(*ii*) **Negative Sequence Voltage Filter.** Negative sequence voltage filter is connected to the secondary side of VT's. It passes Negative Sequence Component (V_2) the circuit voltage and rejects positive sequence and zero sequence components. The relay connected to the output side of negative sequence voltage filter respond to V_2 only.

For simplicity, the three input terminals of negative sequence filter are connected to line side having no zero sequence component (Star connection without earthing)

There are many possible methods of connecting r, L, C to get the filtered negative sequence output.

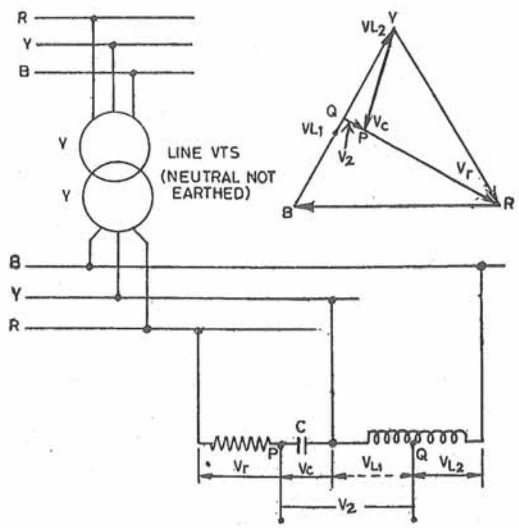


Fig. 38.53. Negative sequence voltage filter.

Consider Fig. 38.52 (*a*). For negative sequence condition of supply voltage (phase sequence YRB or when supply voltage contains negative sequence component) negative sequence voltage V_2 appears across *P*, *V*. When negative sequence component in line voltage is zero, the voltage V_2 is zero.

The same circuit can be used as a positive sequence filter by interchanging supply terminals.

39

Comparators and Level Detectors

Static Relay — Functional Circuits — Comparators — Amplitude Comparators — Rectifier Bridge Comparators — Phase Comparators — Pulse and Squared Input — Direct and Integrating Type Comparators — Integrating Amplitude Comparator — Hybrid Comparator Level Detectors — NPN Transistors — PNP Transistors — Operational Amplifier — Schmitt Trigger .

39.1. STATIC RELAY FUNCTIONAL CIRCUITS

The static relay unit comprises several functional circuits such as :

- input circuit with main CT's, Auxiliary CT's
- rectifiers smoothing circuits, filters
- level detector
- timer circuit
- filter circuit
- directional unit
- comparator
- amplifiers
- setting device
- starting relay
- output stage, etc.

The required functional circuits or units are connected in the final assembly.

Input stage

The input is derived from CT/PT. The output of CT/PT is connected to the auxiliary CT/PT. The input stage of a static relay comprise the following :

- CT's and or PT's.
- Auxiliary CT's or PT's.
- Summation units.
- Filter.

Rectifier and Smoothing Circuit

In single actuating quantity relays, the quantities are rectified in a single rectifier bridge. The output of the rectifier is smoothened to remove the ripple. The output is given to the level detector. Single actuating quantity relays include overcurrent relay, under voltage relay etc.

In double actuating quantity rectifier relay there are generally two rectifier bridges. The output of these bridges is compared. The output of the comparator is given to the measuring unit (level detector) after smoothing.

Comparator

Comparators receive the rectified inputs. After comparison the comparator output is given to the measuring unit.

There are several types of comparators such as amplitude comparator, phase comparator, hybrid comparators.

These are either direct (instantaneous) or integrating type.

Level Detector or Measuring Unit

This unit comprises a multi-stage feedback amplifier. The feedback ensure that for values of unit above a certain level, the output power increases in a step. Hence for input below threshold value, the level detector has no output. For input above threshold value, the output is obtained.

The measuring unit comprises logic circuits, amplifiers and level detector circuit. The logic elements determine the conditions of various input quantities for which output is obtained.

Amplifiers

The output of level detector is further amplified by amplifier. The amplifier strengthens the weaker signal. The output of the amplifier is given to the starting relay or output device.

Time-delay Element

The time-delay element is introduced between level detector and the amplifier. The time-delay can be adjusted by changing R-C combinations.

Output Stage

The output stage of static relay may have one of the following :

— electromagnetic relay such as permanent magnet moving coil relay.

— thyristor in series with trip coil and auxiliary switch.

The operation of the complete relay is a team-work of these functional blocks. The manufacturers supply variety of relays of the same type but having certain modifications to suit particular applications by putting together required functional blocks. For example, a time-delay unit is added to get time delay; volt-ratio box may be added to permit selection of auxiliary supply voltage; output stage may have an electromagnetic relay or a thyristorized trip. Hence, the relay assembly is built up of various blocks, each serving certain specific function. Such blocks are called functional components of static relays. The study of static relays is simplified by studying these functional components first and then the block-diagram of various relays.

Each functional component is built up from discrete components such as resistors, diodes, transistors, capacitors, etc. Some of the components, are soldered on a printed circuit of glass-fibre reinforced expoxi-laminate or the functional component is made up of an integrated circuit. The printed circuit card (or integrated circuit with its connections) together with other components of the relay such as transformers, switches potentiometers, etc. are mounted on a relay base plate.

Alternatively each functional component may be an IC or a group of functional components may be formed on a single IC.

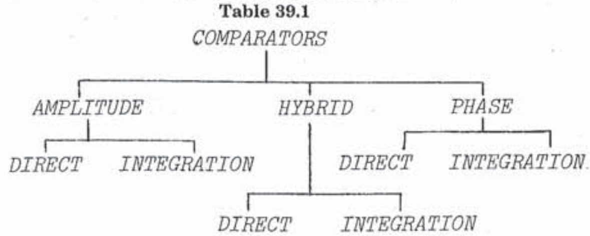
PART I. COMPARATORS

39.2. COMPARATORS

In double actuating quantity relays, two quantities are compared.

For example in circulating current differential protection (Ref. Ch. 28) the current entering in the protected zone (I_1) and current leaving the protected zone (I_2) *are compared.* In phase comparison type carrier current protection type carrier current protection (Ch. 30) the phase angle between signals from sending end and receiving end are compared. In distance relays the ratio of vector V and vector I are compared. These are some examples of comparison studied earlier.

Table 39.1



Comparator is a part of relays which receives two or more inputs to be compared and gives output based on their comparison.

Comparators can be broadly classified as — (1) Amplitude comparator (2) Phase comparator (3) Hybrid comparator.

Comparators are either direct (instantaneous) type or integrating type. In integrating type comparator the output of the comparator is integrated with respect to time. (Ref. Table 39.1.).

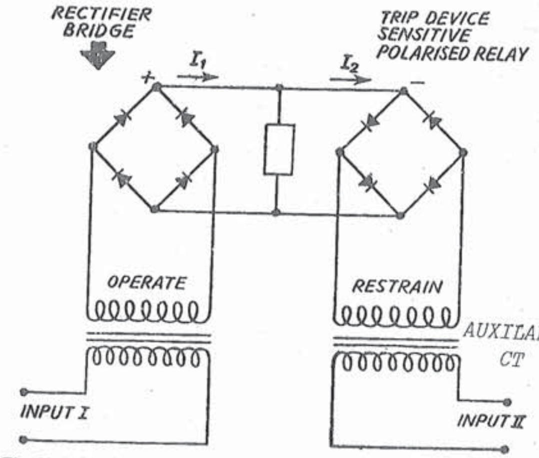


Fig. 39.1. Amplitude comparator circulating current circuit with two inputs.

Multi-input comparators are either single phase or poly-phase, can employ either amplitude or phase comparison or both. In general case of multiple operating inputs and multiple restraining inputs, the operation is governed by an equation.

$$|S_{01}| + |S_{02}| + |S_{03}| \;.... > |S_{r1}| + |S_{r2}| + ...$$

where left hand side gives total operating input and right hand side gives total restraining input.

Hybrid type comparator combines the amplitude comparator and phase comparator.

39.3. AMPLITUDE COMPARATORS

Amplitude comparator compares the magnitude of the two (or more) input, quantities. The phase angle between the two (or more) inputs is not recognised or noticed by the amplitude comparator.

Consider two vectors $\bar{A}$ and $\bar{B}$. It compares the magnitude of these inputs *i.e.*, $|A|$ and $|B|$. The comparator receives two inputs and gives output is the algebraic difference between magnitudes, *i.e.* $|A| - |B|$.

The function of amplitude comparator is illustrated in Fig. 39.2.

Symbol $|A|$ denotes the magnitude of complex function A.

The output $|A| - |B|$ of comparator is :

Positive if	$\lvert A\rvert > \lvert B\rvert$
Negative if	$\lvert A\rvert < \lvert B\rvert$
Zero if	$\lvert A\rvert = \lvert B\rvert$

In some cases the comparator compares the two magnitudes by 'Ratio'. The output of the comparator $|A|/|B|$ is :

greater than 1 if	$\lvert A\rvert > \lvert B\rvert$
less than 1 if	$\lvert A\rvert < \lvert B\rvert$
zero	$\lvert A\rvert = 0.$

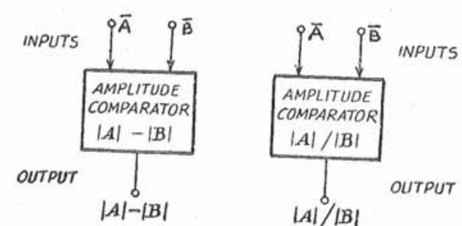


Fig. 39.2. Function of amplitude comparators.

The amplitude comparators are generally in the form of :

Rectifier Bridge Comparators. The input quantities to static relays is either in the form of sinusoidal current derived from main CT or sinusoidal voltage derived from PT. CT or PT give analogous output, faithful to the main circuit quantity.

Each input quantity is given to one full-wave rectifier bridge.

Two full-wave rectifier bridges are connected in opposition and the output relay is connected in parallel to the two rectifier bridges. The output of the rectifier bridge comparator is received by the output stage continuously.

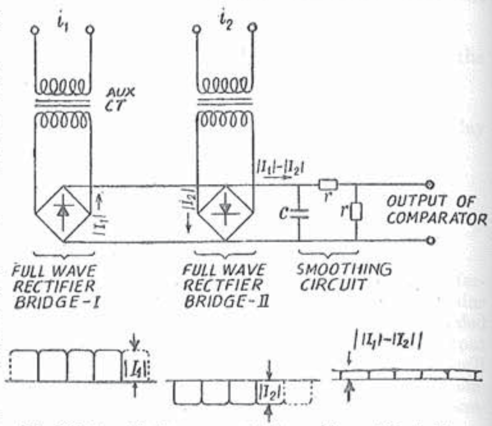


Fig. 39.3. Amplitude comparator formed by rectifier bridges.

Fig. 38.3 (*a*) illustrates the configuration and Fig. 39.3 (*b*) illustrates the waveforms. The output stage receives continuously a direct current equivalent to $|I_1| - |I_2|$.

The output stage is rectifier bridge comparators can have one of the following devices :

— Permanent Magnet Moving Cost Relay

— Sensitive Polarised Relay

— Static Integrator.

When $|I_1| - |I_2|$ exceeds the threshold value, the stage acts and the relay picks-up.

39.4. PHASE COMPARATORS

Phase comparators compare the two (or more) input quantities vectorially. The phase comparators recognised the vector (both magnitude/phase) relationship between the inputs. A vector $\bar{A}$ has magnitude $|A|$ and phase angle say, α. There are two kinds of phase comparators.

(*i*) Phase comparator which recognises only phase angle between input waveforms.

If ϕ is phase angle between vector $\bar{A}$ and $\bar{B}$, the output of phase comparator depends on angle ϕ and the relay responds to the phase angle ϕ between the two inputs.

(*ii*) Phase comparator which recognises the vector product (or division) between two (or more) input quantities.

Thus a phase comparator has output $\bar{A}, \bar{B}$ or $\bar{A}/\bar{B}$.

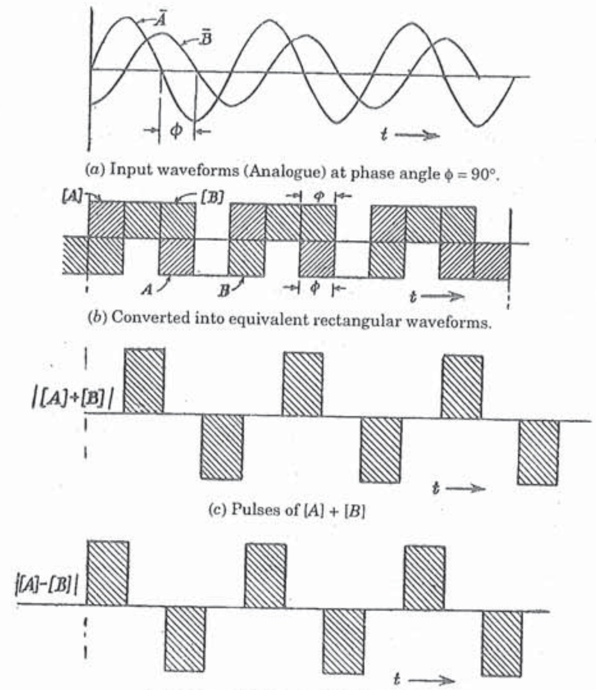
39.5. PHASE COMPARATOR BASED ON RECTANGULAR (OR SQUARED) PULSES

Ref. Fig. 39.4. Suppose the sinusoidal analogous input waveforms $\bar{A}$ and $\bar{B}$ are converted into rectangular waveforms [*A*] and [*B*] before feeding to Phase Comparator.

The magnitude of the input waveform may be disregarded and the comparator recognises only phase angle ϕ in this type of phase comparator.

The rectangular waveform [*A*] is in phase with sinusoidal waveform *A*. Similarly [*B*] in phase with $\bar{B}$.

The comparator receives the rectangular waveforms [*A*] and [*B*]. The resultant waveforms of [*A*] + [*B*] and [*A*] – [*B*] are illustrated in Fig. 39.4 (*c*) and (*d*)



(*a*) Input waveforms (Analogue) at phase angle $\phi = 90°$.

(*b*) Converted into equivalent rectangular waveforms.

(*c*) Pulses of [*A*] + [*B*]

(*d*) Pulses of $|[A]-[B]|$ for $\phi = 90°$.

Fig. 39.4. Use of rectangular inputs in phase comparators.

For, $\phi = 0$ $\quad |[A]+[B]| = |[A]-[B]|$

$\phi < 90°$ $\quad |[A]+[B]| > |[A]-[B]|$

$\phi > 90°$ $\quad |[A]+[B]| < |[A]-[B]|$.

Thus, if the comparator circuit is arranged to measure the difference

$$|[A]+[B]| - |[A]-[B]|,$$

the phase angle between $\bar{A}$ and $\bar{B}$ can be predicted.

The output of the phase comparator is in terms of magnitude.

The other possibilities of phase comparators adopting other techniques (such as phase split inputs, coincidance circuits) are described later. Such comparators can bed readily adopted with logic circuits and are useful in modern relays.

39.6. PHASE COMPARATORS BASED ON VECTOR PRODUCT DEVICES

The vector product devices (such as Hall Effect Generator Ref. Sec. 38.12). Have an output (e_o) given by, say,

$$e_o = AB \sin \phi$$

where A = r.m.s. value of input 1,

B = r.m.s. value of input 2

ϕ = phase angle between 1, 2.

This phase comparator is basically analogue device and cannot be readily adopted in logic circuits.

39.7. DIRECT (INSTANTANEOUS) AND INTEGRATING TYPE COMPARATORS

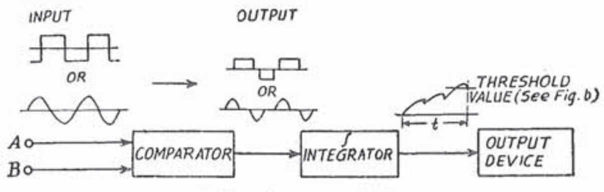
Comparators (Phase or Amplitude) can be either Direct Type of Integrating Type.

In Direct Comparator the 'period' or 'time' of comparison is not recognised. Hence time aspect is not international. (The comparator may have inherent response time).

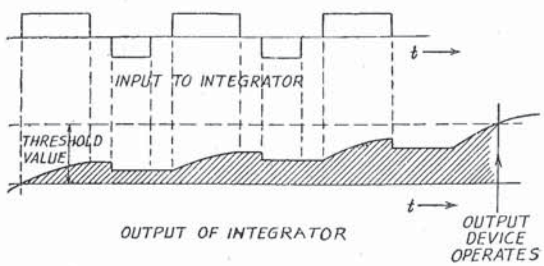
The output of comparator corresponds to the comparison of inputs at *every instant.*

In integrating type comparator, the quantity (generally output) of the comparator is integrated with respect to time. When the integrated output reaches a threshold value the output device operates.

Ref. Fig. 39.5. Two rectangular equivalent inputs are given to comparator. Comparator output $[(A) - (B)]$ is given to integrator.



(*a*) Function of integrator.



(*b*) Details of waveform of integrator input and output.
Fig. 39.5. Integrating Comparator.

(Ref. Sec. 38.24). The integrator generally has a capacitor which gets charged as shown in Fig. 39.5 (*b*). The voltage across the capacitor increases with positive pulse and its duration and decreases with negative pulse and duration. The settings are such that under normal conditions in main circuit, the positive pulses and negative pulses received by the integrator are such that its output does not reach the threshold value. Hence output relay remains open. When the integrator output reaches threshold value, the output device operates.

In Fig. 39.5, square inputs are illustrated. In some other comparators, input are be sinusoidal or triangular.

39.8. INTEGRATING AMPLITUDE COMPARATOR

Fig. 39.6 illustrates the integrating type of amplitude comparator.

The two sinusoidal inputs A and B are given to the input of comparator (*a*). The output $|A - B|$ waveform (*b*) is supplied to the shaper. The shaper converts into equivalent square pulses

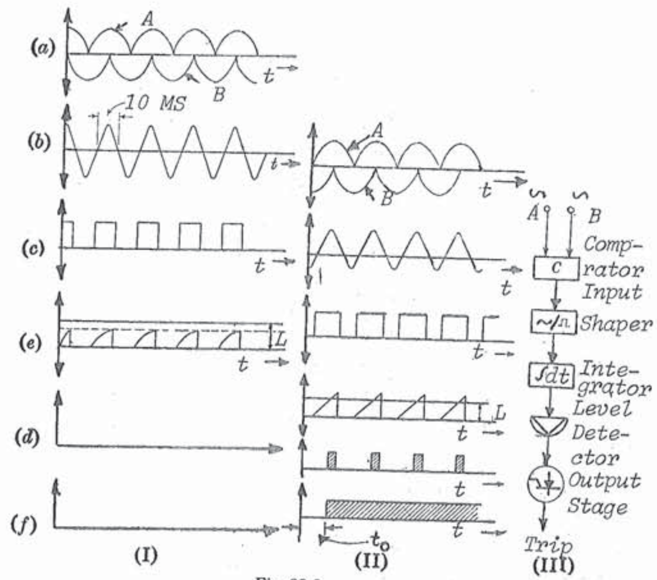


Fig. 39.6.

(*c*). These pulses are given to integrator. The integrator output depends upon duration and magnitude of input square pulses. At the beginning of every pulse, the capacitor in the integrator starts getting charged. When $A > B$ (as shown in II), the triangular output of integrator (*d*) increases above the setting of the level detector (*L*).

When $A < B$, the level detector does not give any output [I-*e*].

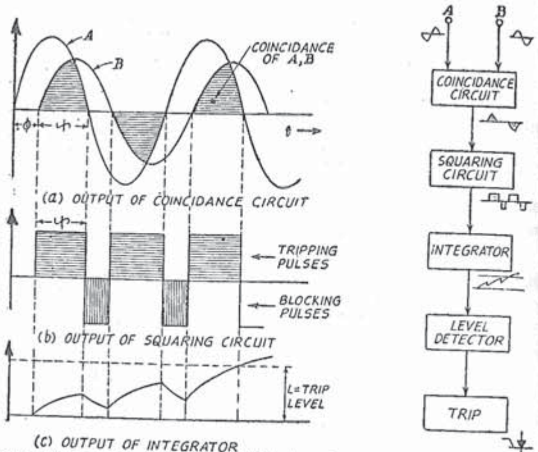
When $A > B$, the level detector gives output [II-*e*] and trip current flows.

39.9. OPERATING TIME

Suppose $A = B$ as shown in Fig. 39.6-I, before fault in main circuit (not shown). At $t = 0$, fault develops in main circuit and $A > B$ (Fig. 39.6-II). The time required for trip current to start flowing is indicated in Fig. 39.6-II *f* by t_o. It is the time required by integrator to charge its capacitor. It is of the order of 5 ms. Further time of about 2 ms is required for operation of output stage. Hence the relay time can be minimised to 10 ms ± 3, *i.e.* $\frac{1}{2}$ cycle.

39.10. COINCIDENCE TECHNIQUES IN PHASE COMPARATORS

Fig. 39.7 illustrates the principle of a phase comparator based on coincidence of sinusoidal inputs. Coincidence denotes overlapping of the two signals. Referring to Fig. 39.7 (*a*), the sinusoidal inputs A and B overlap during the period ϕ. The hatched portion in Fig. (*a*) indicates coincidence. The coincidence circuit has output during this period ϕ. This output is converted into squares in the squaring circuit. The output of squaring circuit is supplied to integrator. The output of the integrator is given to level detector with setting *L*. The pulse are integrated in integrator. When the output of integrator Fig. 39.7 (*c*) exceeds level detector setting *L*, the level detector gives signal to output stage. The thyristor in output stage is thereby triggered.



Output of integrator touches Level l, when $p = 90$ (balance) Tip occurs for $\phi = 90°$.

Fig. 39.7. Phase comparator based on coincidence of sine inputs.

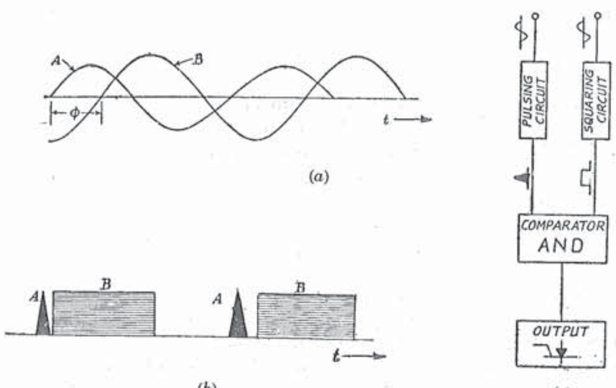
If period ϕ of coincidence between A and B is

(*i*) less than 90°, relay does not operate as the output of integrator always remains below L.

(*ii*) more than 90°, relay operates as the output of the integrator exceeds L.

39.11. SPIKES AND BLOCK COINCIDENCE TECHNIQUE IN PHASE COMPARATOR

Ref. Fig. 39.8. Inputs A and B are sinusoidal. Input A is converted into a spike in a pulsing device. Input B is converted into rectangular blocks in squaring circuit. The converted pulses are shown in Fig. 39.8 (*b*).



(Spike and block not coincident, the output of AND is zero, relay does not operate)

Fig. 39.8. Coincidence phase comparator with spike and block technique.

The spikes and blocks are supplied to an AND gate [Fig. 39.8 (*c*)]. The AND gates gives output when both the rectangular block and the spike coincide.

39.12. PHASE COMPARATOR WITH PHASE SPLITTING TECHNIQUE

Fig. 39.9 illustrates this method in which both the inputs A and B are split into two components A, A and $B, B \angle 45°$. Thus totally four input signals are received by the comparator. The comparator is an AND gate which gives output when all the four inputs are simultaneously positive or negative.

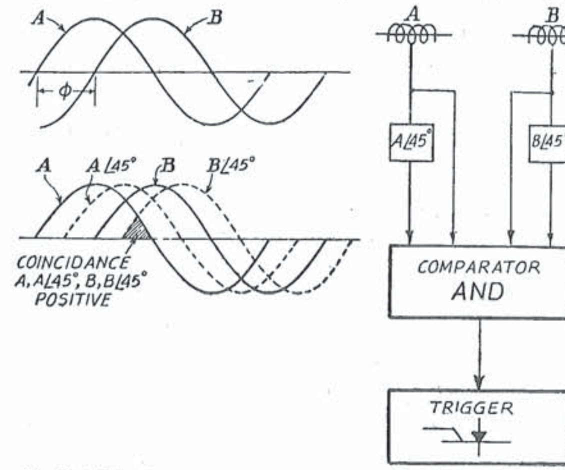


Fig. 39.9. Coincidence phase comparator with phase splitting technique.

The coincidence of all four signals is possible when the phase angle ϕ between A and B satisfies the condition.

$$90° > \phi < -90°$$

39.13. HYBRID COMPARATOR

Hybrid comparator compares both magnitude and phase of the input quantities. It is a Hybrid (mixed version) of amplitude and phase types.

Ref. Fig. 39.10. The inputs are given to a phase comparator. The output of phase comparator is given to Amplitude Comparator. The output stage follows.

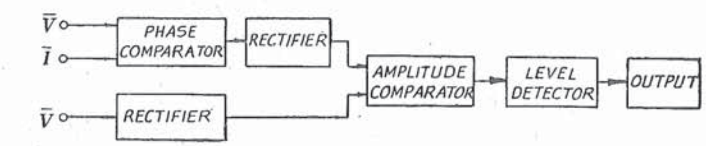


Fig. 39.10. Hybrid comparator (incorporating phase comparator and amplitude comparator) used in a distance relay.

The static impedance relays which compare V and I are generally hybrid comparators. Variety of impedance diagrams (rectangular elliptical) etc. are possible with Hybrid Comparators.

Section II. LEVEL DETECTORS

39.14. LEVEL DETECTOR

A level detector is a functional circuit in a protective relay which determine the level of its inputs with reference to a predetermined setting. Ref. 39.11. When the inputs (*I*) exceed the level (*L*) the output (*O*) of the level detector exceeds and the output stage of the relay gets a triggering signal *via* an amplifier.

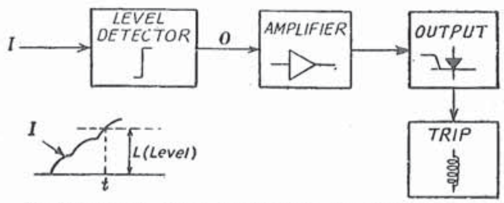


Fig. 39.11. Explaining level detector (when input *I* exceeds level *L*, the output *O* increases).

When input (*I*) is below a certain level, the output is negligibly small.

An Analogue Level detector with operational Amplifier has been described in Sec. 38.15.10. Some other simple circuits are described here.

39.15. LEVEL DETECTOR BY PNP TRANSISTOR

Referring to Fig. 39.12, the input to level detector V_i should have desired level to make the PNP transistor conducting. The base should be negative with respect to emitter. Therefore, base

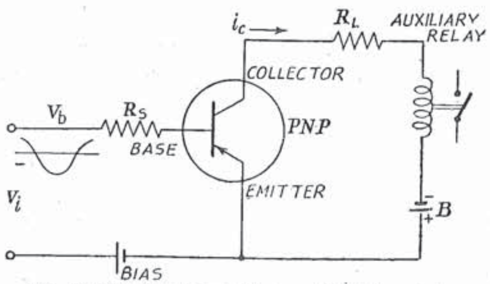


Fig. 39.12 (*a*). Simple level detector with PNP transistor. (When Base of PNP transistor gets a negative voltage with respect to collector, the transistor is turned on).

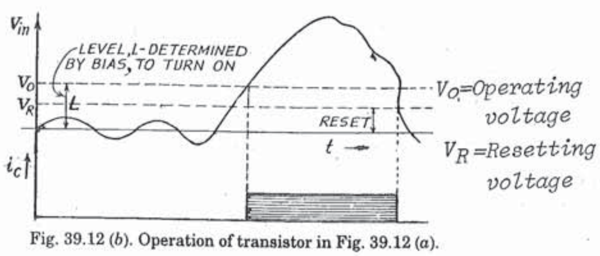


Fig. 39.12 (*b*). Operation of transistor in Fig. 39.12 (*a*).

to emitter voltage (negative) should exceed the positive bias. When the base voltage V_b reaches level *L* determined by the bias, the transistor is turned on. The current i_b flows from battery *B* through emitter, collector, auxiliary permanent magnet moving coil relay. When base to emitter voltage V_b is below threshold level (0.6 *V* silicon transistor) current i_c is zero.

39.16. NPN TRANSISTOR AS LEVEL DETECTOR

Consider the common emitter connection of a NPN transistor (Fig. 39.13). When base to emitter voltage is negative or less than the threshold value no substantial emitter current can flow. When the base to emitter voltage is positive and exceeds the threshold value the transistor is turned on, current i_c flows through collector (and load). I_c is of the order of milliamperes.

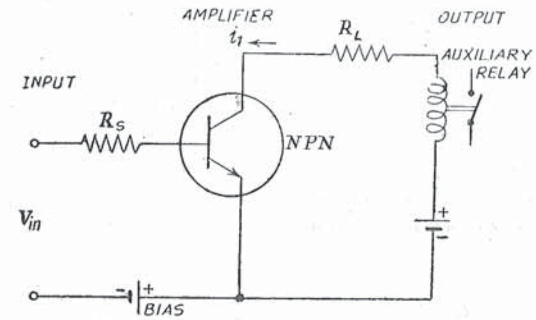


Fig. 39.13. NPN Transistor as level detector.

39.17. SCHMITT TRIGGER WITH OPERATIONAL AMPLIFIER

Ref. Sec 38.24 for application of operational amplifier as a level detector. The circuits shown in Figs. 38.36 and 38.37 are with negative feedback. (Feedback applied to negative terminal of operational amplifier) Negative feedback is generally necessary in feedback control systems for stabilization. However in protective relays negative feedback is generally not necessary and positive feedback is preferred.

In positive feedback, the output is applied to the positive terminal of the operational amplifier. When the operational amplifier is turned into ON state, it remains in ON state till the operating quantity is reduced to below reset level.

Ref. Fig. 39.14, since feedback is positive, the output V_0 is either equal to $+V_{CC}$ or $-V_{CC}$ depending upon the history of the waveform (Hysteresis). Follow the waveform of input in Fig. 39.14 (*c*). When input reaches $+V_{CC}/2$, the output changes its state from $+V_{CC}$ to $-V_{CC}$ and remains at that level till V_i reaches $-V_{CC}/2$.

A sinusoidal input V_i gives a square wave output V_O Schmitt Trigger can be used as a level detector. When input reaches V_{CC}, the output changes its state.

V_0	V_i	V_i *for* $(R_1 = R_2)$
$+V_{CC}$	$V_s < \frac{R_2}{R_1+R_2} V_{CC}$	$V_s < V_{CC}/2$
$-V_{CC}$	$V_s > \frac{R_2}{R_1+R_2} V_{CC}$	$V_s > -V_{CC}/2$

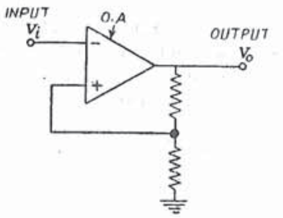


Fig. 39.14 (*b*). Schmitt Trigger with O.A.

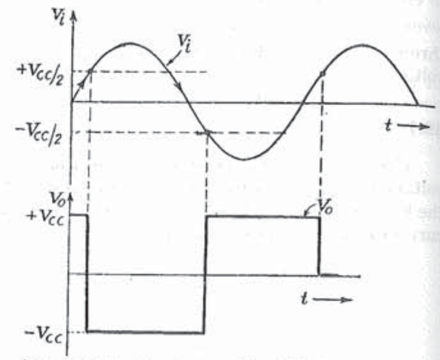


Fig. 39.14 (*c*). Waveforms of V_i and V_0 for $R_1 = R_2$.

39.18. SCHMITT TRIGGER WITH TWO NPN TRANSISTOR

Ref. Fig. 39.15. Transistor Q_1 is normally not-conducting and Q_2 conducting. The potential of base B_2 of transistor Q_2 is determined by the supply voltage V_s and values of resistors R_1, R_2, R_3. Because voltage V_s across supply and ground gets divided across R_1, R_2, R_3 in proportion to their resistances.

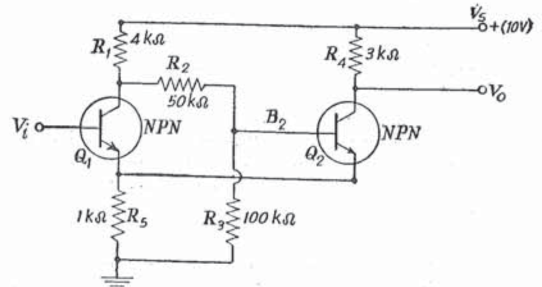


Fig. 39.15 (*a*). Schmitt trigger circuit with two NPN transistors.

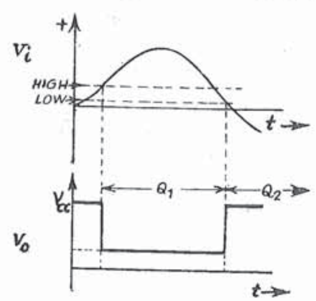


Fig. 39.15 (*b*). Waveform of (*a*).

When V_i reaches threshold value (High) and is positive, Q_1 is turned ON. Current diverts to $Q_1 \cdot Q_1$ is saturated thereby potential of B_2 is dropped below reset value.

Q_2 stops conducting. Thereby the output voltage V_o increases to V_s.

When V_i becomes low (0.6 V for silicon) Q_1 stops conducting and Q_2 starts conducting and driven into saturation. The voltage V_s gets divided across R_4, R_5, and V_0 reduces to low value.

QUESTIONS

1. State the various functional circuits in a static relay with the help of block diagrams. Explain the function of various blocks.
2. Describe the functions of Amplitude Comparator and Phase Comparator. Explain the difference between Direct and Integrating type Amplitude Comparators with the aid of illustrated waveforms.
3. Explain the circuit of an integrating type of phase comparator by means of block diagram and waveforms.
4. Explain the phase comparison technique based on (1) spike and block inputs (2) phase splitting. Illustrate with the help of block diagrams and waveforms.
5. Explain the following :
   — phase splitting technique used in Integrating Type Phase Comparator.
   — use of AND gate in phase comparators.
6. Explain the function of Rectifier Bridge comparator used as amplitude comparator.
7. Illustrate block diagram of an integrating type amplitude comparator having two current inputs having phase difference ϕ.
8. State the function of level detector. Explain the use of Schmitt Trigger circuit as a level Detector. What is the advantage of positive feedback?
9. Write short notes on any two :
   1. Schmitt Trigger with Transistors Level Detector.
   2. Integrating Type phase comparators.
   3. PNP as Level Detector.
   4. Schmitt Trigger with Operational Amplifiers as Level Detector.
   5. Rectifier Bridge comparator Relay.