Chapter – 2

TRANSDUCERS AND DESIGN OF TRANSDUCER SECTION

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A transducer is a device that receives energy from one system and retransmits it, often in a different form, to another system. On the other hand, a sensor is defined as a device that is sensitive to light, temperature, electrical impedance, or radiation level and transmits a signal to measuring or control device.

The term transducer, sensor gage, and/or pick-up, as applied in electronic instrumentation, denotes the magnitude of an applied stimulus converted into an electrical signal proportional to the quantity of the stimulus.

A complete knowledge of the electrical or mechanical characteristics of the transducer is of great importance while choosing a transducer for a particular application.

2.1 IMPORTANT PARAMETERS : [1,2]

1. Ruggedness : Ability to withstand overloads, with safety stops for overload protection. Leads from the transducer should be sturdy and not be easily pulled off.

2. Linearity : Ability of stability and to reproduce the input output characteristics symmetrically and linearly. It is the main factor considered.

3. Repeatability : Ability to reproduce the signal exactly under all environmental condition.

4. High reliability : Minimum error in the measurement, unaffected by temperature, variation and environmental variations.

5. Convenient instrumentation : Sufficiently high analogue output signal with high S/N ratio. The rating of the transducer should be sufficient so that it will not breakdown.

6. Excellent characteristics that can affect the performance in static, quasi-static, and dynamic states.

7. Built-in integrated device with noise, asymmetry, and other defects minimised.

The factors influencing the type of transducer usage and quality of measurements include the following

1. Non-linearity effects.
2. Hysteresis effects.
3. Load alignment effects.
4. Temperature effects.
5. Calibration.
6. Components limitation.
7. Size, if used in physiological work.

2.2 CLASSIFICATION OF TRANSDUCERS :

All electrical transducers are broadly classified under two categories, viz. active and passive. Active transducers are self generating devices, operating under energy conversion principles. They generate an equivalent electrical output signal, e.g. from pressure to charge, without any external energizing source. While passive transducers operate under energy controlling principles. They depend upon the change in some electrical parameter (Resistance, inductance or capacitance) whose excitation or operation requires secondary electrical energy from an external source.

2.3 TEMPERATURE TRANSDUCERS : [1,2]

Many temperature sensors are employed for monitoring and control of temperature and these transducers or sensors work on different principles. The following table summaries the type of transducer its principle of operation and typical application.

Sr. No.	Electrical Parameter & Class of transducer	Principal of operation and nature of device	Typical application
1.	Resistance thermometer	Resistance of pure metal wire with a large positive temperature coefficient of resistance Varies with temperature.	Temperature, radiant heat
2.	Thermistor	Resistance of certain metal oxides with negative temperature coefficient of resistance varies with temperature.	Temperature
3.	Thermocouple and thermopile	An emf is generated across the Junction of two dissimilar metals or semiconductors when that junction is heated	Temperature; heat flow, radiation
4.	Semi Conductors	Junction voltage of p.n. Junction as rate of variation 2.5 $mv/^0c$	Temperature

The characteristics of some of the temperature. Detectors having summarised in the following tables.

2.3.1 : R.T.D. : [2,3]

Parameters of RTD is given in following table :

RTD Material	**Alpha coefficient**	Temperature Range	**Accuracy**	**Advantages**	**Disadvantage**
Platinum	0.0039	-300^{0}F to +1500^{0}F	$\pm$ 1^{0}F	Low cost High stability	Relativelly slow response time (15s) not as linear as copper thermometer
Copper	0.0038	-325^{0}F to +250^{0}F	$\pm$ 0.5^{0}F	High linearity High accuracy in ambient temperature range	Limited temp. range (to 250^0 f
Nickel	0.0067	+ 32^{0}F to –150^{0}F	$\pm$ 0.5^{0}F	Long life High sensitivity High temperature coefficient	More nonlinear than copper Limited temp. range (to 150^0 f

2.3.2 : THERMOCOUPLE : [1,3]

Thermocouples are economical and rugged. They have reasonable good long term stability, linearity owing to, their small size, they respond quickly and are good choice, where fast response is important.

Some common Thermocouples :

Junction materials	Typical useful temperature range	Voltage swingover range (MV)	ANSI Desegnation
Platinum Rhodium	38 to 1800	13.6	B
Tungsten – Rhenium	0 to 2300	37.0	C
Chromal - Constantan	0 to 982	75.0	E
IRON- Constantan	-184 to 760	50.0	J
Chromal – Alumel	-184 to 1260	56.0	K
Platinum - platinum Rohidium	0 to 1593	18.7	R
Copper- constantcy	-184 to 400	28.0	T

2.3.3 : SEMICONDUCTORS (p. n. Junction) [2,4]

Zener diodes are available having breakdown voltage in the range of 1.8 to 200 V & with power ratings from ¼ to 50 W.

The temperature coefficient gives the percent change in break down voltage with temperature. It is gives by the equation.

$$Tc = \frac{\Delta\ V2}{V_2\,(T_1 - T_0\,)} \quad x\ 100 \qquad \%\,/\,^0C$$

Where ΔV_2 is the resulting change in Zener voltage due to the temperature variation

The temperature coefficient can be positive, negative or even zero depending up on the zener voltage levels.

Similarly p. n. Junction voltage of a semiconductor diode varies as 2.5 mV/^{0}C these diodes can be used to sense the temperature over the range of 25^{0}C to 150^{0}C with suitable signal conditioning circuits.

Similarly semiconductor resistance thermometer are used in the temperature range 173^{0}C to 453^{0}C with error of 0.5^{0}C - 1.5^{0}C for high sensitivity, small size and good linearity are important.

2.3.4 : PYROMETER : [2]

Optical pyrometers work on the principle of the changes in colour of a hot body and represent this phenomenon in terms of temperature. When body is heated, initially it becomes red, turns to orange, and finally become a white colour. The real temperature measurement is based upon determination of the variations in colour of the object and comparing it with known values generated with a heated filament.

Sr. No.	Measuring Device	Temperature Range in ^{0}C	Error in ^{0}C	Remark
i	Spectral pyrometer	823 to 3773	5 to 35	Indirect method of Measurement used Only for high temp. Measurements
ii	Band-Radiation pyrometer	773 to 2273	1 to 1.5	
iii	Total Radiation pyrometer	233 to 2273	1 to 1.5	

2.3.5 : THERMISTOR : [2,3]

Thermistores have a negative Temperature coefficient (NTC). The resistance at room temperature (25^0C) for typical commercial units range from 100 Ω to 10M Ω. They are suitable for use only up to about 800^0C. In some cases the resistance of thermistors at room temperature may decrease by 5% for each 1^0C rise in temperature. This high sensitivity to temperature changes makes the thermistor extremely useful for precision temperature measurements, control and compensation. Thermistors are non-linear devices although new units with better linearity over the 0 to 100^0C temperature ranges are available. Various configurations of thermistors like disk type, rod type, washer type, bead type and bush type are available.

Advantge of thermistor.

1. Small size and low cost
2. Fast response over narrow temperature range
3. good sensitivity in the NTC region
4. Cold junction compensation not required due to dependence of resistance on absolute temperature.
5. Contact and lead resistance problems not encountered due to large R_{th} (resistance)

Limitation of thermistor :

1. Non- Linearity in resistance Vs. Temperature characteristics.
2. Unstable for wide temperature range.
3. Very low excitation current to avoid Self heating.
4. Need of shielded power lines, filters etc due to high resistance.

2.4 : CHARACTERISTICS OF THERMISTOR :

We have used thermistor as a temperature sensor because of its fast response and good sensitivity. Also the temperature to be controlled is low (80^0C). The following table gives variation of the resistance of various thermistors as a function of temperature

Table 2.1 : Thermistors Resistance Variation with temperature.

Temp. ^{0}C	Resistance 4.7 KΩ	Resistance 3.3 KΩ	Resistance 2.2 KΩ	Resistance 1 KΩ
90	640	491	380	161
85	723	526	509	194
80	836	650	589	210
75	941	731	699	242
70	1091	890	820	274
65	1272	1090	950	319
60	1473	1280	1108	348
55	1712	1501	1289	426
50	1998	1728	1484	476
45	2394	2122	1607	580
40	2855	2622	1919	700
35	3408	3060	2260	809
30	4078	3685	2785	954
25	4892	3866	2923	1195

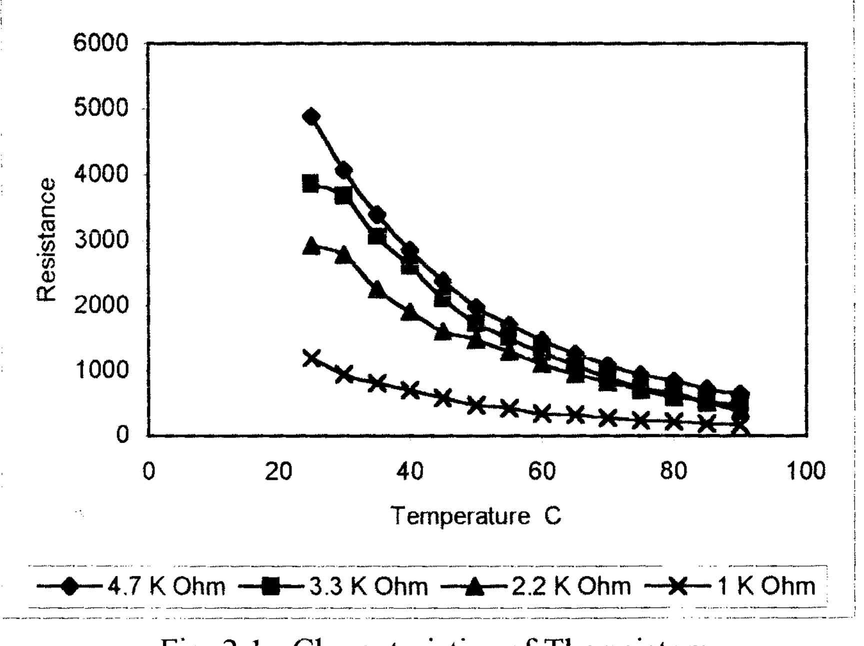


Fig. 2.1 : Characteristics of Thermistors

2.5 : DESIGN OF SENSOR SECTION :

Here thermister of value 4.7 K in series with a fixed resistor R=5K forms the timing resistor network. Astable multivibrator is implemented using IC-555 in a non-conventional manner. The design of which is given by two apporaches-

1. Using single resistor
2. Using Fuzzy Logic

2.5.1 : TIMING GENERATION WITH IC-555

SE/NE a monolithic IC-555 timer was first introduced by Signetics Corporation in the early 1970[5]. It is reliable, easy to use, TTL compatible and low cost device, Absolute ratings of this IC are given in table-I. Details of pin functions are available in many books [5-7]; This IC is widely used as an astable multi-vibrator and a mono-stable multivibrator. Astable multivibrator can be designed with fixed and variable duty cycle ranging from 1%to 99% and with variable frequency.However additional diodes are required to separate the charging and discharging paths to realize variable duty cycle and a capacitor bank to vary the frequency. Astable operation can also be realized by a novel and simple single R-C connection as shown in fig.2.2(a). This is a new configuration and gives 50% duty cycle. Design chart is also given for the selection of components.

Table 2.2 : Specifications of IC 555 [6]

Parameter	SE-555	NE-555
Supply Voltage	5 To 18V	5 To 18V
Power consumption	600 mW	600 mW
Package	T,V, F	T,V,F
Operating temp. range	-55To 125 °C	-65To 125°C
Sinking or sourcing	200 mA	200mA
Frequency range	Fraction of a Hz to 100kHz	Fraction of a Hz to 100KHz

a) WORKING:

The voltage at the pin 3 and pin 2 are out of phase which makes the circuit to work .At the switch on because of the transient behavior voltage across the capacitor being zero (<Vcc/3), the out put at the pin 3 is high. The capacitor charges through R from this output and voltage at the pin 2,6 increases exponentially till it becomes 2Vcc/3; at this point of time the output at pin 3 becomes low which helps for the discharge of the capacitor. when voltage across capacitors pin 2 drops to Vcc/3, the output at pin 3 goes high and the entire cycle repeat's. The result is a square wave output as shown in fig.2.2(b).

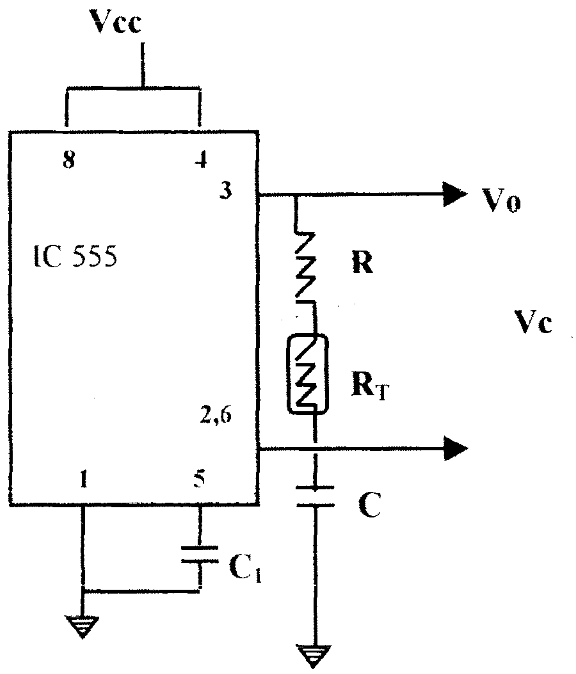
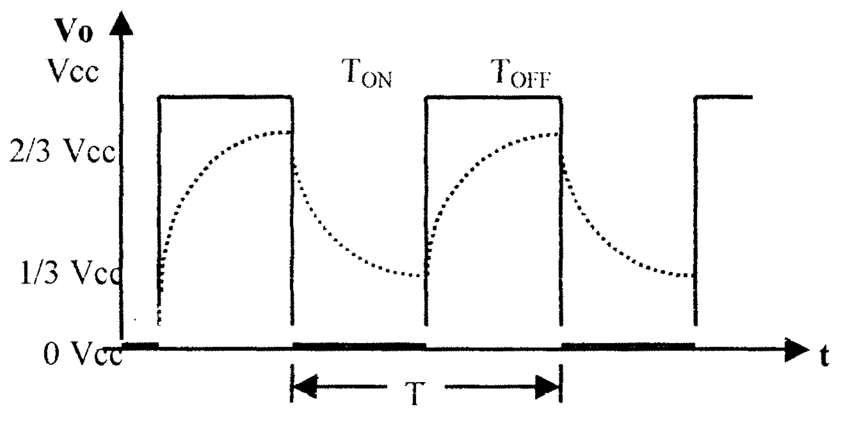


Fig.2.2(a) : Inexpensive timer configuration



[——— = output voltage, ... = capacitor voltage]

Fig.2.2(b) : Output waveforms at pins 3 and 2,6.

b) THEORY: [7]

Voltage across the capacitor at any instant t is given by

$Vc(t)=Vi+(Vf-Vi)e^{-t/RC}$

Vi= initial voltage across the capacitor

Vf= final voltage to which it will charge (source voltage)

For Ton ;Vi= Vcc/3 and Vf=Vcc

Ton lasts till Vc(t)=2Vcc/3

$2Vcc/3=Vcc/3+(Vcc-Vcc/3)e^{-Ton/RC}$

$T_{on}=RC \ln 2$

For T_{off}:

Vi= 2Vcc/3 and Vf=0

T_{off} lasts till Vc(t)=Vcc/3

$Vcc/2=2\ Vcc/3+(0-2\ Vcc/3)\ e^{-Toff/RC}$

$T_{off}=RC \ln 2$

Here $T_{on}=T_{off}$ i.e duty cycle is 50% i.e the output is symmetrical square wave with amplitude equal to Vcc

Total time period $T= T_{off} + T_{off}$

$T = 2RC\ln 2$

$T = 1.4\ RC$

c) **DESIGN GUIDELINES :** [7]

Limit on R: 1KΩ < R < 3.3 MΩ

A decoupling capacitor (C1) above 10μF is recommended to remove unwanted spikes in the output. Pin 5 is PWM input, use C2 in the range 0.1 to 10 μF to avoid PWM due to external voltage or noise.

The minimum value of the timing capacitor C should be greater than the parasitic non-linear capacitance at the pin 6 and 7 (C > 100 p.f.). Choice of the large value of the leakage current. Tantalum capacitor with the low leakage current is suitable as a large value capacitor. Design chart is tabulated and given in Fig.2.3 with the help of which astable multivibrator for the required period can be designed.

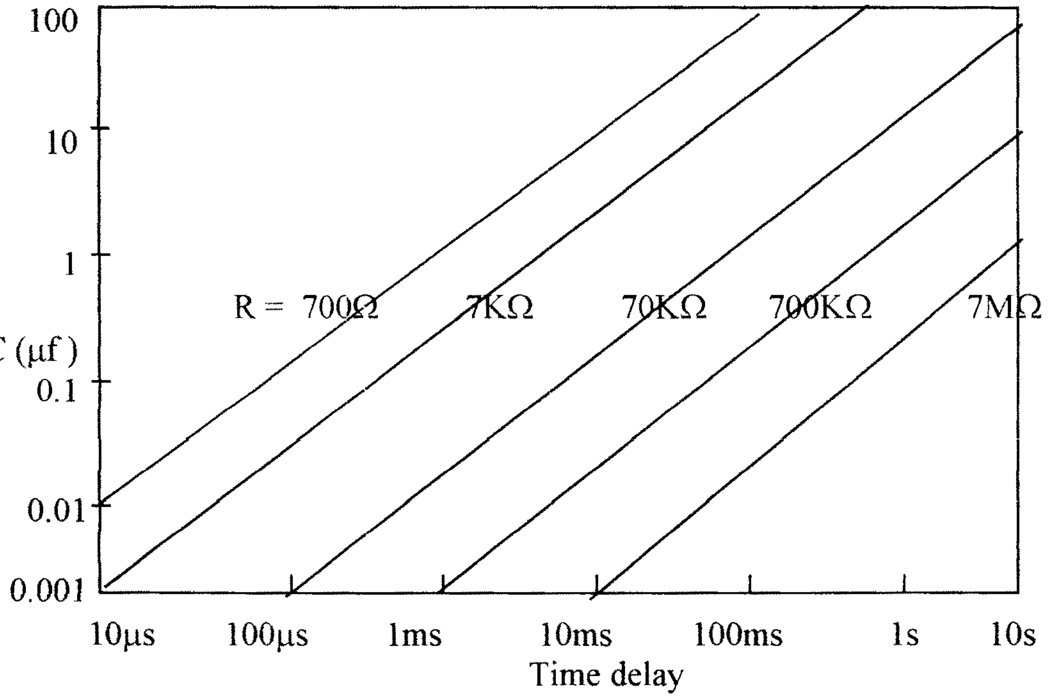


Fig.2.3 : Design chart

Alternatively the formula,

$$T=1.4RC$$

can be used for design, with the same rules followed for selection of R and C.

2.5.2 : DESIGN OF FUZZY ASTABLE MULTI-VIBRATOR :

a) Development of Fuzzy Logic Timer

Designing of 555 timer using the underlying principles of fuzzy sets and fuzzy logic comprises the following steps [8-11] -

1. Fuzzification
2. Knowledge Representation
3. Decision Logic
4. Defuzzification

b) Fuzzification

The frequencies have been divided into various routes such as 0-10Hz, 10-100Hz, 100-1KHz etc and one group in the range 1 KHz to 10 KHz is selected for design. The fuzzy subsets are shown in the fig.2.4(a & b). These subsets appropriately labelled as "f(n)", where "τ(n)" [DoM = Degree of Membership].

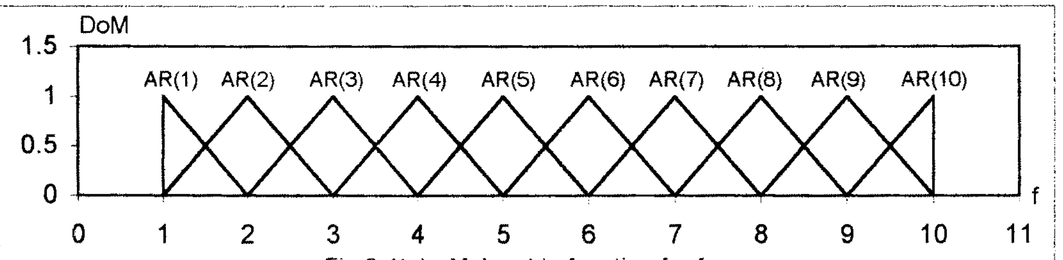


Fig.2.4(a) : Mebership function for frequency

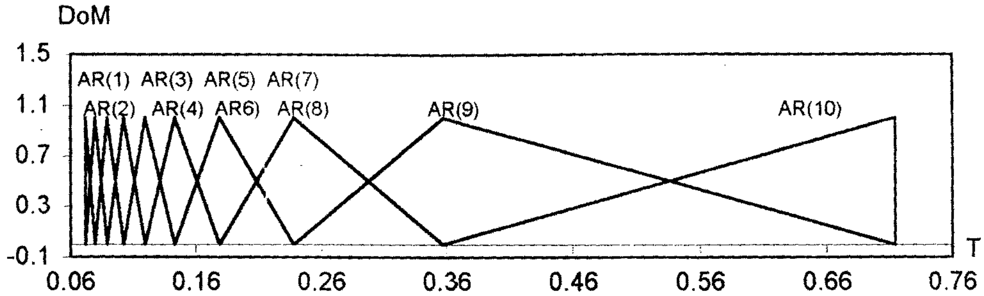


Fig.2.4(b) : Mebership function for time constant

c) Knowledge Representation

The Knowledge-Base (KB) consists of two parts-the Data-Base (DB) and the Rule-Base (RB). The Knowledge relating to range of input frequency and the appropriate size of the capacitor C and hence R formulated in terms of fuzzy inference rules kept stored in the Rule-Base. The information about the membership functions, the partition-ranges, tuning and scaling factors are kept stored in the Data-Base. The general format of fuzzy inference rule is –

"*IF the f is* AR(n) *THEN* τ *is* AB(11-n)

d) Decision Logic

The decision logic is based on the Mamadani's direct method of inference [8,9]. During the inference process the Clipped Fuzzy Sets (CFS) are generated that represent the overall τ at a particular frequency.

e) Defuzzification

The single valued τ at a particular frequency is computed by defuzzifying the Clipped Fuzzy Sets obtained during inference process. Many defuzzification methods [5] are available, however Height Defuzzification (HD) [3] being computationally simple and fast is employed in fuzzy based design.

2.5.3 : CHARACTERISTICS OF TEMPERATURE SENSOR :

In an application IC-555 is designed to give frequency Of 140 Hz at room temperature using $C = 0.47\ \mu f$ and $R = 9.7\ K\Omega$. Here R is taken as combination of thermister with resistance $4.7\ K\Omega$ and carbon resistor of value $5\ K\Omega$ is connected in series with it in order to make the frequency variation linear. It is seen from fig.2.5, that variation is almost linear up to 100^0C.

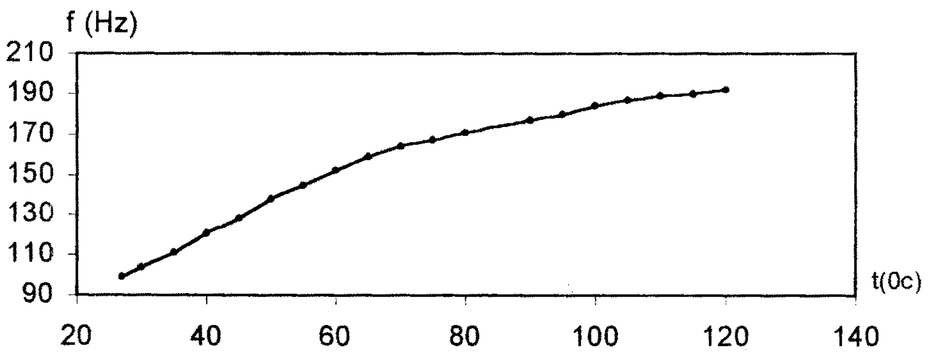


Fig.2.5 : Variation of frequency with temperature

2.5.4 : RESULTS

The error in R is negligible. The value of R obtained from graphical method may not be so accurate. The advantage of fuzzy methodology is that the software uses fixed values of R in the range 1 K to 10 K. For all the decade frequency ranges i.e. 0-10Hz, 10-100Hz, 100-1KHz etc. the value of C is divided by factor of 10 for every higher freqiuncy range starting with C=0.07 μf for 0-10Hz. All the components are standard and easily available. Use of fuzzy logic allows embedding the thumb rules in the designing-process.

Mode	**Frequency**	**Selected Capacitor (C)**	**Resistor (R)**	**Error in R value**
By formula	2.25 KHz	0.07 μf	4.54 KΩ	
By fuzzy route	2.25 KHz	0.07 μf	4.60 KΩ	1.3 %

Table 2.3 : Comparision of Conventional and Fuzzy Design routes

2.5.5 : ADVANTAGES AND DISADVANTAGES :

a) Advantages

1. The circuit is inexpensive.
2. The output is symmetrical square wave.
3. Only one register is required, against two resistors normally required to implement astable mode.
4. The circuit is easy to assemble and design.

b) Disadantage:

1. Slight output ringing could occur which can be eliminated by putting the capacitor to Vcc instead of ground.
2. Only single duty (i.e 50%) is possible.

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