BASIC ELECTRONICS COURSE
THE SCHMITT TRIGGER

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One of the most universal chips is the Hex Schmitt Trigger, known as the 74C14. It is also marketed as 40106, 40014, and 74HC14. These are CMOS chips and are characterised by low current consumption, high input impedance and a supply voltage from 5v to 15v. **(Do not substitute 7414 or 74LS14. They are TTL chips and operate on 4.5v to 5.5v and have low impedance inputs.)**

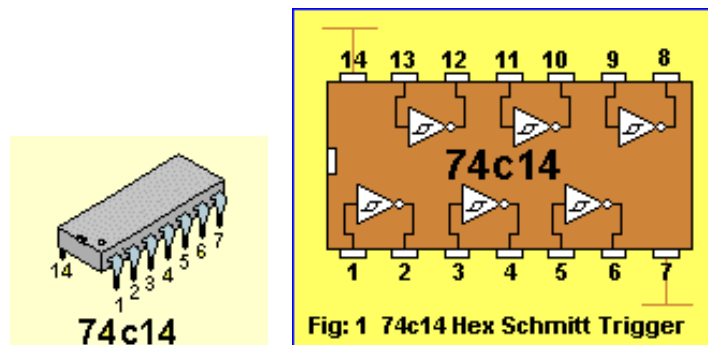Fig: 1 shows the six Schmitt gates in a 74c14 chip.

Fig: 1 74c14 Hex Schmitt Trigger

Fig: 2 shows the symbol for a single input Schmitt Trigger Inverter with power rails:

Fig: 2 Schmitt Symbol
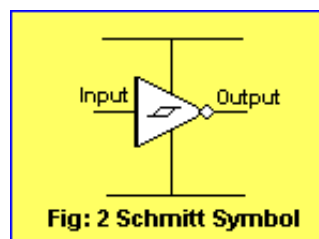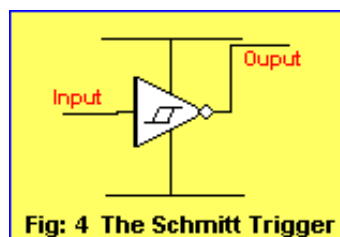
Fig 3 shows the Schmitt Trigger characteristic incorporated into other gates:

Fig: 3 2-Input Schmitt NAND   Schmitt Buffer
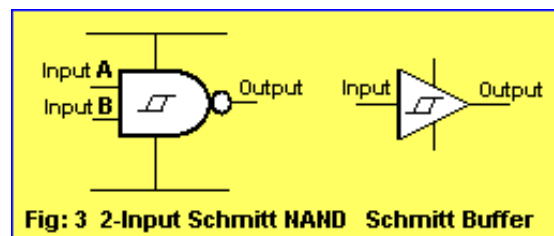
We will concentrate on the single-input Schmitt Trigger gate as contained in the 74c14 IC.
Fig: 4 shows the **Schmitt Trigger Characteristic**:

Fig: 4 The Schmitt Trigger

The output is HIGH until the input rises to 66% of rail voltage.
The output goes LOW when the input goes above 66%.
The output remains HIGH until the input fall to 33%.

A Schmitt Trigger gate can be wired as an oscillator, delay, inverter (and other functions, depending on the surrounding components).
Fig: 5 shows the Schmitt Trigger wired as an **oscillator**, **delay** and **inverter**:

Fig: 5 Schmitt Trigger Oscillator   Schmitt Trigger Delay   Schmitt Trigger Inverter
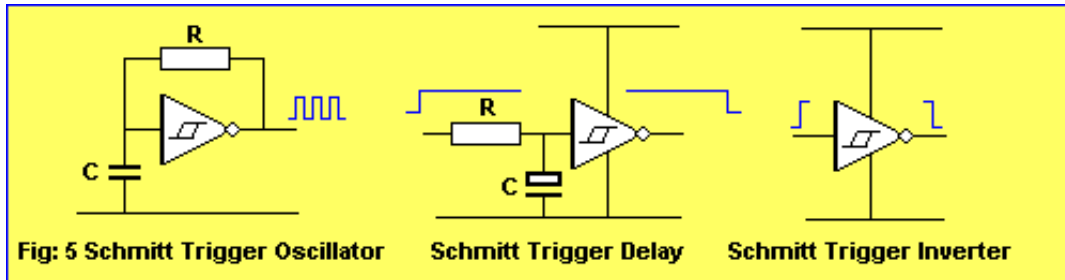
Each of the 6 gates in the 74c14 can be used to create a separate "building block" and this gives the chip a wide range of capabilities.

THE FREQUENCY OF AN OSCILLATOR

When a capacitor and resistor are added to a Schmitt Trigger gate, as shown in the first circuit
of Fig: 5 above, the result is an oscillator called a **MULTIVIBRATOR.** A multivibrator has the feature of producing a square wave and this waveshape can have equal high and low periods (called 50:50 mark:space ratio) or any ratio of high and low periods. The **HIGH** period is called the **MARK** and the**LOW** is called the **SPACE**.
The frequency of an oscillator depends on the value of R and C. There is no fixed "ratio" for these components however it is best to refer to sample circuits to see the values needed for a particular frequency - otherwise you may arrive at "unusual" combinations such as very large capacitors and very small resistors to achieve a high frequency.
The frequency of a Schmitt oscillator is determined by the following equation:

$$f = \frac{1.2}{R \times C}$$

where:
 f = Hertz
 R = Ohms
 C = Farads

An easier equation to work with is:

$$f = \frac{1.2 \times 10^6}{R \times C}$$

where:
 f = Hertz
 R = Ohms
 C = microfarads

Oscillator circuits for the 74c14 can be separated into three categories:
1. Low frequency
2. Medium frequency, and
3. High frequency.
Low frequency oscillators are below 1Hz and can also be classified as DELAY circuits or TIMING circuits.
Medium frequency oscillators range from 1Hz to about 500kHz.
High frequency oscillators are above 500kHz.
We separate circuits into three categories due to the value of capacitor needed.
For **low** frequency oscillators the capacitor is an electrolytic, ranging from 1u to 220u.
For **medium** frequency circuits the capacitor is a ceramic 1n to 100n
For **high** frequency circuits the capacitor is a ceramic 47p to 1n
The value of R should be in the range 10k to 4M7 in all cases.
The maximum frequency for a particular chip will depend on the supply voltage and the type of chip.
Some chips do not like supply voltages below 5v (maximum supply voltage is 15v for all chips in this discussion) while other chips (HS) are especially made for high speed operation. All chips will operate up to 500kHz with a 5v to 12v supply. Requirements outside this range will need special investigation. Some chips are designed to operate down to 2-3v.

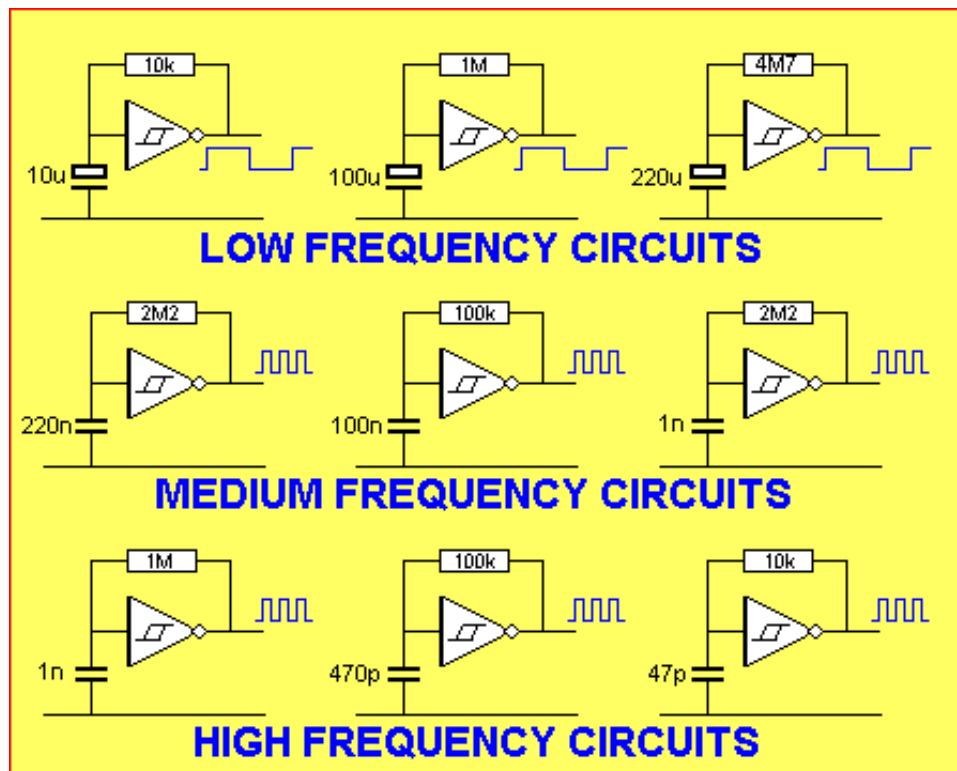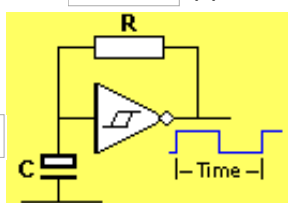Fig: 6 shows sample oscillator circuits with approximate values for R and C.

Fig: 6 Low, Medium and High frequency Schmitt Trigger Oscillators
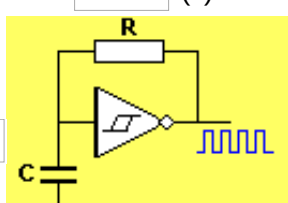
FREQUENCY CALCULATORS

Use the following frequency calculator for **LOW FREQUENCY**
oscillators in the range 1Hz to .001Hz
Times: 1 to 100 secs and longer.

Insert C(u) and R(k). Press Calculate for Time (sec)
For a Delay circuit, "Delay" = charging C from zero to 66%.

For frequencies in the range 1Hz to 120kHz, use the following calculator:
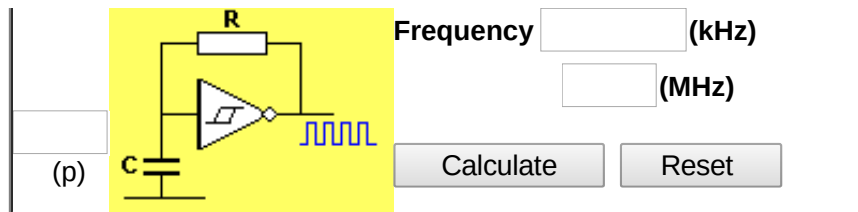Use **C from 1n to 220n** and **R from 10k to 4M7:**

Insert C(n) and R(k).   Press Calculate for Frequency (Hz), (kHz), (MHz)

For frequencies in the range 10kHz to 2.5MHz, use the following calculator:
Use **C from 47p to 1000p** and **R from 10k to 4M7**:

(k)

Frequency [＿＿＿＿] **(kHz)**

[＿＿＿＿] **(MHz)**

(p)

Calculate　　　Reset

Insert C(p) and R(k).　Press Calculate for Frequency (kHz), (MHz)

Each gate of a 74c14 is capable of delivering up to 20mA with a 12v supply, 15mA with a 9v supply and 10mA with a 5v supply. A buffer transistor can be used to increase the output current if needed.
Fig: 7 shows how a buffer transistor is connected to the output of a gate:
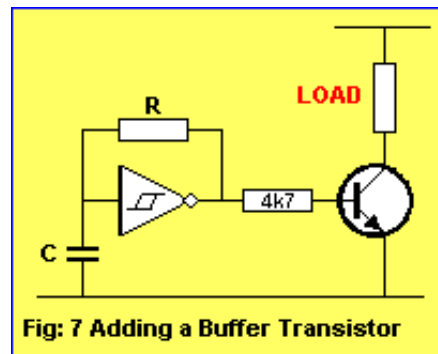

Fig: 7 Adding a Buffer Transistor

The voltage and current (called the "supply") for the 6 gates in a 74c14 comes from pin 14. The ground pin for the chip is pin 7. Each gate on a circuit diagram is normally shown without the power rails. It is understood they are present.
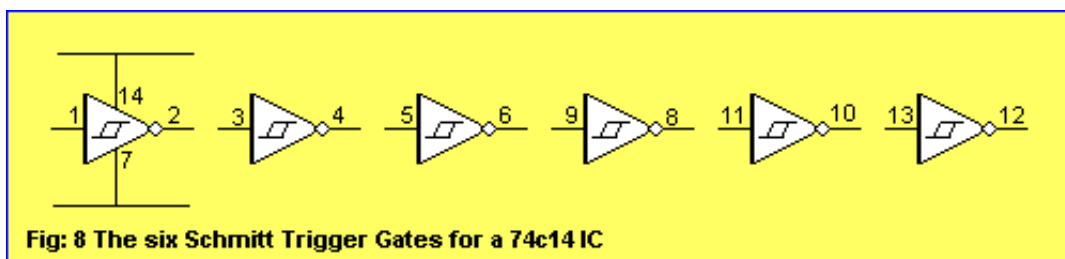Fig: 8 shows the power rails for a 74c14 and the individual gates:

Fig: 8 The six Schmitt Trigger Gates for a 74c14 IC

HOW A GATE WORKS

The next diagram (it is a repeat of Fig: 4 above) shows how the output of a Schmitt gate jumps from HIGH-to-LOW and LOW-to-HIGH as the input voltage rises and falls:
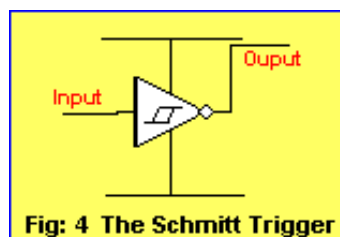

Fig: 4 The Schmitt Trigger

The output of a Schmitt Trigger gate is the opposite of the input. When the input is LOW, the output is HIGH.
As the input rises to 66% of rail voltage, the output **instantly** goes LOW and the input has to fall to 33% of rail voltage for the output to go HIGH.
The gap between 33% and 66% is called the **HYSTERESIS GAP** and this has been specially designed so that the input does not detect small fluctuations.
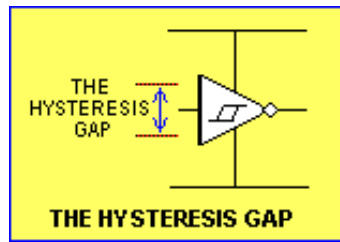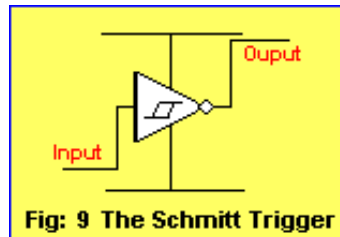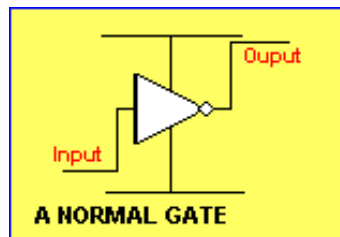
THE HYSTERESIS GAP

Fig: 9 shows a voltage being applied to the Schmitt gate. The voltage is 55% of rail and this is not sufficient to change the output:


Fig: 9 The Schmitt Trigger

The following figure shows a normal gates. It changes when the input rises above about 53% of rail voltage and changes back when the input falls below 47%.

A NORMAL GATE

The following diagram shows the very small gap for a normal chip, where the output jumps from HIGH-to-LOW in an uncontrolled manner:
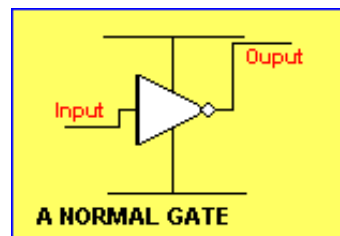

A NORMAL GATE

Here's the secret of a Schmitt gate: Any noise (up to 60%) entering a Schmitt Trigger will not alter the condition of the gate. Any noise up to 55% entering a normal gate will change the output:

Fig: 9 The Schmitt Trigger   A NORMAL GATE
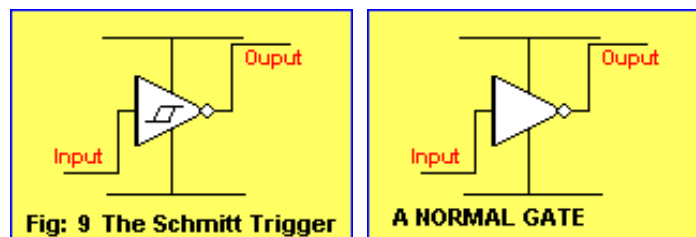
There is one other problem with a normal gate. When the input is in the range of about 47% to 53%, the output goes high/low very rapidly. This is called the **INTERMEDIATE ZONE** and the output does not know if it should be **HIGH or LOW.**
Fig: 10 shows the input voltage varying in this intermediate zone and the output fluctuating very rapidly:

A NORMAL GATE
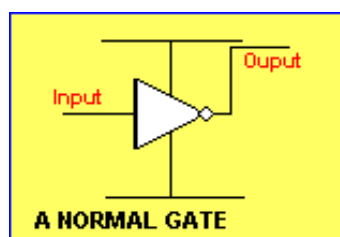
Even a fixed voltage in the intermediate zone will cause the output to fluctuate:


A NORMAL GATE
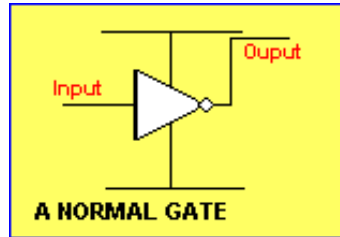
This is due to the high gain of the amplifier in the gate and it does not know if the output should be high or low. It is essential for the input voltage to pass **through this zone** very quickly to prevent the gate "oscillating."
The output will only fluctuate when the input voltage is rising slowly or sits in the zone, as it takes a short period of time for the gate to start oscillating.
For this reason a normal gate is not suitable for low frequency (slow-rising waveforms).
The Schmitt gate does not have this problem.
If the voltage on the input of a Schmitt Trigger rises very slowly, the output changes at 66% and it will only change back to its original state when the voltage drops to 33% of rail voltage. At no time does the gate self-oscillate. This is one of the advantages of the Schmitt Trigger.

Fig: 12 shows how a Schmitt gate can be considered to be similar to a common-emitter NPN transistor:

Fig: 12 A SCHMITT TRIGGER AND A TRANSISTOR
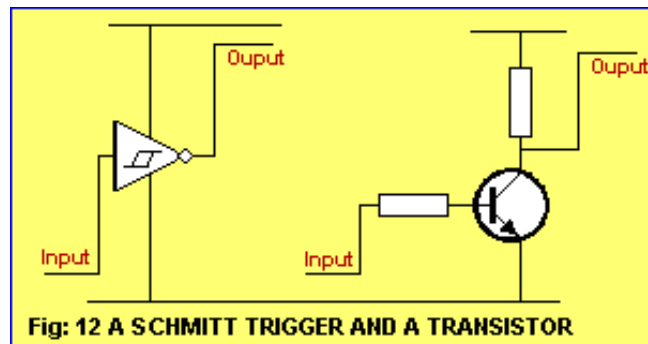
The similarity is only approximate and you can see the general operation of each circuit has some similarities. It is important to note that the two circuits cannot be interchanged without modifying the surrounding components.

SWITCH DEBOUNCE

A Schmitt gate can be used to eliminate noise from a switch. When any type of mechanical switch is closed, the contacts "bounce" due to the dirt and an oxide coating on the contacts and this puts noise on the line. Sometimes this noise is seen as additional pulses by high-speed digital circuits with the result of "false-counting." The Schmitt gate circuit below prevents multiple pulses from being passed to a circuit:

WITHOUT DEBOUNCE   WITH DEBOUNCE
DEBOUNCING A SWITCH
Mouseover to see switch action
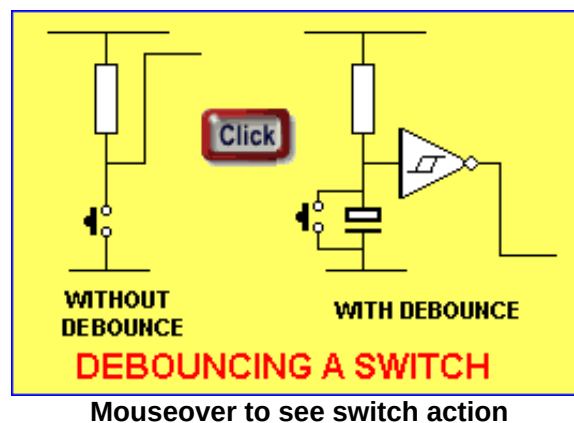
SIGNAL CONDITIONING

The Schmitt Trigger can be used to improve the quality of a signal by speeding up the rise and fall times. The rise and fall time is called the **TRANSITION TIME**. The Schmitt trigger will reshape a waveform into a square wave.
It will also convert a SINEWAVE or ANALOGUE waveform to a SQUAREWAVE.
Any form of improving a signal to a square wave is called **SIGNAL CONDITIONING**.
This is also called **RISE-TIME** improving. The Schmitt Trigger produces a fast-switching digital output suitable for edge triggering.
Fig: 14 shows waveforms improved by a Schmitt Trigger. Only excursions above 66% will appear in the output:

Fig: 14 SIGNAL CONDITIONING
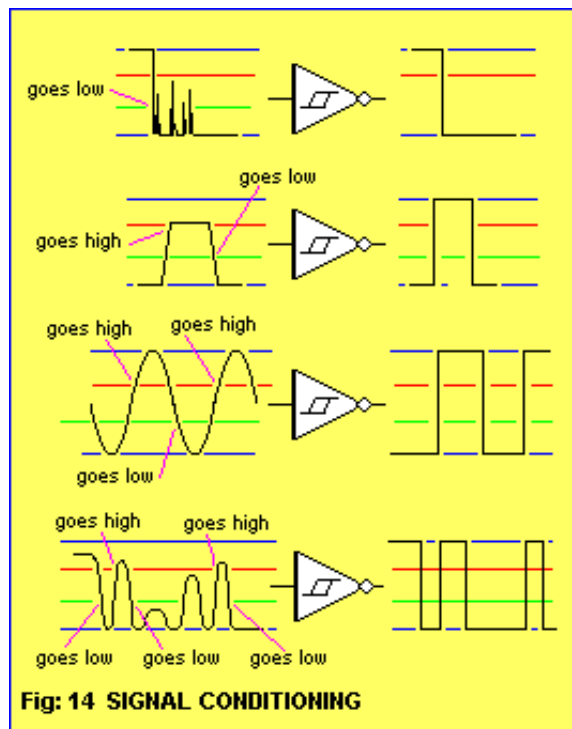
SWITCHING THRESHOLD

The **SWITCHING THRESHOLD** is the point where a signal changes logic states.
A Schmitt Trigger has two thresholds - or **TRIP POINTS**. A positive going threshold (Vt+) and a negative going threshold (Vt-).
The positive going threshold is also called the **UPPER THRESHOLD** and occurs at 66% of rail voltage.
The **LOWER THRESHOLD** occurs at 33% rail voltage.
The difference between the two thresholds is called the **HYSTERESIS ZONE.**
A signal will not change the state of the gate until it passes the positive going threshold. A high signal that enters the Hysteresis Zone will not change the state of the gate until it reaches the negative going threshold.
Besides preventing unwanted oscillation, the Hysteresis Zone also provides noise immunity.

THE 4093 IC

Another common Schmitt Trigger IC is the 4093. This is a Quad 2-Input Schmitt Trigger.

Fig: 15 4093 Quad 2-Input NAND
SCHMITT TRIGGER
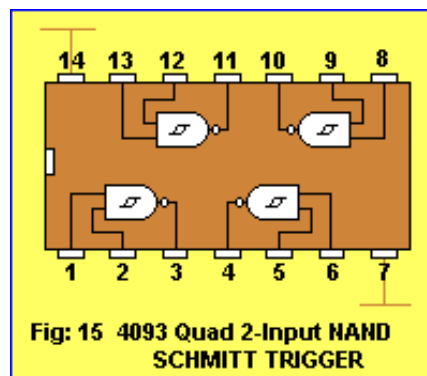
The CD 4093 is sometimes used for its gating capability. One of the inputs of the gate can used to turn the gate on and off. This is called **GATING**. This feature can be achieved with a single-input Schmitt Trigger with a diode. This allows the 74c14 IC to be used.
Fig: 16 shows how to substitute a 4093 NAND gate for a single-input gate:

Fig: 16 SUBSTITUTING A 4093 FOR A 74C14
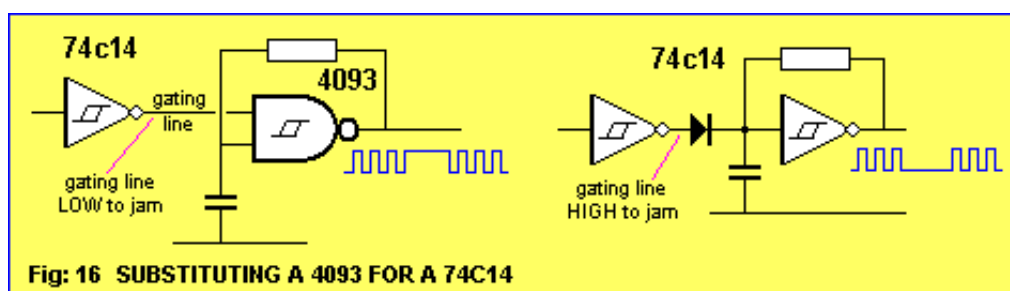
SUBSTITUTING THE 555

The 555 can be replaced by the 74c15 in almost every case, with the advantage of lower quiescent current and the availability of 6 building blocks. The 74c14 Schmitt gate is comparable with the 7555 (the CMOS version of the 555).

Fig 17 shows a 10 MINUTE **TIMER**. The circuit is also called a **DELAY** circuit:

10 MINUTE TIMER
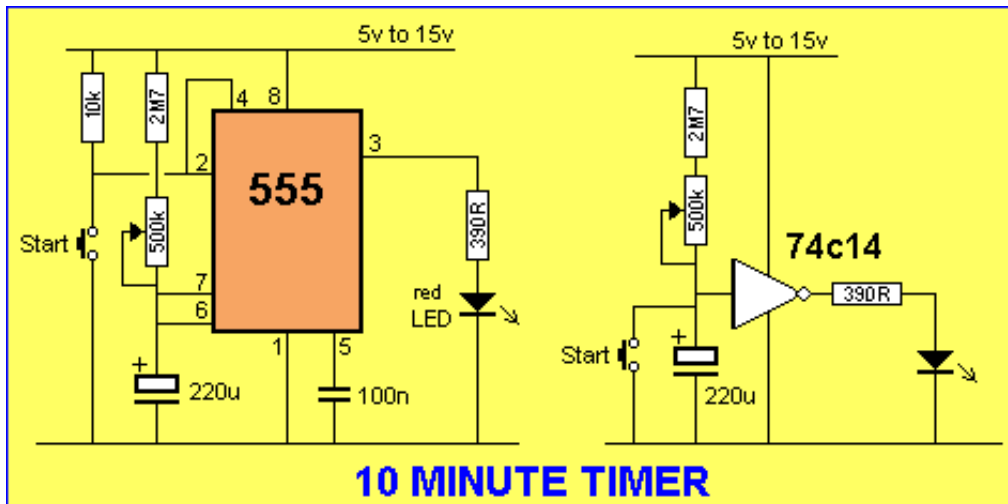
The 555 replaced by a Schmitt gate and a transistor to provide the drive-current:

THE 555 OSCILLATOR AND ITS EQUIVALENT SCHMITT
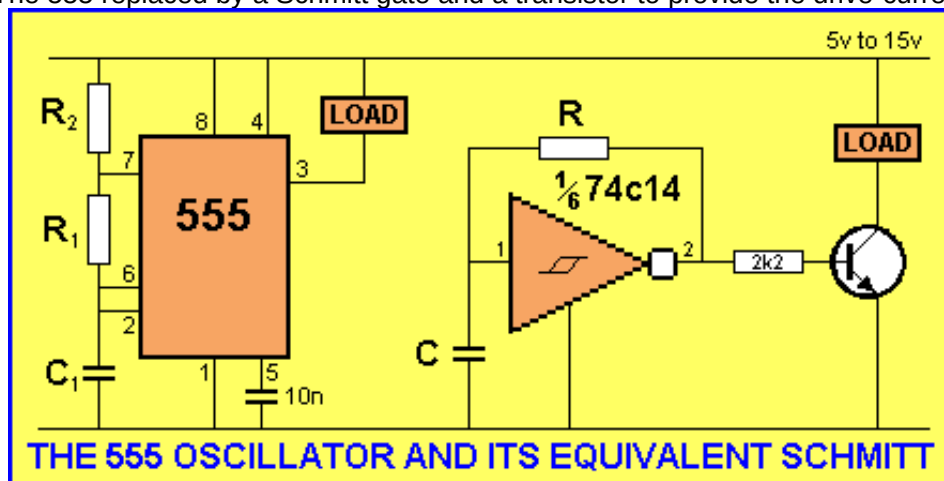
SUMMARY

A Schmitt Trigger is a bistable (two-state) device used to square-up waveforms with slow rise and fall times. The most common applications are **THRESHOLD DETECTION** and **SIGNAL CONDITIONING**. Speeding up the **TRANSITION** (rise and fall) time affects the shape of the waveform, turning poor signals into reliable waveforms capable of driving digital ICs.

The **THRESHOLD DETECTION** feature will prevent signals with insufficient amplitude (such as noise) from activating the clock lines of digital chips.