A NOVEL DESIGN OF THREE-STAGE INSTRUMENTATION AMPLIFIER FOR IMPROVEMENT OF DYNAMIC RANGE AND FREQUENCY RESPONSE

[1]Nilima Warke, [2]J. M.Nair, [3]P. P. Vaidya
[1]Associate Professor, [2]Professor, [3]Professor
[1]Instrumentation Department,
[1]Vivekanand Education Society's Institute of Technology, Mumbai, India

Abstract : This paper proposes the new design of three-stage instrumentation amplifier consisting of five op-amps. A new stage has been added at the input of conventional instrumentation amplifier (IA) which consists of two op-amps and associated circuit to compensate DC offset voltages present in the signal applied at the input of IA. This method makes use of injection of external currents using constant voltage sources. In this proposed configuration, it is possible to compensate for large values of the offset voltage without degrading frequency response of IA. The IA using this method was constructed and tested, and results have been reported in the paper. Experimental results show that the proposed three-stage IA can be used to compensate unwanted DC offset voltages present in the input signal without affecting its differential gain and common mode rejection ratio (CMRR) characteristics with significant improvement in dynamic range. Unlike RC coupled IA, this IA circuit does not require matched components for superior performance and also results in better frequency response and wide dynamic range.

***Index Terms* - Three-stage instrumentation amplifier, frequency response, differential gain, CMRR, dynamic range**

I. INTRODUCTION

Instrumentation amplifier is commonly used for amplification of differential signals in presence of large common mode signals because of which it has numerous applications in the field of low level signal processing including biomedical instrumentation [1].
AC coupling circuits are used commonly to remove unwanted DC offset voltages present in the input signals. But due to finite tolerances of compensating components R and C, common mode input appears as differential signal and gets amplified by high differential gain, resulting in poor CMRR and reduction in dynamic range [2],[3],[4]. Also, low frequency signal components are also attenuated [5].
A new method was also described to compensate these DC offset voltages without R-C network [6],[7] as shown in Fig.1. Based on the theory discussed in [6],[7], a new design of IA has been proposed in this paper.

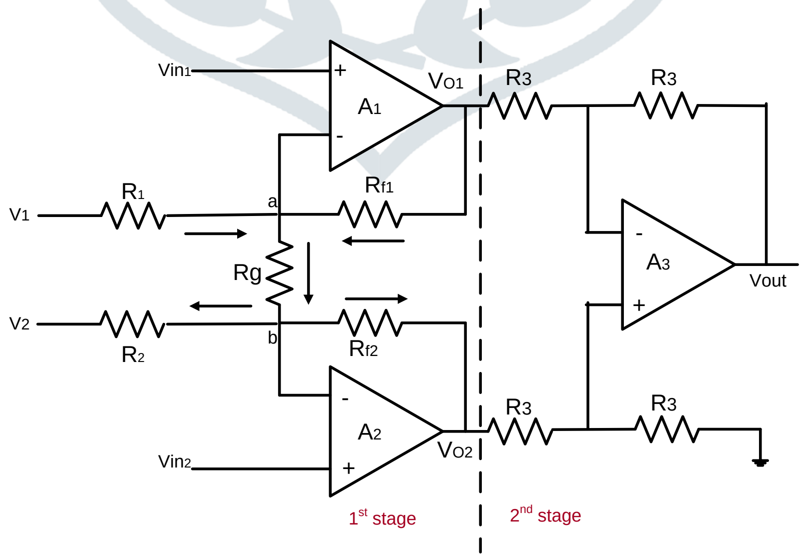

Fig. 1: Instrumentation amplifier with new method of DC voltage compensation [6].

Here, loss of dynamic range due to amplification of DC components present in the input signals of IA was recovered by injecting currents in opposite direction at inverting terminals using constant voltage sources of equal amplitude and opposite polarity [7].

If $R_{f1} = R_{f2} = R_f$, then Vout can be given as --

$$V_{out} = (1+2R_f/R_g+R_f/R_1)(V_a-V_b) \quad (1)$$

Hence,

$$\text{Percentage change in gain} = [(R_f/R_1)/(1+2R_f/R_g)]\ 100 \quad (2)$$

If $R_f >>> R_g$,

$$\text{Change in gain} = [(R_f/R_1) / (2R_f/R_g)]\ 100\ \% \quad (3)$$

$$= (R_g/ 2R_1)\ 100\ \% \quad (4)$$

In case $R_1 >>> R_g$ and R_f, the change in the gain is very small and can be neglected.

The application of V_1 and V_2 introduces additional current in the circuit because of which the current flowing through Rg flows through only R_1, R_2 and Rg and thus the DC current flowing through R_{f1} and R_{f2} reduced to zero.

When $R_1 = R_2 = R$,

$$(V_1 - V_2) / (V_a - V_b) = (2R / R_g) + 1 \quad (5)$$

The gain of instrumentation amplifier should be controlled by Rg. Hence the effect of R on gain should be minimized for which it is required that $R>>>R_g$.

To satisfy this condition

$$(V_1 - V_2) \sim (2R / R_g)(V_a - V_b) \quad (6)$$

Hence $(V_1 - V_2)$ should be very large as compared to $(V_a - V_b)$.

Typically for $R = 100R_g$, $(V_1 - V_2)$ is equal to 10V for $(V_a - V_b) = 50mV$.

For higher value of $(V_a - V_b)$, value of R need to be reduced since it is not possible to increase V_1 particularly for portable battery operated system. To solve this problem the voltage sources V_1 and V_2 can be replaced by voltage controlled current sources I_1 and I_2. These current sources have high output impedance (1Mohm and higher) as required.

In this configuration [7] the gain of IA is decided by Rg, R_{f1} and R_{f2}. To select the higher gain Rf1 and Rf2 have to be large whereas for producing small error in compensation R_{f1} and R_{f2} have to be sufficiently low. Since this selection criterion for R_{f1} and R_{f2} are contradictory, it is difficult to select proper values of R_{f1} and R_{f2} to get high differential gain as well as compensation of offset voltages at the same time, particularly in the case when the range of offset voltages to be compensated is high. To take care of this problem, a new design of three-stage IA is proposed as shown in Fig.2.

II. New Design of Three-Stage Instrumentation Amplifier

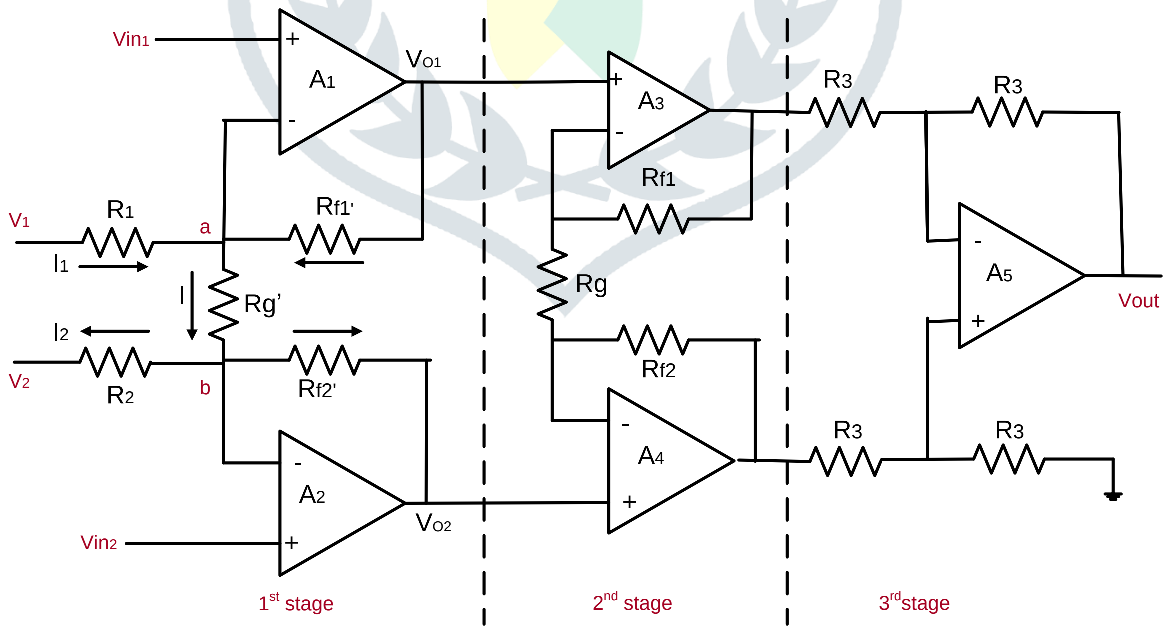

Fig. 2: Three stage instrumentation amplifier circuit

This IA consists of five op-amps instead of three as used conventionally, and it has got three stages of amplification as compared to only two stages used in conventional IA. The first stage consisting of op-amps A_1, A_2, resistances Rg', R_{f1}' and R_{f2}' as well as compensating voltage sources V_1 and V_2. This stage is exclusively used for compensation of DC differential offset voltages to produce distortion less wide dynamic range at the input of op-amps A_3 and A_4. The op-amp A_5 along with resistances R is a conventional differential amplifier which gives the final output. In the 1st stage, the value of R_{f1}' and R_{f2}' can be made as small as possible since it does not affect the gain of the circuit and the gain of the circuit which is decided by the 2nd stage consisting of op-amps A3 and A4, resistances Rg, Rf1 and Rf2. Hence, the gain can be controlled by varying Rg only, and Rf1 and Rf2 can be selected suitably as in the case of conventional IA.

The 1st stage of this proposed new design can be used at input of any commercially available voltage mode or current mode IA regardless of its design to compensate DC differential offset voltages which can have large amplitudes.

III. THREE-STAGE INSTRUMENTATION AMPLIFIER WITH AUTOMATIC OFFSET VOLTAGE COMPENSATION

Three-stage instrumentation amplifier with automatic offset voltage compensation with constant voltage sources is also proposed as shown in Fig. 3 where the required compensation voltages are generated by feedback circuit using integrator, control logic, counter, digital to analog converter (DAC) and inverter. The DC offset voltage present in output of IA is integrated by Op-amp A6 which is used to change the output of a DAC using control logic and counter. Since the digital code of DAC is stable after the compensation of DC offset voltages, only DC offset voltage gets compensated without degrading the frequency response. This operation is achieved using EN/Disable control of counter as shown in Fig.3.

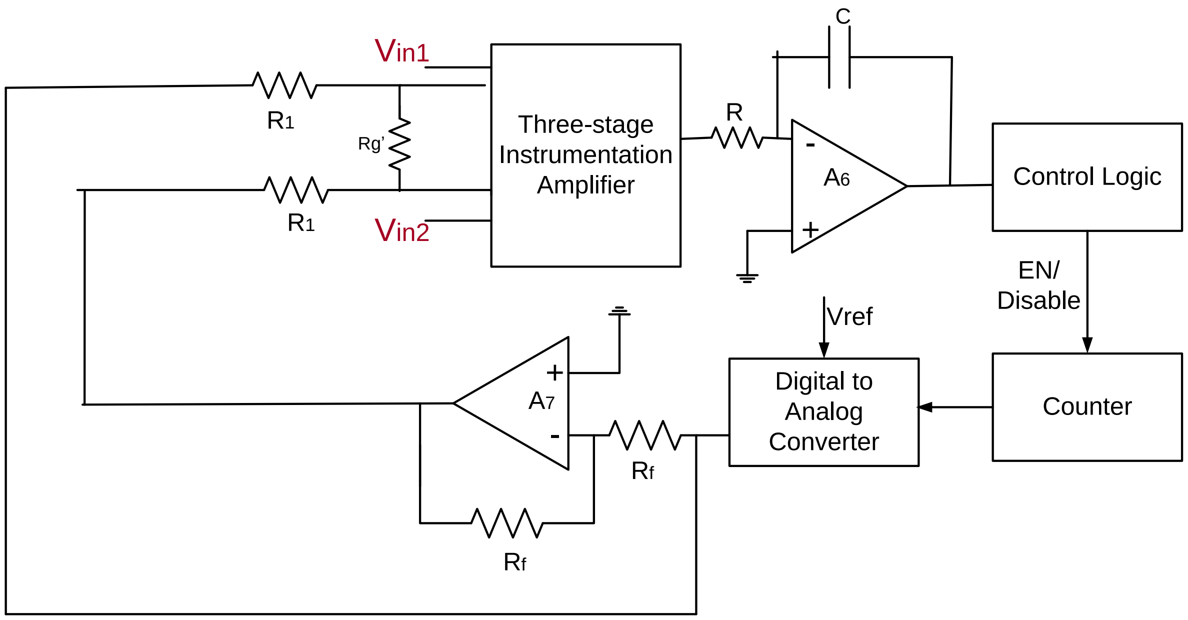

Fig. 3: Three stage instrumentation amplifier circuit with automatic offset voltage compensation with constant voltage sources

IV. RESULTS OF PROPOSED THREE-STAGE INSTRUMENTATION AMPLIFIER

The circuit shown in Fig. 2 was constructed using voltage sources at the inputs of IA to compensate the current flowing through Rg due to differential offset voltage for differential gain of 100. The gain of three-stage IA was adjusted suitably to give overall differential gain nearly 100 to verify performance of both combinations under similar conditions. The circuit was tested for various DC differential and common mode signals to observe the performance of IA. INA118 was used for this purpose with and without addition of the 1st stage of proposed three-stage instrumentation amplifier. Results were obtained and the graphs were plotted as shown in Fig. 4 and 5.

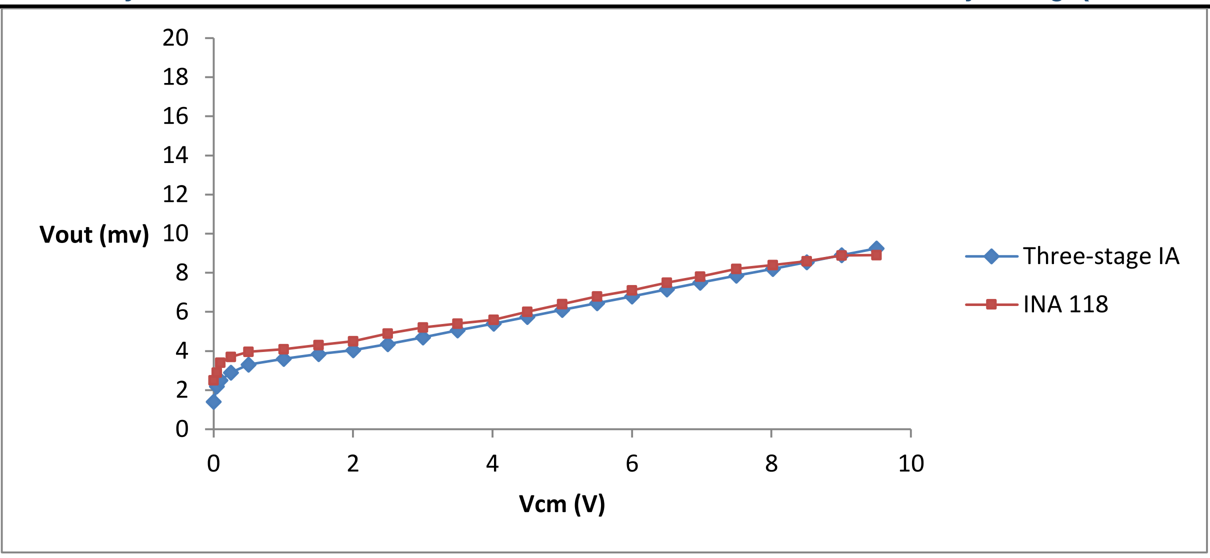

Fig.4: Performance of three-stage of Instrumentation amplifier and INA 118 for common mode voltage

Fig.4 shows the common mode performance of three-stage IA and INA 118 for DC common mode input voltage ranging from 0-10V. Here common mode error ranges from 0.2 to 10 mv in both the IAs.

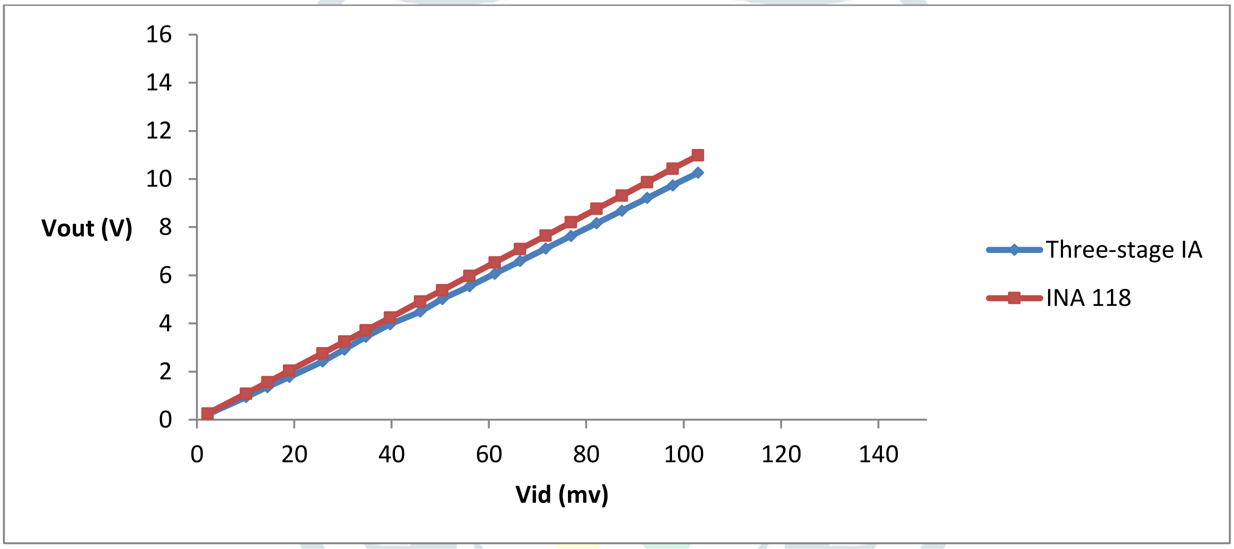

Fig. 5: Performance of three-stage Instrumentation Amplifier and INA 118 for differential voltage

Fig.5 shows the response of three-stage IA and INA 118 for differential input range from 0-100mv. It is observed that differential gain characteristics are linear in both the cases. It was verified that, the offset voltage compensation range is up to 120mv in this three-stage IA which is much higher than using only conventional IA designed as reported in [6],[7]. It is clear that output of conventional IA would have saturated for the differential gain of 100 when the input offset voltage is nearly 100mv reducing the dynamic range to zero.

V. Conclusion

In proposed method, a new stage of compensation has been added at the input of conventional IA resulting into three-stage IA with five op-amps. The 1st stage of this new IA consists of two op-amps and associated resistor network which is utilized for compensation of undesirable DC offset voltages which can have large amplitudes. This stage can be added at the input of any commercially available IA for compensation of DC differential offset voltage without degrading CMRR and frequency response. The compensation of offset voltage can be done manually or automatically using DAC controlled circuit. The circuit has been constructed and tested using manual adjustment. Higher values of offset voltages are compensated with addition of a new stage resulting into improvement in dynamic range without affecting the performance of conventional IA. The results obtained which conclusively proves the effectiveness of this method. Unlike RC coupled IA, this three-stage IA does not require components with tight tolerance.

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