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Operational amplifier and its measurement system for input bias-offset currents

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ABSTRACT

In this paper, we present a report on a very simple microprocessor (µP) -based dedicated instrument which is designed for the measurement of the input bias and input offset currents. The overall system design consists of both hardware and software designs. The designed and constructed system is used in obtaining very accurate values of input bias and input offset currents on the µP control-display panel, one after the other, when the operational amplifier (OP- AMP) under test is connected across the test terminals. The input bias and input offset currents of an OP-AMP depend not only on the ambient temperature but also on the input impedance.

Key words: Microprocessor 8088, Programmable Interface Adapter, Analogue-to-Digital Converter, Input Offset Current, Input Bias Current, OP-AMP, Signal Conditioner, High Accuracy, Assembly Language Programming.

INTRODUCTION

With advances in solid state technology, op-amps have become highly reliable, miniaturized and consistently predictable in performance. They are designed to handle analogue signals which carry information in terms of amplitude and wave shape. For designing 'a circuit containing an op-amp, it is necessary to have the information regarding its parameters. However, the facility for measuring the parameters of linear op-amp (for DC Analysis) in a single instrument is not available indigenously. In this paper, an attempt has been made to determine two of the important parameters, i.e., input bias and offset currents respectively of an op-amp using microprocessor techniques [1, 4]. Although these currents are quite small, but even little deviation from zero results in wide variation in the output voltage. A little mismatch between the input stages of an op-amp causes unequal bias currents flowing into two inputs and it results in the input off-set current not being zero. This is contrary to the basic assumption in circuit analysis.

1. BASIC INTERNAL STRUCTURE AND PROPERTIES OF AN OP-AMP

An OP-AMP is a DC amplifier having a high gain, of the order of 10^4 to 10^8. Such an amplifier can perform summing, integration, differentiation, or act as comparator with suitable feedback networks.

The block diagram of an OP-AMP, shown in Figure 1, consists of a four-stage direct-coupled amplifier in cascade.

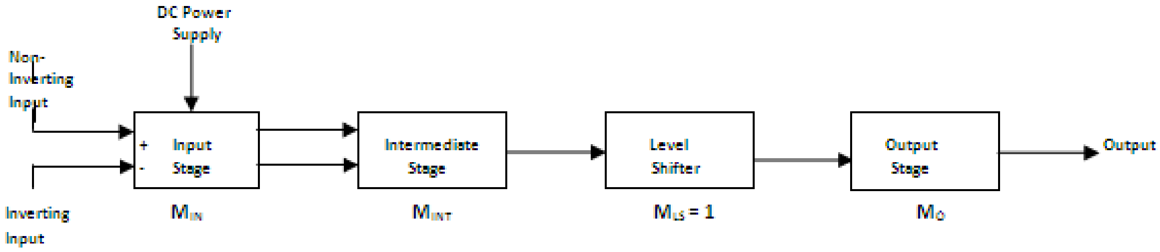


Fig. 1: Block Diagram of an OP-AMP

Overall gain (or overall amplification) = M_{IN} x M_{INT} x Mo (very high).
The first input stage is a double-ended high-gain differential amplifier. The intermediate stage is a single-ended differential amplifier. The third stage is a level shifter which is used as an emitter follower circuit.

The final stage is a push-pull complementary amplifier. With low output impedance and minimum offset voltage and currents the power gain ranges from 5 to 20 for this output stage.

An ideal OP-AMP exhibits the following electrical characteristics [5]:
1) Infinite voltage gain. That is, $A_v = \infty$.
2) Infinite input resistance. That is $R_i = \infty$.
3) Zero output resistance. That is $R_o = 0$.
4) Zero output voltage when input voltage is zero.
5) Infinite bandwidth.
6) Infinite common-mode rejection ratio (CMRR). That is CMRR = ∞.
7) Infinite slew rate.

The measured parameters of an OP-AMP in our research and study are the input bias current and the input offset current.

The input offset current (I_{ios}) is the algebraic difference between the currents that flow into the inverting and non-inverting terminals of an OP-AMP. And, the input bias current (I_{ib}) is the average of the currents that flow into the inverting and non-inverting terminals of an OP-AMP [6].

MATERIALS AND METHODS

The basic principle of the measuring system reported here incorporates generation of a voltage signal corresponding to the input bias and input off-set currents of an OP-AMP respectively. This signal is fed to the µP through various interfacing circuits. After suitable programming of the µP, we can measure and display very accurate values of these currents.

The continuous (dedicated) subroutines for inputting data, processing data, calibrating, reading and displaying the measured data are written in 8088 assembly programming language. These error-free subroutines or functions are then “burnt” into EPROM sub-unit of the 8088 control/processor unit by using an assembler/EPROM programmer kit. The two input channels (one for I_{ib} and the other for I_{ios}) are enclosed in a constant-temperature enclosure because ambient temperatures affect their outputs.

The input impedance of the OP-AMP can be varied by using an electronic linear potentiometer. Thus, the input impedance (R_{in}) for I_{ib} and/or I_{ios} can be set before measurements.

When the 2:1 analogue multiplexer is switched to position ch1, then channel 1 is chosen for measuring $I_{ib.}$ When the 2:1 analogue multiplexer is switched to position ch2, then channel 2 is chosen for measuring I_{ios} .It should be noted that as long as the system is on and the dedicated program is running, both I_{ib} and I_{ios} can be measured at any instant for any given R_{in} and ambient temperature.

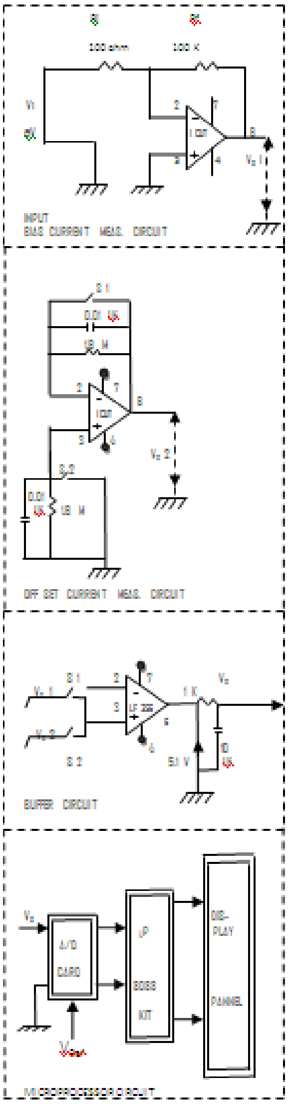
For any set of I_{ib} and I_{ios} readings taken, both upper and lower limits of any one reading can be taken also by using the UL and LL switches on the control- display panel.

2. SYSTEM DEVELOPMENT

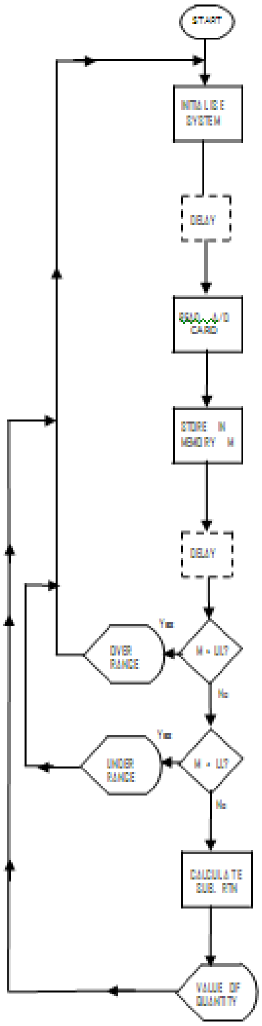
Basically, every dedicated instrument involves hardware and software parts. The design of each of them is presented as follows.

The hardware involves the designs of circuits, relay drive, buffer amplifier, input bias current (I_b) and off-set current (I_{ios}) measuring units. The software consists of initialization, service, calculation, and display subroutines. Use of software in assembly language displays the exact value of the measured parameter on the µP display panel.

The instrument is software-controlled in such a way that it enables easier modification and allows implementation of complex control functions like selection and sorting of operational amplifiers.



POINT 7: + 12 VOLTS
POINT 4: - 12 VOLTS
Fig. 2: The Complete Circuit.



UL: UPPER LIMIT
LL: LOWER LIMIT
Fig. 3: Generalised Flow Chart For Measuring The Input Current Parameters Of The OP-AMP.

4.1 HARDWARE DESIGN

Figure 2 shows the hardware adopted. The output signal, proportional to the parameter being measured, from I_{ib} and I_{ios} measuring units, is fed to the microprocessor 8088 through a buffer amplifier circuit and analogue-to-digital converter (ADC-0809). It consists of designing of input bias current and offset current measuring units and buffer circuits [2, 3, 4].

The system, being designed, constructed and tested, has two auto-current sensors, two signal conditioners, and analogue multiplexer, an analogue–to- digital converter, and a control–display panel. The display is digital and has a good resolution, and its readings are in nA.

(i) Input Bias Current Measuring Circuit:

The unit designed for measuring input bias current which can be designed as the average of two input bias currents $I_b(-)$ and $I_b(+)$ at both inputs inverting and non-inverting terminals of an OP-AMP. Relations used for I_b are:
Gain of the given circuit = R_F/R_i =100k/100 =1000;

$I_b = I_1 + I_2$ (1)
$I_1 = 0$ and $I_2 = V_o$ (bias)/R_2.

Therefore,
$I_b = I_2 = V_o$(bias)/R_2 = 0.056V/100k = 560 nA.
As it can be clearly seen, I_{ib} varies from 100 nA to 1 µA [5].

(ii) Input Off-Set Current Measuring Unit:

Input off-set current is an indicator of degree of mismatching between two bias currents and is a measure of matching of input-stage transistor pair. It is a temperature-sensitive specification of an OP-AMP and changes with time. The mathematical relations involved are:

$I_{ios} = I_b (+) - I_b (-)$; (2)
Gain of OP-AMP = 1.

$I_b (+) = V_o/R_1$ = 125 V/1.656 M = 75.48 nA, when S1 is open.
$I_b (-) = -V_o/R_2$ = 31.2 mV/1.656 M = 18.84 nA, when S2 is open.
I_{ios} = 75.48 – 18.84 = 56.64 nA.

I_{ios} varies from 30 nA to 200 nA, from our research and measurements.

4.2 SOFTWARE DESIGN

In the software design firstly, the system is initialized. After delay, the A/D card is read and stored in memory M. This memory is compared with upper limit and lower limit under different conditions; either Over Range or Under Range is displayed, otherwise, the exact value of the parameter is displayed on µP output panel, when calculation subroutine is called.

The assembly language program has the following modules which are coded in the 8088 assembly language:

1. INIT: This subroutine initializes the system.
2. INDATA: This function input the input data signal and identifies the channel number.
3. PROCESSDATA: This subroutine processes and calibrates the data signal.
4. UPPERLIMIT: This function is used to determine the upper limit (+) of the averaged instantaneous reading (I_{ib} or I_{ios}).
5. LOWERLIMIT: This procedure is employed in the determination of the lower limit (-) of the average instantaneous reading.
6. DISPLAY: This subroutine is meant for displaying the upper limit value, lower limit value and the averaged instantaneous value of the (I_{ib} or I_{ios}) reading.

These subroutines are sequentially called at the appropriate times into the main action block of the running software.

4.3 TESTING AND MEASUREMENTS

Operational amplifier LM380 is a 14-pin integrated circuit (IC) which is used for testing the designed and constructed measurement system. Pins 2 and 6 are the non-inverting and inverting pins of LM380.

In order to measure the values of I_{ib} and I_{ios} for LM380 at any room temperature (which is measured with mercury-in – glass thermometer (0 to 110^0C)), we carry out the following:

1. Insert securely the LM 380 OP-AMP in its socket, taking note of the pin- out configurations.
2. Power up all sections of the measurement system.
3. Set the switches in the correct positions, and choose channel 1 or 2.
4. Take the readings of upper limit value, average value and lower limit of the instantaneous I_{ib} (channel 1) or I_{ios} (channel 2).
5. The input resistance (R_{in}) was varied from 1 MΩ to 10 MΩ.
6. Thus, for each value of R_{in} (from 1 MΩ to 10 MΩ), the corresponding values of upper limit, average and lower limit of I_{ib} and I_{ios} were noted and recorded.
7. Given some set of values I_{ib} and I_{ios} as the corresponding theoretical values [5], the percentage deviations and percentage errors, could be calculated as follows:

$$\%\,error = \pm\frac{(Theoretical\,value - Measured\,average\,value)}{Theoretical\,value}\times 100\% \qquad (3)$$

$$\%\,deviation = \pm 0.5\frac{(Upper\,\lim it - Lower\,\lim it)}{Average\,value}\times 100\% \qquad (4)$$

Table 1 displays the various values of R_{in} and the corresponding values of I_{ib} and I_{ios} measured for LM 380 using the system.

Table 1: Table of measurements and results obtained for LM 380 using the constructed measurement system.

R_{in}/ Ω	I_{ib}(nA)			I_{ios} (nA)		
	UL	AVE	LL	UL	AVE	LL
1M0	100.02	100.00	99.98	55.03	55.00	54.97
2M0	150.01	150.00	149.99	85.02	85.00	84.98
3M0	205.02	205.00	204.98	110.01	110.00	109.99
5M0	275.03	275.00	274.97	160.02	160.00	159.98
6M0	320.01	320.OO	319.99	190.03	190.00	189.97
8M0	390.02	390.00	389.98	245.01	245.00	244.99
10M0	475.03	475.00	474.97	305.03	305.00	304.97

Ambient temperature θ_A *= 25ºC ±0.5ºC*
UL = upper limit value
AVE = averaged instantaneous value
LL = lower limit value.

Table 2 gives an analysis of the measurement data in table 1. Percentage errors and percentage deviations for I_{ib} and I_{ios} for various R_{in} values were computed.

The percentage errors in the measurement of I_{ib} and I_{ios} were computed by using the following two formulae:

$$\%\,error\,(I_{ib}) = \pm\frac{(I_{ib}\,Theoretical\,value - I_{ib}\,Measured\,average\,value)}{Theoretical\,value\,I_{ib}}\times 100\% \qquad (5)$$

$$\%\,error\,(I_{ios}) = \pm\frac{(I_{ios}\,Theoretical\,value - I_{ios}\,Measured\,average\,value)}{Theoretical\,value\,I_{ios}}\times 100\% \qquad (6)$$

Table 2: Table of percentage errors and percentage deviations for LM 380 OP-AMP's I_{ib} and I_{ios} measurements under different R_{in} values.

S/N	R_{in}/Ω	I_{ib} (nA)		% error (I_{ib}) ± %	% devi-ation (I_{ib}) ± %	I_{ios} (nA)		% error (I_{ios}) ± %	% devi-ation (I_{ios}) ± %
		Avera-ge value	Theoretical value			Avera-ge value	Theor-etical value		
1	1M	100.0	100.5	0.50	0.020	55.0	55.5	0.90	0.055
2	2M	150.0	150.2	0.13	0.007	85.0	86.0	1.20	0.024
3	3M	205.0	206.0	0.49	0.010	110.0	112.0	1.80	0.009
4	5M	275.0	277.0	0.72	0.011	160.0	161.0	0.62	0.013
5	6M	320.0	322.0	0.62	0.003	190.0	192.0	1.04	0.016
6	8M	390.0	393.0	0.76	0.005	245.0	246.0	0.41	0.004
7	10M	475.0	476.0	0.21	0.006	305.0	307.0	0.65	0.010

On the other hand, the percentage deviations in the measurements of the OP-AMP's current parameters were computed by using the following formulas:

$$\%\ deviation\ (I_{ib}) = \pm 0.5 \frac{(Upper\ \lim it\ I_{ib} - Lower\ \lim it\ I_{ib})}{Average\ value\ I_{ib}} \times 100\% \qquad (7)$$

$$\%\ deviation\ (I_{ios}) = \pm 0.5 \frac{(Upper\ \lim it\ I_{ios} - Lower\ \lim it\ I_{ios})}{Average\ value\ I_{ios}} \times 100\% \qquad (8)$$

CONCLUSION

This dedicated instrument is very fast in operation and gives the exact values of I_b and I_{ios} of an OP-AMP, one after the other. Both these parameters are temperature-sensitive specifications of an OP-AMP. Input off-set current value is always smaller than that of input bias current. A number of OP-AMPs of same design have different values of the above parameters. Several OP-AMPs have been tested and this measuring system yields satisfactory results. Efforts are being directed towards designing circuits that would measure other parameters of linear integrated circuits using similar techniques. It is observed that for LM 380 OP-AMP, at 25°C:

1. Whilst the input resistance varies from 1 MΩ to 10 MΩ, I_{ib} varies from 100 nA to 475 nA, and I_{ios} varies correspondingly from 55 nA to 305 nA
2. For any value of R_{in}, I_{ib} is correspondingly greater than $I_{ios.}$
For example, at R_{in} = 10 MΩ, I_{ib} = 475 nA which is greater than the value of I_{ios} of 305 nA.
3. The highest percentage error (Table 2) of ± 0.76 percent in the measurement of I_{ib} occurs at R_{in} = 8 MΩ.
4. On the other hand, the maximum percentage error (Table 2) of ± 1.80 percent in the measurement of I_{ios} is obtained when R_{in} = 3 MΩ.

In conclusion, therefore, it can be said that the designed and constructed dedicated instrument, which is recommended for adoption, possesses the stimulating characteristics of high reliability, high accuracy (i.e., very low percentage error), high resolution and high stability (i.e., extremely low percentage deviation).

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