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A Modified analog integrator for continuous pulse operation Of a nuclear fusion device with reduced drift

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Abstract: - Analog integrators using operational amplifiers are often subjected to the internal difficulties like offset and drift error. It is mainly due to the offset voltage and bias current of an op-amp. It causes drift in the output which increases with respect to time. In the proposed method an analog integrator has been designed for 2s duration with low drift and offset error. It has been designed for the nuclear fusion device which requires integration of signal for long duration of time. In this method the hardware design of the integrator with low offset induced drift has been implemented for real time operation in nuclear fusion device**.**

Keywords: - drift, flux, Integrator, offset, op-amp.

I. INTRODUCTION

Nuclear fusion is a reaction which happens in sun and stars. One of the device uses this nuclear fusion concept is called Tokamak (Toroidal chamber with magnetic coils).It is a device using a magnetic field to confine a plasma in the shape of torus or doughnut for producing controlled thermonuclear fusion power, which can be used for generation of electricity. In these devices, the magnetic fields are used for the confinement of plasma, since no solid material could withstand the extremely high temperature of the plasma. Real time experimental data analyses in magnetic fusion devices require an accurate measurement of magnetic field just outside the plasma boundary [1]. The magnetic field measurements are usually made by integration of signals from the magnetic coils. The produced signal is proportional to the rate of change of field [2].

High accuracy integrators are required for the accurate measurement of steady state long pulses. It is really a big challenge to build a high accuracy integrator, since the integrators are subjected to intrinsic difficulties such as Integration drift and saturation of the integrator. *Integration drift* is due to offset and temperature induced drift of the amplifier, noise etc. The integration drift increases with time, which introduces an absolute error and also limits the integration working duration at a certain specified accuracy. *Saturation of the integrator* occurs in the case of high flux variation such as disruption [3].

The op-amp has input offset voltage (Vios) and the input bias current (Ib). In the absence of input voltage or at zero frequency (d.c), op-amp gain is very high. The input offset voltage gets amplified and appears at the output as an error voltage. The bias current also results in a capacitor charging current and adds its effect in an output error voltage. The two components, due to high dc gain of op-amp cause output to ramp up or down depending upon the polarities of offset voltage/bias current. After sometime, output of op-amp may achieve its saturation level. Hence, there is possibility of op-amp saturation due to such an error voltage and it is very difficult to pull op-amp out of saturation. These difficulties are eliminated in the proposed methodology.

The new integrator has to be designed for the requirements of long pulse integration. Fig.1 shows the general block diagram of the long pulse integrator. The system should have the integral module, signal conditioning module and error correcting module. The output signal of the integrator will be transmitted directly to the plasma control system (PCS) for the plasma equilibrium and shape control, and to the data acquisition system (DAS) for the physical analysis.

II. PROPOSED METHOD

Individual diagnostic systems are installed on the tokamak taking into account measurement requirements, shielding, vacuum boundaries and activation requirements, length and complexity of transmission lines, and maintenance requirements as well as requirements for confinement of radioactive and toxic materials [4]. The integrator system has to fulfil the requirement of magnetic diagnostics. This system is mainly composed of an integrator module, amplifier module and an ARM Controller. The integrator module used for actual integration and the amplifier module used for drift reduction and amplification[5]. The ARM controller has been used to switch the samples of coil input to the integrator and the dummy load. It has been done for finding the offset voltage present in the coil input. The block diagram of the proposed integrator system is shown in fig.2.

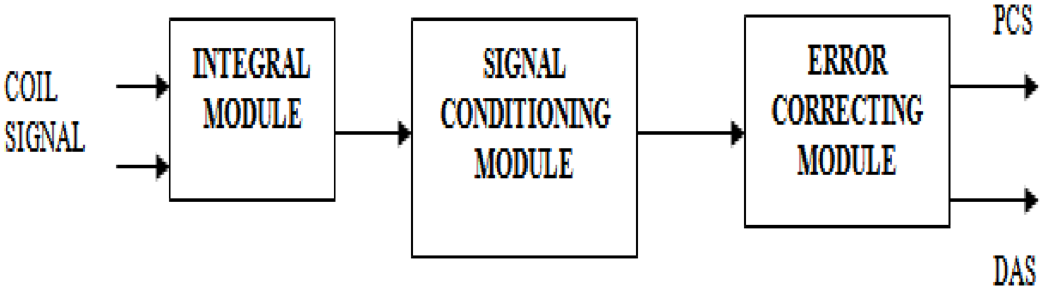

Fig. 1: General block diagram of long pulse integrator

A. *Integrator Module*

It has two integrators namely integrator1 and integrator2.In order to calculate the correct drift value, the same type of integrators should be selected. Both inputs of integrator1 are grounded and the inverting terminal of integrator2 is connected to the test input signal. The capacitor has been discharged before the application of input. The output of the integrators1 and 2 is equal to Vo1 and Vo2 which is given by

$$Vo1=-1/RC \int [RIos1-Vos1]\, dt \qquad (1)$$

$$Vo2=-1/RC \int [Vin (t) +RIos2-Vos2]\, dt \qquad (2)$$

Where Vin (t) is the input signal, Ios1 and Ios2 are the input offset currents of integrator1 and 2 and Vos1 and Vos2 are the input offset voltages of integrator1 and 2. The output of the integrator2 gives the actual integration of the test signal and the output of integrator1 is taken as reference for calculating offset induced drift in an integrator. Hence the two integrators should be selected with same characteristics for getting the same input offset voltage and bias current. LTC1151 op-amp IC has been selected for implementing integrator in this method. It is a dual-in-pack IC so that both integrators can be designed from a single IC which is having similar internal characteristics. It has been minimized easily with the help of instrumentation amplifier.

B. *Instrumentation amplifier:*

In this method, a three op-amp instrumentation amplifier is used (from fig.3). It is composed of two stages. The op-amp A3 and A4 are the non-inverting amplifiers forming the input stage. The op-amp A5 is the normal difference amplifier forming an output stage of the amplifier.Vo1 and Vo2 are the input from the integrator module to the op-amps A3 and A4.The output of the instrumentation amplifier is taken from the op-amp5, which is given by,

$$Vo = R2/R1 (Vo4-Vo3) \qquad (3)$$

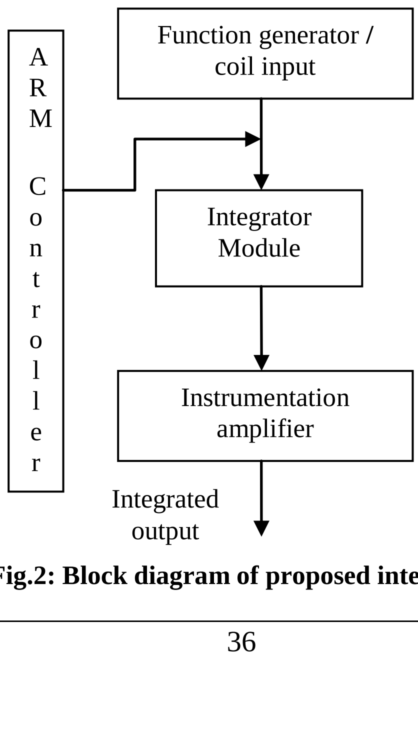

Fig.2: Block diagram of proposed integrator

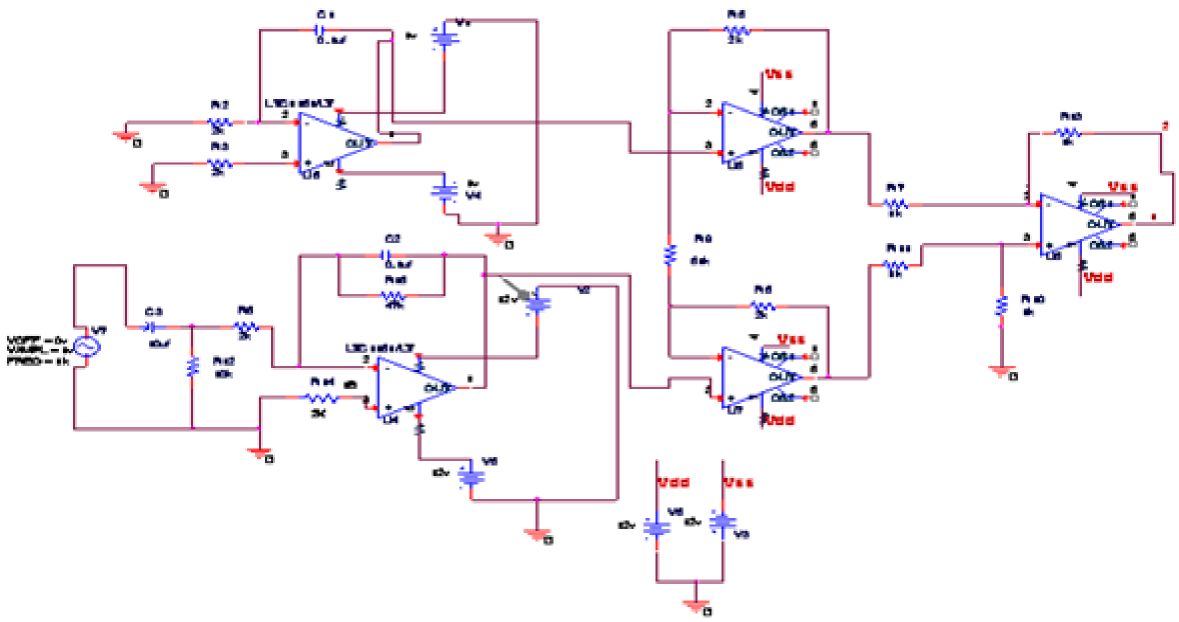

Fig.3: Circuit of integrator and amplifier module

Where Vo3 and Vo4 are the outputs of op-ampA3 and A4, Which is given to the inputs of A5.The instrumentation amplifier used in the proposed method for drift reduction. After some duration the offset voltage has been saturated and reaches a dc supply voltage of an op-amp. Since offset voltage affect the overall performance of the integrator, this offset induced drift and saturation effect has to be minimized by the proposed method. Hence, in the proposed method an instrumentation amplifier has been utilized in order to eliminate the error. In this system it is actually used as a difference amplifier which subtracts the offset error value of the integrator and produces a drift free output signal.

C. *ARM Controller:*

ARM controller has been used in this method, for switching the input from the coil to the integrator and dummy load. LPC2148 controller has been used in this method. It is mainly used for finding the offset present in the magnetic coil input.

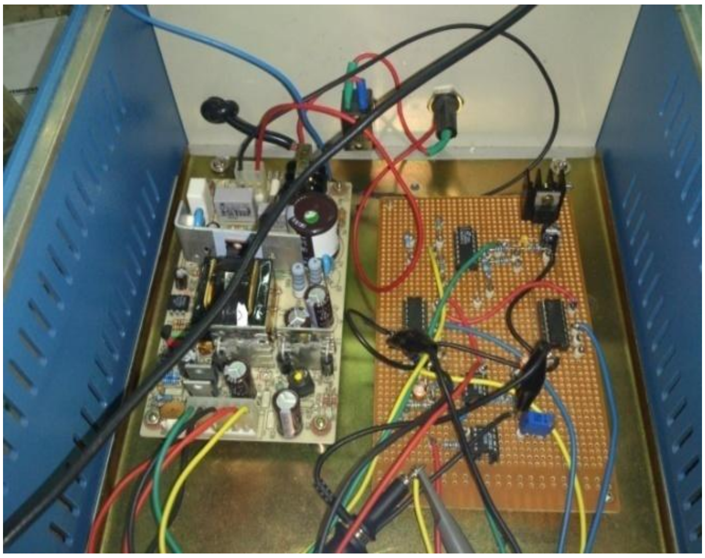

Fig. 4: Hardware design of proposed integrator and amplifier module

III. RESULTS AND DISCUSSION

Analog integrators are subjected to the internal difficulties. In this proposed method, the switch s1 (series with resistor) present in the feedback used to discharge the capacitor before the input signal has applied. Hence, the saturation effect of capacitor has been controlled by closing the switch s1 before giving the input and it has to be opened at the time of input. The switch s2 has been used to connect only the feedback capacitor to the output. It means whenever the switch s1 is closed that time s2 should be open (absence of input signal).Similarly, when the switch s1 is opened then the switch s2 has to be closed (presence of input signal).

The input offset voltage and bias current of the integrator has been eliminated with the help of instrumentation amplifier which is actually used as a difference amplifier.

Fig.4shows that the snapshot of hardware design of the proposed integrator. In this hardware the integrator module and amplifier module along with a power supply has been kept inside.

Fig.5a, 5b and 5c show the output of the integrator with different input signals like sine, pulse and triangle. The output signal has been observed for 2s duration. There is no obvious drift error and saturation effects have been found during the 2s duration.

At the time of integration the offset voltage and saturation effects are the two main causes have to be observed. The saturation of the output occurs mainly due to the small voltage present in the feedback capacitor before giving the input signal. It has to be discharged every time with the help of closing the switch s1 which is in series with resistor. Similarly, the offset induced drift has been eliminated by using instrumentation amplifier after the integrator module.

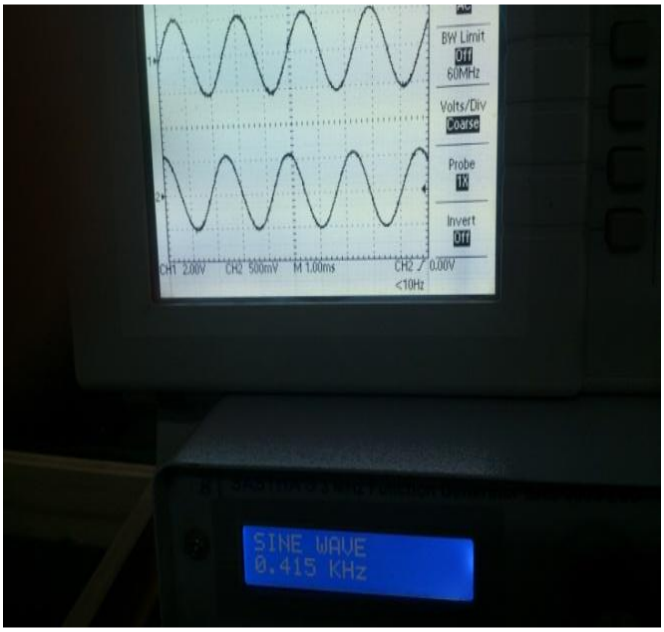

Fig. 5a: Input and output waveform of proposed integrator(Sine wave)

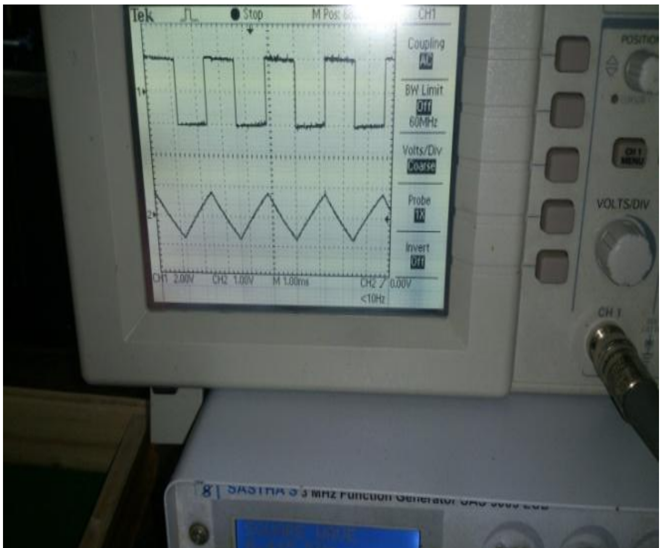

Fig. 5b: Input and output waveform of proposed integrator (pulse)

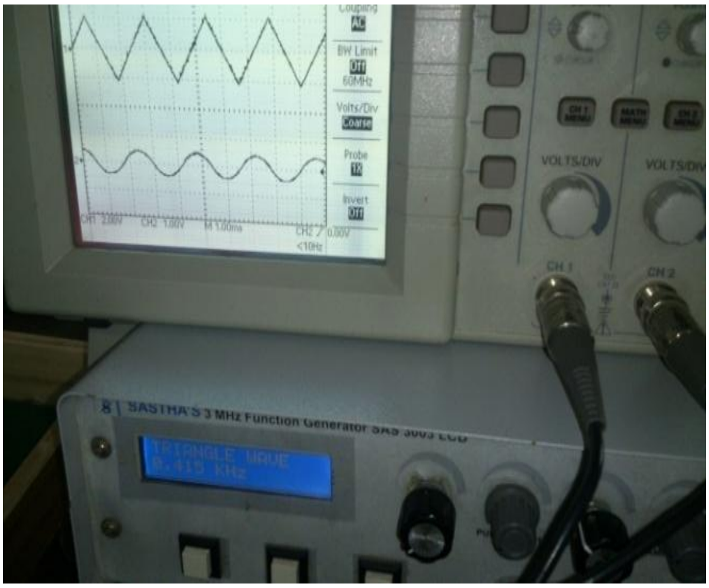

Fig.5c: Input and output waveform of proposed integrator (triangular wave)

IV. CONCLUSION

In this paper, the hardware of the modified analog integrator has been designed using operational amplifiers. Irrespective of the previous method, the arm controller has been used for switching the input signal between the actual input and the dummy load .It has been used for finding the offset value of the input signal. There is no obvious offset in the input signal, since it is directly from the function generator. However, there may be a chance of offset in the coil input when it has been connected in real time. Hence, in future design the offset in the input signal has to be eliminated with the help of arm controller present in this integrator system.

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