VOLTAGE TO FREQUENCY CONVERTER: MODELING AND DESIGN

A thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology
In
Electrical Engineering

By

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Rajesh Kumar Barik (108EE042)

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National Institute of Technology,
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NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that the thesis entitled "**Voltage to Frequency Converter: Modeling and Design**" submitted by **Jyoti Ranjan Behera** and **Rajesh Kumar Barik** in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Electrical Engineering** at the **National Institute of Technology, Rourkela** is an authentic work carried out by them under my supervision.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma

Date:

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Acknowledgement

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Abstract

In this thesis a study on conventional voltage to frequency converter is given. A linear voltage to frequency converter is assumed i.e. the output frequency level changes with the varying input voltage level. Then as per the findings of our study a voltage to frequency converter is designed and a physical model of the designed circuit is prepared. A transformer and full wave rectifier are used to reach the optimal dc voltage level while the regulator is used for controlled power supply. An op-Amp based voltage to frequency converter is designed whose output is obtained through a 555 timer. The main operation of the op-Amp is to serve as a voltage integrator which is necessary for triangular wave generation and also as a comparator for converting the triangular wave into square wave. The timer circuit is operated in monostable mode. A simple and low cost voltage to frequency converter design and its performance analysis is the main objective of this thesis.

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CHAPTER: 1

INTRODUCTION

1.1. Introduction

A voltage-to-frequency converter (VFC) is an oscillator .Its frequency is linearly proportional to the control voltage. The voltage to frequency (VFC)/counter ADC is monotonic and free of missing codes. It integrates noise and can consume very small amount of power. The voltage to frequency converter(VFC) is also very useful for telemetry applications, since the VFC, which is cheap ,small, and low-powered can be mounted on the experimental subject (patient, artillery shell, wild animal, communication etc.) and communicate with the counter by the telemetry link as shown in Figure 1[1]

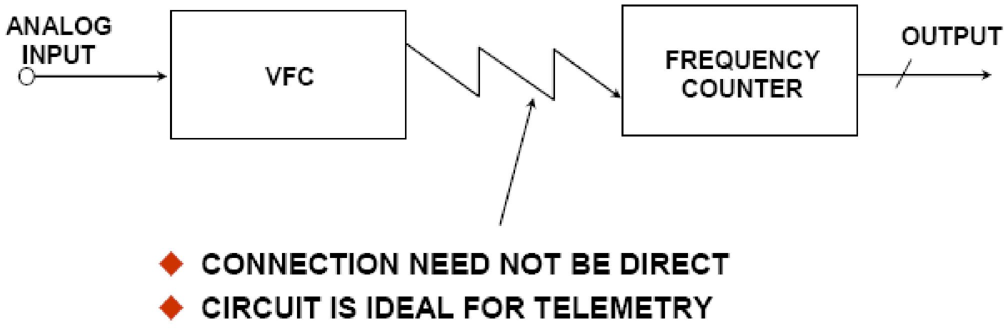

Figure 1: Voltage-to-Frequency Converters (VFC) and Frequency Counter Make a Low-Cost, Versatile, High-Resolution ADC [1]

Voltage-to-frequency converters are sometimes needed in some instrumentation applications. In the present correspondence we shall discuss a new voltage-to-frequency converter which can obtain the excellent linearity between the input voltage and the frequency of oscillation. The linearity of this converter can be improved by adjusting the variable resistor connected to the op-Amp [2],[3].

There are two common VFC architectures: the current-steering multi vibrator VFC and the charge-balance VFC [1]. The charge-balanced VFC may be made in synchronous (clocked) or asynchronous forms. There are many more VFO (variable frequency oscillator) architectures, including the 555 timer which is a unique functional building block, the key feature of VFCs is linearity, and a few VFOs are very linear.

1.1.1. A Current-Steering VFC:

The current-steering multi vibrator VFC is actually a current-to-frequency converter rather than a VFC, but, as shown in Figure 2, practical circuits invariably contain a voltage-to-current converter at the input side. The principle of operation is that: the current discharges the capacitor until the threshold is reached, and when the c terminals of the capacitor are reversed, the half-cycle is repeats itself again. The waveform across the capacitor is obtained a linear triangular wave, but the waveform on either terminal with respect to ground is the more complex waveform shown.

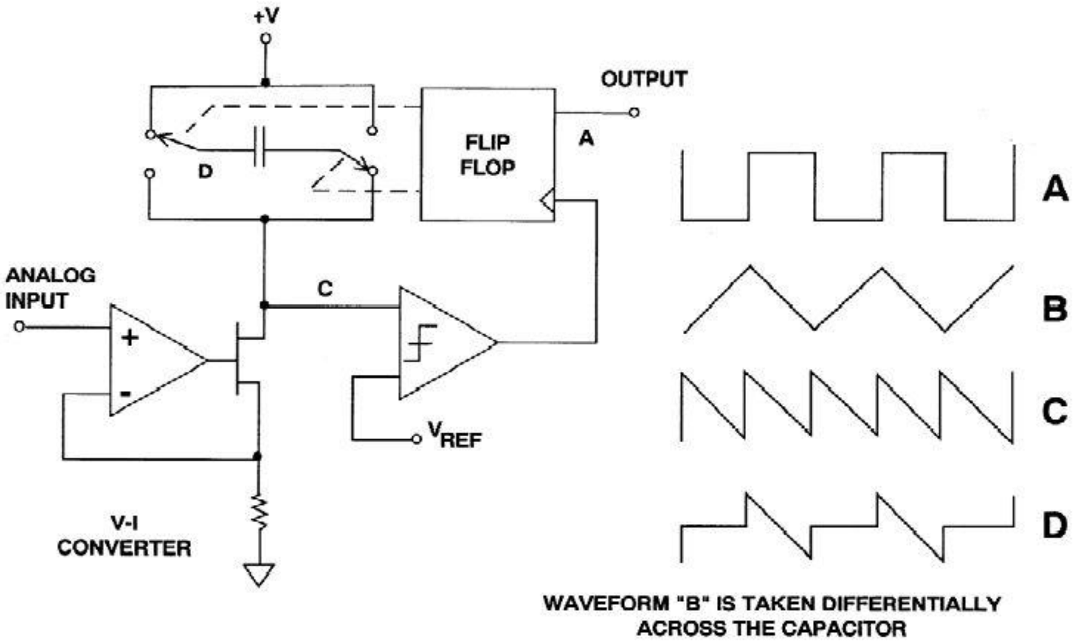

Figure 2: A Current-Steering VFC

Practical VFCs of this type have linearity around 14 bits, and comparably stable, although these may be used in ADCs without missing codes with higher resolution. The performance limits are set by threshold noise, comparator threshold temperature coefficient, and stability and the dielectric absorption (DA) of the capacitor, which is a discrete component. The comparator/voltage reference structures are shown in the diagram is more of a representation of the function performed than the actual circuit used in that diagram, which has much more integrated with the switching, and correspondingly difficult to analyze.

This type of VFC is a simple, low-powered, and, inexpensive and mostly run for a wide range of supply voltages. They are basically suited for low cost medium accuracy ADC and data telemetry applications.

1.1.2. Charge Balance Voltage-to-Frequency Converter (VFC)

The charge balance VFC shown in Figure 3 is more complex, and more accurate and more demanding in its supply voltage and current requirements, Practical VFCs of this type have linearity around 16-18 bits.

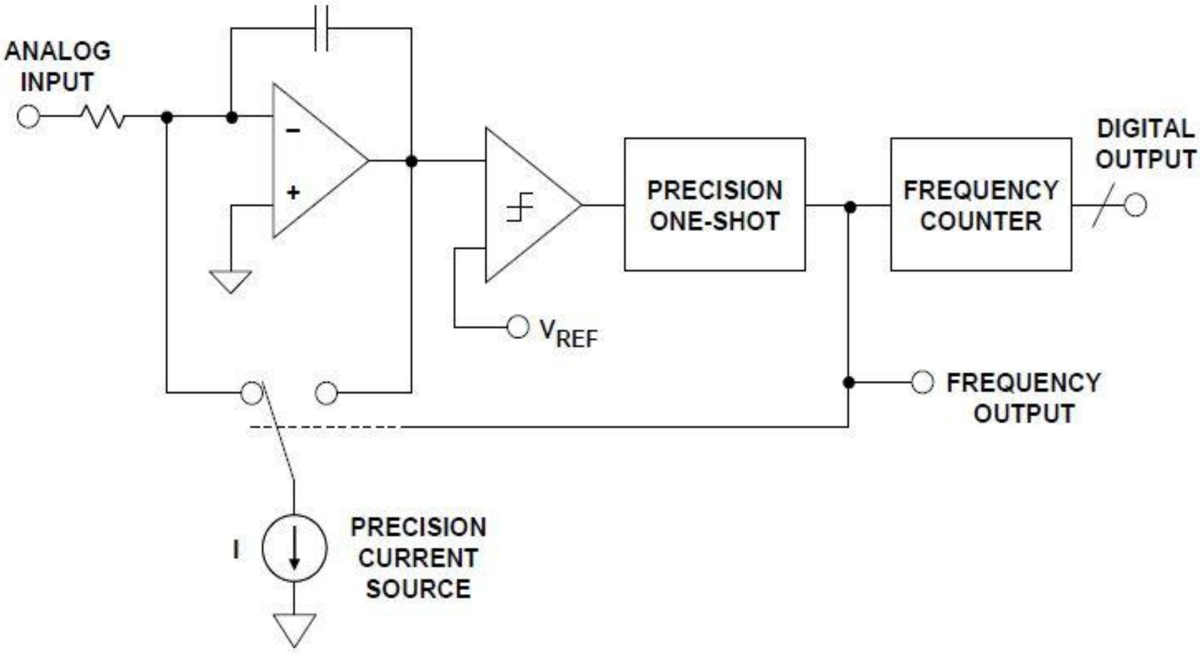

Figure 3: Charge Balance Voltage-to-Frequency Converter (VFC)

The integrator capacitor is charged by the signal as shown in Figure 3. When it exceeds the comparator threshold, a fixed amount of charge is removed from the capacitor, but the input current flow continuously during discharge, therefore no input charge is lost. The fixed amount of charge is defined by the precision current source and the pulse width of the monostable. Thus the output pulse rate is accurately proportional to the rate at which the integrator charges from the input.

At low frequencies, the limits on the performance of this VFC are set by the stability of the current source and the monostable timing (which only depends on the monostable capacitor, among other things). The exact value and temperature stability of the integration capacitor do not affect the accuracy, although its dielectric absorption (DA) and leakage do. At the high frequencies, the second-order effects, switching transients in the integrator and the precision of the monostable when it is retriggered very soon after a pulse is end, take their toll on the accuracy and the linearity.

The changeover switch in the current source addresses the integrator transient problem. Therefore by using a changeover switch instead of the on/off switch, more common on older VFC designs: (a) there are no on/off transients in the precision current source and (b) the output stage of the integrator sees a constant load, most of the time the current from the source flows directly in the output stage; but during charge balance, it still flows in the output stage, through the integration capacitor.

1.1.3. Synchronous VFC (SVFC):

The stability and transient behavior of the precision monostable create more problems, but that issue may be avoided by replacing the monostable with a clocked bistable multi vibrator. This arrangement circuit is known as a synchronous VFC or SVFC and is shown in Figure 4.

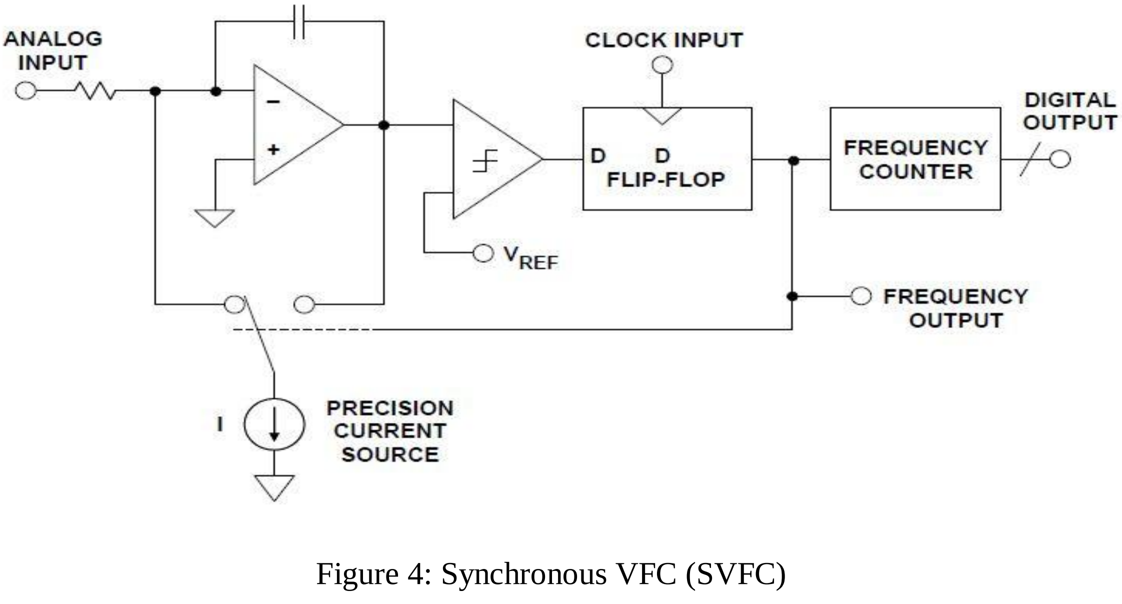

Figure 4: Synchronous VFC (SVFC)

The difference from the previous circuit is very small; the charge balance pulse length is now defined by two successive edges of the external clock. If this clock has very low jitter, the charge will be very accurately defined, but the output pulse will also be synchronous with the clock. Synchronous VFCs of this type are capable of up to 18-bit linearity and excellent temperature stability.

This synchronous behavior is convenient in many applications, since the synchronous data transfer is often easier to handle than asynchronous. It means that, however the output of asynchronous VFC ***(***SVFC) is not a pure tone (plus harmonics, of course).The Synchronous VFC ***(***SVFC) is like a conventional VFC, it contains components harmonically related to the clock frequency.

1.2 Objective

Objectives of this thesis are

- Modeling and design of a low cost voltage to frequency converter
- A physical circuit implementation of the proposed circuit
- To obtain the relationship between input voltage and output frequency

CHAPTER 2:

LITERATURE REVIEW

2. Voltage to frequency converter

The Voltage to frequency converter is accepting voltage input and converting it into frequency. The voltage to frequency converter works on the principle of current integrator and comparator. The Voltage to frequency converter in the first stage integrate the dc voltage input and that is converted in to a ramp signal that signal is compared with a comparator which provides either +V or –V output and that is again feed back to the integrator so the integrator output is a triangular wave .The slope of the triangular wave or ramp signal is proportional to the input analog voltage. The comparator section compares the integrator output with zero reference and generates the square wave.

2.1.Monostable Vibrator

It is also called as a one-shot multi vibrator. This circuit requires an external triggering pulse to change the state of the output, hence its name one-shot multi vibrator. It is a pulse generating circuit, the duration of the pulse is determined by the RC network connected externally to the 555 timers.

In *a* stable state the outputs of the circuit is approximately at logic low level or zero. When an external trigger pulse is applied to that, the output is tends to go high. The external RC network connected to the timer determines the time output remains high. But at the end of the timing interval, the output is automatically reverts back to its logic low level. The output stays low until the trigger is applied. Then the cycle repeats.

2.1.1. Monostable operation

The timer lends itself to three basic operating modes:

1. Monostable (one-shot)
2. Astable (oscillatory)
3. Time delay

One of the simplest and most widely used operating modes of the timer is the monostable (one-shot). When the output is low i.e. the circuit is in a stable state, the transistor Q1 is ON and the capacitor C is shorted to ground. However, upon application of a –ve trigger pulse to pin –2, transistor Q1 is turned OFF which releases the short circuit across the external capacitor C and drives the o/p high. The capacitor C now starts charging up towards Vcc through the RA. When the voltage across the capacitor equals to 2/3 Vcc, Comparator 1s output switches From low to high which in turn drives the output to low state via the output of the flip-flop? At that time, the output of the flip-flop turns transistor Q1 ON, enhances capacitor C rapidly discharges to transistor. The output of the Monostable remains low until a trigger pulse again applied. Then the cycles are repeats.

The time during which the output remains high is given by

$$T_p = 1.1 R_a C$$

Where

T is in seconds.

R is in ohms.

C is in Farads.

The voltage level trips the threshold comparator, which in turn drives the output low and turns on the discharge.

When the IR signal is transmitted the sensor at the (R,R) section catches the signal and that signal to trigger pin-2 of IC 555,which in turn trigger the circuit and thus the output remains high. It remains high until the charging and discharging of capacitor through the resistor and C values decide the ON time. The output pin–3 of IC 555 is connected to the base of the transistor BC548 to the resistor 1K and 57Kand the collector is connected to the Vcc. Due to the forward biasing of the transistor the transistor saturates or conduct. A small emitter current i.e. (the voltage) flows to the anode terminal of LED and thus in turn conduct the LED i.e. in ON state due to the diode action.

Similarly whenever a trigger pulse (IR signal) i.e. applied the LED will become ON state. The ON time is decided by the R&C value of the circuit

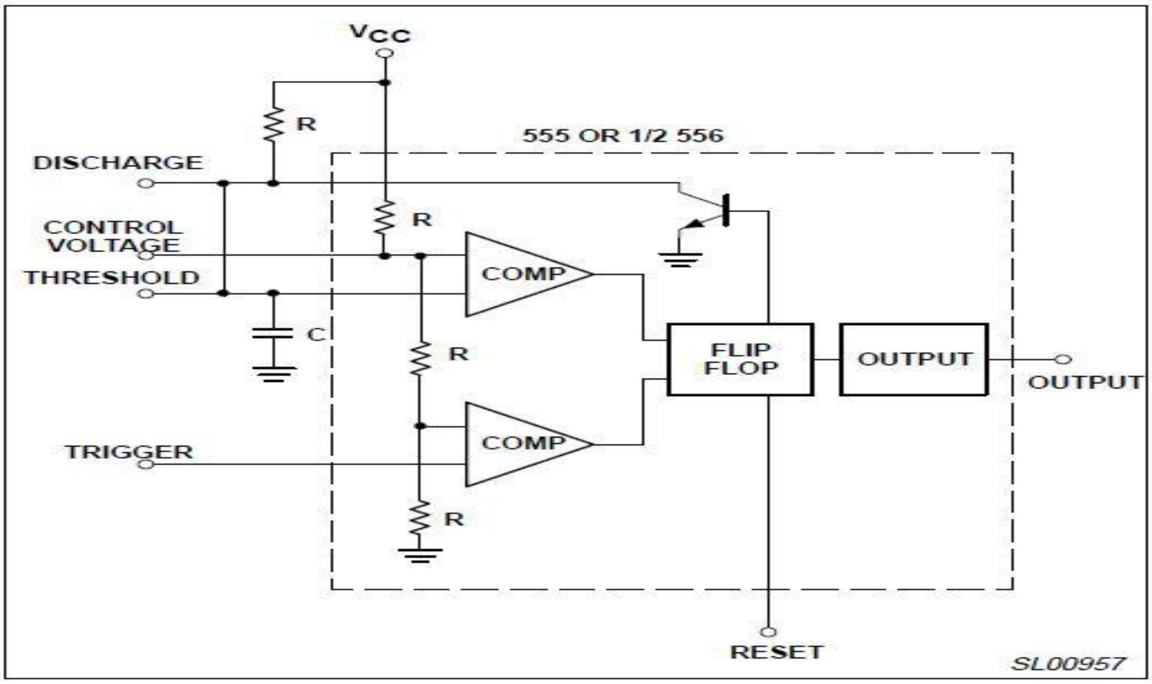

Figure 5: Monostable Operation

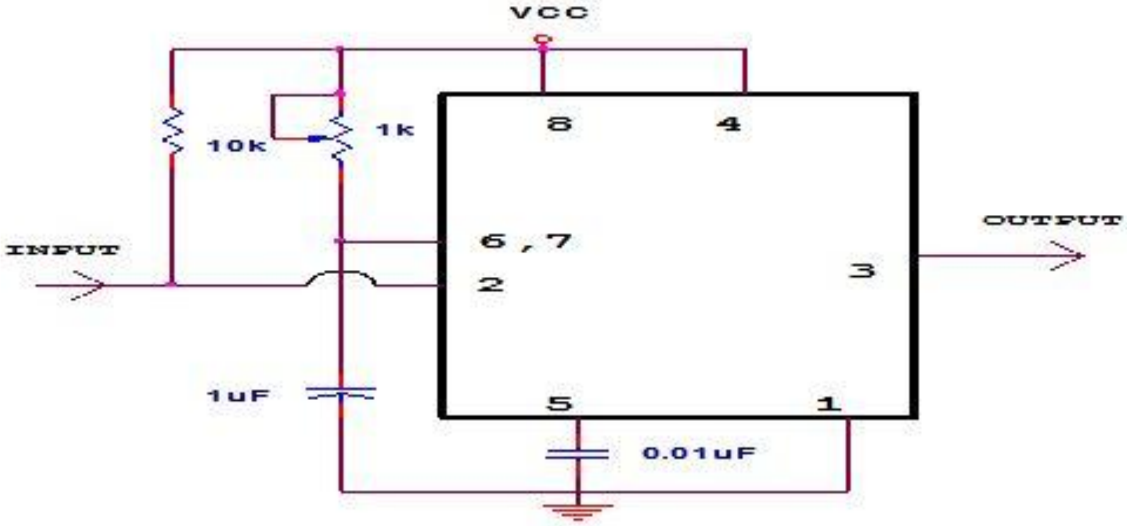

Figure 6 : Monostable (555 timer) pin configuration

2.2. Application

2.2.1. Analog to Digital Conversion:

Analog-to-Digital conversion can be realized with a simple and low-cost method based on a voltage-to-frequency converter (VFC). The output of a VFC is a digital pulse train whose repetition rate is proportional to the amplitude input of the analog signal (Fig. 7).

We only need a simple digital circuit to convert the pulse train in a binary word. One frequently suggests to perform this conversion by counting the number of pulses of the VFC output signal within a constant period t_c, This number id proportional to the frequency of the VFC and thus to the analog input signal. However, in this method, the conversion time, which is equal to the period t_c will become quite long so that the sampling rate f_s, applied on the input signal will be very low.

For the resolution of n bits, the difference between the maximum number of pulses and the minimum number has to be equal to 2^n-1.

$[\ tc/(t+)\ ] - [\ tc/(t-)]=2^n-1$

With

$t += [\ \ 1/(f+)]$, f+ = max frequency of the VFC

$t -= [\ \ 1/(f-)]$, f- = min frequency of the VFC

Or

$$t_c = (\ 2^n\text{-}1)\ \frac{(t+)*(t-)}{(t-)-(t+)} \qquad (1)$$

And

$$f_s = 1/t_c = 1/(\ 2^n - 1)\ \ *\ \frac{(t-)*(t+)}{(t+)*(t-)}\quad ; \qquad (2)$$

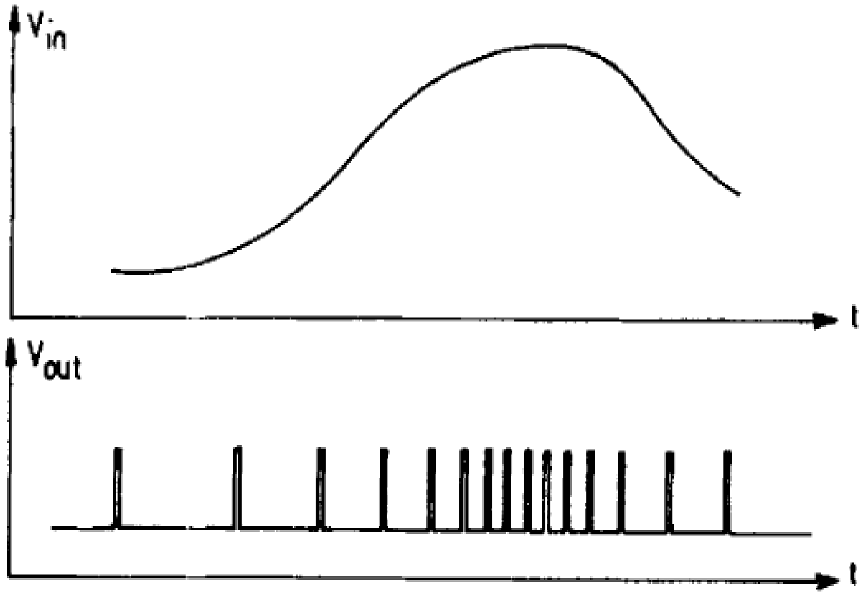

Figure 7: Input Analog signal and corresponding output signal of a V to F Converter.

As we know, components of a signal with a frequency higher than $f_s/2$ are filtered out by sampling. Therefore, we propose an alternative way of converting the output signal of the VFC into a binary number: we measure the period of the output signal by counting the number of pulses of a stable high frequency clock within I period. A simple calculation in the computer which reads this number is sufficient to get a number proportional to the analog signal. The most important requirements to the VFC for this application are: accuracy, conversion linearity, and temperature stability. Such converters are now available. Some of them are realized in an integrated circuit, others need no external adjustments to achieve the rated performance. Since the supplementary circuit to perform the whole A/D conversion is digital there are good perspectives for constructing an A/D as an adjustment-free digital integrated circuit.

2.2 **Linear Voltage-Frequency Conversion**:

The first step of this circuit is an integration of a positive voltage v which only differs from the input voltage Vin by a constant and by the sign (eventually)

v=$\pm v_{in}$+K. (3)

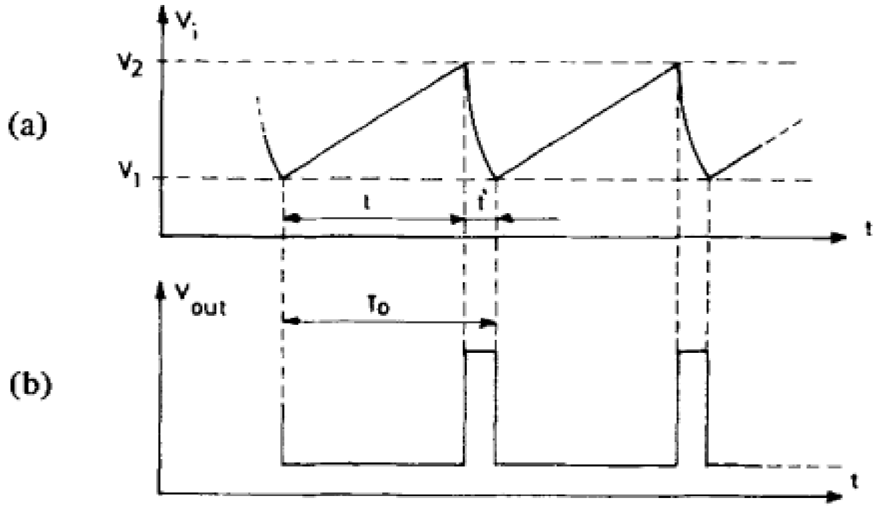

Figure 8 : Correspondence between Vin, the output signal of the integrator

(a) And V_{out} , the output signal of the VFC (b).

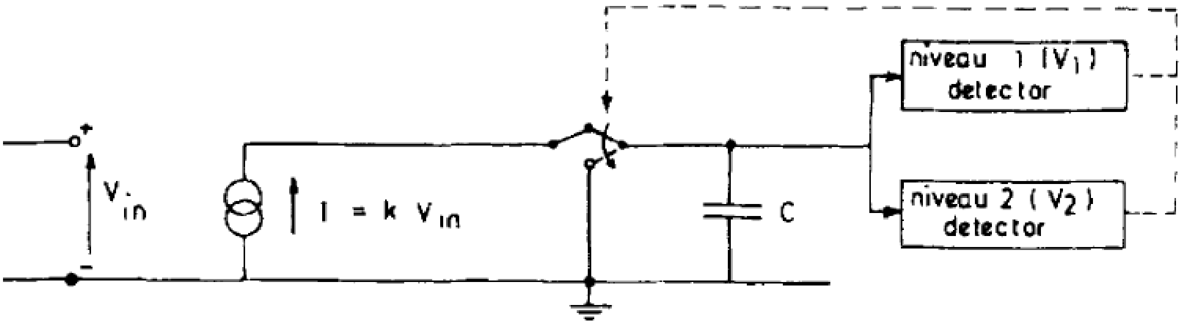

Figure 9 : Schematic of a VFC.

The starting value of the integration is a constant level V_1 (Fig.8 (a))

$$v_i = V_1 + \int_0^t v.dt$$

When the level V_2 is reached, the logic level of the output signal volt, changes (Fig. 8(b)) and the integrator falls to the levelV_1 during the period t'. Then the output level of the VFC is changed and a new integration starts. The integration is realized by loading a capacitance (starting from a voltageV_1) with a current proportional to the voltage v

(Fig.9). Therefore, the capacitance can be connected with a voltage-controlled current source or placed in the feedback loop of an operational amplifier. For the detection of the levels V_1 and V_2 one uses comparators or a flip-flop. It is important to notice that, in this method, there is a linear relation between the voltage v and $1\ /\ t$, with t equal to the distance between pulses (Fig.8 (a))

$$V=k.\frac{1}{t}\ . \tag{4}$$

The frequency f of the output signal of the VFC (Fig. 8(b)) is

$$f=\frac{1}{T0}=\frac{1}{(t+t')} \tag{5}$$

The relation between the input voltage v and the output frequency f follows from (4) and (5)

$$v=k.\frac{f}{(1-t'.f)}=f/1-\frac{t'}{(t+t')} \tag{6}$$

The voltage v is approximately linear with the frequency f: the pulse widtht' has to be much smaller than the period To = t + t'.

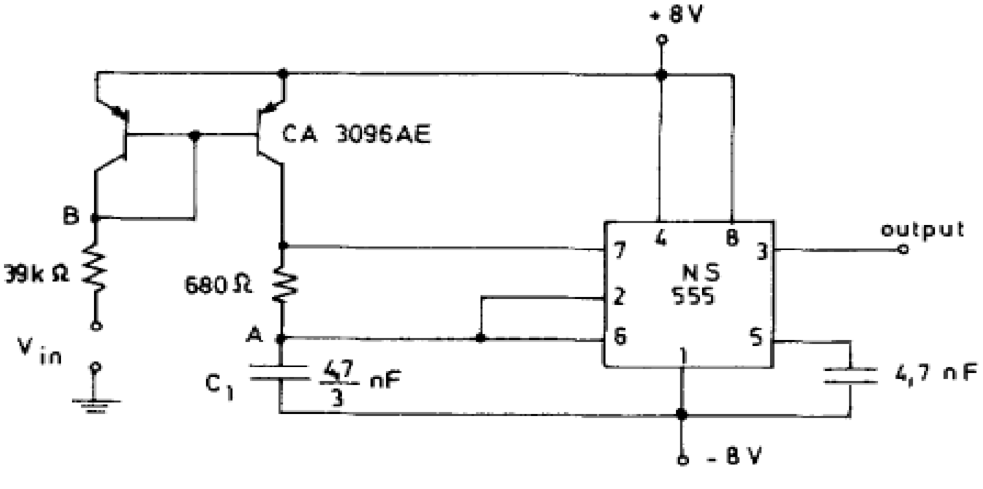

Figure 10 : A schematic of simple VFC circuit.

CHAPTER 3:

MODELING AND DESIGN

3. Circuit Description

3.1. Power Supply (+12v,-12v)

The power supply designed for catering a fixed demand connected in this thesis. The basic requirement for designing a power supply is as follows,

1. The different voltage levels required for operating the devices. Here +5 Volts required for operating microcontroller. And +12 and –12Volt is required for drivers and amplifiers and comparators etc.

2. The current requirement of each device or load must be added to estimate the final capacity of the power supply.

The power supply always specified with one or multiple voltage outputs along with a current capacity. As it is estimate the requirement of power is approximately as follows,

Out Put Voltage = +5Volt, +12Volt and –12Volt

Capacity = 1000mA

The power supply is basically consists of three sections as follows,

1. Step down section
2. Rectifier Section
3. Regulator section

3.2. Design principle

There are two methods for designing power supply, the average value method and peak value method. In case of small power supply peak value method is quit economical, for a particular value of DC output the input AC requirement is appreciably less. In this method the DC output is approximately equal to V_m. A full wave bridge rectifier is designed using four diodes and the output of the rectifier is filtered with a capacitor.

There are two capacitors connected in this power supply, one for filtering and providing back up to positive power supply and other one for providing backup and filter action to the negative power supply. The capacitor value is decided so that it will provide back up for the voltage and current during the discharging period of the DC output. In this case the output with reference to the center tap of the transformer is taken in to consideration, though the rectifier designed is a full wave bridge rectifier but the voltage across the load is a half wave rectified output. The Regulator section used here is configured with a series regulator LM78XX and 79XX the XX represents the output voltage and 78 series indicates the positive voltage regulator 79 series indicates the negative regulator for power supply. The positive regulator works satisfactorily between the voltage XX+2 to 40 Volts DC. The output remains constant within this range of voltage. The negative regulator works satisfactorily between the voltage - (XX+2) to -40 Volts DC. The output will remains constant within this range of voltage.

3.3. Circuit connection

In this we were using Transformer (9-0-9) v / 1mA, IC 7805, 7912 & 7812, diodes IN 4007, LED & resistors.

Here 230V, 50 Hz ac signal is given as input to the primary of the transformer and the secondary of the transformer is given to the bridge rectification diode. The positive output of the bridge rectifier is given as input to the IC regulator (7805 &7812) through capacitor (1000mf/35v). The negative output of the rectifier section feed to the input of the IC 7912 through a capacitor of (1000mf/35v). The output of the IC regulator is given to the LED through resistors to act as indicator.

3.4. Circuit Explanations

When an ac signal is given to the primary side of the transformer, due to the changing in flux an e.m.f is induced in the coil (primary)due to the “faraday’s law of electromagnetic induction and transfer to the secondary coil of the transformer”. The flux which is the base of inducing voltage in the transformer is same for both the windings” Transformer is a static device which transformer electrical energy from one circuit to another circuit without changing the frequency”. In the circuit the diodes are connected in a full wave bridge fashion. The secondary coil of the transformer is connected to the full wave bridge circuit for rectification purposes.

During the +ve cycle of the ac signal the diodes D2 & D4 conduct due to the forward bias of the diodes and diodes D1 & D3 does not conduct due to the reversed bias of the diodes. Similarly during the –ve cycle of the ac signal the diodes D1 & D3 conduct due to the forward bias of the diodes and the diodes D2 & D4 does not conduct due to reversed bias of the diodes. The output of the full wave bridge rectifier is not a power dc along with rippled ac is also present. To overcome this type of effect, a capacitor is connected to the output of the diodes (D2 & D3). Which removes the unwanted ac signal and thus a pure dc is obtained. Here we need a fixed dc voltage, that’s for we are using IC regulators (7805 & 7812 and 7912).”Due to voltage regulation in a circuit that supplies a constant voltage regardless of changes in load current”. This IC’s are specially designed as fixed voltage regulators and with adequate heat sinking can deliver output current in excess of 1Amp. The output of the full wave bridge rectifier is given as input to the IC regulator through capacitor with respect to GND and thus a fixed output is obtained. The output of the IC regulator (7805 & 7812 and 7912) is given to the LED for indication purpose through the resistor. Due to the forward bias of the LED, the LED glows ON state, and the output are obtained from the pin no-3.

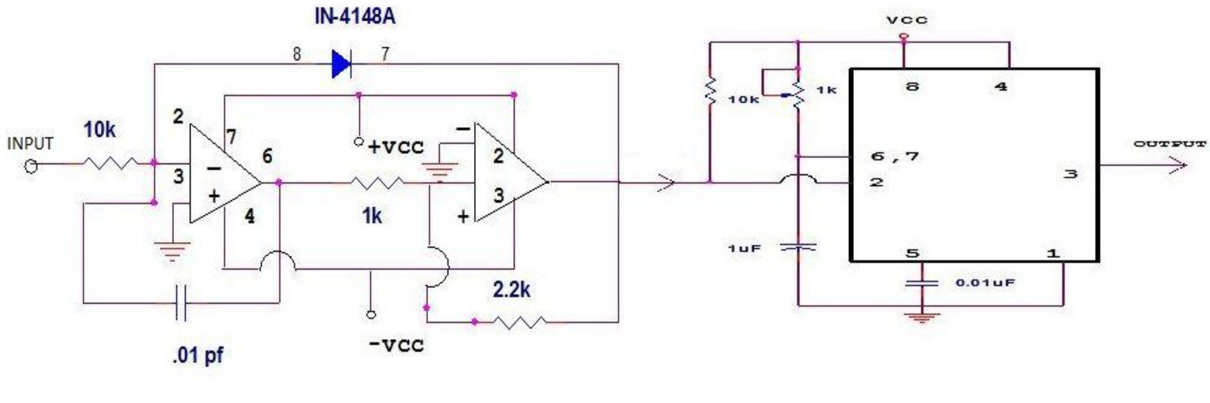

Figure 11: a simple and low cost VFC using op-amp and 555 timer (monostable)

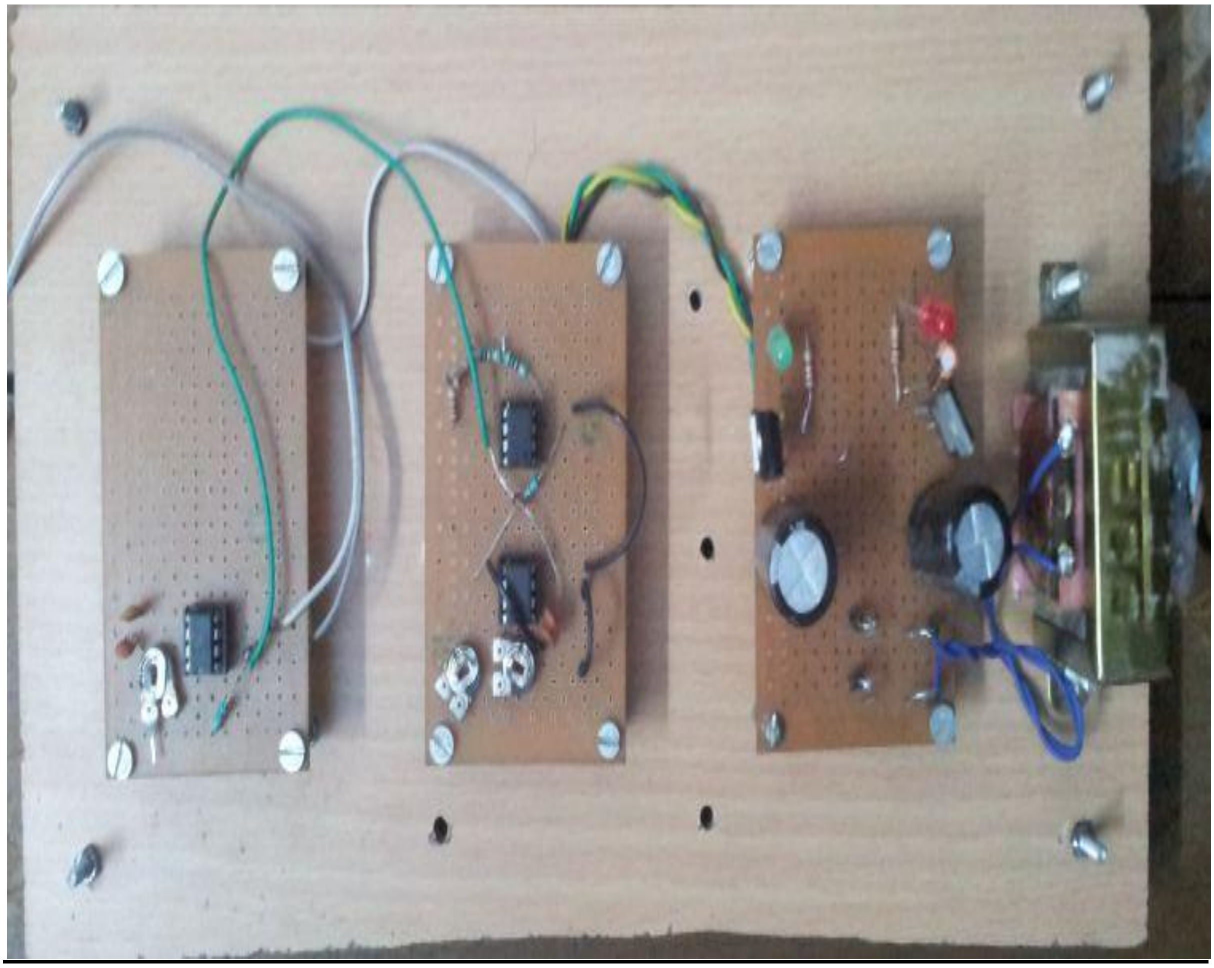

Figure 12: Physical Model of a low cost VFC circuit.

CHAPTER 4:

RESULTS & DISCUSSIONS

4. Result

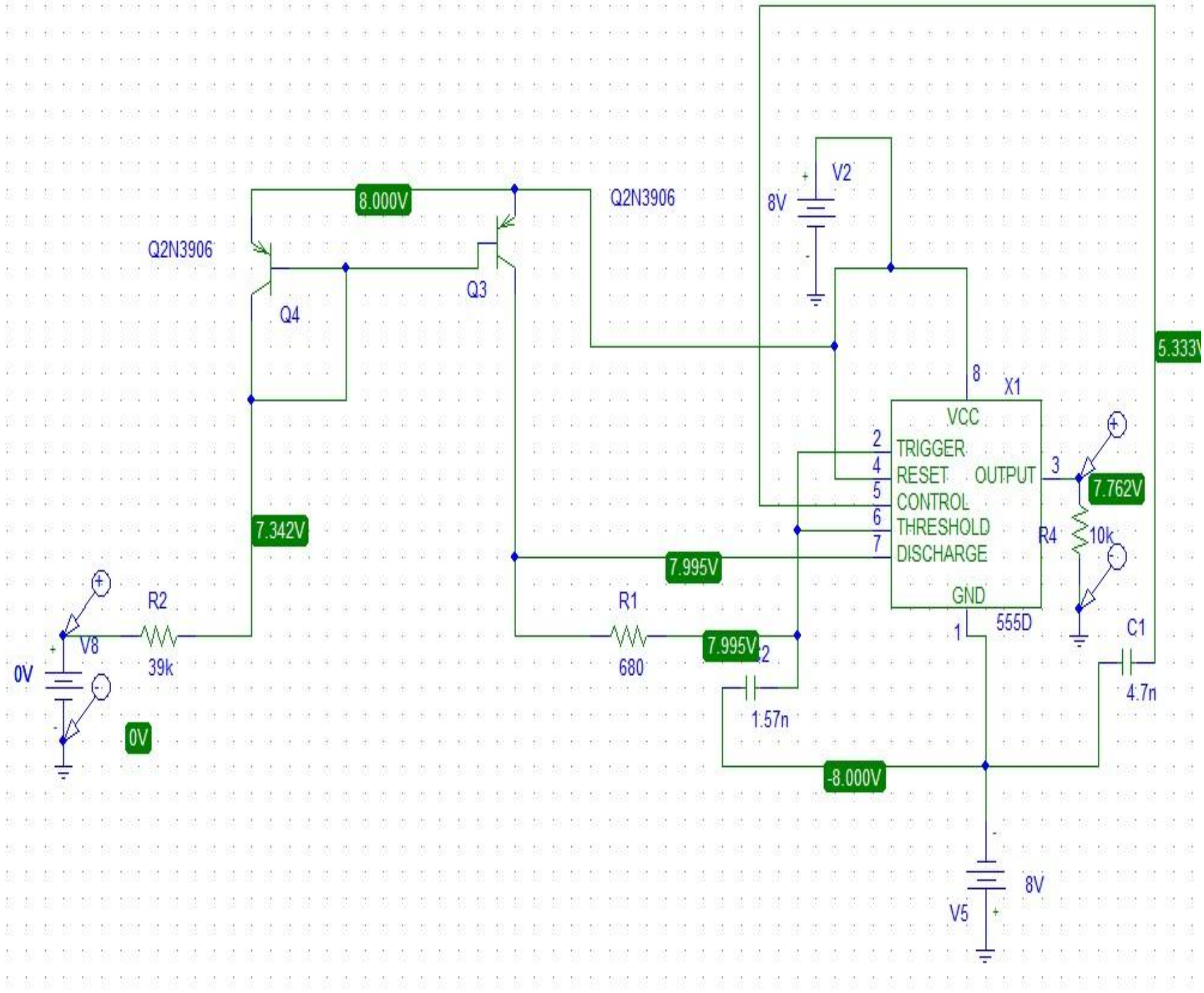

Figure 13: PSpice model of a simple VFC circuit.

A circuit, proposed [7], has been tested. We only have to choose another value of the supply voltage to get a symmetrical input voltage range between - 5 and +5 V (Fig. 10). The signal v1 of (Fig. 10) is realized in the point A by the capacitance C_1 and a voltage-controlled current source consisting of a current mirror of two p-n-p transistors. Since the voltage in the point B is fixed, the current through the input resistor (39 kΩ) is proportional to the input voltage. The current in the transistors of the current mirror is same. We also used a polycarbonate capacitance for C, to assure greater temperature stability. The correspondence between the input voltage and the output signal frequency will be discussed below.

When we choose 0V as the value of supply voltage the output fundamental frequency of the 555 timer came out 43.25 KHz

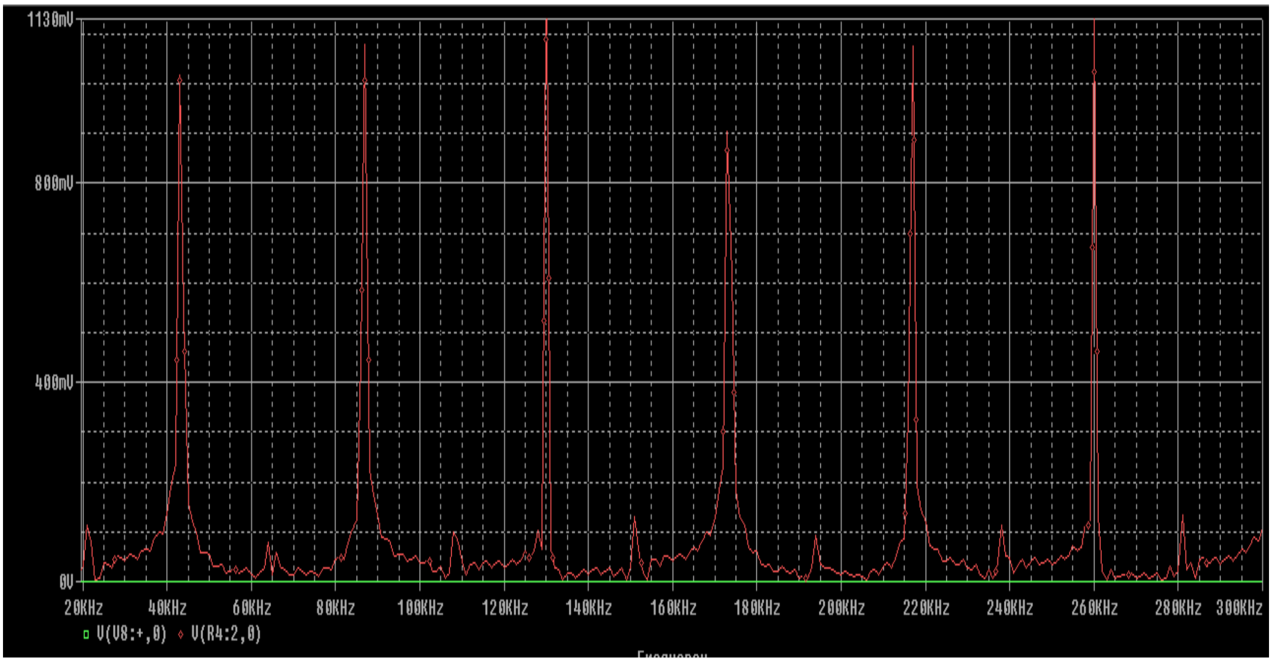

Figure 14: Output 1

When we choose 2V as the value of supply voltage the output fundamental frequency of the 555 timer came out 32.10 KHz.

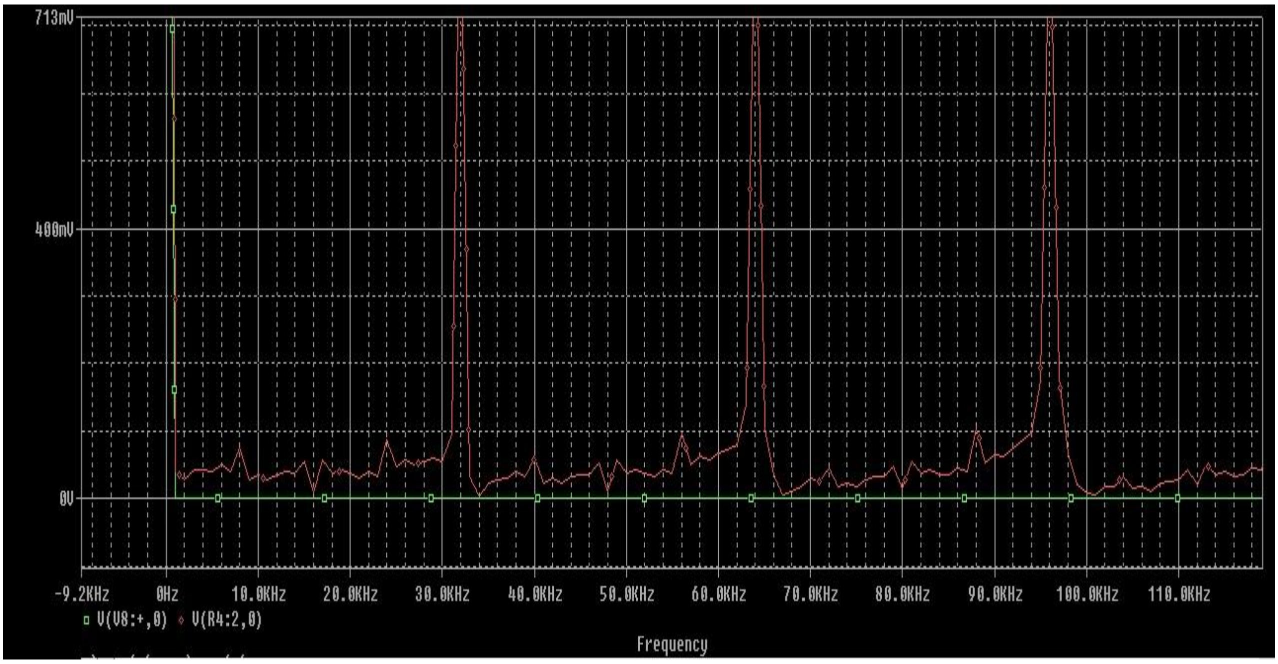

Figure 15: Output 2

When we choose-2V as the value of supply voltage the output fundamental frequency of the 555 timer came out 53.90 KHz.

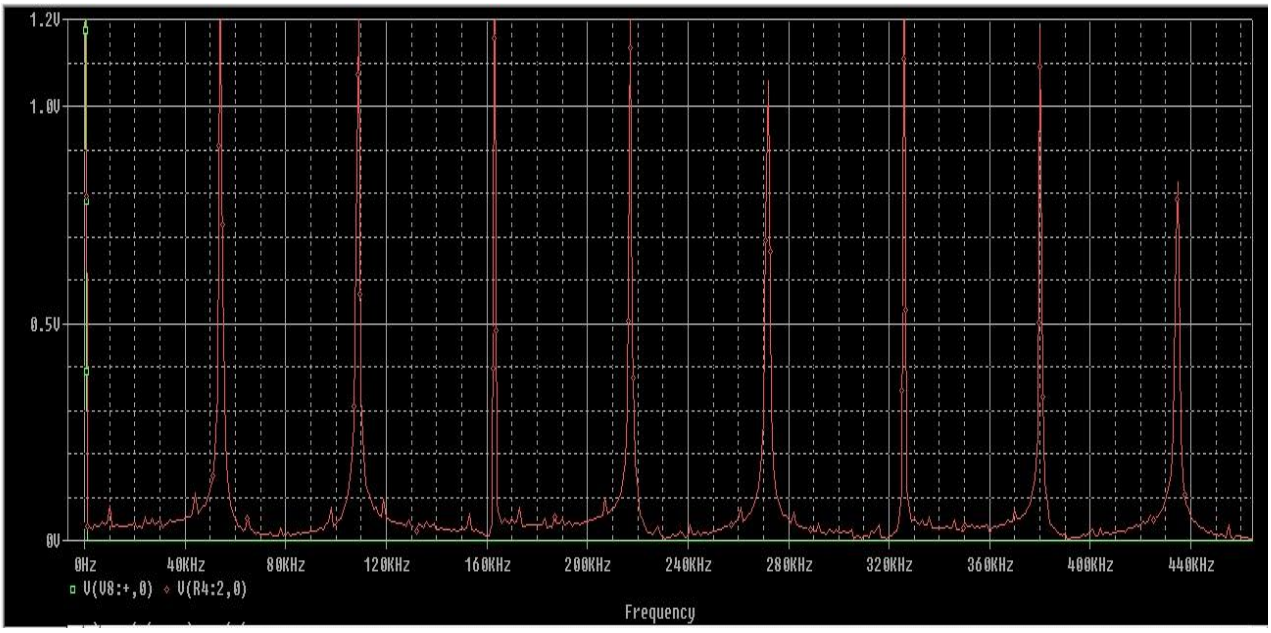

Figure 16: Output 3

When we choose 5V as the value of supply voltage the output fundamental frequency of the 555 timer came out 14.50 KHz.

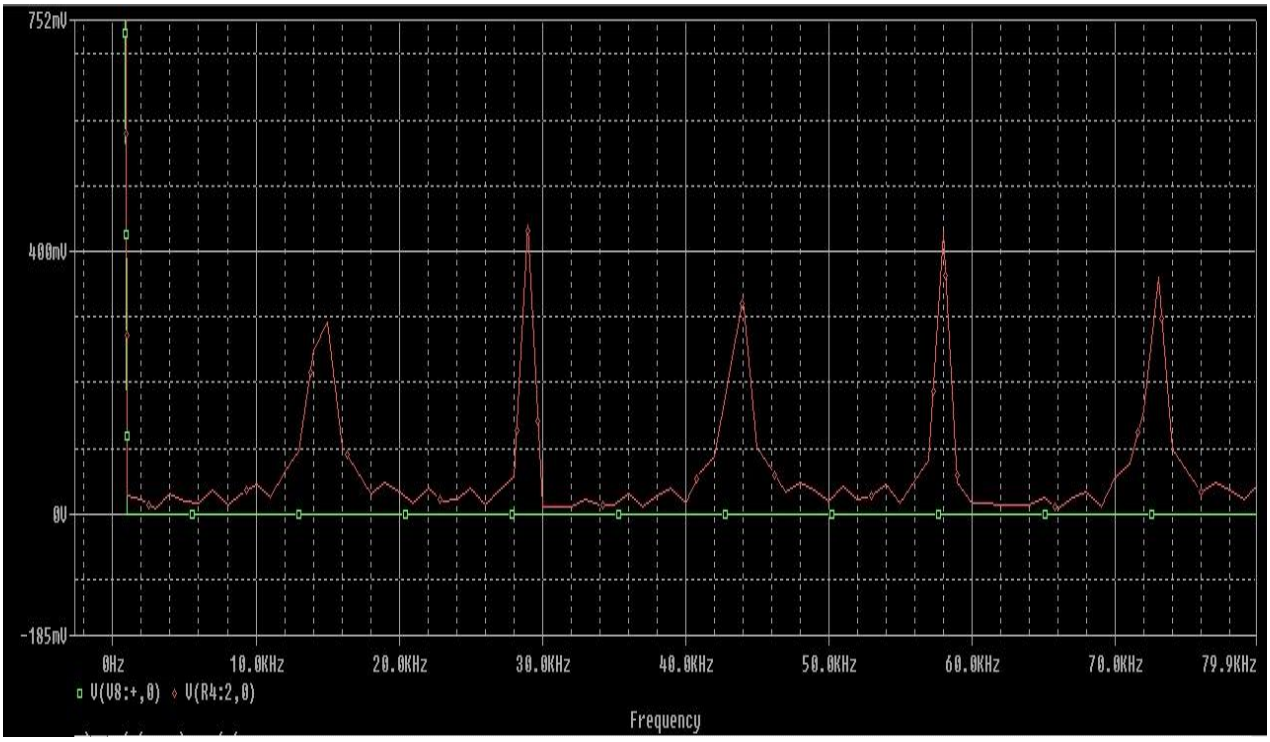

Figure 17: Output 4

When we choose -5V as the value of supply voltage the output fundamental frequency of the 555 timer came out 70.00 KHz

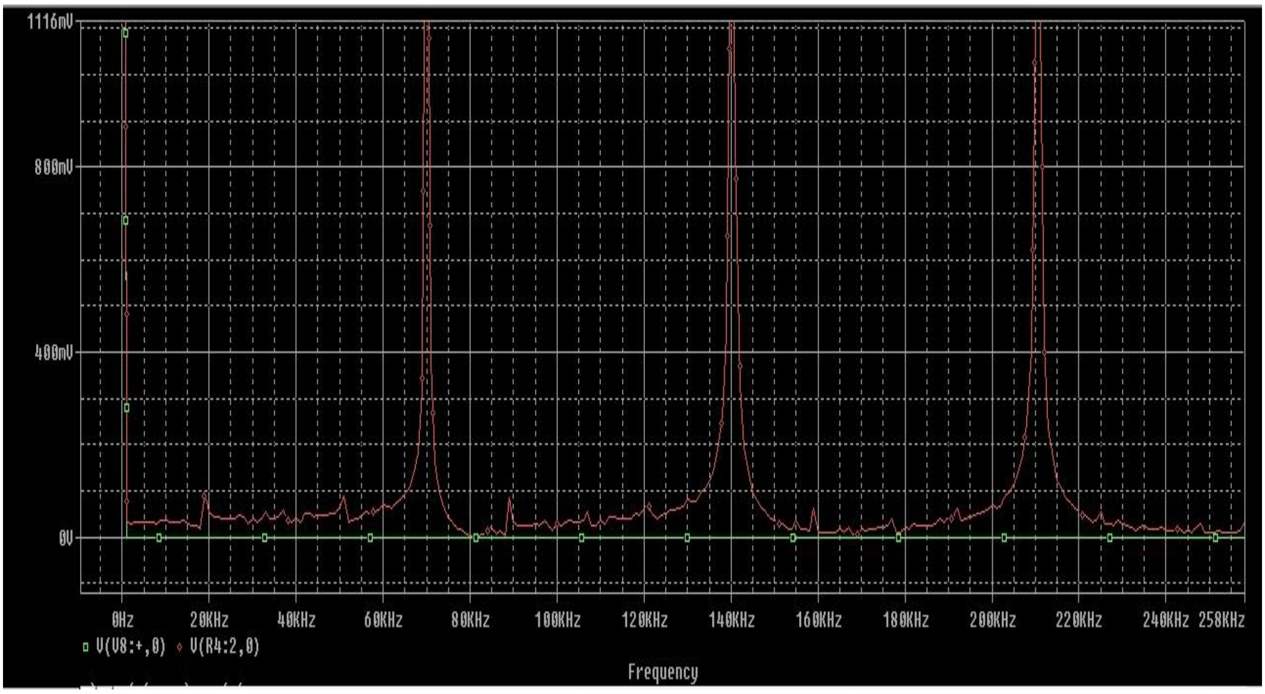

Figure 18: Output 5

Table 1: Input Voltage Vs Output frequency (Of Fig. 10)

Input voltage v_{in} $(volts)$	Output frequency $f = \frac{1}{(t+t')}$ (KHz)	
	f	Δf
-5.00	70.00	15.30
-2.00	53.90	11.65
0.00	43.25	11.15
2.00	32.10	17.60
5.00	14.50	

Table 2 : Input Voltage Vs Output frequency (Of Fig. 11)

Input voltage v(in volts)		Output frequency(f) (in KHz)	
v	Δv	f	Δf
1.04	0.68	1.647	1.242
1.72	0.32	2.889	0.431
2.04	0.22	3.320	0.402
2.26	0.95	3.722	0.682
3.21		4.404	

4.1. Output Frequency with variable input voltage

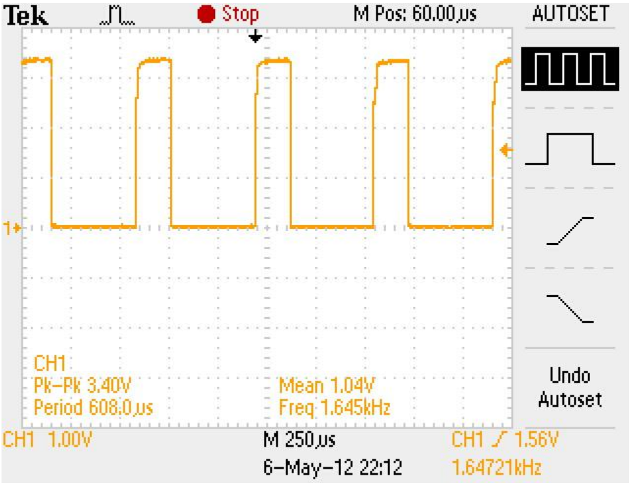

Figure 19: V=1.04 V, f=1.648 kHz

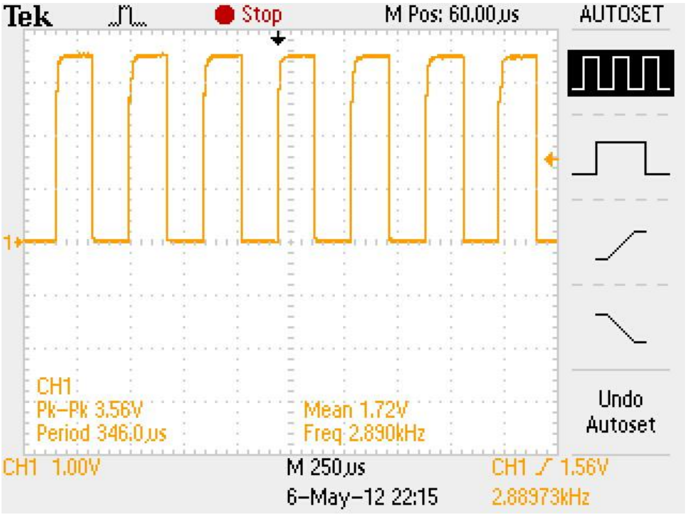

Figure 20: V=1.72 V, f=2.889 kHz

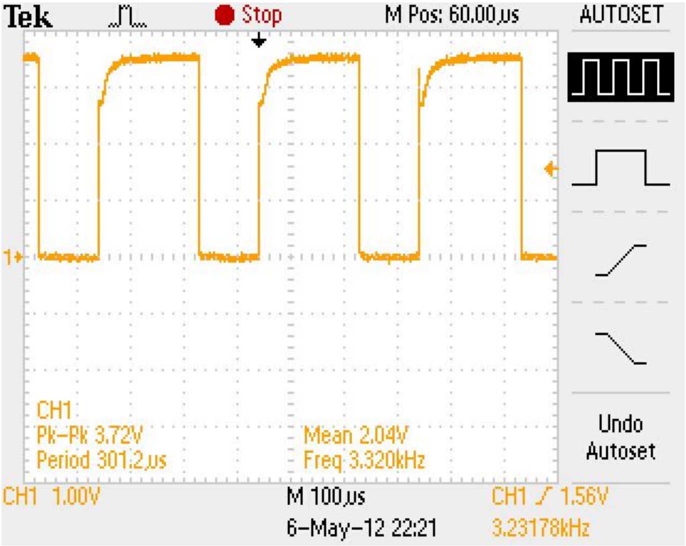

Figure 21: V=2.04 V, f=3.231 kHz

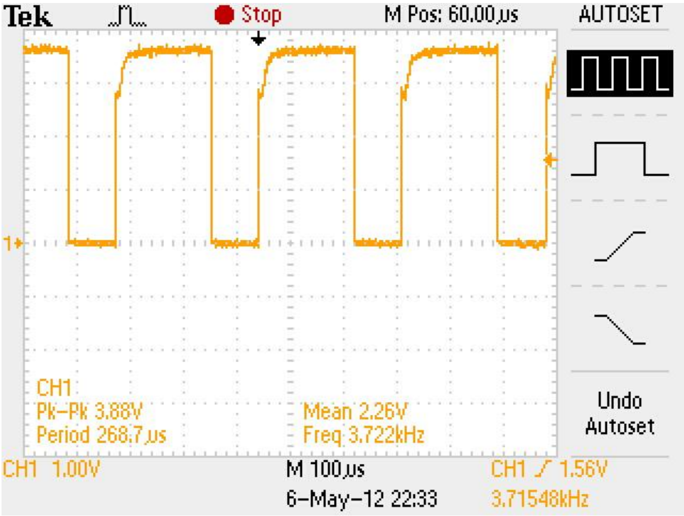

Figure 22: V=2.26 V, f=3.722 kHz

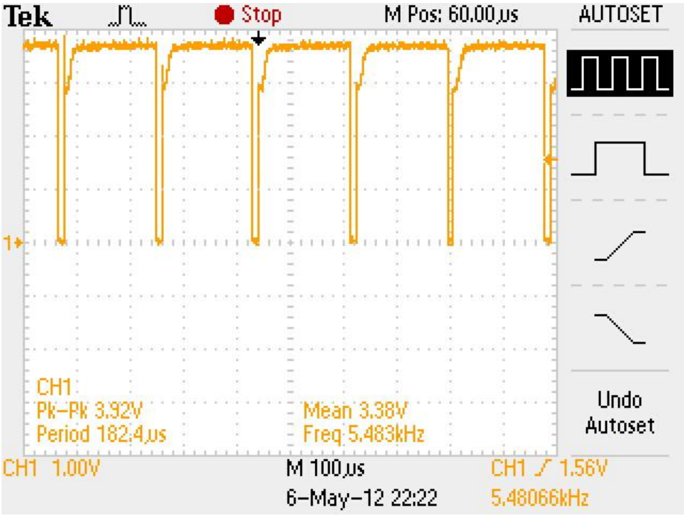

Figure 23: V=3.38 V, f=5.480 kHz

CHAPTER 5:

CONCLUSION

Conclusion

In this thesis two types of voltage to frequency converter models are discussed. For one model Pspice is implemented and simulations are obtained, while for the other type a simple and low cost VFC converter is designed. As conclusion, from Table 1 and Table 2 linear relationship between input voltage and output frequency is found out. With varying supply voltage, the frequency level changes. In table 1 when the supply voltage is increased the output frequency decreases. The change in frequency level is inversely proportional to the change in control voltage for the simple VFC circuit but in table 2 when the supply voltage is increased the output frequency increases. The change in frequency level is directly proportional to the change in control voltage. So finally it is found out that the relationship between input voltage and output frequency is linear. When supply voltage changes, the frequency level changes.

REFERENCE

References

[1] John L. Lindesmith, "Voltage-to-Digital Measuring Circuit," U.S. Patent 2,835,868, filed September 16, 1952, issued May 20, 1958. (Voltage-to-frequency ADC).

[2] J.G.Graeme, G. E. Tobey, and L. P. Huelsman, Operational Amplifiers. New York: McGraw-Hill, 1971.

[3] K.Taniguchi, "A design of the voltage-to-frequency converter," Trans. Inst. Elect. Commun. Eng. (Japan), vol. 57, pp. 597-599, Oct.1974.

[4] PaulKlonowski, "Analog-to-Digital Conversion Using Voltage-to-Frequency Converters," Application Note AN-276, Analog Devices, Inc. (a good application note on VFCs).

[5] James M. Bryant, "Voltage-to-Frequency Converters," Application Note AN-361, Analog Devices, Inc. (a good overview of VFCs).

[6] Walt Jung, "Operation and Applications of the AD654_IC V-F Converter," Application Note AN-278, Analog Devices, Inc.

[7] R. Tenny, "Linear VCO made from a 555 timer," Electron. Des, p. 96, Oct. 1975.

[8] "High-accuracy voltage-to-frequency converter," Panelectronics, no.2,p.46,1976.

[9] J. M. andeursenv And J. A. Peperstraetep “Analog-to-Digital Conversion Based on a Voltage-to-Frequency Converter” Vol. IECI-26, No. 3, August 1979.

[10] WaltKester, *Analog-Digital Conversion*, Analog Devices, 2004, ISBN 0-916550-27-3,0-Chapter 3. Also available as *The Data Conversion Handbook*, Elsevier/Newnes, 2005, ISBN 7506-7841-0, Chapter 3.