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Design, Simulation, and Applications of Op Amp Integrators

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Abstract: ***Any analogue circuit must have an Integrator as a fundamental circuit element since it solves differential equations primarily by performing the mathematical operation of Integration. In analogue computing, the integrator is also utilised as a storage component. It is utilised in the kinds of circuits where the beginning condition has a significant impact on subsequent calculations. With the use of the simulation programme Edvin Xp, the current study aims to determine the fundamental application of integrator circuits in engineering design & simulation. The history of opamp development, opamp fundamentals, integrator design and simulation, and finally a handful of the most important integrator applications are covered in this essay.***

Index Terms: Operational amplifier (OPAMP), Analog to digital converter (ADC), I/O(input output)

I INTRODUCTION

The basics of the opamp covers the history, details of an ideal opamp and opamp applications.

1.1 History

1941: A DC Coupled, high gain, inverting feedback amplifier, is first found in US patent 2,401,779 " summing amplifier" filed by Karl D.Swartzel Jr, of Bell Labs in 1941. This design used three vacuum tubes to achieve a gain of 90dB and operated on voltage rails of (+ or -) 350 volts.
1947: in 1947, the Opamp was first formally defined and named in a paper by Prof.John R.Ragazzini of Columbia University. This Op-amp designed by Loebe Julie, was superior in a variety of ways. It had two major innovations. Its in out stage used a ling-tailed triode pair with loads matched to reduce drift in the output and far more importantly, it was the first p-amp design to have two inputs (inverting and non-inverting).
1961: 1961 were producing solid state, discrete Op-amps. The P45 had a gain of 94dB and a ran on (+ or -) 15V.
1962: First Op-amp in potted modules.
1963: First monolithic IC Op-amp.

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1986: Release of the µA741-would be seen as a nearly ubiquitous chip.
1966: First Varactor bridge Op-amps.
1970: First High-speed, low input current FET design.
1972: Single sided supply Op-amps being produced.

II.OPERATIONAL AMPLIFIER

An operational amplifier, often known as an op-amp, is a differential input, high gain, DC-coupled electrical voltage amplifier with typically a single output. Normally, the op-output amp's is controlled by either positive feedback, which promotes regeneration gain and oscillation, or negative feedback, which significantly dictates the size of its output voltage gain. Important typical qualities include high input impedance at the input terminals and low output impedance. The Op-amp is one type of differential amplifier. Other types of differential amplifier include the,

- Fully differential amplifier (similar to the op-amp, but with 2 outputs).
- The instrumentation amplifier (usually built from 3 op-amps).
- The isolation amplifier (similar to the instrumentation amplifier, but which works fine with common-mode voltages that would destroy an ordinary op-amp).
- Negative feedback amplifier (usually built from 1 or more op-amps and a resistive feedback network).

Ideal Op-amp:

The figure below shows an example of an ideal operational amplifier. The main part in an amplifier is the dependent voltage source that increases in relation to the voltage drop across Rin, thus amplifying the voltage difference between V+ and V-. Many uses have been found for Op-amp and an ideal Op-amp seeks to characterize the physical phenomena that make Op-amps useful

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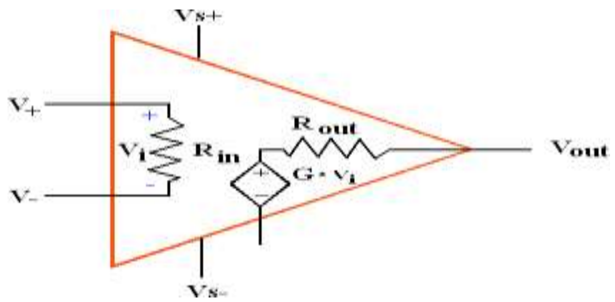

Fig.1. Ideal op amp

Vs+ and Vs- are not connected to the circuit within the Op-amp because they power the dependent voltage source's circuit. These are notable, however, because they determine the maximum voltage the dependent voltage source can output.

For any input voltage the ideal Op-amp has,

a. Infinite open-loop gain.
b. Infinite bandwidth.
c. Infinite input impedance
d. Zero offset voltage.
e. Infinite slew rate.
f. Zero output impedance and
g. Zero noise.

Applications:

- Audio and video-frequency pre-amplifiers and buffers
- Voltage comparators
- Differential amplifiers
- Differentiators and integrators
- Filters
- Precision rectifiers
- Precision peak detectors
- Voltage and current regulators
- Analog calculators
- Analog-Digital converters
- Digital-Analog converters
- Voltages clamps
- Oscillations and waveform generators.

III.INTEGRATOR

The Integrator is a circuit using OP-AMP that performs the mathematical operation of Integration. The integrator acts like a storage element that "produces a voltage output which is proportional to the integral of its input voltage with respect to time". In other words the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

IV. SIMULATION RESULT

The opamp integrator is simulated using EDVIN XP as below.

Mixed Mode Simulator is used for the simulation of the integrator. The circuit is preprocessed first and by selecting the transient analysis from the analysis options the output of the circuit is displayed in the waveform viewer. Note that to view the waveform output first set the waveform markers wherever required. This can be done by selecting the Set Waveform Content from the Instrument Option. Please see the fig1.bmp.

$$V_{out} = \int_0^t \frac{V_{in}}{RC}\,dt + V_{initial}$$

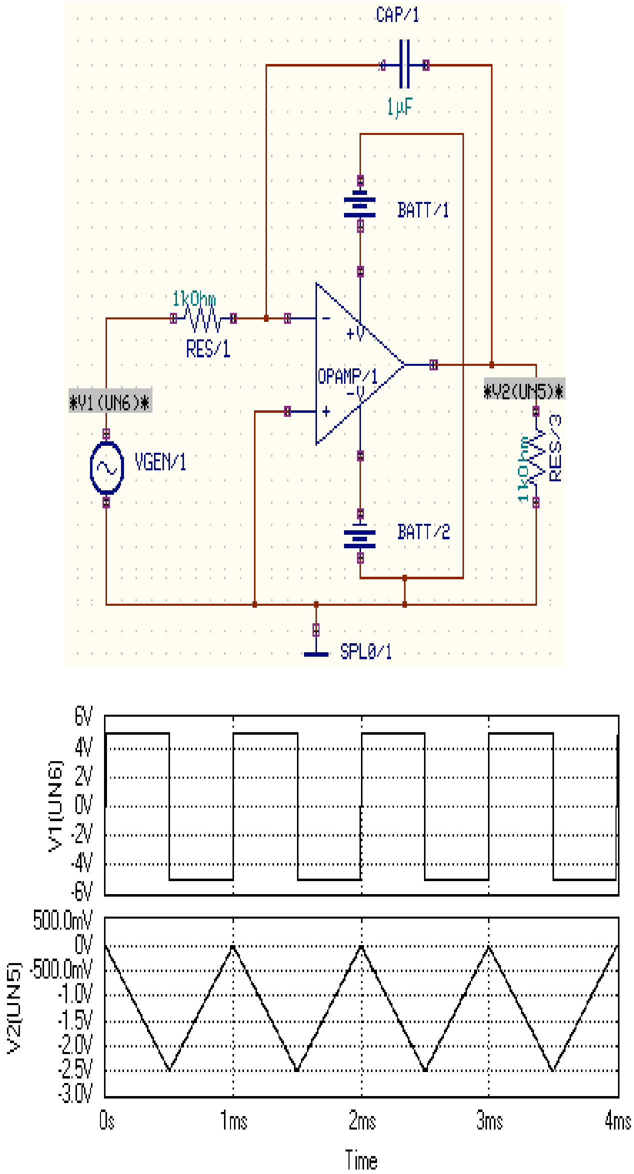

Fig .2 Integrator And I/O Waveforms in EDWinXP

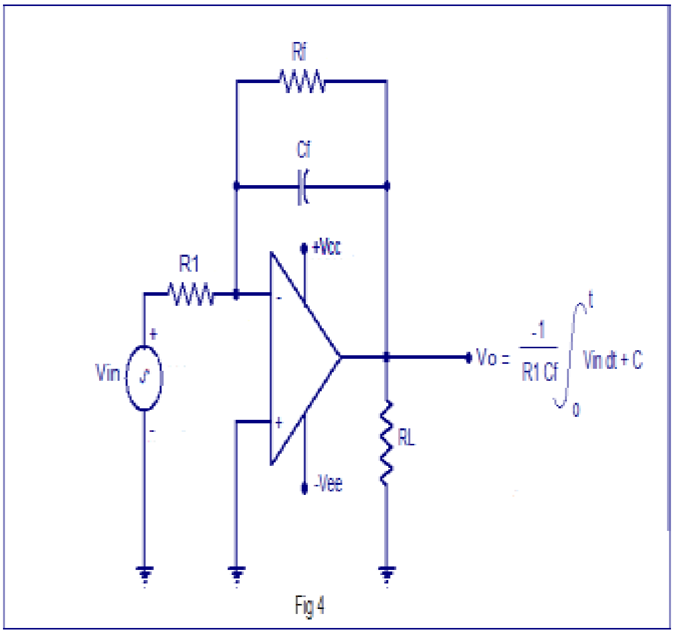

Fig.3 Practical opamp Integrator

V. SPICE SIMULATION

SPICE's source statement named PULSE is a convenient way to generate a repeating pulsed waveform according to syntax

PULSE({v1} {v2} {tdelay} {trise} {tfall} {width} {period}).

So the statement

VRESET 4 0 PULSE(0V 5V 0 0.1US 0.1US 100US 110US)

creates a repeating pulse from VRESET that's defined by 0V for 100us and 5V for 10us for a total period of 110us. The rise and fall times are 0.1 us.

SPICE FILE

```
OPINT.CIR - OPAMP INTEGRATOR
*
* CONTROL VOLTAGE FOR S1
VRESET   4      0      PULSE(0V 5V 0 0.1US
0.1US 100US 110US)
R4       4      0      1MEG
*
* INPUT VOLTAGE
VS       1      0      DC     -1
*
R1       1      2      10K
C1       2      3      1000PF
S1       2 3    4 0    SRES
XOP      0 2    3      OPAMP1
*
.MODEL   SRES   VSWITCH(VON=0      VOFF=5
RON=100 ROFF=10MEG)
*
* OPAMP MACRO MODEL, SINGLE-POLE
```

```
*              | inverting input
*              | |  output
*              | | |
.SUBCKT OPAMP1     1  2   6
* INPUT IMPEDANCE
RIN        1          2          10MEG
* GAIN BW PRODUCT = 10MHZ = DCGAIN x POLE1
* DC GAIN (100K) AND POLE 1 (100HZ)
EGAIN      3 0        1 2        100K
RP1        3          4          1K
CP1        4          0          1.5915UF
* OUTPUT BUFFER AND RESISTANCE
EBUF       5 0        4 0        1
ROUT       5          6          10
.ENDS
*
* ANALYSIS
.TRAN      1US        220US
* VIEW RESULTS
.PLOT      TRAN       V(1) V(3)
.PRINT     TRAN V(1) V(3)
.PROBE
.END
```

VI. APPLICATION OF INTEGRATOR

The various applications of opamp Integrator are described as below.

Ramp Generator:

The integrator basically works like this: whatever current I you get flowing in R1, gets integrated across capacitor C1. The output voltage Vo is simply the voltage across C1. One great application of the integrator is generating a ramp voltage. You can do this by placing a fixed voltage at VS that forces a constant current through R1. The capacitor then integrates this current creating a ramping voltage. The circuit essentially integrates the input current Is = VS / R1 across capacitor C1. After a time interval T, the output is the capacitor voltage described by

$$V_o = -\frac{1}{C1}\int_0^T \frac{V_s}{R1}\,dt$$

If a constant voltage is applied at VS, the output voltage increases steadily (ramp). The ramp's voltage at any time T is predicted by the simplified equation

$$V_o = -\frac{1}{C1} \times \frac{V_s}{R1} \times T$$

By Changing VS, R1 or C1 we can generate ramps faster or slower than the original circuit.

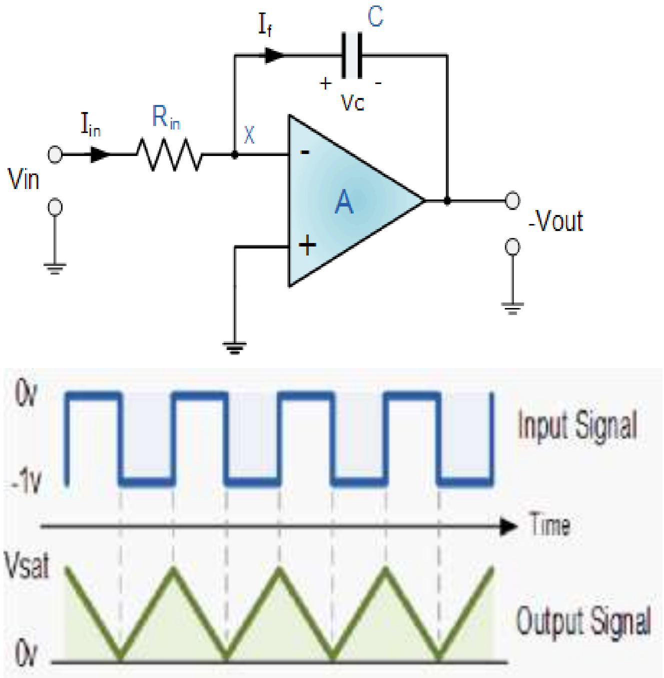

Fig.4 opamp integrator as ramp generator.

We know from first principals that the voltage on the plates of a capacitor is equal to the charge on the capacitor divided by its capacitance giving Q/C. Then the voltage across the capacitor is output Vout therefore: -Vout = Q/C. If the capacitor is charging and discharging, the rate of charge of voltage across the capacitor is given as:

$$V_c = \frac{Q}{C} \qquad V_c = V_x - V_o = 0 - V_o$$

$$\therefore -\frac{dV_{out}}{dt} = \frac{dQ}{Cdt} = \frac{1}{C} \times \frac{dQ}{dt}$$

But dQ/dt is electric current and since the node voltage of the integrating op-amp at its inverting input terminal is zero, X = 0, the input current I(in) flowing through the input resistor, Rin is given as:

$$I_{in} = \frac{V_{in-0}}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current flowing through the feedback capacitor C is given as:

$$I_f = C\frac{dV_{out}}{dt} = C\frac{dQ}{dt} = \frac{dQ}{dt} = \frac{dV_{out}}{dt}C$$

Assuming that the input impedance of the op-amp is infinite (ideal op-amp), no current flows into the op-amp terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$I_{in} = I_f = \frac{V_{in}}{R_{in}} = \frac{dV_{out}}{dt}C$$

$$\therefore \frac{V_{in}}{V_{out}}\frac{dt}{R_{in}C} = 0$$

From which we derive an ideal voltage output for the **OP-amp Integrator** as.

$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\,dt = -\int_0^t V_{in}\frac{dt}{R_{in}C}$$

To simplify the math's a little, this can also be re-written as:

$$V_{out} = -\frac{1}{j\omega RC} \times V_{in}$$

Where jω = 2π*f* and the output voltage Vout is a constant 1/RC times the integral of the input voltage Vin with respect to time. The minus sign (-) indicates a 180° phase shift because the input signal is connected directly to the inverting input terminal of the op-amp.

Integrator as a Active Low Pass Filter:

If we changed the above square wave input signal to that of a sine wave of varying frequency the **Op-amp Integrator** performs less like an integrator and begins to behave more like an active "Low Pass Filter", passing low frequency signals while attenuating the high frequencies. At 0Hz or DC, the capacitor acts like an open circuit blocking any feedback voltage resulting in very little negative feedback from the output back to the input of the amplifier. Then with just the feedback capacitor, C, the amplifier effectively is connected as a normal open-loop amplifier which has very high open-loop gain resulting in the output voltage saturating.

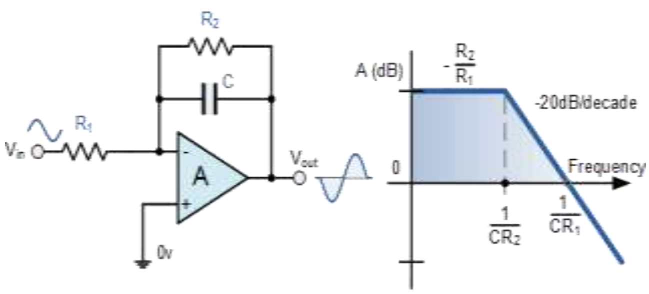

Fig.5 Opamp integrator as low pass filter.

This circuit connects a high value resistance in parallel with a continuously charging and discharging capacitor. The addition of this feedback resistor, R_2 across the capacitor, C gives the circuit the characteristics of an inverting amplifier with finite closed-loop gain of R_2/R_1 at very low frequencies while acting as an integrator at higher frequencies has the capacitor shorts out the feedback resistor, R_2.

The AC Op-amp Integrator with DC Gain Control is explained in the below.

$$Dc\ voltage\ gain\ (AV_{o)} = -\frac{R_2}{R_1}$$

$$AC\ voltage\ gain\ (AV_{)} = -\frac{R_2}{R_1} \times \frac{1}{(1 + 2\pi fCR)}$$

$$corner\ frequency\ f_o = \frac{1}{2\pi C R_2}$$

Unlike the DC integrator amplifier above whose output voltage at any instant will be the integral of a waveform so that when the input is a square wave, the output waveform will be triangular. For an AC integrator, a sinusoidal input waveform will produce another sine wave as its output which will be 90^o out-of-phase with the input producing a cosine wave. Furthermore, when the input is triangular, the output waveform is also sinusoidal. This then forms the basis of a *Active Low Pass Filter* as seen before in the filters section tutorials with a corner frequency given as.

The Analog Computers:

An analog computer is a form of computer that uses the continuously-changeable aspects of physical phenomena such as electrical, mechanical, or hydraulic quantities to model the problem being solved. In contrast, digital computers represent varying quantities incrementally, as their numerical values change.

Setting up an analog computer required scale factors to be chosen, along with initial conditions—that is, starting values. Another essential was creating the required network of interconnections between computing elements. Sometimes it was necessary to re-think the structure of the problem so that the computer would function satisfactorily. No variables could be allowed to exceed the computer's limits, and differentiation was to be avoided, typically by rearranging the "network" of interconnects, using integrators in a different sense.

Running an electronic analog computer, assuming a satisfactory setup, started with the computer held with some variables fixed at their initial values. Moving a switch released the holds and permitted the problem to run. In some instances, the computer could, after a certain running time interval, repeatedly return to the initial-conditions state to reset the problem, and run it again.

Electronic analog computers typically have front panels with numerous jacks (single-contact sockets) that permit patch cords (flexible wires with plugs at both ends) to create the interconnections which define the problem setup. In addition, there are precision high-resolution potentiometers (variable resistors) for setting up (and, when needed, varying) scale factors. In addition, there is likely to be a zero-center analog pointer-type meter for modest-accuracy voltage measurement. Stable, accurate voltage sources provide known magnitudes.

Typical electronic analog computers contain anywhere from a few to a hundred or more operational amplifiers ("op amps"), named because they perform mathematical operations. Op amps are a particular type of feedback amplifier with very high gain and stable input (low and stable offset). They are always used with precision feedback components that, in operation, all but cancel out the currents arriving from input components. The majority of op amps in a representative setup are summing amplifiers, which add and subtract analog voltages, providing the result at their output jacks. As well, op amps with capacitor feedback are usually included in a setup; they integrate the sum of their inputs with respect to time.

Integrating with respect to another variable is the nearly-exclusive province of mechanical analog integrators; it is almost never done in electronic analog computers. However, given that a problem solution does not change with time, time can serveas one of the variables.

Other computing elements include analog multipliers, nonlinear function generators, and analog comparators.

In Analog to Digital Converters:

An integrating ADC is a type of analog-to-digital converter that converts an unknown input voltage into a digital representation through the use of an integrator. In its most basic implementation, the unknown input voltage is applied to the input of the integrator and allowed to ramp for a fixed time period (the run-up period). Then a known reference voltage of opposite polarity is applied to the integrator and is allowed to ramp until the integrator output returns to zero (the run-down period). The input voltage is computed as a function of the reference voltage, the constant run-up time period, and the measured run-down time period. The run-down time measurement is usually made in units of the converter's clock, so longer integration times allow for higher resolutions. Likewise, the speed of the converter can be improved by sacrificing resolution.

Converters of this type can achieve high resolution, but often do so at the expense of speed. For this reason, these converters are not found in audio or signal processing applications. Their use is typically limited to digital voltmeters and other instruments requiring highly accurate measurements.

The basic integrating ADC circuit consists of an integrator, a switch to select between the voltage to be measured and the reference voltage, a timer that determines how long to integrate the unknown and measures how long the reference integration took, a comparator to detect zero crossing, and a controller. Depending on the implementation, a switch may also be present in parallel with the integrator capacitor to allow the integrator to be reset (by discharging the integrator capacitor). The switches will be controlled electrically by means of the converter's controller (a microprocessor or dedicated control logic). Inputs to the controller include a clock (used to measure time) and the output of a comparator used to detect when the integrator's output reaches zero.

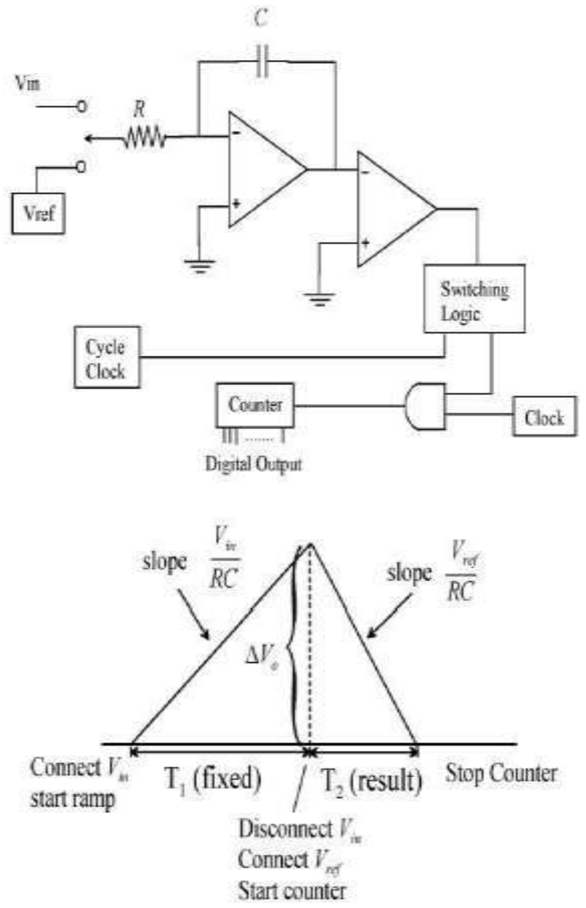

Fig.6 Opamp integrator as ADC.

The conversion takes place in two phases: the run-up phase, where the input to the integrator is the voltage to be measured, and the run-down phase, where the input to the integrator is a known reference voltage. During the run-up phase, the switch selects the measured voltage as the input to the integrator. The integrator is allowed to ramp fora fixed period of time to allow a charge to build on the integrator capacitor. During the run-down phase, the switch selects the reference voltage as the input to the integrator. The time that it takes forthe integrator's output to return to zero is measuredduring this phase.

In order for the reference voltage to ramp the integrator voltage down, the reference voltage needs to have a polarity opposite to that of the input voltage. In most cases, for positive input voltages, this means that the reference voltage will be negative. To handle both positive and negative input voltages, a positive and negative reference voltage is required.

The selection of which reference to use during the run-down phase would be based on the polarity of the integrator output at the end of the run-up phase. That is, if the integrator's output were negative at the end of the run-up phase, a negative reference voltage would be required. If the integrator's output were positive, a positive reference voltage would be required.

Integrator output voltage in a basic dual-slope integrating ADC

The basic equation for the output of the integrator (assuming a constant input) is:

$$V_{out} = \frac{V_{in}}{RC}\, t_{int} + V_{initial}$$

Assuming that the initial integrator voltage at the start of each conversion is zero and that the integrator voltage at the end of the run down period will be zero, we have the following two equations that cover the integrator's output during the two phases of the conversion:

$$V_{out-up} = -\frac{V_{in}}{RC} \times t_u$$

$$V_{out-up} = -\frac{V_{ref}}{RC} \times t_d + V_{out-up} = 0$$

The two equations can be combined and solved for V_{in}, the unknown input voltage:

$$V_{in} = -V_{ref}\,\frac{t_d}{t_u}$$

From the equation, one of the benefits of the dual-slope integrating ADC becomes apparent: the measurement is independent of the values of the circuit elements (R and C).

VI. CONCLUSION

The simulation of an opamp integrator is the major topic of this research. The simulation's findings allow us to state the following. The input offset voltage of the op amp causes an error voltage to be produced at the output when the integrator's various applications are evaluated, and when vin = 0, the integrator delivers open loop gain since the capacitor works as an open circuit for DC voltage. Therefore to obtain error free output voltage a resistor is connected in parallel with the feedback capacitor as shown in the practical integrator circuit fig.3. RF limits the low frequency gain and reduces error in the output voltage.
Further enhancement of this paper can be that any application can be designed , simulated .

REFERENCES

1. Ramakant A.Gayakwad, “Op-Amps and linearintegrated Circuits”
2. A. Younis and M. Hassoun, “A High Speed Fully Differential CMOS Opamp,” *Proceedings of the IEEE Midwest Symposium on Circuits and Systems*, Vol. 2, pp. 780-783, August 2000.

3. National Semiconductor Linear Applications (I and II), published by National Semiconductor

4. National Semiconductor Audio Handbook, published by National Semiconductor IC Op-Amp Cookbook - Walter G Jung (1974), published by Howard W Sams & Co.,Inc. ISBN 0-672-20969-1

5. Data sheets from National Semiconductor, Texas Instruments, Burr-Brown, Analog Devices, Philips and many others.

6. AN166 - Basic Feedback Theory, Philips Semiconductors Application Note, Dec 1988 Opamps For Everyone - by Ron Mancini, Editor in Chief, Texas Instruments, Sep 2001