A DEVELOPMENT OF DENSITOMETER FOR MEDICAL APPLICATION BY INTERFACE TO COMPUTER

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It is normal practice for workers in radiation areas to wear a film badge. Radiation exposure of the film produces film blackening or film density. The degree of blackening is determined using a densitometer. However, the imported device is costly and few of them could be provided for routine use.

The purpose of this study was to develop a computer-interface densitometer for medical applications along with the determination of its performance characteristics and operational limitations.

Electronic circuitry of the densitometer were designed, constructed and tested until a suitable combination circuit was achieved. Most of the materials used were locally available. The MCS-51 microcontroller was used to control the operation systems of the densitometer and the Visual Basic 6.0 was used in programming for user interface via RS-232 serial communications interface.

The densitometer was tested for accuracy and precision as well as its compatible with standard device, a Victoreen densitometer. An acceptable accuracy of 0.53% and a precision range of 0 to 6.09% were found. Studies in a parallel manner to the Victoreen densitometer showed that our present instrument could respond to not more than 14 steps of densities, with OD values ranging between 0.05 to 2.31 while the Victoreen could cover a wider range up to 21 steps of densities, with OD values ranging from 0.05 to 3.04.

The development of a densitometer as presented in this study could provide satisfactory information on film densities in the useful range in diagnostic radiology and radiation protection. Further research needs to be conducted to obtain the most appropriate computer-interface densitometer with better performance characteristics for the most benefit to people concerned with radiation.

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บุษปภัทร นาถวงษ์ : การพัฒนาเครื่องวัดความดำของฟิล์มสำหรับใช้ในทางการแพทย์ โดยการเชื่อมต่อกับคอมพิวเตอร์ (A DEVELOPMENT OF DENSITOMETER FOR MEDICAL APPLICATION BY INTERFACE TO COMPUTER). คณะกรรมการควบคุมวิทยานิพนธ์ : มฤลี ตัณฑวิรุฬห์, M.Sc., มานัส มงคลสุข, M.Sc., สุรพันธ์ ยิ้มมั่น, M.Eng. 157 หน้า. ISBN 974-664-144-1

ตามปกติแล้วผู้ที่ปฏิบัติงานในพื้นที่ที่เกี่ยวข้องกับรังสีจะต้องติดฟิล์มแบดจ์ ซึ่งเป็นอุปกรณ์ที่ใช้ในการตรวจวัดรังสีประจำบุคคล ส่วนของฟิล์มที่ได้รับรังสีจะเป็นสีดำหลังจากที่ผ่านกระบวนการล้างฟิล์มแล้ว ระดับความดำของฟิล์มสามารถวัดได้โดยใช้เครื่องวัดความดำของฟิล์ม (densitometer) อย่างไรก็ตาม ประเทศไทยได้นำเข้าเครื่องวัดความดำของฟิล์มมาจากต่างประเทศ ซึ่งมีราคาแพงมาก

วัตถุประสงค์ของการศึกษาคือ การพัฒนาเครื่องวัดความดำฟิล์มให้สามารถเชื่อมต่อกับคอมพิวเตอร์มาประยุกต์ใช้ในทางการแพทย์ พร้อมด้วยการทดสอบคุณสมบัติ และข้อจำกัดในการทำงานของเครื่อง

การศึกษาในครั้งนี้ได้ทำการออกแบบ สร้างเครื่องวัดความดำฟิล์ม และทดสอบวงจรทางอิเล็กทรอนิกส์จนได้วงจรรวมที่เหมาะสม โดยใช้อุปกรณ์ที่หาได้ภายในประเทศเป็นส่วนใหญ่ ใช้ไมโครคอนโทรลเลอร์ MCS-51 เป็นส่วนประกอบที่สำคัญในการควบคุมการทำงานของเครื่อง ใช้โปรแกรม Visual basic 6.0 ในการออกแบบหน้าจอ และการติดต่อสื่อสารแบบอนุกรมผ่านทาง RS-232

มีการทดสอบความถูกต้องของค่าความดำฟิล์ม และความแม่นยำในการวัด โดยทำการเปรียบเทียบกับเครื่องวัดความดำฟิล์มมาตรฐาน (Victoreen densitometer) ผลการศึกษาพบว่า มีความถูกต้องในการวัด0.53%และมีความแม่นยำในการวัดอยู่ในช่วงระหว่าง 0-6.09% ซึ่งเป็นค่าที่ยอมรับได้ เมื่อทำการศึกษาควบคู่ไปกับเครื่องมาตรฐานVictoreen จะพบว่าเครื่องของเราสามารถวัดความดำฟิล์มได้ไม่เกิน 14 step ค่า OD อยู่ในช่วง 0.05-2.31 ในขณะที่เครื่องมาตรฐานสามารถวัดได้ 21 step ค่า OD อยู่ในช่วงตั้งแต่ 0.05-3.04

เครื่องวัดความดำฟิล์มที่ถูกพัฒนาขึ้นจากการศึกษาในครั้งนี้ สามารถวัดค่าความดำฟิล์มเป็นที่น่าพอใจในช่วงใช้งานทางด้านรังสีวินิจฉัย และการป้องกันอันตรายจากรังสี การทำวิจัยต่อไปควรพัฒนาให้เครื่องมีประสิทธิภาพการทำงาน เพื่อให้บุคคลที่ปฏิบัติงานเกี่ยวข้องกับทางรังสีใช้ประโยชน์ได้อย่างสูงสุด

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CHAPTER I

INTRODUCTION

1.1 Background and Rationale

Exposure of the x-ray film produced film blackening, or density. The degree of film blackening is directly related to the intensity of radiation reaching a film. In diagnostic radiology, a radiographic film examination depends on the visibility of diagnostic important information on the film. A wide range of density differences can be measured using an instrument called a densitometer. This device is an optical density analyzer. It is mainly consisted of a light source and a photodiode sensor. The sensor of the densitometer generate output that is linearity related to changes in the light intensity being measured. Also in radiation protection it is used to measure the degrees of blackening on the film badge which is used as a routine control of personal whole-body radiation dose.

Since it is rare indeed to find densitometers among departmental equipment due to limited expenses. Also an imported densitometer is very expensive and the facilities for the supply of spare parts is limited. It is then of interest, in this thesis, to design and construct the prototype of densitometer using components which are locally available.

1.2 Objectives of the Thesis

1.2.1 To design and construct a densitometer that could provide maximum information in response to series of density as much as possible.

1.2.2 To study the physical characteristics of the light source and sensor to be used in the design of the electronic circuitry.

1.2.3 To test the performance characteristics of the instrument e.g. reliability in operation and its operational limitations.

1.2.4 To study its compatibility with other high price densitometers.

CHAPTER II

LITERATURE REVIEW

2.1 Film Construction

The primary purpose of diagnostic radiologic apparatus and techniques is to transfer information from an x-ray and gamma beam to the eye-brain complex of the radiologist. Radiographic film is one medium for information transfer. Construction and characteristics of radiographic film are similar to photographic film. The structure is built up in layers upon the base which provides a support as shown in Figure 2.1.

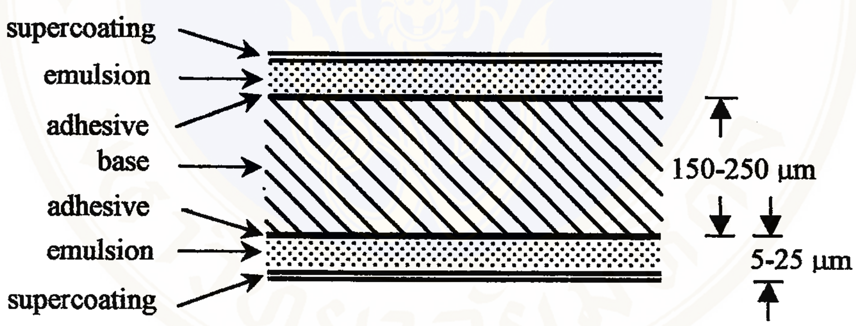

Fig. 2.1 Cross-sectional view of radiographic film.

2.1.1 Film Base

Film base is a transparent sheet of plastic made of a synthetic polyester. This polyester is normally tinted blue for less eyestrain. The function of the film base is to provide a rigid structure onto which the emulsion can be coated. The base is flexible and unbreakable to allow easy handling, but it is sufficiently rigid to be snapped into a view box. The sensitive emulsion is coated on both sides of the base. Between the emulsion and the base is a thin coating of adhesive layer to ensure uniform adhesion of the emulsion to the base. The sensitive emulsion is protected by a thin layer of gelatin called supercoating or anti-abrasive layer to prevent mechanical damage. The thickness of a sheet ranges from 200 to 300 μm (about 0.25 nm). The diagram in Figure 2.1 shows all these layers built up to form a complete radiographic film in cross section.

2.1.2 Emulsion

Emulsion is the material in which x-ray or light photons from screens interact and transfer information. The two most important ingredients of a radiographic emulsion are homogeneous gelatin and silver halide mixture. Most x-ray film has emulsion coated on both sides of the base. Emulsion thickness will vary with film type but is usually no thicker than 0.5 mm.

Gelatin

Radiographic gelatin is mostly made from cattle bone. It has certain characteristics as suspending and binding agent which keep the silver halide grains well dispersed and prevent the clumping of grains. It is clear, light transmitted, and sufficiently porous for the processing chemicals to penetrate to the crystals of silver halide during processing without destroying its strength or performance. Gelatin is available in reasonable large quantity and uniform quality.

Silver Halide

Silver halide is the light-sensitive photographic material in the emulsion. The silver halide in radiographic film is about 90 to 99% silver bromide ($AgBr$) and about 1 to 10% silver iodide (AgI). The silver halide in a radiographic emulsion is in the form of small crystals suspended in the gelatin. The crystal is formed from ions of silver (Ag^+), ions of bromide (Br^-) and ions of iodine (I^-) arranged in a cubic lattice as shown in Figure 2.2 (1, 2, 3).

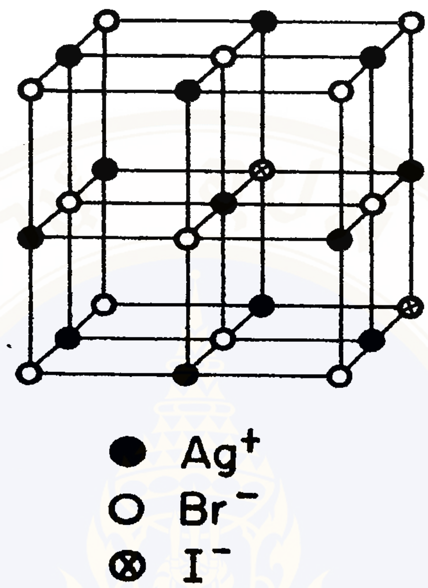

Figure 2.2 The silver iodo-bromide crystal lattice.

The shape and lattice structure of silver halide crystal are not perfect because a perfect crystal has almost no radiographic sensitivity. The imperfection results in the imaging property of crystals. A point defect consists of a silver ion which has moved out of its normal position in the crystal lattice. These interstitial silver ions may move in the crystal as Figure 2.3. Chemical sensitization of a crystal is produced by adding a sulfur containing compound to the emulsion which reacts with silver halide to form silver sulfide (AgS). The silver sulfide is usually located on the surface of crystal. This sensitizer has been given the name sensitivity speck which traps electrons to begin formation of the latent image centers.

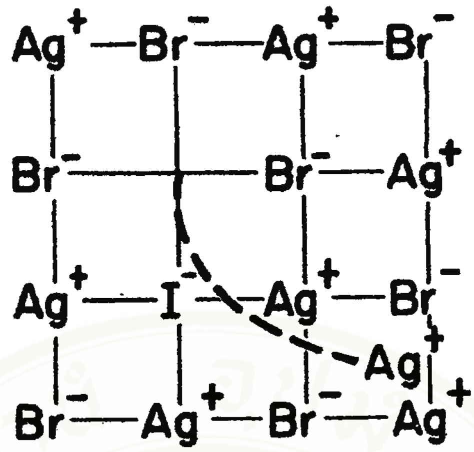

Figure 2.3 A point defect.

2.2 Formation of Latent Image

The radiation incident on the radiographic film deposits energy in the emulsion primarily by photoelectric interaction with the atoms of the silver halide crystal. This energy is deposited in a pattern representative part of the anatomy being radiographed. If the film is observed immediately after exposure, no image would be seen in which called a latent image. With proper chemical processing the latent image becomes a manifest image.

Figure 2.4 shows a schematic diagram of the development of a two atom latent image according to the Gurney-Mott hypothesis (1). The energy absorbed from a light photon gives an electron in the bromine ion enough energy to flee.

$$Br^{-} + \text{light photon} \longrightarrow Br + \text{electron}$$

A site of crystal imperfection such as an AgS sensitivity speck may act as an electron trap. The captured and temporarily fixed electron gives the sensitivity speck a negative charge and attracts the mobile interstitial Ag^{+} ions in the crystal. Therefore, silver ion is neutralized at the speck by the electron to form a single silver atom (Ag). The negative bromide ions that have lost electrons are converted into neutral bromine atoms which leave the crystal and taken up by the gelatin of the emulsion.

$$Ag^{+} + \text{electron} \longrightarrow Ag$$

This single silver atom then acts as an electron trap for a secondary electron when light photon energy absorbed in the crystal again. The negative charge causes a second silver ion to migrate to the trap to form a two-atom silver nucleus. Growth of silver atoms at the site of the original sensitivity speck continues by repeated trapping of electrons and then neutralizing them with interstitial silver ions. Metallic silver is black. It is silver which produces the dark areas seen on a developed radiograph.

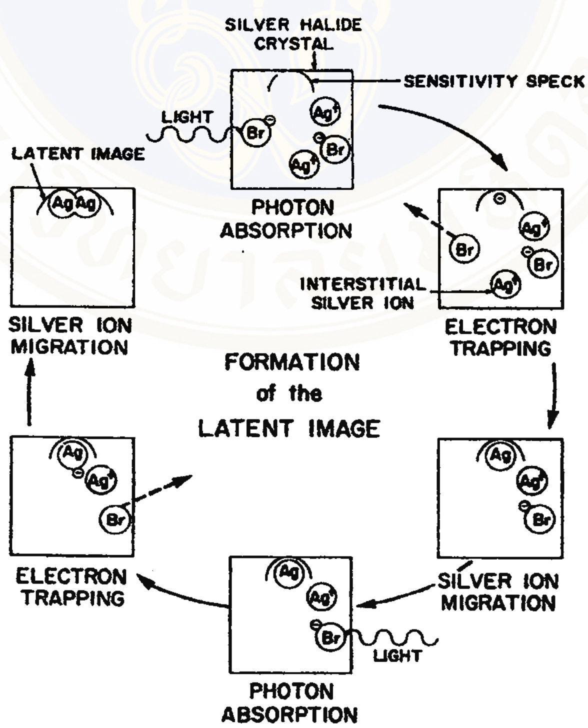

Figure 2.4 Formation of the latent image.

A single silver halide crystal may have one or many of these centers in which atomic silver atoms are concentrated as the clump. These clumps of silver atoms are termed "latent image centers" and are the sites at which the developing process will cause visible amounts of metallic silver to be deposited.

Crystals with silver deposited at the sensitivity speck will be developed into black grains that appear dark and negative film results. Crystals that have not been irradiated will remain crystalline and inactive. It must be removed during fixation, leaving a clear film but the fixing solution must remove silver halide without damaging the image formed by metallic silver (1, 2).

Unexposed x-ray film that has been processed appears quite lucent. It easily transmits light but not images. On the other hand, exposed x-ray film that has been processed appears various shades of gray and heavily exposed film appears black. The study of the relationship between the intensity of exposure of the film and the blackness after processing is called sensitometry (2).

2.3 Optical Density

The degree of film blackening is directly related to the intensity of radiation reaching film. The measurement of film blackness is a photographic density or optical density; usually, only the word density is used. The optical density depend on the exposure received by the film, which in turn depends on the intensity of the incident beam and on the thickness and composition of the object being radiographed as Figure 2.5 (1, 4).

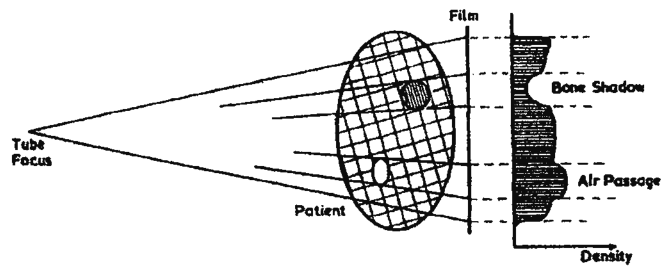

Figure 2.5 The principle of the radiograph.

The instrument used to measure optical density is called a densitometer (4). Optical density is expressed as a number. This number is actually a logarithm, using the common base 10. Basing the definition on the logarithm of the ratio of incident and transmitted intensities has three important advantages (5)

1. It represents accurately what the eye sees, since the physiological response of the eye is also logarithmic to visible light.

2. A very wide range of ratios can be accommodated and the resulting number for the optical density is small and manageable.

3. The total optical density of two films superimposed is simply the sum of their individual optical densities.

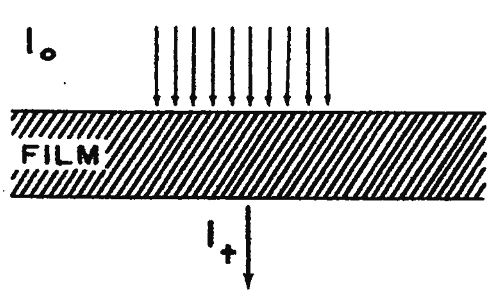

Figure 2.6 Radiographic optical density.

Table 2.1 Relationship of optical density of radiographic film to light transmission through the film

Percent of light transmitted $(I_t / I_0) \times (100)$	Fraction of light transmitted (I_t / I_0)	Optical density $(\log I_0 / I_t)$
100	1	0
50	1/2	0.3
32	8/25	0.5
25	1/4	0.6
12.5	1/8	0.9
10	1/10	1
5	1/20	1.3
3.2	4/125	1.5
2.5	1/30	1.6
1.25	1/80	1.9
1	1/100	2
0.5	1/200	2.3
0.32	2/625	2.5
0.125	1/800	2.9
0.1	1/1000	3
0.05	1/2000	3.3
0.032	1/3125	3.5
0.01	1/10,000	4

Optical density is defined by an equation:

$$OD = \log (I_0/I_t) \tag{2.1}$$

Where OD is optical density, I_0 is light incident on a film and I_t is light transmitted through the film. Refer to Figure 2.6. If 10 arrows (photons) of light strike on one side of film and only 1 photon passed through the film, then $I_0 = 10$, $I_t = 1$ and OD = 1 (1). I_0/ I_t measures the opacity of the film (the ability of film to stop light). The reciprocal of optical density I_t/ I_0 measures the fraction of light transmitted by the film and is called transmittance (1). Normally, radiographic film contains optical densities ranging from near 0 to 4. These optical densities correspond to clear and black, respectively. Table 2.1 shows the range of light transmission corresponding to various levels of radiographic optical density.

2.3.1 Base Plus Fog Substraction

Unexposed x-ray film allows no more than about 80% of incident light photons to be transmitted. Most unexposed and processed radiographic film has a optical density in the range of 0.1 to 0.15, corresponding to 79% and 71% transmission, respectively. These undesirable optical densities are due to base density and fog density. The base density is the optical density inherent in the base of the film. It is due to the composition of the base and the tint added to the base. Base density usually has a value of approximately 0.05. Film fog results from inadvertent exposure of film during storage, undesirable chemical contamination, improper processing and a number of other influences such as heat and age. Fog density on a processed radiograph should not exceed 0.05. Although fog is optical density, it is present prior to normal exposure and is not considered the results of patient exposure. The evaluation optical density produced by the exposure alone, base plus fog density must be subtracted from the total density (2, 6).

$$OD_{net} = OD_{total} - (B+F) \qquad (2.2)$$

2.3.2 Characteristic Curve

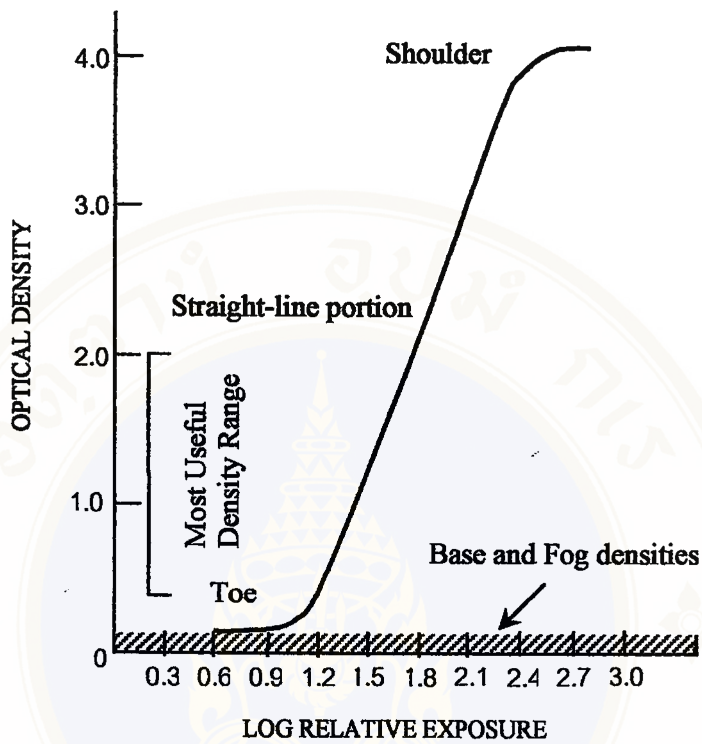

Figure 2.7 Characteristic curve

The relationship between optical density and exposure is called a characteristic curve or sometimes an H & D curve (named after F. Hurter and V.C. Driffield who first published such a curve in England in 1890) (1, 2, 7). A typical characteristic curve is shown in Figure 2.7. At low and high exposure levels, large variations in exposure result in only a small change in optical density. These portions of the characteristic curve are called the toe and shoulder, respectively. At intermediate exposure levels, small changes in exposure result in large changes in optical density. This region is called the straight-line portion, the area for proper exposure. The exposure values for a characteristic curve are presented in logarithm. The log relative exposure is used as the scale along the x axis.

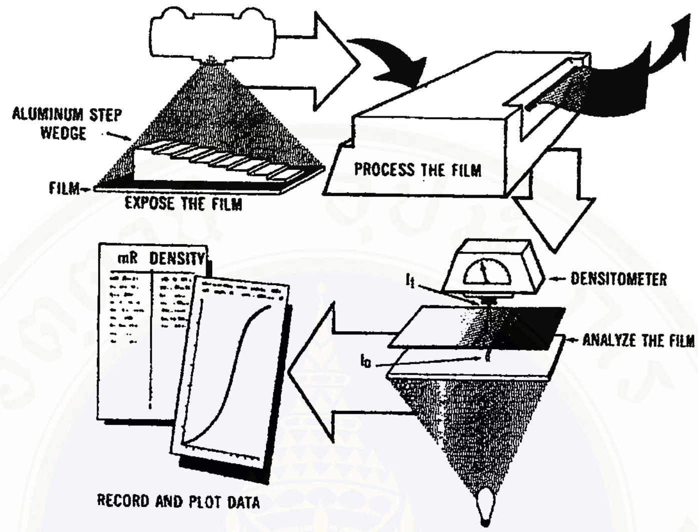

Figure 2.8 Steps involved in construction of a characteristic curve.

Two apparatuses are needed to construct a characteristic curve, an aluminium step wedge and a densitometer. The steps involved are outlined in Figure 2.8. First, the film is exposed through the aluminum step wedge at standard technique. When processed, the x-ray film will have areas of increasing optical density corresponding to sections of step wedge with decreasing thickness. The processed film is analyzed in the densitometer. The data are recorded and plotted result in a characteristic curve. Figure 2.9 shows exposure in mR and log relative exposure along the same scale. The log relative exposure scale is usually presented in increments of 0.3 because the log of 2 is 0.3. An increase in log relative exposure of 0.3 results from doubling the exposure (2).

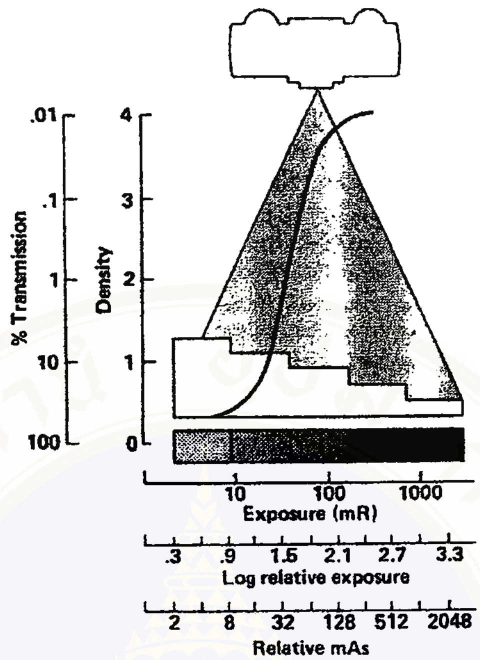

Figure 2.9 Relationship among exposure, log relative exposure and relative mAs for typical screen-film combination. Relationship between percent transmission and density.

2.4 Basic Principle of Optical Density Measurement

Figure 2.10 shows the basic principle of optical density measurement. A light source generates a small beam in which an impinge the exposed film, reflected, transmitted and absorbed are occurred by the nature of interaction (6). These light signal is detected by photodetector to convert the light signal into an electrical signal. The signal amplifier is used to amplify the electrical signal and exhibit optical density value to analog display.

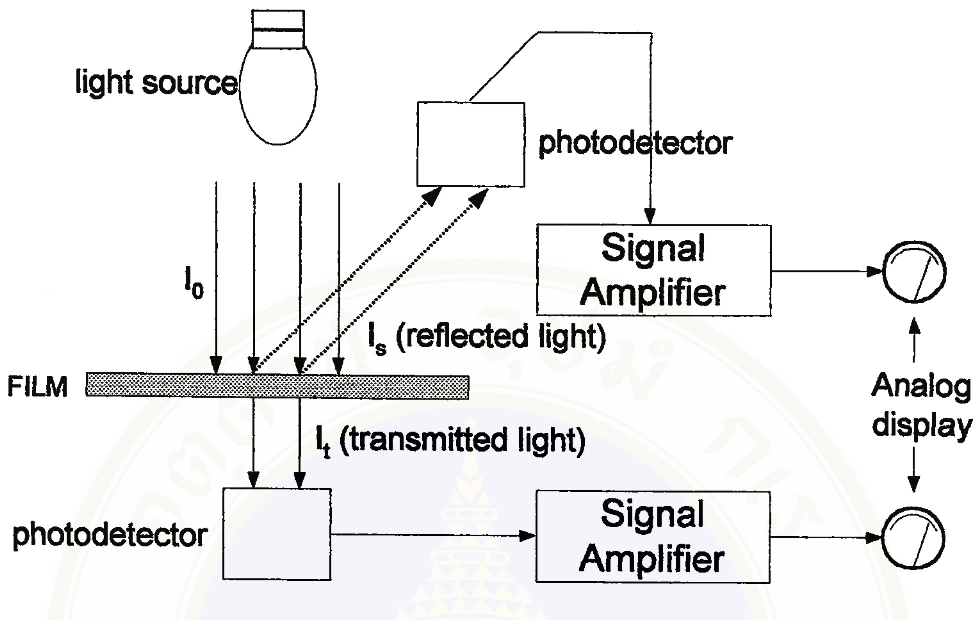

Figure 2.10 Basic principle of density measurement.

2.5 Basic System of Densitometer

Densitometer is the device that used to measure optical density of film. A densitometer consisted of power supply, light source, photodetector, amplifier and display. The power supply functions as an electrical supplier to other parts of the instrument. A Light source generates primary beam through an aperture onto the surface of exposed film. Undesirable external beam is restricted by a small hole aperture. The light transmitted at the other side of film is measured by the photodetector as light signal. The light is filtered with a yellow filter to compensate for the blue tint in the film base (6). The light signal from photodetector is converted to an electrical signal which gained up by DC amplifier with zero balancing circuit. The measured signal is then calculated by using the logarithmic ratio of I_0/I_t on the operation of the logarithmic amplifier and displays the density number on digital meter. The densitometer must be daily calibrated and zeroed prior to the reading of each film. Figure 2.11 shows block diagram of the basic transmission densitometer (6).

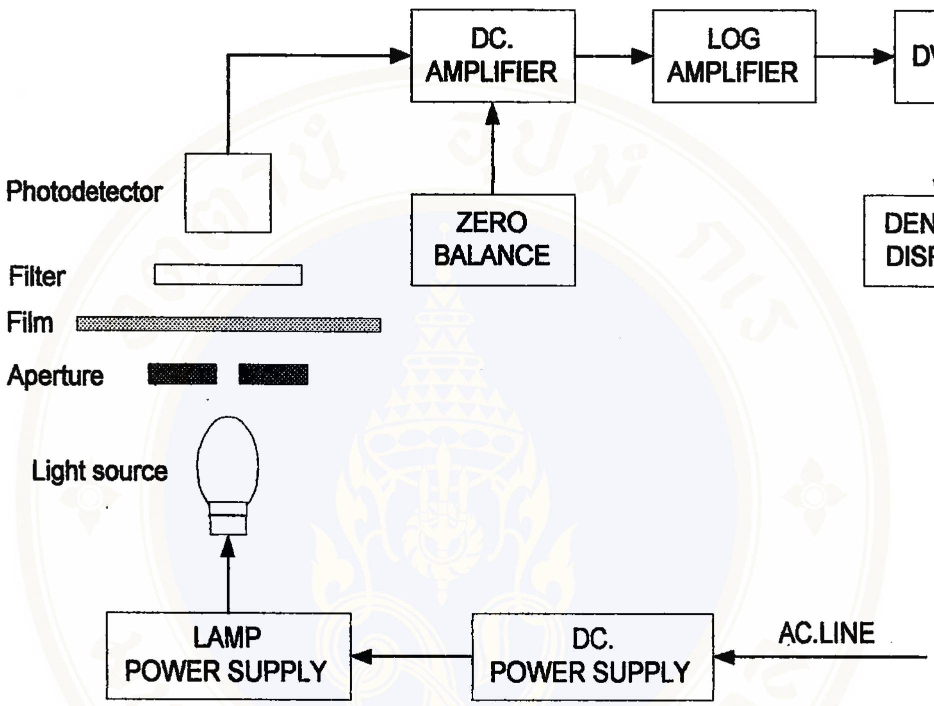

Figure 2.11 Block diagram of the basic transmission densitometer

2.6 Optoelectronics

The light is electromagnetic wave which has 3×10^8 meters/second velocity. The wavelength of visible light is ranged between 400 nm (purple light) to 800 nm (red light). The light operated electronic device is known as optoelectronics. It has an applicable range of operation between ultraviolet and infrared regions of the electromagnetic spectrum which is wider than the visible region. The electromagnetic spectrum and the operatable spectrum for optoelectronics device is shown in Figure 2.12.

An optoelectronics device can be considered to consist of two parts, a light detector or sensor and a light source or emitter (8).

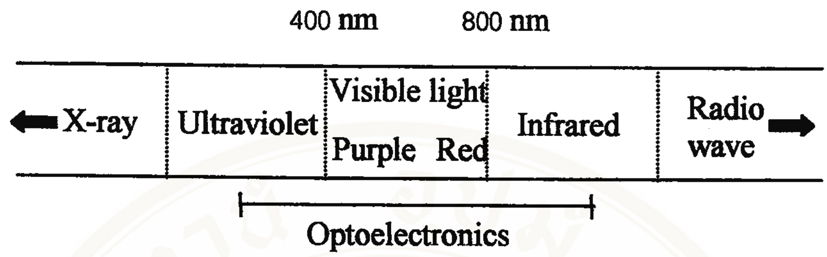

Figure 2.12 Spectrum of electromagnetic wave and operatable spectrum for optoelectronics device.

2.6.1 Sensor

2.6.1.1 Light Dependent Resistor : LDR

LDR is a device which changes its resistance when illuminated. Their configuration and symbol are shown in Figure 2.13. Normally, LDR has high resistance about 2 MΩ when it is dark. When illuminated, resistance may decrease to minimum resistance of about 100 Ω. One advantage of these device in some applications is that they respond to different wavelengths of light in a manner similar to the human eye. Unfortunately, the response is non-linear and very slow, taking a hundred milliseconds to respond to a change in light intensity.

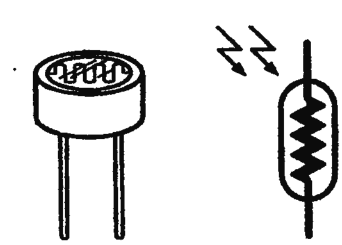

Figure 2.13 Configuration and symbol of LDR.

2.6.1.2 Photovoltaic Cell or Solar Cell

The voltage is generated when it has incident light but with rather low power. Under sunlight each cell generates voltage about 0.4 volt and current between 20-100 milliampere.

The relationship between voltage and light intensity changes in logarithmic fashion while the relationship between current and light intensity is linear. The solar cell is costly, it is suitable to the circuit only when battery or power supply are undesirable.

2.6.1.3 Photodiode

Photodiode operates in the presence of incident light. The symbol of photodiode is shown in Figure 2.14. Under operation the photodiodes must be connected to reverse bias, by connecting anode to negative power supply and cathode to positive power supply. With incident light the photodiode has flow current through itself. However, there is a 10 μA leakage current when no incident light. With incident light, the current increasingly flows to about 100 μA.

Figure 2.14 The symbol of photodiode.

The photodiode is a low power, high impedance device and the circuit designed are more complex than LDR. The response to light is linear and the sensitivity is higher than LDR since its response consume only 200 nanosecond.

2.6.1.4 Phototransistor

Figure 2.15 showed the basic circuit of phototransistor. Phototransistor is a device which combines the photoconductive properties of the photodiode and the current amplification of a transistor.

Phototransistor has a little more leakage current than photodiode. However, it is more sensitive than LDR and less sensitive than photodiode when operate at the frequency not more than 100 kHz.

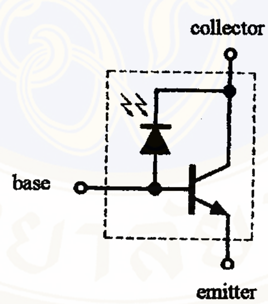

Figure 2.15 The basic circuit of phototransistor.

Comparisons of advantages and disadvantages of various types of sensors are shown in Table 2.2

Table 2.2 Comparisons of advantages and disadvantages for various sensors.

Type of sensor	Advantage	Disadvantage
LDR	- No costly - Obvious changing while operate - Easy connecting circuit for application	- Sensitive to temperature - Very slowly operate - Non-linearity
Photovoltaic or Solar cell	- Linearity and logarithm - can operate by no power supply	- costly - slowly operate
Photodiode	- linearity - very quickly operate - small size - can wide apply	- no obvious changing while operate - generate low output signal level
Phototransistor	- can directly connect to small load - quickly operate	- non-linearity - sensitive to temperature

2.6.2 Emitter

2.6.2.1 LED (Light Emitting Diode)

LED is a semiconductor diode which produces light when a current passes through it. The characteristics of these devices are similar to those of other semiconductor diodes but with different operating voltages. LED must be connected to series of the resistors to limit current flow through it. The light output from an LED is approximately proportional to the current passing through it; a typical small device have an operating voltage between 2 to 5 volts and a maximum current of 30 mA.

2.6.2.2 Incandescent bulb

Incandescent bulb emits more bright light than LED. The emission is arisen by a current flow through the filament. The glass cover of filament is a disperser of light. In application, electronic circuit is connected as Figure 2.16. The transistor is used to replace the switch, as a controller to on-off of bulb.

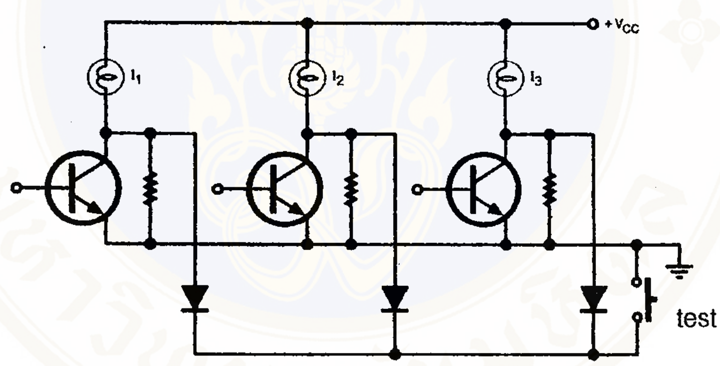

Figure 2.16 The bulb-controlled circuit using the transistor.

2.6.2.3 Neon

The configuration of neon is a gas bulb. It operates with current in the same magnitude as LED and must be connected to series of resistors to limit current flow through the bulb.

Furthermore, there are other devices that considered as an emitter and a sensor. These devices are called optical coupling devices (9).

2.6.3 Optical Coupling Devices

2.6.3.1 Photocoupler

Photocoupler is sometime called photoisolator. It is a small IC which combine the light source and a sensor in a same package. The light source can be either a small LED or photodiodes or infred LEDs and the sensor can be either photocell or photodiode or phototransistor. Flows of current applied to the device are converted into light which is then converted back into a corresponding electrical signal.

2.6.3.2 Photosensor or Photointerrupter

Photosensor is a device consists of a light sensor (phototransistor) and emitter housed within a single package. It differs from photocoupler that light generated externally by an emitter is detected by a sensor which is in the same unit. Two physical arrangements are widely used a direct emission type and a reflection type.

A. Direct emission type

A direct emission type of photosensor is shown in Figure 2.17. The emitter and sensor are arranged to face each other on either side of a slot in the device. In the absence of any object within a slot, light from the source will reach the sensor and this will produce a current in the output circuit. If the slot is obstructed, the light path will be broken and the output current will be reduced.

The infrared LED is used as a light emitting source. Either the phototransistor or the darlington phototransistor is used as sensor.

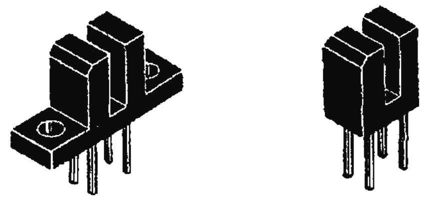

Figure 2.17 The direct emission type of photosensor.

B. Reflecting type

A reflective device is sometime called a reflectional photointerrupter. It is a device in which the light source and a sensor are mounted adjacent to each other on one face of a unit. The presence of a reflective object close to this face will cause light from the source to reach the sensor causing current to flow in the output circuit. The infrared LED is used as light emitting source. Either the phototransistor or the darlington phototransistor is used as sensor.

CHAPTER III

MATERIALS AND METHODS

The design study and construction of the densitometer can be divided into two major parts as follows:

1. Electrical part (Hardware)
2. Programmable part (Software)

3.1 Hardware

Hardware is included to the circuitry in different parts. A generalized system is illustrated in schematic diagram as shown in Figure 3.1. The main function of each individual parts are given as follows:

1. Light Source and Light Sensor

Light Source generates primary beam and the light sensor detects light signal from the light source and changes light signal into electrical signal.

2. Inverting Amplifier

An amplifier which have the effect of producing a 180° phase shift between the output and input signals. A negative output signal from light sensor is inverted to positive.

3. Analog to Digital Converter

Electrical signal is changed into digital signal by analog to digital converter.

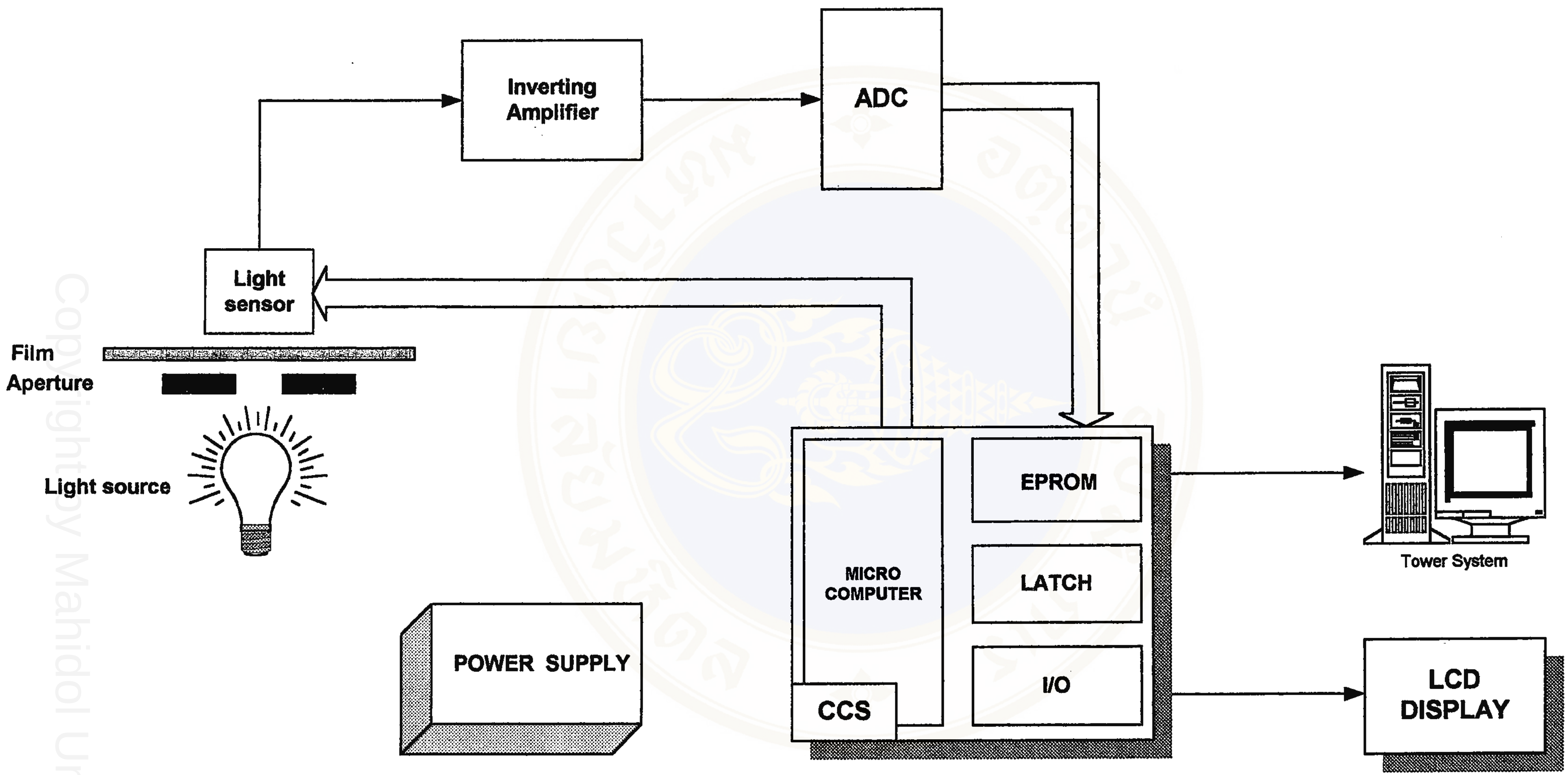

Figure 3.1 Block diagram of densitometer.

4. Central Control Section

Central control section which is included to the microcontroller is an operating control section of densitometer. The operational instructions of densitometer are stored in EPROM.

5. Display

Optical density and different operational mode statuses are displayed on the LCD.

6. Power Supply

An external circuit that have the primary function of supplying current to different circuitry parts of densitometer. It has the LED bar indicator which is used to indicate battery status.

The operation of different circuits can be depicted as follows:

3.1.1 Light Source

The current sink principle is used in this light source circuitry. Red LED is used as light source for this experiment. The light source circuit constructed as shown in Figure 3.2.

The current flows through LED and R_1 should not exceed 56 mA. That can be simply calculated (Ohm's law).

$$I = \frac{V}{R_1}$$

where V is voltage of TL062 pin 3 that obtained by the adjustment 10 kΩ variable resistance. Input voltage applied to pin 3 of TL062 must be defined, for instance, if 0.5 V input voltage is applied to pin 3, current flows through LED and R_1 as:

$$I = \frac{0.5V.}{10\Omega}$$

$$I = 0.05A = 50\,mA$$

In this an example, the current flows through R_1 of 50 mA is not exceed 56 mA. The principle of current sink can see in Appendix A.

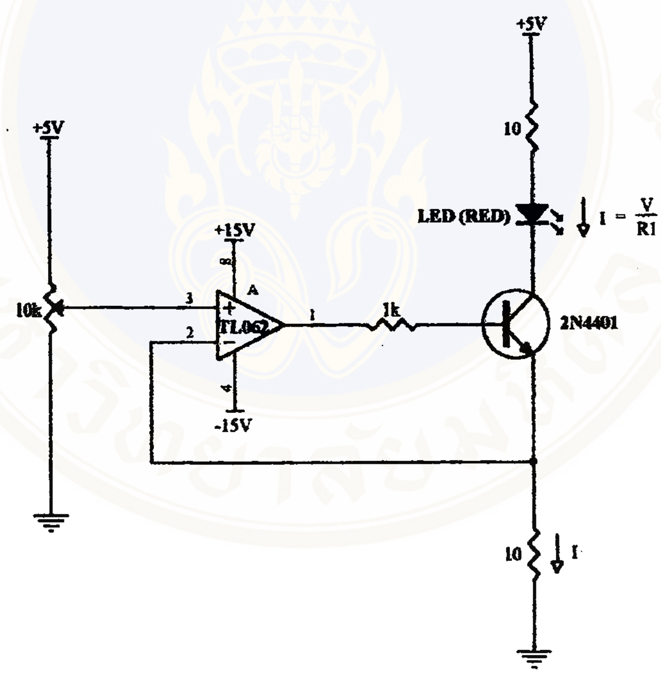

Figure 3.2 Light source circuit configuration.

3.1.2 Light Sensor

Photodiode is used as light sensor in this experiment. The light sensor circuitry constructed as shown in Figure 3.3. Pin 2 of OPA121 is connected to pin 5 of a probe connector which is a cathode pin of the photodiode and pin 3 of OPA121 is connected to pin 9 of a probe connector which is an anode pin of photodiode. Output voltage at pin 6 of OPA121 achieves the negative voltage. OPA121 specification is shown in Appendix E.

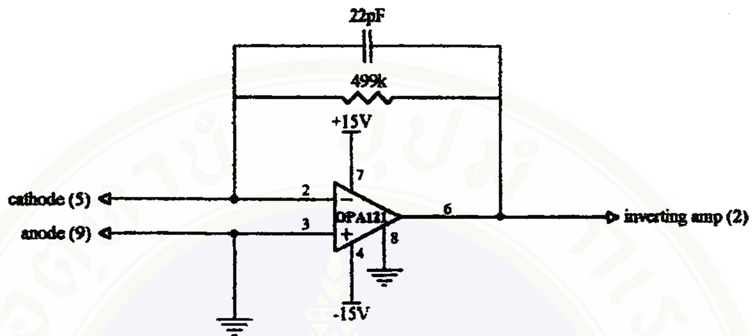

Figure 3.3 Light sensor circuit configuration.

3.1.3 Inverting Amplifier

The negative output voltage of OPA121 is inverted to positive by inverting amplifier. The inverting amplifier circuit is shown in Figure 3.4.

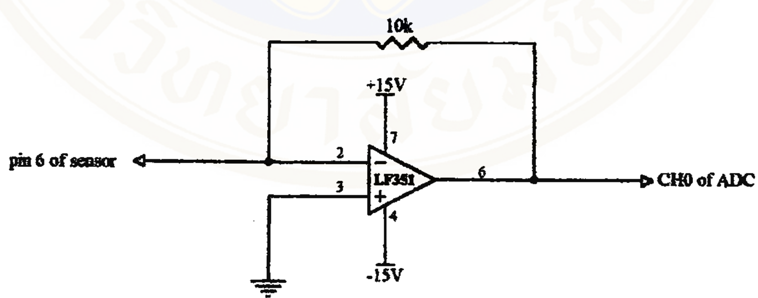

Figure 3.4 Inverting amplifier circuit configuration.

3.1.4 Analog to Digital Converter

Figure 3.5 shows LTC1298 IC connection. LTC1298 IC is a 2-channel, 12 bit A/D converter. LTC1298 specification is shown in Appendix E.

ADC-12 bit can be calculated as the follows:

1. Number of value or number of code can be exhibited as:

$$m = 2^n$$

when n = bit number

$$m = 2^{12}$$

$$m = 4096$$

2. Number of maximum value or max code value can be exhibited as:

$$B_{max} = 2^n - 1$$

$$B_{max} = 2^{12} - 1$$

$$B_{max} = 4098$$

3. Resolution value or quantization is exhibited by code as:

$$Q = FS/m$$

$$Q = 5/4098$$

$$Q = 0.0012 \text{ V.}$$

4. Maximum voltage can be exhibited by code as:

$$X_{QM} = FS - Q$$

$$X_{QM} = 5V - 0.0012$$

$$X_{QM} = 4.99 \text{ V.}$$

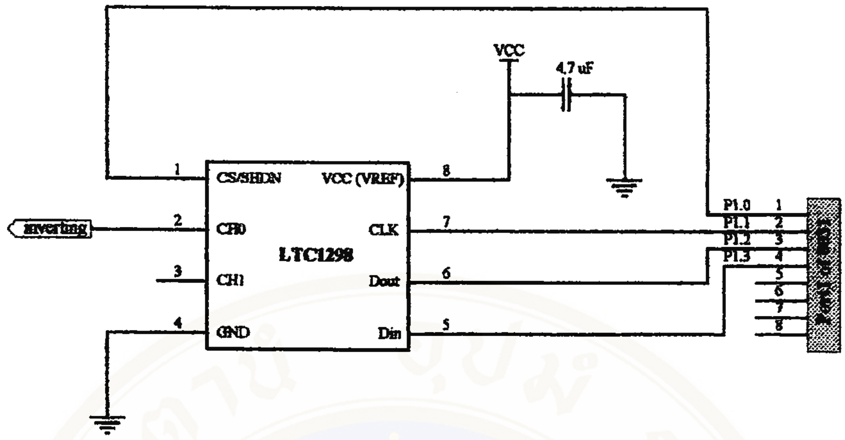

Figure 3.5 LTC1298 configuration.

3.1.5 Central Control Section

Central control section (CCS) is a controller of the densitometer system. The circuit configuration is shown in Figure 3.6. The CCS circuit consists of three major components:

3.1.5.1 Microcomputer 8031 : A controller to all operation system.

3.1.5.2 EPROM 27256 : All Instruction is stored in EPROM 27256 program memory. The program instruction is to be discussed in the software part.

3.1.5.3 RS-232 : It is a serial port performing a serial communication to different computer equipment such as computer, Telex or FAX, etc, Standard RS-232 is frequently used for decreasing incompatible problem between signals of the equipment.

3.1.6 Display

The LCD 16 characters 2 lines with yellow back light is used to display an optical density value and various operational statuses as tabulated in Table 3.1.

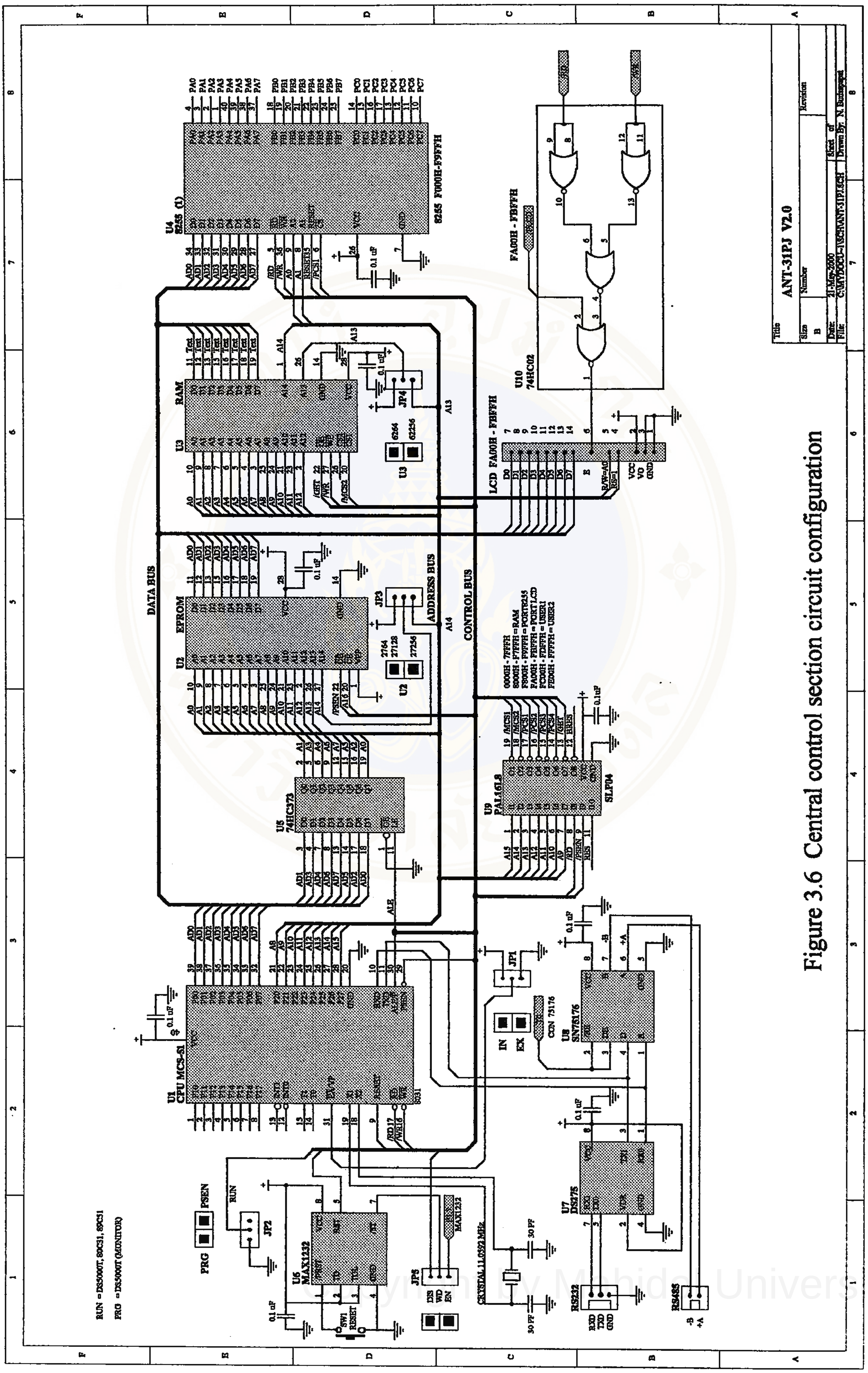

Figure 3.6 Central control section circuit configuration

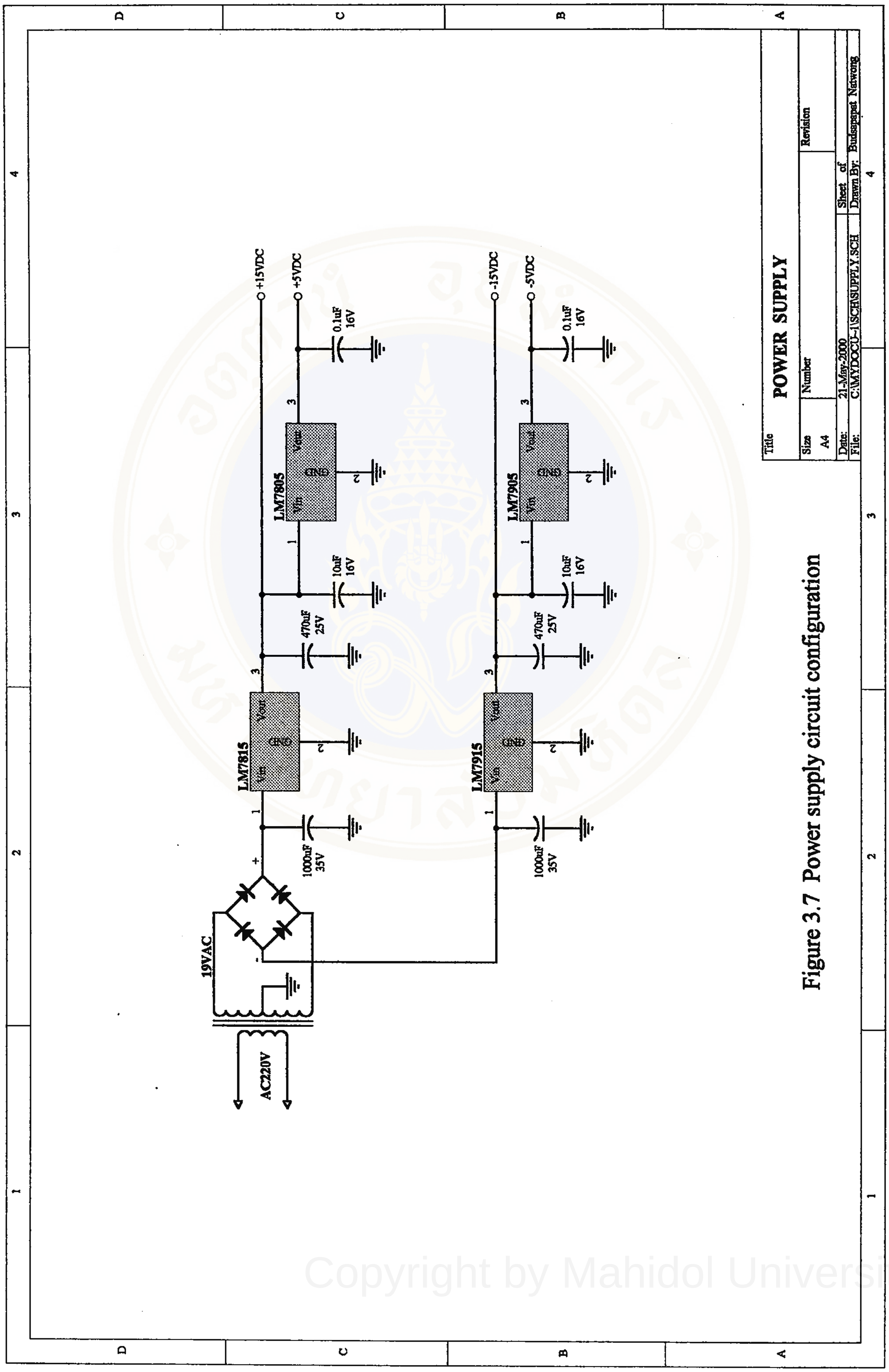

Figure 3.7 Power supply circuit configuration

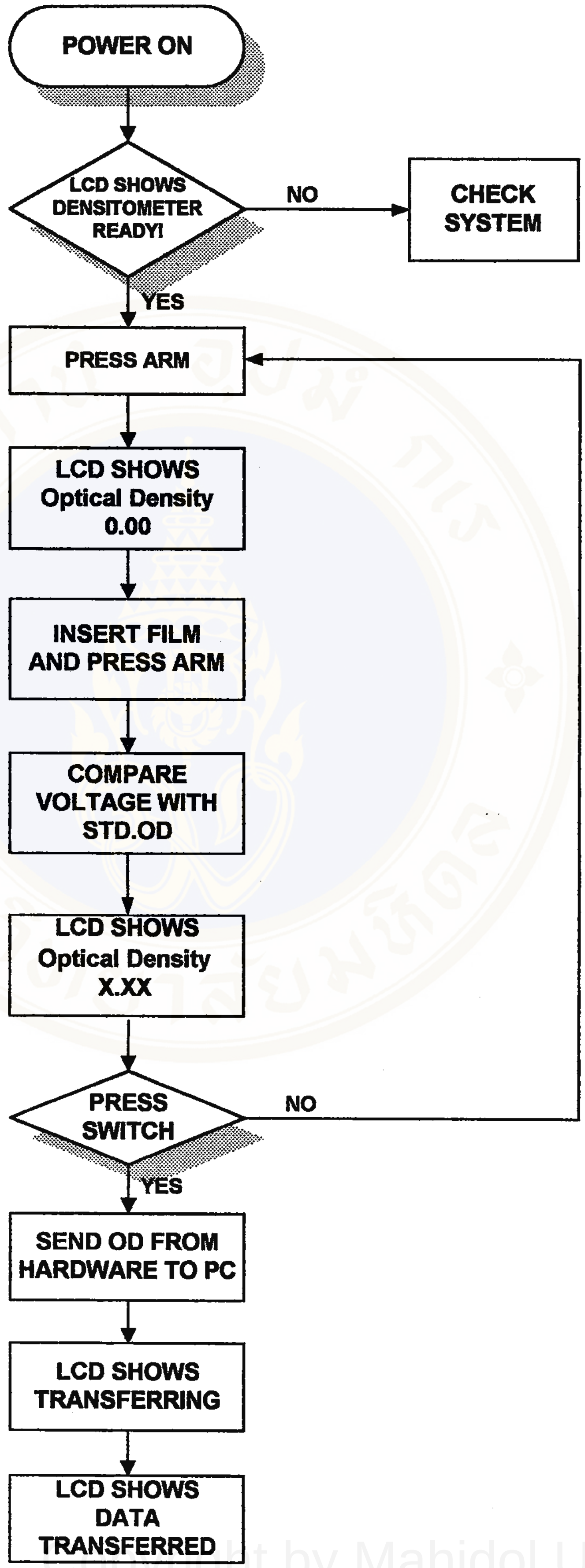

Figure 3.8 Flow chart of program control operational system.

Table 3.1 The LCD displays at various statuses.

Status	Display
Power ON	DENSITOMETER READY !
Measurement	OPTICAL DENSITY X.XX
OD is sent from RAM to PC	TRANSFERRING
OD from RAM sent to PC	DATA TRANSFERRED

3.1.7 Power Supply

Power supply is a supplier of current to different circuits of densitometer. As illustrated in Figure 3.7 the sequence of operations are as the follows: Transformer decreases voltage from 220 VAC to 19 VAC. Bridge rectifier changes the alternating current to direct current. Both positive and negative currents is filtered for smoothing by 1000 μF capacitors before they enter LM7815 and LM7915 IC regulator, respectively. LM7815 regulates voltage into +15 VDC. The LM7915 IC regulates voltage into -15 VDC. The LM7805 IC regulates voltage into +5 VDC. There is a set of 10 μF and 0.1 μF capacitors that filtrates the frequency of +5 VDC. The LM7905 IC regulates voltage into -5 VDC. Also there is a set of 10 μF and 0.1 μF capacitors that filtrates the frequency of -5 VDC.

3.2 Software

The operations of the densitometer and computer are carried out by executing instructions which are written in assembly language and visual basic 6.0, respectively.

3.2.1 Assembly Language

Assembly language is used in programming the MCS-51 microcontroller unit for controlling the operational system of densitometer. Flow chart of all operational programming is illustrated as in Figure 3.8. All program can see in Appendix D.

When power is at ON position, LCD show "DENSITOMETER READY!". If LCD does not show, the system is to be checked by user. When the display message indicates that the densitometer is ready for operation. The arm is pressed to the measured position and the LCD will show "Optical Density 0.00". When the film strip is inserted and arm is pressed, the output voltage from inverting amplifier is compared to standard optical density and then the LCD shows "OPTICAL DENSITY X.XX". When the SEND switch is activated, optical density is sent to computer for exhibiting a graph. In the moment that hardware is transferring data from densitometer to computer via serial port, LCD shows "TRANSFERRING". When the data is sent to the computer, LCD will show "DATA TRANSFERRED". If the switch is not activated, it will return to the measured position again or to the end of measurement.

3.2.2 Visual Basic 6.0

Visual basic 6.0 is used in programming for designing user-interface and interfacing between densitometer and computer via serial port.

The programming of communication via serial port by Visual Basic constituted details as follows (12, 13):

1. It must have MSComm Control that exists when Visual Basic is installed.

2. Custom Control MSComm.OCX (for the Visual Basic 4 up) is defined by selecting MSComm.OCX from the menu Project → Components → at Control, select the Microsoft Comm Control 6.0 (when the writer use Visual Basic 6) will appear the Control MSComm (shown as the telephone picture) in the toolbox section.

3. Control MSComm is to be put in Form as desired.

4. Properties to Control are defined and then write the functions which are related to MSComm.

MSComm Control is used for communication both receiving and sending the data to the serial port. There are two communications as follows:

1. **Event-driven communications** or interrupt-driven communications. When the data are entered, will appear the CommEvent to the OnComm Events.

2. **Polling communications** with loop for checking the data from serial port at all time.

MSComm Control included Events and Properties as follows.

1. **MSComm Control Events**

MSComm Control will have only one event as the OnComm Events that includes the CommEvent property as follows.

- When the communications are failed, will display in the CommEvent property as tabulated in Table 3.2.

- When the status of communications are arisen, will display in the CommEvent property as tabulated in Table 3.3.

The above CommEvent will arise with the status of communication defined.

Table 3.2 CommEvent property when the communication failed.

CommEvent Property	Definition
ComEventBreak	Break signal is received.
ComEventCDTO	Time out while waiting the CD signal (Carrier Detect).
ComEventCTSTO	Time out while waiting the CTS signal (Clear To Send).
ComEventDSRTO	Time out while waiting the DSR signal (Data Set Ready).
ComEventFrame	Frame error that is not find end bit.
ComEventOverrun	Overrun error that is receiving the data not overtake in processing.
ComEventRxOver	Overflow of buffer for receiving the data or receive the character after receiving the EOF Char.
ComEventRxParity	Parity error that is incorrect parity bit of the character received.
ComEventTxFull	Buffer sends the data is full.
ComEventDCB	Unexpectable appears error.

Table 3.3 CommEvent property when the communication arisen.

CommEvent Property	Definition
ComEvCD	CD (Carrier Detect) changes status that is Receive Line Signal Detect (RLSD).
ComEvCTS	CTS (Clear To Send) changes status.
ComEvDSR	DSR (Data Set Ready) changes status.
ComEvFlag	Flag indicator signal is detected.
ComEvReceive	Receiving the data keep to InputBuffer.
ComEvSend	Sending the data out from OutputBuffer.
ComEvEof	EOF character is found.

2. **MSComm Control Property**

MSComm Control Property is tabulated in Table 3.4.

Table 3.4 MSComm Control property.

MSComm Control Property	Definition
Break	Defining or clearing break signal.
CDHolding	Checking the Carrier Detect (CD) signal that whether have remain the status.
CDTimeout	Defining the value or making time value (millisecond) that wait the Carrier Detect (CD) signal.
CommEvent	Making the result of appearing Event of communication.

CommPort	Defining or making the result of comport number opened.
CTSHolding	Checking the Clear To Send (CTS) signal that whether have remain the status.
CTSTimeout	Defining the value or making time value (millisecond) that wait the Clear To Send (CTS) signal.
DSRHolding	Checking the Data Set Ready (DSR) signal that whether have remain the status.
DSRTimeout	Defining the value or making time value (millisecond) that wait the Data Set Ready (DSR) signal.
DTREnable	Enabling the Data Terminal Ready (DTR) signal.
Handshaking	Defining the handshaking by hardware for monitor the sending and receiving data.
InBufferCount	Making the result of data number is in receiving data buffer.
InBufferSize	Defining or making the result of receiving data buffer size
Input	Making the result or removing the data from receiving data buffer.
InputLen	Defining or making the result of data number that will bring from receiving data buffer.
Interval	Defining the speed rate for using in polling mode.
NullDiscard	Defining to receive Null Character is kept in receiving data buffer.
OutBufferCount	Number of data are waiting in sending data buffer.
OutBufferSize	Defining or making the result of sending data buffer.

Output	Sending the data to sending data buffer for out the data.
ParityReplace	If data error appeared, define to send this character replace.
PortOpen	Defining or making the result of port status that opened or closed.
Rthreshold	Defining or making the result of data number is kept in receiving data buffer before the CommEvent arises in receiving the data.
RTSEnable	Enabling the Request To Send (RTS) signal.
Settings	Defining the baud rate, parity, data and stop bit.
Sthreshold	Defining or making the result of data number is kept in sending data buffer before the CommEvent arise in sending the data.

There are important contents as the following.

1. **General** is included:

ComPort Defining the port number for communication to RS-232 such as Com1, Com2, etc.

Setting Defining the baud rate, parity, data number and stop bit such as 9600, n, 8, 1

HandShaking It defined four type:

1. ComNone
2. ComXonXoff
3. ComRTS

4. ComRTSXonXoff

2. **Buffer** is included:

InBufferSize It is used for defining the buffer for receiving the data.

OutBufferSize It is used for defining the buffer for sending the data.

Rthreshold It is used for defining to arise Event-driven for receiving data.

Sthreshold It is used for defining arise the Event-driven for sending data.

Inputlen It is used for defining the data number are read from receiving data buffer.

EOFEnable End Of File (EOF).

3. **Hardware**

ParityReplace It for defining the character that will replace when parity error is arisen.

NullDiscard It for defining that whether receive the null character.

RTSEnable It for enabling the Request To Send (RTS) signal.

DTREnable It for enabling the Data Terminal Ready (DTR) siganl.

There are other properties that must be defined in the operation of MSComm Control.

1. **ComPort** is defined by using the CommPort Property such as MSComm1.CommPort = 1 when Com1 is used.

2. **Settings** are defined by using Setting Property such as MSComm1.Settings = "9600, N, 8, 1" when 9600 baud rate, no parity, 8 data and 1 stop bit are used.

3. **InputLen** is defined by using the InputLen Property such as MSComm1.InputLen = 0 is reading all the data in buffer when Input Property is used.

4. **PortOpen** is defined by using the PortOpen Property such as MSComm1.PortOpen = True is opening port.

5. **Rthreshold** is defined by using Rthreshold Property when the Event-driven is desired such as MSComm1.Rthreshold = 1 for all arising the Event-driven when there is data in receiving data buffer.

When the procedure is programmed, will appear user-interface for communication control. These can be illustrated by flow chart in Figure 3.9 as follows:

When communication control user-interface is opened, ComPort can be set with computer port operated. ComPort opened that can wait data from densitometer hardware. Data received from densitometer that is displayed on text box and then shows graph. Furthermore, data can be saved in hard disk. User-interface configuration can see in Appendix C.

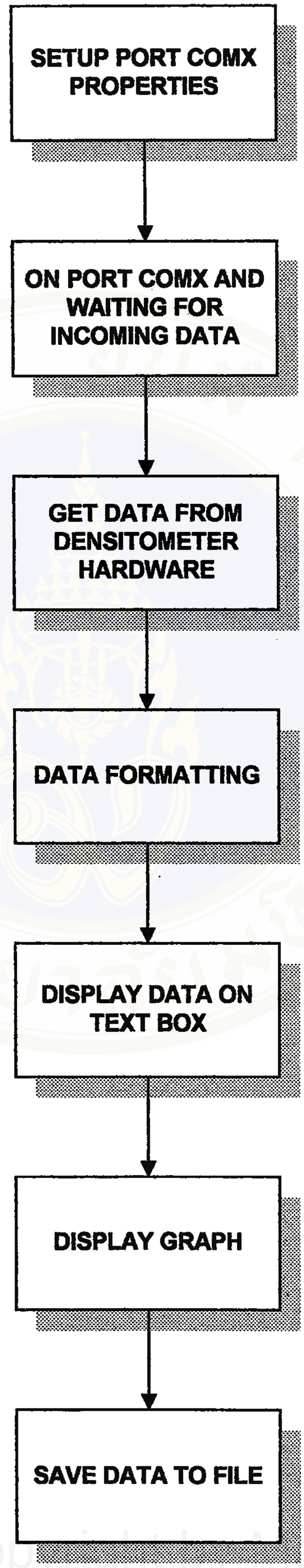

Figure 3.9 Flow chart of communication control.

CHAPTER IV

RESULTS

All results of the experiments were shown in Tables 4.1 to 4.6 and Figures 4.1 to 4.2.

4.1 Output Voltage from Sensor Section.

Table 4.1 shows the output voltage obtained from output terminal (pin 6) of sensor section. They are all negative signals.

Table 4.1 Output voltage obtained from sensor section.

Step film no.	Voltage (V)
1	-3.686
2	-2.352
3	-1.548
4	-1.049
5	-0.742
6	-0.523
7	-0.375
8	-0.255
9	-0.182
10	-0.128
11	-0.091
12	-0.065
13	-0.046
14	-0.033
15	-0.023
16	-0.016
17	-0.012
18	-0.008
19	-0.005
20	-0.003
21	-0.002

4.2 Output Voltage from Inverting Amplifier.

Table 4.2 shows the output voltage obtained from output terminal (pin 6) of inverting amplifier. Signals from sensor section output are inverted into positive signal.

Table 4.2 Output voltage obtained from inverting amplifier.

Step film no.	Voltage (V)
1	3.686
2	2.352
3	1.548
4	1.049
5	0.742
6	0.523
7	0.375
8	0.255
9	0.182
10	0.128
11	0.091
12	0.065
13	0.046
14	0.033
15	0.023
16	0.016
17	0.012
18	0.008
19	0.005
20	0.003
21	0.002

4.3 Comparison of Output Voltage using Multimeter and ADC-12 Bit.

Tables 4.3 and 4.4 show output voltage obtained from using Fluke multimeter and ADC-12 bit, respectively. It is considered that output voltages from Fluke multimeter can demonstrated more number of levels of step film than the ADC-12 bit.

Table 4.3 Output voltage measured by Fluke multimeter.

Step film no.	Output voltage (V)
1	3.686
2	2.352
3	1.548
4	1.049
5	0.742
6	0.523
7	0.375
8	0.255
9	0.182
10	0.128
11	0.091
12	0.065
13	0.046
14	0.033
15	0.023
16	0.016
17	0.012
18	0.008
19	0.005
20	0.003
21	0.002

Table 4.4 Output signal obtained from ADC-12 bit.

Step	Bit number											
Film no.	12	11	10	9	8	7	6	5	4	3	2	1
1	*	*				*		*	*			
2		*	*	*	*	*			*	*	*	
3		*		*			*	*				
4			*	*	*				*		*	
5			*		*			*				*
6				*	*		*	*		*	*	*
7				*		*			*		*	
8					*	*	*	*		*	*	*
9					*		*	*			*	
10						*	*		*	*		
11						*		*	*	*		
12						*						*
13							*	*	*	*		
14								*	*	*	*	
15								*				*
16							*				*	

* represents bright LED.

As shown in Tables 4.3 and 4.4, the Fluke multimeter could verify 21 different readings while only 16 steps of densities could be read from the ADC-12 bit. This can be explained by the limited capability of the ADC-12 bit in measuring high intensity areas of the step film.

4.4 Optical Density and Step Number Relationship.

Graph plotted between optical densities and step numbers of standard film measured by Victoreen densitometer was shown in Figure 4.1. A linear relationship between optical density and step number was observed. Victoreen could cover a wide range up to 21 steps of densities with OD values ranges from 0.05 to 3.04.

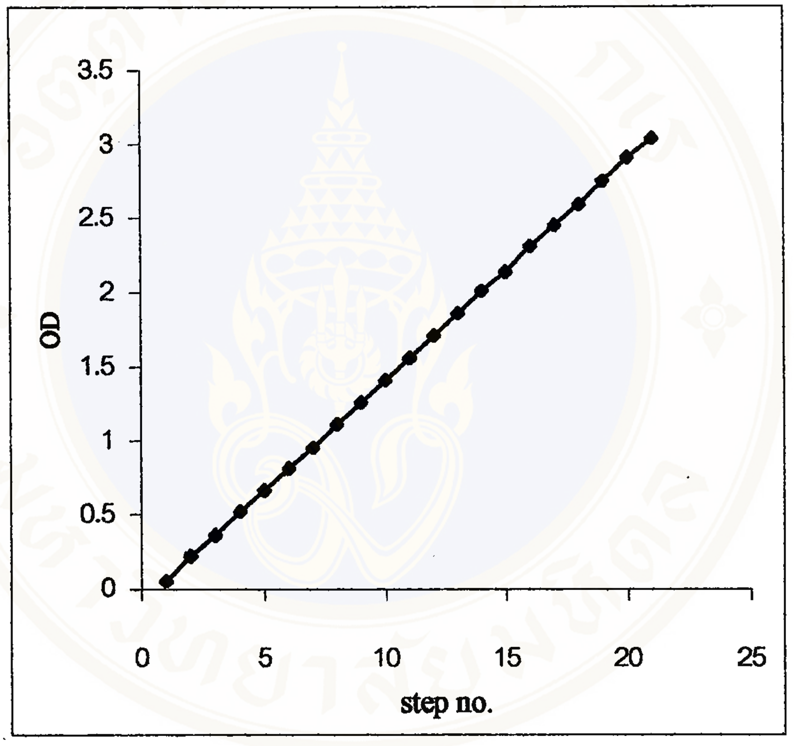

Figure 4.1 Relationship between optical density measured by Victoreen densitometer and step number of standard film.

4.5 Accuracy of densitometer

Table 4.5 Optical Density obtained from Victoreen and densitometer constructed.

Step film no.	Optical Density		% Difference
	Victoreen Densitometer	Densitometer	
1	0.05	0.05	0
2	0.22	0.22	0
3	0.36	0.36	0
4	0.52	0.52	0
5	0.66	0.66	0
6	0.81	0.81	0
7	0.95	0.95	0
8	1.11	1.11	0
9	1.26	1.26	0
10	1.41	1.41	0
11	1.56	1.56	0
12	1.71	1.71	0
13	1.86	1.86	0
14	2.01	2.01	0
15	2.14	2.31	7.94

Mean difference = 0.53 %

Test of accuracy was carried out by comparing, for each step of film blackening, the percentage difference between optical density measured by Victoreen densitometer and our presented densitometer as shown in Table 4.5. It was found that the OD readings from both densitometers were exactly of the same values until after step 14, a percentage difference of 7.94 was observed. This could be concluded that the performance of our designed densitometer is likely to be well accepted with an accuracy of less than ±10%.

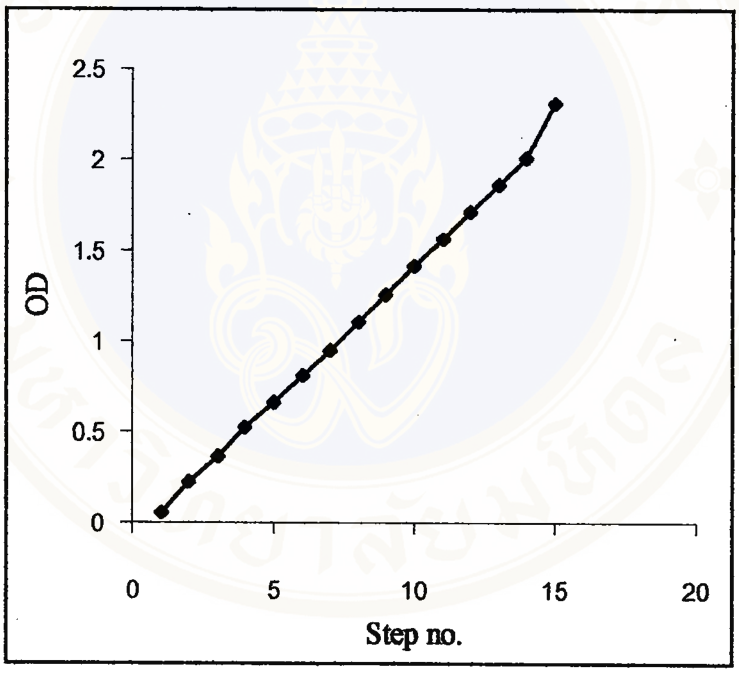

Figure 4.2 Relationship between optical density measured by our presented densitometer and step number of standard film.

After the output voltage was converted into optical density by the microcontroller. As shown in Figure 4.2, although a linear relationship between optical density measured by our densitometer and step number was also observed, the linearity was found to limit at step 14.

4.6 Test of Precision

Repeatability of optical density measurement at different levels of step film blackening was tabulated in Table 4.6. The optical density were made 10 times at each step under the same conditions. The %CV was found to range from 0 to 6.09 %. As shown in the table, after step 12 the measured optical densities were not reproducible with the %CV varied between 3.33 to 6.09 or an average of 1%. After step 15 the instrument was unable to verify the differences in densities with OD values above 2.31.

Table 4.6 Repeatability test of densitometer.

Step film no.	Measurement Number										Mean	SD	%CV
	1	2	3	4	5	6	7	8	9	10			
1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.050	0	0
2	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.220	0	0
3	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.360	0	0
4	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.520	0	0
5	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.660	0	0
6	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.810	0	0
7	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.950	0	0
8	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.110	0	0
9	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.260	0	0
10	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.410	0	0
11	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.560	0	0
12	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.710	0	0
13	1.86	1.86	1.86	1.86	2.01	1.86	1.86	1.86	1.86	2.01	1.890	0.063	3.33
14	2.01	2.01	2.01	2.31	2.31	2.01	2.01	2.01	2.01	2.01	2.070	0.126	6.09
15	2.31	2.31	2.31	2.31	2.31	2.01	2.01	2.31	2.31	2.31	2.250	0.126	5.60
16	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0
17	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0
18	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0
19	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0
20	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0
21	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.310	0	0

Mean %CV = 1%

CHAPTER V

CONCLUSION AND DISCUSSION

5.1 Conclusion

When different steps film were measured by Fluke multimeter, 21 steps of film density can be detected while the ADC-12 bit can detected only 16 steps of film density. The performance of our presented densitometer was tested for an accuracy and precision of measurements. Differences in the measurement of optical density between Victoreen densitometer and our presented densitometer was not found until after step 14. The overall %CV of 0.53 is very well accepted. An acceptable range was found to lies between step 1 to 14. It is observed that after step 14, with increasing densities, our densitometer can not discriminate differences in optical density while the Victoreen densitometer can verify the film density up to step 21. This could be explained by the operational limitation of the ADC-12 bit. Coefficient of variation in the measurement of precision was found to range from 0 to 6.09 % which is likely to be accepted with the mean %CV of less than ±5%. Optical density can be measured in range from 0.05-2.31. Since the most useful range of density in diagnostic radiology is 0.25 to 2, it can be concluded that our design densitometer could provide satisfactory information required in the region of correct exposure.

5.2 Discussion

Problems Found in Experiments

1. The aperture of light source and sensor alignment was difficult to set up. This decreases the initial light beam intensity to the sensor.
2. A mechanical adjustment of the distance between light source and sensor is difficult to keep constant. Under this condition output voltage obtained in each measurement is not reproducible.
3. Light source position and sensor is not close enough to gain a wide range of differences in optical density, and the number of levels which could be measured is uncertained (i.e. less than 21).
4. Microcontroller MCS-51 used in an operational control is unable to calculate logarithm.
5. Light source and sensor specifications are not found.
6. The software which have been written to convert the output voltage into OD by relating to the known value of OD. Without reference OD values in the program memory, the output voltage can not search for its corresponding OD. In this situation result can not be shown.
7. The ADC 12 bit has limited ability to discriminate voltage differences in the high density area of the film strip.

Suggestion

1. The light source and sensor circuit should be modified to improve filtration signal from both analog and digital sections.

2. The distance between light source and sensor should be improved to make the working condition fixed at anytime when the arm is pressed to the measured position.
3. The distance between light source and sensor should be adjusted nearer to each other as much as possible.
4. The aperture of light source and sensor should be improved to maximum alignment.
5. The dimensions of the densitometer should be adjusted to a smaller size to suit as portable densitometer.
6. Further research needs to be conducted using microcontroller with high-performance. A 16-bit ADC may be used to improve the efficiency in calculation and control of the operational system.

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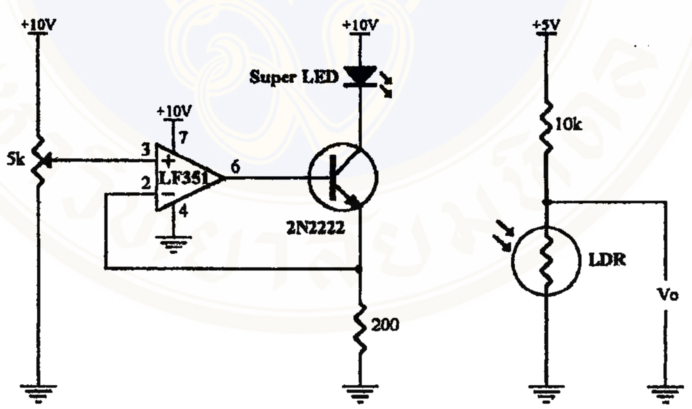
APPENDIX

APPENDIX A

EXPERIMENT

To improve the performance of densitometer, different steps of the experiments and an alteration of external circuitry and devices are to be discussed. By simply changing their components and studying their physical attributes, in response to variations in the light intensity, until suitable combination circuitry are achieved. The experiments can be arranged in order as follows:

1. Current Sinks and Voltage Divider



(a) (b)

Figure A.1 The circuits constructed for operating of light source and sensor

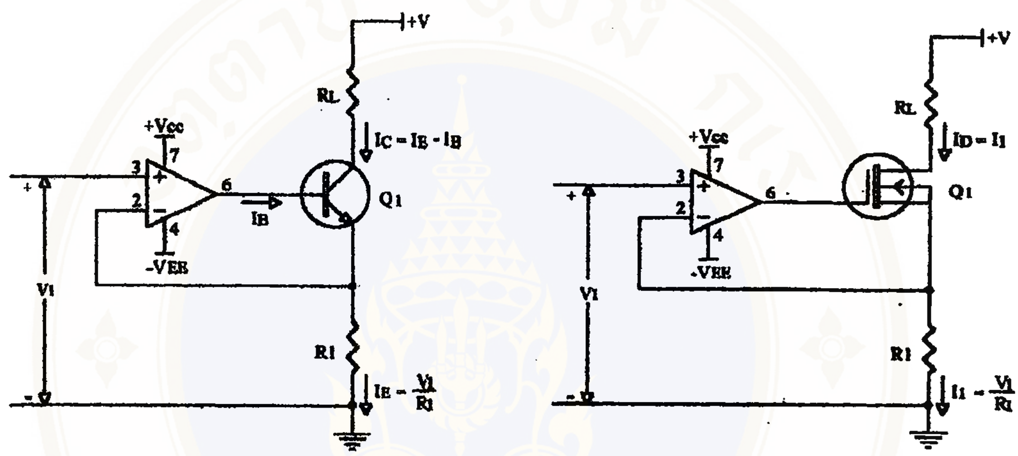
(a) Current sinks for light source section.

(b) Voltage divider for sensor section.

Figure A.1 shows the circuits which are designed and constructed for operating of light source and sensor sections that can be illustrated as the followings:

1.1 Current Sink

Two current sink circuits are illustrated in Figure A.2(a) and b. These are similar to the current sources in Figure A.3(b) and A.4(b) except that an npn bipolar transistor and an n-channel MOSFET are now used. The operation and the design approach for each circuit is similar to those for the current source circuits.



(a) Current sink using a bipolar transistor

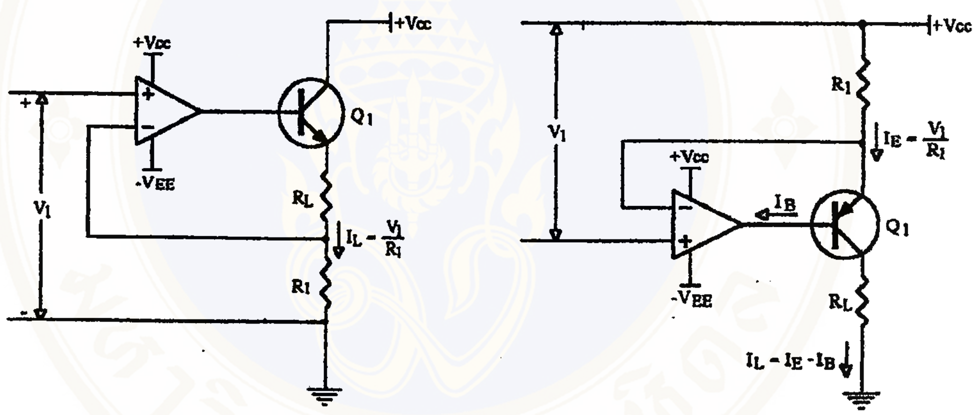
(b) Current sink using a power MOSFET

Figure A.2 A current sink circuit (a) using a bipolar transistor to maintain a constant sink current by holding the emitter current at V_I / R_1. (b) Using a MOSFET (or a FET) to give a sink current precisely equal to the current through R_1.

1.2 Current Sources

A current source is a circuit that supplies a constant current in the conventional direction from positive to negative. Thus, current flows out from the positive terminal of a current source. A current sink also has a constant current level, but the current direction is into the ungrounded terminal of current sink.

A current source circuit in which the load resistor is floating (i.e., not grounded) is shown in Figure A.3(a). The circuit functions like a non-inverting amplifier with V_1 appearing across R_1, so the load current is always $I_L = V_1/R_1$. This is independent of load resistance variations as long as the total voltage drop across R_1 and R_L does not exceed the output voltage range of the op-amp, and as long as the transistor has sufficient collector-emitter voltage to keep it operational. If the maximum load current is less than 25 mA, the transistor may not be required. Voltage V_1 can be derived from a potential divider or from a zener diode.

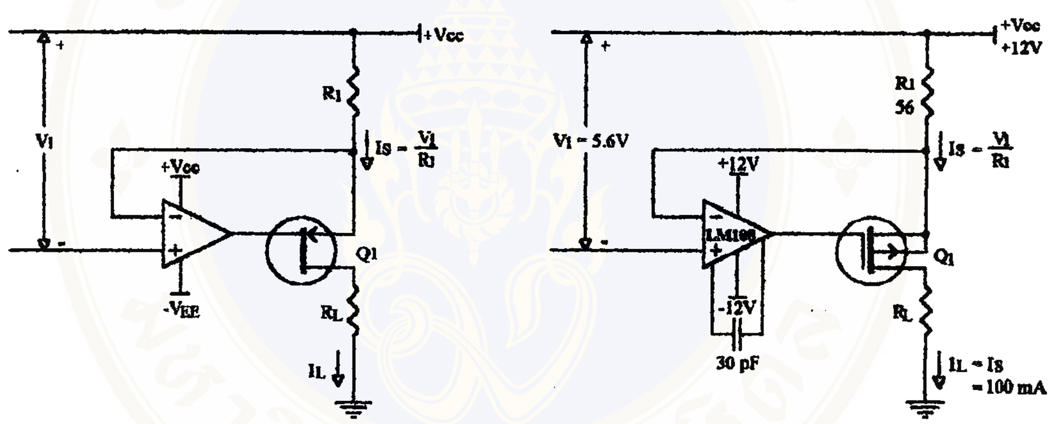


(a) Constant current circuit for a floating load

(b) Constant current source for grounded load

Figure A.3 A constant current source (a) with a floating load it behaves like a non-inverting amplifier circuit to keep $I_L = V_1/R_1$. (b) For a grounded load, a pnp transistor is used and again V_1/R_1 keeps the load current constant.

In Figure A.3(b), V_1 is the voltage between +Vcc and the op-amp non-inverting input terminal. The pnp transistor emitter terminal is connected to the op-amp inverting input, so that the circuit behaves as a voltage follower with V_1, once again, appearing across resistor R_1. The constant input voltage maintains a constant current through R_1, and thus maintains the transistor emitter and collector currents constant. Note that the voltage drop across R_L puts the transistor collector voltage above ground level. Allowing a minimum collector-emitter voltage of 3 V, the transistor emitter must be at least (I_LR_L+3 V) above ground level.



(a) Use of a FET gives an output current equal to Is

(b) A power MOSFET can be employed for high output current levels

Figure A.4 The use of a FET or a MOSFET in a constant current circuit produces an output current which precisely equals to the current through resistor R_1.

The load current is the transistor collector current in the circuit of Figure A.3 (b). This is slightly different from I_1 because of the transistor base current. Substituting a p-channel FET in place of the bipolar transistor, as shown in Figure A.4(a), improves the circuit performance. Because the FET drain and source currents are equal, the load current is more precisely equal to the current through R_1. Figure A.4(b) shows the use of a power MOSFET for high load current situations (14).

1.3 Voltage Divider

The essential circuit of a voltage divider, also called a potential divider is shown in Figure A.5.

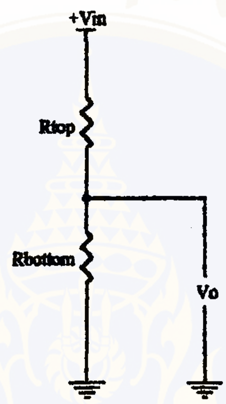


Figure A.5 Potential divider circuit

In principle, two resistors R_{top} and R_{bottom} are connected in series with V_{in}, which is often the power supply voltage. The V_{in} is connected above R_{top}. The output voltage V_{out} is the voltage across R_{bottom} and is given by:

$$V_{out} = [R_{bottom}/(R_{bottom}+R_{top})] \times V_{in}$$

It may help to remember that R_{bottom} appear on the top line of the formula because V_{out} is measured across R_{bottom}.

In Figure A.5, if one of the resistors in the voltage divider is replaced by an LDR that LDR is used as R_{bottom}., and the circuit becomes Figure A.6 as the following :

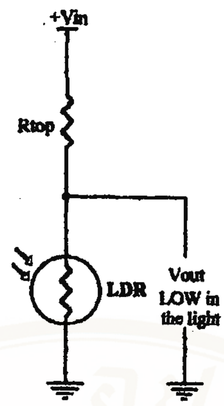


Figure A.6 Voltage divider circuit which LDR is used as R_{bottom}.

In other word, this circuit gives a LOW voltage when the LDR is in the light and a HIGH voltage when the LDR is in the shade. The voltage divider circuit gives an output voltage which changes with illumination. Figure A.7 shows the voltage divider built with the LDR in place of R_{top}:

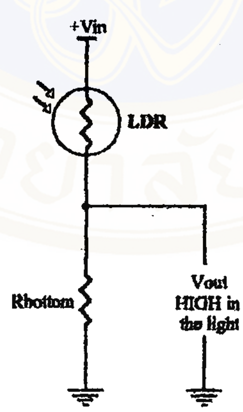


Figure A.7 Voltage divider circuit which LDR is used as R_{top} .

The action of the this circuit is reversed. That is, V_{out} becomes HIGH when the LDR is in the light, LOW when the LDR is in the shade. In fact, the voltage dividers are most sensitive when the R_{bottom} and R_{top} have equal values (15):

Results

1. Output voltage across LDR is 0.24 V when there is no test film between light source and sensor.
2. Output voltage across LDR is 4.4 V when film is between light source and sensor.
3. When different step films are measured, the output voltage across LDR slightly change and have different noise signals.

1.4 Analog to Digital Converter Stand Alone

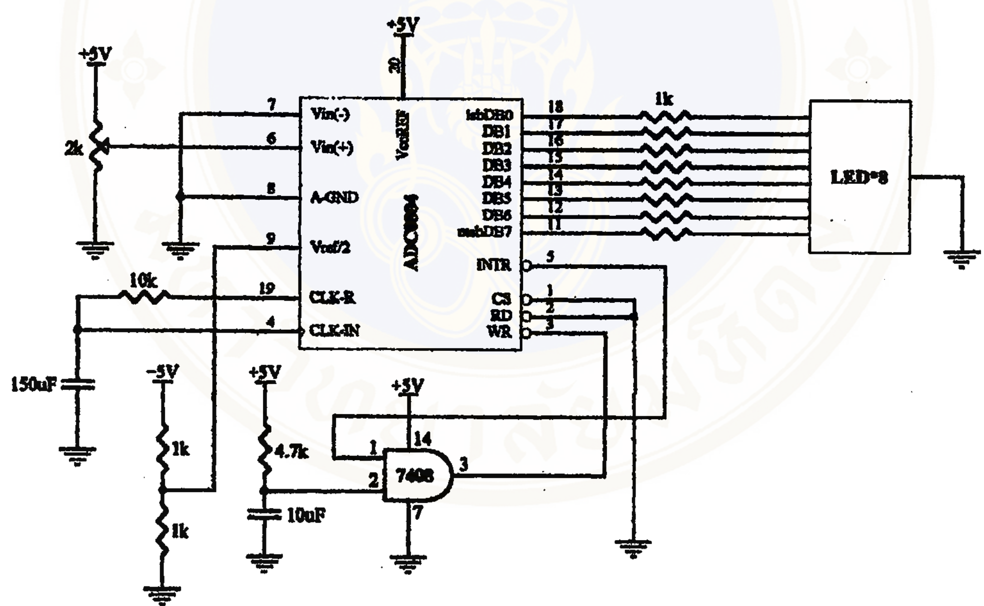


Figure A.8 ADC-0804 stand alone configuration.

Figure A.8 shows the ADC-0804 stand alone which is designed and constructed in consideration to the change of signal from output voltage across sensor devices. Stand alone mean that this circuit can operate by itself and not require the microcontroller. If the total bits of ADC are changed and stable, output voltage signal can be taken to operate. The eight LEDs indicate the variation of bits. The bright LED exhibit variational bits.

ADC-0804 is IC for conversion the analog signal into digital signal. Details are as the follows:

1. It converts signal by Successive approximation method.
2. The output signal is 8 bit.
3. The conversion time is 100 μs.
4. There is a circuit for generating clock in chip.
5. The operation can be defined by microprocessors or operate in stand alone.
6. The maximum input voltage is 5 V.
7. The output is logic 3 states.

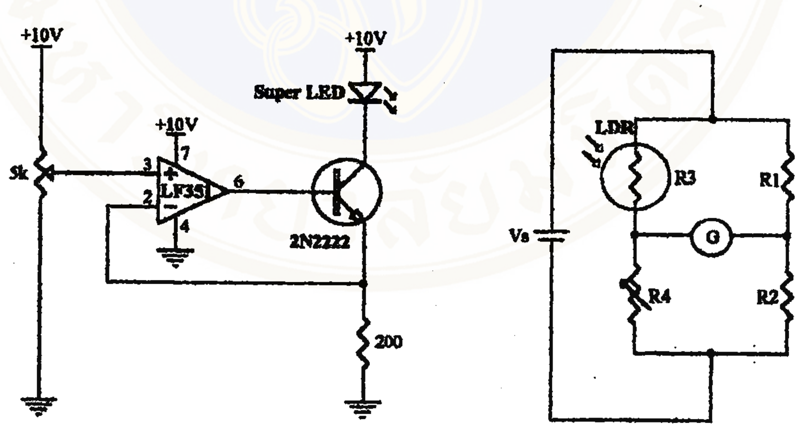


Figure A.9 Current sinks for the light source section and wheatstone bridge for the sensor section.

2. Light Source Section Using Current Sinks and Wheatstone Bridge Circuit in the Sensor Section

Figure A.9 shows the circuits which are designed and constructed for operating of light source and sensor sections. The principle of wheatstone bridge circuit is shown in Figure A.10.

2.1 Wheatstone Bridge

Wheatstone bridge is the bridge circuit used for determining the resistance value. The circuit is included four arms of resistors connected which is used to measure the intermediate value of resistance (1-100 kΩ). The determination can make by comparing the resistance value needed to know to the known resistance value (16). R_1, R_2, R_3 and R_x connection is shown in Figure A.10. Rx is unknown value and R_3 is a variable resistor. R_1 and R_2 are known resistor and constant value.

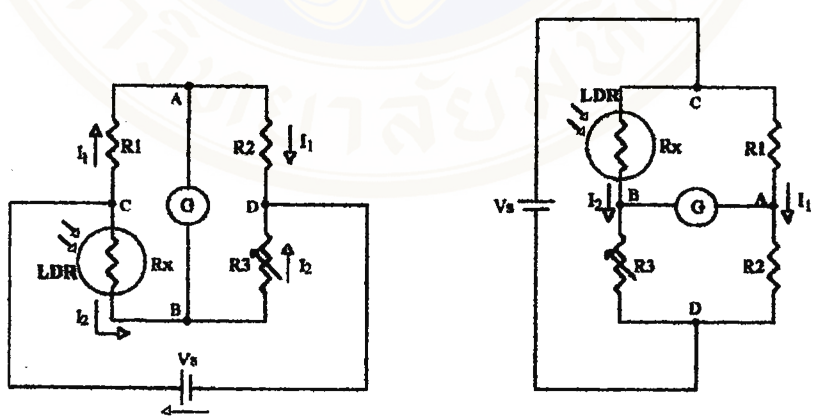


Figure A.10 Basic wheatstone bridge circuit.

When standard resistance R_3 is adjusted until scale of a galvanometer reads zero which is a moment when there is no current flow through the galvanometer. This occurs when the bridge is balanced. At balance there is no current from A to B; therefore A and B are at the same potential.

When the bridge is balanced, the voltage across R_1 and R_x are equal and voltage across R_2 and R_3 are also equal (17), so

$$V_1 = V_x \quad \text{(A-1)}$$

$$\text{and} \quad V_2 = V_3 \quad \text{(A-2)}$$

$$\text{but} \quad V_1 = I_1R_1 \quad \text{(A-3)}$$

$$V_2 = I_1R_2 \quad \text{(A-4)}$$

$$V_3 = I_2R_3 \quad \text{(A-5)}$$

$$V_x = I_2R_x \quad \text{(A-6)}$$

Substitute V_1 and V_x from equation (A-3) and (A-6) in equation (A-1), so

$$I_1R_1 = I_2R_x \quad \text{(A-7)}$$

Substitute V_2 and V_3 from equation (A-4) and (A-5) in equation (A-2), so

$$I_1R_2 = I_2R_3 \quad \text{(A-8)}$$

Dividing the equation (A-8) by equation (A-7) and solving,

$$\frac{R_1}{R_2} = \frac{R_x}{R_3} \quad \text{or} \quad \frac{R_1}{R_x} = \frac{R_2}{R_3} \quad \text{or} \quad R_x = \frac{R_1 R_3}{R_2} \quad \text{(A-9)}$$

In the circuit of Figure A.9, to obtain the suitable change of step film, the resistance value of R_1 and R_2 is varied by using a 2 kΩ variable resistor ($R_{trimpot}$) and R_{volume} of 10 kΩ is used as R_4.

Result

Table A.1 Change of step film with resistance value

R_1 and R_2 (kΩ)	R_{volume} (kΩ)	Step Film
0.99	10	1-14
1	10	6-19
1.2	10	1-12
2	10	1-12
3.3	10	1-12
39	10	1-12
0.91	10	1-12
0.10	10	1-12
0.50	10	1-12

When supply voltage is 9 volts, R_1 and R_2 are 0.99 kΩ, R_{volume} is 10 kΩ, changes of step film is between 1-14 steps.

3. Light Source and Sensor Section Using Optointerrupt with Voltage Divider Circuit

The optointerrupt is used in this experiment. It consists of a QT941 light source and a H21A1 light sensor. They are separated by a slot with a minimum distance between the source and the sensor. The configuration of optointerrupt is shown in Figure A.11.

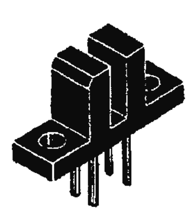


Figure A.11 Configuration of optointerrupt.

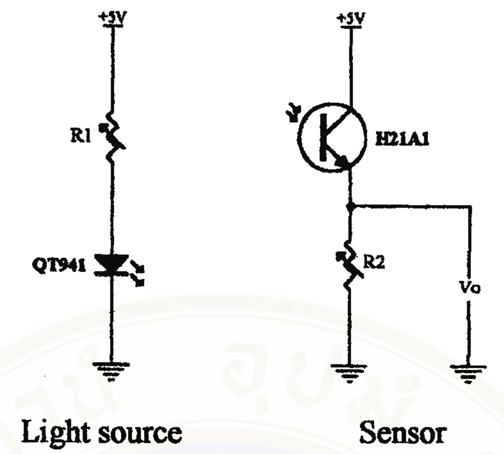


Figure A.12 The circuit of light source and sensor section using the optointerrupt.with voltage divider.

Given +V = 5 V., $R_1 = R_2 = 1\ k\ \Omega$ in Figure A.12. It is observed that the output voltage measured by oscilloscope can not be recorded due to high frequency noise generated from the circuit. This problem is solved by using first-order low-pass active filter as shown in Figure A.13.

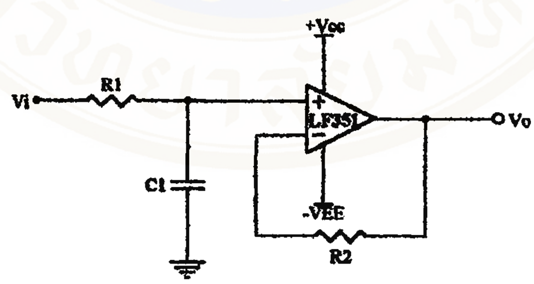


Figure A.13 First-order low-pass active filter.

When the first-order low-pass active filter circuit was connected to output voltage of sensor section as shown in Figure A.14, there is no change in the output voltage. Thus, the first-order low-pass active filter is replaced by the voltage follower circuit as shown in Figure A.15.

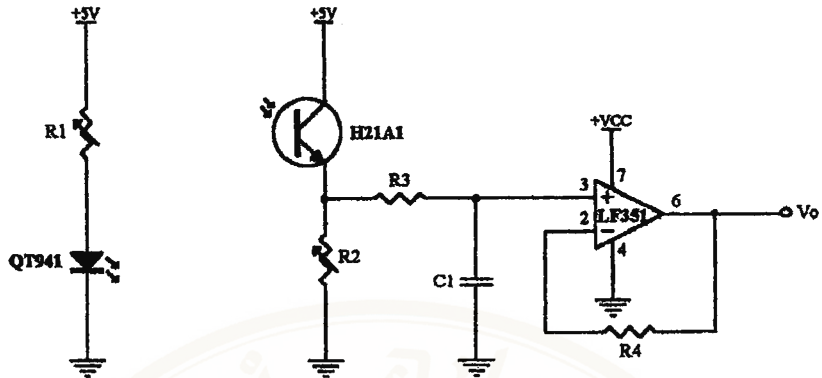


Figure A.14 A first-order low-pass active filter circuit connected to the output voltage of the optointerrupt voltage divider.

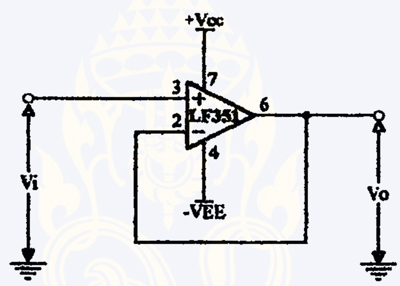


Figure A.15 A voltage follower circuit.

3.1 A Voltage Follower Circuit

The IC operational amplifier lends itself to wide variety of applications. The very simplest of these is the voltage follower circuit illustrated in Figure A.15. The inverting input terminal is connected directly to the output terminal and the signal is applied to the non-inverting input terminal. The output voltage now faithfully follows the input, giving the circuit a gain of 1. The impedance of this circuit is that it has a very high input impedance and a very low output impedance. If the input voltage (at terminal 3) was +1 V, or –1 V, or almost any other level, the output voltage would be virtually the same as the input (14).

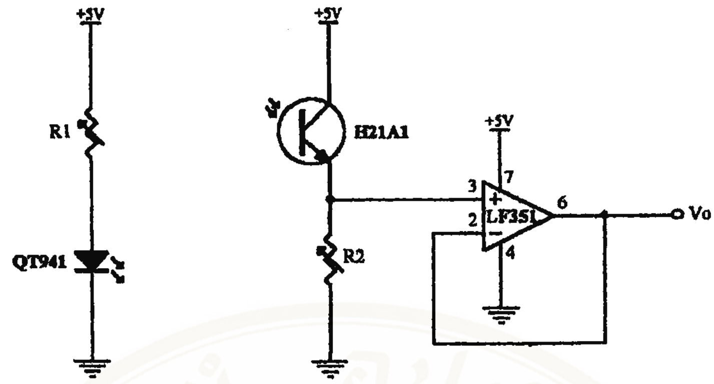


Figure A.16 A voltage follower circuit connected to an output voltage of sensor section.

Result

When the voltage follower circuit was connected to an output voltage of sensor section, a gain of unity can not be obtained which is disagreed with the theory.

4. Change the Light Source of the Optointerrupt from QT941 to MLED930 but with the same H21A1 Sensor

The circuit used in this experiment is similar to those shown in Figure A.12, but changing the light source from QT941 to MLED930 with the same H21A1 sensor. The configuration of MLED930 is shown in Figure A.17.

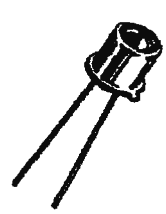


Figure A.17 Configuration of MLED930.

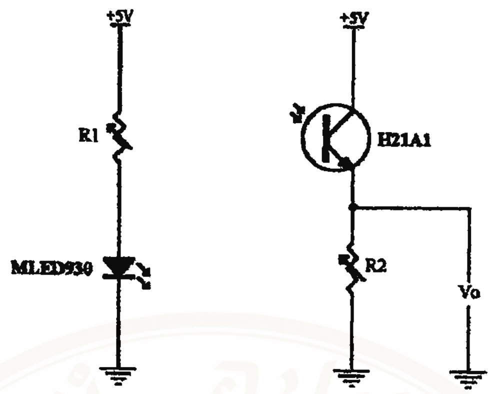


Figure A.18 The circuit of light source and sensor section with a voltage divider using the MLED930 and H21A1.

Result

The output voltage obtained from Figure A.17 is shown in Table A.2. Given $R_1 = R_2 = 1\ k\Omega$.

Table A.2 Output voltage at various step film.

Step Film	Vo (mV)
1	960
2	960
3	960
4	940
5	880
6	820
7	700
8	560
9	380
10	200
11	80
12	40

5. Light Source Using MLED930 and SLD-0509CP Sensor

The circuit used in this experiment is similar to those shown in Figure A.18, but substitute the sensor from H21A1 to SLD-0509CP and retain the MLED930 light source. The configuration of SLD-0509CP is shown in Figure A.19 and the circuitry in Figure A.20.

Figure A.19 Configuration of SLD-0509CP.

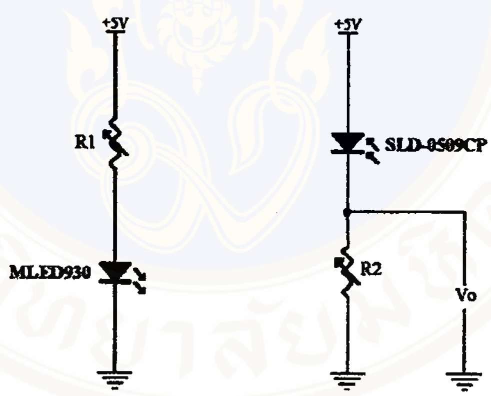


Figure A.20 The circuit of light source and sensor section with a voltage divider using the MLED930 and SLD-0509CP.

Result

At different step film densities, a change in output voltage could not be observed from the test circuit constructed as in Figure A.20. It is concluded that the MLED930 light source and SLD-0509CP sensor can not be used in the circuit.

6. Light Source Using Incandescent Lamp and LDR Sensor

The circuit used in this experiment is similar to those shown in Figure A.20, but changing the light source and the sensor to incandescent lamp and LDR, respectively.

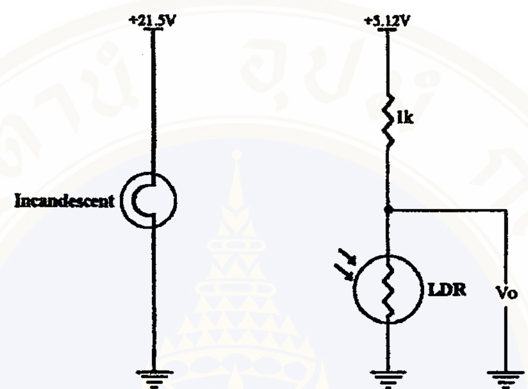


Figure A.21 The circuit of light source and sensor section using incandescent lamp and LDR with a voltage divider .

The circuit in Figure A.21 is tested by using soft wires for signal connecting. The output voltage are measured for six times. The results are shown in the Tables A.3 and A.4 along with the graph plotted between V_o and step. Results in Table A.3 were measured from a test film and in Table A.4 from a standard film.

In Table A.5 results are obtained from the same circuit but using hard wired for signal connection instead of soft wires.

Table A.3 The results of test film reading obtained from the circuit in Figure A.21 when soft wires are electrically connected.

Step Film (test film)	Vo (V)		
	1	2	3
No film	0.75	0.74	0.75
1	0.92	0.90	0.90
2	0.92	0.92	0.92
3	0.98	0.98	0.98
4	1.06	1.06	1.06
5	1.16	1.16	1.16
6	1.30	1.30	1.30
7	1.52	1.52	1.52
8	1.90	1.90	1.90
9	2.32	2.36	2.32
10	3.08	3.12	3.08
11	3.92	3.96	3.92
12	4.48	4.52	4.48
13	4.80	4.80	4.72
14	4.88	4.96	4.88
15	4.96	5.00	4.96
16	4.96	5.04	4.96

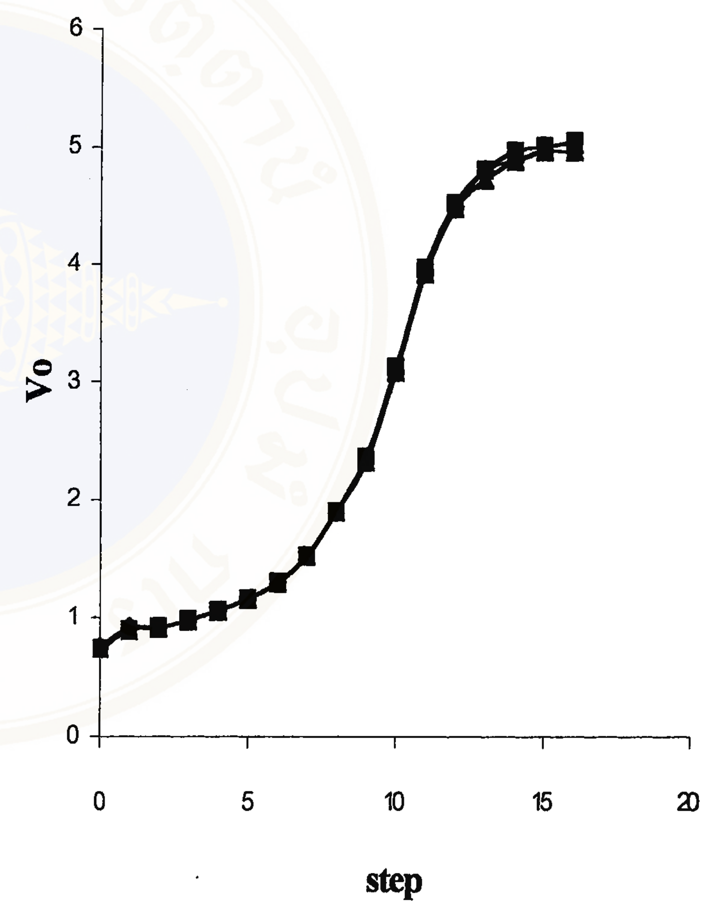


Table A.4 The results of standard film reading obtained from the circuit in Figure A.21 when soft wires is used for signal connection.

Step Film (std. Film)	Vo (V)		
	1	2	3
No Film	0.74	0.75	0.76
1	0.92	0.94	0.94
2	0.92	0.94	0.94
3	0.94	0.96	0.96
4	0.96	0.98	0.98
5	0.98	1.00	1.00
6	1.02	1.04	1.04
7	1.10	1.12	1.12
8	1.22	1.26	1.26
9	1.46	1.48	1.48
10	1.92	1.92	1.96
11	2.68	2.72	2.68
12	3.68	3.72	3.60
13	4.40	4.40	4.32
14	4.88	4.72	4.64
15	5.04	4.96	4.88
16	5.12	5.12	5.12

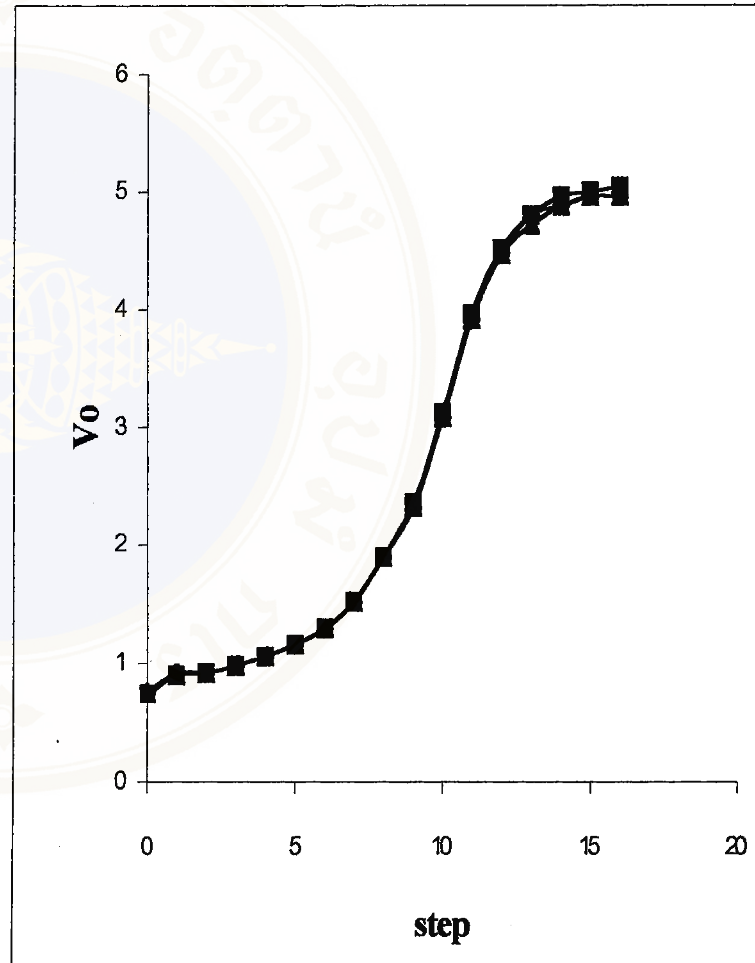
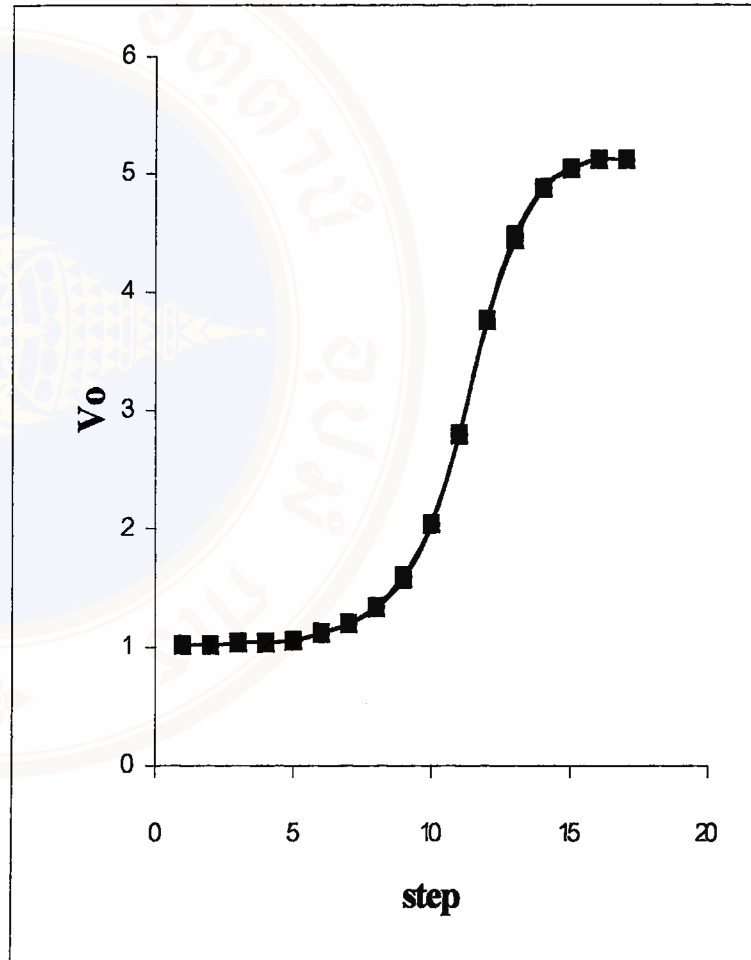


Table A.5 The results of standard film reading obtained from the circuit in Figure A.21 when hard wires are electrically connected.

Step (std. Film)	Vo (V)		
	1	2	3
No film	0.80	0.80	0.80
1	1.02	1.02	1.02
2	1.02	1.02	1.02
3	1.04	1.04	1.04
4	1.04	1.04	1.04
5	1.06	1.06	1.06
6	1.12	1.12	1.12
7	1.20	1.20	1.20
8	1.34	1.34	1.34
9	1.60	1.60	1.58
10	2.04	2.04	2.04
11	2.80	2.80	2.80
12	3.76	3.76	3.76
13	4.48	4.48	4.45
14	4.88	4.88	4.88
15	5.04	5.04	5.04
16	5.12	5.12	5.12



When incandescent lamp is used as light source, rising in temperature can be detected. Consequently, the output voltages of each measurement are not equal. Furthermore, type of wire also affect the output voltage. Soft wires caused more unstable output voltage than hard wires.

7. Light Source Using Incandescent Lamp and LDR Sensor with Wheatstone Bridge Circuit in the Sensor Section

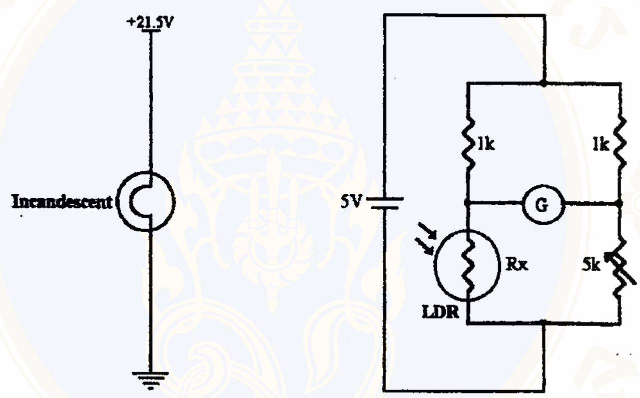


Figure A.22 The circuit of light source and sensor section using incandescent lamp and LDR with wheatstone bridge circuit.

The output signals from wheatstone bridge circuit are measured by analog to digital converter stand alone. Tables A.6-A.10 contain values of output signals obtained from changing the bits of analog to digital converter along with graph plotted between bit and step of film. The output signals are measured for five times (M_1-M_5) for determining the precision of measurements.

Table A.6 The output signals obtained from the circuit in Figure A.22 (M_1).

Step	Bits ADC								Value
(Std. Film)	8	7	6	5	4	3	2	1	
1			*	*				*	49
2			*	*			*		50
3			*	*		*		*	53
4			*	*	*			*	57
5			*	*	*	*	*		62
6		*				*	*		70
7		*		*			*		82
8		*	*			*	*		102
9	*							*	129
10	*		*		*				168
11	*	*			*	*	*		206
12	*	*	*		*				232
13	*	*	*	*		*		*	452
14	*	*	*	*	*		*	*	251
15	*	*	*	*	*	*			252
16	*	*	*	*	*	*	*	*	255

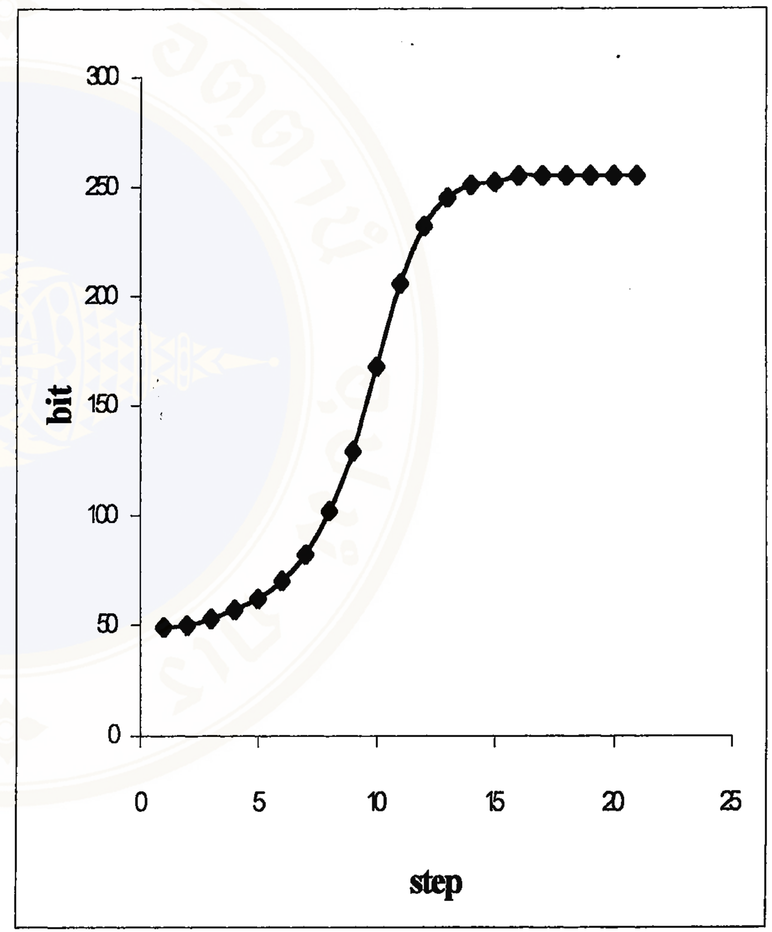


Table A.7 The output signals obtained from the circuit in Figure A.22 (M_2).

Step	Bits ADC								Value
(Std. Film)	8	7	6	5	4	3	2	1	
1			*	*				*	49
2			*	*			*		50
3			*	*				*	49
4			*	*			*		50
5			*	*			*	*	51
6			*	*		*		*	53
7			*	*	*			*	57
8		*							64
9		*			*	*		*	77
10		*	*			*	*	*	103
11	*				*	*		*	141
12	*		*	*	*	*		*	189
13	*	*	*					*	225
14	*	*	*	*		*			244
15	*	*	*	*	*	*			252
16	*	*	*	*	*	*	*	*	255

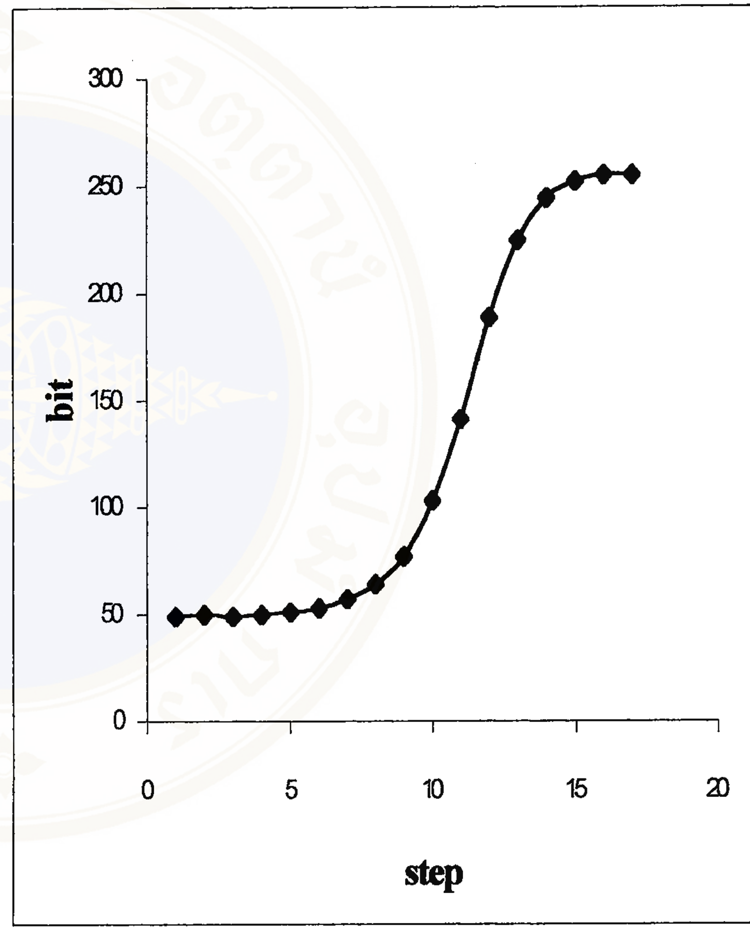


Table A.8 The output signals obtained from the circuit in Figure A.22 (M_3).

Step	Bits ADC								Value
(Std. Film)	8	7	6	5	4	3	2	1	
1			*		*	*			40
2			*		*	*			40
3			*		*	*		*	41
4			*		*	*		*	41
5			*		*	*	*	*	43
6			*	*			*		50
7			*	*			*	*	53
8			*	*			*	*	51
9		*			*			*	73
10		*	*				*	*	99
11	*				*				136
12	*		*	*	*			*	185
13	*	*		*	*	*	*		222
14	*	*	*	*			*	*	243
15	*	*	*	*	*		*	*	251
16	*	*	*	*	*	*	*		254
17	*	*	*	*	*	*	*	*	255

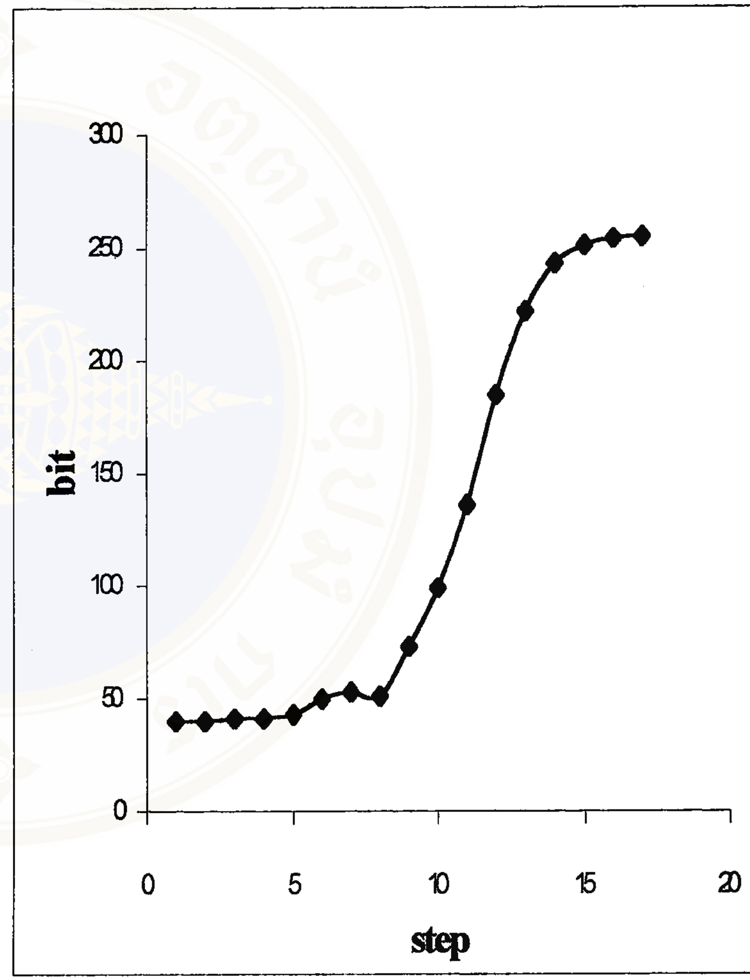


Table A.9 The output signals obtained from the circuit in Figure A.22 (M_4).

Step (Std. Film)	Bits ADC 8	7	6	5	4	3	2	1	Value
1			*		*	*	*		46
2			*		*	*	*		46
3			*		*	*	*		46
4			*		*	*	*	*	47
5			*	*				*	49
6			*	*			*		50
7			*	*		*	*		54
8			*	*	*	*			60
9		*			*			*	73
10		*	*				*	*	99
11	*				*				136
12	*		*	*	*			*	185
13	*	*		*	*	*		*	221
14	*	*	*	*			*		242
15	*	*	*	*	*		*		250
16	*	*	*	*	*	*		*	253
17	*	*	*	*	*	*	*	*	255

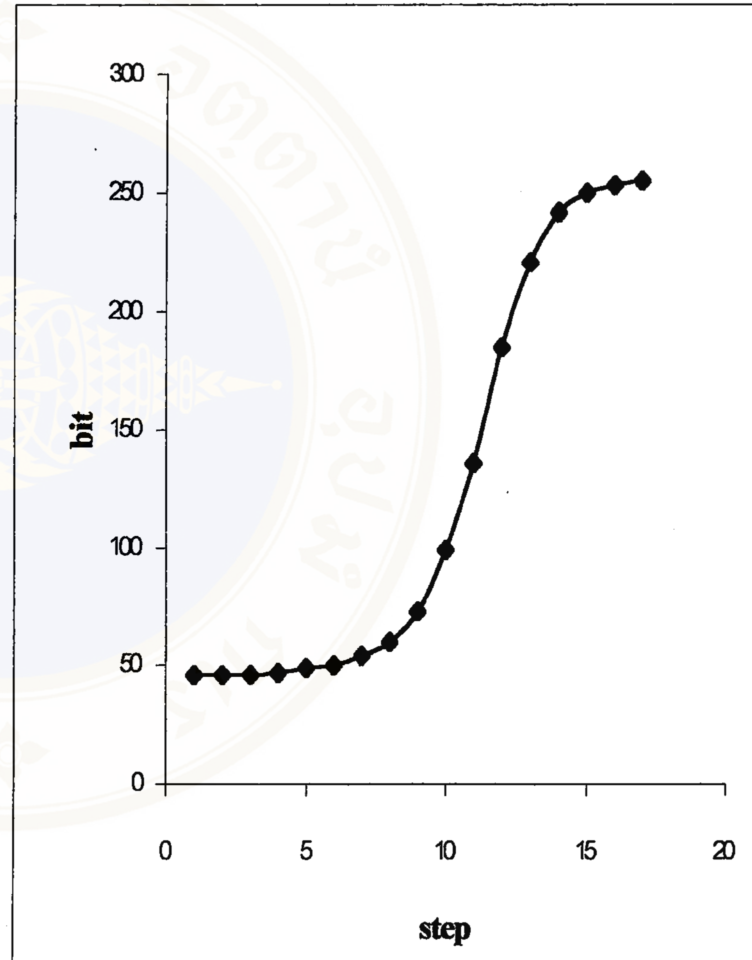
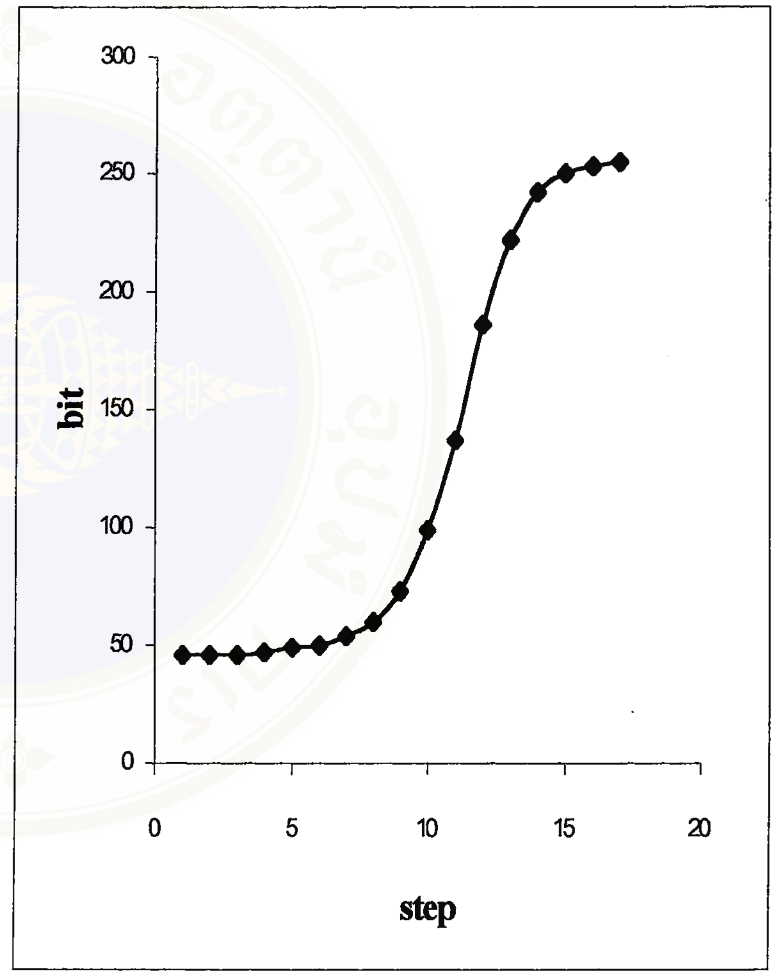


Table A.10 The output signals obtained from the circuit in Figure A.22 (M_5).

Step (Std. Film)	Bits ADC								Value
	8	7	6	5	4	3	2	1	
1			*		*	*	*		46
2			*		*	*	*		46
3			*		*	*	*		46
4			*		*	*	*	*	47
5			*	*				*	49
6			*	*			*		50
7			*	*		*	*		54
8			*	*	*	*			60
9		*			*			*	73
10		*	*				*	*	99
11	*				*			*	137
12	*		*	*	*		*		186
13	*	*		*	*	*	*		222
14	*	*	*	*			*		242
15	*	*	*	*	*		*		250
16	*	*	*	*	*	*		*	253
17	*	*	*	*	*	*	*	*	255



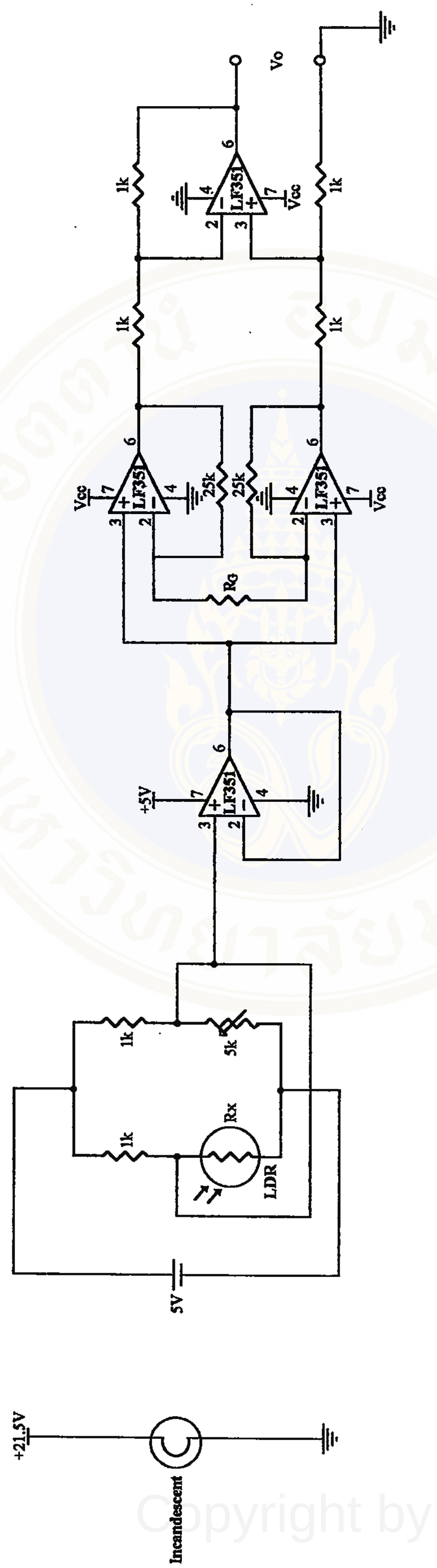


Figure A.23 The combination circuit of the experiment in section 8 using the instrumentation amplifier to amplify the output signal.

8. Amplification of the Output Signal by Instrumentation Amplifier

This experiment is similar to section 7, but with some modification by connecting the voltage follower circuit to output terminal of the wheatstone bridge circuit for the purpose of signal filtration. Furthermore, the instrumentation amplifier circuit is connected to output of the voltage follower circuit to amplify the output voltage as shown in Figure A.23. The principle of instrumentation amplifier can be illustrated as follows:

8.1 Instrumentation Amplifier Circuit

The instrumentation amplifier circuit shown in Figure A.24 is a combination of the differential input/output amplifier (stage 1) and the difference amplifier (stage 2). The difference amplifier uses the differential output voltages from the differential input/output amplifier to drive a grounded load. For instrumentation purposes, most loads have one grounded terminal, otherwise ground loops and static electricity could cause problems. So, the ability to drive a grounded load is necessary. The differential input/output stage offers a very high input resistance at each input terminal. The voltage gain of the complete circuit is,

$$A_v = A_{v1} \times A_{v2}$$

Where A_{v1} is the voltage gain of stage 1 and A_{v2} is the stage 2 gain.

$$A_v = \frac{2R_1 + R_2}{R_2} \times \frac{R_5}{R_4}$$

The overall voltage gain can be controlled by adjustment of R_2. The common mode signal attenuation for the instrumentation amplifier is that provided by the difference amplifier. This can be maximized by making resistor R_7 adjustable. The dc output voltage level can be controlled if R_7 is connected to an adjustable bias voltage instead of being directly grounded.

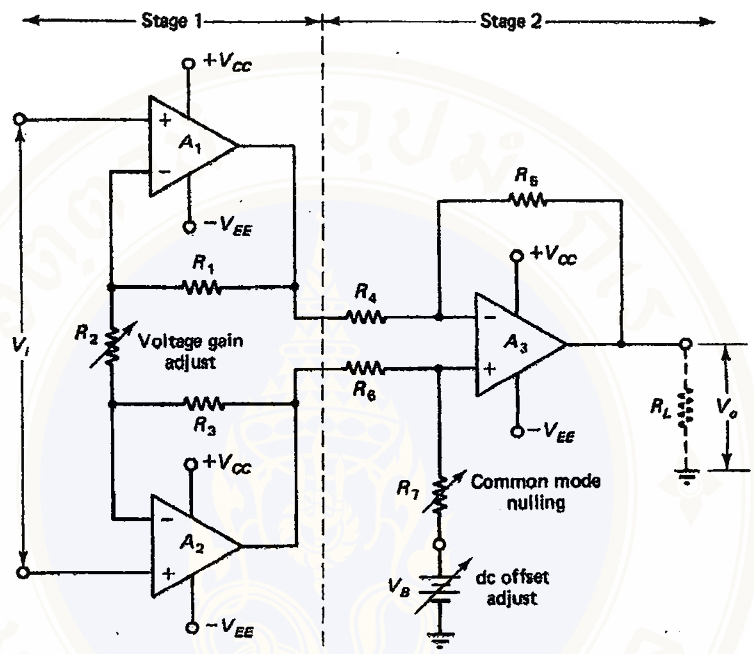


Figure A.24 Instrumentation amplifier consisting of a differential input/output, amplifier input stage and a difference amplifier output stage.

8.2 Integrated Circuit Instrumentation Amplifier

Instrumentation amplifiers are available in a single integrated circuit package. Figure A.25 shows the simplified circuit of the LH0036 IC instrumentation amplifier. In this circuit, difference amplifier resistors R_3, R_4, R_5, and R_6 are of equal value; so that the voltage gain of that stage is 1. The overall voltage gain for the circuit is set by the externally connected resistor R_G.

$$A_v = \frac{2R_1 + R_G}{R_G}$$

With $R_1 = R_2 = 25\ k\Omega$, the equation for R_G becomes,

$$R_G = \frac{50\ k\Omega}{A_v - 1}$$

If R_G is left as infinity, the voltage gain is 1, while $R_G = 50\ \Omega$ give a voltage gain of approximately 1000. Resistor R_6 is trimmed by the manufacturer to yield a common mode rejection ratio greater than 80 dB. R_6 is also terminated at pin 9, which is usually grounded. Instead of grounding pin 9, it can be connected to a bias voltage source for dc output voltage level control. The LH0036 has an input impedance of 300 MΩ, a voltage gain adjustable from 1 to 1000, and it can operate with supply voltages ranging from ±1 V to ±18 V (14).

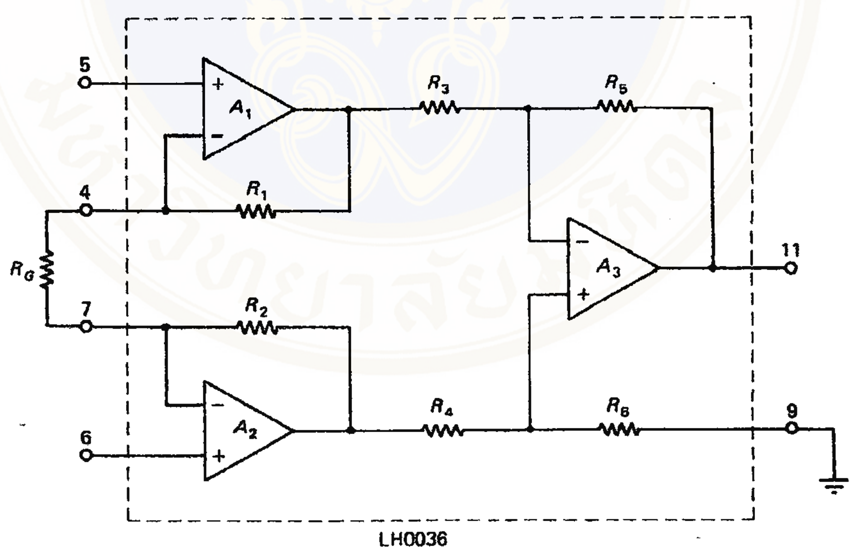


Figure A.25 Simplified circuit of a LH0036 IC instrumentation amplifier. The voltage gain is programmed by selection of resistor R_G.

Result

The ability of step film measurement reduced when the voltage follower is connected to output of the wheatstone bridge, but the output signals are smooth.

9. Amplification of the Output Signals by Non-Inverting Amplifier

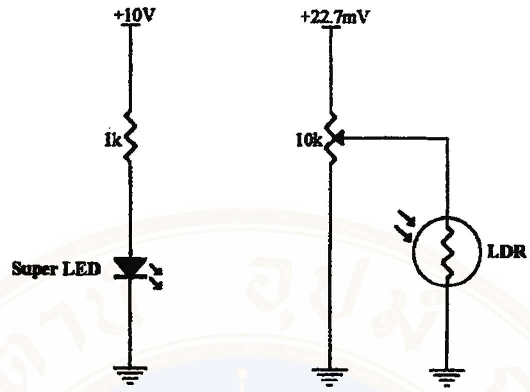


Figure A.26 The circuit of light source and sensor section using the super LED light source and LDR sensor.

The light source and sensor circuit was connected as in Figure A.26. A variable voltage between 7.36 to 32.1 mV was obtained simply by connecting a constant voltage across a 10 kΩ variable resistance voltage divider. The output voltage measured at different step of film densities were tabulated in Tables A.11-A.14 along with a characteristic curve plotted between step film and output voltage.

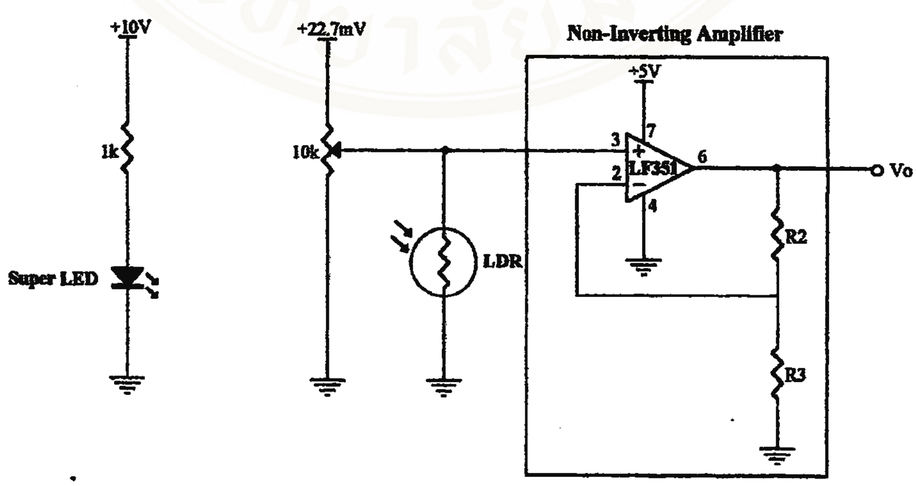


Figure A.27 The circuit included light source and sensor section with non-inverting amplifier.

In Figure A.27 a selected 32.1 mV output voltage of sensor section is used as input voltage to be amplified at different gain (Av) by non-inverting amplifier.

The output voltages measured at different steps of density at Av = 10, 23, 36, 49,62 and 620 were tabulated in Tables A15 to A.20 along with their characteristic curve plotted between step film and output voltage.

It is important to consider that the sensors generate output voltage related to changes in optical density being measured. Since the 8 bit ADC can respond to an output voltage of at least 19 mV. The differences in the output voltage between steps of film of less than 19 mV will not be able to show differences in optical densities. It is then necessary to provide a suitable external circuitry to convert variation in the sensor into a useful signal.

Table A.11 The output signals obtained from the circuit in Figure A.26 by applying 7.36 V of input voltage

Step	Vo
0	0.79
1	0.79
2	0.79
3	0.79
4	0.83
5	0.86
6	0.89
7	0.97
8	1.08
9	1.34
10	1.79
11	2.53
12	3.48
13	4.16
14	4.49
15	4.68
16	4.75
17	4.77
18	4.79
19	4.8
20	4.8
21	4.8

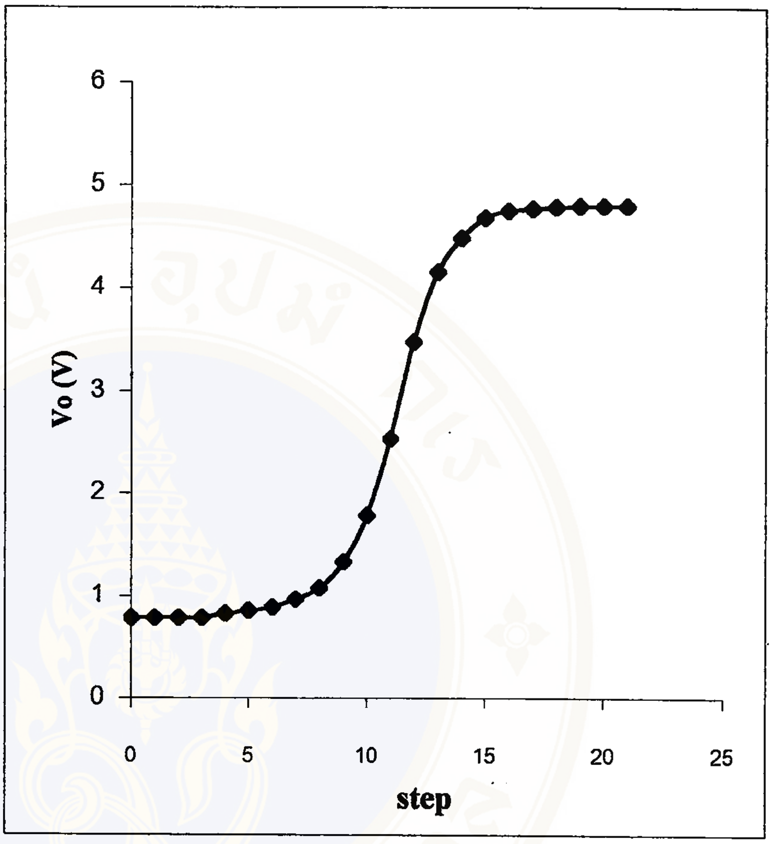


Table A.12 The output signals obtained from the circuit in Figure A.26 by applying 3.53 V of input voltage.

Step Film	Vo (V)
0	0.32
1	0.33
2	0.33
3	0.33
4	0.35
5	0.36
6	0.38
7	0.4
8	0.47
9	0.58
10	0.81
11	1.14
12	1.61
13	2.01
14	2.21
15	2.29
16	2.34
17	2.35
18	2.36
19	2.37
20	2.37
21	2.38

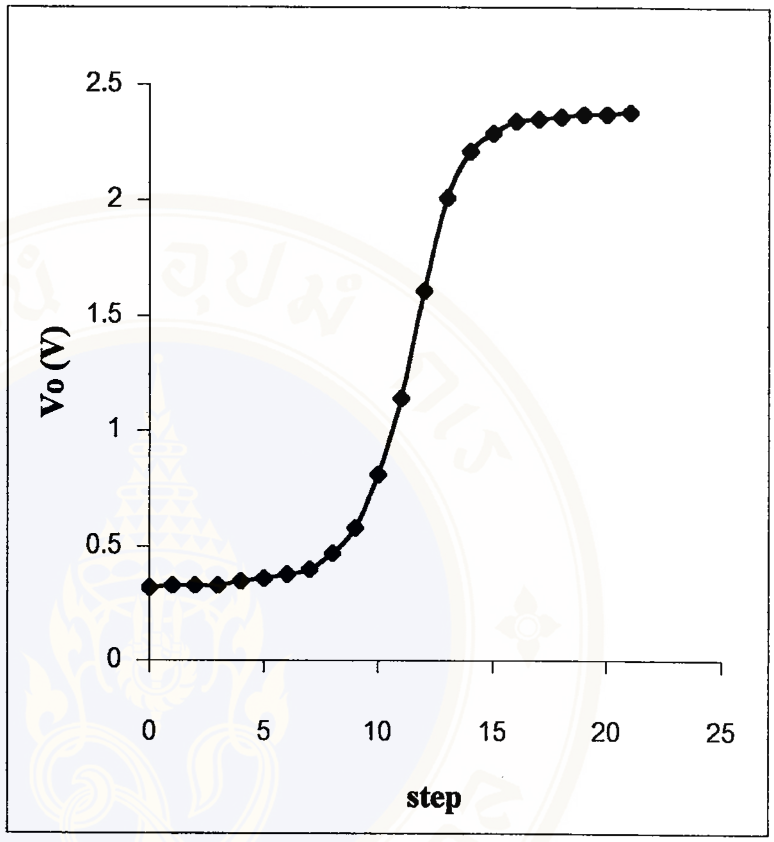


Table A.13 The output signals obtained from the circuit in Figure A.26 by applying 307 mV of input voltage

Step	Vo
0	33
1	35
2	35
3	36
4	36
5	38
6	40
7	44
8	50
9	63
10	89
11	123
12	185
13	232
14	260
15	270
16	276
17	278
18	279
19	279
20	280
21	280

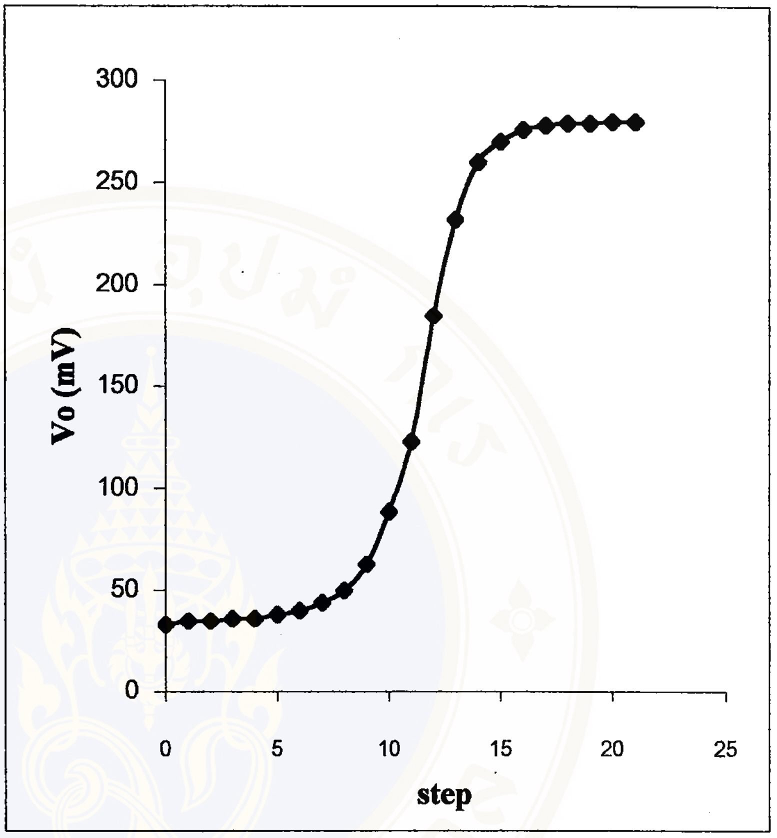


Table A.14 The output signals obtained from the circuit in Figure A.26 by applying 32.1 mV of input voltage

Step	Vo
0	4.7
1	4.9
2	5
3	5
4	5.1
5	5.3
6	5.7
7	6.3
8	7.4
9	9.5
10	14.3
11	23.1
12	41.1
13	61.5
14	79.6
15	88.2
16	92.4
17	94
18	94.8
19	95.5
20	95.9
21	96.1

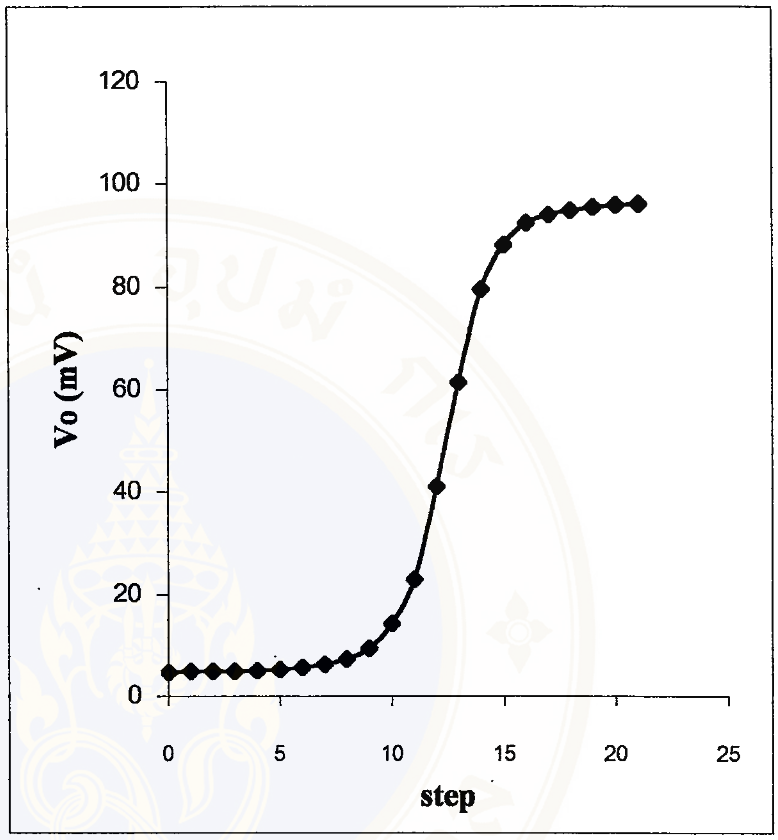


Table A.15 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 10.

Step	Vo
0	57.9
1	58
2	58.8
3	59.8
4	60.7
5	62.1
6	65.7
7	70.7
8	80.8
9	97.8
10	134
11	188.2
12	267
13	324
14	366
15	381
16	389
17	392
18	394
19	396
20	396
21	396

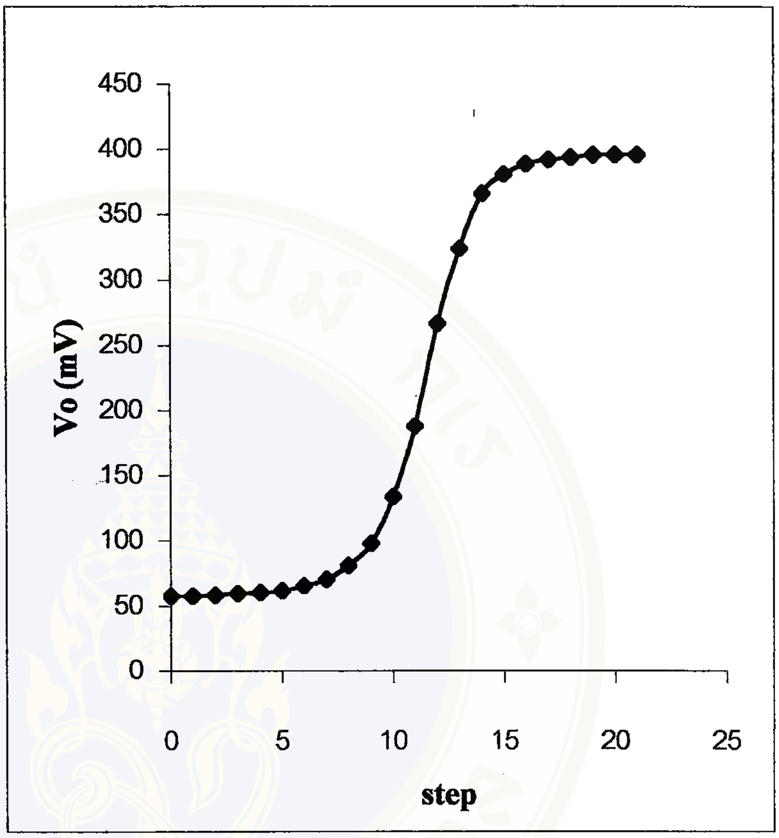


Table A.16 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 23.

Step	Vo
0	119
1	118
2	122
3	123
4	126
5	128
6	137
7	148
8	167
9	203
10	280
11	399
12	565
13	708
14	789
15	825
16	842
17	848
18	852
19	854
20	856
21	860

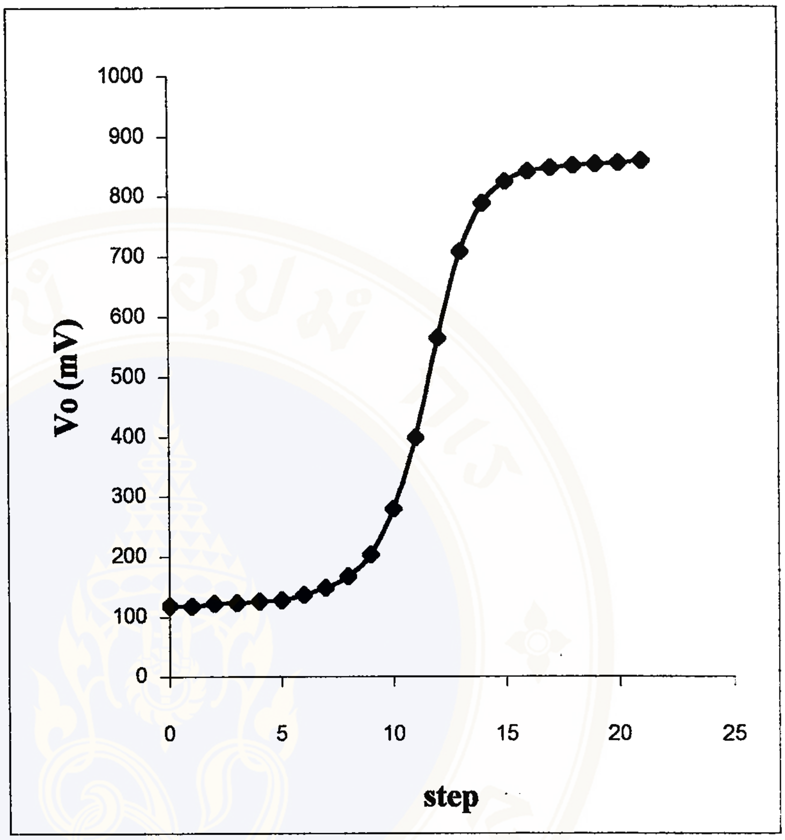


Table A.17 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 36.

Step	Vo
0	150.3
1	153.5
2	155.3
3	157.4
4	160.8
5	166.1
6	172.8
7	187.8
8	212
9	262
10	369
11	540
12	805
13	1034
14	1190
15	1257
16	1291
17	1305
18	1317
19	1322
20	1327
21	1330

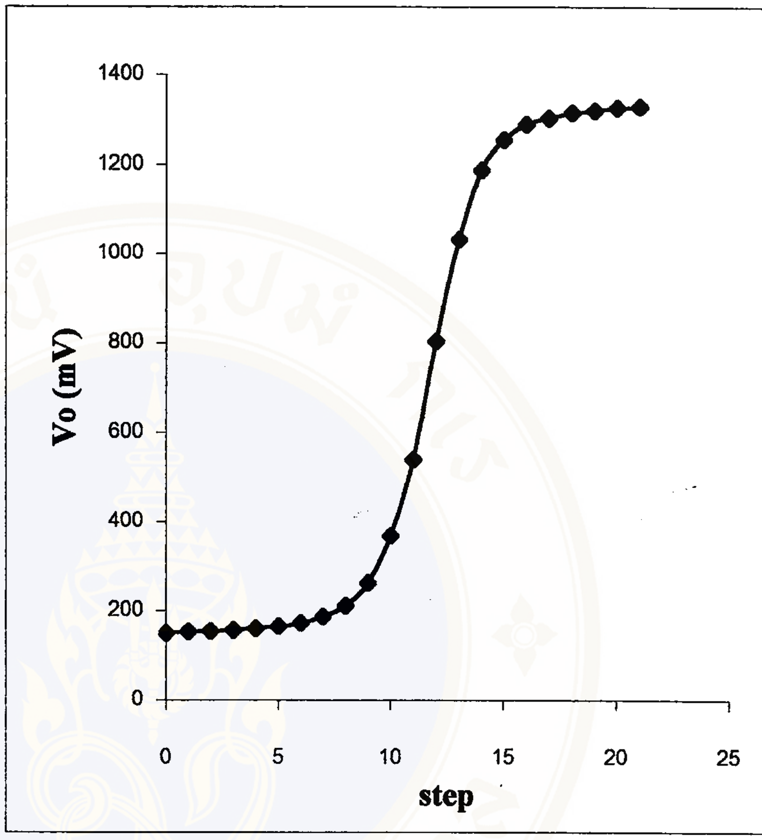


Table A.18 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 49.

Step	Vo
0	233
1	236
2	238
3	252
4	257
5	265
6	279
7	299
8	341
9	419
10	585
11	853
12	1265
13	1613
14	1846
15	1939
16	1982
17	1996
18	2010
19	2020
20	2020
21	2030

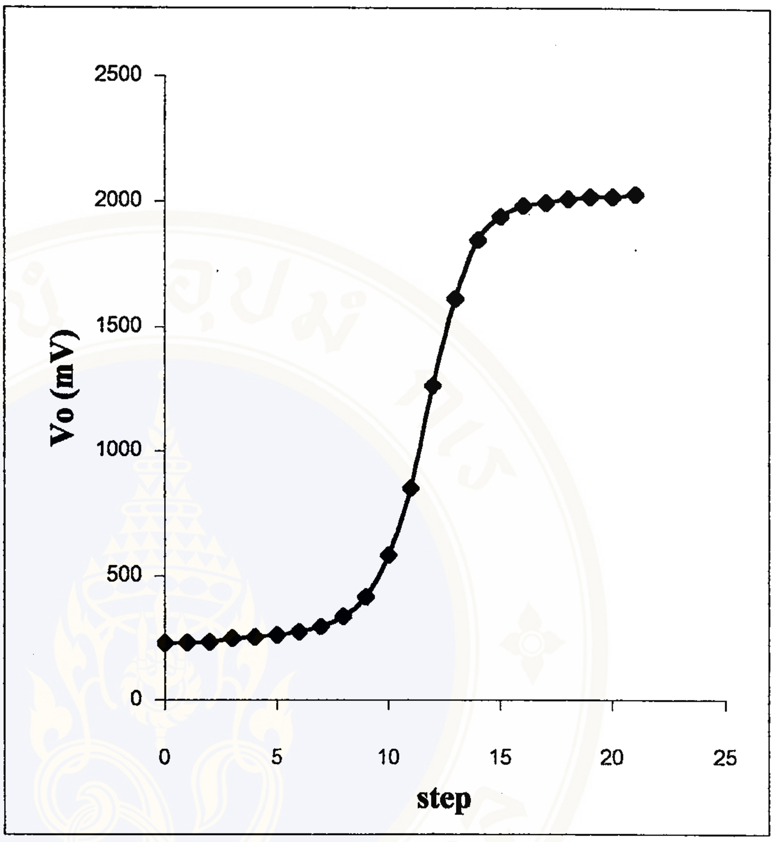


Table A.19 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 62.

Step	Vo
0	336
1	337
2	338
3	343
4	349
5	356
6	377
7	408
8	464
9	570
10	782
11	1161
12	1703
13	2220
14	2550
15	2690
16	2760
17	2780
18	2790
19	2800
20	2810
21	2820

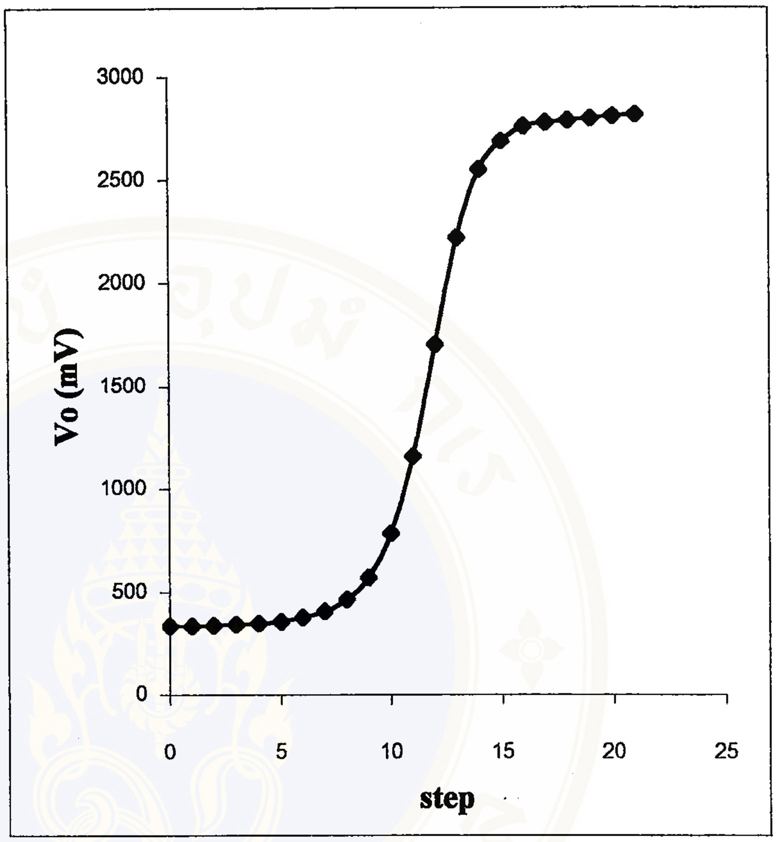
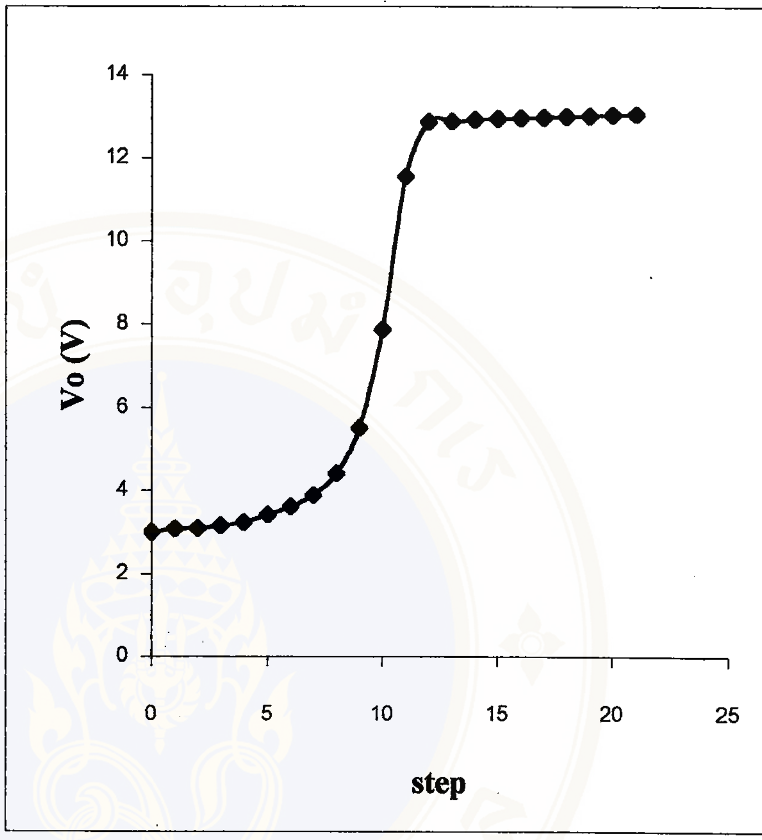


Table A.20 The output signals obtained from the circuit in Figure A.27 with an amplifier gain of 620.

Step	Vo
0	3.01
1	3.09
2	3.1
3	3.17
4	3.25
5	3.42
6	3.62
7	3.89
8	4.41
9	5.52
10	7.89
11	11.56
12	12.88
13	12.9
14	12.93
15	12.96
16	12.97
17	12.99
18	13.01
19	13.03
20	13.05
21	13.07



APPENDIX B

CIRCUITS

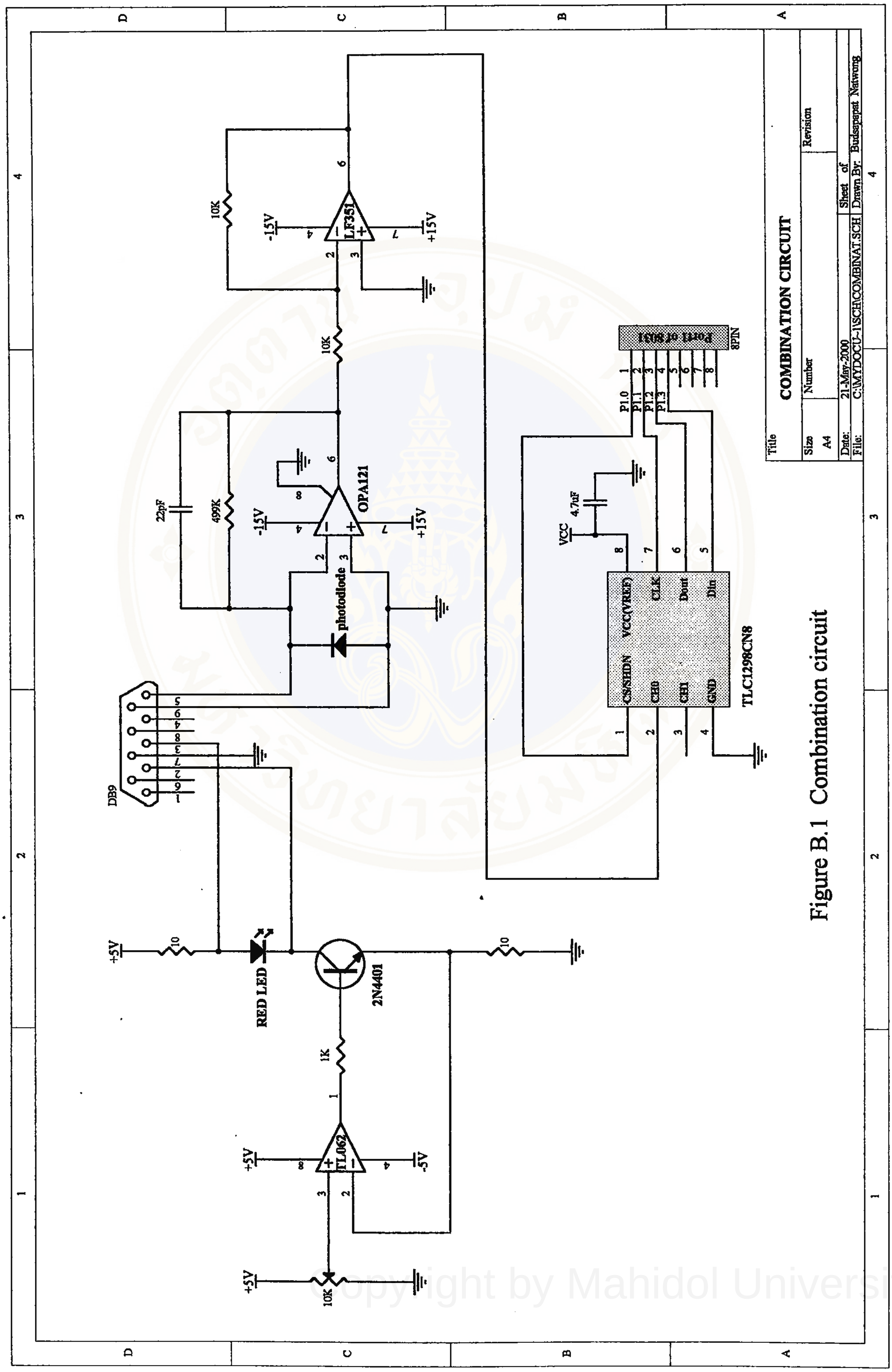


Figure B.1 Combination circuit

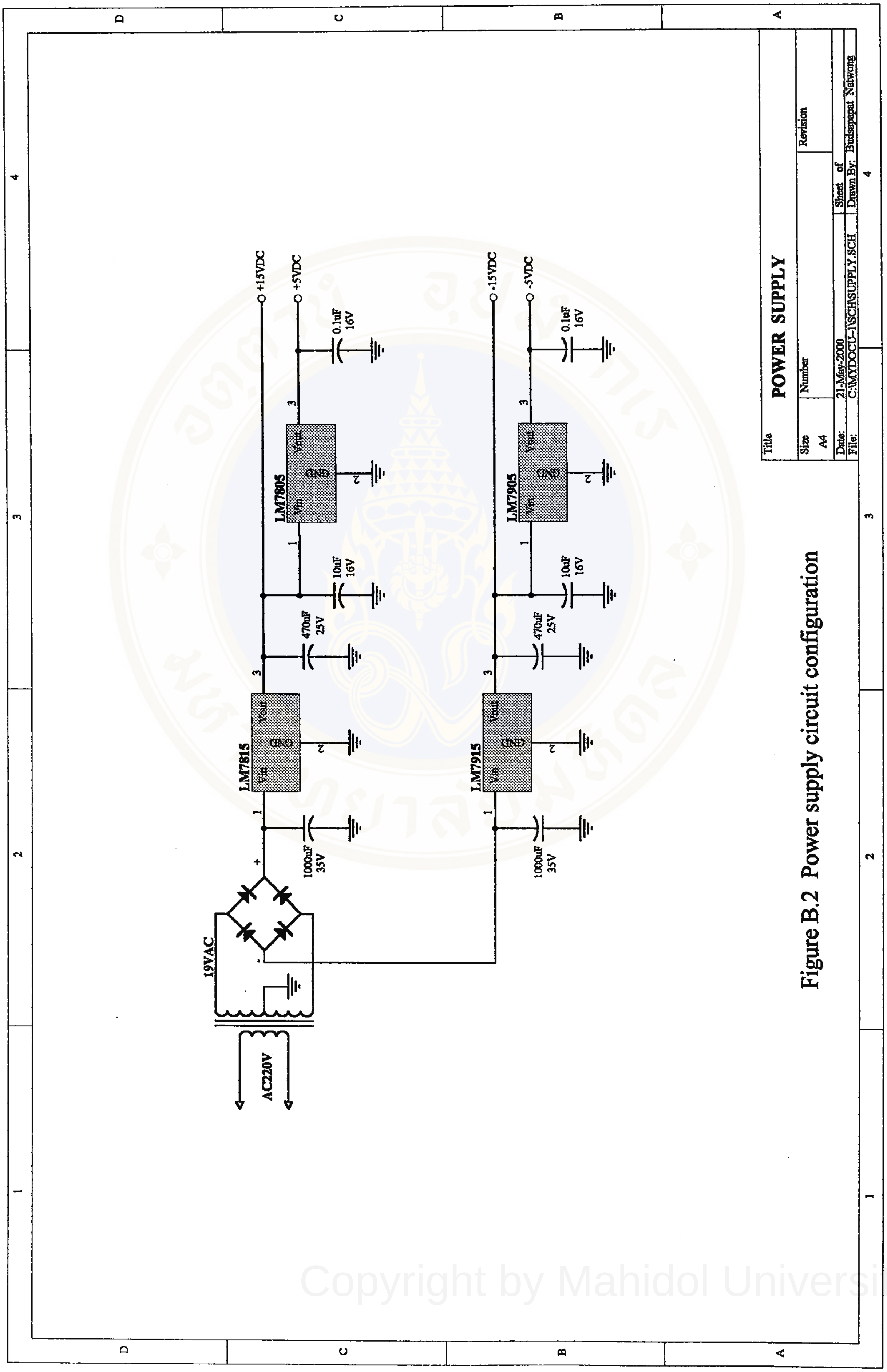


Figure B.2 Power supply circuit configuration

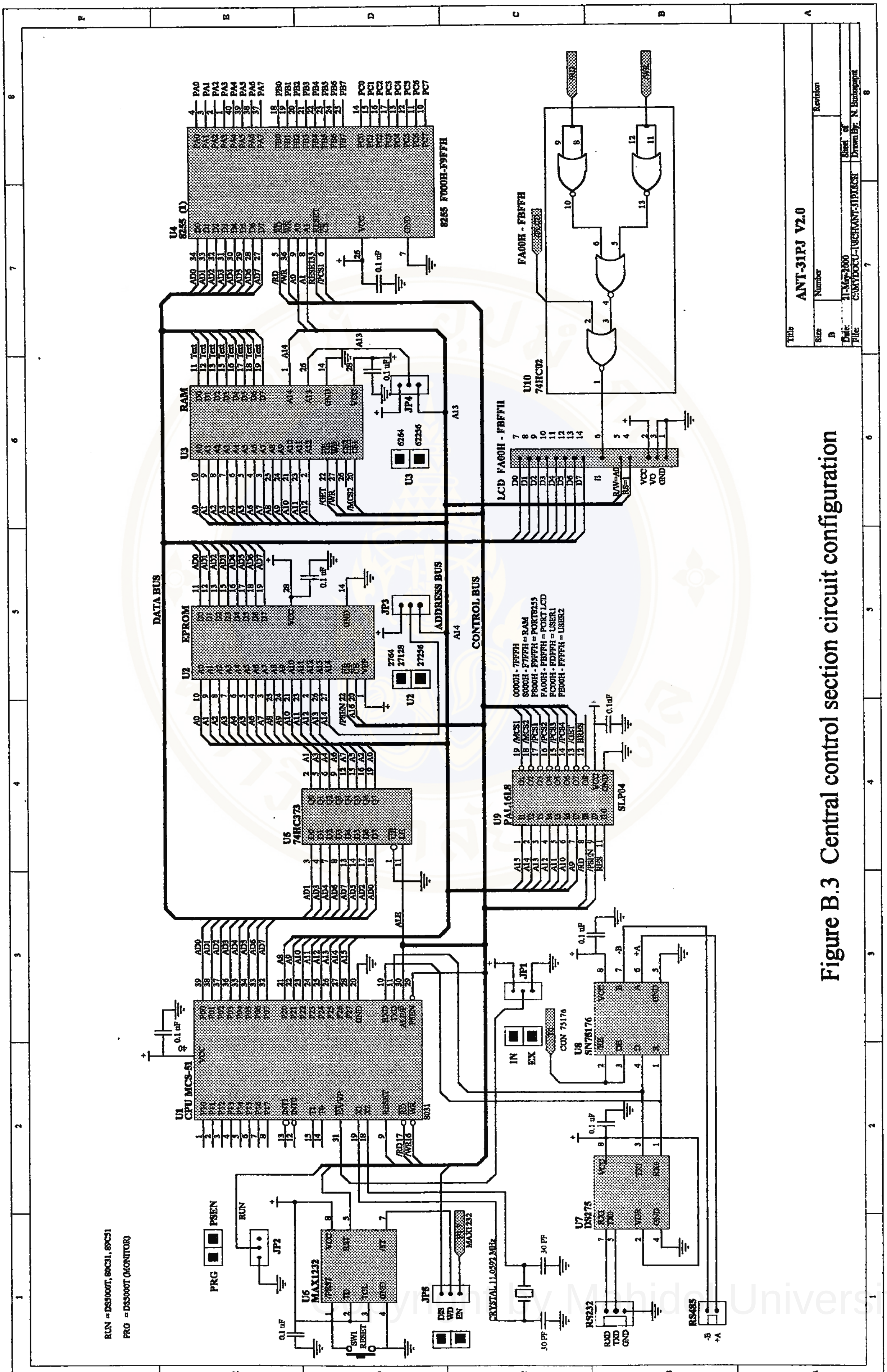


Figure B.3 Central control section circuit configuration

APPENDIX C

SPECIFICATION AND OPERATION

Specifications

Feature	Specification
Range	0.05OD to 2.31OD minimum
Aperture	5 mm.
Light source	Red LED
Sensor	Photodiode
Display	16 characters 2 Lines LCD
Indicator	SEND : Red LED will bright on control panel when send button is activated. RESET : RED LED will bright on control panel when reset button is activated.
Controls	Power switch ON/OFF; Send button; Reset button.
Power supply	± 5 V. and ± 15 V.
Dimension (H×W×D)	11.5 cm × 16.5 cm × 30.2 cm

Photograph of Densitometer

Figure C.1 Photograph of densitometer (front)

Figure C.2 Photograph of densitometer (rear)

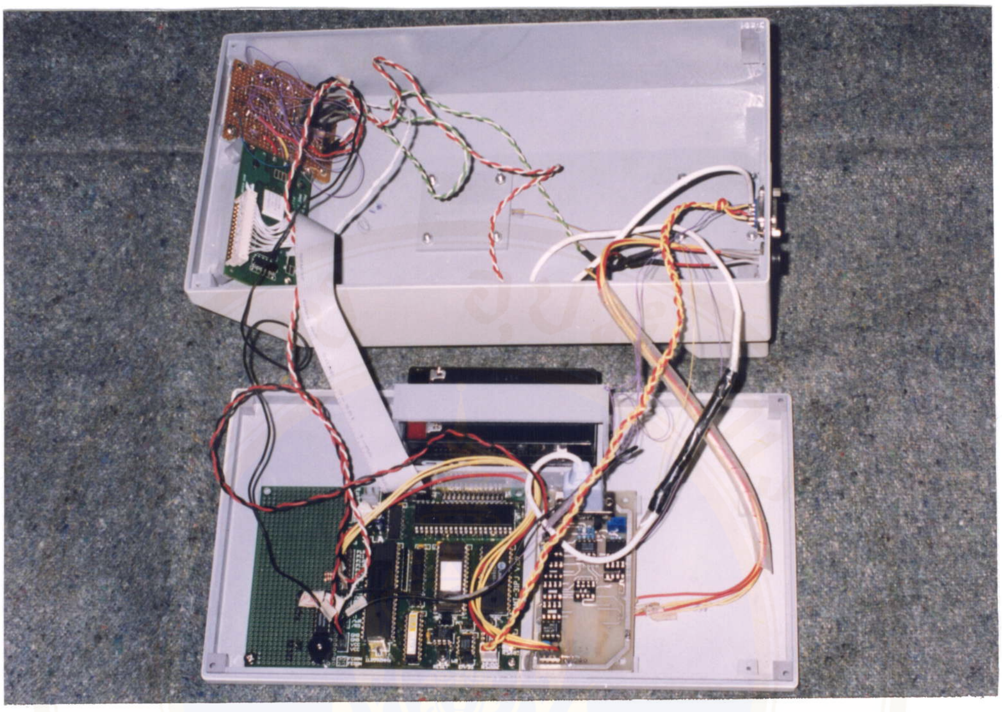


Figure C.3 Photograph of densitometer (inside)

Figure C.4 Photograph of power supply case (top view)

Operation of Densitometer

1. Pressing POWER switch to the start densitometer. When power is on, green LED at switch will illuminate.
2. When the densitometer is ready the LCD appears "DENSITOMETER READY!" message.
3. Ensure that initial optical density value display 0.00 OD by pressing arm after the LCD appears "Optical Density 0.00".
4. Insert film strip between light source and sensor.
5. Optical density is measured by pressing arm and then LCD appears "Optical Density X.XX" (X.XX represents the measured value of optical density).
6. If optical density in each value is required to proceed to the computer for showing the graph and saving data, press SEND switch and red LED labelled Send will illuminate.
7. When SEND switch is pressed, LCD appears "TRANSFERRING!" message and when optical density is sent to computer, LCD appears "DATA TRANSFERRED" message.
8. If each value of optical density is not required to proceed to the computer and successive measurements is needed, repeat steps 3-5.
9. Pressing POWER switch to end the densitometer. When power is off, green LED will not illuminate.

NOTE : Step 3 should be made to set zero reading in every measurement.

NOTE : RESET switch is used to reset system when densitometer has a problem.

NOTE : This densitometer can use with a battery by disconnecting the power supply.

Operation of Software

1. Communication between densitometer and computer can operate by clicking OffCom button and then OffCom changes to OnCom.

2. When optical density was sent from densitometer, each value is inserted into the textbox with order of sending value from densitometer as shown in Figure C.5.

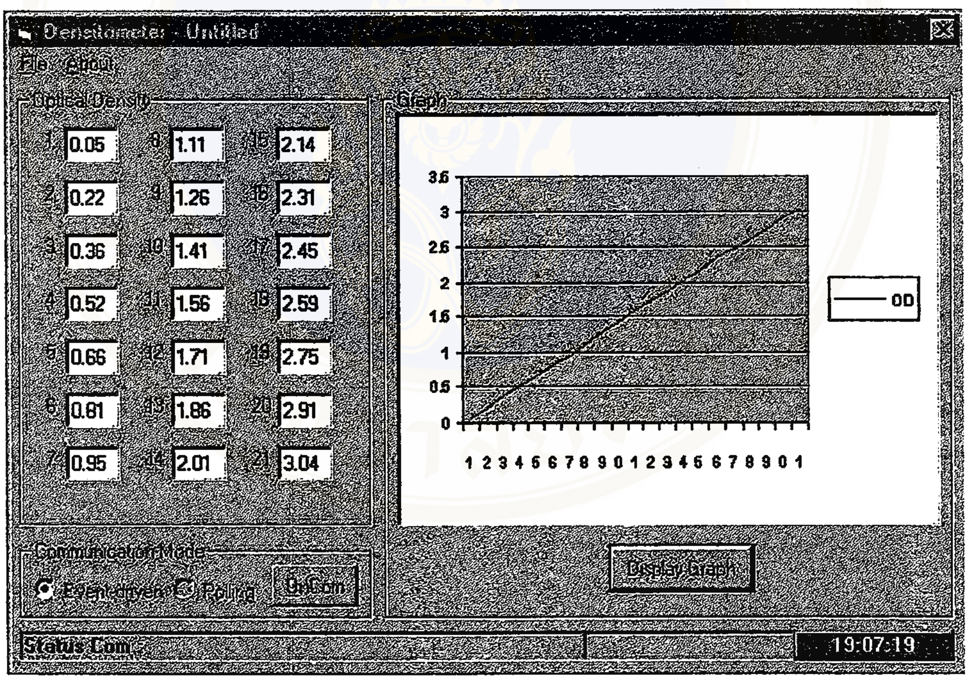


Figure C.5 User-Interface used with densitometer configuration.

3. If operator wants to show graph, click Display Graph button.

4. If operator wants to open old files for application, click File menu and Open, respectively.

5. If operator wants to save or save as files, click File menu and Save or Save as, respectively.

6. If operator wants to setup computer port, click File menu and Communication Setup will appear CommPort Properties as shown in Figure C.6.

NOTE : This program can save and print same as other application program.

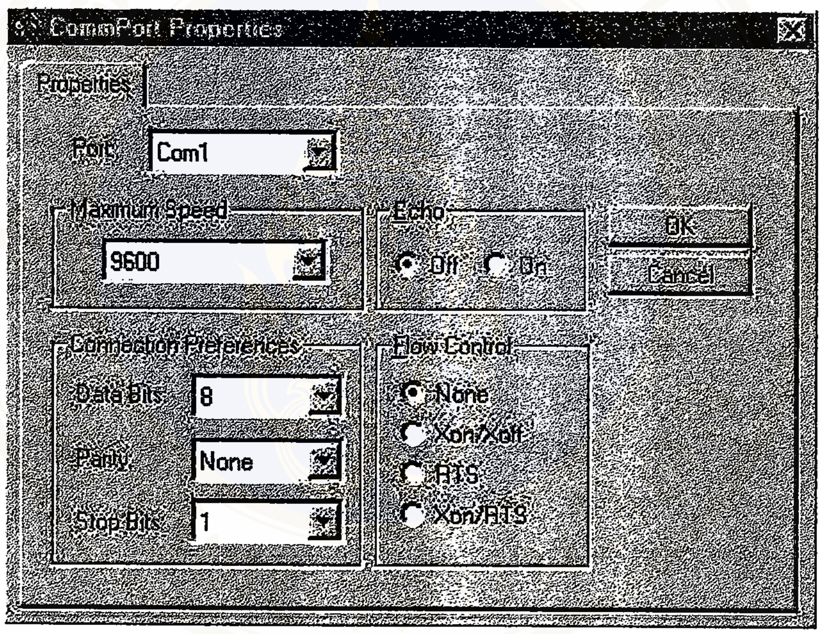


Figure C.6 CommPort Properties configuration.

APPENDIX D

PROGRAM

```
ORG     0000H
LJMP    MAIN

ORG     0050H
LCD00   EQU  0FA00H
LCD01   EQU  0FA01H
LCD10   EQU  0FA02H
LCD11   EQU  0FA03H

DOUT    EQU  P1.2
CLK     EQU  P1.1
DIN     EQU  P1.3
CS      EQU  P1.0

DAT11   EQU  20H
DAT22   EQU  21H
DAT33   EQU  22H
DAT1    EQU  23H
DAT2    EQU  24H
DAT3    EQU  25H
DAT4    EQU  26H
DAT_1   EQU  27H
DAT_2   EQU  28H
DAT_3   EQU  29H
DAT_4   EQU  2AH
BHI     EQU  30H
BLO     EQU  31H
```

```
INITLCD: MOV  DPTR,#LCD00
         MOV  A,#38H
         MOVX @DPTR,A
         LCALL CHKBF
         MOV  A,#0CH
         MOVX @DPTR,A
         LCALL CHKBF
         MOV  A,#01H
         MOVX @DPTR,A
         LCALL CHKBF
         MOV  A,#06H
         MOVX @DPTR,A
         LCALL CHKBF
         RET

CHKBF: PUSH  DPH
       PUSH  DPL
       MOV   DPTR,#LCD01
   BF: MOVX  A,@DPTR
       JB    ACC.7,BF
       POP   DPL
       POP   DPH
       RET

DELAY: MOV   R7,#00H
   DE: MOV   R6,#00H
       DJNZ  R6,$
       DJNZ  R7,DE
       RET

INIT8255: MOV  R0,00H
          MOV  DPTR,#0F803H
          MOV  A,#89H
    NEXT: MOVX @DPTR,A
```

```
        DJNZ  R0,NEXT
        RET
INITSERL: MOV   SCON,#53H
        MOV   TMOD,#20H
        MOV   TCON,#40H
        MOV   TH1,#0FDH
        SETB  TR1
        RET

ADC_READ: CLR    CS
        NOP
        CLR    CLK
        MOV    R5,#04H
   ADC1: RLC    A
        MOV    DIN,C
        SETB   CLK
        NOP
        CLR    CLK
        DJNZ   R5,ADC1
        SETB   CLK
        NOP
        CLR    CLK
        MOV    R5,#04H
   ADC2: MOV    C,DOUT
        SETB   CLK
        NOP
        CLR    CLK
        RLC    A
        DJNZ   R5,ADC2
        ANL    A,#0FH
        MOV    R1,A
        CLR    A
        MOV    R5,#08H
   ADC3: MOV    C,DOUT
```

```
        SETB  CLK
        NOP
        CLR   CLK
        RLC   A
        DJNZ  R5,ADC3
        MOV   R0,A
        SETB  CS
        RET
;**********************************************

MAIN: LCALL  INIT8255
        LCALL  INITLCD
        MOV   DPTR,#MTEXT11
        LCALL  MTD11
        MOV   DPTR,#MTEXT12
        LCALL  MTD21
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        LCALL  DELAY
        MOV   DPTR,#MTEXT21
        LCALL  MTD11
        MOV   DPTR,#MTEXT22
        LCALL  MTD21

        MOV   R5,#00H
LOOP: JB    P1.6,LOOP
        MOV   R5,#00H
        SETB  CS
        SETB  CLK
```

```
    LCALL  OD_ZERO
    LCALL  DELAY
LOOP2: JNB    P1.6,LOOP2
    JB     P1.6,$
    MOV    A,#0D0H
    LCALL  DELAY
    LCALL  DELAY
    LCALL  DELAY
    LCALL  ADC_READ
    MOV    BHI,R1          ; KEEP DATA BIT HI
    MOV    BLO,R0          ; KEEP DATA BIT LO
  ;////////////////////////////
    MOV    DPTR,#0F801H
    MOV    A,R1
    MOVX   @DPTR,A
    MOV    DPTR,#0F800H
    MOV    A,R0
    MOVX   @DPTR,A
  ;////////////////////////////
    LCALL  TABLE
    LCALL  OD_DIS
LOOP4: JB     P1.5,LOOP3
    LCALL  SERIAL
    MOV    DPTR,#MTEXT21
    LCALL  MTD11
    MOV    DPTR,#MTEXT32
    LCALL  MTD21
    LCALL  OD_DIS
LOOP3: JNB    P1.6,LOOP4
    JB     P1.6,LOOP4
    JMP    LOOP
;*********************************************************
SERIAL: MOV   DPTR,#MTEXT31
    LCALL  MTD11
```

```
        MOV   DPTR,#MTEXT32
        LCALL MTD21
        LCALL DELAY
        LCALL DELAY
        LCALL INITSERL
        JNB   TI,$
        CLR   TI
        MOV   SBUF,DAT_2
        JNB   TI,$
        CLR   TI
        MOV   SBUF,DAT_3
        JNB   TI,$
        CLR   TI
        MOV   SBUF,DAT_4
        LCALL DELAY
        MOV   DPTR,#MTEXT41
        LCALL MTD11
        MOV   DPTR,#MTEXT42
        LCALL MTD21
        LCALL DELAY
        LCALL DELAY
        LCALL DELAY
        RET

TABLE: MOV   A,BHI
        ANL   A,#0FH
        CJNE  A,#0CH,TWO
        MOV   A,BLO
        CJNE  A,#10H,ONE1
 ONE2: MOV   DAT_2,#30H
        MOV   DAT_3,#32H
        MOV   DAT_4,#30H
        RET
 ONE1: JC    ONE2
```

```
    CJNE  A,#20H,ONE3
ONE4: MOV   DAT_2,#38H
    MOV   DAT_3,#31H
    MOV   DAT_4,#30H
    RET
ONE3: JC   ONE4
    CJNE  A,#30H,ONE5
ONE6: MOV   DAT_2,#36H
    MOV   DAT_3,#31H
    MOV   DAT_4,#30H
    RET
ONE5: JC   ONE6
    CJNE  A,#40H,ONE7
ONE8: MOV   DAT_2,#34H
    MOV   DAT_3,#31H
    MOV   DAT_4,#30H
    RET
ONE7: JC   ONE8
    CJNE  A,#50H,ONE9
ONE10: MOV   DAT_2,#32H
    MOV   DAT_3,#31H
    MOV   DAT_4,#30H
    RET
ONE9: JC   ONE10
    CJNE  A,#60H,ONE11
ONE12: MOV   DAT_2,#30H
    MOV   DAT_3,#31H
    MOV   DAT_4,#30H
    RET
ONE11: JC   ONE12
    CJNE  A,#70H,ONE13
ONE14: MOV   DAT_2,#38H
    MOV   DAT_3,#30H
    MOV   DAT_4,#30H
```

```
    RET
ONE13: JC    ONE14
    MOV   DAT_2,#35H
    MOV   DAT_3,#30H
    MOV   DAT_4,#30H
    RET

TWO:  CJNE   A,#07H,THREE
    MOV   A,BLO
    CJNE  A,#10H,TWO1
TWO2: MOV   DAT_2,#30H
    MOV   DAT_3,#32H
    MOV   DAT_4,#30H
    RET
TWO1: JC    TWO2
    CJNE  A,#20H,TWO3
TWO4: MOV   DAT_2,#34H
    MOV   DAT_3,#33H
    MOV   DAT_4,#30H
    RET
TWO3: JC    TWO4
    CJNE  A,#30H,TWO5
TWO6: MOV   DAT_2,#32H
    MOV   DAT_3,#33H
    MOV   DAT_4,#30H
    RET
TWO5: JC    TWO6
    CJNE  A,#40H,TWO7
TWO8: MOV   DAT_2,#30H
    MOV   DAT_3,#33H
    MOV   DAT_4,#30H
    RET
TWO7: JC    TWO8
    CJNE  A,#50H,TWO9
```

```
TWO10: MOV   DAT_2,#38H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
       RET
TWO9:  JC    TWO10
       CJNE  A,#60H,TWO11
TWO12: MOV   DAT_2,#36H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
       RET
TWO11: JC    TWO12
       CJNE  A,#70H,TWO13
TWO14: MOV   DAT_2,#34H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
       RET
TWO13: JC    TWO14
       MOV   DAT_2,#32H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
       RET

THREE: CJNE  A,#05H,FOUR
       MOV   A,BLO
       CJNE  A,#10H,THREE1
THREE2: MOV  DAT_2,#33H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
       RET
THREE1: JC   THREE2
       CJNE  A,#20H,THREE3
THREE4: MOV  DAT_2,#34H
       MOV   DAT_3,#32H
       MOV   DAT_4,#30H
```

```
        RET
THREE3: JC      THREE4
        CJNE    A,#30H,THREE5
THREE6: MOV     DAT_2,#36H
        MOV     DAT_3,#32H
        MOV     DAT_4,#30H
        RET
THREE5: JC      THREE6
        CJNE    A,#40H,THREE7
THREE8: MOV     DAT_2,#38H
        MOV     DAT_3,#32H
        MOV     DAT_4,#30H
        RET
THREE7: JC      THREE8
        CJNE    A,#50H,THREE9
THREE10: MOV    DAT_2,#30H
        MOV     DAT_3,#33H
        MOV     DAT_4,#30H
        RET
THREE9: JC      THREE10
        CJNE    A,#60H,THREE11
THREE12: MOV    DAT_2,#32H
        MOV     DAT_3,#33H
        MOV     DAT_4,#30H
        RET
THREE11: JC     THREE12
        CJNE    A,#70H,THREE13
THREE14: MOV    DAT_2,#34H
        MOV     DAT_3,#33H
        MOV     DAT_4,#30H
        RET
THREE13: JC     THREE14
        MOV     DAT_2,#36H
        MOV     DAT_3,#33H
```

```
    MOV   DAT_4,#30H
    RET
FOUR: CJNE  A,#03H,FIVE
    MOV   A,BLO
    CJNE  A,#10H,FOUR1
FOUR2: MOV   DAT_2,#38H
    MOV   DAT_3,#33H
    MOV   DAT_4,#30H
    RET
FOUR1: JC    FOUR2
    CJNE  A,#20H,FOUR3
FOUR4: MOV   DAT_2,#30H
    MOV   DAT_3,#34H
    MOV   DAT_4,#30H
    RET
FOUR3: JC    FOUR4
    CJNE  A,#30H,FOUR5
FOUR6: MOV   DAT_2,#32H
    MOV   DAT_3,#34H
    MOV   DAT_4,#30H
    RET
FOUR5: JC    FOUR6
    CJNE  A,#40H,FOUR7
FOUR8: MOV   DAT_2,#34H
    MOV   DAT_3,#34H
    MOV   DAT_4,#30H
    RET
FOUR7: JC    FOUR8
    CJNE  A,#50H,FOUR9
FOUR10: MOV   DAT_2,#36H
    MOV   DAT_3,#34H
    MOV   DAT_4,#30H
    RET
FOUR9: JC    FOUR10
```

```
        CJNE  A,#60H,FOUR11
FOUR12: MOV   DAT_2,#38H
        MOV   DAT_3,#34H
        MOV   DAT_4,#30H
        RET
FOUR11: JC    FOUR12
        CJNE  A,#70H,FOUR13
FOUR14: MOV   DAT_2,#30H
        MOV   DAT_3,#35H
        MOV   DAT_4,#30H
        RET
FOUR13: JC    FOUR14
        MOV   DAT_2,#32H
        MOV   DAT_3,#35H
        MOV   DAT_4,#30H
        RET
FIVE:  CJNE  A,#02H,SIX
        MOV   A,BLO
        CJNE  A,#10H,FIVE1
FIVE2: MOV   DAT_2,#31H
        MOV   DAT_3,#35H
        MOV   DAT_4,#30H
        RET
FIVE1: JC    FIVE2
        CJNE  A,#20H,FIVE3
FIVE4: MOV   DAT_2,#32H
        MOV   DAT_3,#35H
        MOV   DAT_4,#30H
        RET
FIVE3: JC    FIVE4
        CJNE  A,#30H,FIVE5
FIVE6: MOV   DAT_2,#36H
        MOV   DAT_3,#35H
        MOV   DAT_4,#30H
```

```
    RET
FIVE5: JC    FIVE6
    CJNE  A,#40H,FIVE7
FIVE8: MOV   DAT_2,#38H
    MOV   DAT_3,#35H
    MOV   DAT_4,#30H
    RET
FIVE7: JC    FIVE8
    CJNE  A,#50H,FIVE9
FIVE10: MOV  DAT_2,#30H
    MOV   DAT_3,#36H
    MOV   DAT_4,#30H
    RET
FIVE9: JC    FIVE10
    CJNE  A,#60H,FIVE11
FIVE12: MOV  DAT_2,#32H
    MOV   DAT_3,#36H
    MOV   DAT_4,#30H
    RET
FIVE11: JC   FIVE12
    CJNE  A,#70H,FIVE13
FIVE14: MOV  DAT_2,#34H
    MOV   DAT_3,#36H
    MOV   DAT_4,#30H
    RET
FIVE13: JC   FIVE14
    MOV   DAT_2,#36H
    MOV   DAT_3,#36H
    MOV   DAT_4,#30H
    RET
 SIX: CJNE  A,#01H,SIXX
    MOV   A,BLO
  ; ANL   A,#80H
    CJNE  A,#0F0H,SIX1
```

```
SIX2: MOV   DAT_2,#31H
      MOV   DAT_3,#38H
      MOV   DAT_4,#30H
      RET
SIXX: JMP   EIGHT
SIX1: JNC   SIX2
      CJNE  A,#0E0H,SIX3
SIX4: MOV   DAT_2,#33H
      MOV   DAT_3,#38H
      MOV   DAT_4,#30H
      RET
SIX3: JC    SIX4
      CJNE  A,#0D0H,SIX5
SIX6: MOV   DAT_2,#35H
      MOV   DAT_3,#38H
      MOV   DAT_4,#30H
      RET
SIX5: JNC   SIX6
      CJNE  A,#0C0H,SIX7
SIX8: MOV   DAT_2,#37H
      MOV   DAT_3,#38H
      MOV   DAT_4,#30H
      RET
SIX7: JC    SIX8
      CJNE  A,#0B0H,SIX9
SIX10: MOV  DAT_2,#39H
      MOV   DAT_3,#38H
      MOV   DAT_4,#30H
      RET
SIX9: JC    SIX10
      CJNE  A,#0A0H,SIX11
SIX12: MOV  DAT_2,#31H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
```

```
      RET
SIX11: JC    SIX12
      CJNE  A,#90H,SIX13
SIX14: MOV   DAT_2,#33H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
      RET
SIX13: JC    SIX14
      CJNE  A,#80H,SEVEN
SIX15: MOV   DAT_2,#35H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
      RET
SEVEN:  JC    SIX15
      CJNE  A,#70H,SEVEN1
SEVEN2: MOV   DAT_2,#35H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
      RET
SEVEN1: JC    SEVEN2
      CJNE  A,#60H,SEVEN3
SEVEN4: MOV   DAT_2,#37H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
      RET
SEVEN3: JC    SEVEN4
      CJNE  A,#50H,SEVEN5
SEVEN6: MOV   DAT_2,#39H
      MOV   DAT_3,#39H
      MOV   DAT_4,#30H
      RET
SEVEN5: JC    SEVEN6
      CJNE  A,#40H,SEVEN7
SEVEN8: MOV   DAT_2,#32H
```

```
        MOV   DAT_3,#30H
        MOV   DAT_4,#31H
        RET
SEVEN7: JC    SEVEN8
        CJNE  A,#30H,SEVEN9
SEVEN10: MOV   DAT_2,#36H
        MOV   DAT_3,#30H
        MOV   DAT_4,#31H
        RET
SEVEN9: JC    SEVEN10
        CJNE  A,#20H,SEVEN11
SEVEN12: MOV   DAT_2,#38H
        MOV   DAT_3,#30H
        MOV   DAT_4,#31H
        RET
SEVEN11: JC    SEVEN12
        CJNE  A,#10H,SEVEN13
SEVEN14: MOV   DAT_2,#30H
        MOV   DAT_3,#31H
        MOV   DAT_4,#31H
        RET
SEVEN13: JC    SEVEN14
EIGHT:  MOV   A,BHI
        CJNE  A,#00H,TAB
        MOV   A,BLO
        CJNE  A,#0E0H,EIGHT1
EIGHT2:  MOV   DAT_2,#31H
        MOV   DAT_3,#31H
        MOV   DAT_4,#31H
        RET
TAB:  JMP   TABLE0
EIGHT1: JNC   EIGHT2
        CJNE  A,#0D0H,EIGHT3
EIGHT4: MOV   DAT_2,#33H
```

```
        MOV    DAT_3,#31H
        MOV    DAT_4,#31H
        RET
EIGHT3: JNC     EIGHT4
        CJNE   A,#0C0H,EIGHT5
EIGHT6: MOV    DAT_2,#35H
        MOV    DAT_3,#31H
        MOV    DAT_4,#31H
        RET
EIGHT5: JNC     EIGHT6
        CJNE   A,#0B0H,EIGHT7
EIGHT8: MOV    DAT_2,#34H
        MOV    DAT_3,#32H
        MOV    DAT_4,#31H
        RET
EIGHT7: JNC     EIGHT8
        CJNE   A,#0A0H,NINE
 NINE1: MOV    DAT_2,#36H
        MOV    DAT_3,#32H
        MOV    DAT_4,#31H
        RET
  NINE: JNC     NINE1
        CJNE   A,#90H,NINE2
 NINE3: MOV    DAT_2,#38H
        MOV    DAT_3,#32H
        MOV    DAT_4,#31H
        RET
 NINE2: JNC     NINE3
        CJNE   A,#80H,NINE4
 NINE5: MOV    DAT_2,#30H
        MOV    DAT_3,#33H
        MOV    DAT_4,#31H
        RET
 NINE4: JNC     NINE5
```

```
        CJNE   A,#70H,NINE6
NINE7: MOV    DAT_2,#32H
        MOV    DAT_3,#33H
        MOV    DAT_4,#31H
        RET
NINE6: JNC     NINE7
        CJNE   A,#60H,NINE8
NINE9: MOV    DAT_2,#34H
        MOV    DAT_3,#33H
        MOV    DAT_4,#31H
        RET
NINE8: CJNE   A,#69H,TEN1
 TEN2: MOV    DAT_2,#31H
        MOV    DAT_3,#34H
        MOV    DAT_4,#31H
        RET
 TEN1: JNC     TEN2
        CJNE   A,#66H,TEN3
 TEN4: MOV    DAT_2,#33H
        MOV    DAT_3,#34H
        MOV    DAT_4,#31H
        RET
 TEN3: JNC     TEN4
        CJNE   A,#63H,TEN5
 TEN6: MOV    DAT_2,#35H
        MOV    DAT_3,#34H
        MOV    DAT_4,#31H
        RET
 TEN5: JNC     TEN6
        CJNE   A,#61H,TEN7
 TEN8: MOV    DAT_2,#38H
        MOV    DAT_3,#34H
        MOV    DAT_4,#31H
        RET
```

```
TEN7: JNC    TEN8
      CJNE   A,#50H,TEN9
TEN10: MOV   DAT_2,#32H
      MOV    DAT_3,#35H
      MOV    DAT_4,#31H
      RET
TEN9: JNC    TEN10

ELEVEN: MOV  A,BLO
      CJNE   A,#40H,TWELVE
ELEVEN1: MOV DAT_2,#36H
      MOV    DAT_3,#35H
      MOV    DAT_4,#31H
      RET
TWELVE: JNC  ELEVEN1
      MOV    A,BLO
      CJNE   A,#30H,THREETH
TWELVE1: MOV DAT_2,#31H
      MOV    DAT_3,#37H
      MOV    DAT_4,#31H
      RET
THREETH: JNC TWELVE1
      MOV    A,BLO
      CJNE   A,#20H,FOURTH
THREETH1: MOV DAT_2,#36H
      MOV    DAT_3,#38H
      MOV    DAT_4,#31H
      RET
FOURTH: JNC  THREETH1
      MOV    A,BLO
      CJNE   A,#10H,FIFTH
FOURTH1: MOV DAT_2,#31H
      MOV    DAT_3,#30H
      MOV    DAT_4,#32H
```

```
        RET
FIFTH: JNC    FOURTH1
        MOV   A,BLO
        CJNE  A,#03H,SIXTH
FIFTH1: MOV   DAT_2,#34H
        MOV   DAT_3,#31H
        MOV   DAT_4,#32H
        RET
SIXTH: JNC    FIFTH1
        MOV   A,BLO
        CJNE  A,#01H,SIXTH1
SIXTH2: MOV   DAT_2,#31H
        MOV   DAT_3,#33H
        MOV   DAT_4,#32H
        RET

SIXTH1: JC    SIXTH2
        MOV   A,#BLO
        CJNE  A,#00H,TABLE0
        MOV   DAT_2,#35H
        MOV   DAT_3,#34H
        MOV   DAT_4,#32H
        RET
TABLE0: MOV   DAT_2,#30H
        MOV   DAT_3,#30H
        MOV   DAT_4,#30H
        RET
OD_ZERO:
        MOV   DAT_2,#30H
        MOV   DAT_3,#30H
        MOV   DAT_4,#30H
        LCALL OD_DIS
        RET
```

```
STD:
    MOV  DPTR,#LCD00
    MOV  A,#81H
    MOVX @DPTR,A
    LCALL CHKBF
    MOV  DPTR,#LCD10
    MOV  A,R0           ;DATA1
    MOVX @DPTR,A
    LCALL CHKBF

    MOV  DPTR,#LCD00
    MOV  A,#0C1H
    MOVX @DPTR,A
    LCALL CHKBF
    MOV  DPTR,#LCD10
    MOV  A,R1           ;DATA2
    MOVX @DPTR,A
    LCALL CHKBF
    RET


OD_DIS:
    MOV  DPTR,#LCD00
    MOV  A,#0C9H
    MOVX @DPTR,A
    LCALL CHKBF
    MOV  DPTR,#LCD10
    MOV  A,DAT_2        ;DATA2
    MOVX @DPTR,A
    LCALL CHKBF
    MOV  DPTR,#LCD00
    MOV  A,#0C8H
    MOVX @DPTR,A
```

```
        LCALL CHKBF
        MOV   DPTR,#LCD10
        MOV   A,DAT_3          ;DATA3
        MOVX @DPTR,A
        LCALL CHKBF
        MOV   DPTR,#LCD00
        MOV   A,#0C7H
        MOVX @DPTR,A
        LCALL CHKBF
        MOV   DPTR,#LCD10
        MOV   A,#2EH          ; .
        MOVX @DPTR,A
        LCALL CHKBF
        MOV   DPTR,#LCD00
        MOV   A,#0C6H
        MOVX @DPTR,A
        LCALL CHKBF
        MOV   DPTR,#LCD10
        MOV   A,DAT_4          ;DATA4
        MOVX @DPTR,A
        LCALL CHKBF
        RET

CHKBF1: PUSH  DPH
      PUSH  DPL
      MOV   DPTR,#LCD01
  BF1: MOVX  A,@DPTR
      JB    ACC.7,BF1
      POP   DPL
      POP   DPH
      RET

MTEXT11: DB  " DENSITOMETER "
MTEXT12: DB  "    READY!   "
```

```
MTEXT21: DB  " OPTICAL DENSITY"
MTEXT22: DB  "     X.XX      "

MTEXT31: DB  " TRANSFERRING "
MTEXT32: DB  "              "

MTEXT41: DB  "    DATA      "
MTEXT42: DB  " TRANSFERRED "

MTD11: MOV  R0,#16D
       MOV  A,#80H        ;ADRESS LINE1.1 [00 - 0F]
       ACALL STD1
       RET
MTD21: MOV  R0,#16D
       MOV  A,#0C0H       ;ADRESS LINE2.1 [40 - 4F]
       ACALL STD1
       RET

STD1: PUSH  DPH
       PUSH  DPL
       MOV   DPTR,#LCD00
       MOVX @DPTR,A
       LCALL CHKBF1
       POP   DPL
       POP   DPH
WTD1: CLR   A
       MOVC  A,@A+DPTR
       PUSH  DPH
       PUSH  DPL
       MOV   DPTR,#LCD10
       MOVX @DPTR,A
       LCALL CHKBF1
```

```
        POP  DPL
        POP  DPH
        INC  DPTR
        DJNZ R0,WTD1
        RET

END
```

APPENDIX E

DATASHEET

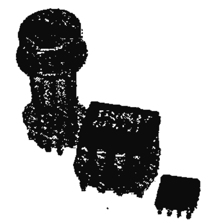
Cost estimation

Devices	Cost/Unit (Baht)	Unit	Prices (Baht)
1. Pulse oximeter probe	16,000	1	16,000
2. ANT-31 microcontroller board	1,300	1	1,300
3. LCD display	700	1	700
4. EPROM 27256	80	1	80
5. LF351	30	1	30
6. LTC1298	250	1	250
7. OPA121	950	1	950
8. TL062	200	1	200
9. Micro-switch	20	1	20
10. Socket IC 8 pin	10	4	40
11. DB9	30	3	90
12. Jack	40	1	40
13. Header (M)	10	2	20
14. Header (F) 3 pins	0.37	10	3.70
15. Header (F) 4 pins	0.67	10	6.70
16. Internal pin of header (F)	0.30	56	16.80
17. Resistor trimpot 25 round	35	1	35
18. Resistor 1%	1	10	10
19. Resistor 5%	0.50	10	5
20. Capacitor	5	10	50
21. Switch ON/OFF	80	1	80
22. Switch ON/OFF of supply	50	1	50
23. Switch send	80	1	80
24. Switch reset	80	1	80
25. LM7805	10	1	10
26. LM7815	10	1	10
27. LM7905	10	1	10

Cost estimation

Devices	Cost/Unit (Baht)	Unit	Prices (Baht)
28. LM7915	10	1	10
29. Fuse box	10	1	10
30. Transformer	180	1	180
31. Multi-purpose PCB	200	1	200
32. PCB	300	1	300
33. Ventilator	100	1	100
34. Plug 220V	150	1	150
35. Densitometer case	3,500	1	3,500
36. Supply case	500	1	500
		Total	25,117.2

BURR - BROWN®



OPA121

Low Cost Precision *Difet*® OPERATIONAL AMPLIFIER

FEATURES

- LOW NOISE: 6nV/√Hz typ at 10kHz
- LOW BIAS CURRENT: 5pA max
- LOW OFFSET: 2mV max
- LOW DRIFT: 3µV/°C typ
- HIGH OPEN-LOOP GAIN: 110dB min
- HIGH COMMON-MODE REJECTION: 86dB min

APPLICATIONS

- OPTOELECTRONICS
- DATA ACQUISITION
- TEST EQUIPMENT
- MEDICAL EQUIPMENT
- RADIATION HARD EQUIPMENT

DESCRIPTION

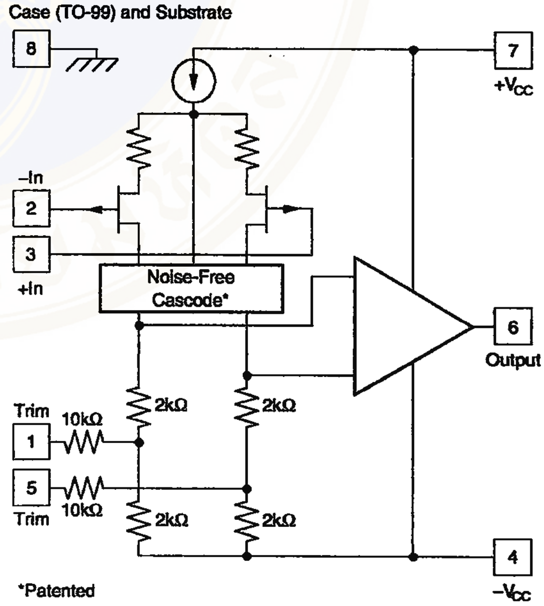
The OPA121 is a precision monolithic dielectrically-isolated FET (*Difet*®) operational amplifier. Outstanding performance characteristics are now available for low-cost applications.

Noise, bias current, voltage offset, drift, open-loop gain, common-mode rejection, and power supply rejection are superior to BIFET® amplifiers.

Very low bias current is obtained by dielectric isolation with on-chip guarding.

Laser-trimming of thin-film resistors gives very low offset and drift. Extremely low noise is achieved with new circuit design techniques (patented). A new cascode design allows high precision input specifications and reduced susceptibility to flicker noise.

Standard 741 pin configuration allows upgrading of existing designs to higher performance levels.



OPA121 Simplified Circuit

Difet®, Burr-Brown Corp.
BIFET®, National Semiconductor Corp.

International Airport Industrial Park • Mailing Address: PO Box 11400 • Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd. • Tucson, AZ 85706
Tel: (520) 746-1111 • Twx: 910-952-1111 • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

PDS-539F Printed in U.S.A. September, 1993

SPECIFICATIONS

ELECTRICAL

At V_{CC} = ±15VDC and T_A = +25°C unless otherwise noted. Pin 8 connected to ground.

PARAMETER	CONDITIONS	OPA121KM MIN	OPA121KM TYP	OPA121KM MAX	OPA121KP, KU MIN	OPA121KP, KU TYP	OPA121KP, KU MAX	UNITS
INPUT								
NOISE								
Voltage, f_O = 10Hz	(1)		40			50		nV/√Hz
f_O = 100Hz	(1)		15			18		nV/√Hz
f_O = 1kHz	(1)		8			10		nV/√Hz
f_O = 10kHz	(1)		6			7		nV/√Hz
f_B = 10Hz to 10kHz	(1)		0.7			0.8		µVrms
f_B = 0.1Hz to 10 Hz	(1)		1.6			2		µVp-p
Current, f_B = 0.1Hz to 10Hz	(1)		15			21		fA, p-p
f_O = 0.1Hz thru 20kHz	(1)		0.8			1.1		fA/√Hz
OFFSET VOLTAGE(2)								
Input Offset Voltage	V_{CM} = 0VDC		±0.5	±2		±0.5	±3	mV
Average Drift	T_A = T_{MIN} to T_{MAX}		±3	±10		±3	±10	µV/°C
Supply Rejection		86	104		86	104		dB
			±6	±50		±6	±50	µV/V
BIAS CURRENT(2)								
Input Bias Current	V_{CM} = 0VDC Device Operating		±1	±5		±1	±10	pA
OFFSET CURRENT(2)								
Input Offset Current	V_{CM} = 0VDC Device Operating		±0.7	±4		±0.7	±8	pA
IMPEDANCE								
Differential			10^{13} ‖ 1			10^{13} ‖ 1		Ω ‖ pF
Common-Mode			10^{14} ‖ 3			10^{14} ‖ 3		Ω ‖ pF
VOLTAGE RANGE								
Common-Mode Input Range		±10	±11		±10	±11		V
Common-Mode Rejection	V_{IN} = ±10VDC	86	104		82	100		dB
OPEN-LOOP GAIN, DC								
Open-Loop Voltage Gain	R_L ≥ 2kΩ	110	120		106	114		dB
FREQUENCY RESPONSE								
Unity Gain, Small Signal			2			2		MHz
Full Power Response	20Vp-p, R_L = 2kΩ		32			32		kHz
Slew Rate	V_O = ±10V, R_L = 2kΩ		2			2		V/µs
Settling Time, 0.1%	Gain = −1, R_L = 2kΩ		6			6		µs
0.01%	10V Step		10			10		µs
Overload Recovery, 50% Overdrive(3)	Gain = −1		5			5		µs
RATED OUTPUT								
Voltage Output	R_L = 2kΩ	±11	±12		±11	±12		V
Current Output	V_O = ±10VDC	±5.5	±10		±5.5	±10		mA
Output Resistance	DC, Open Loop		100			100		Ω
Load Capacitance Stability	Gain = +1		1000			1000		pF
Short Circuit Current		10	40		10	40		mA
POWER SUPPLY								
Rated Voltage			±15			±15		VDC
Voltage Range, Derated Performance		±5		±18	±5		±18	VDC
Current, Quiescent	I_O = 0mADC		2.5	4		2.5	4.5	mA
TEMPERATURE RANGE								
Specification	Ambient Temperature	0		+70	0		+70	°C
Operating	Ambient Temperature	−40		+85	−25		+85	°C
Storage	Ambient Temperature	−65		+150	−55		+125	°C
θ Junction-Ambient			200			150(4)		°C/W

NOTES: (1) Sample tested. (2) Offset voltage, offset current, and bias current are specified with the units fully warmed up. (3) Overload recovery is defined as the time required for the output to return from saturation to linear operation following the removal of a 50% input overdrive. (4) 100°C/W for KU grade.

ELECTRICAL (FULL TEMPERATURE RANGE SPECIFICATIONS)

At V_{CC} = ±15VDC and $T_A = T_{MIN}$ to T_{MAX} unless otherwise noted.

PARAMETER	CONDITIONS	OPA121KM			OPA121KP, KU			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
TEMPERATURE RANGE								
Specification Range	Ambient Temperature	0		+70	0		+70	°C
INPUT								
OFFSET VOLTAGE(1)								
Input Offset Voltage	V_{CM} = 0VDC		±1	±3		±1	±5	mV
Average Drift			±3	±10		±3	±10	μV/°C
Supply Rejection		82	94		82	94		dB
			±20	±80		±20	±80	μV/V
BIAS CURRENT(1)								
Input Bias Current	V_{CM} = 0VDC Device Operating		±23	±115		±23	±250	pA
OFFSET CURRENT(1)								
Input Offset Current	V_{CM} = 0VDC Device Operating		±16	±100		±16	±200	pA
VOLTAGE RANGE								
Common-Mode Input Range		±10	±11		±10	±11		V
Common-Mode Rejection	V_{IN} = ±10VDC	82	98		80	96		dB
OPEN-LOOP GAIN, DC								
Open-Loop Voltage Gain	$R_L \geq 2k\Omega$	106	116		100	110		dB
RATED OUTPUT								
Voltage Output	$R_L = 2k\Omega$	±10.5	±11		±10.5	±11		V
Current Output	V_O = ±10VDC	±5.25	±10		±5.25	±10		mA
Short Circuit Current	V_O = 0VDC	10	40		10	40		mA
POWER SUPPLY								
Current, Quiescent	I_O = 0mADC		2.5	4.5		2.5	5	mA

NOTE: (1) Offset voltage, offset current, and bias current are measured with the units fully warmed up.

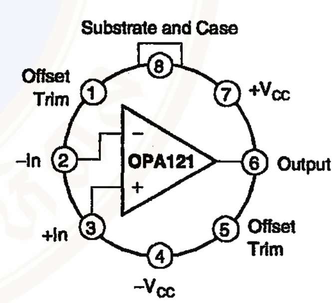
ABSOLUTE MAXIMUM RATINGS

Supply .... ±18VDC
Internal Power Dissipation(1) 500mW
Differential Input Voltage .... ±36VDC
Input Voltage Range .... ±18VDC
Storage Temperature Range
 M package .... –65°C to +150°C
 P, U packages .... –55°C to +125°C
Operating Temperature Range
 M package .... –40°C to +85°C
 P, U packages .... –25°C to +85°C
Lead Temperature
 M, P packages (soldering, 10s) .... +300°C
 U package (soldering, 3s) .... +260°C
Output Short-Circuit Duration(2) .... Continuous
Junction Temperature .... +175°C

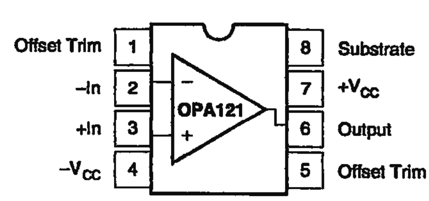
NOTES: (1) Packages must be derated based on θ_{JA} = 150°C/W (P package); θ_{JA} = 200°C/W (M package); θ_{JA} = 100°C/W (U package). (2) Short circuit may be to power supply common only. Rating applies to +25°C ambient. Observe dissipation limit and T_J.

CONNECTION DIAGRAMS

Top View **M-Package** TO-99 (Hermetic)



Top View **P-Package** Plastic Mini-DIP
U-Package Plastic SOIC



PACKAGE INFORMATION

MODEL	PACKAGE	PACKAGE DRAWING NUMBER(1)
OPA121KM	TO-99	001
OPA121KP	8-Pin Plastic DIP	006
OPA121KU	8-Pin SOIC	182

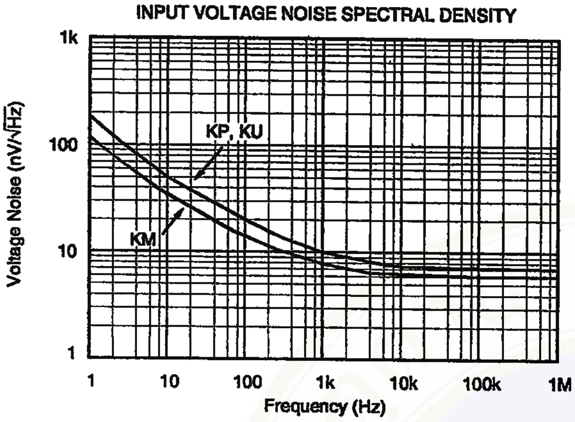
NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix D of Burr-Brown IC Data Book.

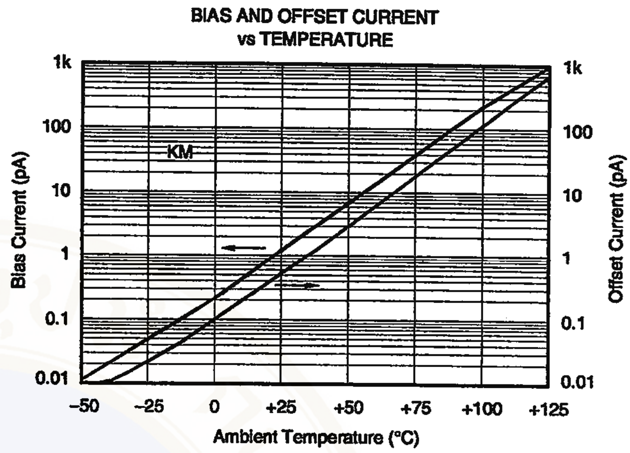
ORDERING INFORMATION

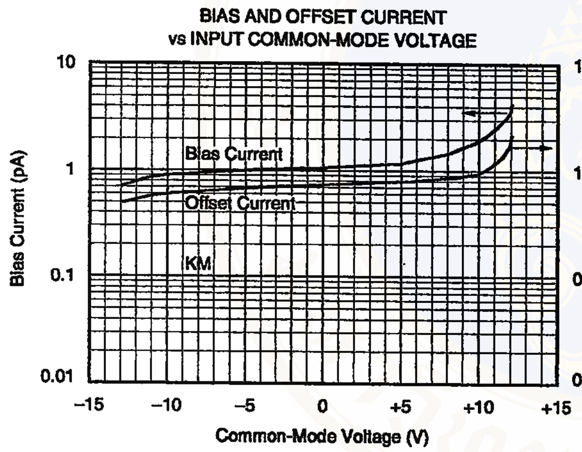
MODEL	PACKAGE	TEMPERATURE RANGE
OPA121KM	TO-99	0°C to +70°C
OPA121KP,	8-Pin Plastic DIP	0°C to +70°C
OPA121KU	8-Pin SOIC	0°C to +70°C

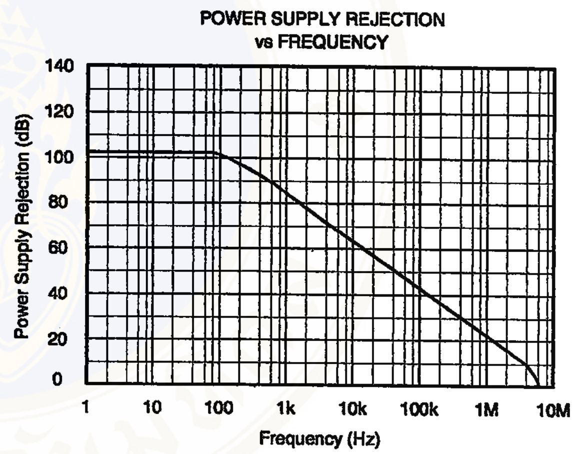
TYPICAL PERFORMANCE CURVES

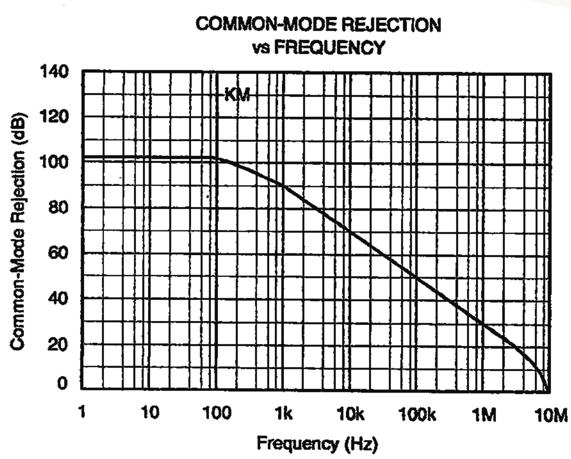
T_A = +25°C, V_{CC} = ±15VDC unless otherwise noted.

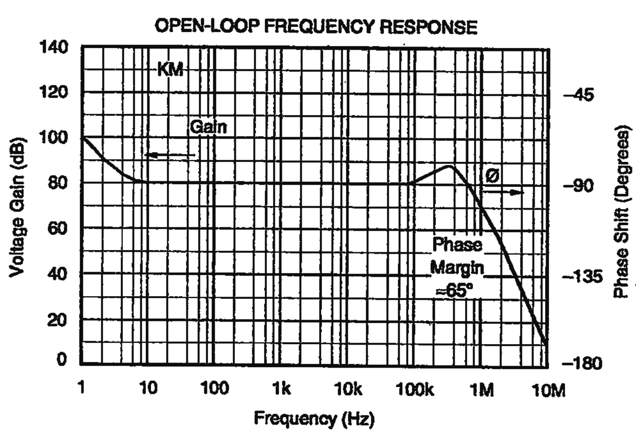






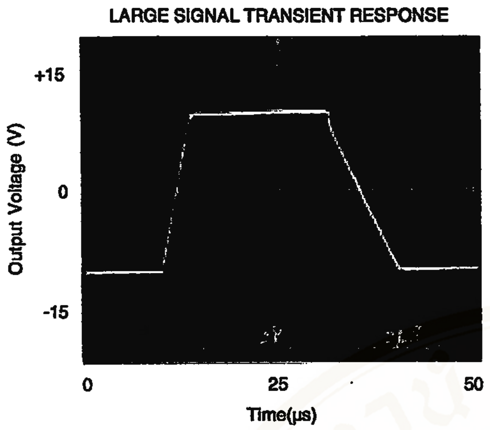


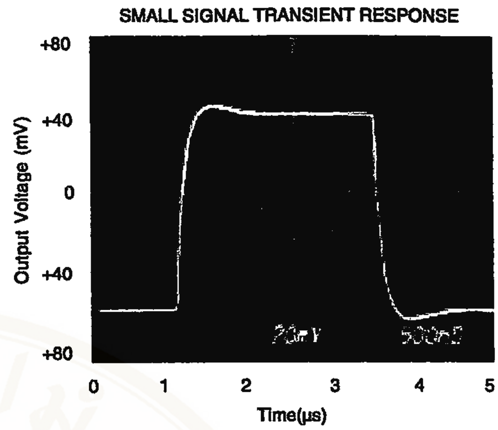


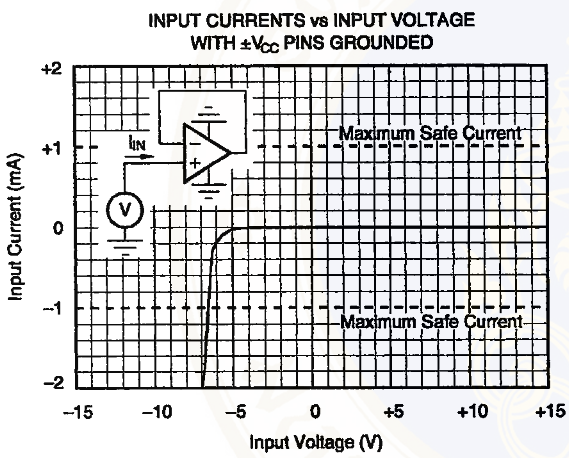


TYPICAL PERFORMANCE CURVES (CONT)

$T_A = +25°C$, $V_{CC} = ±15VDC$ unless otherwise noted.







APPLICATIONS INFORMATION

OFFSET VOLTAGE ADJUSTMENT

The OPA121 offset voltage is laser-trimmed and will require no further trim for most applications. As with most amplifiers, externally trimming the remaining offset can change drift performance by about 0.3µV/°C for each 100µV of adjusted offset. Note that the trim (Figure 1) is similar to operational amplifiers such as 741 and AD547. The OPA121 can replace most BIFET amplifiers by leaving the external null circuit unconnected.

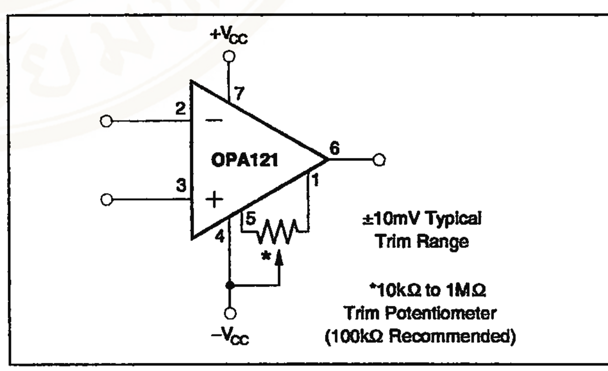


FIGURE 1. Offset Voltage Trim.

INPUT PROTECTION

Conventional monolithic FET operational amplifiers require external current-limiting resistors to protect their inputs against destructive currents that can flow when input FET gate-to-substrate isolation diodes are forward-biased. Most BIFET amplifiers can be destroyed by the loss of $-V_{CC}$.

Unlike BIFET amplifiers, the ***Difet*** OPA121 requires input current limiting resistors only if its input voltage is greater than 6V more negative than $-V_{CC}$. A 10kΩ series resistor will limit input current to a safe level with up to ±15V input levels even if both supply voltages are lost.

Static damage can cause subtle changes in amplifier input characteristics without necessarily destroying the device. In precision operational amplifiers (both bipolar and FET types), this may cause a noticeable degradation of offset voltage and drift.

Static protection is recommended when handling any precision IC operational amplifier.

GUARDING AND SHIELDING

As in any situation where high impedances are involved, careful shielding is required to reduce "hum" pickup in input leads. If large feedback resistors are used, they should also be shielded along with the external input circuitry.

Leakage currents across printed circuit boards can easily exceed the bias current of the OPA121. To avoid leakage problems, it is recommended that the signal input lead of the OPA121 be wired to a Teflon™ standoff. If the OPA121 is to be soldered directly into a printed circuit board, utmost care must be used in planning the board layout. A "guard" pattern should completely surround the high-impedance input leads and should be connected to a low-impedance point which is at the signal input potential.

The amplifier case should be connected to any input shield or guard via pin 8. This insures that the amplifier itself is fully surrounded by guard potential, minimizing both leakage and noise pickup (see Figure #2).

If guarding is not required, pin 8 (case) should be connected to ground.

BIAS CURRENT CHANGE VERSUS COMMON-MODE VOLTAGE

The input bias currents of most popular BIFET operational amplifiers are affected by common-mode voltage (Figure 3). Higher input FET gate-to-drain voltage causes leakage and ionization (bias) currents to increase. Due to its cascode input stage, the extremely-low bias current of the OPA121 is not compromised by common-mode voltage.

Teflon™ E.I. du Pont de Nemours & Co.

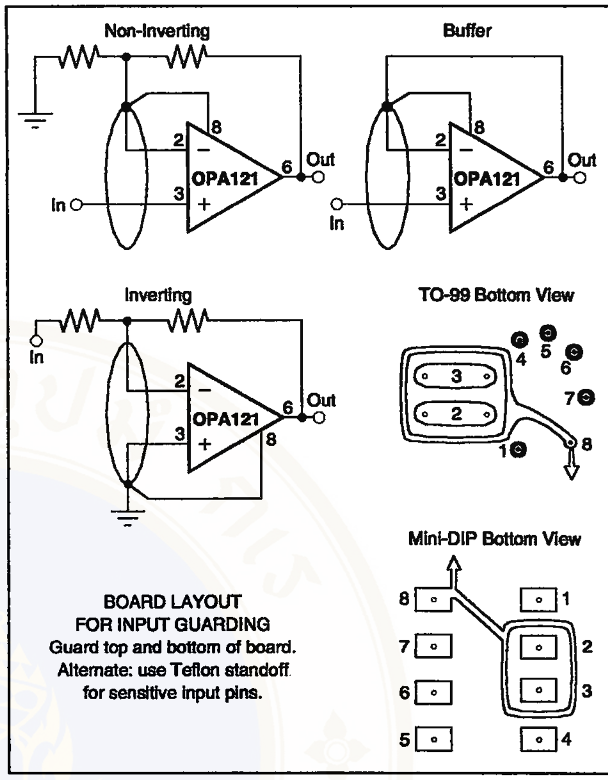


FIGURE 2. Connection of Input Guard.

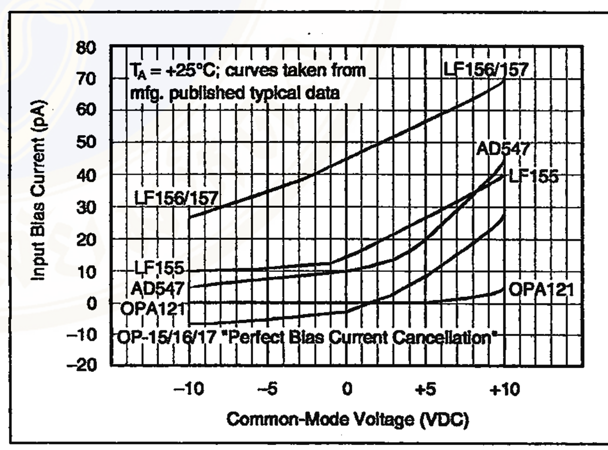


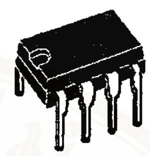
FIGURE 3. Input Bias Current vs Common-Mode Voltage.

SGS-THOMSON MICROELECTRONICS

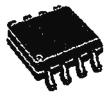
TL062 TL062A - TL062B

LOW POWER J-FET DUAL OPERATIONAL AMPLIFIERS

- VERY LOW POWER CONSUMPTION : 200µA
- WIDE COMMON-MODE (UP TO V_{CC}^{+}) AND DIFFERENTIAL VOLTAGE RANGES
- LOW INPUT BIAS AND OFFSET CURRENTS
- OUTPUT SHORT-CIRCUIT PROTECTION
- HIGH INPUT IMPEDANCE J-FET INPUT STAGE
- INTERNAL FREQUENCY COMPENSATION
- LATCH UP FREE OPERATION
- HIGH SLEW RATE : 3.5V/µs



N
DIP8
(Plastic Package)



D
SO8
(Plastic Micropackage)

DESCRIPTION

The TL062, TL062A and TL062B are high speed J-FET input dual operational amplifier family. Each of these J-FET input operational amplifiers incorporates well matched, high voltage J-FET and bipolar transistors in a monolithic integrated circuit.

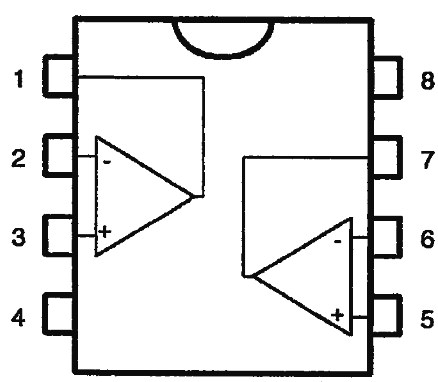
The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

ORDER CODES

Part Number	Temperature Range	Package	
		N	D
TL062M/AM/BM	-55°C, +125°C	•	•
TL062I/AI/BI	-40°C, +105°C	•	•
TL062C/AC/BC	0°C, +70°C	•	•

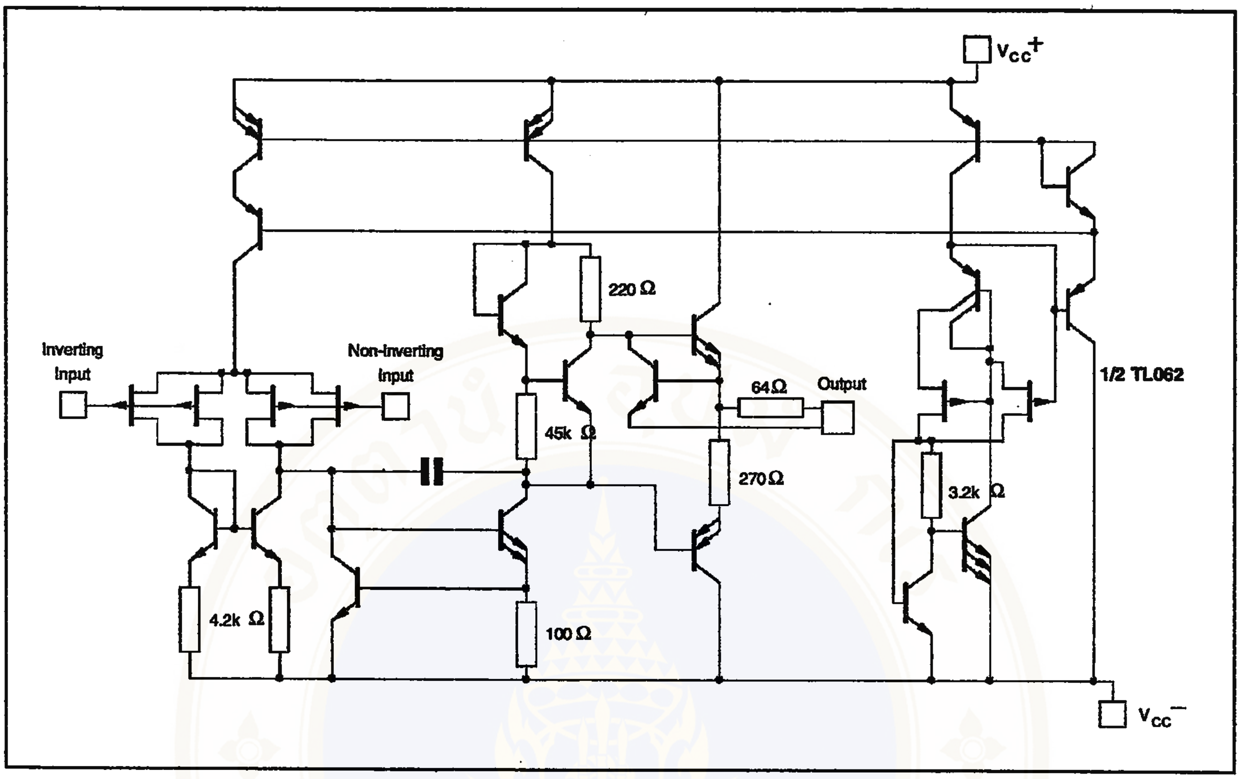
Example : TL062IN

PIN CONNECTIONS (top view)



1 - Output 1
2 - Inverting input 1
3 - Non-inverting input 1
4 - V_{CC}^{-}
5 - Non-inverting input 2
6 - Inverting input 2
7 - Output 2
8 - V_{CC}^{+}

SCHEMATIC DIAGRAM



MAXIMUM RATINGS

Symbol	Parameter	TL062M,AM,BM	TL062I,AI,BI	TL062C,AC,BC	Unit
V_{CC}	Supply Voltage - (note 1)	±18	±18	±18	V
V_i	Input Voltage - (note 3)	±15	±15	±15	V
V_{id}	Differential Input Voltage - (note 2)	±30	±30	±30	V
P_{tot}	Power Dissipation	680	680	680	mW
	Output Short-Circuit Duration (Note 4)	Infinite	Infinite	Infinite	
T_{oper}	Operating Free-Air Temperature Range	-55 to +125	-40 to +105	0 to +70	°C
T_{stg}	Storage Temperature Range	- 65 to + 150	- 65 to + 150	- 65 to + 150	°C

Notes :
1. All voltage values, except differential voltage, are with respect to the zero reference level (ground) of the supply voltages where the zero reference level is the midpoint between V_{CC}^+ and V_{CC}^-.
2. Differential voltages are at the non-inverting input terminal with respect to the inverting input terminal.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 volts, whichever is less.
4. The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

ELECTRICAL CHARACTERISTICS

$V_{CC} = \pm 15V$, $T_{amb} = 25^oC$ (unless otherwise specified)

Symbol	Parameter	TL062M			TL062I			TL062C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage ($R_s = 50\Omega$) $T_{amb} = 25^oC$ $T_{min.} \leq T_{amb} \leq T_{max.}$		3	6 15		3	6 9		3	15 20	mV
DV_{io}	Temperature Coefficient of Input Offset Voltage ($R_s = 50\Omega$)		10			10			10		µV/°C
I_{io}	Input Offset Current * $T_{amb} = 25^oC$ $T_{min.} \leq T_{amb} \leq T_{max.}$		5	100 20		5	100 10		5	200 5	pA nA
I_{ib}	Input Bias Current * $T_{amb} = 25^oC$ $T_{min.} \leq T_{amb} \leq T_{max.}$		30	200 50		30	200 20		30	400 10	pA nA
V_{icm}	Input Common Mode Voltage Range	±11.5	+15 -12		±11.5	+15 -12		±11	+15 -12		V
V_{OPP}	Output Voltage Swing ($R_L = 10k\Omega$) $T_{amb} = 25^oC$ $T_{min.} \leq T_{amb} \leq T_{max.}$	20 20	27		20 20	27		20 20	27		V
A_{vd}	Large Signal Voltage Gain ($R_L = 10k\Omega$, $V_o = \pm 10V$) $T_{amb} = 25^oC$ $T_{min.} \leq T_{amb} \leq T_{max.}$	4 4	6		4 4	6		3 3	6		V/mV
GBP	Gain Bandwidth Product ($T_{amb} = 25^oC$, $R_L = 10k\Omega$ $C_L = 100pF$)		1			1			1		MHz
R_i	Input Resistance		10^{12}			10^{12}			10^{12}		Ω
CMR	Common Mode Rejection Ratio ($R_s = 50\Omega$)	80	86		80	86		70	76		dB
SVR	Supply Voltage Rejection Ratio ($R_s = 50\Omega$)	80	95		80	95		70	95		dB
I_{cc}	Supply Current (Per Amplifier) ($T_{amb} = 25^oC$, no load, no signal)		200	250		200	250		200	250	µA
V_{O1}/V_{O2}	Channel Separation ($A_v = 100$, $T_{amb} = 25^oC$)		120			120			120		dB
P_D	Total Power Consumption (Each Amplifier) ($T_{amb} = 25^oC$, no load, no signal)		6	7.5		6	7.5		6	7.5	mW

* Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive. Pulse techniques must be used that will maintain the junction temperature as closes to the ambient temperature as possible.

ELECTRICAL CHARACTERISTICS (continued)

$V_{CC} = \pm 15V$, $T_{amb} = 25^oC$

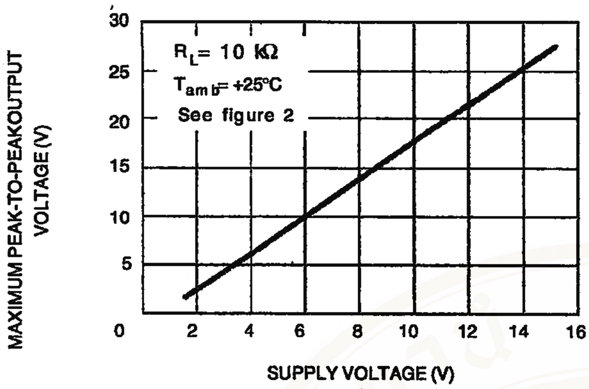
Symbol	Parameter	TL062C,I,M			Unit
		Min.	Typ.	Max.	
SR	Slew Rate ($V_i = 10V$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$)	1.5	3.5		V/µs
t_r	Rise Time ($V_i = 20mV$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$)		0.2		µs
K_{OV}	Overshoot Factor ($V_i = 20mV$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$) (see figure 1)		10		%
e_n	Equivalent Input Noise Voltage ($R_s = 100\Omega$, f = 1KHz)		42		$\frac{nV}{\sqrt{Hz}}$

ELECTRICAL CHARACTERISTICS (continued)
$V_{CC} = \pm 15V$, $T_{amb} = 25^\circ C$ (unless otherwise specified)

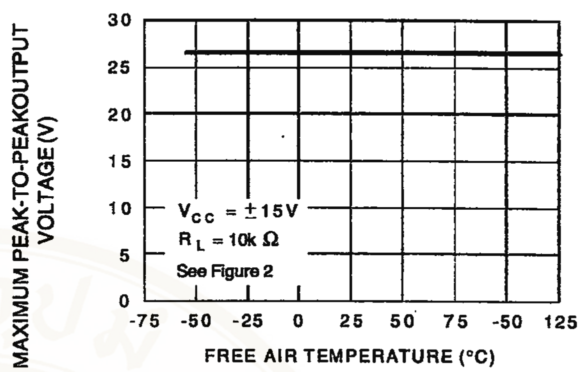
Symbol	Parameter	TL062AC,AI, AM			TL062BC,BI,BM			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input Offset Voltage ($R_s = 50\Omega$) $T_{amb} = 25^\circ C$ $T_{min.} \le T_{amb} \le T_{max.}$		3	6 7.5		2	3 5	mV
DV_{io}	Temperature Coefficient of Input Offset Voltage ($R_s = 50\Omega$)		10			10		µV/°C
I_{io}	Input Offset Current * $T_{amb} = 25^\circ C$ $T_{min.} \le T_{amb} \le T_{max.}$		5	100 3		5	100 3	pA nA
I_{ib}	Input Bias Current * $T_{amb} = 25^\circ C$ $T_{min.} \le T_{amb} \le T_{max.}$		30	200 7		30	200 7	pA nA
V_{icm}	Input Common Mode Voltage Range	±11.5	+15 -12		±11.5	+15 -12		V
V_{OPP}	Output Voltage Swing ($R_L = 10k\Omega$) $T_{amb} = 25^\circ C$ $T_{min.} \le T_{amb} \le T_{max.}$	20 20	27		20 20	27		V
A_{vd}	Large Signal Voltage Gain ($R_L = 10k\Omega$, $V_o = \pm 10V$) $T_{amb} = 25^\circ C$ $T_{min.} \le T_{amb} \le T_{max.}$	4 4	6		4 4	6		V/mV
GBP	Gain Bandwidth Product ($T_{amb} = 25^\circ C$, $R_L = 10k\Omega$, $C_L = 100pF$)		1			1		MHz
R_i	Input Resistance		10^{12}			10^{12}		Ω
CMR	Common Mode Rejection Ratio ($R_s = 50\Omega$)	80	86		80	86		dB
SVR	Supply Voltage Rejection Ratio ($R_s = 50\Omega$)	80	95		80	95		dB
I_{cc}	Supply Current (Per Amplifier) ($T_{amb} = 25^\circ C$, no load, no signal)		200	250		200	250	µA
V_{O1}/V_{O2}	Channel Separation ($A_v = 100$, $T_{amb} = 25^\circ C$)		120			120		
P_D	Total Power Consumption (Each Amplifier) ($T_{amb} = 25^\circ C$, no load, no signal)		6	7.5		6	7.5	mW
SR	Slew Rate ($V_i = 10V$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$)	1.5	3.5		1.5	3.5		V/µs
t_r	Rise Time ($V_i = 20mV$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$)		0.2			0.2		µs
K_{OV}	Overshoot Factor ($V_i = 20mV$, $R_L = 10k\Omega$, $C_L = 100pF$, $A_V = 1$) - (see figure 1)		10			10		%
e_n	Equivalent Input Noise Voltage ($R_s = 100\Omega$, $f = 1KHz$)		42			42		$\frac{nV}{\sqrt{Hz}}$

* The input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive. Pulse techniques must be used that will maintain the junction temperature as close to the ambient temperature as possible.

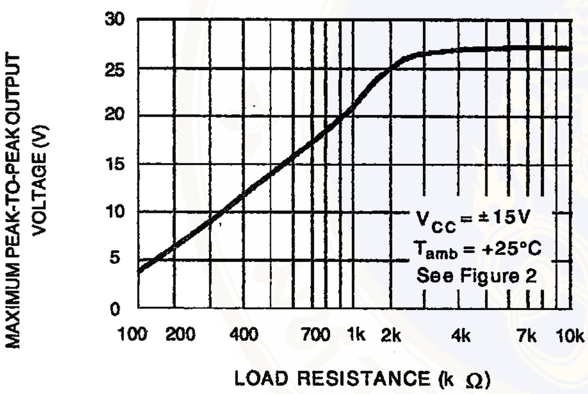
MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE VERSUS SUPPLY VOLTAGE



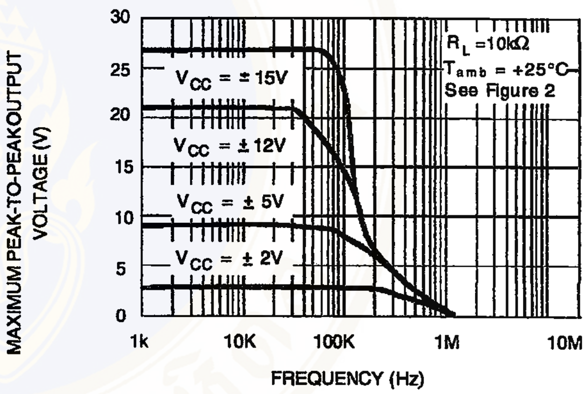
MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE VERSUS FREE AIR TEMP.



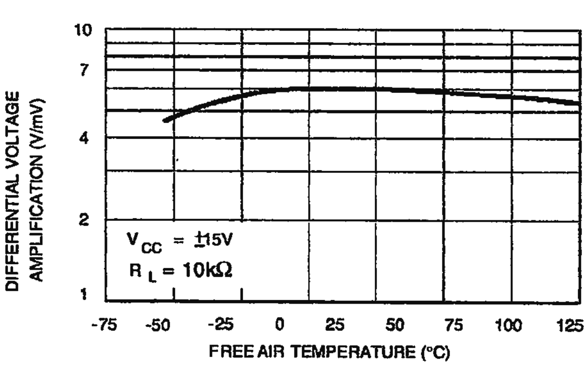
MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE VERSUS LOAD RESISTANCE



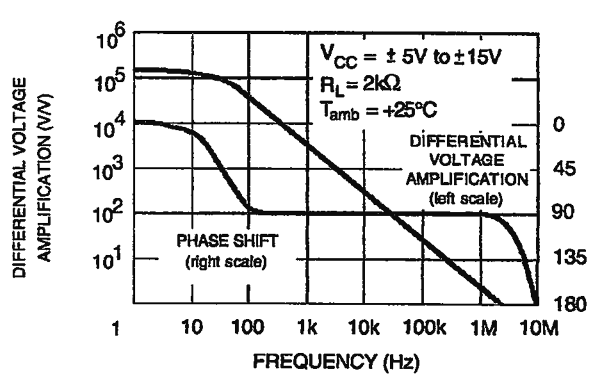
MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE VERSUS FREQUENCY



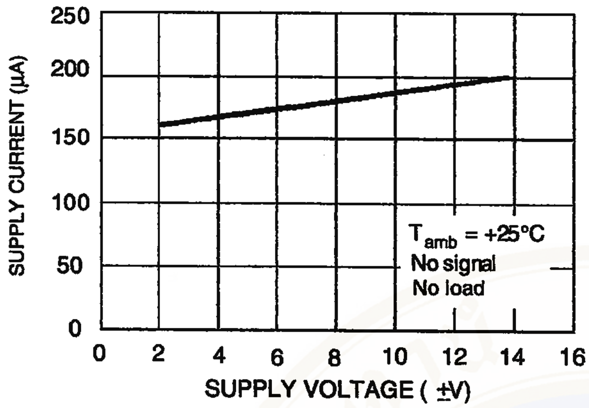
DIFFERENTIAL VOLTAGE AMPLIFICATION VERSUS FREE AIR TEMPERATURE



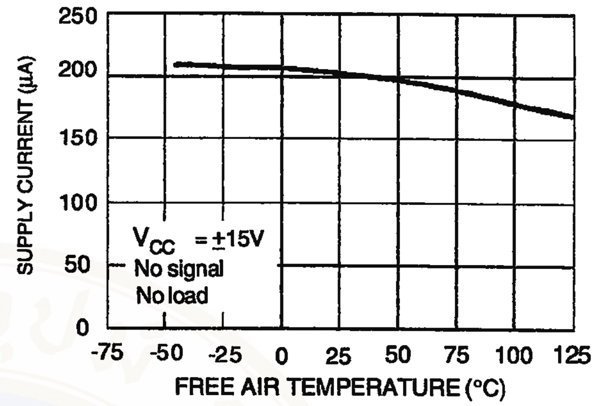
LARGE SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE SHIFT VERSUS FREQUENCY



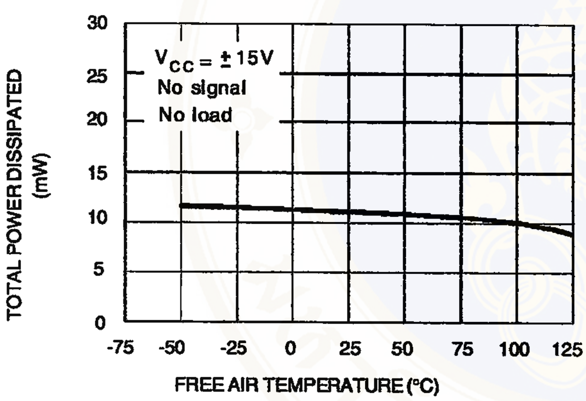
SUPPLY CURRENT PER AMPLIFIER VERSUS SUPPLY VOLTAGE



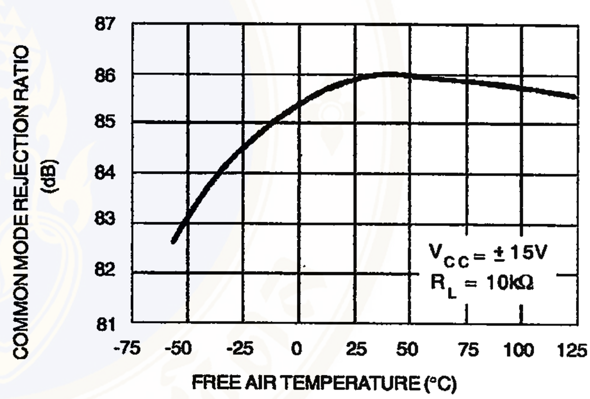
SUPPLY CURRENT PER AMPLIFIER VERSUS FREE AIR TEMPERATURE



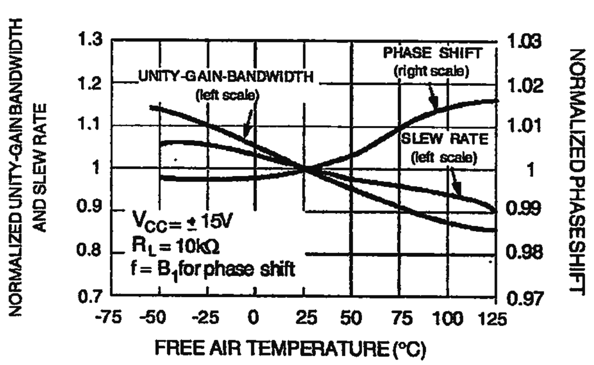
TOTAL POWER DISSIPATED VERSUS FREE AIR TEMPERATURE



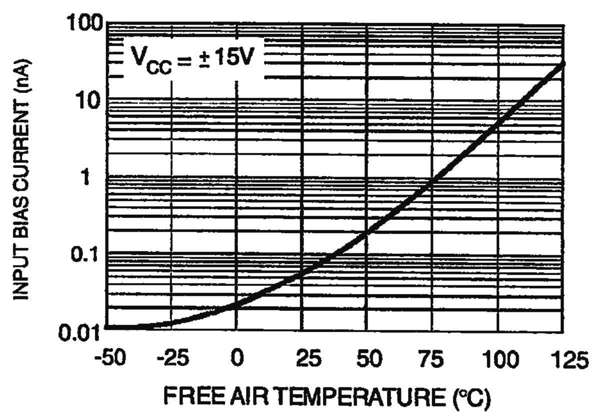
COMMON MODE REJECTION RATIO VERSUS FREE AIR TEMPERATURE



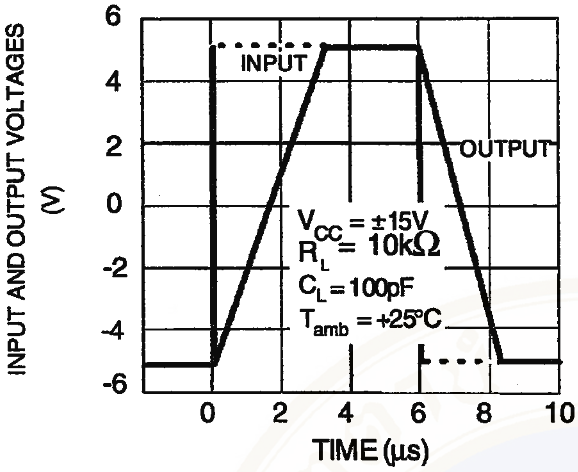
NORMALIZED UNITY GAIN BANDWIDTH SLEW RATE, AND PHASE SHIFT VERSUS TEMPERATURE



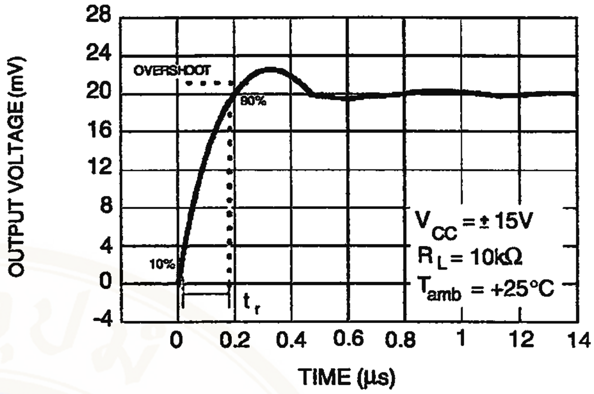
INPUT BIAS CURRENT VERSUS FREE AIR TEMPERATURE



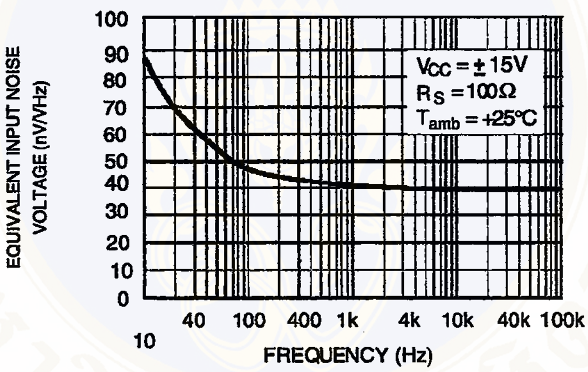
VOLTAGE FOLLOWER LARGE SIGNAL PULSE RESPONSE



OUTPUT VOLTAGE VERSUS ELAPSED TIME



EQUIVALENT INPUT NOISE VOLTAGE VERSUS FREQUENCY



PARAMETER MEASUREMENT INFORMATION

Figure 1 : Voltage follower

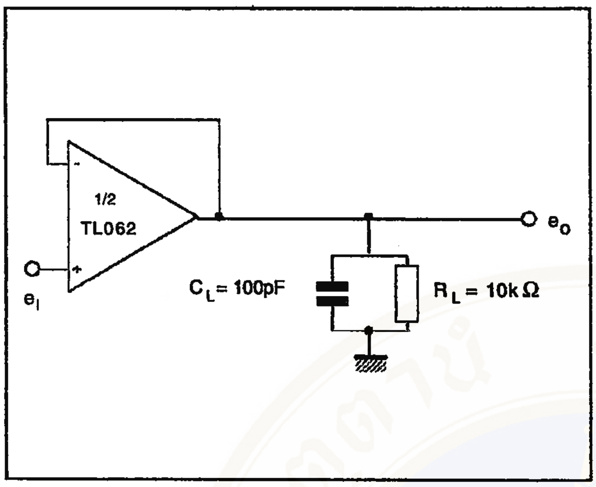
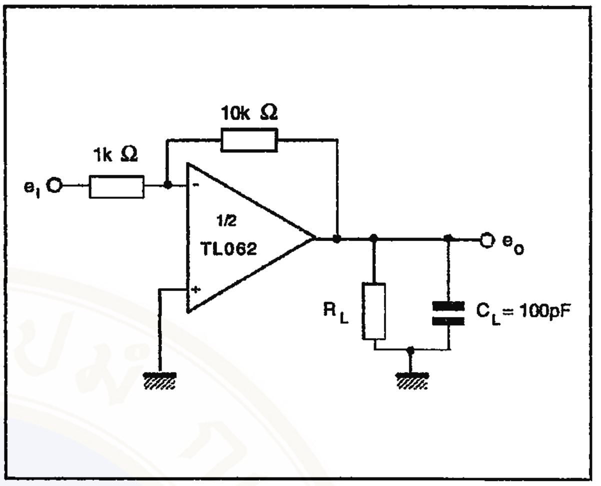
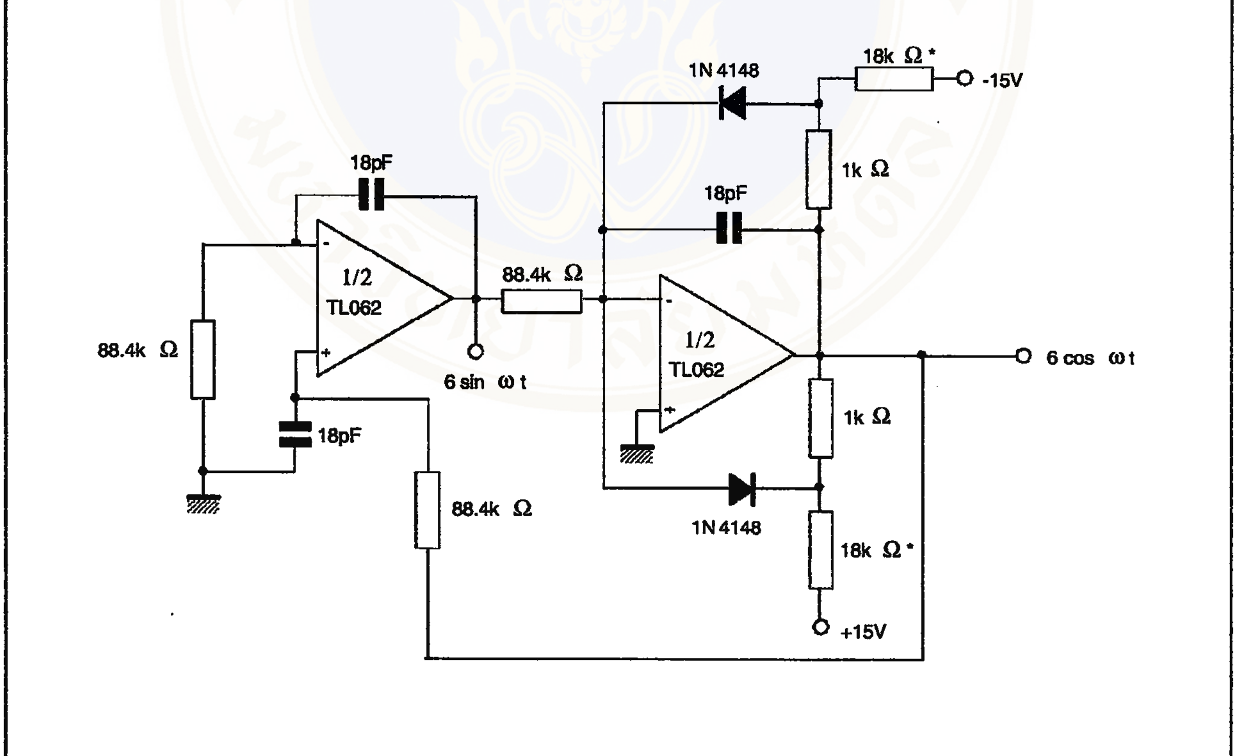


Figure 2 : Gain-of-10 inverting amplifier



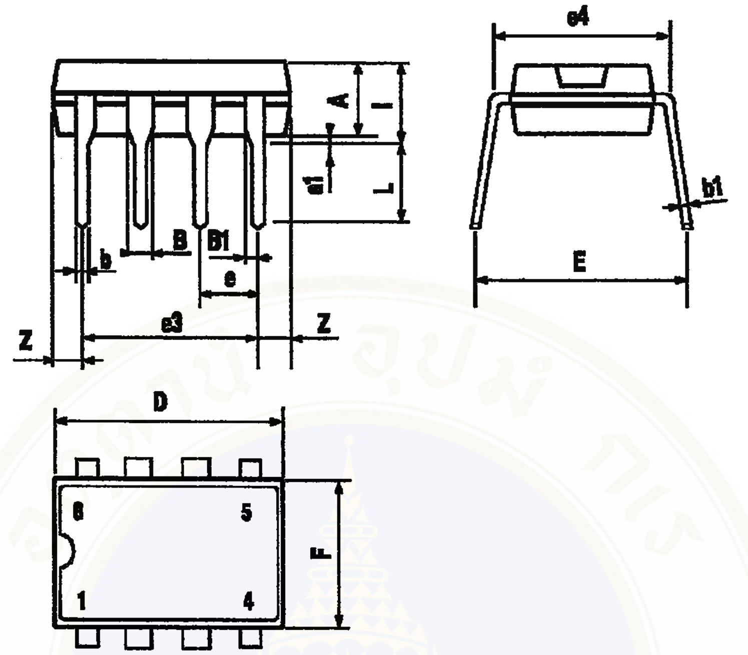
TYPICAL APPLICATION

100KHz QUADRATURE OSCILLATOR



* These resistor values may be adjusted for a symmetrical output

PACKAGE MECHANICAL DATA
8 PINS - PLASTIC DIP

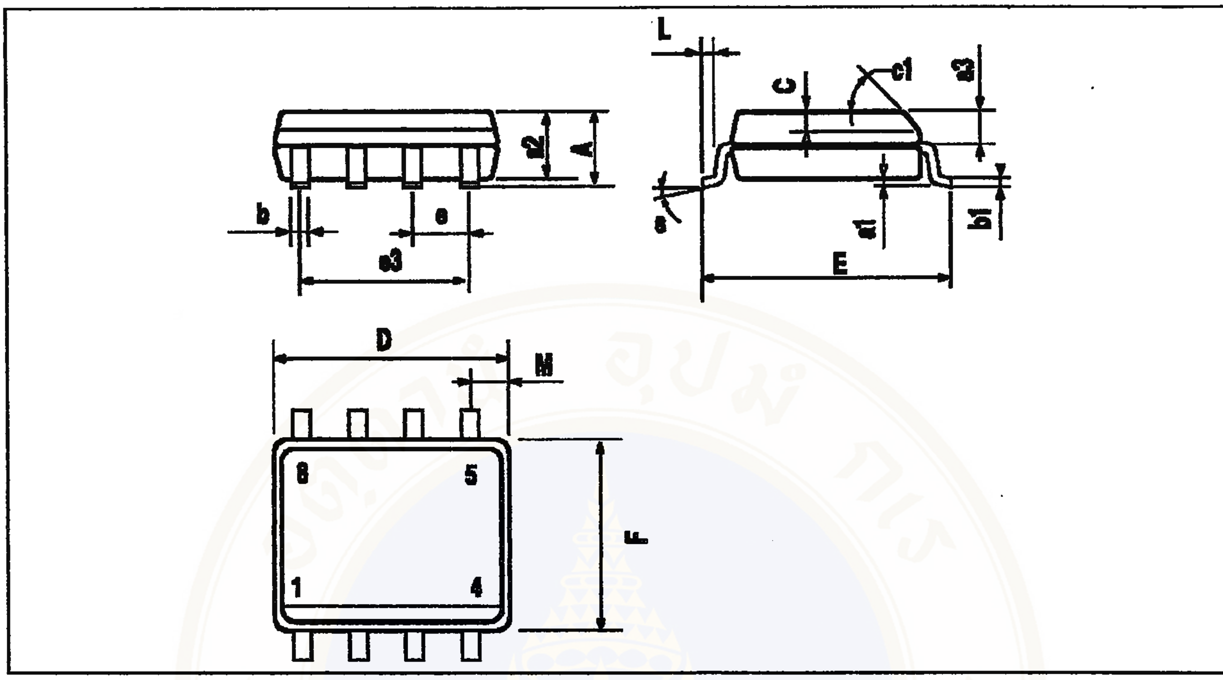


PM-DIP8.EPS

Dimensions	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A		3.32			0.131	
a1	0.51			0.020		
B	1.15		1.65	0.045		0.065
b	0.356		0.55	0.014		0.022
b1	0.204		0.304	0.008		0.012
D			10.92			0.430
E	7.95		9.75	0.313		0.384
e		2.54			0.100	
e3		7.62			0.300	
e4		7.62			0.300	
F			6.6			0260
i			5.08			0.200
L	3.18		3.81	0.125		0.150
Z			1.52			0.060

DIP8.TBL

PACKAGE MECHANICAL DATA
8 PINS - PLASTIC MICROPACKAGE (SO)



PM-SO8.EPS

Dimensions	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
a1	0.1		0.25	0.004		0.010
a2			1.65			0.065
a3	0.65		0.85	0.026		0.033
b	0.35		0.48	0.014		0.019
b1	0.19		0.25	0.007		0.010
C	0.25		0.5	0.010		0.020
c1	45° (typ.)					
D	4.8		5.0	0.189		0.197
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		3.81			0.150	
F	3.8		4.0	0.150		0.157
L	0.4		1.27	0.016		0.050
M			0.6			0.024
S	8° (max.)					

SO8.TBL

LINEAR TECHNOLOGY

LTC1286/LTC1298

Micropower Sampling 12-Bit A/D Converters In S0-8 Packages

FEATURES

- **12-Bit Resolution**
- **8-Pin SOIC Plastic Package**
- **Low Cost**
- **Low Supply Current: 250μA Typ.**
- Auto Shutdown to 1nA Typ.
- Guaranteed ±3/4LSB Max DNL
- Single Supply 5V to 9V Operation
- On-Chip Sample-and-Hold
- 60μs Conversion Time
- Sampling Rates:
  - 12.5 ksps (LTC1286)
  - 11.1 ksps (LTC1298)
- I/O Compatible with SPI, Microwire, etc.
- Differential Inputs (LTC1286)
- 2-Channel MUX (LTC1298)
- 3V Versions Available: LTC1285/LTC1288

APPLICATIONS

- Battery-Operated Systems
- Remote Data Acquisition
- Battery Monitoring
- Handheld Terminal Interface
- Temperature Measurement
- Isolated Data Acquisition

DESCRIPTION

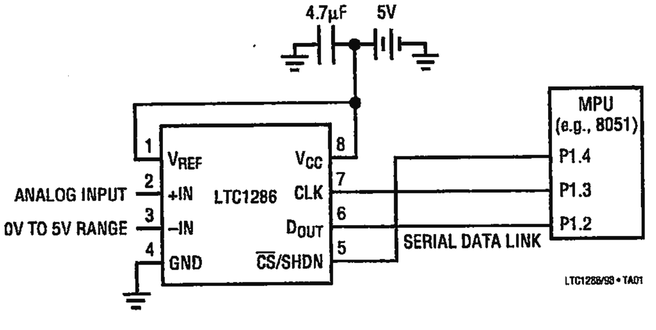
The LTC1286/LTC1298 are micropower, 12-bit, successive approximation sampling A/D converters. They typically draw only 250μA of supply current when converting and automatically power down to a typical supply current of 1nA whenever they are not performing conversions. They are packaged in 8-pin SO packages and operate on 5V to 9V supplies. These 12-bit, switched-capacitor, successive approximation ADCs include sample-and-holds. The LTC1286 has a single differential analog input. The LTC1298 offers a software selectable 2-channel MUX.

On-chip serial ports allow efficient data transfer to a wide range of microprocessors and microcontrollers over three wires. This, coupled with micropower consumption, makes remote location possible and facilitates transmitting data through isolation barriers.

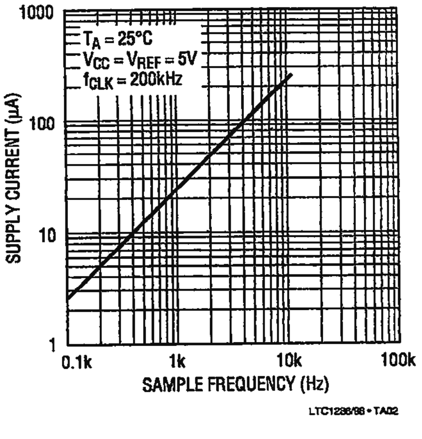
These circuits can be used in ratiometric applications or with an external reference. The high impedance analog inputs and the ability to operate with reduced spans (to 1.5V full scale) allow direct connection to sensors and transducers in many applications, eliminating the need for gain stages.

TYPICAL APPLICATIONS

25μW, S0-8 Package, 12-Bit ADC Samples at 200Hz and Runs Off a 5V Supply



Supply Current vs Sample Rate

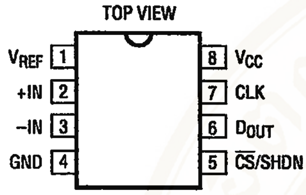


ABSOLUTE MAXIMUM RATINGS (Notes 1 and 2)

Supply Voltage (V_{CC}) to GND 12V
Voltage
Analog and Reference .... −0.3V to V_{CC} + 0.3V
Digital Inputs .... −0.3V to 12V
Digital Output .... −0.3V to V_{CC} + 0.3V
Power Dissipation 500mW
Operating Temperature Range
LTC1286C/LTC1298C .... 0°C to 70°C
LTC1286I/LTC1298I .... −40°C to 85°C
Storage Temperature Range .... −65°C to 150°C
Lead Temperature (Soldering, 10 sec.) .... 300°C

PACKAGE/ORDER INFORMATION

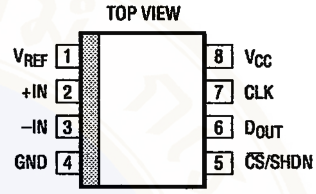
TOP VIEW



N8 PACKAGE
8-LEAD PLASTIC DIP
T_{JMAX} = 150°C, θ_{JA} = 130°C/W

ORDER PART NUMBER
LTC1286CN8 LTC1286IN8

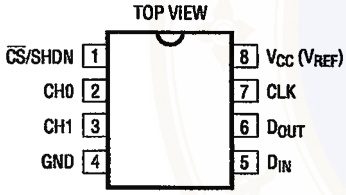
TOP VIEW



S8 PACKAGE
8-LEAD PLASTIC SOIC
T_{JMAX} = 150°C, θ_{JA} = 175°C/W

ORDER PART NUMBER
LTC1286CS8 LTC1286IS8
PART MARKING
1286C 1286I

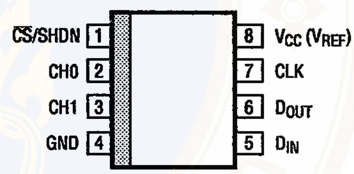
TOP VIEW



N8 PACKAGE
8-LEAD PLASTIC DIP
T_{JMAX} = 150°C, θ_{JA} = 130°C/W

ORDER PART NUMBER
LTC1298CN8 LTC1298IN8

TOP VIEW



S8 PACKAGE
8-LEAD PLASTIC SOIC
T_{JMAX} = 150°C, θ_{JA} = 175°C/W

ORDER PART NUMBER
LTC1298CS8 LTC1298IS8
PART MARKING
1298C 1298I

Consult factory for military grade parts.

RECOMMENDED OPERATING CONDITIONS

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{CC}	Supply Voltage (Note 3)	LTC1286 LTC1298	4.5 4.5		9.0 5.5	V V
f_{CLK}	Clock Frequency	V_{CC} = 5V	(Note 4)		200	kHz
t_{CYC}	Total Cycle Time	LTC1286, f_{CLK} = 200kHz LTC1298, f_{CLK} = 200kHz	80 90			µs µs
t_{hDI}	Hold Time, D_{IN} After CLK↑	V_{CC} = 5V	150			ns
$t_{su\overline{CS}}$	Setup Time $\overline{CS}$↓ Before First CLK↑ (See Operating Sequence)	LTC1286, V_{CC} = 5V LTC1298, V_{CC} = 5V	2 2			µs µs
t_{suDI}	Setup Time, D_{IN} Stable Before CLK↑	V_{CC} = 5V	400			ns
t_{WHCLK}	CLK High Time	V_{CC} = 5V	2			µs
t_{WLCLK}	CLK Low Time	V_{CC} = 5V	2			µs
$t_{WH\overline{CS}}$	$\overline{CS}$ High Time Between Data Transfer Cycles	V_{CC} = 5V	2			µs
$t_{WL\overline{CS}}$	$\overline{CS}$ Low Time During Data Transfer	LTC1286, f_{CLK} = 200kHz LTC1298, f_{CLK} = 200kHz	75 85			µs µs

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CONVERTER AND MULTIPLEXER CHARACTERISTICS (Note 5)

PARAMETER	CONDITIONS		LTC1286 MIN	LTC1286 TYP	LTC1286 MAX	LTC1298 MIN	LTC1298 TYP	LTC1298 MAX	UNITS
Resolution (No Missing Codes)		●	12			12			Bits
Integral Linearity Error	(Note 6)	●		±3/4	±2		±3/4	±2	LSB
Differential Linearity Error		●		±1/4	±3/4		±1/4	±3/4	LSB
Offset Error		●		3/4	±3		3/4	±3	LSB
Gain Error		●		±2	±8		±2	±8	LSB
Analog Input Range	(Note 7 and 8)	●	$-0.05V$ to $V_{CC} + 0.05V$						V
REF Input Range (LTC1286) (Notes 7, 8, and 9)	$4.5 \le V_{CC} \le 5.5V$ $5.5V < V_{CC} \le 9V$		$1.5V$ to $V_{CC} + 0.05V$ $1.5V$ to $5.55V$						V V
Analog Input Leakage Current (Note 10)		●			±1			±1	μA

DIGITAL AND DC ELECTRICAL CHARACTERISTICS (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{IH}	High Level Input Voltage	$V_{CC} = 5.25V$	●	2			V
V_{IL}	Low Level Input Voltage	$V_{CC} = 4.75V$	●			0.8	V
I_{IH}	High Level Input Current	$V_{IN} = V_{CC}$	●			2.5	μA
I_{IL}	Low Level Input Current	$V_{IN} = 0V$	●			−2.5	μA
V_{OH}	High Level Output Voltage	$V_{CC} = 4.75V$, $I_O = 10\mu A$ $V_{CC} = 4.75V$, $I_O = 360\mu A$	● ●	4.0 2.4	4.64 4.62		V V
V_{OL}	Low Level Output Voltage	$V_{CC} = 4.75V$, $I_O = 1.6mA$	●			0.4	V
I_{OZ}	Hi-Z Output Leakage	$\overline{CS}$ = High	●			±3	μA
I_{SOURCE}	Output Source Current	$V_{OUT} = 0V$			−25		mA
I_{SINK}	Output Sink Current	$V_{OUT} = V_{CC}$			45		mA
R_{REF}	Reference Input Resistance (LTC1286)	$\overline{CS} = V_{CC}$ $\overline{CS}$ = GND			5000 55		MΩ kΩ
I_{REF}	Reference Current (LTC1286)	$\overline{CS} = V_{CC}$ $t_{CYC} \ge 640\mu s$, $f_{CLK} \le 25kHz$ $t_{CYC} = 80\mu s$, $f_{CLK} = 200kHz$	● ● ●		0.001 90 90	2.5 140 140	μA μA μA
I_{CC}	Supply Current	$\overline{CS} = V_{CC}$	●		0.001	±3.0	μA
		LTC1286, $t_{CYC} \ge 640\mu s$, $f_{CLK} \le 25kHz$ LTC1286, $t_{CYC} = 80\mu s$, $f_{CLK} = 200kHz$	● ●		200 250	400 500	μA μA
		LTC1298, $t_{CYC} \ge 720\mu s$, $f_{CLK} \le 25kHz$ LTC1298, $t_{CYC} = 90\mu s$, $f_{CLK} = 200kHz$	● ●		290 340	490 640	μA μA

DYNAMIC ACCURACY $f_{SMPL} = 12.5kHz$ (LTC1286), $f_{SMPL} = 11.1kHz$ (LTC1298) (Note 5)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
S/(N +D)	Signal-to-Noise Plus Distortion Ratio	1kHz/7kHz Input Signal		71/68		dB
THD	Total Harmonic Distortion (Up to 5th Harmonic)	1kHz/7kHz Input Signal		−84/−80		dB
SFDR	Spurious-Free Dynamic Range	1kHz/7kHz Input Signal		90/86		dB
	Peak Harmonic or Spurious Noise	1kHz/7kHz Input Signal		−90/−86		dB

AC CHARACTERISTICS (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
t_{SMPL}	Analog Input Sample Time	See Operating Sequence			1.5		CLK Cycles
$f_{SMPL(MAX)}$	Maximum Sampling Frequency	LTC1286 LTC1298	● ●	12.5 11.1			kHz kHz
t_{CONV}	Conversion Time	See Operating Sequence			12		CLK Cycles
t_{dDO}	Delay Time, CLK↓ to D_{OUT} Data Valid	See Test Circuits	●		250	600	ns
t_{dis}	Delay Time, $\overline{CS}$↑ to D_{OUT} Hi-Z	See Test Circuits	●		135	300	ns
t_{en}	Delay Time, CLK↓ to D_{OUT} Enable	See Test Circuits	●		75	200	ns
t_{hDO}	Time Output Data Remains Valid After CLK↓	C_{LOAD} = 100pF			230		ns
t_f	D_{OUT} Fall Time	See Test Circuits	●		20	75	ns
t_r	D_{OUT} Rise Time	See Test Circuits	●		20	75	ns
C_{IN}	Input Capacitance	Analog Inputs, On Channel Analog Inputs, Off Channel Digital Input			20 5 5		pF pF pF

The ● denotes specifications which apply over the full operating temperature range.

Note 1: Absolute maximum ratings are those values beyond which the life of a device may be impaired.

Note 2: All voltage values are with respect to GND.

Note 3: These devices are specified at 5V. For 3V specified devices, see LTC1285 and LTC1288.

Note 4: Increased leakage currents at elevated temperatures cause the S/H to droop, therefore it is recommended that $f_{CLK} \geq$ 120kHz at 85°C, $f_{CLK} \geq$ 75kHz at 70° and $f_{CLK} \geq$ 1kHz at 25°C.

Note 5: V_{CC} = 5V, V_{REF} = 5V and CLK = 200kHz unless otherwise specified.

Note 6: Linearity error is specified between the actual end points of the A/D transfer curve.

Note 7: Two on-chip diodes are tied to each reference and analog input which will conduct for reference or analog input voltages one diode drop below GND or one diode drop above V_{CC}. This spec allows 50mV forward bias of either diode for 4.5V ≤ V_{CC} ≤ 5.5V. This means that as long as the reference or analog input does not exceed the supply voltage by more than 50mV the output code will be correct. To achieve an absolute 0V to 5V input voltage range will therefore require a minimum supply voltage of 4.950V over initial tolerance, temperature variations and loading. For 5.5V < V_{CC} ≤ 9V, reference and analog input range cannot exceed 5.55V. If reference and analog input range are greater than 5.55V, the output code will not be guaranteed to be correct.

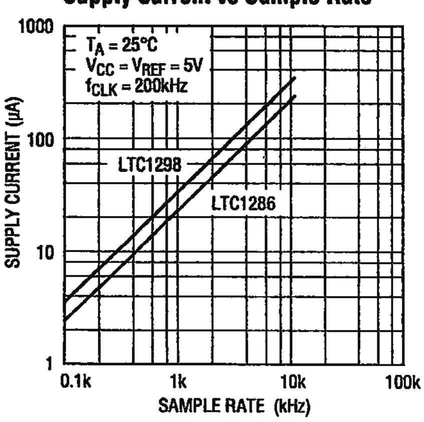
Note 8: The supply voltage range for the LTC1286 is from 4.5V to 9V, but the supply voltage range for the LTC1298 is only from 4.5V to 5.5V.

Note 9: Recommended operating conditions

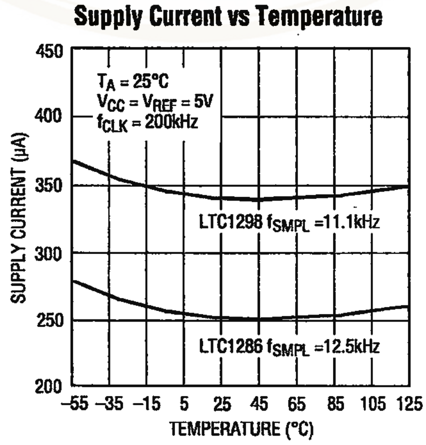
Note 10: Channel leakage current is measured after the channel selection.

TYPICAL PERFORMANCE CHARACTERISTICS

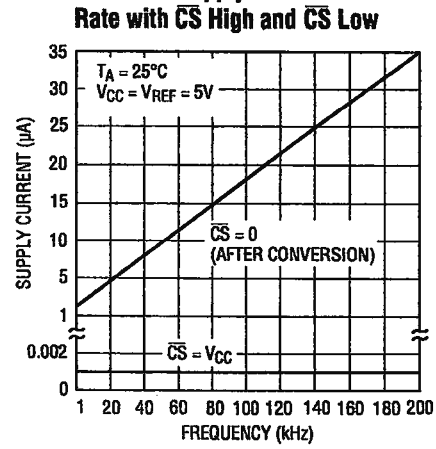
Supply Current vs Sample Rate



Supply Current vs Temperature



Shutdown Supply Current vs Clock Rate with $\overline{CS}$ High and $\overline{CS}$ Low



LINEAR TECHNOLOGY

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