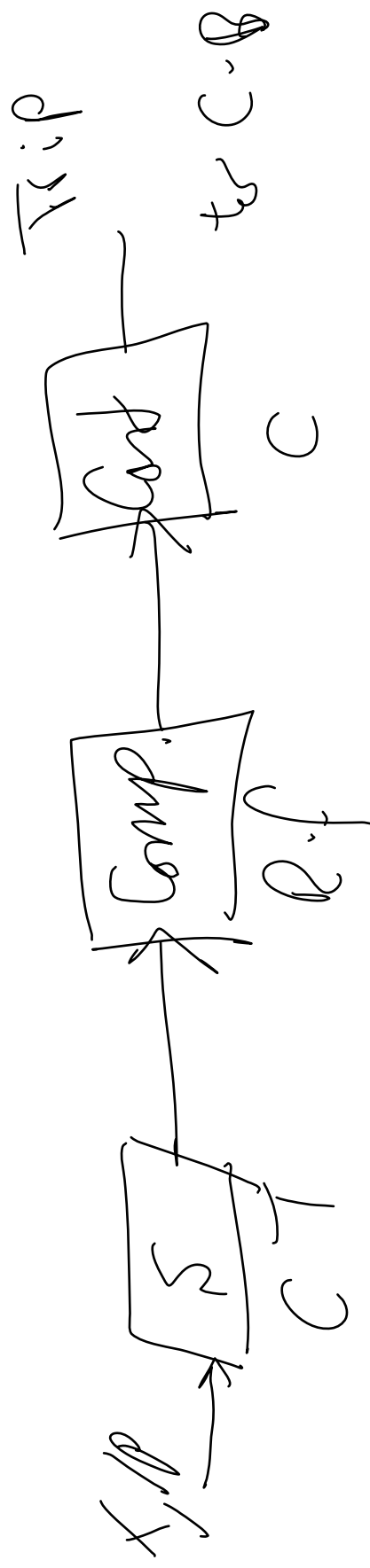
Elements of a Protection system



- **Transducer**
 - Such as P.T and C.T.
- **Breaker**
 - CB to isolate the fault
- **Re lay**
 - To detect fault and remove it
- **Supply**
 - To produce tripping power of breaker and operate relay
 - Should be uninterrupted such as batteries and UPS

Relay Construction

- Based on the elements of protection system the relay construction can be divided into three subsystem
- Sensing
- Comparison
- Control action (trip)



Relay Function

- The relay function is depending on the abnormal situation that should be protected so, the relay may be
 - Over load
 - Over and under voltage
 - Over and under frequency
 - Reverse power
 - Short circuit
 - Etc.
- The selection of relaying function depends mainly on the equipment that should be protected

Relay Types

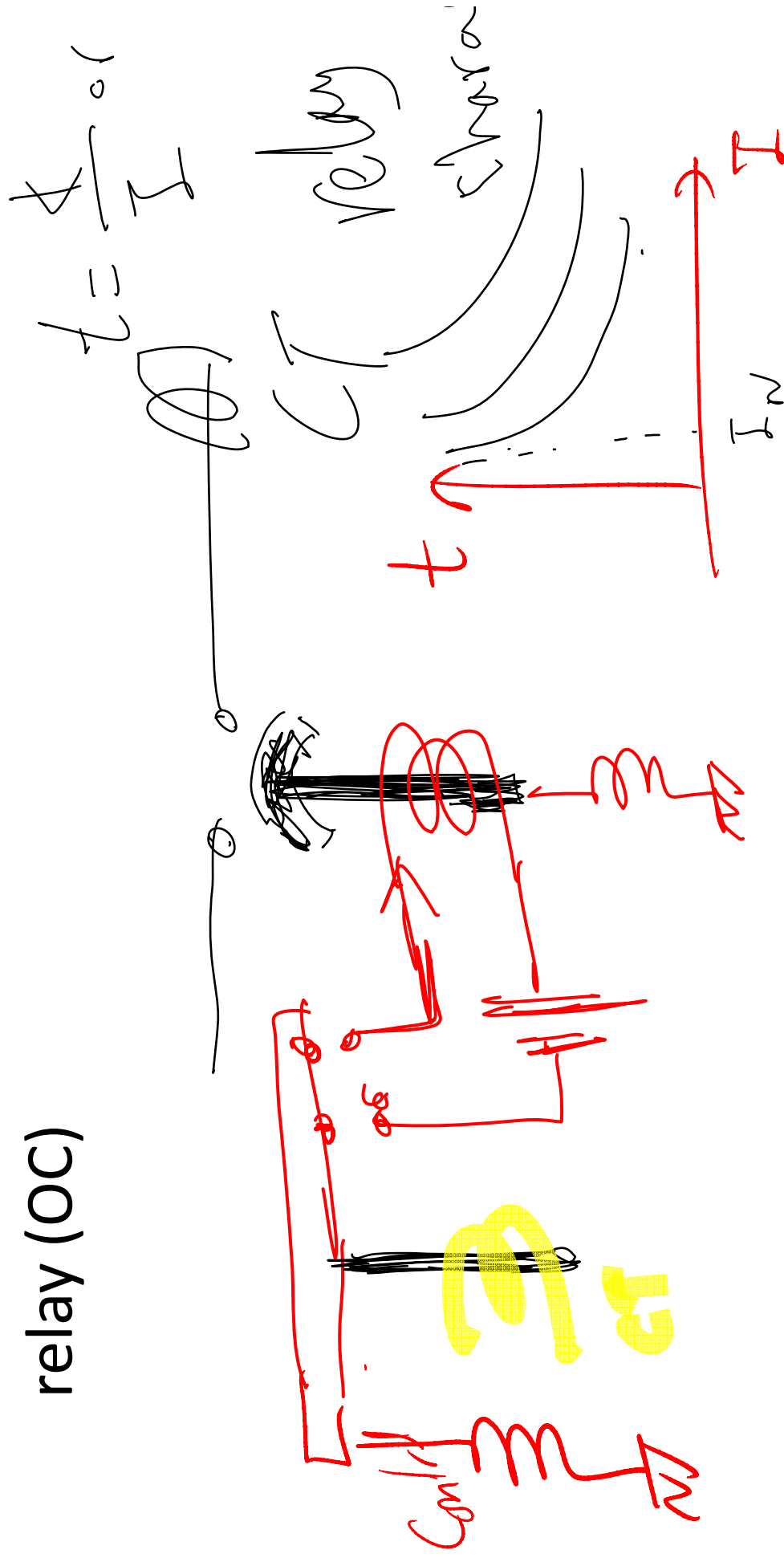
- The relay types can be classified based on the techniques used to perform its function such as
 - Conventional (Electro-mechanical relay)
 - Solid state relay
 - Digital relay

Conventional relay

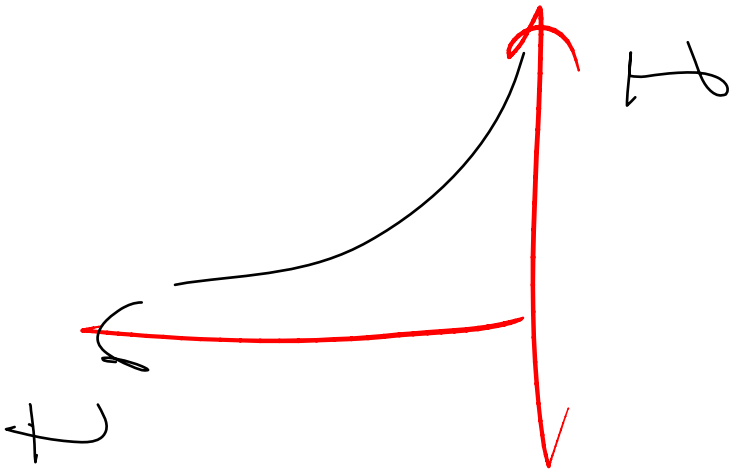
- It is an electro-mechanical device, it has the advantage that
 - Robust
 - Easy to maintenance
 - While it has disadvantage
 - Large size
 - High power consumption
 - It depends on moving parts which need more maintenance
 - Each relay perform a single function

Example

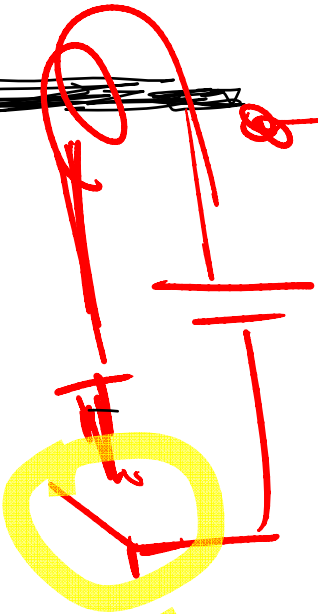
- Discuss the basic structure of over current relay (OC)



CT
A



Builds ϵ



opening
switch



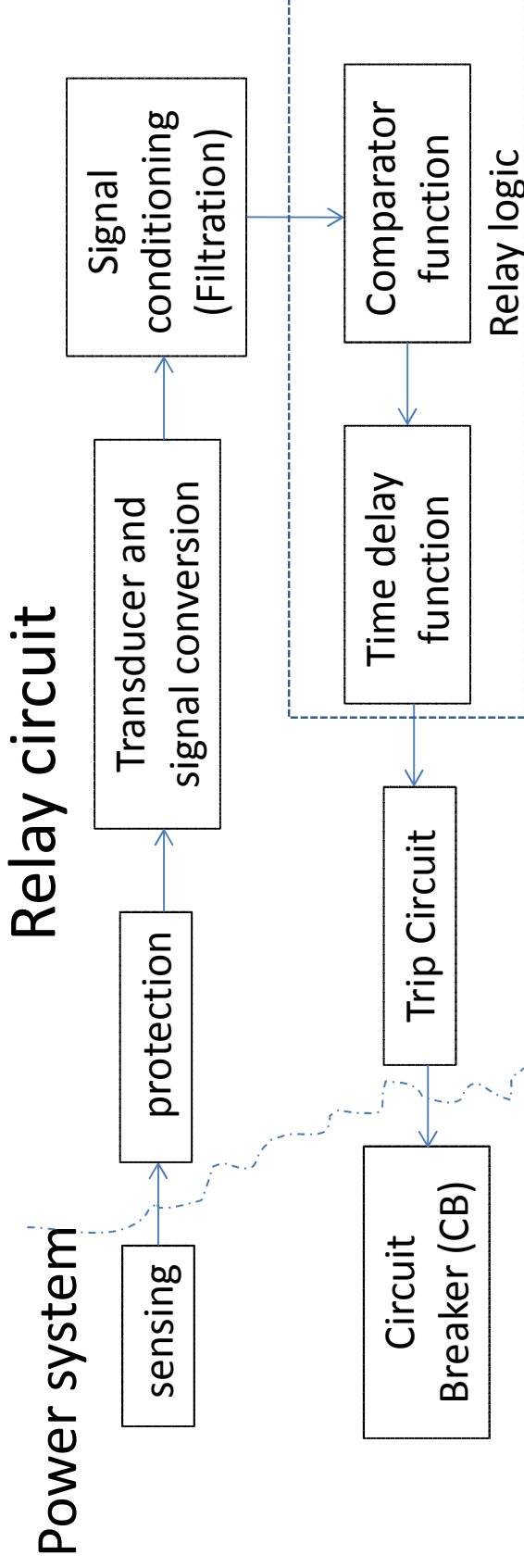
Lecture 2: Solid state relay

Fundamentals

- Basic fundamental of static relay
- Logic Signal conditioning
- Analog Signal Conditioning
- Comparator circuits
- Time delay circuit
- Example of static relay

Solid State Relay

- It has no moving parts most of its components are static device based on semi-conductor materials.
- The main parts



Solid State Relay

- 1- Sensing: voltage and current sensors such as CT and PT
- 2- Protection: Zener diode, current limiter, etc...
- 3- Transducer: such as hall transducer, F/V, AC-DC, etc...
- 4- Signal conditioning: Low pass filter,...
- 5- Comparer: voltage and current comparators, ...
- 6- Time delay circuit: trip time calculation circuit
- 7- Trip circuit: Signal conditioning to operate CB

Solid State Relay

- **Advantages:**
 - Small size
 - Easy to mounted
 - Fast response
 - Low power consumption
 - No moving parts(less maintenance)
 - Can perform more sophisticated function
- **Disadvantages**
 - Less robust to vibration & Temp.
 - Different circuit for different function
 - Less flexible

Signal Conditioning

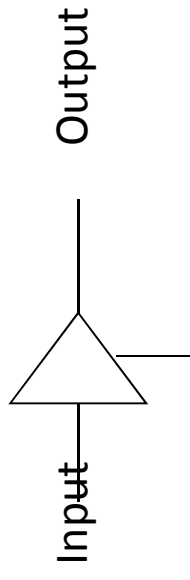
- It is the Adjustment of signal to be suitable to the next stage (controller, display, etc...) for example
 - Amplification
 - Attenuation
 - Filtration
 - Isolation
 - Linearization
 - Excitation
 - Conversion
 - Etc.
- Analog signal conditioning
- Binary signal Conditioning
- Digital Signal Conditioning

Logic Signal Conditioning

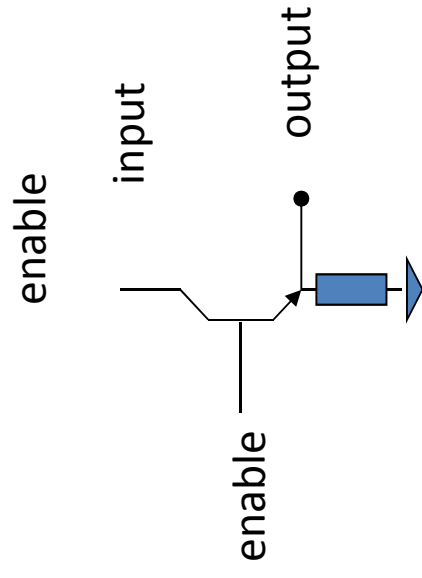
- Two state signal (high-low)
 - High: 5v, 12V, 24v (dc)
 - 24, 110, 220 v (ac)

- Buffer (Isolation)

- Tri-state buffer

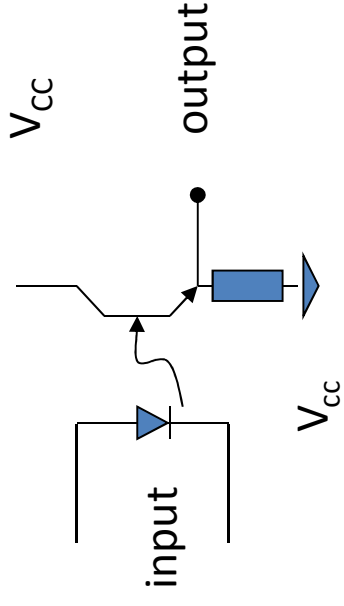


- Using Transistor

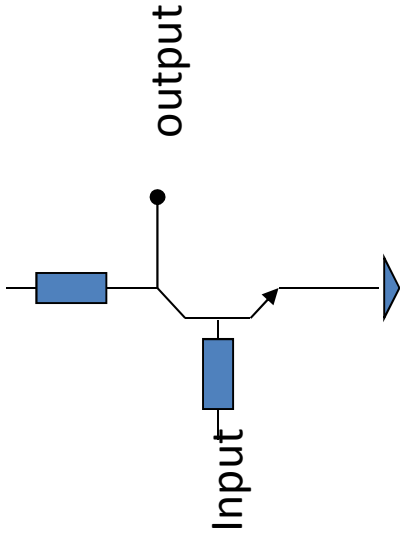


Logic Signal Conditioning (cont.)

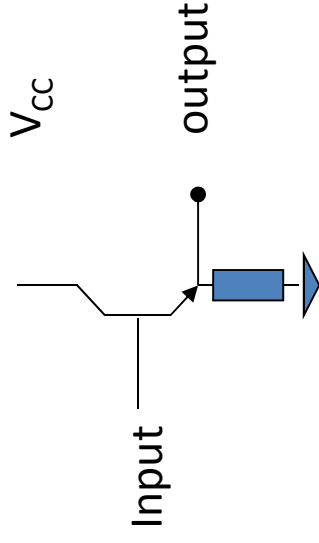
- Opt. isolation
 - Photo Diode
 - Photo transistor
 - Photo triac
- Relay



• 2. Inverter

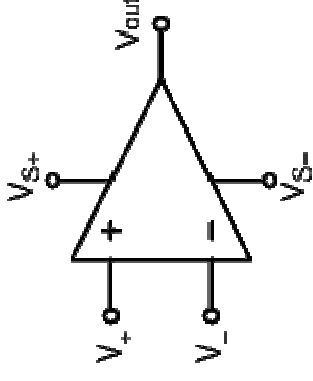
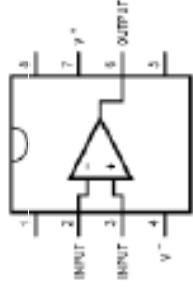
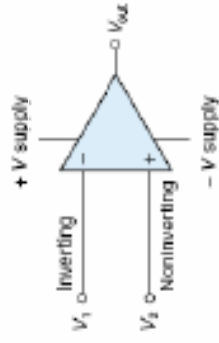


• 3. Amplifier



Analog signal Conditionig

- It Depends mainly on OP-Amp

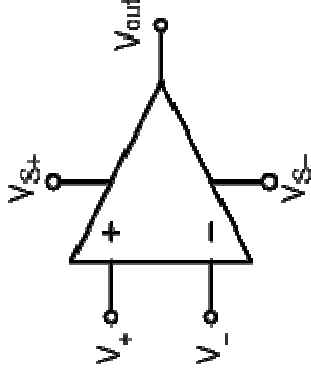


$$V_{out} = A(V_2 - V_1)$$

- V_{out} = Output voltage.
- A = Open-loop gain.
- V_1 = Inverting input.
- V_2 = Noninverting input.

Analog signal Conditionig

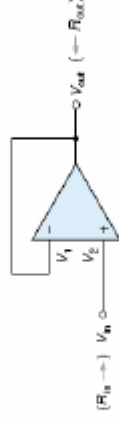
- It Depends mainly on OP-Amp



- Unity Gain

❖ Buffer

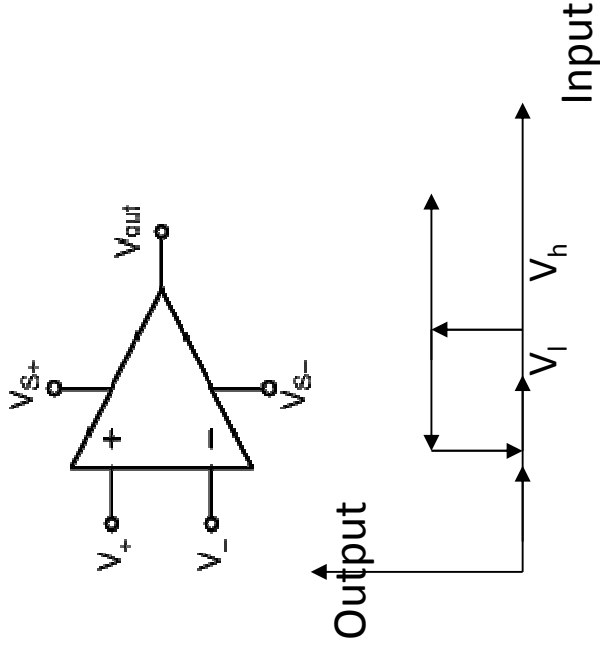
$$V_{out} = V_{in}$$



The buffer can be used to keep the voltage level constant but increasing the current (take the current from the power supply circuit)

Analog Signal Conditioning (Cont.)

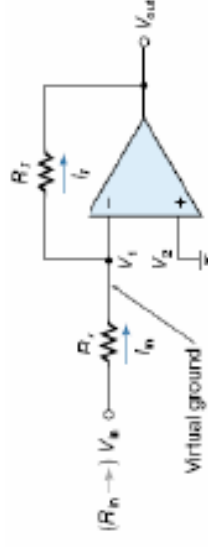
- Addition and subtraction
- Integrator
- Linearization
- Comparator
 - Normal comparator
 - Hysteresis



Analog signal conditioning

❖ Inverting Amplifier

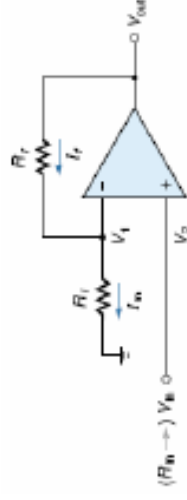
$$V_{\text{out}} = -V_{\text{in}} (R_f / R_i)$$



The inverting amplifier can amplify the signal with certain gain but with inverting the polarity of the input signal.

❖ Non-inverting Amplifier

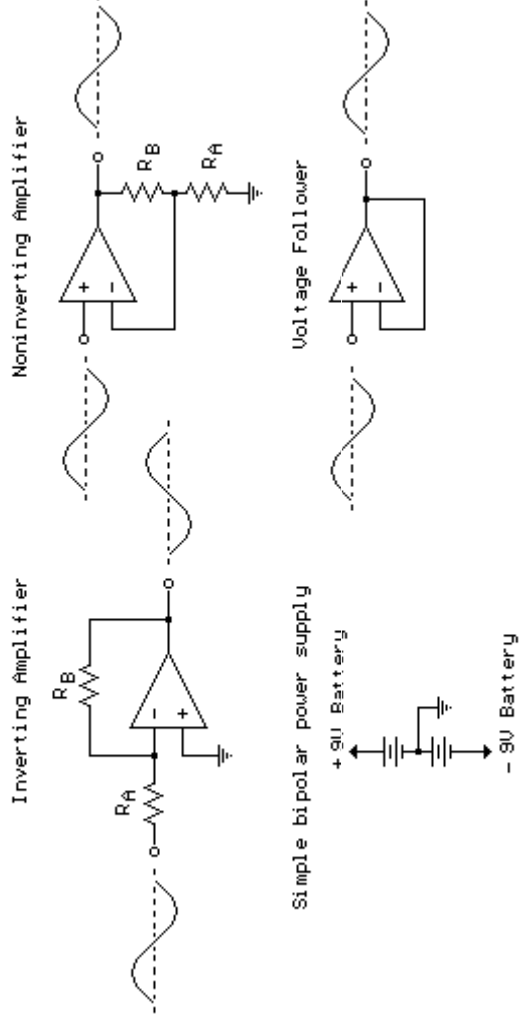
$$V_{\text{out}} = V_{\text{in}} ((R_f / R_i) + 1)$$



The non-inverting amplifier can amplify the signal with certain gain with the same polarity of the input signal.

Analog signal Conditionig

- Unity Gain
- Amplifier



Analog Signal Conditioning (Cont.)

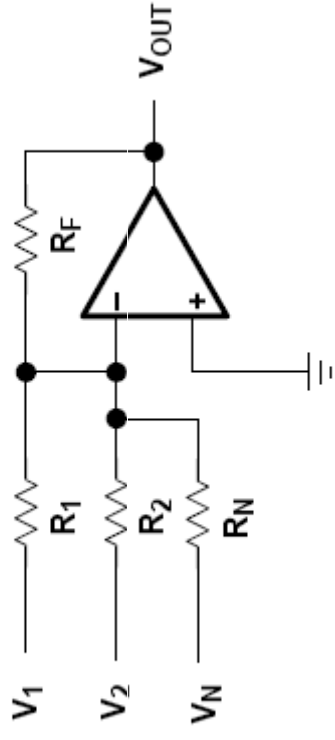
- Addition and subtraction

$$V_{\text{OUTN}} = -\frac{R_F}{R_N} V_N$$

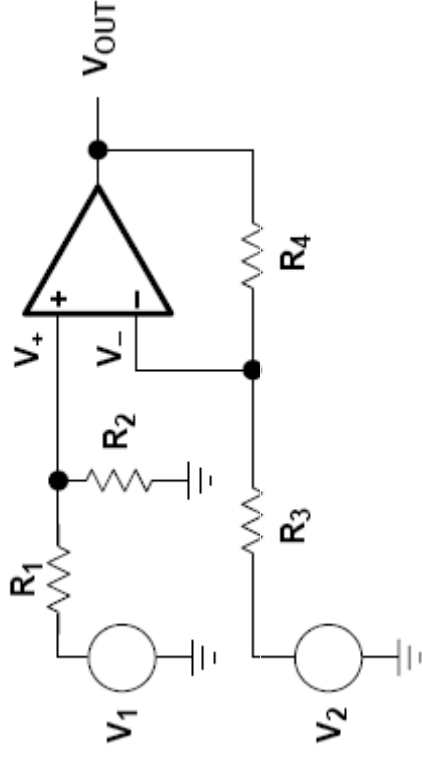
$$V_{\text{OUT1}} = -\frac{R_F}{R_1} V_1$$

$$V_{\text{OUT2}} = -\frac{R_F}{R_2} V_2$$

$$V_{\text{OUT}} = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \frac{R_F}{R_N} V_N\right)$$



Differential amp



$$V_{+} = V_1 \frac{R_2}{R_1 + R_2}$$

$$V_{\text{OUT}1} = V_{+}(G_{+}) = V_1 \frac{R_2}{R_1 + R_2} \left(\frac{R_3 + R_4}{R_3} \right)$$

$$V_{\text{OUT}2} = V_2 \left(-\frac{R_4}{R_3} \right)$$

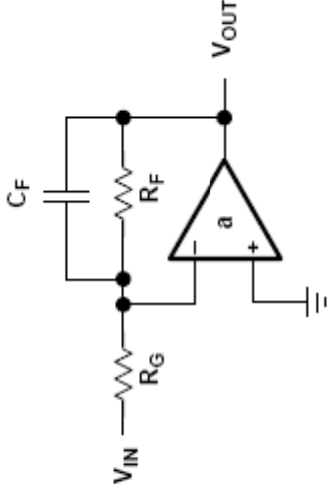
$$V_{\text{OUT}} = V_1 \frac{R_2}{R_1 + R_2} \left(\frac{R_3 + R_4}{R_3} \right) - V_2 \frac{R_4}{R_3}$$

When $R_2 = R_4$ and $R_1 = R_3$, Equation 3–13 reduces to Equation 3–14.

$$V_{\text{OUT}} = (V_1 - V_2) \frac{R_4}{R_3}$$

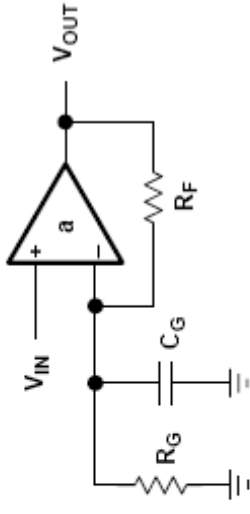
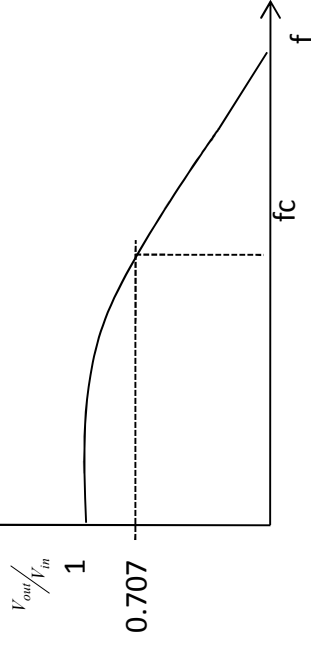
Analog signal conditioning

Analog filters



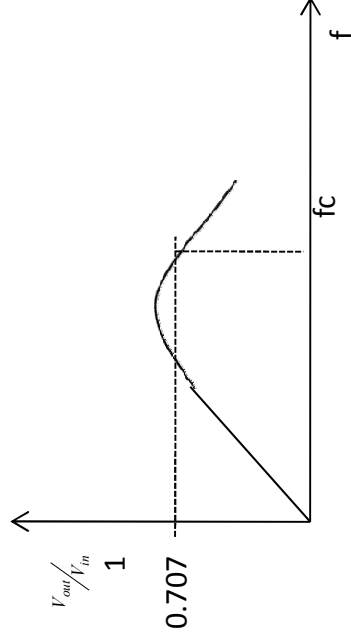
Low-Pass Filter

$$\frac{V_{OUT}}{V_{IN}} = - \frac{X_C \parallel R_F}{R_G}$$



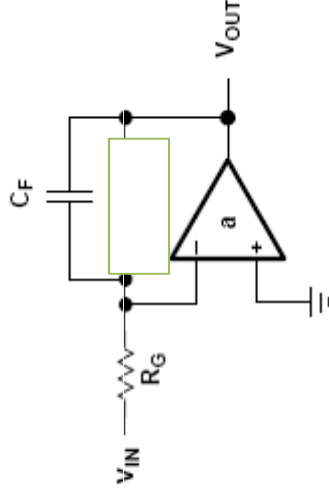
High-Pass Filter

$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_F}{X_C \parallel R_G}$$



Analog signal conditioning

- Signal Integration



$$V_o = -\frac{1}{R_G C_F} \int_0^t V_i(t) dt$$

Analog signal conditioning

- Signal Conversion
 - Current to voltage
 - Voltage to current
- Assignment
 - Write a report about voltage-to-current and current-to-voltage methods

Comparator Circuit

- Amplitude (Direct or Integration)
- Phase (Direct or Integration)
- Hybrid (Direct or Integration)

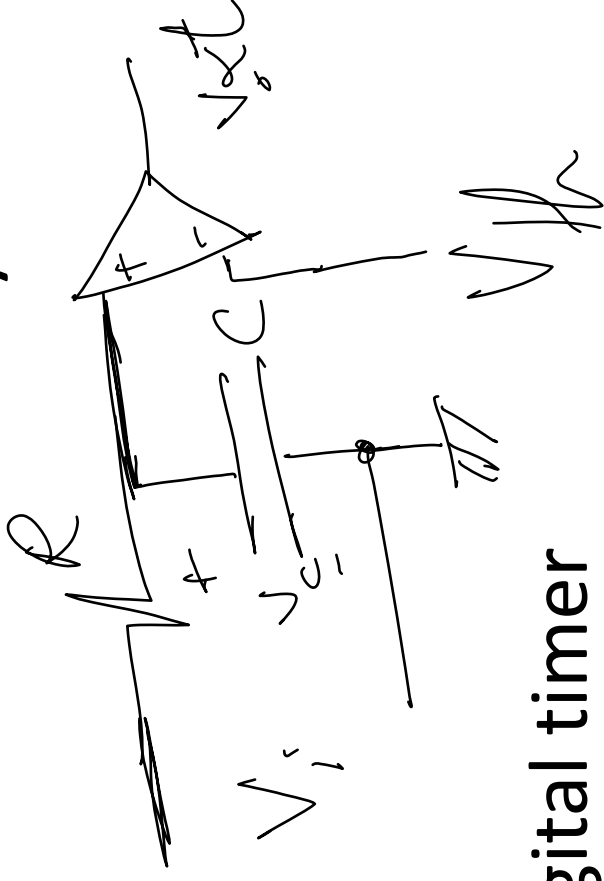
Time delay Circuit

- The simple circuit to generate time delay is

RC circuit $-t/RC$

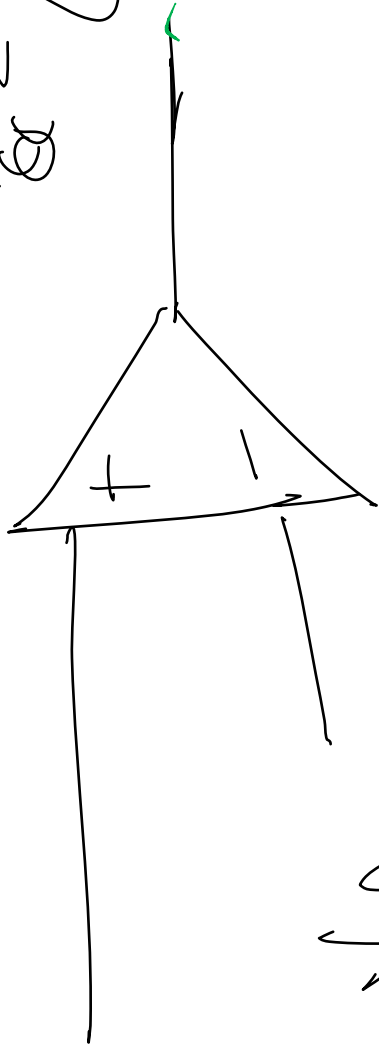
$$V_c = V_i (1 - e^{-t/RC})$$

$$t = RC \log \left(\frac{V_i}{V_i - V_c} \right)$$

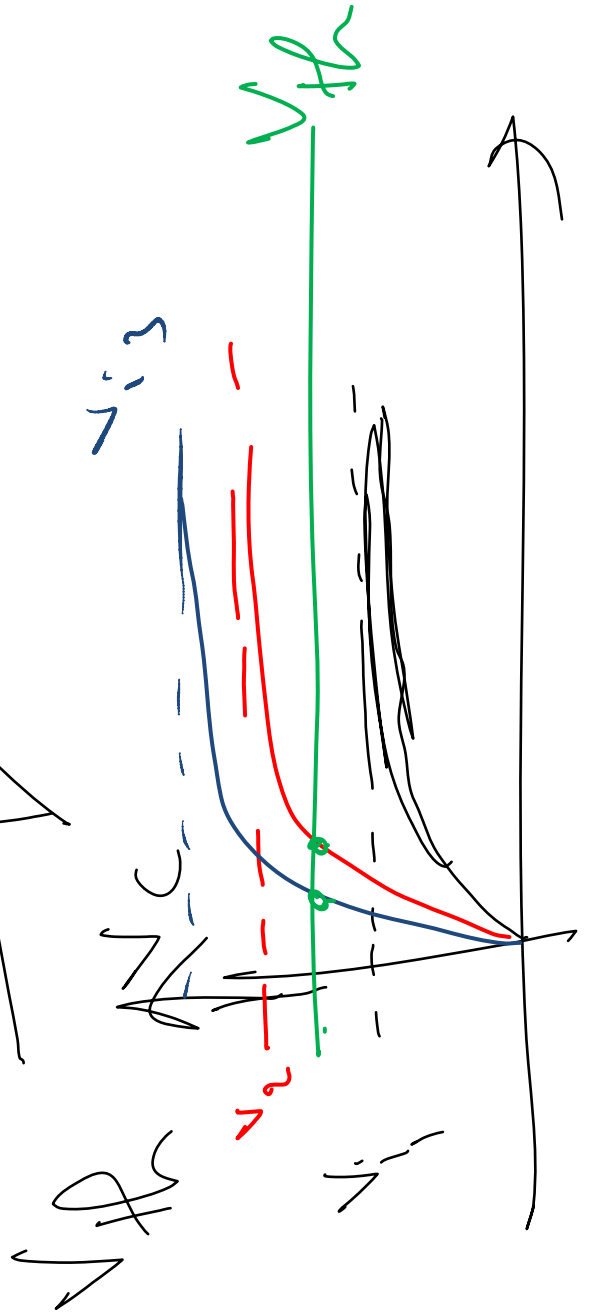


- It can be built using digital timer

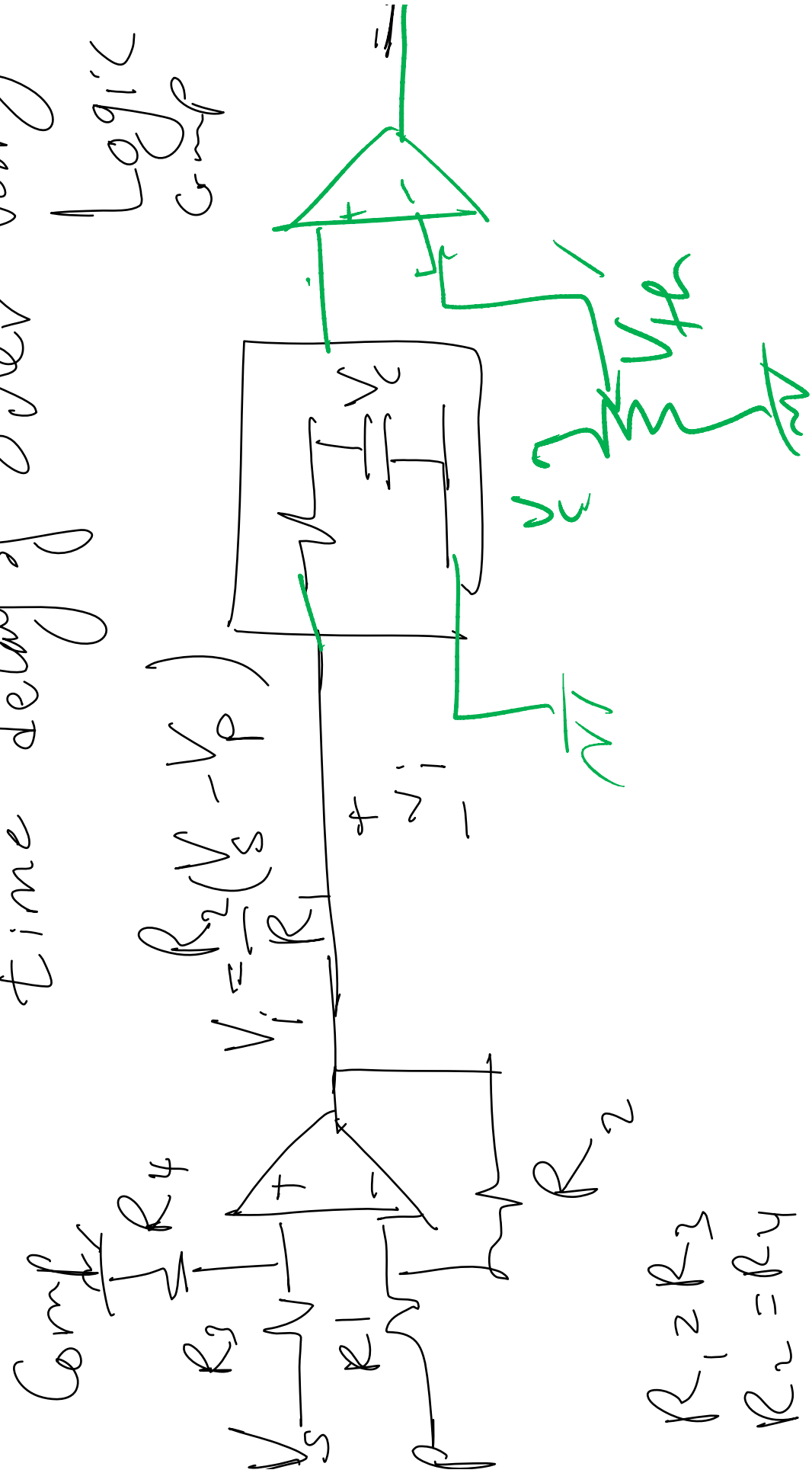
V_{ce2} } $+V_{ce2}$ ✓
 $-V_{ce2}$ ✓



V_c



time delay of over voltage
Logic Comp



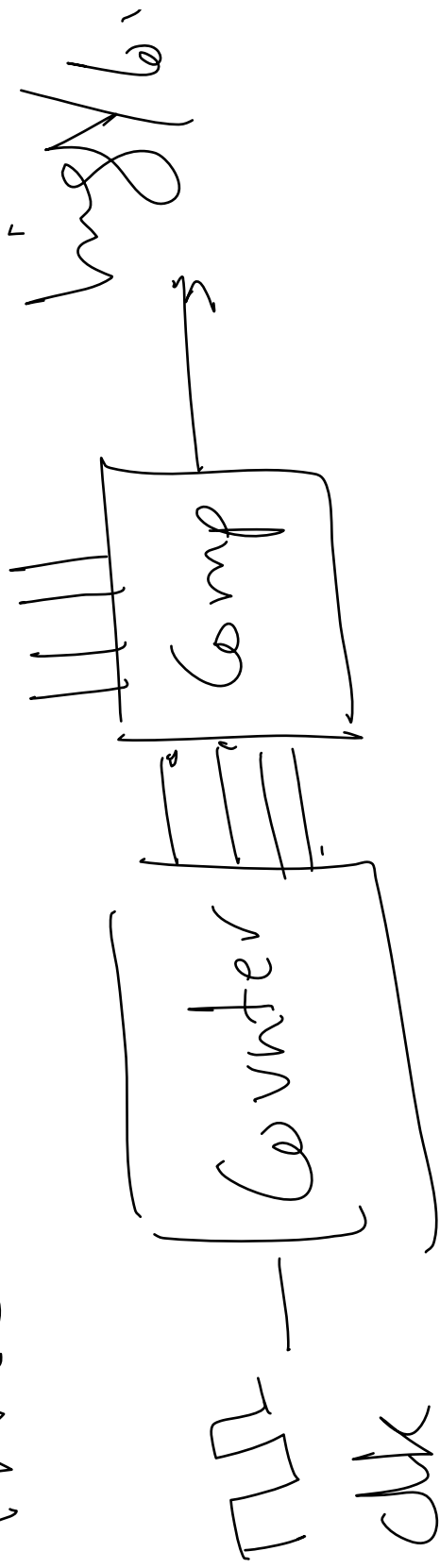
$$V_i = \frac{R_2}{R_1} (V_s - V_p)$$

$$R_1 = R_3$$

$$R_2 = R_4$$

Timer

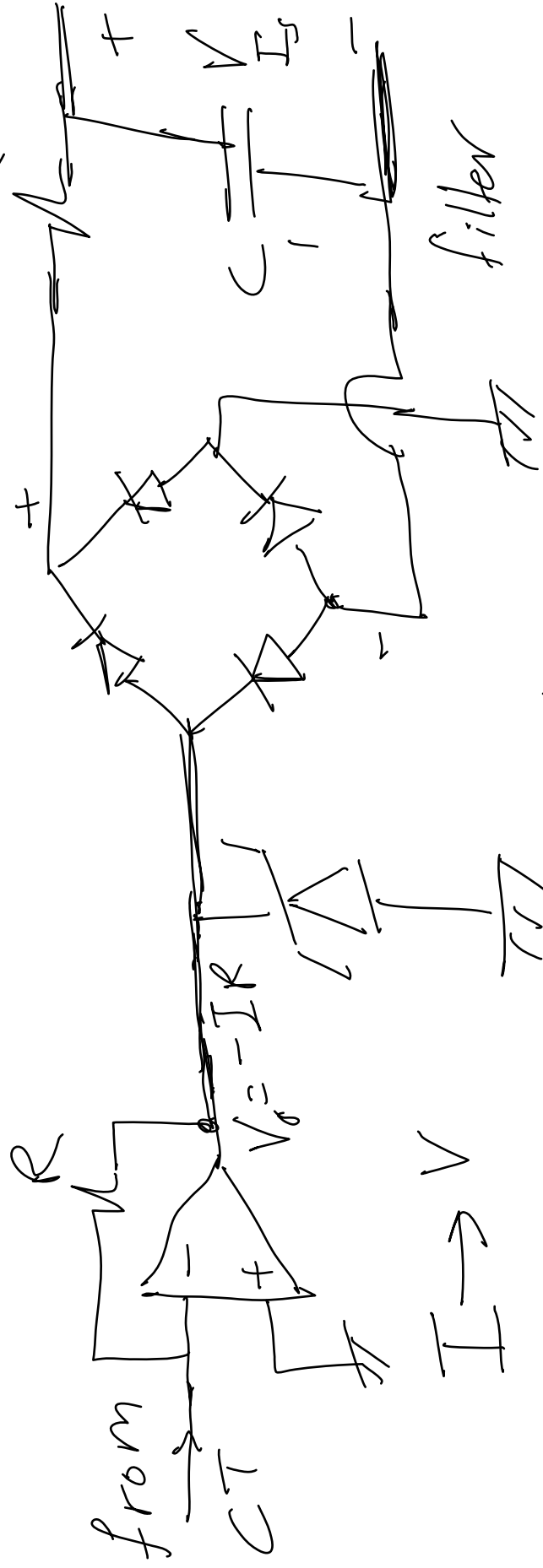
Count = 10 (Variable)



1MHz

it is required to generate 10ms delay

Example: over current relay

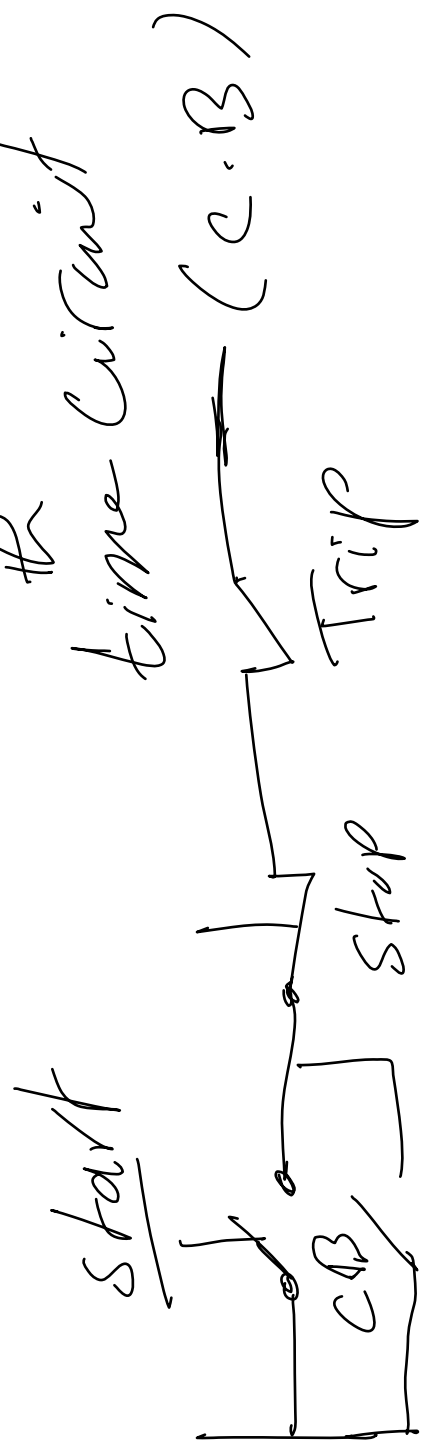


or Hall
Sensors
protection red.



Comparator

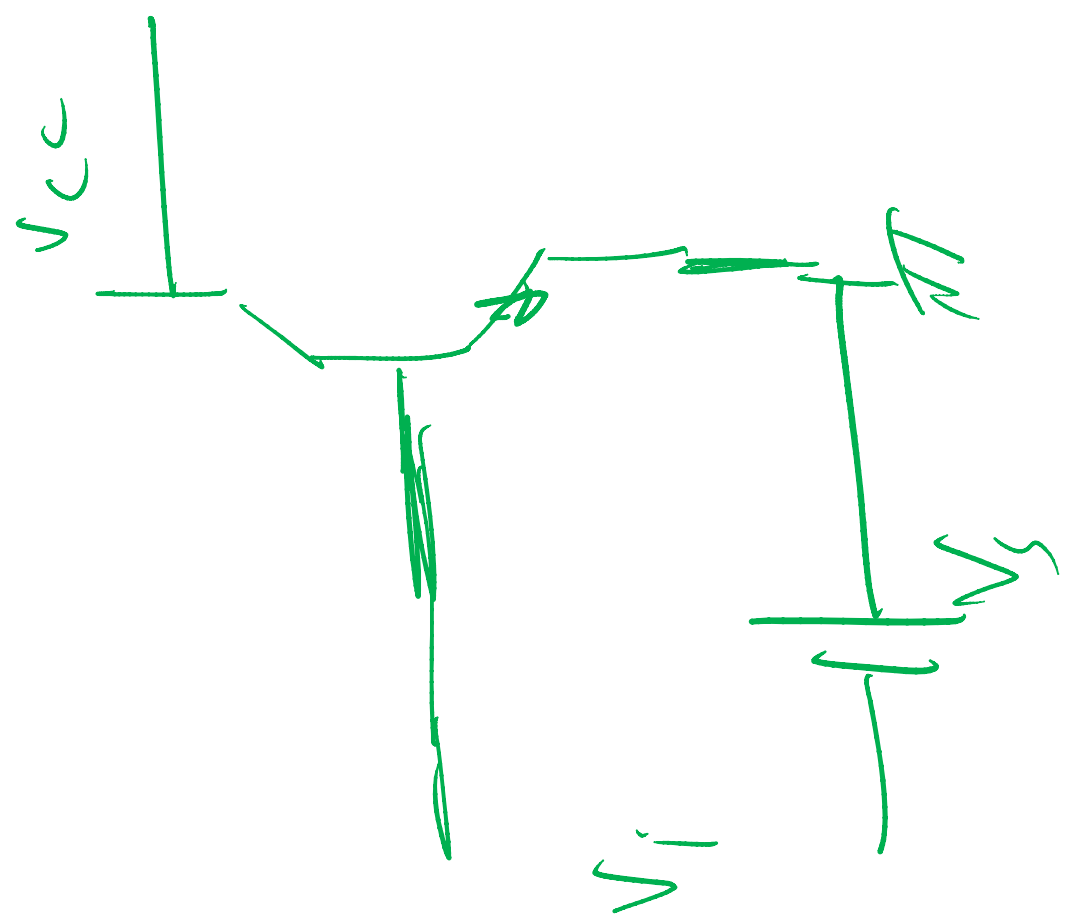
N^{th} time circuit





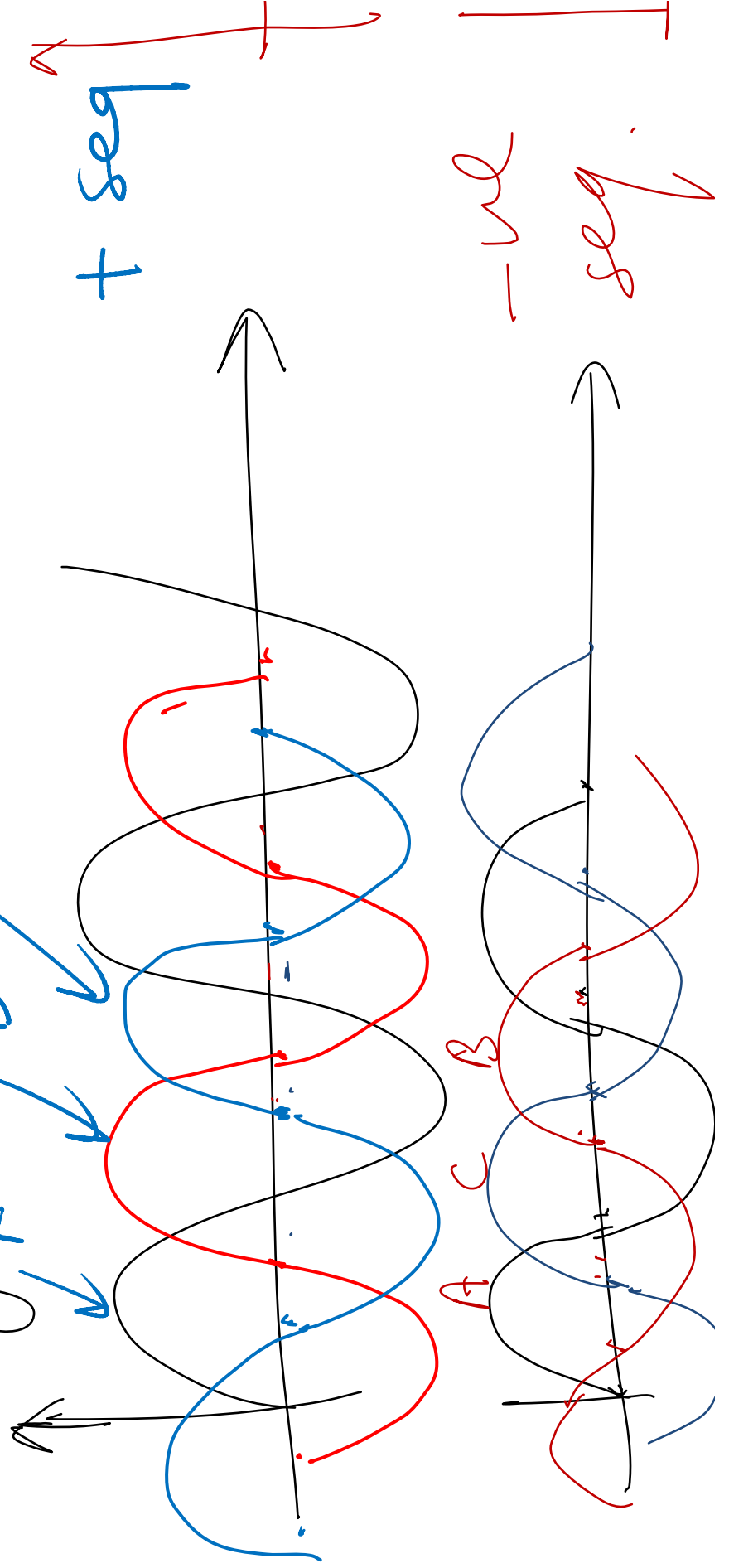
$V_o = V_{CC}$

$V_i < V_o$



2.

Design a phase sequence Relay.

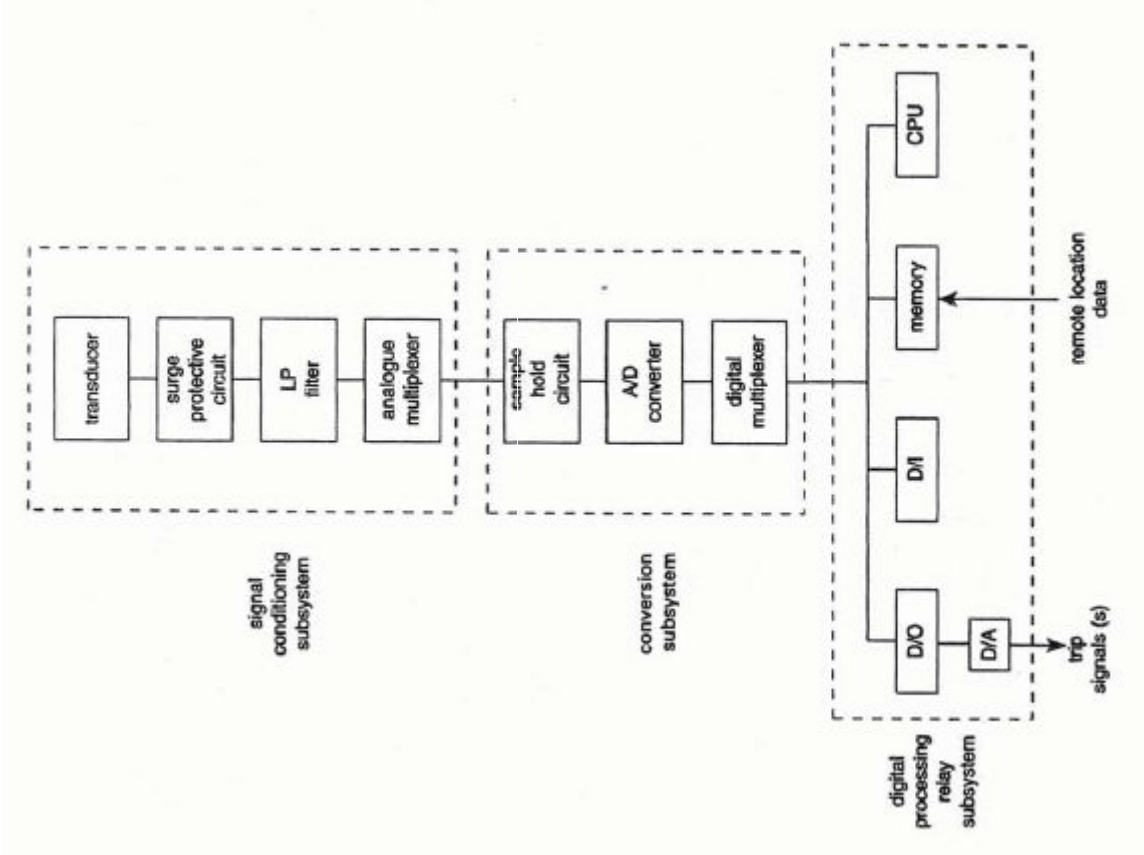


Digital Relay Fundamentals

- Introduction
- Digital relay components
- Mathematical background
 - How to implement discrete differentiation and integration
 - How to estimate a value between two sample or predict a value in the future

Introduction

- Background
- Advantages of digital relay
- Overview of Digital relay structure



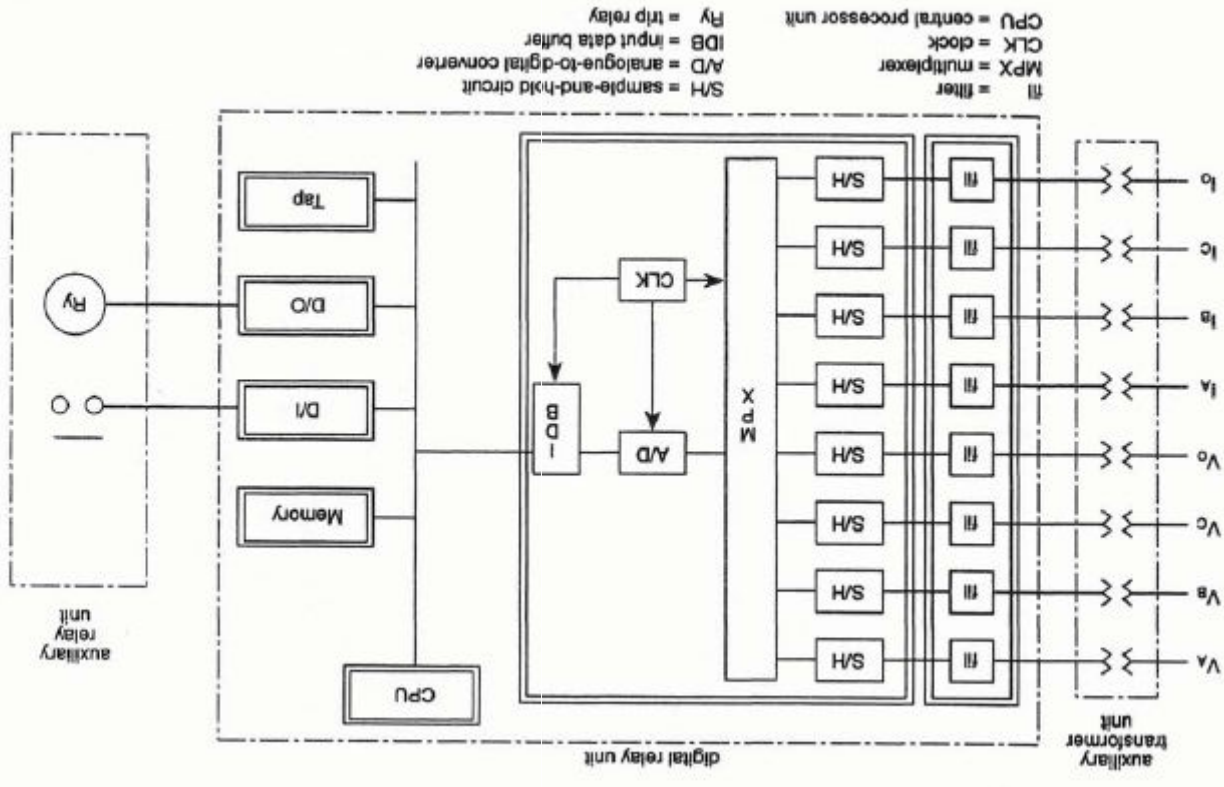


Figure 3.16 Digital relay unit

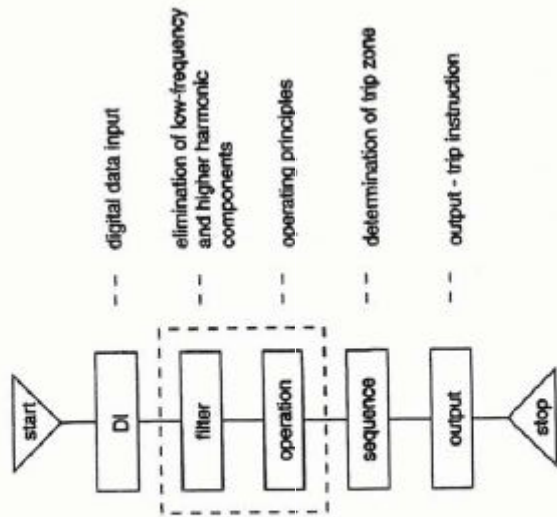


Figure 3.15 Flow chart for the software of a digital protective relay

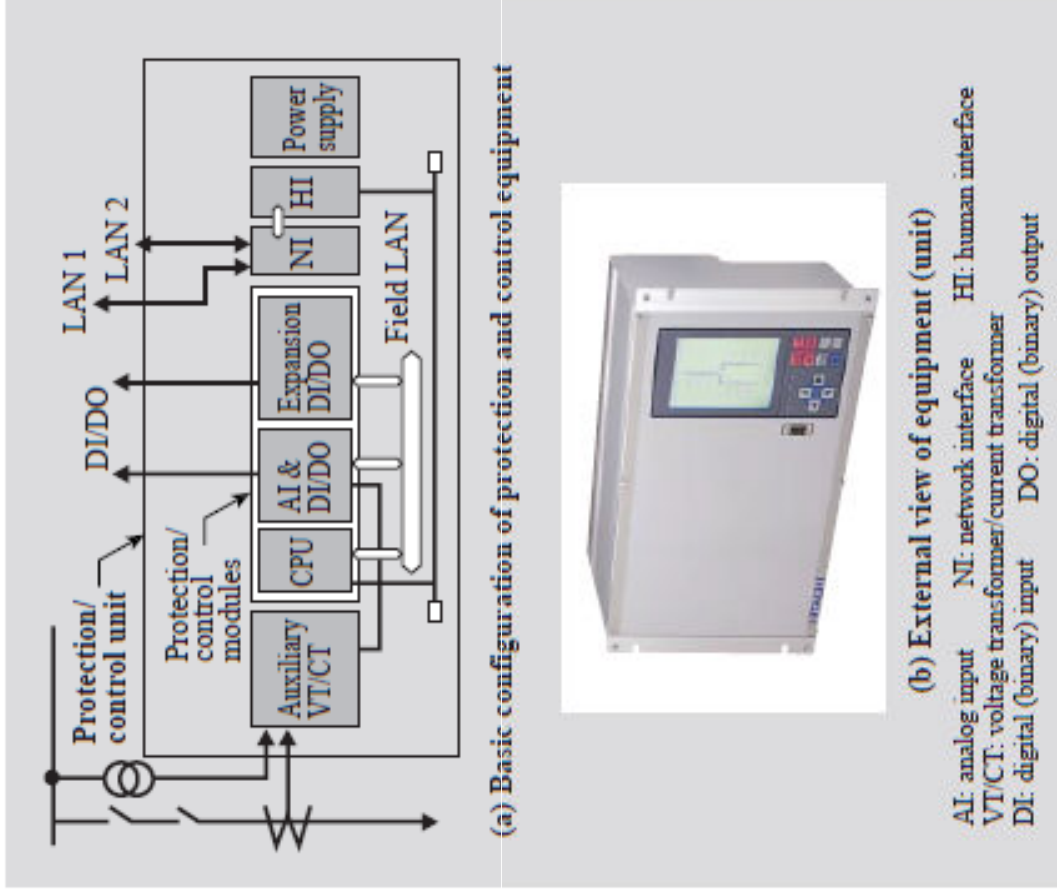


Fig. 1— Basic Configuration and External View of Compact-Type Digital Protection and Control Equipment for Power Systems.

Difference equation

1. Backward differences

1. For continuous function $f(t)$

2. $f_k = f(t_0 + kh)$

3. $\nabla f_k = f_k - f_{k-1}$

4. $\nabla^n f_k = \nabla^{n-1} f_k - \nabla^{n-1} f_{k-1}$

Where t_0 is the initial value, h the sampling interval, k the sampling number

• Forward differences

1. $\Delta f_k = f_{k+1} - f_k$

2. $\Delta^n f_k = \Delta^{n-1} f_{k+1} - \Delta^{n-1} f_k$

1. Shift operator

1. $f_{k+1} = f(t_k + h) = E f_k$

2. $f_{k+r} = f(t_k + rh) = E^r f_k$

3. $E = 1 + \Delta$

$$\nabla = 1 - E^{-1}$$

Forward interpolation

$$f_{i+1} = f(x_i + h) \longrightarrow f_{i+p} = E^p f_i$$

$$= E^p f_i$$

$$f_{i+p} = (1 + \Delta)^p f_i$$

$$= [1 + k_1 \Delta + k_2 \Delta^2 + k_3 \Delta^3 + \dots + k_p \Delta^p] f_i$$

where any value k_m is often known as the m th binomial coefficient, given by

$$k_m = \frac{p(p-1)(p-2) \dots (p-m+1)}{m!}$$

$$f_{i+p} = f_i + p \Delta f_i + \frac{p(p-1)}{2!} \Delta^2 f_i + \frac{p(p-1)(p-2)}{3!} \Delta^3 f_i + \dots + \frac{p(p-1)(p-2) \dots (p-n+1)}{n!} \Delta^n f_i$$

Backward interpolation

$$f_{N+p} = E^p f_N \longrightarrow f_{N+p} = (1 - \nabla)^{-p} f_N$$

$$f_{N+p} = [1 - k_{1b} \nabla + k_{2b} \nabla^2 - k_{3b} \nabla^3 + \dots + k_{pb} \nabla^p] f_N$$

The binomial coefficients k_{1b}, k_{2b}, \dots take the form

$$k_{mb} = \frac{p(p+1)(p+2) \dots (p+m-1)}{m!}$$

$$f_{N+s} = f(x_N + sh) = f_N + s \nabla f_N + \frac{s(s+1)}{2!} \nabla^2 f_N + \frac{s(s+1)(s+2)}{3!} \nabla^3 f_N + \dots + \frac{s(s+1)(s+2) \dots (s+n-1)}{n!} \nabla^n f_N$$

Estimation and data Prediction

$$f_{k+r} = (t_k + rh) = E^r f_k; 0 < r < 1$$

– using backward differences

$$f_{k+r} = f_k + r \nabla f_k + \frac{r(r+1)}{2!} \nabla^2 f_k + \frac{r(r+1)(r+2)}{3!} \nabla^3 f_k + \dots + \frac{r(r+1)(r+2)\dots(r+n-1)}{n!} \nabla^n f_k$$

– Using forward differences

$$f_{k+r} = f_k + r \Delta f_k + \frac{r(r-1)}{2!} \Delta^2 f_k + \frac{r(r-1)(r-2)}{3!} \Delta^3 f_k + \dots + \frac{r(r-1)(r-2)\dots(r-n-1)}{n!} \Delta^n f_k$$

– By replacing the differences operator by the equivalent form the new equation is called equation

- Example: find the recursive equation of the backward prediction function by approximating the result to the second term

$$f_{k+r} = f_k + r\Delta f_k + \frac{r(r-1)}{2!} \Delta^2 f_k$$

$$f_{k+r} = f_k + r(f_k - f_{k-1}) + \frac{r(r-1)}{2!} (\Delta f_k - \Delta f_{k-1})$$

$$f_{k+r} = f_k + r(f_k - f_{k-1}) + \frac{r(r-1)}{2!} (f_k - 2f_{k-1} - f_{k-2})$$

$$f_{k+r} = af_k + bf_{k-1} + cf_{k-2}$$

$$a = 1 + r + \frac{r(r-1)}{2!},$$

$$b = 2 \frac{r(r-1)}{2!} - r,$$

$$c = -\frac{r(r-1)}{2!}$$

Numerical differentiation

$$f'_k = \lim_{r \rightarrow 0} \frac{\partial}{\partial r} f_{k+r} = \lim_{r \rightarrow 0} \frac{\partial}{\partial r} f(t_k + rh)$$

$$f''_k = \lim_{r \rightarrow 0} \frac{\partial^2}{\partial r^2} f_{k+r} = \lim_{r \rightarrow 0} \frac{\partial^2}{\partial r^2} f(t_k + rh)$$

Backward

$$f'_k = f'(t_k) = \frac{1}{h} \left(\nabla + \frac{1}{2} \nabla^2 + \frac{1}{3} \nabla^3 + \dots \right) f_k$$

$$f''_k = f''(t_k) = \frac{1}{h^2} \left(\nabla^2 + \nabla^3 + \frac{11}{12} \nabla^4 + \frac{5}{6} \nabla^5 + \dots \right) f_k$$

forwrad

$$f'_k = f'(t_k) = \frac{1}{h} \left(\Delta - \frac{1}{2} \Delta^2 + \frac{1}{3} \Delta^3 - \dots \right) f_k$$

$$f''_k = f''(t_k) = \frac{1}{h^2} \left(\Delta^2 - \Delta^3 + \frac{11}{12} \Delta^4 - \dots \right) f_k$$

Numerical differentiation

- Approximate differentiation

- First term

$$f'_k = f'(t_k) \cong \frac{1}{h}(\nabla)f_k$$

$$f'_k = f'(t_k) \cong \frac{1}{h}(f_k - f_{k-1})$$

- Second term

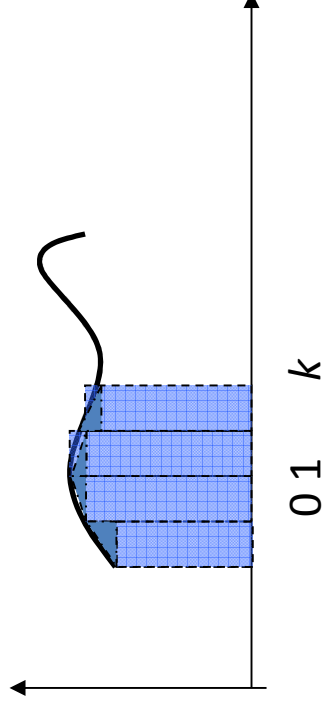
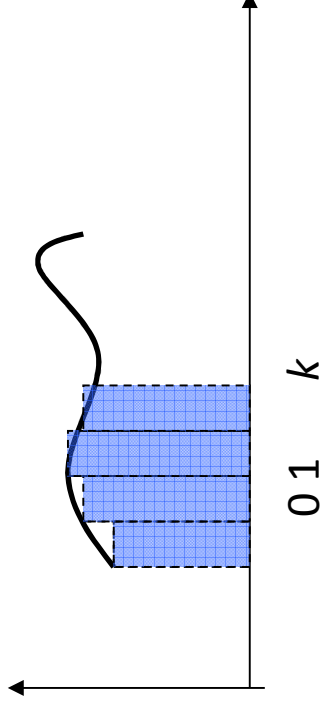
$$f'_k = f'(t_k) \cong \frac{1}{h}\left(\nabla + \frac{1}{2}\nabla^2\right)f_k$$

$$f'_k = f'(t_k) \cong \frac{1}{h}\left(f_k - f_{k-1} + \frac{1}{2}(f_k - 2f_{k-1} + f_{k-2})\right)$$

$$f'_k \cong \frac{1}{h}\left(1.5f_k - 2f_{k-1} + \frac{1}{2}f_{k-2}\right)$$

Numerical Integration

- Rectangle approximation



Sinusoidal-wave based algorithm

Chapter 4:

Pure sine wave algorithm

Build a program to deduce the following parameters

1- voltage magnitude

2- current magnitude

3- phase shift

4- circuit impedance (Z, R, X)

For a given data file (data1) where sampling time 1ms and the signal frequency 50hz each row of the data1 file is [sample#, $v(k), i(k)$]