3.1. Introduction:

The problems of matching a detector to an electronic system (amplifier) should be given a particular attention where the device has to operate with small signals. In optoelectronic system, the detector converts the input optical signal to subsequent electronic signal by its action. Afterwards, the low level signal has to be amplified by suitable amplifier. The analog signal processing electronic is most important in any instrumentation system and optoelectronic system design.

3.2. DETECTOR ACTION:

The detector which has been selected after various considerations as described in chapter -II is a phototransistor (L14G1 & L14G2). The action of the phototransistor is to convert light into electrical signal as described below.

The phototransistor is a common junction transistor with photodiode -amplifier combination as shown in figure 5.13 in chapter-V. The circuit is connected in common-emitter configuration. The base terminal is not connected and is left floating so as to operate it as a two terminal device.

The absorption of light causes generation of carriers in the base region, which are then separated by the collector junction. The electrons cross the junction
and move into the n-collector region while the holes remain in the base. The field produced by the space charge of holes cannot reduce the charge in the base at the expense of base current \( (I_B = 0) \). The space charge field thus lowers the potential barrier of the emitter junction causing an additional injection of electrons into the base. The photo-current produced by the incident light plays here the role of base current. The output characteristics of the phototransistor are consequently similar to those of a bipolar transistor. The experimentally observed characteristic curves of the phototransistors used are shown in figure 2.18 of chapter-II. In comparison with a common photodiode, the phototransistor affords current amplification by \( \beta \) times and exhibits the total responsivity equal to,

\[
S_p = S_D \beta \tag{3.01}
\]

where, \( S_D \) is the current responsivity of the photodiode formed by the emitter junction of the transistor; and \( \beta \) is the common current gain factor \( (h_{FE}) \).

The relation between photon generated base-current, \( I_B \) and the emitter-current, \( I_E \) of a phototransistor is\(^4\),

\[
I_E = I_B (h_{FE} + 1) \tag{3.02}
\]

The relation 3.02 shows that sensitivity of a phototransistor can be influenced by different bias level at the base created by different intensity of the illumination.

The switching time of the phototransistor is usually governed by the RC time-constant of the phototransistor combined with the low base-current and normally unterminated base contact causing high input impedance and multiplied by
the voltage gain \((A_v)\) of the amplifier. The requirement for high transfer ratio and low switching time call for a decrease in the base-width \((W_B)\), which generally tends to reduce the device photosensitivity. The trade off between the opposing requirements necessitates lowering the speed of phototransistors which usually lies between \(10^{-5}\) and \(10^{-6}\) sec. [Table-2.01 of Chapter-II].

3.3. AMPLIFIER DESIGN AND SELECTION:

In designing the optoelectronic system reported here, various instrumentation amplifiers\(^5-7\) under different configurations have been fabricated and tested making use of computer soft-ware Electronic Workbench (version 5.0)\(^8\) and PC Trace (version 2.6)\(^9\). The characteristic performances of different instrumentation amplifiers were studied with the specific aim of detecting and amplifying weak photovoltaic signals with reasonable fidelity and accuracy. The various configurations of instrumentation amplifiers designed include amplifiers using op-amp UA 741\(^10-12\), op-amp LM 308\(^13,14\) and also amplifier designed using quad op-amp LM 324\(^15,16\) etc. The amplifiers have been designed as that of the basic instrumentation amplifiers, but occasionally with slight modifications, as par the results obtained from the simulations carried out by using Electronic Workbench.

An instrumentation amplifier (IA) is a precision differential voltage gain device that is intended for use when acquisition of a useful signal becomes difficult. The instrumentation amplifier is one of the most useful, precise and versatile amplifiers available at present. The basic instrumentation amplifier circuit consists of three op-amps and seven resistors as seen in figure 3.01. To simplify circuit analysis,
the instrumentation amplifier is actually formed by connecting a buffered amplifier to a basic differential amplifier. The op-amp A\textsubscript{3} and its four equal resistors R form a differential amplifier with a gain of 1. Only the A\textsubscript{3} resistors have to be matched. The primed resistor R\textprime{} can be made variable to balance out any common-mode voltage. Only one resistor, aR, is used to set the gain of the amplifier according to the equation,

\[ \frac{V_0}{(E_1 - E_2)} = 1 + \frac{2}{a} \] .............................. 3.03

where, \[ a = \frac{aR}{R} \]

\( E_1 \) is applied to the (+) input and \( E_2 \) is applied to the (-) input

Output \( V_0 \) is proportional to the difference between the input voltages.

The characteristic features of instrumentation amplifier are:

1. The voltage gain from differential input \((E_1 - E_2)\) to single-ended output is set by one resistor.

2. The input impedances of both the inputs are very high and do not change as the gain is varied.

3. Output \( V_0 \) does not depend on the voltage common to both \( E_1 \) and \( E_2 \) (common-mode voltage), but only on their difference.
Use of precision (1%) resistors in an instrumentation amplifier guarantees a specified level of performance. In some specific applications, it is desirable to offset the output voltage to a reference level other than 0V. In some other applications sensing voltage at the load becomes necessary to minimize any mismatch between the instrumentation amplifier and the load. Thus, to improve the versatility and the performance of the instrumentation amplifier, the negative feedback loop around op-amp A₃ is broken and three terminals are provided, namely, the output terminal O, sense terminal S and reference terminal R.

Slight modifications were carried out to the basic instrumentation amplifier circuit during the process of design and selection of a suitable instrumentation amplifier for the reported optoelectronic system. For example, in the instrumentation amplifier shown in Figure 3.02, the modification made is that, the variable resistance between the two input stages of the amplifier has been removed and both the input terminals are grounded by a couple of resistors. An extra resistor (variable preset) is connected in series with the output terminal of the first stage of each amplifier to compensate the difference of the value of the resistors in each of the input terminals of the second stage of the amplifier (op-amp A₃ in Fig. 3.02).
Fig. 3.01: Instrumentation Amplifier.

Fig. 3.02: A modified form of instrumentation amplifier.
As stated earlier, various configurations of instrumentation amplifiers were fabricated in the process of designing and selection of a suitable amplifier for the designed optoelectronic system which include use of op-amp UA 741, op-amp LM 308 and also use of quad op-amp LM 324 and a comparative study have been made. The photo-detector signal is applied at the input terminal of the op-amp (A1) of the instrumentation amplifier for proper amplification. The photographs of a few separate circuit configurations of instrumentation amplifiers fabricated during the process are given here. Photograph 3.03 shows the circuit of an instrumentation amplifier designed by using op-amp UA 741. Similarly, the photographs 3.04 and 3.05 show circuits of the instrumentation amplifiers designed by using op-amp LM 308 and quad op-amp LM 324. Photograph 3.05(a) is the modified circuit of the instrumentation amplifier designed using LM324. It shows that the circuit contains twelve resistors for each of the op-amp within the IC connected externally. Now, when the circuit simulation is done using EDA tool (Electronic Workbench, version 5.0) for LM324 quad op-amp, the number of resistors used is minimized in the simulated circuit as shown in photograph 3.05(b).

A detailed study among the characteristics of the various configurations of designed instrumentation amplifier shows that the amplifier with LM 308 has a much larger gain-bandwidth product than the amplifier designed with the UA 741. The use of quad op-amp LM 324 [Fig.3.10(a)] which comprises of four identical in-built individual op-amps in a single package helps to overcome the anomalies and mismatching among the different stages of the instrumentation amplifier, which often arises during assembling of separate individual op-amps while
designing instrumentation amplifier. The use of the quad op-amp also makes the amplifier circuit compact in size.

Finally, photo-detector signal amplification has also been carried out by using the modular version of precision instrumentation amplifier AD524 (Fig. 3.11). Use of modular version in single packages makes the amplifier circuit extremely stable and useful where accuracy is concerned. Although these packages are relatively costlier, yet as far as performance and precision are concerned, these amplifiers are well worth the price, as its performance cannot be matched by the average op-amp. Taking into account, all these matchless features of the modular version of instrumentation amplifier, AD 524 has been finally selected for fabrication and design of our optoelectronic system.

The circuit details, the simulation results along with their characteristics performances obtained from the real-time values of the various amplifiers designed and fabricated during the process of amplifier design and selection have been given in details (Fig. 3.06 to Fig. 3.11).
Photograph 3.03: Instrumentation amplifier using UA 741.

Photograph 3.04: Instrumentation amplifier using LM 308.
Photograph 3.05(a): Instrumentation amplifier using LM 324
(designed without simulation)

Photograph 3.05(b): Instrumentation amplifier using LM 324
(designed after simulation)
Fig. 3.06(a): Block-diagram of the Instrumentation Amplifier designed in Differential mode using op-amp UA 741

Fig. 3.06(b): Frequency Response of the Instrumentation Amplifier Designed in Fig. 3.08(a)
Fig. 3.07(a): Circuit Diagram of the Instrumentation Amplifier Designed under Different configuration using op-amp UA 741

Fig. 3.07(b) Simulated output of the Instrumentation Amplifier designed as in Fig. 3.09(a)
Fig. 3.07(c): Frequency Response of Instrumentation Amplifier [Fig. 3.09(a)]

Fig. 3.07(d): Transfer Characteristics of Amplifier [Fig. 3.09(a)]
Fig. 3.08(a): Block-diagram of the Instrumentation Amplifier Designed under Different configuration using op-amp UA 741

Fig. 3.08(b): Simulated output of the Instrumentation Amplifier designed as in Fig. 3.10(a)
Fig. 3.08(c): Frequency Response of Instrumentation Amplifier [Fig. 3.10(a)]
Fig. 3.09(a): Block-diagram of the Instrumentation Amplifier designed in Differential mode using op-amp LM 308

Fig. 3.09(b): Simulated output of the Instrumentation Amplifier designed as in Fig. 3.11(a)
Differential Input Vs. Output of the Instrumentation Amplifier designed
(Changing Input voltage & keeping Noise fixed)

Fig. 3.09(c): Diff. Input Vs. Output of Instrumentation Amplifier [Fig. 3.11(a)]
(changing Input signal & keeping Noise signal fixed)

Differential Input Vs. Output of Instrumentation Amplifier designed
(keeping input voltage fixed & changing noise)

Fig. 3.09(d): Diff. Input vs. Output of Instrumentation Amplifier [Fig. 3.11(a)]
(keeping Input signal fixed & changing Noise signal)
Fig. 3.10(a): Pin configuration of quad Op-amp LM 324

Fig. 3.10(b): Block-diagram Instrumentation Amplifier designed by using LM 324
Fig. 3.10(c): Simulated output-signal of the Instrumentation Amplifier designed as in Fig. 3.12(a)

Fig. 3.10(d): Differential Input Vs. Output characteristics of Instrumentation Amplifier of Fig. 3.12(a)
Fig. 3.11(a): Pin configuration of Precision Instrumentation Amplifier AD 524

Fig. 3.11(b): Functional Block-diagram of AD 524
Fig. 3.11(c): Operating Connections of AD 524 for Gain, $G = 100$.

Fig. 3.11(d): Block-diagram Instrumentation Amplifier designed by using AD 524.
Fig. 3.11(e): Simulated output-signal of the Instrumentation Amplifier designed as in Fig. 3.13(d)

Photograph 3.11(f): The amplifier section of the Designed Optoelectronic System employing AD 524
3.4. SCANNING AND REGENERATION OF THE SPECIMEN IMAGE:

THE FLY-BACK BLANKING CIRCUIT:

The concept of scanning of a specimen means, to collect point to point information of the specimen by exploring its surface with the help of a focused incident beam of light. The intensity of spatially transmitted or reflected light from each point of the specimen, which carries point to point information of the specimen is then collected by suitable detectors for further signal processing. In progressive horizontal scanning, the focused beam of incident light is made to sweep across a horizontal line from the left towards right covering all the picture elements and is then quickly returned to the left to scan the next line. For proper scanning of a specimen it becomes necessary to blank out the detector during the horizontal retrace of the scanning beam of light. Blanking out of the detector during horizontal retrace of the scanning beam of light is accomplished by the use of a fly-back blanking circuit.

A transistor based fly-back blanking circuit has been designed and fabricated for the purpose of blanking out the detector during horizontal retrace of the scanning beam of light (Fig. 3.12). The basic idea of the fly-back blanking circuit design is to drive an amplifier transistor \( T_2 \) with another driver transistor \( T_1 \). The driver transistor is activated by a square wave pulse from a function generator which is of the same order of the pulse that drives the vibrator coil of the specimen holder. The output of the driver transistor is the power source for the amplifying transistor \( T_2 \), through which the detector signal passes to the signal display section of the system. Thus the amplifying transistor is being activated and deactivated in accordance with the rate of vibration of the horizontal vibrating system attached to the
specimen holder which helps in blanking out of the signal during horizontal retrace of the scanning beam of light while scanning the specimen.

Later on, blanking out of the signal during retrace of the scanning beam has also been experimented with the help of an IC based fly-back blanking circuit using Quad Bilateral Switch IC, No: CD4016BC (Fig. 3.13). The CD4016BC is basically intended for use in the transmission or multiplexing of analog or digital signals. It is also pin-to-pin compatible with CD4066BC. Finally, the transistor based fly-back blanking circuit has been replaced by IC based fly-back blanking circuit using Quad Bilateral Switch CD4016BC (Photograph 3.14) in the designed optoelectronic system as it is found to be far superior to the transistor based circuit. The salient features of bilateral switching IC, CD4016BC are its wide supply voltage range (3V to 15V), wide range of digital and analog switching (±7.5V<sub>PEAK</sub>), high degree of linearity (0.4% distortion), extremely low “ON” switch leakage (0.1nA) etc. Use of the quad switching IC also provides a compact and easily replaceable facility to the fly-back blanking circuit.
Fig. 3.12(a): Block-diagram of the Transistor-based Fly-back blanking circuit.

Fig. 3.12(b): Circuit-diagram of the Transistor-based Fly-back blanking circuit.
Fig. 3.13: Connection Diagram of CD4016BC

Photograph 3.14: Fly-back blanking circuit using Quad IC: CD4016BC.
3.5. THE POWER-SUPPLY SECTION:

The power-supply section that does the job of converting the available source of power into different voltages as required by the system is one of the most important sections of the system. Taking into account, the different regulated voltages required for the various sections of the optoelectronic system e.g. the amplifier section, the vibrating system, the fly-back blanking circuit and the light-chopper, several power-supplies have been fabricated. An IC regulated linear power-supply has been designed using regulator ICs 7805, 7809, 7812, 7912 and 7818 as seen in figure 3.15. Later, the linear power-supply has been replaced by a Switch Mode Power-Supply (SMPS) as seen in figure 3.16.

Although, linear supplies are well known for their extremely good line and load regulation, low output-voltage ripple and almost negligible RF and EM interference, switching power supplies, on the other hand, have much higher efficiency (typically 80 percent against 50 percent in case of linear supplies) and reduced size/weight for given power delivering capability. Quite often, compactness and efficiency are two major selection criteria. An improved efficiency and reduced size/weight are particularly significant while designing a power-supply for a compact instrument where a number of different regulated output voltages are required. Also, unlike linear supplies, efficiency in switching supplies does not suffer as the unregulated-input to regulated-output difference becomes large\(^{23,24}\).
Photograph. 3.15: Linear Power-Supply

Photograph. 3.16: Switching Mode Power-Supply (SMPS)
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Linear Supply</th>
<th>Switching Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Regulation</td>
<td>0.02 - 0.05%</td>
<td>0.05 - 0.1%</td>
</tr>
<tr>
<td>Load Regulation</td>
<td>0.02% - 0.10%</td>
<td>0.10 - 1.0%</td>
</tr>
<tr>
<td>Output Ripple</td>
<td>1.5 - 5 mV</td>
<td>25 - 100 mV</td>
</tr>
<tr>
<td>Efficiency</td>
<td>40 - 50%</td>
<td>70 - 90 %</td>
</tr>
<tr>
<td>Power-Density</td>
<td>0.5 W / inch</td>
<td>2.5 W / inch</td>
</tr>
<tr>
<td>Transient Recovery</td>
<td>50 μS</td>
<td>200 μS</td>
</tr>
<tr>
<td>Hold-up time</td>
<td>2mS</td>
<td>32mS</td>
</tr>
</tbody>
</table>

Table 3.01 compares the major characteristics of linear and switching supplies. The characteristics which are significant from a designer’s point of view and where a switching supply has a high degree of superiority over a linear supply are efficiency and power-density. While power density indicates the size and weight vis-à-vis is power delivering capacity, the transient recovery time is the time required by the supply output voltage to settle within the accuracy limits after a step change in load current or the unregulated input.
References:


3. L. Sharupich and N. Tugov; Optoelectronics; Mir Publisher, Moscow; p. 79; 1987.


9. SCH Capture and PCB Layout Application Software; Version 2.6; © Steve Poulsen and Dong Ehlers; 1993.


17. Precision Instrumentation Amplifier AD524 data-sheet; Analog Devices, Inc., USA; 1999.


