LIGHT TRANSDUCERS & CONTROL

MODULE G13

SAFETY RULES

Carefully follow the instructions contained in this handbook as they supply important indications on the safety of the installation, use and maintenance.

Keep this handbook at hand for any further help.

UNPACKING
After the packaging has been removed, set all accessories in order so that they are not lost and check the equipment integrity. In particular, check that the equipment is integral and shows no visible damage.

Before connecting the power supply to the equipment, be sure wires are connect correctly with the power supply unit.

The power supply cables must be set so that they cannot be trodded upon or squeezed by objects.

On the equipment, there are some slots or opening for the ventilation; to ensure a reliable operation and to protect the equipment from overheating, they must not be blocked or covered. This equipment must be in such a position to enable a proper aeration.

Do never set the equipment on trolleys, supports, tripods, stirrups o unstable tables. The equipment could fall causing damages to the collided persons or it can damage itself. Any installation of the equipment must follow the instructions of the manufacturer and must be carried out using recommended accessories.

This equipment must be employed only for the use it has been conceived, i.e. as educational equipment, and must be used under the direct survey of expert personnel. Any other use is unproper and so dangerous. The manufacturer cannot be considered responsible for eventual damages due to unproper, wrong or unreasonable uses.

PRECAUTIONS!
In order to safeguard the user's safety and the equipment operation, when using electrical equipment some fundamental rules must be followed. In particular the following regulation for use must be followed:

Ambient temperature: from 0 to 45°C.
Relative humidity: from 20 to 80 %.
Avoid any quick shift of temperature and humidity.

In case of fault and/or bad operation, turn off the equipment and do not tamper it. In case of reparation, ask the center for technical assistance or ask exclusively original spare parts. If these conditions are not respected, the equipment can be compromised.

In case of penetration of objects or liquids inside the equipment, and make it checked by qualified personnel before using again.

CLEANING THE EQUIPMENT
Use a soft and dry cloth to clean the container and the silk screen panel. Do never use insecticide or chemical products or solvents for cleaning.

VIBRATIONS OR COLLISIONS
Be careful not to cause vibrations or collisions.

CONTENTS

1 DESCRIPTION OF THE MODULE

Description of the Module

Module G13 with unit TY13/EV enables the study of light transducers and carries out the automatic control of light.
Module G13 consists of 7 separate blocks (see spaces enclosed inside dotted lines in figure 1.1).
These blocks are:
- Set-point
- PID Controller
- Error Amplifier
- Power Amplifier
- Signal Conditioners
  - Photoresistor Conditioner
  - Photodiode Conditioner
  - Phototransistor Conditioner

We are going to analyse the operation of all these blocks in the following chapters, from an electrical point of view and also as a system (input/output ratio and transfer function).
Module G13 is powered by a dual voltage equal to ±12 Vdc 0.5A and a voltage equal to 30Vdc 0.5A.
The external unit TY13/EV (see fig 1.2) contains the actuator (3-Watt incandescent lamp), 3 different light transducers (photodiode, phototransistor, photoresistor) and a second actuator to generate a trouble signal.
The connection between unit TY13/EV and module G13 is achieved via a cable with a 8-pole socket and two unipolar wires: the power amplifier is connected to the actuator via these two wires, while the module powers the transducers and receives their output signals via the 8-pole cable.
The connection between the two parts is achieved by inserting the proper cables on the right side of module G13 (which is called LIGHT PROCESS UNIT).

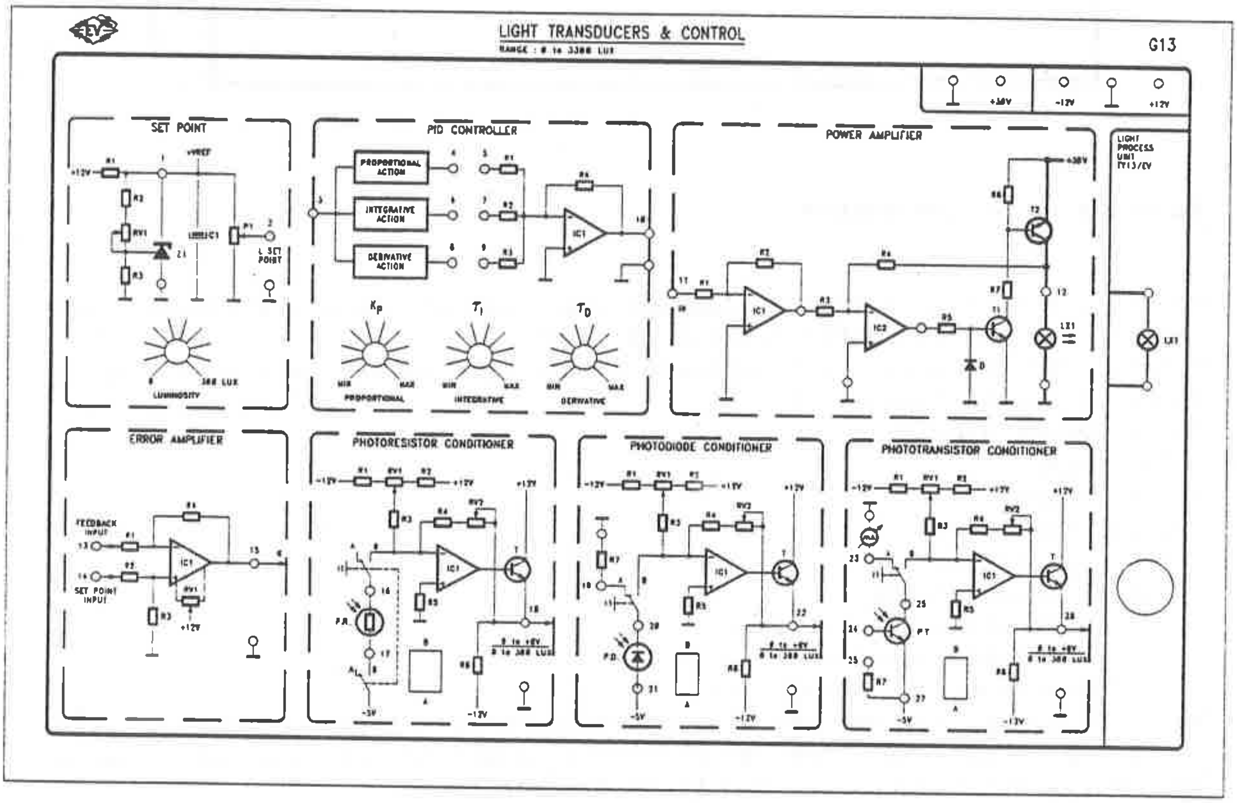

LIGHT TRANSDUCERS & CONTROL
G13
SET POINT
LUMINOSITY
PID CONTROLLER
PROPORTIONAL ACTION
INTEGRATIVE ACTION
DERIVATIVE ACTION
PROPORTIONAL
INTEGRATIVE
DERIVATIVE
POWER AMPLIFIER
LIGHT PROCESS UNIT
ERROR AMPLIFIER
FEEDBACK INPUT
SET POINT INPUT
PHOTORESISTOR CONDITIONER
PHOTODIODE CONDITIONER
PHOTOTRANSISTOR CONDITIONER

fig. 1.1

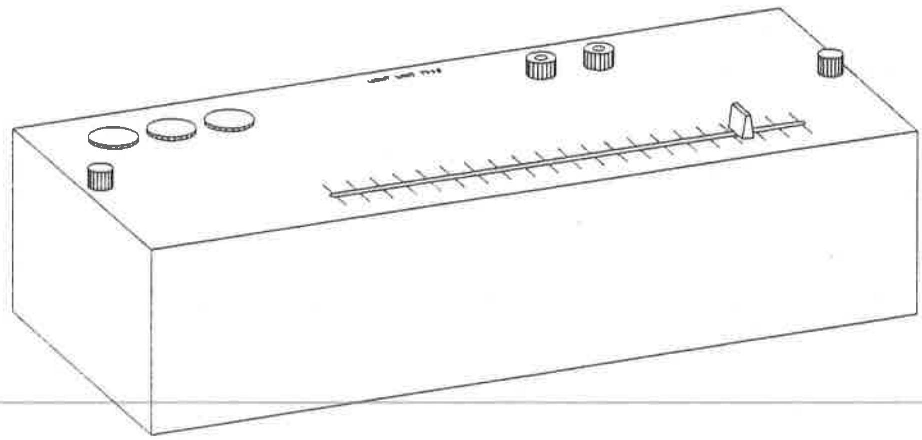


fig. 1.2

2. LIGHT TRANSDUCERS

2.1 Transducer General Concept

Devices converting energy from one form to another are generally called TRANSDUCERS.
Hereafter, this term is used to define those devices which transforms a physical quantity into an electrical one.
The typical block diagram of a transducer is represented in fig. 1.1.
The output electrical quantity of a transducer can be a voltage, a current, a resistor and so on.
According to the different output electrical quantity, transducers are divided into digital or analog: with analog transducers, a D.C. electric input corresponds to a D.C. electrical output proportional to the measured quantity. While in a digital transducer, it corresponds to a series of digital signals.
Generally speaking, this conversion needs such an energy absorption that the transducer is a trouble for the analysed process.

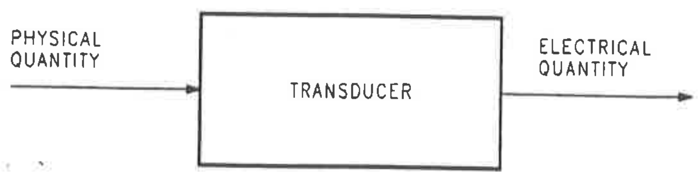


fig. 2.1

The following chapters analyse the detailed characteristics of each single light transducer used in unit TY13/EV.
Each of them has specific and common characteristics, among which the main ones are:

- **Range**
  It is the difference between the minimum and maximum value of the physical quantity to be measured by the transducer.

- **Proportionality factor**
  It is the ratio between input and output values of a certain quantity.

- **Linearity error**
  It is the deviation of the proportionality factor between input and output and is expressed in percentage of the maximum output value.

- **Accuracy (measurement error)**
  It is the maximum deviation between the measured and the effective value and is expressed in percentage of the f.s.d..

- **Response speed**
  It indicates the speed of the output quantity to follow the input variations

- **Stability**
  It is the constant ratio between input and output under all operating conditions.

- **Repeatability**
  It is the tolerance inside which values of the same measurement are included and is normally expressed as a part of accuracy.

2.1.1 Linearity of a Transducer

A large part of transducers is linear type and, during experimentation, the percentage linearity is a major data.
As the procedure for the calculation of the linearity is the same for all transducers, we are now to describe it and we will always refer to it in the development of all the experiences.
In order to determine the transducer input/output curve, a set of measurement is carried out, by detecting the output values corresponding to the different input values of the input physical quantity.
Once the Cartesian diagram is plotted with the points of the measurements detected, the **line**, approximating these points at best, can be traced.

It is the best fitting straight line.

At this point, two lines, parallel and equidistant to the best fitting straight line, can be traced, in a way to include all points of the diagram.
Then, a line parallel to the y-axis has to be traced, and the points where it crosses the two parallel lines are called V1 and V2 (fig. 2.2)
The percentage linearity, referred to the f.s.d., is given by:

$$\text{Lin. } [\%] = \pm \frac{1}{2} \cdot \frac{|V2 - V1|}{V\ f.s.} \cdot 100$$

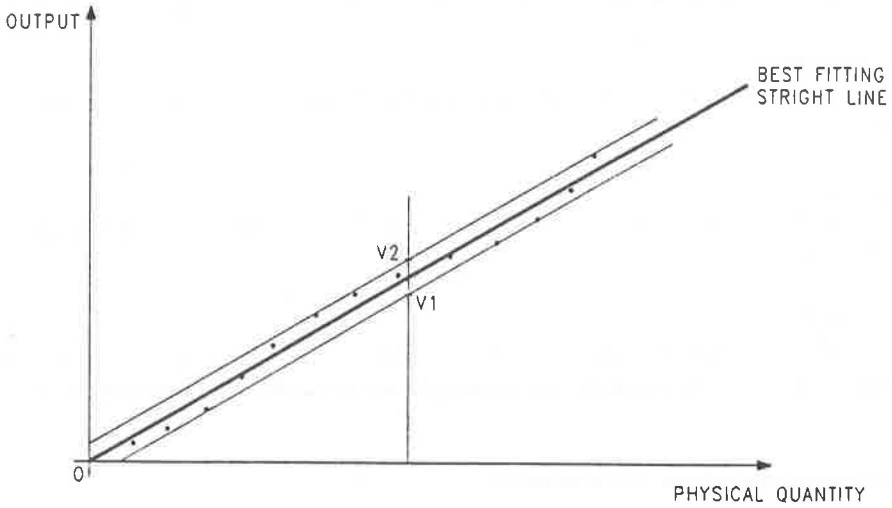


fig. 2.2

2.1.2 Signal Conditioner

Usually, the output electrical quantity of a transducer cannot be directly manipulated.
For example, the output voltage range may not be the wished one, the supplied signal power may be too low, the electric quantity may not be the one requested, and so on.
For these reasons, the transducer is never supplied alone but with a SIGNAL CONDITIONER.
The signal conditioner is an instrument converting an electrical quantity into another electrical one which is more suitable to the

specific application.
In the block diagrams, the signal conditioner is represented as in figure 2.3.

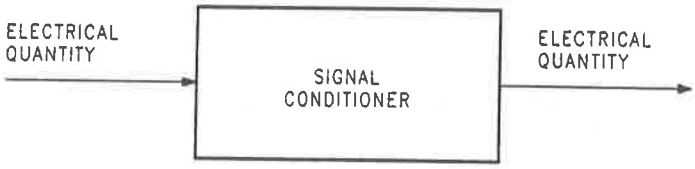


figure 2.3

In most cases, the transducer is integrated into the process to be strictly in contact with the physical quantity to transduce, so the block diagrams generally represent the **Process**, the **Transducer** and the **Signal Conditioner** as in fig. 2.4.

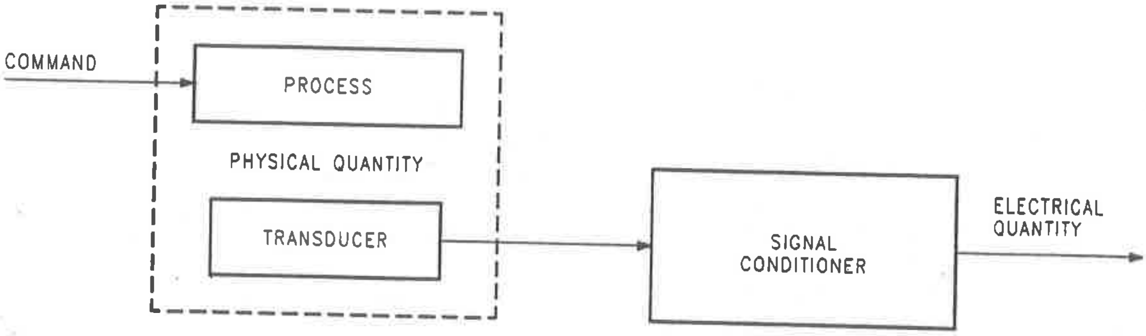


fig. 2.4

2.2 Light Transducers

Light transducers are devices which transform the light radiation into an electrical quantity (resistance, current) and can be used in industry as light transducers and also as indirect transducers of other physical quantities such as position, angular speed and so on.
A light radiation is that region of the electromagnetic spectrum which includes the infrared, visible and ultraviolet components.
Part of the light radiation can be detected by the human eye and is defined as visible radiation or "**Light**". The human eye, anyway, is differently affected by the different wave-lengths of the visible radiation.
Fig. 2.5 shows the generally accepted division of the electromagnetic spectrum: note how limited is the visible part.

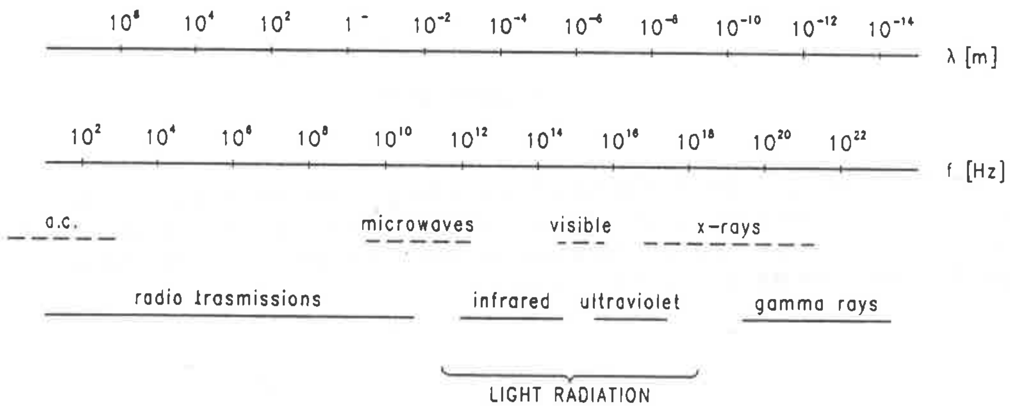


fig. 2.5

The table of fig. 2.6 shows the measurement units of the International System concerning the electromagnetic radiation.
In the study of the electromagnetic radiation, **Photometry** deals strictly with the light phenomena and the units adopted are different from the ones of the International System of measurement as they refer to the characteristics of the human eye.
Particularly, the **light flow** is detected by the radiation flow by weighting it with the standard sensitivity curve of the eye as function of the different wavelengths.
Fig. 2.7 shows the measurement units related to the light quantities; note that when the flow units change, all the other units change, too.

PARAMETER	SYMBOL	DEFINITION	UNIT
RADIANT ENERGY	Qe		joule
RADIANT FLOW	P	$P=\frac{Q}{T}$	joule/s=watt
RADIANT INTENSITY	J	$I=\frac{P}{\omega}$	watt/steradian
RADIATION	H	$H=\frac{P}{A}$	watt/m²

fig. 2.6

PARAMETER	SYMBOL	DEFINITION	UNIT	SYMBOL
LIGHT ENERGY	Qv		lumen*secondo	lm.s
LIGHT FLOW	F	$F=\frac{Qv}{t}$	lumen	lm
LIGHT INTENSITY	I	$I=\frac{F}{\omega}$	lumen/steradian= candela	cd
ILLUMINATION	E	$E=\frac{F}{A}$	lumen/m² =lux	lx

fig. 2.7

Interacting with substance, the light radiation produces different effects.
Among which, there is the **"Photoelectric Effect"** which consists in the liberation of electrons by electromagnetic radiation incident on a metal surface and in case of semiconductors, in the generation of electron-hole pairs.
The first phenomenon is called photoemission and is applied to phototubes, photomultipliers and so on.
As far as concerns the photelectric effects on semiconductors, they can be divided into two kinds and precisely:

1 · Photoconductive Effect

The conductivity of a semiconductor bar depends on the intensity of the light radiation which strikes it.

2 · Photoelectric effect on the junction (Photovoltaic Effect)

The current across a reversely biased P-N junction depends on the intensity of the light radiation.
If the junction is not biased, an electromotive force is generated across it (**Photovoltaic effect**).
Devices belonging to the first category are called photoresistors, while those belonging to the second are called photodiodes, photelectric cells and phototransistors.

Hereafter follow a detailed analysis of these devices.

2.2.1 Photoresistors

The photoresistor is a passive semiconductor component without junction. Figure 2.8 shows the resistance-irradiation characteristic curve of the photoresistor, with related symbol.

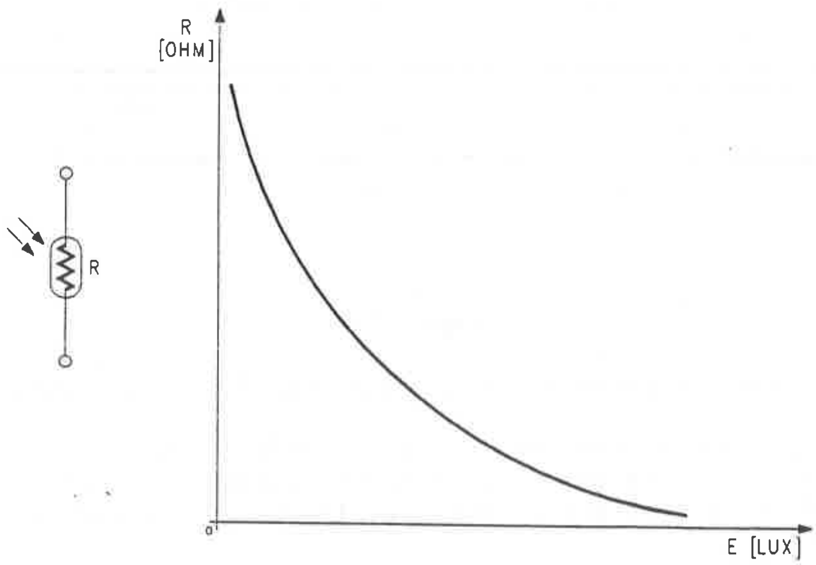


fig. 2.8

When crossed by a light radiation, it varies its resistance as a result of the photoconductive effect: the resistance drops when the light increases.
In dark conditions, the photoresistor practically acts as an insulating piece, as it has resistance values measured in MΩ (dark resistance); if strongly illuminated it has very low resistance values measured up to some tens of Ω.
The material used for a photoresistor determines the wavelength at which the device presents the maximum sensitivity.
The following materials are used as photosensible materials: crystal of cadmium sulphide or lead for sensors within the visible range and crystal of cadmium selenide for sensors in the infrared range.
The parameters of a photoresistor are, in addition to the characteristic curve or the resistive values related to determine light values, are:

- **The wavelength at which it presents the maximum sensitivity.**
- **The maximum power which can be dissipated.**
- **The maximum voltage peak.**

The photoresistor used in unit TY13/EV has the following main characteristics (see data sheet for details):

- **Resistance (10.76 Lux) : 100 KΩ**
- **Resistance (1076 Lux) : 2400 Ω**
- **Minimum dark resistance : 4 MΩ**
- **Maximum voltage peak : 250 V**
- **Maximum dissipable power : 100 mW**
- **Maximum sensitivity: 0.55 µm**

2.2.2 Signal Conditioners for Photoresistor

Refer to figure 2.9.
With switch I1 in the position A, the transducer is disconnected from the rest of the circuit so that it can be analysed without the influence of the other components.

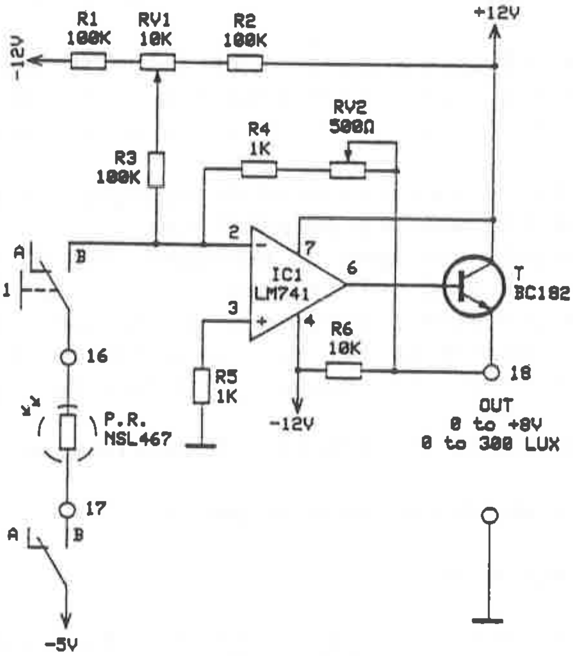


fig. 2.9

Practically, it is possible to insert a multimeter between terminals 16 and 17 for the direct measurement of the resistance of the photoresistor. With I1 to the position B, the photoresistor is connected to the rest of the circuit, particularly to the inverting input of IC1.
N.B.: the voltage equal to -5Vdc, connected to the photoresistor, is taken from -12Vdc via the circuit of figure 2.10

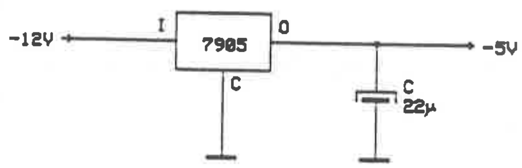


fig 2.10

The amplifier IC1 is connected as inverting amplifier. The input signal consists of a fixed voltage (-5Vdc), while, being the inverting input a virtual ground point, what varies is the resistance of the transducer and consequently the current across the feedback chain (R4 and RV2).
R1, R2, R3 and RV1 are used to zero the offset voltage of IC1 and the voltage generated by the photoresistor at dark.
The transistor T is used to amplify the output current of IC1, which is necessary as the value of the photoresistor (and consequently R4+RV2) is very low.
IC1 varies its output until the voltage of the emitter of the transistor (point from which the signal for the feedback is effectively taken) does not reach such a level to make the same amplifier operate in the linearity region (voltage of the inverting input equal to the voltage of the non inverting input).
The output of the signal conditioner is calibrated so that a light of 300 LUX corresponds to an output voltage of 8 volt.

2.2.3 Photodiode

The photodiode is a device which structure is similar to a common semiconductor diode, with a P-N junction, and, for this kind of use, it is reversely biased.
In dark conditions, the photodiode operates as a common semiconductor diode, while, when the junction is crossed by a light radiation, the reverse current increases.
Fig 2.11 shows a typical relation between illumination and reverse current together with the symbol of the device.

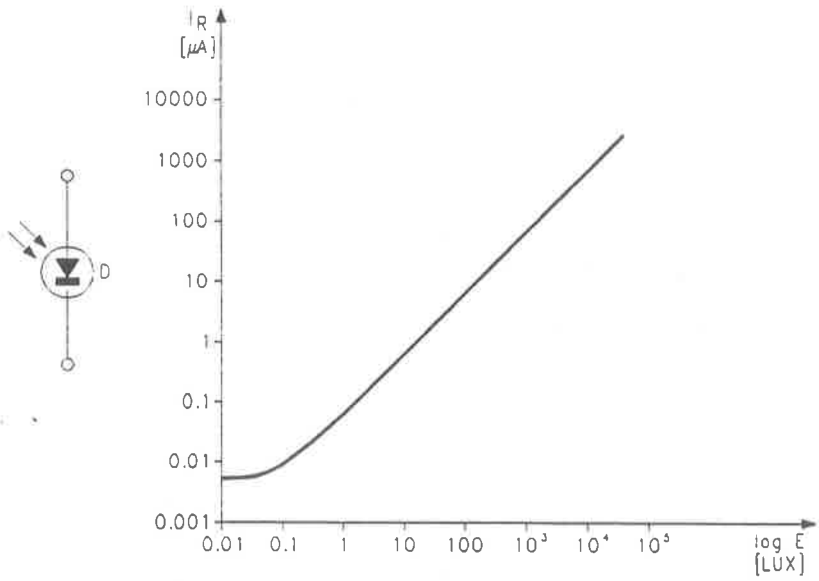


fig. 2.11

The reverse current of photodiodes can take values ranging inside some nA and some tens of mA and the mostly used semiconductor materials are silicon, germanium, gallium arsenide and other semiconductor compounds.
Particularly, silicon photodiodes have the maximum sensitivity to light radiations with wavelength ranging within 0.8 and 0.9 µm, while germanium photodiodes within 1.6 and 1.8 µm, i.e. in the region of the infrared.
The characteristics can be improved with a P-I-N structure, i.e. interposing a not doped semiconductor (Intrinsic) between the two doped semiconductors P and N.
If a photodiode, which is not biased and without load, is illuminated, it is crossed by a voltage generated inside the junction by the interaction between the light radiation and the semiconductive material (photovoltaic effect).
If, then a load is applied to the photodiode, there is a passage of current and , in this way , a generator of electrical energy is created.
The above said is the operating principle of **"Photovoltaic cells"** (further details on these devices can be found in specialized literature).
The typical parameters of photodiodes, beside the characteristic curve or the resistive values concerning some light values, are:

- **The maximum reverse voltage which can be applied across it.**
- **The maximum power which can be dissipated.**
- **Maximum switching speed (rise and fall times).**

The photodiode used in unit TY13/EV is P-I-N silicon type has the following characteristics (see data sheet for details):

- **Maximum reverse voltage: 32 V DC**
- **Maximum sensitivity : 0.9 um**
- **Maximum dark current : 30 nA**
- **Reverse current with illumination equal to 1mW/cm2 : 50 uA**
- **No-load voltage (1000 lux) : 350 mV**
- **Rise and fall times : 50 ns**

2.2.4 Signal Conditioner for Photodiode

Refer to figure 2.12.
With switch I1 in the position A, the transducer is disconnected from the operational amplifier and connected to resistor R7 so that it can be analysed without the influence of the other components.
Practically, it is possible to insert a voltmeter between terminal 20 and ground for the direct measurement of the voltage drop across R7 on the photodiode: in fact the photodiode varies the reverse current which crosses it as function of the electromagnetic radiation which strikes it.
With I1 in the position B, the photodiode is connected to the operational amplifier, particularly to the reverse input of IC1.
N.B.: the voltage equal to -5Vdc, connected to the photoresistor, is taken from -12Vdc via the circuit of figure 2.10
The amplifier IC1 is connected as inverting amplifier. In this case, the usable signal consists of the reverse current of the photodiode removes more or less current from the node of the reverse input.
R1, R2, R3 and RV1 are used to zero the offset voltage of IC1 and to bias the photodiode.
The transistor T is used to amplify the output current of IC1, and, above all, to present a similar situation to the one of the photoresistor.
IC1 varies its output until the voltage of the emitter of the transistor T (point from which the feedback signal is effectively taken) does not reach such a level to make the same amplifier operate in the linearity region (voltage of the inverting input equal to the voltage of the non inverting input).
The output of the signal conditioner is calibrated so that a light of 300 LUX corresponds to an output voltage of 8 volt.

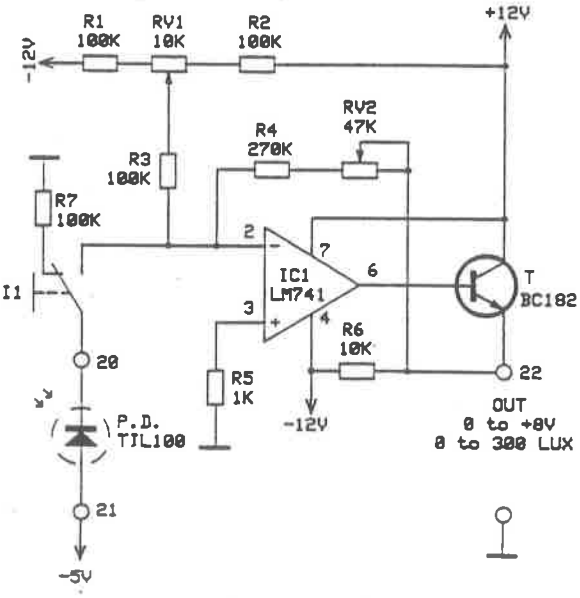


fig. 2.12

2.2.5 Phototransistor

The phototransistor is a device with a structure similar to the one of a standard transistor, but with a photosensible base.
It is generally NPN kind, it is powered with a positive voltage between Collector and Emitter and the Base can be left open or connected to the emitter with a resistor.
In this second case, the sensitivity of the phototransistor can be adjusted by varying the value of the resistor used.
On dark conditions, the current of the collector Ic is minimum and increases with illumination.
Fig. 2.13 shows the symbol with the typical diagram of the connection of the phototransistor; furthermore it shows the characteristic curve with the relation between the variations of Ic and the variations of the illumination E.
The main parameters of a phototransistor, in addition to the characteristic curve, are:

- **The maximum dark current**
- **The wavelength of maximum sensitivity**
- **The switching speed (rise and fall times)**
- **The maximum admitted values of current, voltage and power.**

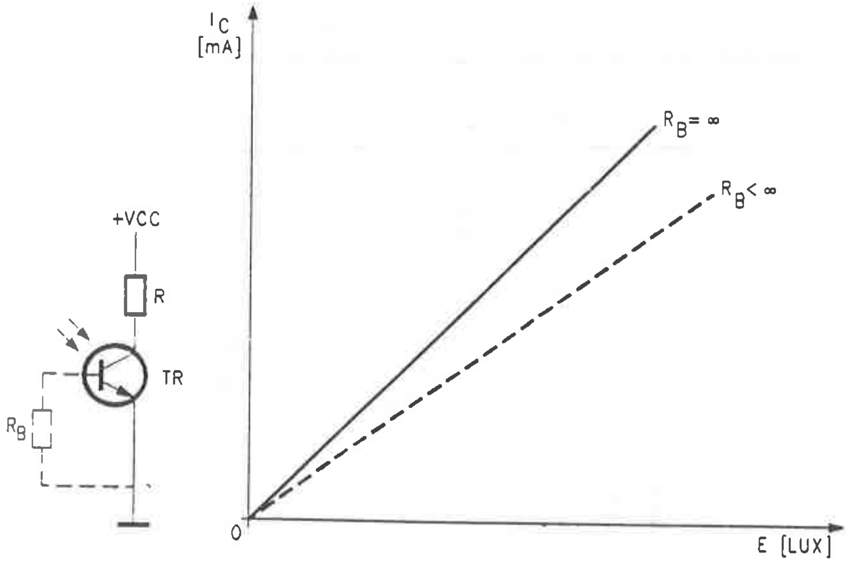


fig. 2.13

The phototransitor used in the equipment has the following main characteristics (see data sheets for details):

- **Dark current : 20 uA**
- **Rise time : 8 µs**
- **Fall time : 6 µs**
- **Vceo max. : 30 V DC**

2.2.6 Signal Conditioner for Phototransistor

Refer to figure 2.14.
With switch I1 in the position A, the transducer is disconnected from the operational amplifier and connected to resistor R7 so that it can be analysed without the influence of the other components.
Practically, it is possible to insert an ammeter between terminals 23 and the terminal connected to ground for the direct measurement of the current generated by the phototransistor by photovoltaic effect.

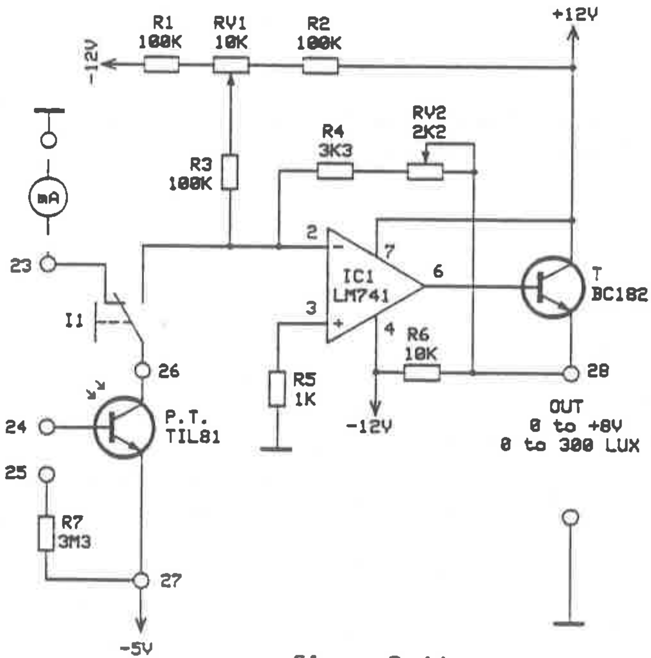


fig. 2.14

With I1 in the position B, the photodiode is connected to the operational amplifier, particularly to the reverse input of IC1.
N.B.: the voltage equal to -5Vdc connected to the photoresistor is taken from -12Vdc via the circuit of figure 2.10
The amplifier IC1 is connected as inverting amplifier. In this case, the usable signal consists of the collector current of the photodiode which removes current from the node of the reverse input in a quantity which depends on the radiation which strikes the base of the phototransistor.
R1, R2, R3 and RV1 are used to zero the offset voltage of IC1 and the voltage generated by the photoresistor at dark.
The transistor T is used to amplify the output current of IC1 and above all to present a very similar situation to the one of the signal conditioners seen before.
IC1 varies its output until the voltage of the emitter of the transistor T (point from which the feedback signal is effectively taken) does not reach such a level to make the same amplifier operate in the linearity region (voltage of the inverting input equal to the voltage of the non inverting input).
The output of the signal conditioner is calibrated so that a light of 300 LUX corresponds to an output voltage of 8 volt.

2.3 Exercises

This section deals with the most significant exercises on light transducers.

Before starting the exercises, check that the signal conditioners have already been calibrated according to the procedures described in the related chapter.

Note on the light source

The illumination necessary to carry out the test on the light transducers is supplied by an incandescent lamp with tungsten filament, powered with 24V which produces the light intensity I of 3 candles.
This lamp is fitted inside the process unit which is provided with a device to move away the sensors from the lamp, so that the energy striking the transducers is varied.
Hereafter, we consider the effect of the reflection inside the unit as not affecting (on this purpose the internal walls have been painted black), the light source as punctiform and the irradiation as uniform in all directions.

The solid angle related to a sphere is equal to $4 \cdot \pi$ steradian, so, with the relation of fig. 2.7 we have:

$$F = 4 \cdot \pi \cdot I \ [\text{lumen}]$$

$$E = \frac{F}{A} = \frac{4 \cdot \pi \cdot I}{4 \cdot \pi \cdot R} = \frac{I}{R} \ [\text{lux}]$$

Referring to the position indications on the panel over unit TY13/EV, we obtain the illumination shown in fig. 2.15 to which we refer during the exercises.

SENSOR FILAMENT DISTANCE [cm]	ILLUMINATION [LUX]	GRADUATED SCALE [cm]
3	3330	0
4	1875	1
5	1200	2
6	830	3
7	612	4
8	468	5
9	370	6
10	300	7
11	248	8
12	208	9
13	177	10
14	153	11
15	133	12
16	117	13
17	104	14
18	93	15
19	83	16
20	75	17
21	68	18
22	62	19
23	57	20

fig. 2.15

2.3.1 Detection of the Characteristic Curve of the Photoresistor

The purpose of this exercise is to determine the characteristic curve of the photoresistor at variation of the illumination.

- Carry out the circuit of figure 2.16 and connect module G13 to unit TY13/EV as in figure 2.17
- Set the switch of the PHOTORESISTOR CONDITIONER block to the position A
- Set the multimeter to measure the resistance and connect it between terminals 16 and 17.
- Connect module G13 to all the necessary supplies.
- Set the lamp to the maximum distance with the slide.
- Set the potentiometer of the SET-POINT block to the maximum value (300 Lux) and the PROPORTIONAL potentiometer of the PID CONTROLLER block to the maximum value.
- Move the lamp near the light transducers with the slide and in correspondence to the divisions shown on the panel of unit TY13/EV, read the resistance value indicated by the multimeter and report them in table 2.1 (column OHM).
- Plot a graph with illumination on the x-axis and resistance on the y-axis and draw the points detected.
- The characteristic curve of the transducer is obtained by joining these points.
- Remove the multimeter from terminals 16 and 17, take the switch to B and insert the multimeter, selected as voltmeter for d.c. voltage, between terminal 18 and ground.

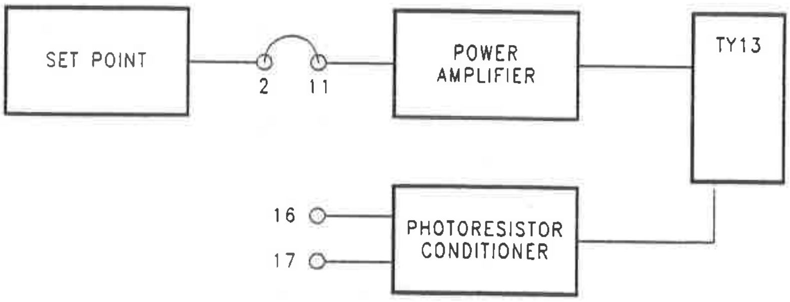


fig. 2.16

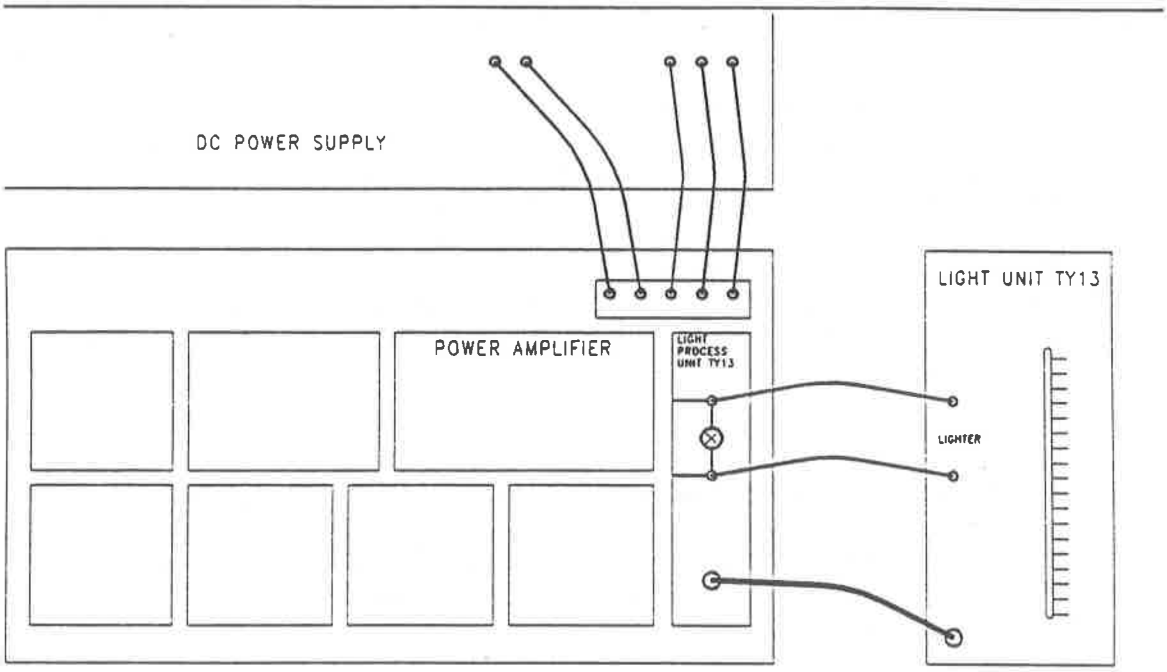


fig. 2.17

- Repeat all the last measurements: in this case measure the response of the transducer together with the one of the signal conditioner.
- Plot a graph with illumination on the x-axis and voltage on the y-axis and draw the points detected.
- The characteristic curve of the transducer together with its signal conditioner is obtained by joining these points.
- Confront the quality of the two graphs.

tab. 2.1

LUX	OHM	VOLT

2.3.2 Determination of the Linearity of the Photoresistor

The purpose of this exercise is to determine the linearity of the system composed by the photoresistor and by the related signal conditioner.
As the characteristic curve of the transducer is far from being a straight line, there is a slight linearity of the system.
Proceed as in the last exercise. When the table and graph have been completed, follow the procedure described in chapter 2.1.1.

2.3.3 Plotting of the Characteristic Curve of the Photodiode

The purpose of the exercise is to plot the characteristic curve of the photodiode, together with its signal conditioner, at variations of the illumination.

- Carry out the circuit of figure 2.18 and connect module G13 to unit TY13/EV as in figure 2.17
- Set the switch of the PHOTODIODE CONDITIONER block to the position A
- Set the multimeter for voltage measurements and connect it between terminal 19 and ground.
  In this case, although a current is generated by the transducer, it is preferable to measure the fall this current determines on the resistor R7 as the same current is a very small.
- Connect module G13 to all the necessary supplies.
- Set the lamp to the maximum distance with the slide.
- Set the potentiometer of the SET-POINT block to the maximum value (300 Lux) and the PROPORTIONAL potentiometer of the PID CONTROLLER block to the maximum value.
- Move the lamp near the light transducers with the slide and in correspondence to the divisions shown on the panel of unit TY13/EV, read the resistance value indicated by the multimeter and report them in table 2.2.
- Plot a graph with illumination on the x-axis and voltage of the diode cathode on the y-axis and draw the points detected.
- The characteristic curve of the transducer is obtained by joining these points.
- Remove the voltmeter from terminal 19, take the switch to B and insert the voltmeter between terminals 19 and ground.
- Repeat all the last measurements: in this case measure the response of the transducer together with the one of the signal conditioner.
- Plot a graph with illumination on the x-axis and voltage on the y-axis and draw the points detected.
- The characteristic curve of the transducer together with the one of its signal conditioner is obtained by joining these points.
- Confront the quality of the two graphs.

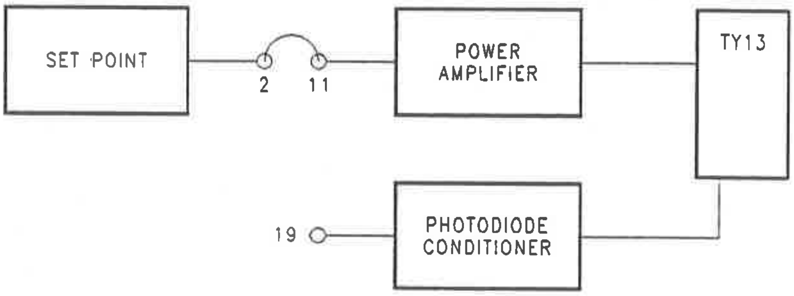


fig. 2.18

tab. 2.2

LUX	Vout(19)	Vout(22)

2.3.4 Determination of the Linearity of the Photodiode

The purpose of this exercise to determine the linearity of the system composed by the photodiode and its signal conditioner.
Proceed as in the last exercise. When the table and graph have been completed, follow the procedure described in chapter 2.1.1.

2.3.5 Plotting of the Characteristic Curve of the Phototransistor

The purpose of this exercise is to plot the characteristic curve of the photoresistor at variations of the illumination.

- Carry out the circuit of figure 2.19 and connect module G13 to unit TY13/EV as in figure 2.17
- Set the switch of the PHOTOTRANSISTOR CONDITIONER block to the position A
- Set the multimeter for current measurements and connect its terminals between terminal 23 and ground.
- Connect module G13 to all the necessary supplies.
- Set the lamp to the maximum distance with the slide.
- Set the potentiometer of the SET-POINT block to the maximum value (300 Lux) and the PROPORTIONAL potentiometer of the PID CONTROLLER block to the maximum value.
- Move the lamp near the light transducers with the slide, and in correspondence to the divisions shown on the panel of unit TY13/EV, read the resistance values indicated by the multimeter and report them in table 2.3.
- Plot a graph with illumination on the x-axis and current on the y-axis and draw the points detected.
- The characteristic curve of the transducer is obtained by joining these points.
- Remove the multimeter terminal 23 and ground, take the switch to B and insert the multimeter, selected as voltmeter for d.c. voltage, between terminal 28 and ground.
- Repeat all the last measurements: in this case measure the response of the transducer together with the one of the signal conditioner.
- Plot a graph with illumination on the x-axis and voltage on the y-axis ordinates and draw the points detected.
- The characteristic curve of the transducer together with its signal conditioner is obtained by joining these points.
- Confront the quality of the two graphs.

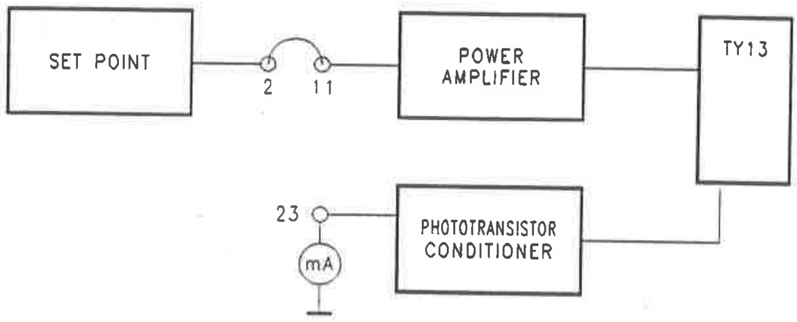


fig. 2.19

tab. 2.3

LUX	AMPERE(μA)	VOLT

2.3.6 Determination of the Linearity of the Phototransistor

The purpose of this exercise is to determine the linearity of the system composed by the phototransistor and the related signal conditioner. Proceed as in the last exercise. When the table and graph have been completed, follow the procedure described in chapter 2.1.1.

3. THE AUTOMATIC CONTROL

3.1 GENERAL FEATURES

Before dealing with the description of light control, let's make a summary of the main concepts of automatic control which are necessary for the understanding of the same process.
We want to point out that this handbook is not a treatise on Automatic Controls, but only takes the concepts of this theory which are necessary to explain process controls.
A "**PHYSICAL PROCESS**" , which can be simply called "**PROCESS**" is a set of physical transformations and /or of substance and /or energy transmissions.
Examples of industrial processes are: oil refinery, metal rolling, steam production, and so on.
These complex processes consists of elementary processes, which are the subjects of this handbook.
The theory of Automatic Controls demonstrates, in fact, that the knowledge of the single parts of the systems gives the knowledge of the system as a whole.
"**CONTROL**" means the control actions to be performed to obtain the wished course of the process.
"**AUTOMATIC CONTROL**" means the control performed without man's operation.
These actions will be performed by the devices of the " **CONTROL SYSTEM**".
Manual control is when man's action varies according to the results from the comparison among the assumed and established values of the controlled quantity.
Automatic control is when the system itself can control the control variables in order to cancel the difference among the assumed and established values of the controlled quantity.
"**INPUT**" or "**SET-POINT**" is the stimulus (or excitation) applied to the control system.
The "**OUTPUT**" is the variable of the process which is to be controlled.
"**SYSTEM**", is the union of process and control system.

3.1.1 Block Diagram

When studying control systems, it is useful to graphically describe the interaction among the different components in order to point out the transmitted information stream and the actions of each process variable onto the others.
This graphical representation is called "FUNCTIONAL BLOCK DIAGRAM".
Fig. 3.1 shows a functional block with input and output oriented segments representing the information stream.

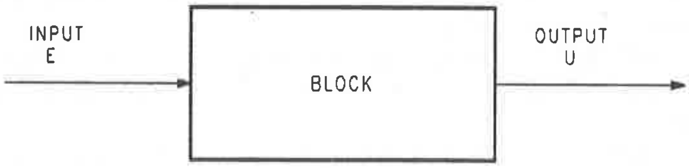


fig. 3.1

A block can be characterised only by defining the output as a function of the input.
The most accurate way to do it is by using the **"Transfer Function"**, which can generally be expressed with :

$$F = \frac{U}{E}$$

where E is the input signal (with variable s, see Laplace transf.) and U is the output signal (always with variable s).
Addiction and subtraction are represented with adding and subtracting poles; they are replaced by circles in which the + and - signs are indicated as necessary for the arrows entering or leaving the circle (fig. 3.2).
Any number of inputs may enter an adder.

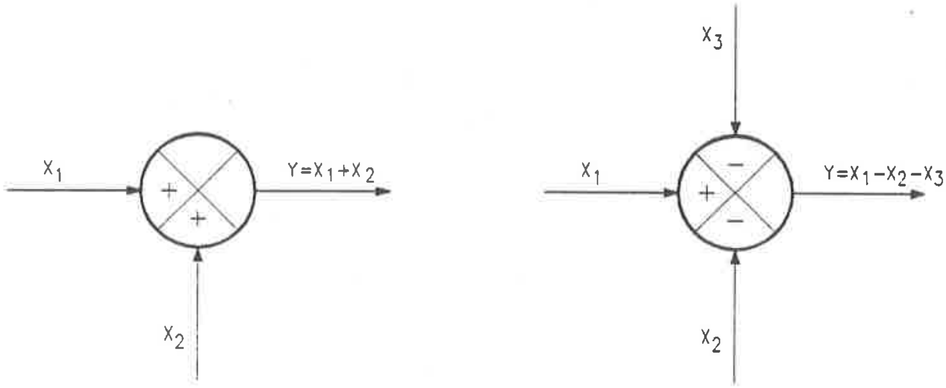


fig. 3.2

If the same signal is to be used as an input variable into more than one block or adder, a branch point is used (fig. 3.3).
From a starting block representation of the system, it is possible to change two or more elementary blocks with a single block whose transfer function will correspond to the combination of each block transfer function, representing the whole system with a single block.
The rules collecting this operations are called "block diagram algebra".

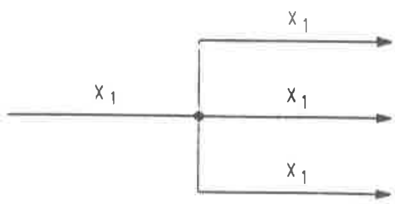


fig. 3.3

3.1.2 Control Systems Classification

The control systems are classified into two general categories, precisely:

* **Open-loop systems.**

* **Closed-loop or Feedback Systems**

Open-loop systems are those in which the control action is independent of the output. In closed-loop systems, the control action depends, in some way on the output.
The difference among the values of the controlled and the reference quantity will produce an action aimed at cancelling the difference itself.
Fig. 3.4 shows the block diagram of a negative feedback control system.

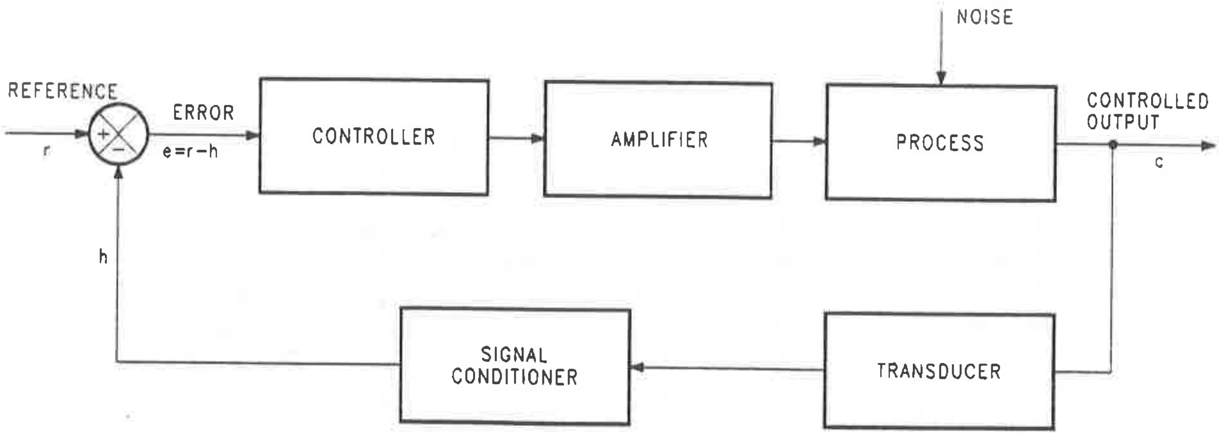


fig. 3.4

The meaning of the blocks and the signals is the following:

- **Controller:** It is the group of devices required to generate the particular control signal to be applied to the amplifier and then to the process.
- **Transducer and Signal Conditioner:** are the devices converting the controlled output quantity into a Set-Point homogeneous one.
- **Error signal:** it is the signal obtained from the difference between the Set-Point and the feedback signal coming from the Signal Conditioner.
- **Disturbance:** it is an unwished (input) signal which affects the value of the output.

The **main advantages** of closed-loop control in respect to open-loop one can be listed as follows:

- **Less sensibility to parametric variations**
- **Less influence on the disturbing quantities**

These advantages are important because parameters variations and disturbances are unexpected.

3.1.3 Canonical Form of Feedback Systems

Let us examine the feedback system represented by the block diagram in fig. 3.5.
This configuration is known as the " **Canonical form**" of a feedback control system.
Any feedback system, of any degree of complexity, may be reduced to the canonical form.

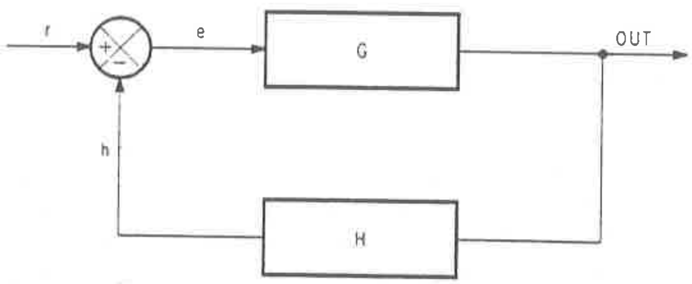


fig. 3.5

3.1.4 Linear Systems - Differential Equations

A system may be defined as LINEAR (and may therefore normally be described by a linear differential equation) if it satisfies the following requirements: if an input X1(t) produces an output Y1(t) and an input X2(t) produces an output Y2(t), then an input C1·X1(t)+C2·X2(t) produces an output C1·Y1(t) + C2·Y2(t), for every pair of inputs X1(t) and X2(t) and every pair of real constants C1 and C2.
In other words, the concept of linearity may be represented by the effect superposition.
Actually, no physical system can be described with precision by a linear differential equation with constant coefficients; however many systems may be described, although on limited operational fields, using this type of equations.
The solution of a linear differential equation with constant coefficients, is the response of the system which it describes. It may be divided into two parts:

- **free response**
- **forced response**

Free response is the solution of the differential equation when the input variable is identically zero.
A forced response is the solution to the differential equation when all starting conditions are equal to zero.
The sum of these two responses represents the **total response** of the system.
The total response may also be considered as the sum of two particular responses:

- **transient response**
- **steady-state response**

These terms are often used to specify the characteristics of the system and can be derived with particular input canonical functions.

3.1.5 The Laplace Transform

Some of the techniques used in solving engineering problems are based on the replacement of functions of a real variable (normally time) by functions or representations depending on the frequency.
The Laplace transform is a transformation technique relating time functions to frequency dependent functions of a complex variable.
The mathematical transformation is extremely useful in solving linear differential equations with constant coefficients.
When the problem has been solved in terms of complex functions, this transformation must be inverted in order to return to the time domain (Inverse Laplace Transform).

3.1.6 Canonical Functions

The following functions are mainly used when studying control systems:

- **unit impulse function**
- **unit step function**
- **unit ramp function**

Each of these functions is linked to the others by one or more integrations or derivations.
These functions are important because the response obtained by the process with these inputs, supplies information for the same system characterisation.
Particularly, the characteristics are:

- **Sensibility**
- **Accuracy**
- **Response speed**
- **Stability**

3.1.7 Sensitivity of a Control System

Sensitivity can be defined as the smallest variation of the reference quantity causing variations on the output quantity, or as the smallest error producing a control action.

3.1.8 Accuracy of a Control System.

Accuracy is the approximation with which a controlled quantity is kept to a set-point value.
The difference between the effective and the set-point values of the controlled quantity is defined as **error.**
Accuracy and errors can be measured in steady and in transient conditions as well; in the first case there is a static error, in the second a dynamic one.

3.1.9 Speed of Response - Time of Response

The speed of response is the speed of a system to reach a new balance; it depends on the time constants, that is the delays produced by the different elements of the system.
Similarly the time of response is the time employed to reach the balance.
The time of response can be measured in two different ways, as the following figure shows (fig. 3.6).
Here we refer to the first way.

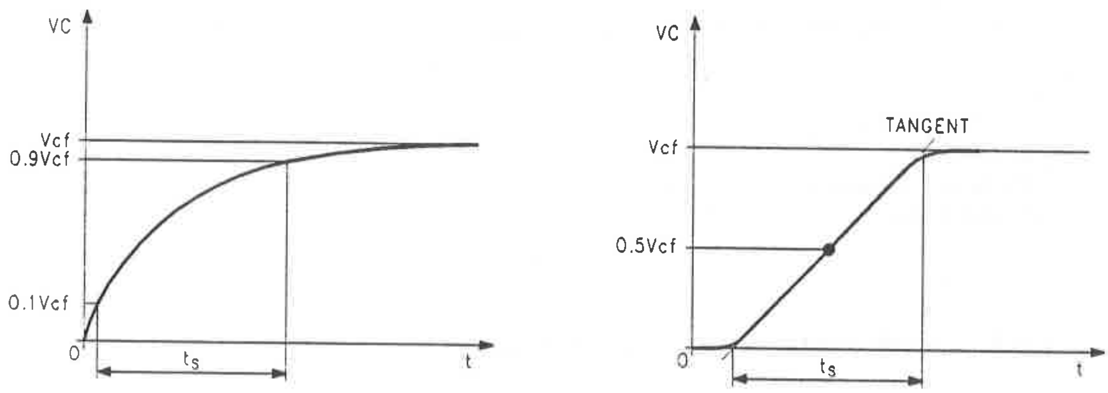


fig. 3.6

3.1.10 Stability of a Control System.

Stability is the system ability to reach the balance with aperiodic or damped oscillating operation.
With permanent or increasing oscillations, the system will be defined as unstable.
Instability occurs when delay elements are present in the control system components: this causes over-regulations phenomena which may generate permanent oscillations.
Fig. 3.7 shows three different transient operations: aperiodic, damped periodic and permanent periodic.

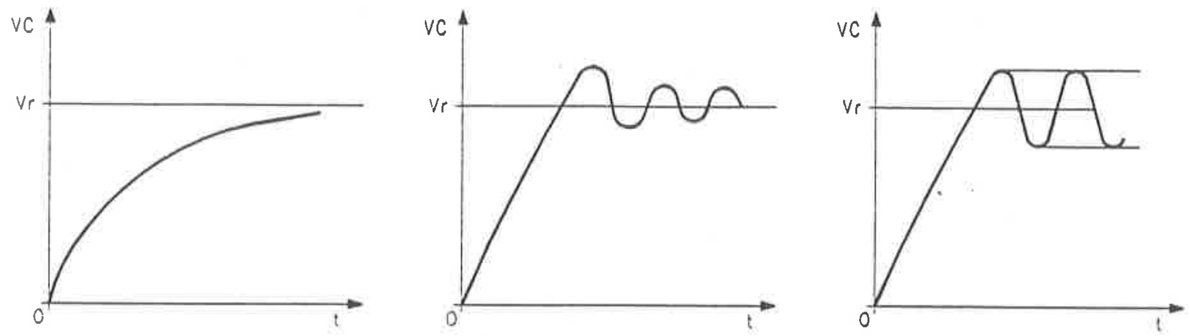


fig. 3.7

With damped oscillations, the maximum value reached by the controlled quantity in transient conditions (Vcm) and its ratio in respect to the finished transient condition (Vc∞) (fig. 3.9) are important.

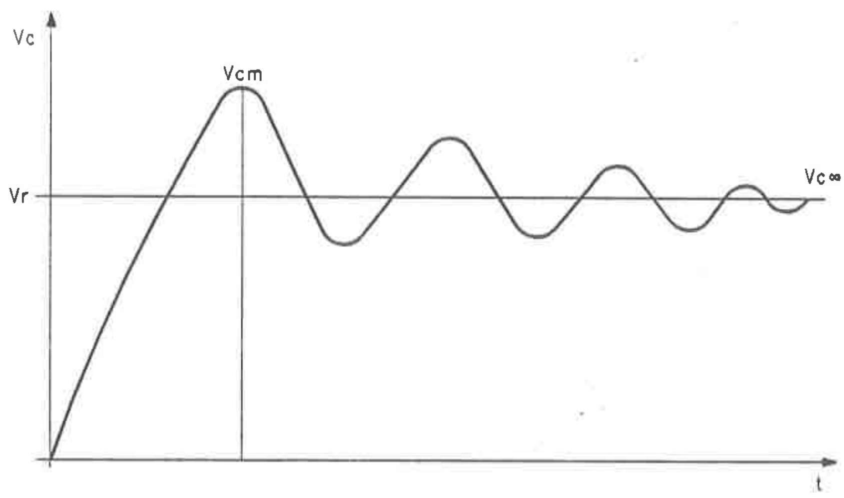


fig. 3.8

The following ratio is defined as over-elongation:

$$Se = \frac{Vcm - Vc\infty}{Vc\infty}$$

3.1.11 Control System Analysis

The main purpose of analysing a feedback control system is to determine the following characteristics:

*** transient response**
*** steady state response**
*** degree of stability**

It is often not sufficient to know whether a system is stable; it is therefore normally necessary to determine the relative stability which is closely linked to the system transient response.
As it is difficult to study (i.e. directly solve the differential equation) systems above second-order in the time domain, different **GRAPHIC METHODS** exists allowing the analysis of feedback control systems.
They are:

* Root locus plot (s-domain study)

* Bode diagram (w-domain study)

* Nyquist diagram (w-domain study)

* Nichols chart (w-domain study)

3.2 Control System Design

As regards the design, the main purpose is to obtain the desired behavioral specifications, in terms of speed response, accuracy and stability.
The latter may be classified as follows:

* **frequency-domain specifications**

* **time-domain specifications.**

Frequency-domain specifications are normally presented in the following terms:

a) gain margin

b) phase margin

c) bandwidth

d) cutoff rate

e) resonance amplitude peak

f) resonance frequency

Time-domain specifications are normally defined in terms of unit-step response, which has one steady state component and one transient component.
Steady state performance is indicative of the accuracy of the system, while transient performance is indicative of the speed of response and the relative stability.
Typical time domain specifications are:

a) overshoot

b) delay time

c) rise time

d) settling time

e) dominant time constant

Considering that the transfer function of the system is difficult to modify, it is necessary to introduce an appropriate compensating block, the "**CONTROLLER**" (fig. 3.4).
The controller can be active type (amplifier, integrative, derivative or with two or three positions) or passive type (lag network and lead network).
The parameters of a standard regulator can be modified in order to obtain the desired responses of the process (controller prearrangements).

Standard regulators which are normally used in industry are active type, and all include proportional, integrative and derivative actions and controlled parameters which give rise to the actions of the type explained below.
For some applications, a two-position (ON-OFF) controller can be used for unidirectional systems while a three-position controller for bidirectional ones.
A controller of the last type determines the interval application of power to the actuator with consequent "triangular" operation of the controlled variable.

3.2.1 Proportional Action (P)

This action is introduced by an amplifier/attenuator.
The output, apart from the coefficient of amplification/attenuation, is identical to the output.
Fig. 3.9 shows an amplifier /attenuator whose transfer function value is KP.

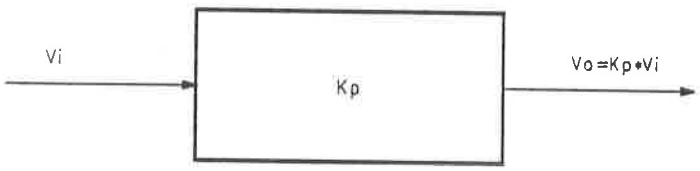


fig. 3.9

3.2.2 Integrative Action (I)

This action is introduced by a pure integrator.
The block transfer function (fig. 3.10) producing the integrative action, is:

$$W(s) = \frac{KI}{s} = \frac{1}{\tau I \cdot s}$$

where τI is the "time constant of the integrative action".
The output, relative to a step input, presents a linear delay. After a period equivalent to the time of the integrative action, the output reaches the value of the input (fig. 3.11).

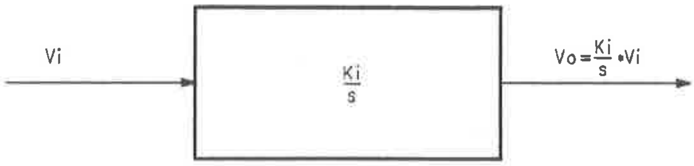


fig. 3.10

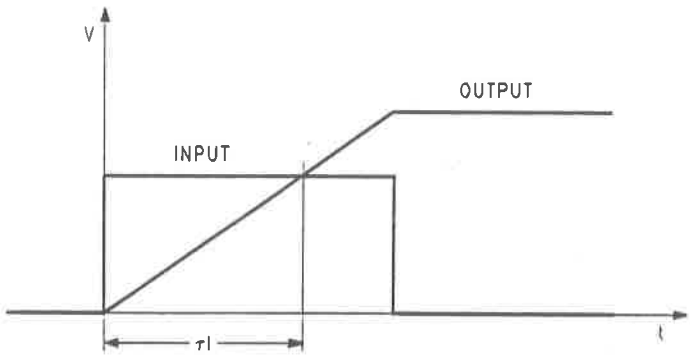


fig. 3.11

Note that after reaching the input value, the output continues to increase at the same rate until the input returns to zero.

3.2.3 Derivative Action (D)

The action is introduced by a pure derivator (fig. 3.12).
The output relative to a linear ramp input is equal to the value that the input will have after a time equivalent to the period of the derivative action.
The transfer function is:

$$W(s) = s \cdot KD = s \cdot \tau D$$

where τD is called "time constant of the derivative action" (see fig. 3.13).

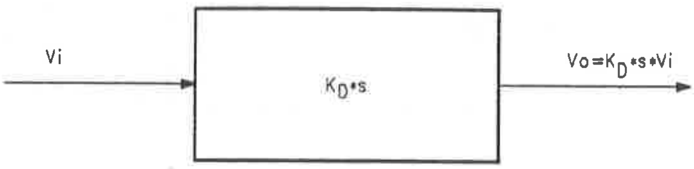


fig. 3.12

The output value, which is equivalent to the value that the input will have after the time τD, is maintained until the input slope changes.

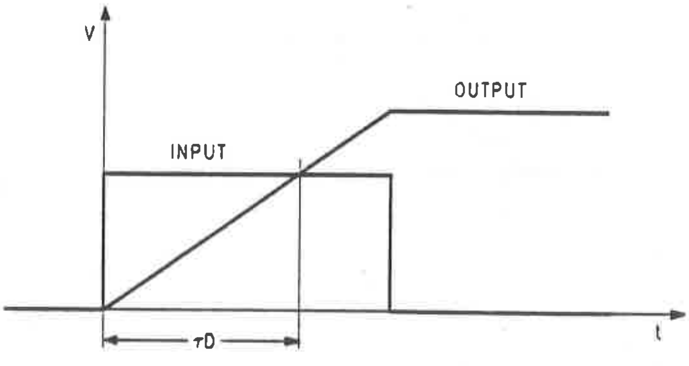


fig. 3.13

3.2.4 Combined PID Action

Let's now consider the combined effect of the proportional, integrative and derivative actions as shown in fig. 3.14.

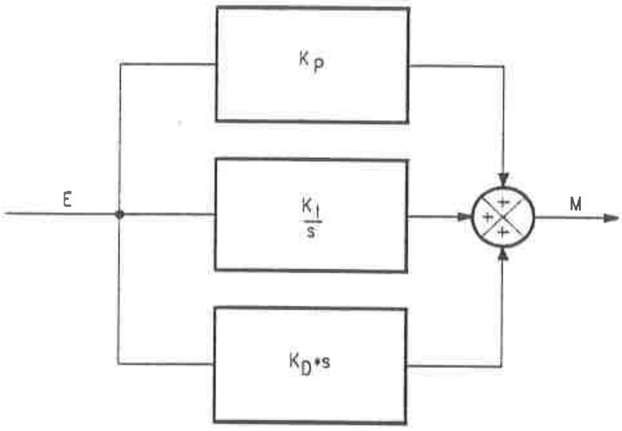


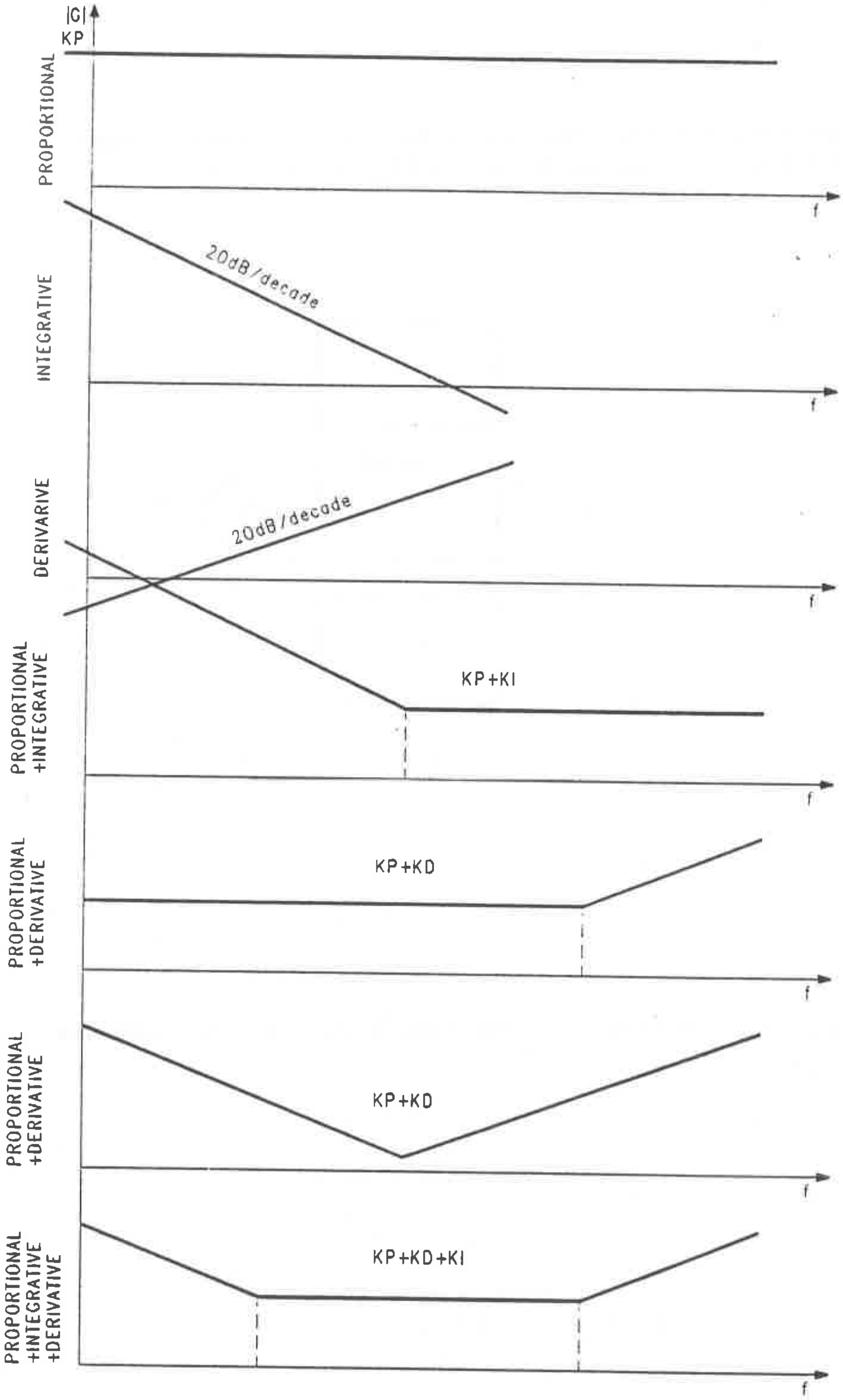
fig. 3.14

The transfer function of the regulator, which combines the three actions, is:

$$W(s) = KP + \frac{KI}{s} + KD \cdot s$$

$$W(s) = \frac{Kp \cdot s + KI + KD \cdot s^2}{s}$$

Note that the global function of the PID is formed by a pole (in the origin) and by two zeroes (not in the origin).



BODE diagrams for different kind of controllers

fig. 3.15

3.3 PID Controller

The PID controller "shapes" the error behaviour so to obtain the required one across the output for the physical quantity under test. The block diagram of the PID controller is the one shown in figure 3.16. The electrical diagram of the PROPORTIONAL block is shown in figure 3.17.

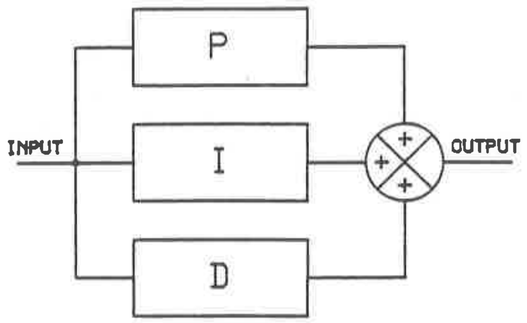


fig. 3.16

This block is composed by an operational amplifier with inverse connection which gain (constant of proportionality of the proportional controller) is given by the ratio between the resistance composed by the set of R7 and of P2 with R5.

$$Kp = (R7+P2)/R5$$

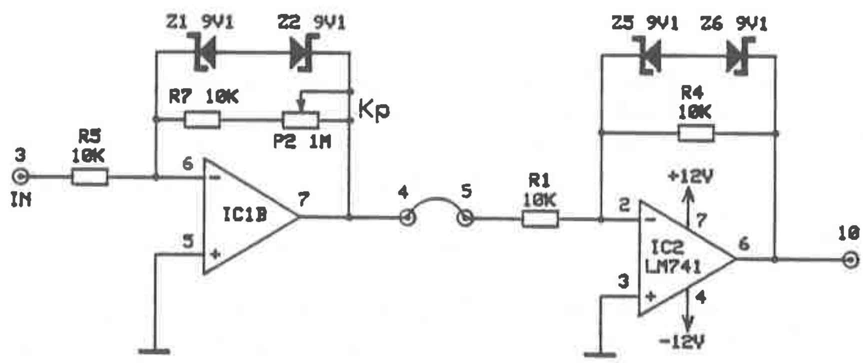


fig. 3.17

The output of the PROPORTIONAL block is shifted of 180° (inverting amplifier) in respect to the input but this is not a problem as the output of the PID controller is carried out by a reverse amplifier which takes the phase back to 0°. The two Zener diodes Z1 and Z2 prevents the output of the oeprational amplifier to get into saturation: in fact when the output voltage gets over the characterisitic value of the diode (in this case 9.1V) its impedance drops, limiting the gain of the amplifier.
The electrical diagram of the INTEGRATIVE block is shown in figure 3.18. This block is composed by an operational amplifier connected as pure integrator which time constant is given by the value of the set of R6 and P1 multiplied by C2: by varying P1, it is then possible to vary the time constant of the integrative action.
The same considerations made for the proportional block can be made also as far as concerns the phase ratio between input and output.

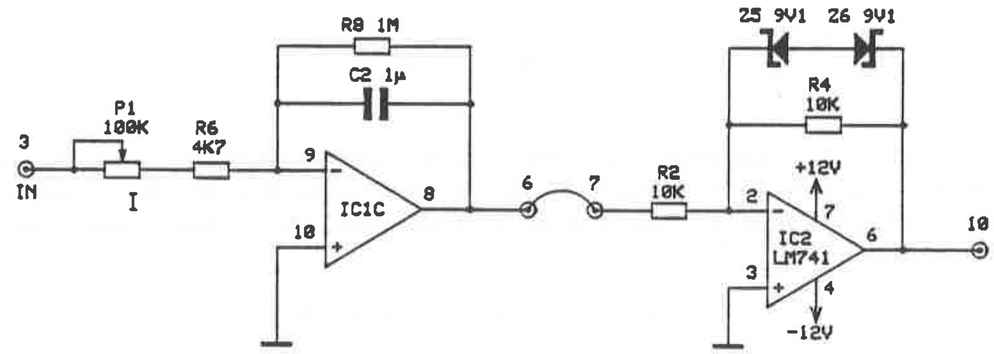


fig. 3.18

The electrical diagram of the DERIVATIVE block is shown in figure 3.19. This block is composed by an operational amplifier connected as shunt which time constant is given by the set of R8 and P3 multiplied by C1: by varying P3, it is, then, possible to vary the time constant of the derivative action.
The capacitor C3 reduces the influence of high frequency disturbances that in this case are very high.
The same considerations made for the proportional block can be made also as far as concerns the phase ratio between input and output.

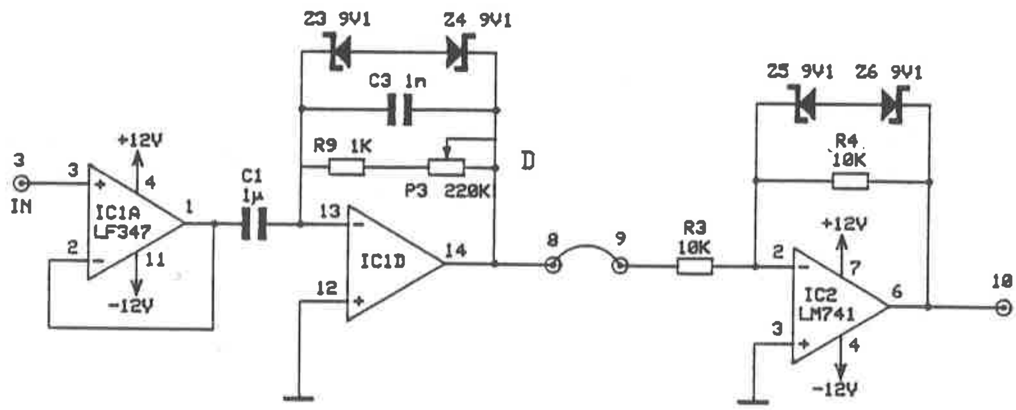


fig. 3.19

3.4 EXERCISES

The following instruments are necessary in order to carry out the experiments:

- Function generator

- Dual-trace oscilloscope

3.4.1 Check the Output Voltage Waveform of a Proportional Controller and Measure the Proportional Constant

- Carry out the circuit shown in fig. 3.20
- Set the "DERIVATIVE" potentiometer to the maximum value
- Connect the module to the voltages ±12 Vdc
- Apply a square wave signal with 100 Hz frequency, 100 mV amplitude and null mean value between point 10 and ground
- Connect one probe of the oscilloscope to point 10 and synchronize the instrument to this signal
- Connect the other probe of the oscilloscope to point 17
- Set up the IC1 amplifier gain to the minimum value with the "PROPORTIONAL" knob of the potentiometer

- Compare the difference between the output and input signal
- Compare the output and input voltage wave-forms
- Calculate the proportionality constant Kp of the proportional controller (Kp is the ratio between amplitude of the output and input voltage)
- Change amplifier IC1 amplification with the potentiometer "PROPORTIONAL" knob and check the output voltage variations and Kp
- Vary the wave-form of the input signal from square to sine and then to delta and observe the proportional controller response to this kind of signals

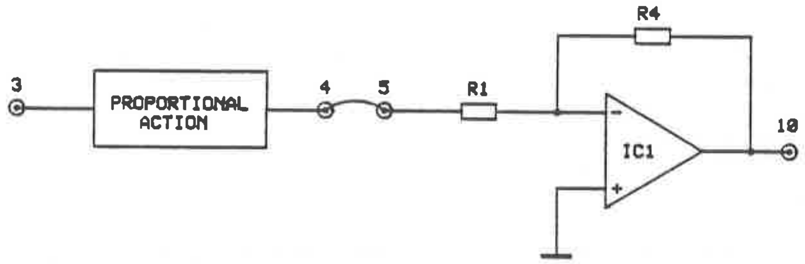


fig. 3.20

3.4.2 Check the Output Voltage Waveform of a Integrative Controller and Measure the Time Constant

- Carry out the circuit of figure 3.21
- Connect the module only to the voltages ±12 Vdc
- Apply a square-wave signal with 100-Hz frequency, 2-Volt amplitude and null mean value across point 10
- Connect one probe of the oscilloscope to point 10 and synchronize the instrument to this signal
- Connect the other probe of the oscilloscope to point 17
- Set up integrator time constant to the minimum value with the "INTEGRATIVE" knob of the potentiometer.

- Compare the output and the input voltage waveform and comment.
- Calculate the theoretical time constant KI of the controller with integrative action as given by the values of the components shown in fig. 3.21
- Calculate the time constant KI of the proportional controller (KI is the time the output employs to reach the input signal amplitude)
- Change the time constant with the potentiometer "INTEGRATIVE " knob and check the output voltage variations and KI
- Change the input signal frequency and control the variations on the output
- Apply a sine-wave signal with 100-Hz frequency, 2-Vpp amplitude and null mean value
- Check how the output signal is the integrate of the input signal and how, by acting on the potentiometer knob, there is a variation of the time constant on this signal.

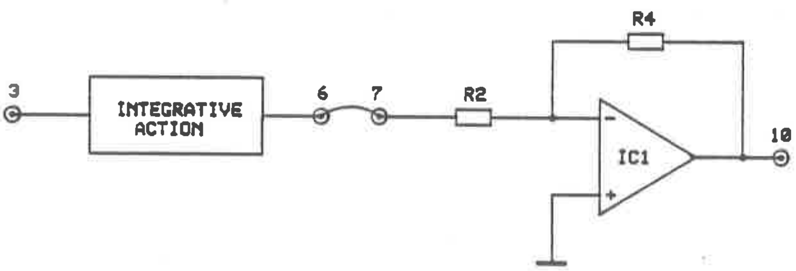


fig. 3.21

3.4.3 Check the Output Voltage Waveform of a Derivative Controller and Measure the Time Constant

- Carry out the circuit of figure 3.22
- Connect the module only to the voltages ±12 Vdc (disconnect the +30 Vdc power supply)
- Apply a delta wave signal with 100-Hz frequency, 0.5-Volt amplitude and null mean value across point 10
- Connect one probe of the oscilloscope to point 10 and synchronize the instrument to this signal
- Connect the other probe of the oscilloscope to point 17
- Set up the proportional constant to the minimum value with the "DERIVATIVE" knob of the potentiometer
- Compare the output and the input voltage wave form and comment
- Calculate the theoretical time constant KD of the controller with derivative action as given by the values of the components shown in fig. 3.22
- With the oscilloscope, calculate the time constant KD of the controller with derivative action (KD is the time necessary for the input to reach the value of the output signal)
- Vary the time constant and check how the output voltage and KD vary, by acting on the potentiometer "DERIVATIVE" knob
- Change the input voltage frequency and check the output voltage variations
- Now, apply a sine-wave signal with 100-Hz frequency, 2-Vpp amplitude and null mean value
- Check how the output signal is the derivate of the input signal and how the time constant variation affects this signal, by using the knob of the potentiometer.

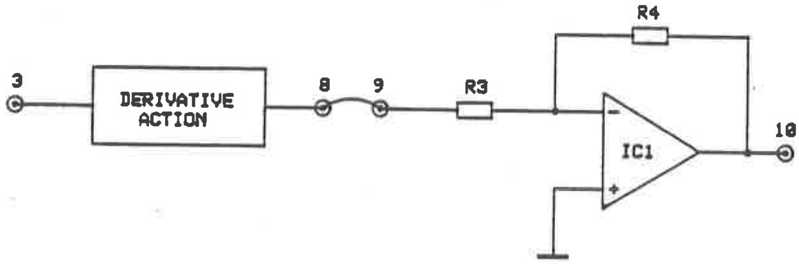


fig. 3.22

3.4.4 Check the Output Voltage Waveform of a Proportional-Integrative Controller

- Carry out the circuit of figure 3.23
- Apply a square wave signal with 50-Hz frequency and 2-Volt amplitude across point 10
- Connect one probe of the oscilloscope to point 10 and synchronize the instrument to this signal
- Connect the other probe of the oscilloscope to point 17
- Set up the proportional constant Kp to the minimum value with the "PROPORTIONAL" knob of the potentiometer
- Set the time constant of the integrator to the minimum value, by acting on the potentiometer "INTEGRATIVE" knob
- Compare the output and the input voltage waveform and comment
- Switch the time and the proportionality constants from the minimum to the maximum value and check the output voltage variations
- Change the input voltage frequency and check the output voltage variations.

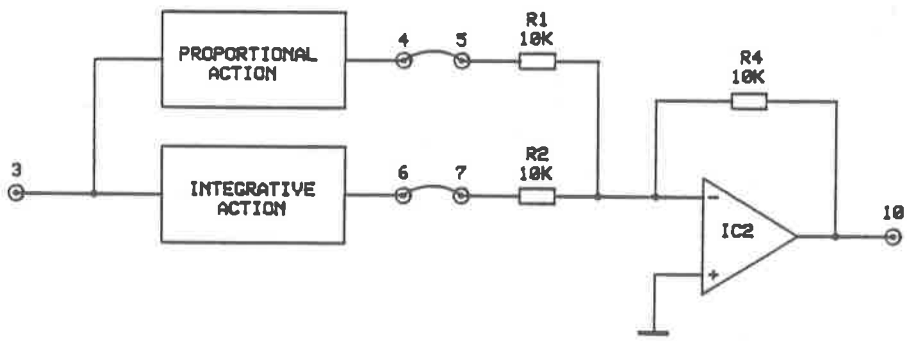


fig. 3.23

3.4.5 Checking of the Waveform of the Output Voltage of a PID (Proportional-Integrative-Derivative) Controller

- Carry out the circuit of fig. 3.24
- Apply a square-wave signal with 50-Hz frequency, 2-V amplitude and null mean value across point 10
- Connect one probe of the oscilloscope to point 10 and synchronize the instrument to this signal
- Connect the other probe of the oscilloscope to point 17
- Set the proportionality constant Kp to the minimum value by acting on the potentiometer "PROPORTIONAL" knob
- Set the time constant of the integrator to the minimum value, by using the potentiometer "INTEGRATIVE" knob
- Set the time constant of the derivator to the minimum value, by using the potentiometer "DERIVATIVE" knob
- Compare the output voltage wave-form to the input one and comment your analysis
- Vary the time and the proportionality constants from the minimum value to the maximum and check how the output voltage varies
- Change the input voltage frequency and check the variations of the output signal
- In particular, check which are the frequencies where the proportional, the derivative and the integrative actions have more weight.

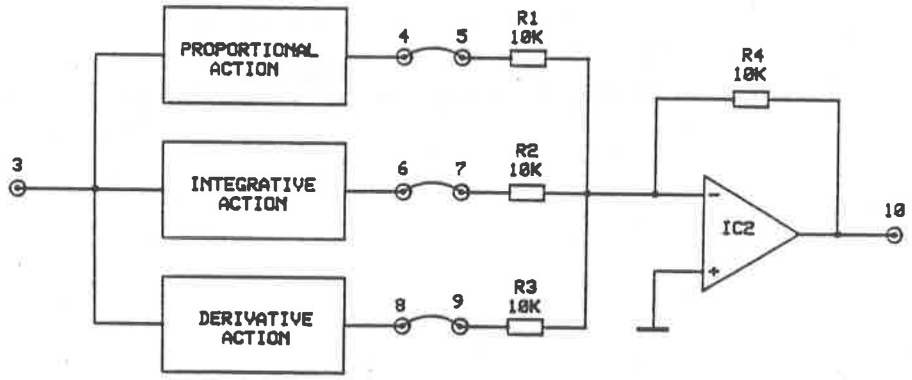


fig. 3.24

CHAPTER 4

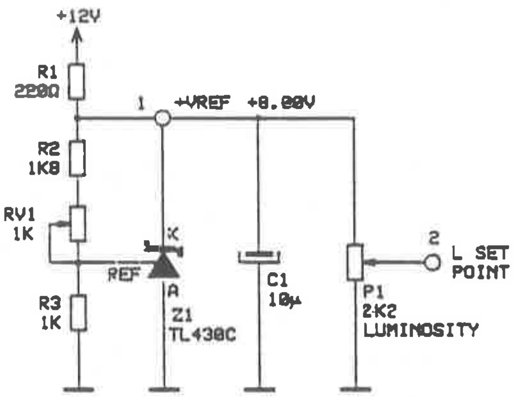
AUTOMATIC CONTROL OF LIGHT

4.1 ELECTRICAL DECSRIPTION OF THE BLOCKS COMPOSING THE CONTROL

4.1.1 Set-Point

The SET-POINT block supplies the input signal for the whole module. The block is carried out with the circuit of figure 4.1. The electronic component Z1 is a variable voltage reference: in fact it operates in order to vary the voltage of cathode K (terminal 1) until the voltage of the REF point is not equal to a set-point voltage inside the same regulator.
This set-point voltage is equal to about 2.7V, while the REF voltage depends on the voltage of cathode K and on the resistive divider composed by R2, R3, RV1.
Using the trimmer RV1, the value of the divider can be changed until it reaches the required voltage value across the cathode.
The resistor R1 causes the voltage drop between the supply voltage (+12Vdc) and the required voltage on the cathode.
Take a part of the voltage generated by Z1 with the potentiometer P1, adjustable with the LUMINOSITY knob on the module.

fig. 4.1



This voltage is the reference signal for the whole module.
The capacitor C1 is used to filter the input or output voltage variations at a high speed.

4.1.2 Error Amplifier

The "ERROR AMPLIFIER " (fig. 4.2) is the block which compares the input value (set-point) and the obtained output value.
It consists of an operational amplifier with differential configuration, the output of which is given (as R4/R1=R3/R2) by the difference between the signals presents at the two inputs multiplied by the ratio R4/R1.
The trimmer RV1 cancels the offset voltage of the operational amplifier.

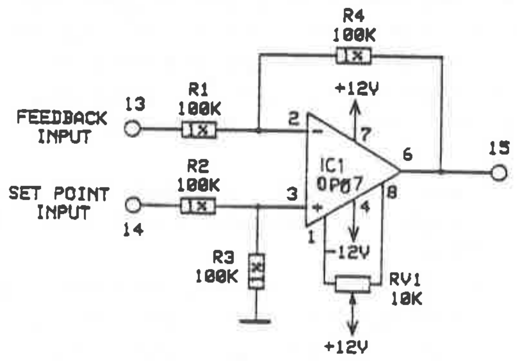


fig. 4.2

4.1. PID Controller

The PID controller has already been analysed on chapter 3.3.

4.1.3 Power Amplifier

The power amplifier takes the output signal of the PID controller, adapts the range amplitude of the actuator and, above all, amplifies the power so that it can be applied to the same actuator.

The diagram of the POWER AMPLIFIER inserted on module G13 is shown on figure 4.3.
The actuator under test (the incandescent lamp on unit TY13) has a range of 24Vdc while the PID controller has a range of 8Vdc: the two signals are proportional ifthe voltage gain of the power amplifier is 3.75.
The operational amplifier IC2 is connected as inverting amplifier. In this case, its voltage gain is given by:

$$G = -Rf/Ri$$

where Rf is the feedback resistance (resistor between the output and the inverting input) and Ri is resistor connected between the input and the inverting pin. In this case, it results that:

$$G = -R4/R3 = -100K/33K \approx -3$$

The explanation if the total circuit includes the analysis of the operation of the two transistors. Particularly, the operational amplifier varies its output until the voltage across point 12 reaches the value equal to the input (terminal 6) multiplied by the gain of the same amplifier.

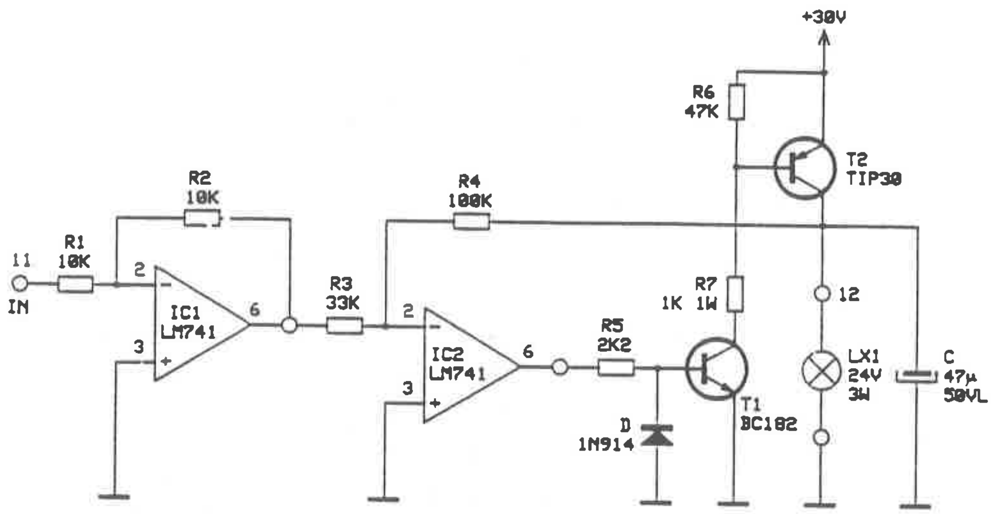


fig. 4.3

By rising the voltage across 6, the input current across the base of T1 increases and so does the collector increases proportionally. This means that the voltage applied across the base of T2 drops and consequently the current of the collector of T2, which determines the voltage across point 12, increases.
The capacitor C1 stabilizes the system preventing oscillations. The resistors R6 and R7 bias T2, the diode D1 limits the negative voltage which can be applied to the base of T1 (especially for transistors, at starting, for variations of the current absorbed by the lamp and so on...).

4.2 Control with P Controller

With this kind of controller, the output signal is proportional to the input signal: what can be varied is the proportionality constant.
The above said is true only with ideal controllers; with real controllers, if the input signal is too high or if the proportionality factor is too high, there are risks of saturation and consequently of a non-linear behaviour.
It is evident that the behaviour is linear only for a limited range of input values (proportional band).
Refer to figure 4.4.
The error signal, obtained by the comparison between the signal supplied by the signal conditioner of the transducer and the set-point signal, is amplified by a factor KP.

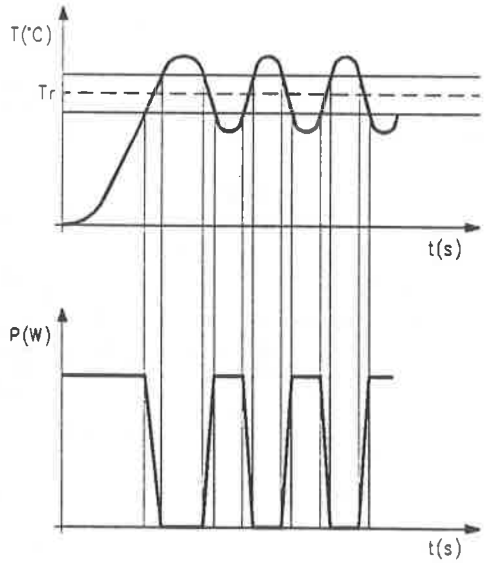


fig. 4.4

Outside the proportional band, the controller determines an ON/OFF power output, this means that all the available power or nothing is applied to the actuator (this is an area without proportional behaviour), while inside it the power is modulated.

When in steady state conditions (once the transitors are terminated), the power coming from the amplifier to the actuator, depends on the power supplied to the load and on the actuator efficiency.
Note that for this kind of controller, the error is never null, but depends on the coefficient KP and, consequently, on the value of the same proportional band. This can also be explained by saying that the error different from zero is necessary to obtain an output voltage different from zero.
Different light behaviours as function of time depend on the chosen proportional band.
Fig. 4.5 shown different light behaviours with:

a) too large Bp

b) correct Bp

c) too narrow Bp

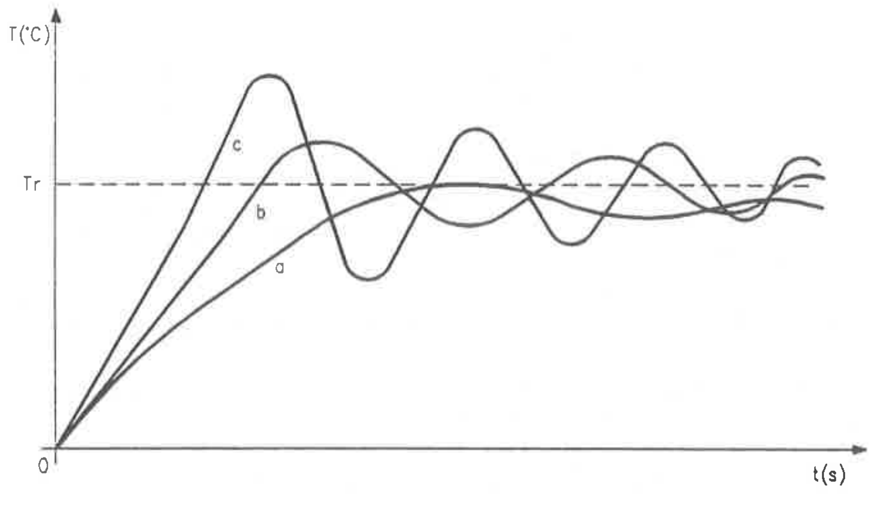


fig. 4.5

4.3 Control with P I and P I D Controllers

We have seen that the main disadvantage of the proportional controller is its constant need of an input voltage different from zero (and, consequently, an error different from zero in closed-loop control systems) to obtain an output voltage different from zero. With the integrative action, there may be an output different from zero with null input and so the steady state error can be reduced to zero.
In the integrative controller, the output voltage is the integrate of the input voltage.
It may happen that the inertia of the system is very high, so the integrative action introduces some phase displacements which take the system to unstable conditions (generation of oscillations). For this reason, the integrative action can be united to the proportional one.
If the oscillations remain, the derivative action is inserted, together with the proportional and the integrative ones, so to create a more effective starting control action.
In the derivative controller, the output is the derivate of the input function and so it has a strong influence on the rapidly changing zero signals. As a limit, when the input voltage is constant and different from zero, its output is null.
With the process evolution, the derivative action is replaced by the integral one to cancel the regulating error in respect to the value on steady state.

4.4 Controller Set-up

When the standard PID regulator is inserted in a feedback process, the problem arises of determining the parameters KP, KI and KD which are necessary for an accurate regulation (according to the given specifications) of the controlled quantity.
Generally, this problem is solved by choosing the KP value first, excluding the other two actions, and then obtaining the value of KI first and of KD after.
Procedures, obtained by several empirical tests on the processes, are available which permits to determine the controller set-up for the best response.
Standard setting procedures may be classified into two groups, depending on whether the set-up is based on:

a) the behaviour at the limit of stability of the entire feedback system;

b) the time response of the process at the step input.

The procedures included in the first group assume that it is possible to bring the (closed-loop) control system to the limit of its stability by adjusting the parameters of the controller.
When at the limit of stability, it is obvious that the oscillations of the variable quantities must not damage the process.
The best-known of the proposed procedures is the Ziegler-Nichols one, which consists in the following operations:

- exclusion of the integrative action
- exclusion of the derivative action
- increase of KP, starting from the minimum value, until the closed-loop system reaches the limit of stability
- measurement of the value KPc of KP which makes the system unstable
- detection of the period Tc of the oscillation which occurs in the system above the limit of stability.

Once the two values KPc and Tc are obtained, the Ziegler-Nichols method suggests setting the parameters of the regulator, in the various possible cases, as shown in the following table:

CONTROLLER	KP	KP/KI	KD/KP
P	0.5•KPc		
P I	0.45•KPc	0.85•Tc	
P I D	0.6•KPc	0.5•Tc	0.12•Tc

The procedures belonging to the second group include the possibility to measure the indicial response of the open-loop process.
Ziegler and Nichols have developed the formulae for this group too, which can be summed up as follows (refer to fig. 4.6):

- Open the feedback loop
- Take the gain KP to unit value
- Exclude the integrative and derivative action
- Set a unit step signal at the input and analyse the response of the signal conditioner output, which will be as shown in fig. 4.6 where the three fundamental parameters are pointed out:

  * K = gain
  * Tm = dead time
  * T = time constant

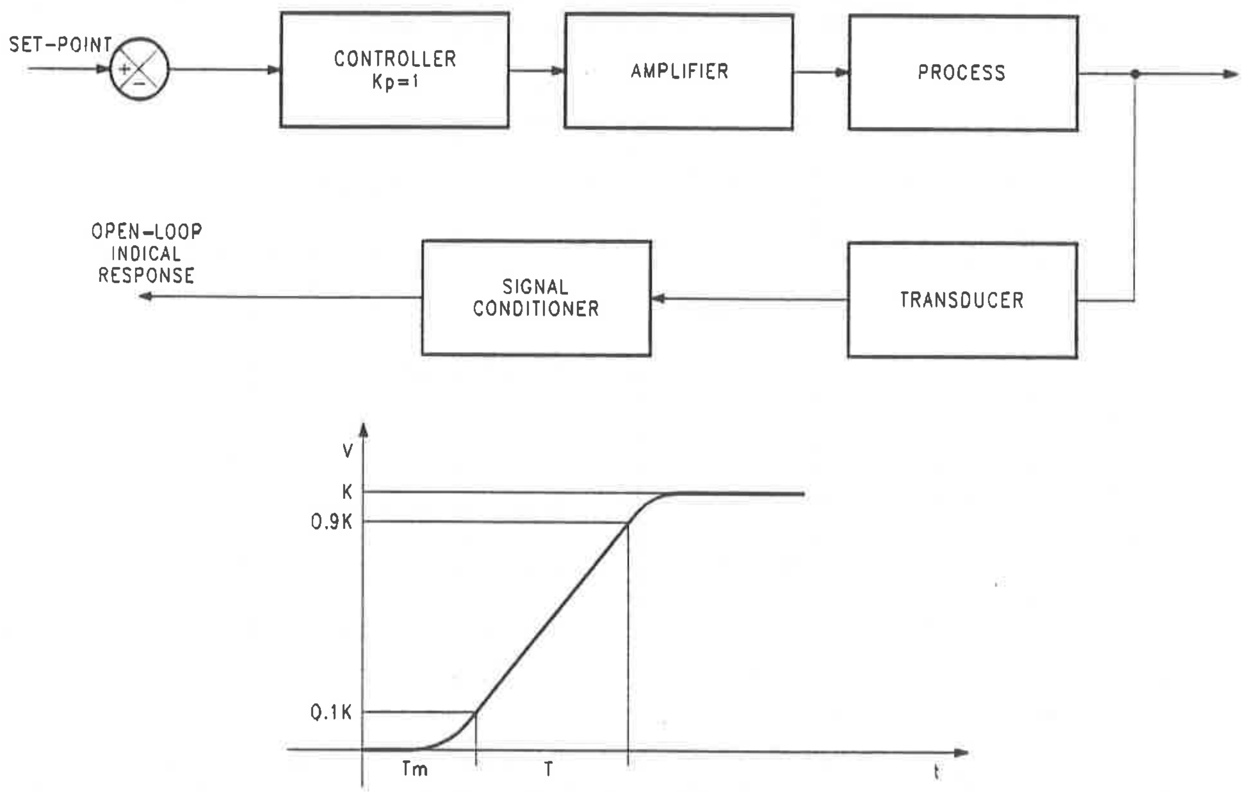


fig. 4.6

With this method, Ziegler and Nichols have developed the formulae used to obtain the values of KP, τI and τD of the basic parameters. These formulae are listed in the following table.

CONTROLLER	KP	KP/KI	KD/KP
P	$\frac{1}{K}\cdot\frac{T}{Tm}$		
P I	$\frac{0.9}{K}\cdot\frac{T}{Tm}$	3.3·Tm	
P I D	$\frac{1.2}{K}\cdot\frac{T}{Tm}$	2·Tm	0.5·Tm

4.5 Exercises

4.5.1 Automatic Open-loop Control of Light

- Carry out the circuit of figure 4.7
- Connect module G13 to unit TY13/EV as shown in figure 2.17
- Set the slide of unit TY13/EV to the position 300 lux and the switches of the signal conditioners (PHOTORESISTOR, PHOTODIODE, PHOTOTRANSISTOR CONDITIONER) to the position B
- With the set-point apply a voltage of 4 Volt: this voltage corresponds to a light of 150 lux
- Measure the output voltage of the signal conditioner of the phototransistor. This voltage must be very near 4 Volt
- Take the slide to the position 370 lux
- Repeat the measurement of the output voltage of the signal conditioner of the phototransistor
- Note a strong increase of voltage which represents the light. Which is the reason?
- Repeat the measurement using the other two transducers present in unit TY13 (photoresistor and photodiode).
- Repeat the last measurements for all the SET-POINT values reported in table 4.1
- Report the set-point voltage/light diagrams in fig. 4.8 in the two cases with the slide in the position 300 lux and 370 lux.
- Confront the values obtained in the two positions different from the slide

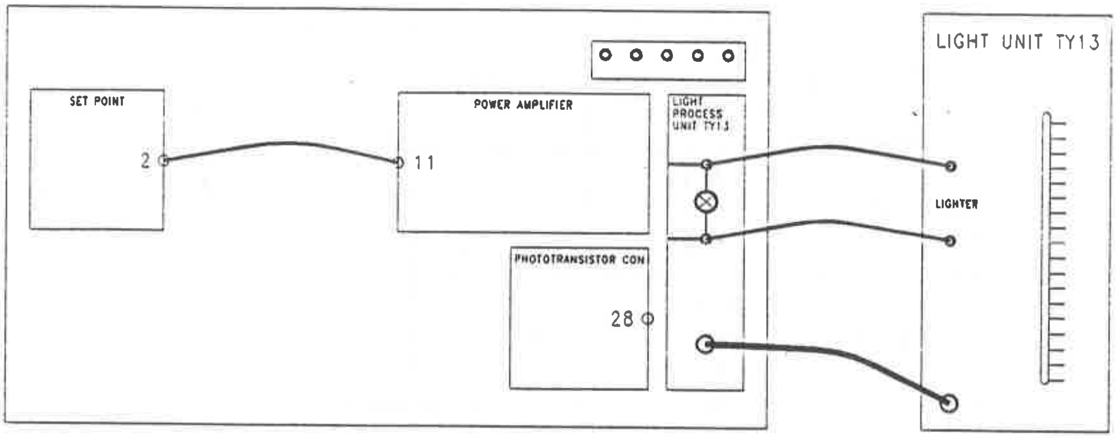


fig. 4.7

SET-POINT	300 lux	370 lux
1 volt		
2 volt		
3 volt		
4 volt		
5 volt		
6 volt		
7 volt		
8 volt		

tab 4.1

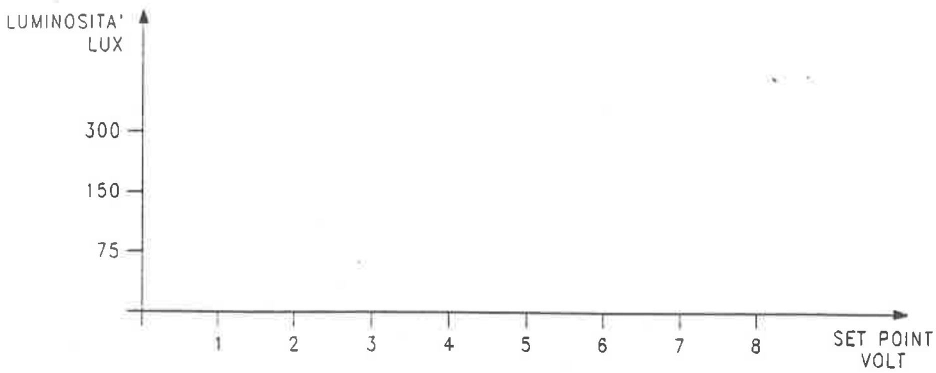


fig. 4.8

4.5.2 Automatic Closed-loop Control of Light

- Carry out the circuit of figure 4.9
- Connect module G13 to unit TY13/EV as shown in figure 2.17
- Set the slide of unit TY13/EV to the position 300 lux and the switches of the signal conditioners (PHOTORESISTOR, PHOTODIODE, PHOTOTRANSISTOR CONDITIONER) to the position B
- Set the PID CONTROLLER to the maximum with the PROPORTIONAL knob and to the minimum with the INTEGRATIVE one
- With the set-point, apply a voltage of 4 Volt: this voltage corresponds to a light of 150 lux
- Measure the output voltage of the signal conditioner of the phototransistor. This voltage must be very near 4 Volt
- Take the slide to the position 370 lux: this causes a light value of 370 lux for a voltage of 24Volt applied to the lamp when this is near the transducers
- Repeat the measurement of the output voltage of the signal conditioner of the phototransistor
- Why does the measured voltage keep close to 4 Volt?
- Repeat the measurement carried out before for all the SET-POINT values shown in table 4.1
- Report the set-point voltage/light diagrams in a figure like 4.8 in the two cases with the slide in the position 300 lux and 370 lux.
- Confront the values obtained in this case with the ones obtained in the open-loop control.

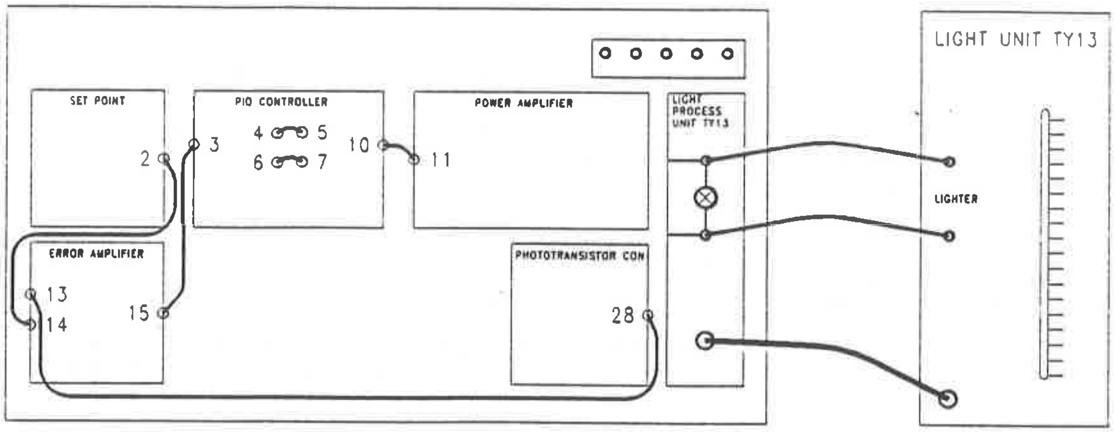


fig. 4.9

SET-POINT	300 lux	370 lux
1 volt		
2 volt		
3 volt		
4 volt		
5 volt		
6 volt		
7 volt		
8 volt		

tab. 4.2

4.5.3 Closed-loop Automatic Control of Light: Effect of the Different Components of the PID Controller

- Carry out the circuit of figure 4.10
- Set the slide of unit TY13/EV to the position 300 lux and the switches of the signal conditioners (PHOTORESISTOR, PHOTODIODE, PHOTOTRANSISTOR CONDITIONER) to the position B
- Insert only the proportional action of the controller (connect only terminals 4 and 5) and take the PROPORTIONAL handle to the minimum value
- With the set-point knob, apply a voltage of 4 Volt and measure the voltage of terminal 15 (output of the error amplifier) which corresponds to the difference between the set-point and the obtained output quantity
- Increase the gain of the Proportional controller, by acting on the PROPORTIONAL knob, taking care not to take the system into oscillation
- Measure the output voltage of the error amplifier and detect how the error varies as function of the proportional action
- Insert the integrative action by connecting terminals 6 and 7 and take the INTEGRATIVE potentiometer to the minimum value: measure the error
- Set the INTEGRATIVE potentiometer to half stroke and the PROPORTIONAL potentiometer to the minimum
- Note how the integrative action tends to zero the error
- Note how the integrative action diminishes the error but tends to make the system oscillate (unstable conditions)
- Now, introduce the derivative action and observe how this action takes the system back to stable conditions.

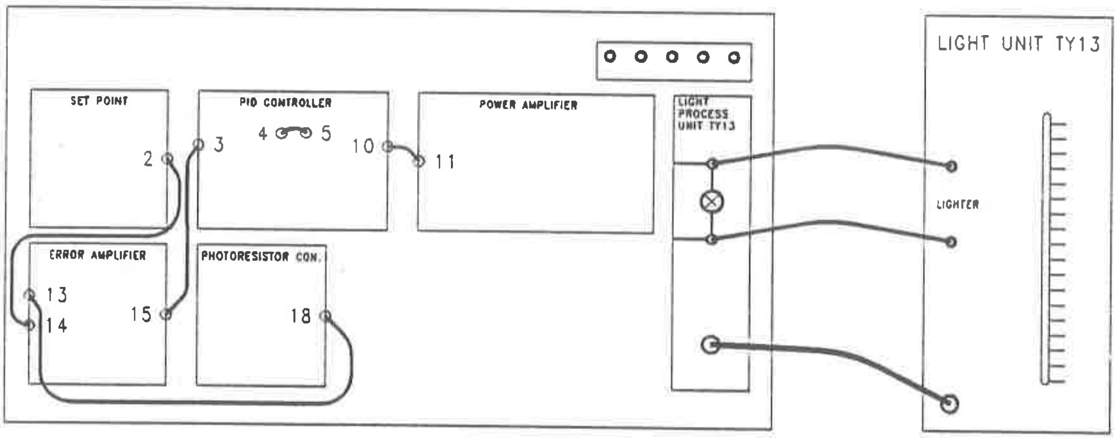


fig. 4.10

4.5.4 System Step Stress: Variations of the PID CONTROLLER Constants

- Carry out the circuit of figure 4.11
- Set the slide of unit TY13/EV to the position 300 lux and the switches of the signal conditioners (PHOTORESISTOR, PHOTODIODE, PHOTOTRANSISTOR CONDITIONER) to the position B
- Set the function generator for a square-wave output with amplitude ranging from 0 and +4 Volt and frequency of 100 Hz and apply this signal between terminal 14 and ground.
- Apply one probe of the oscilloscope to the output of the signal generator
- Set the PID CONTROLLER to operate with the three actions inserted contemporarily
- Apply the second probe of the oscilloscope to terminal 28 and check the system response to the input stress.
- Change the weight of three actions and check the system response to these variations
- Combine the PID CONTROLLER by removing one or more actions and observe how the system responds to step stresses with P, I, D, PI, PD, ID and PID controllers

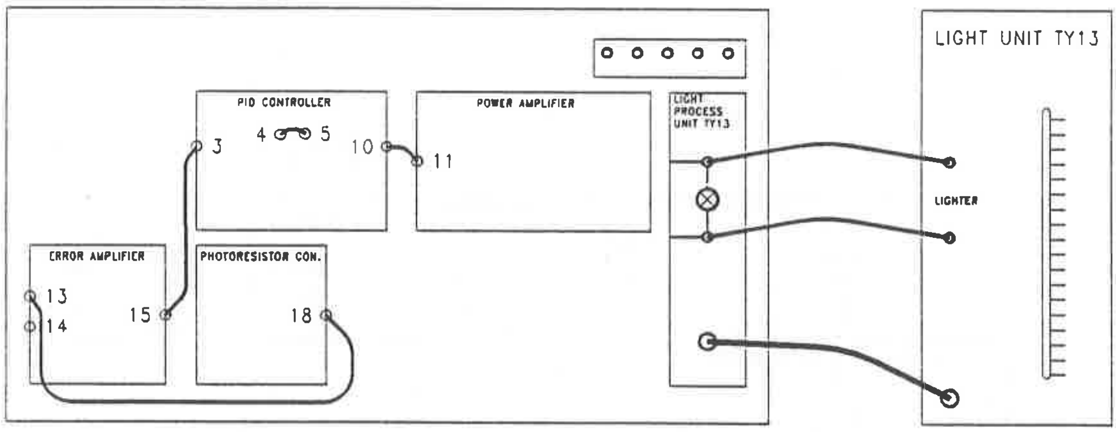


fig. 4.11

APPENDIX A

CALIBRATIONS

In the following pages we describe the calibration procedures of module G13.
For the calibration of any single block, carry out only the connections described in any single calibration procedure
To identify the trimmers used in the calibration, refer to figure A

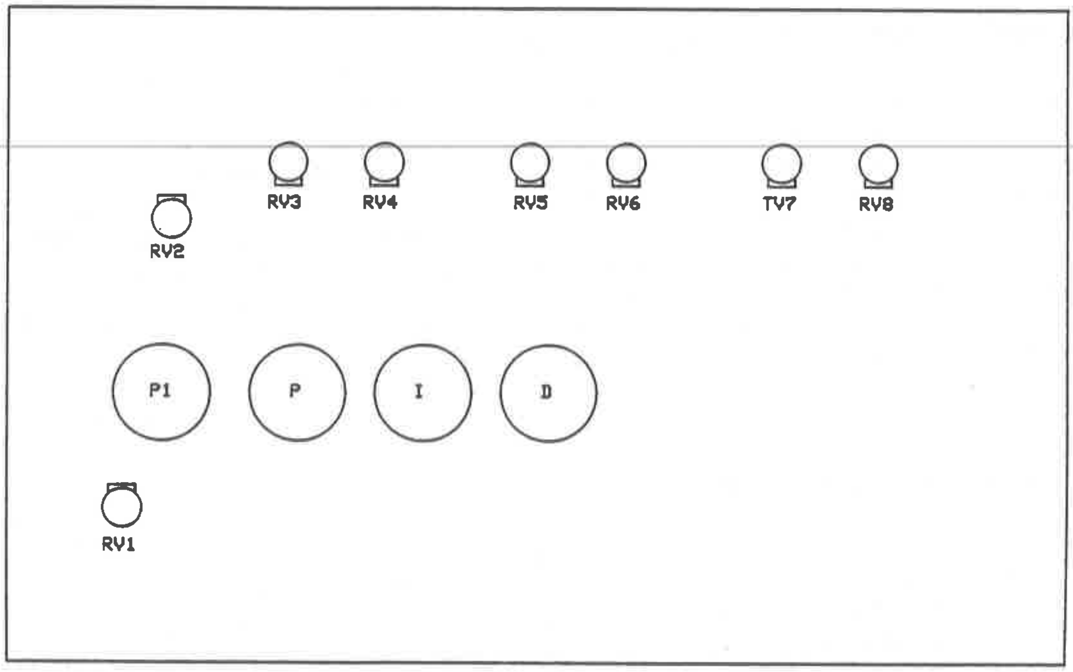


fig. A

SET-POINT Block

- Connect module G13 to all the necessary voltages
- Act on RV1 until the voltage of terminal 1 reaches 8 volt.

ERROR AMPLIFIER Block

- Connect module G13 to all the necessary voltages
- Shortcircuit terminals 13 and 14 and act on RV2 until the voltage of terminal 15 drops to 0 volt.

PHOTORESISTOR CONDITIONER Block

- Connect module G13 to all the necessary voltages
- Connect module G13 to unit TY13/EV according to figure 2.17
- Set the slide of the external unit TY13/EV to the position 300 lux
- Connect terminal 2 to 11 and, by acting on the SET-POINT handle, apply a voltage of 0 Volt to the input of the power amplifier (terminal 11)
- Act on RV3 until the voltage of terminal 18 drops to 0 volt
- Take the SET-POINT voltage to 8 Volt
- Act on RV4 until the output voltage present across terminal 18 drops to 8 Volt.

PHOTODIODE CONDITIONER Block

- Connect module G13 to all the necessary voltages
- Connect module G13 to unit TY13/EV according to figure 2.17
- Set the slide of the external unit TY13/EV to the position 300 lux
- Connect terminal 2 to 11 and, by acting on the SET-POINT handle, apply a voltage of 0 Volt to the input of the power amplifier (terminal 11)
- Act on RV5 until the voltage of terminal 22 drops to 0 volt
- Take the SET-POINT voltage to 8 Volt
- Act on RV6 until the output voltage present across terminal 22 is equal to 8 Volt.

PHOTOTRANSISTOR CONDITIONER Block

- Connect G13 to all the necessary voltages
- Connect module G13 to unit TY13/EV according to figure 2.17
- Set the slide of the external unit TY13/EV to the position 300 lux
- Connect terminal 2 to 11 and, with the SET-POINT handle, apply a voltage of 0 Volt to the input of the power amplifier (terminal 11)
- Act on RV7 until the voltage across terminal 28 drops to 0 volt
- Take the SET-POINT voltage to 8 Volt
- Act on RV8 until the output voltage present across terminal 28 is equal to 8 Volt.

APPENDIX B

BIBLIOGRAPHY

* Transducer interfacing handbook
Analog Device Inc. - Norwood, Massachussetts

* E. Cometta
"Misura della temperatura"
ed. Delfino, Milano

* C. Torresan
"Automazione degli impianti chimici e termici"
ed. Hoepli, Milano

* DC Motors - Speed controls - Servo systems
Electro Craft Co. - Hopkins, Minn.

* Linear Application Data Book
Natonal Semiconductor Corporation - Santa Clara, California

* R. Mialich, G. Rossi
"Elettronica Industriale - Sistemi e Automazione"
ed. Calderini, Bologna

* G. Figini

"Servomeccanismi, Teoria della regolazione Automatica"

Ed. Delfino

* A. Lepschy , A. Ruberti

"Lezioni di Controlli Automatici"

Ed. Siderea

* L. Pallottini

"Sistemi ed Automazione"

Ed. Cupido

* C. Torresan

"Automazione di Impianti Chimici e Termici"

Ed. Hoepli

* A. Cupido

"Elettronica Industriale"

Ed. Cupido

* R. Cresta

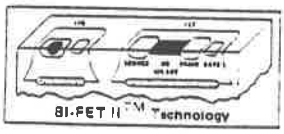
"Elettronica Industriale"

Ed. Hoepli

APPENDIX C

DATA SHEETS

National Semiconductor



LF147/LF347/LF347B Wide Bandwidth Quad JFET Input Operational Amplifiers

General Description

The LF147 is a low cost, high speed quad JFET input operational amplifier with an internally trimmed input offset voltage (BI-FET II™ technology). The device requires a low supply current and yet maintains a large gain bandwidth product and a fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The LF147 is pin compatible with the standard LM148. This feature allows designers to immediately upgrade the overall performance of existing LF148 and LM124 designs.

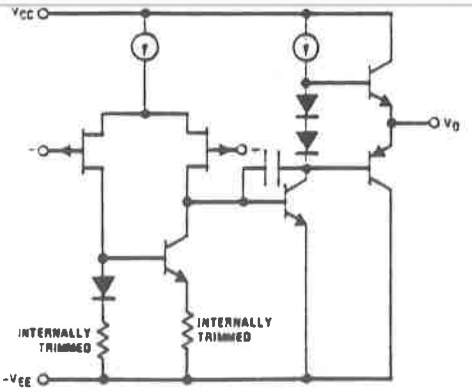
The LF147 may be used in applications such as high speed integrators, fast D/A converters, sample-and-hold circuits and many other circuits requiring low input offset voltage, low input bias current, high input impedance, high slew rate and wide bandwidth. The device has low noise and offset voltage drift.

Features

- Internally trimmed offset voltage — 5 mV max
- Low input bias current — 50 pA
- Low input noise current — 0.01 pA/√Hz
- Wide gain bandwidth — 4 MHz
- High slew rate — 13 V/μs
- Low supply current — 7.2 mA
- High input impedance — $10^{12}\Omega$
- Low total harmonic distortion $A_V = 10$, $R_L = 10k$, $V_O = 20$ Vp-p, BW = 20 Hz – 20 kHz — <0.02%
- Low 1/f noise corner — 50 Hz
- Fast settling time to 0.01% — 2 μs

Simplified Schematic

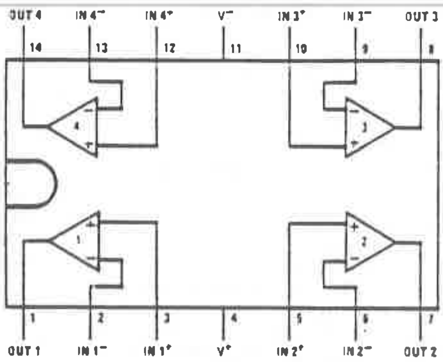
¼ Quad



TL/H/5647-13

Connection Diagram

Dual-In-Line Package



TL/H/5647-1

Top View

Order Number LF147D, LF347D, LF147J, LF347BJ, LF347J, LF347M, LF347WM, LF347BN or LF347N
See NS Package Number D14E, J14A, M14A, M14B or N14A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

	LF147	LF347B/LF347
Supply Voltage	±22V	±18V
Differential Input Voltage	±38V	±30V
Input Voltage Range (Note 1)	±19V	±15V
Output Short Circuit Duration (Note 2)	Continuous	Continuous
Power Dissipation (Notes 3 and 9)	900 mW	1000 mW
T_j max	150°C	150°C
θ_{jA}		
Cavity DIP (D) Package		80°C/W
Ceramic DIP (J) Package		70°C/W
Plastic DIP (N) Package		75°C/W
Surface Mount Narrow (M)		100°C/W
Surface Mount Wide (WM)		85°C/W

	LF147	LF347B/LF347
Operating Temperature Range	(Note 4)	(Note 4)
Storage Temperature Range	$-65°C \le T_A \le 150°C$	
Lead Temperature (Soldering, 10 sec.)	260°C	260°C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)		260°C
Small Outline Package		
Vapor Phase (60 seconds)		215°C
Infrared (15 seconds)		220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

ESD rating to be determined.

DC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions	LF147			LF347B			LF347			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_{OS}	Input Offset Voltage	$R_S = 10\ k\Omega$, $T_A = 25°C$ Over Temperature		1	5 8		3	5 7		5	10 13	mV mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	$R_S = 10\ k\Omega$		10			10			10		μV/°C
I_{OS}	Input Offset Current	$T_j = 25°C$, (Notes 5, 6) Over Temperature		25	100 25		25	100 4		25	100 4	pA nA
I_B	Input Bias Current	$T_j = 25°C$, (Notes 5, 6) Over Temperature		50	200 50		50	200 8		50	200 8	pA nA
R_{IN}	Input Resistance	$T_j = 25°C$		10^{12}			10^{12}			10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	$V_S = \pm 15V$, $T_A = 25°C$ $V_O = \pm 10V$, $R_L = 2\ k\Omega$ Over Temperature	50 25	100		50 25	100		25 15	100		V/mV V/mV
V_O	Output Voltage Swing	$V_S = \pm 15V$, $R_L = 10\ k\Omega$	±12	±13.5		±12	±13.5		±12	±13.5		V
V_{CM}	Input Common-Mode Voltage Range	$V_S = \pm 15V$	±11	+15 −12		±11	+15 −12		±11	+15 −12		V V
CMRR	Common-Mode Rejection Ratio	$R_S \le 10\ k\Omega$	80	100		80	100		70	100		dB
PSRR	Supply Voltage Rejection Ratio	(Note 7)	80	100		80	100		70	100		dB
I_S	Supply Current			7.2	11		7.2	11		7.2	11	mA

AC Electrical Characteristics (Note 5)

Symbol	Parameter	Conditions	LF147			LF347B			LF347			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Amplifier to Amplifier Coupling	$T_A = 25°C$, $f = 1\ Hz - 20\ kHz$ (Input Referred)		−120			−120			−120		dB
SR	Slew Rate	$V_S = \pm 15V$, $T_A = 25°C$	8	13		8	13		8	13		V/µs
GBW	Gain-Bandwidth Product	$V_S = \pm 15V$, $T_A = 25°C$	2.2	4		2.2	4		2.2	4		MHz
e_n	Equivalent Input Noise Voltage	$T_A = 25°C$, $R_S = 100\Omega$, $f = 1000\ Hz$		20			20			20		$nV/\sqrt{Hz}$
i_n	Equivalent Input Noise Current	$T_j = 25°C$, $f = 1000\ Hz$		0.01			0.01			0.01		$pA/\sqrt{Hz}$

Note 1: Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

Note 2: Any of the amplifier outputs can be shorted to ground indefinitely, however, more than one should not be simultaneously shorted as the maximum junction temperature will be exceeded.

Note 3: For operating at elevated temperature, these devices must be derated based on a thermal resistance of θ_{jA}.

Note 4: The LF147 is available in the military temperature range $-55°C \leq T_A \leq 125°C$, while the LF347B and the LF347 are available in the commercial temperature range $0°C \leq T_A \leq 70°C$. Junction temperature can rise to T_j max = 150°C.

Note 5: Unless otherwise specified the specifications apply over the full temperature range and for $V_S = \pm 20V$ for the LF147 and for $V_S = \pm 15V$ for the LF347B/LF347. V_{OS}, I_B, and I_{OS} are measured at $V_{CM} = 0$.

Note 6: The input bias currents are junction leakage currents which approximately double for every 10°C increase in the junction temperature, T_j. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P_D. $T_j = T_A + \theta_{jA} P_D$ where θ_{jA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

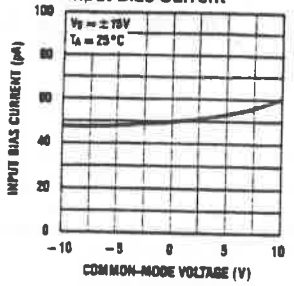
Note 7: Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice from $V_S = \pm 5V$ to $\pm 15V$ for the LF347 and LF347B and from $V_S = \pm 20V$ to $\pm 5V$ for the LF147.

Note 8: Refer to RETS147X for LF147D and LF147J military specifications.

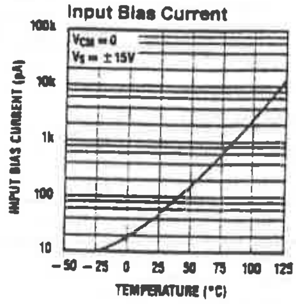
Note 9: Max. Power Dissipation is defined by the package characteristics. Operating the part near the Max. Power Dissipation may cause the part to operate outside guaranteed limits.

Typical Performance Characteristics

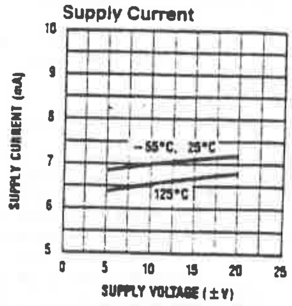
Input Bias Current



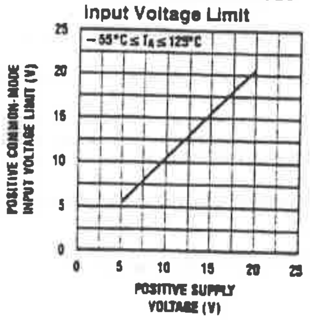
Input Bias Current



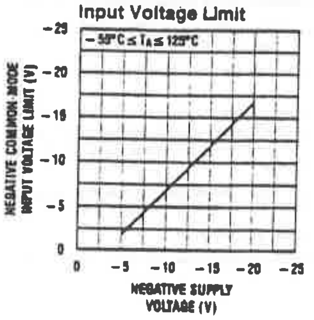
Supply Current



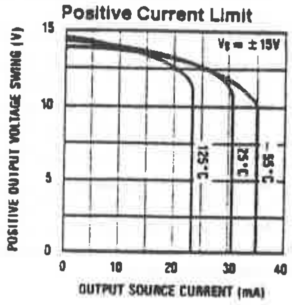
Positive Common-Mode Input Voltage Limit



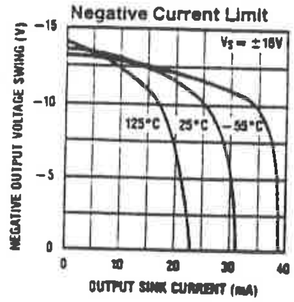
Negative Common-Mode Input Voltage Limit



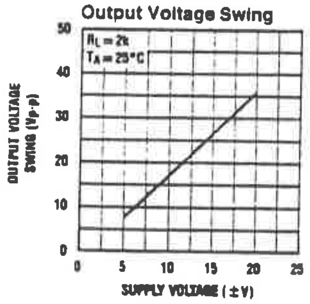
Positive Current Limit



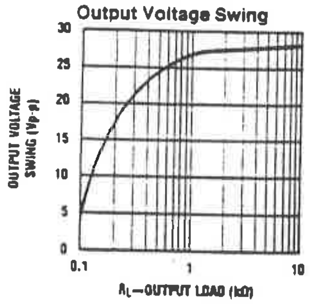
Negative Current Limit



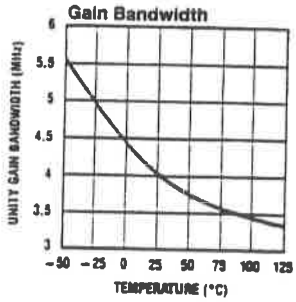
Output Voltage Swing



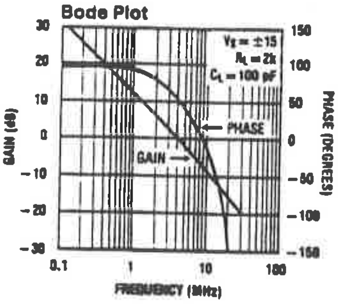
Output Voltage Swing



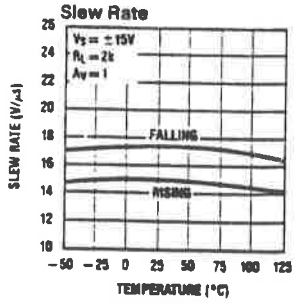
Gain Bandwidth



Bode Plot



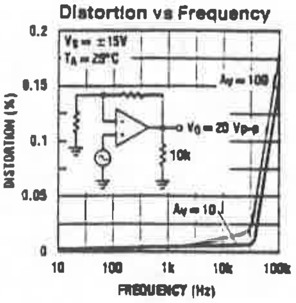
Slew Rate



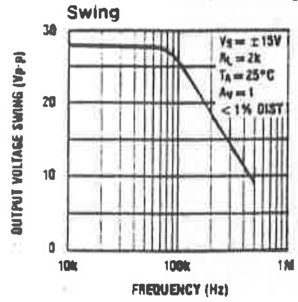
TL/H/5647-2

Typical Performance Characteristics (Continued)

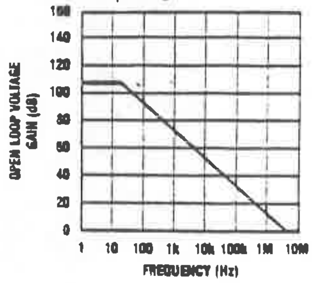
Distortion vs Frequency



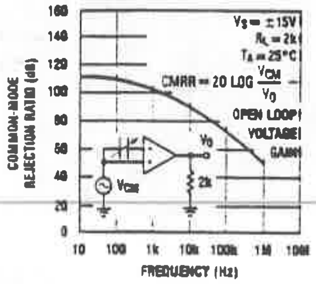
Undistorted Output Voltage Swing



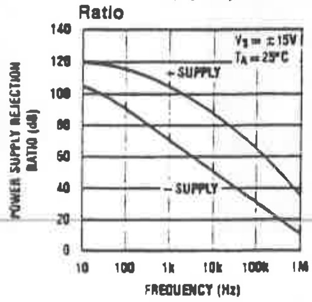
Open Loop Frequency Response



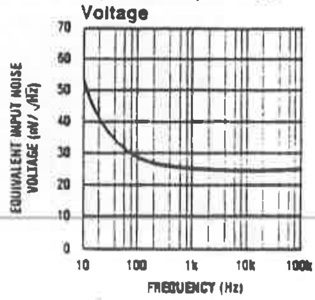
Common-Mode Rejection Ratio



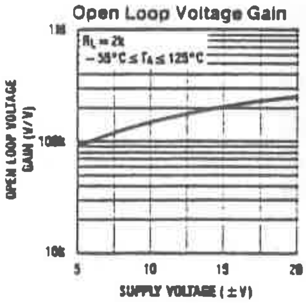
Power Supply Rejection Ratio



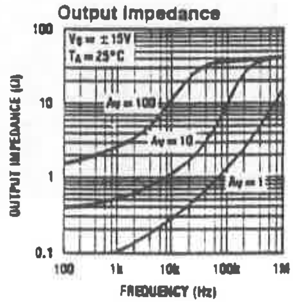
Equivalent Input Noise Voltage



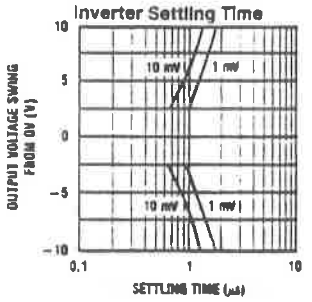
Open Loop Voltage Gain



Output Impedance



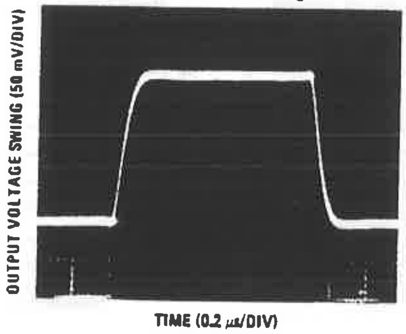
Inverter Settling Time



TL/H/5647-3

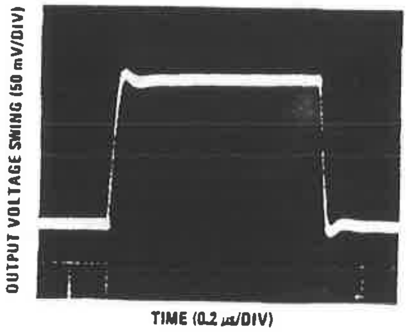
Pulse Response $R_L = 2\ k\Omega$, $C_L = 10\ pF$

Small Signal Inverting



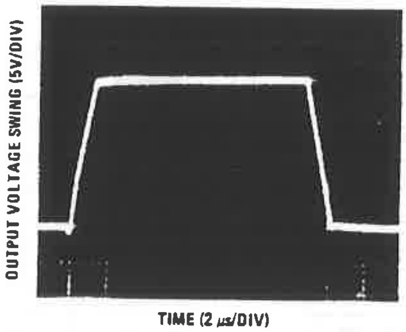
TL/H/5647-4

Small Signal Non-Inverting



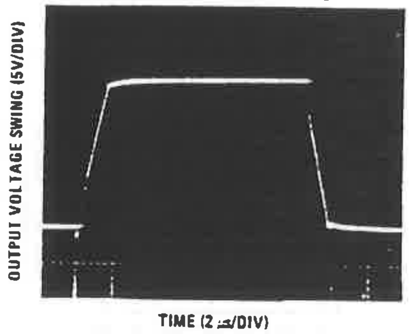
TL/H/5647-5

Large Signal Inverting



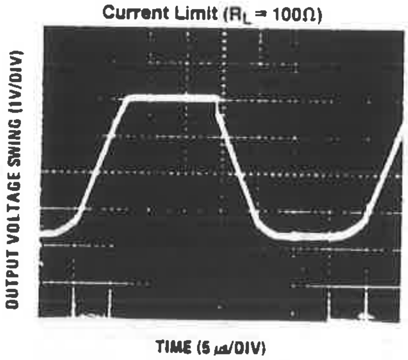
TL/H/5647-6

Large Signal Non-Inverting



TL/H/5647-7

Current Limit ($R_L = 100\Omega$)



TL/H/5647-8

Application Hints

The LF147 is an op amp with an internally trimmed input offset voltage and JFET input devices (BI-FET II™). These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore, large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

Exceeding the negative common-mode limit on either input will force the output to a high state, potentially causing a reversal of phase to the output. Exceeding the negative common-mode limit on both inputs will force the amplifier

Application Hints (Continued)

output to a high state. In neither case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output; however, if both inputs exceed the limit, the output of the amplifier will be forced to a high state.

The amplifiers will operate with a common-mode input voltage equal to the positive supply; however, the gain bandwidth and slew rate may be decreased in this condition. When the negative common-mode voltage swings to within 3V of the negative supply, an increase in input offset voltage may occur.

Each amplifier is individually biased by a zener reference which allows normal circuit operation on ±4.5V power supplies. Supply voltages less than these may result in lower gain bandwidth and slew rate.

The LF147 will drive a 2 kΩ load resistance to ±10V over the full temperature range. If the amplifier is forced to drive heavier load currents, however, an increase in input offset voltage may occur on the negative voltage swing and finally reach an active current limit on both positive and negative swings.

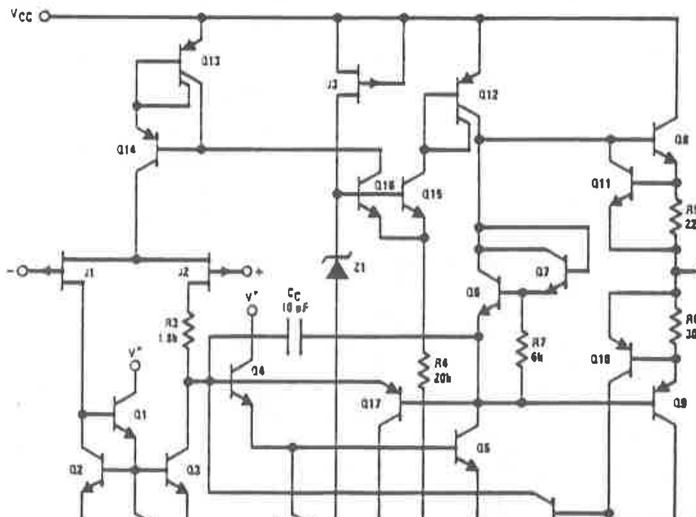
Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Because these amplifiers are JFET rather than MOSFET input op amps they do not require special handling.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize "pick-up" and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately 6 times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

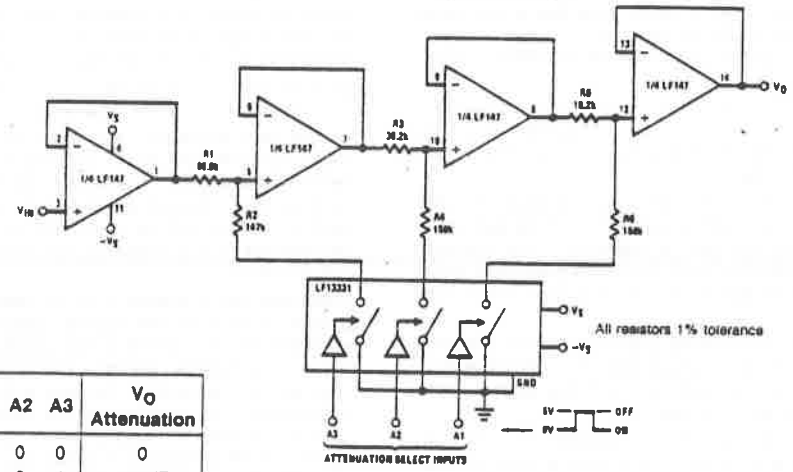
Detailed Schematic



TL/H/5647-9

Typical Applications

Digitally Selectable Precision Attenuator

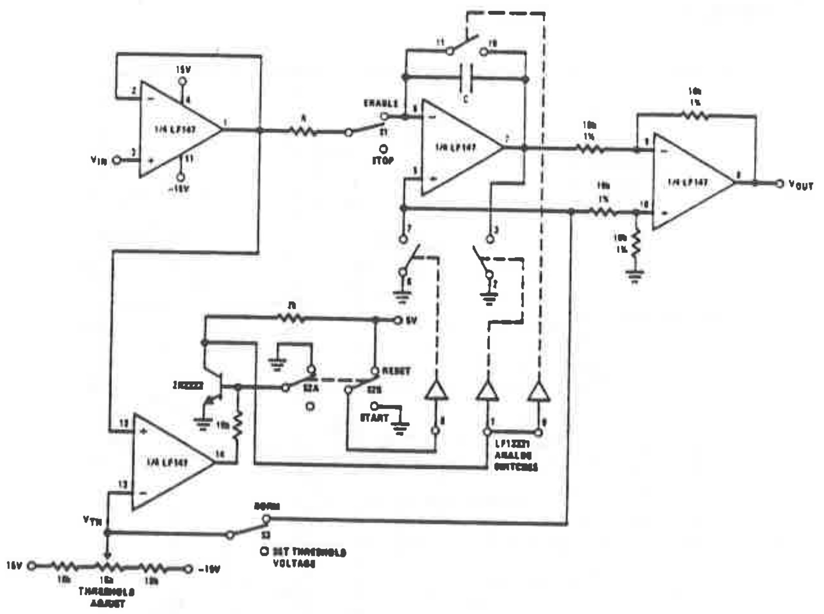


A1	A2	A3	V_O Attenuation
0	0	0	0
0	0	1	−1 dB
0	1	0	−2 dB
0	1	1	−3 dB
1	0	0	−4 dB
1	0	1	−5 dB
1	1	0	−6 dB
1	1	1	−7 dB

TL/H/5647-10

- Accuracy of better than 0.4% with standard 1% value resistors
- No offset adjustment necessary
- Expandable to any number of stages
- Very high input impedance

Long Time Integrator with Reset, Hold and Starting Threshold Adjustment



TL/H/5647-11

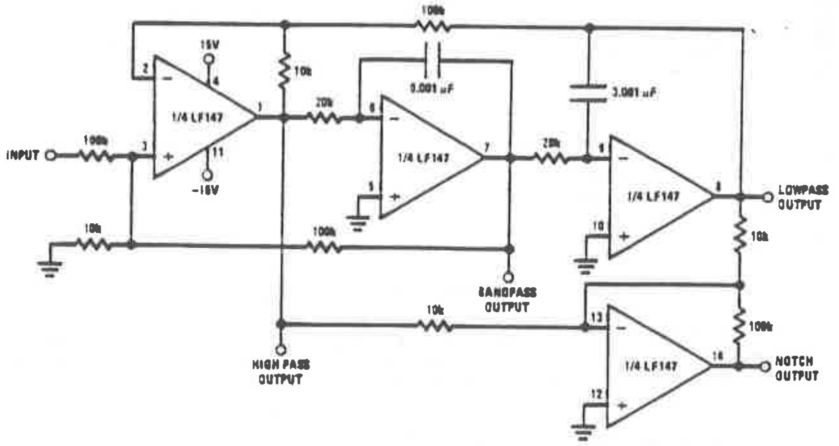
- V_{OUT} starts from zero and is equal to the integral of the input voltage with respect to the threshold voltage:

$$V_{OUT} = \frac{1}{RC}\int_0^t (V_{IN} - V_{TH})dt$$

- Output starts when $V_{IN} \geq V_{TH}$
- Switch S1 permits stopping and holding any output value
- Switch S2 resets system to zero

Typical Applications (Continued)

Universal State Variable Filter



TL/H/5647-12

For circuit shown:

$f_0 = 3$ kHz, $f_{NOTCH} = 9.5$ kHz

$Q = 3.4$

Passband gain:

- Highpass—0.1
- Bandpass—1
- Lowpass—1
- Notch—10

- $f_0 \times Q \leq 200$ kHz
- 10V peak sinusoidal output swing without slew limiting to 200 kHz
- See LM148 data sheet for design equations

LINEAR
INTEGRATED
CIRCUITS

TYPES uA741M, uA741C
GENERAL-PURPOSE OPERATIONAL AMPLIFIERS

BULLETIN NO. DL-S 11363, NOVEMBER 1970—REVISED OCTOBER 1979

- Short-Circuit Protection
- Offset-Voltage Null Capability
- Large Common-Mode and Differential Voltage Ranges
- No Frequency Compensation Required
- Low Power Consumption
- No Latch-up

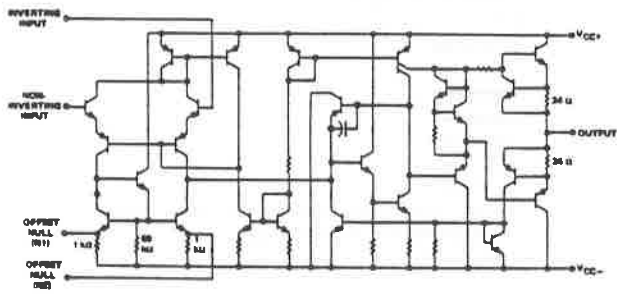
description

The uA741 is a general-purpose operational amplifier featuring offset-voltage null capability.

The high common-mode input voltage range and the absence of latch-up make the amplifier ideal for voltage-follower applications. The device is short-circuit protected and the internal frequency compensation ensures stability without external components. A low-value potentiometer may be connected between the offset null inputs to null out the offset voltage as shown in Figure 2.

The uA741M is characterized for operation over the full military temperature range of −55°C to 125°C; the uA741C is characterized for operation from 0°C to 70°C.

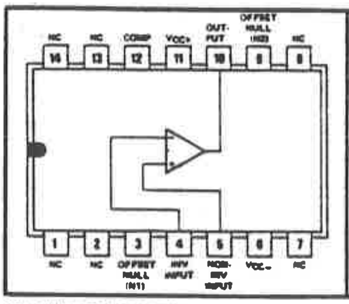
schematic



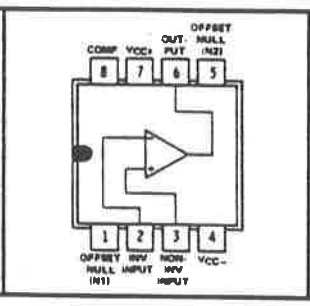
Resistor values shown are nominal

terminal assignments

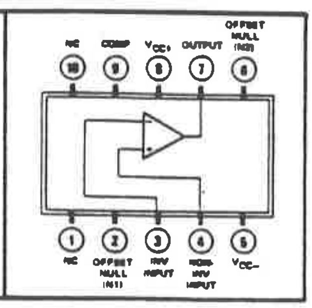
J OR N DUAL-IN-LINE OR W FLAT PACKAGE (TOP VIEW)



JG OR P DUAL-IN-LINE PACKAGE (TOP VIEW)



U FLAT PACKAGE (TOP VIEW)



NC—No internal connection

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

		uA741M	uA741C	UNIT
Supply voltage V_{CC+} (see Note 1)		22	18	V
Supply voltage V_{CC-} (see Note 1)		−22	−18	V
Differential input voltage (see Note 2)		±30	±30	V
Input voltage (either input, see Notes 1 and 3)		±15	±15	V
Voltage between either offset null terminal (N1/N2) and V_{CC-}		±0.5	±0.5	V
Duration of output short-circuit (see Note 4)		unlimited	unlimited	
Continuous total power dissipation at (or below) 25°C free-air temperature (see Note 5)		500	500	mW
Operating free-air temperature range		−55 to 125	0 to 70.	°C
Storage temperature range		−65 to 150	−65 to 150	°C
Lead temperature 1/16 inch (1,6 mm) from case for 60 seconds	J, JG, U, or W package	300	300	°C
Lead temperature 1/16 inch (1,6 mm) from case for 10 seconds	N or P package		260	°C

NOTES:
1. All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at the noninverting 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 either power supply. For the uA741M only, the unlimited duration of the short-circuit applies at (or below) 125°C case temperature or 75°C free-air temperature.
5. For operation above 25°C free-air temperature, refer to Dissipation Derating Curves, Section 2. In the J and JG packages, uA741M chips are alloy-mounted; uA741C chips are glass-mounted.

electrical characteristics at specified free-air temperature, V_{CC+} = 15 V, V_{CC-} = −15 V

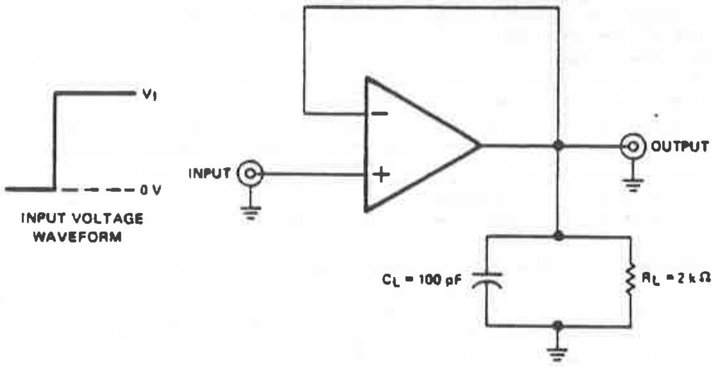
PARAMETER		TEST CONDITIONS†		uA741M			uA741C			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	R_S < 10 kΩ	25°C		1	5		1	6	mV
			Full range			6			7.5	
$\Delta V_{IO(adj)}$	Offset voltage adjust range		25°C		±15			±15		mV
I_{IO}	Input offset current		25°C		20	200		20	200	nA
			Full range			500			300	
I_{IB}	Input bias current		25°C		80	500		80	500	nA
			Full range			1500			800	
V_{ICR}	Common-mode input voltage range		25°C	±12	±13		±12	±13		V
			Full range	±12			±12			
V_{OPP}	Maximum peak-to-peak output voltage swing	R_L = 10 kΩ	25°C	24	28		24	28		V
		R_L ≥ 10 kΩ	Full range	24			24			
		R_L = 2 kΩ	25°C	20	26		20	26		
		R_L ≥ 2 kΩ	Full range	20			20			
A_{VD}	Large-signal differential voltage amplification	R_L ≥ 2 kΩ, V_O = ±10 V	25°C	50	200		20	200		V/mV
			Full range	25			15			
r_i	Input resistance		25°C	0.3	2		0.3	2		MΩ
r_o	Output resistance	V_O = 0 V, See Note 6	25°C		75			75		Ω
C_i	Input capacitance		25°C		1.4			1.4		pF
CMRR	Common-mode rejection ratio	R_S < 10 kΩ	25°C	70	90		70	90		dB
			Full range	70			70			
k_{SVS}	Supply voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	R_S < 10 kΩ	25°C		30	150		30	150	µV/V
			Full range			150			150	
I_{OS}	Short-circuit output current		25°C		±25	±40		±25	±40	mA
I_{CC}	Supply current	No load, No signal	25°C		1.7	2.8		1.7	2.8	mA
			Full range			3.3			3.3	
P_D	Total power dissipation	No load, No signal	25°C		50	85		50	85	mW
			Full range			100			100	

† All characteristics are specified under open-loop operation. Full range for uA741M is −55°C to 125°C and for uA741C is 0°C to 70°C.
NOTE 6: This typical value applies only at frequencies above a few hundred hertz because of the effects of drift and thermal feedback.

operating characteristics, $V_{CC+} = 15$ V, $V_{CC-} = -15$ V, $T_A = 25°C$

PARAMETER		TEST CONDITIONS	uA741M			uA741C			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
t_r	Rise time	$V_I = 20$ mV, $R_L = 2$ kΩ, $C_L = 100$ pF, See Figure 1		0.3			0.3		µs
	Overshoot factor			5%			5%		
SR	Slew rate at unity gain	$V_I = 10$ V, $R_L = 2$ kΩ, $C_L = 100$ pF, See Figure 1		0.5			0.5		V/µs

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT

FIGURE 1—RISE TIME, OVERSHOOT, AND SLEW RATE

TYPICAL APPLICATION DATA

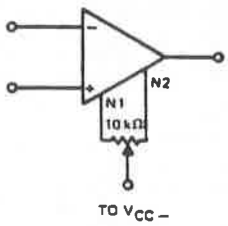


FIGURE 2—INPUT OFFSET VOLTAGE NULL CIRCUIT

TYPICAL CHARACTERISTICS

INPUT OFFSET CURRENT
vs
FREE-AIR TEMPERATURE

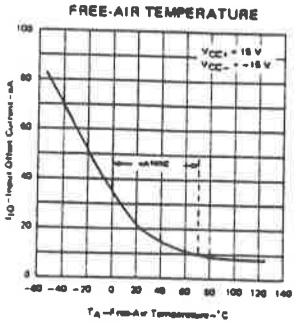
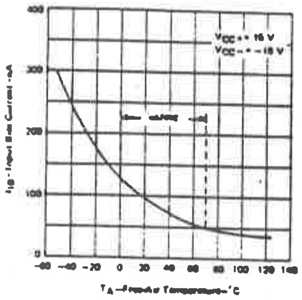


FIGURE 3

INPUT BIAS CURRENT
vs
FREE-AIR TEMPERATURE



FIGUER 4

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
vs
LOAD RESISTANCE

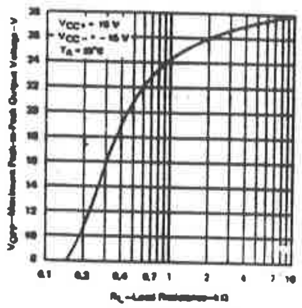


FIGURE 5

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
vs
FREQUENCY

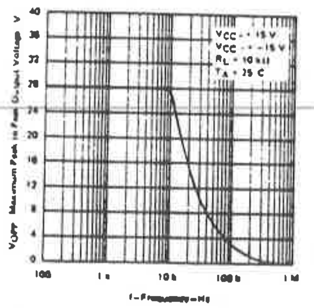


FIGURE 6

OPEN-LOOP LARGE-SIGNAL
DIFFERENTIAL
VOLTAGE AMPLIFICATION
vs
SUPPLY VOLTAGE

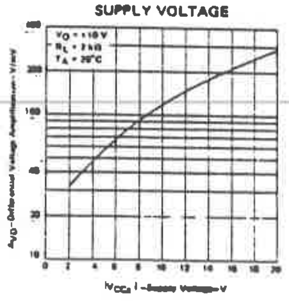


FIGURE 7

OPEN-LOOP LARGE-SIGNAL
DIFFERENTIAL
VOLTAGE AMPLIFICATION
vs
FREQUENCY

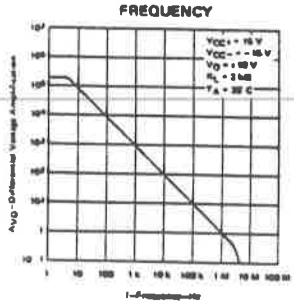


FIGURE 8

COMMON-MODE REJECTION RATIO
vs
FREQUENCY

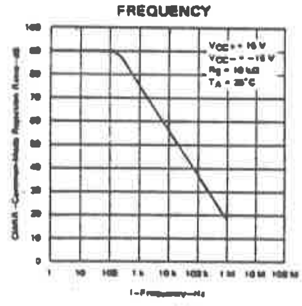


FIGURE 9

OUTPUT VOLTAGE
vs
ELAPSED TIME

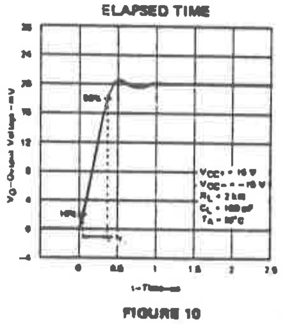


FIGURE 10

VOLTAGE-FOLLOWER
LARGE-SIGNAL PULSE RESPONSE

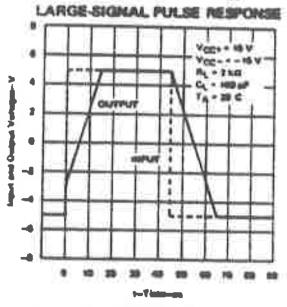


FIGURE 11

TYPES TL431M, TL431I, TL431C
ADJUSTABLE PRECISION SHUNT REGULATORS

D2410, JULY 1978–REVISED DECEMBER 1982

- Equivalent Full-Range Temperature Coefficient . . . 30 ppm/°C Typ
- Temperature Compensated for Operation Over Full Rated Operating Temperature Range
- Adjustable Output Voltage
- Fast Turn-On Response
- Sink Current Capability . . . 1 mA to 100 mA
- Low (0.2-Ω Typ) Dynamic Output Impedance
- Low Output Noise Voltage

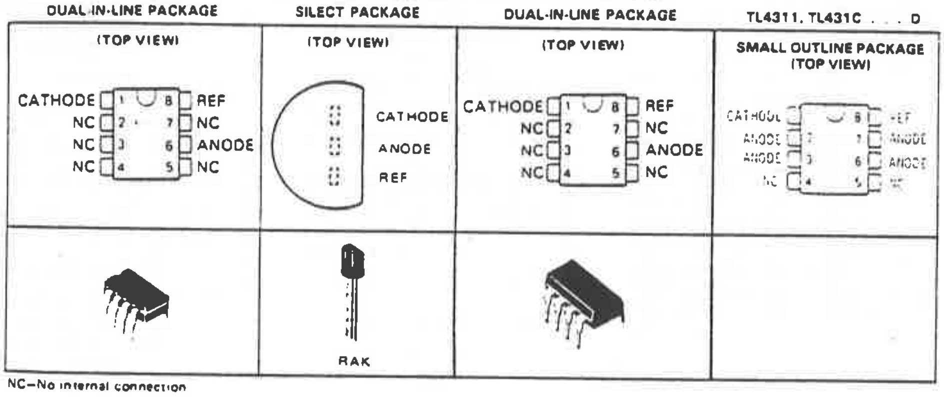
description

The TL431 is a three-terminal adjustable regulator series with guaranteed thermal stability over applicable temperature ranges. The output voltage may be set to any value between V_{ref} (approximately 2.5 volts) and 36 volts with two external resistors (see Figure 16). These devices have a typical dynamic output impedance of 0.2 Ω. Active output circuitry provides a very sharp turn-on characteristic, making these devices excellent replacements for zener diodes in many applications.

The TL431M is characterized for operation over the full military temperature range of −55°C to 125°C. The TL431I is characterized for operation from −40°C to 85°C, and the TL431C from 0°C to 70°C.

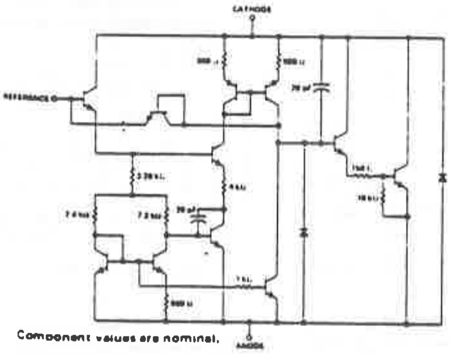
terminal assignments

TL431M . . . JG DUAL-IN-LINE PACKAGE | TL431I, TL431C . . . LP SILECT PACKAGE | TL431I, TL431C . . . P DUAL-IN-LINE PACKAGE | TL431I, TL431C . . . D



NC–No internal connection

schematic



Component values are nominal.

functional block diagram

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Cathode voltage (see Note 1)		37 V
Continuous cathode current range		−100 mA to 150 mA
Reference input current range		−50 μA to 10 mA
Continuous power dissipation at (or below) 25°C free-air temperature (see Note 2):	D package	833 mW
	JG package	1050 mW
	LP package	775 mW
	P package	1000 mW
Operating free-air temperature range:	TL431C	0°C to 70°C
	TL431I	−40°C to 85°C
	TL431M	−55°C to 125°C
Storage temperature range		−65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds:	JG package	300°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds:	LP, P or D package	260°C

NOTES: 1. Voltage values are with respect to the anode terminal unless otherwise noted.
2. For operation above 25°C free-air temperature, refer to the Dissipation Derating Table.

DISSIPATION DERATING TABLE

PACKAGE	POWER RATING	DERATING FACTOR	ABOVE T_A
JG	1050 mW	8.4 mW/°C	25°C
LP	775 mW	6.2 mW/°C	25°C
P	1000 mW	8.0 mW/°C	25°C

FREE-AIR TEMPERATURE
DISSIPATION DERATING CURVE

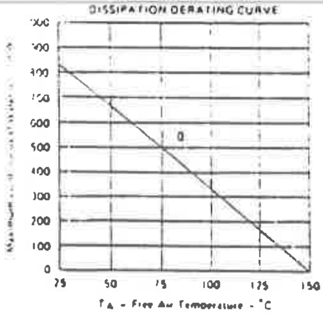


FIGURE 1

recommended operating conditions

	MIN	MAX	UNIT
Cathode voltage, V_{KA}	V_{ref}	36	V
Cathode current, I_K, (for regulation)	1	100	mA

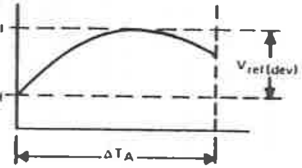
electrical characteristics at 25°C free-air temperature (unless otherwise noted)

PARAMETER		TEST CIRCUIT	TEST CONDITIONS		TL431M MIN	TL431M TYP	TL431M MAX	TL431I MIN	TL431I TYP	TL431I MAX	TL431C MIN	TL431C TYP	TL431C MAX	UNIT
V_{ref}	Reference input voltage	1	$V_{KA} = V_{ref}$, $I_K = 10$ mA		2440	2495	2550	2440	2495	2550	2440	2495	2550	mV
$V_{ref(dev)}$	Deviation of reference input voltage over full temperature range‡	1	$V_{KA} = V_{ref}$, $I_K = 10$ mA, T_A = full range†			22	44		15	30		8	17	mV
$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	Ratio of change in reference input voltage to the change in cathode voltage*	2	$I_K = 10$ mA	$\Delta V_{KA} = 10\ V - V_{ref}$		−1.4	−2.7		−1.4	−2.7		−1.4	−2.7	mV/V
				$\Delta V_{KA} = 36\ V - 10\ V$		−1	−2		−1	−2		−1	−2	mV/V
I_{ref}	Reference input current*	2	$I_K = 10$ mA, $R1 = 10\ k\Omega$, $R2 = \infty$			2	4		2	4		2	4	μA
$I_{ref(dev)}$	Deviation of reference input current over full temperature range‡*	2	$I_K = 10$ mA, $R1 = 10\ k\Omega$, $R2 = \infty$, T_A = full range†			1	3		0.8	2.5		0.4	1.2	μA
I_{min}	Minimum cathode current for regulation	1	$V_{KA} = V_{ref}$			0.4	1		0.4	1		0.4	1	mA
I_{off}	Off-state cathode current	3	$V_{KA} = 36$ V, $V_{ref} = 0$			0.1	1		0.1	1		0.1	1	μA
$\lvert z_{ka} \rvert$	Dynamic impedance§	1	$V_{KA} = V_{ref}$, $I_K = 1$ mA to 100 mA, $f \leq 1$ kHz			0.2	0.5		0.2	0.5		0.2	0.5	Ω

† Full temperature range is −55°C to 125°C for the TL431M, −40°C to 85°C for the TL431I, and 0°C to 70°C for the TL431C.

‡ The deviation parameters $V_{ref(dev)}$ and $I_{ref(dev)}$ are defined as the differences between the maximum and minimum values obtained over the rated temperature range. The equivalent full range temperature coefficient of the reference input voltage αV_{ref} is defined as

$$\lvert \alpha V_{ref} \rvert \left(\frac{ppm}{°C}\right) = \frac{\left(\frac{V_{ref(dev)}}{V_{ref} @ 25°C}\right) \times 10^6}{\Delta T_A}$$



where ΔT_A is the rated operating free-air temperature range of the device.

αV_{ref} can be positive or negative depending on whether minimum V_{ref} or maximum V_{ref}, respectively, occurs at the lower temperature (see Figure 8).

Example: Max V_{ref} = 2500 mV @ 30°C, Min V_{ref} = 2492 mV @ 0°C, V_{ref} = 2495 mV @ 25°C, ΔT_A = 70°C for TL431C

$$\lvert \alpha V_{ref} \rvert = \frac{\left(\frac{8\ mV}{2495\ mV}\right) \times 10^6}{70°C} \approx 46\ ppm/°C$$

Because minimum V_{ref} occurs at the lower temperature, the coefficient is positive.

§ The dynamic impedance is defined as

$$\lvert z_{ka} \rvert = \frac{\Delta V_{KA}}{\Delta I_K}$$

When the device is operated with two external resistors (see Figure 2), the total dynamic impedance of the circuit is given by

$$\lvert z' \rvert = \frac{\Delta V}{\Delta I} \approx \lvert z_{ka} \rvert \left(1 + \frac{R1}{R2}\right)$$

*For M suffix devices these parameters are guaranteed but not tested.

PARAMETER MEASUREMENT INFORMATION

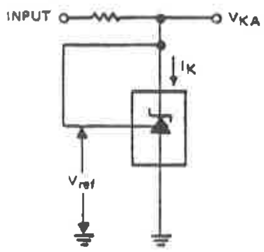


FIGURE 1—TEST CIRCUIT FOR $V_{KA} = V_{ref}$

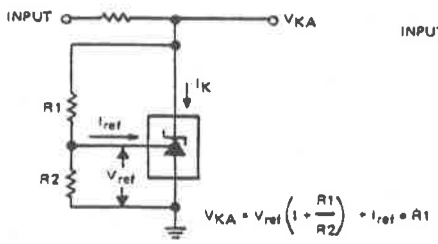


FIGURE 2—TEST CIRCUIT FOR $V_{KA} > V_{ref}$

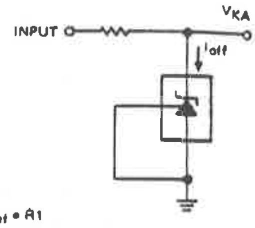


FIGURE 3—TEST CIRCUIT FOR I_{off}

TYPICAL CHARACTERISTICS

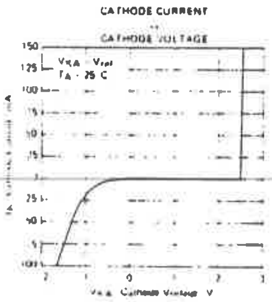


FIGURE 4

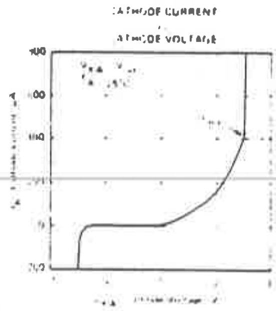


FIGURE 5

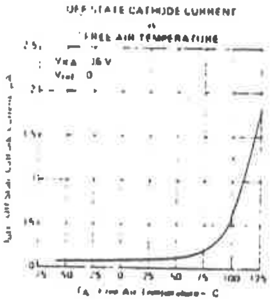


FIGURE 6

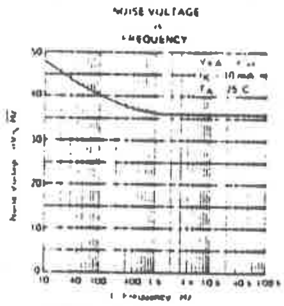


FIGURE 7

TYPICAL CHARACTERISTICS

REFERENCE INPUT VOLTAGE
vs
FREE-AIR TEMPERATURE

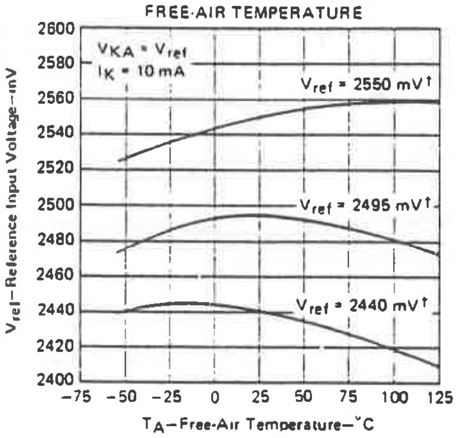


FIGURE 8

REFERENCE INPUT CURRENT
vs
FREE-AIR TEMPERATURE

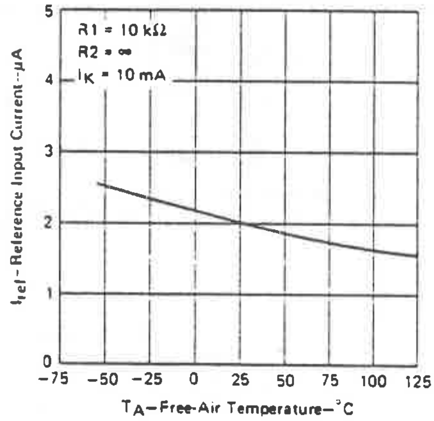


FIGURE 9

CHANGE IN REFERENCE INPUT VOLTAGE
vs
CATHODE VOLTAGE

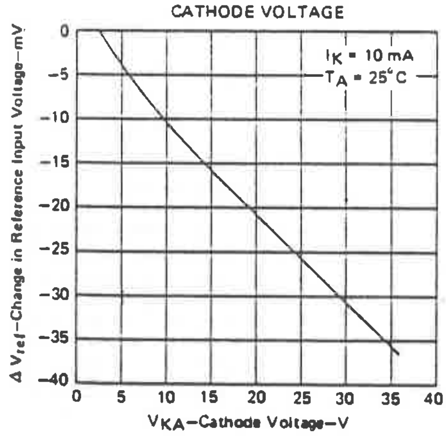


FIGURE 10

DYNAMIC IMPEDANCE
vs
FREE-AIR TEMPERATURE

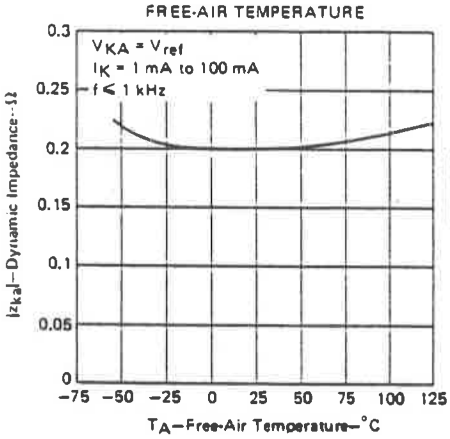


FIGURE 11

†Data is for devices having the indicated value of V_{ref} at I_K = 10 mA, T_A = 25°C.

TYPICAL CHARACTERISTICS

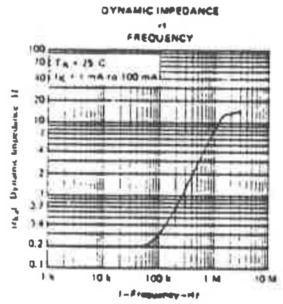
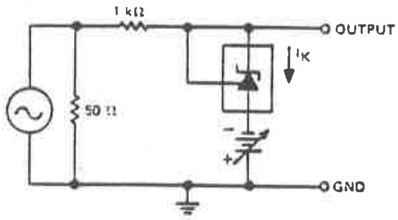


FIGURE 12



TEST CIRCUIT FOR DYNAMIC IMPEDANCE

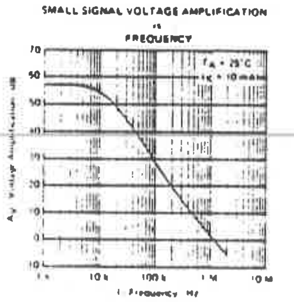
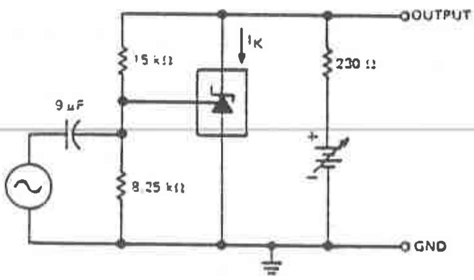


FIGURE 13



TEST CIRCUIT FOR VOLTAGE AMPLIFICATION

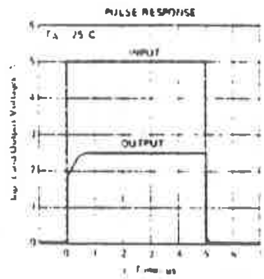
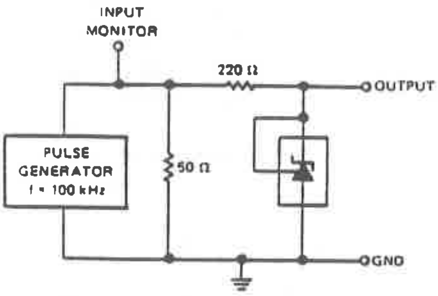
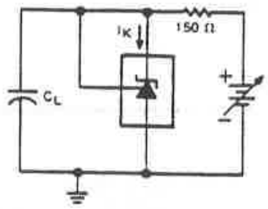


FIGURE 14

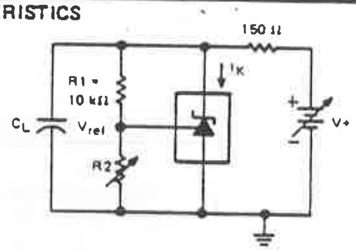


TEST CIRCUIT FOR PULSE RESPONSE

TYPICAL CHARACTERISTICS



TEST CIRCUIT FOR CURVE A BELOW



TEST CIRCUIT FOR CURVES B, C, AND D BELOW

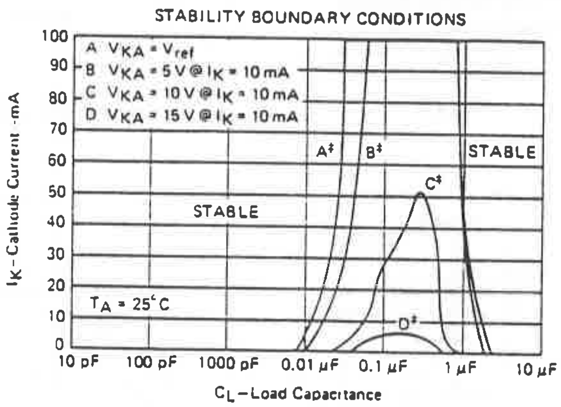


FIGURE 15

‡The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, R2 and V+ were adjusted to establish the initial V_{KA} and I_K conditions with $C_L = 0$. V+ and C_L were then adjusted to determine the ranges of stability.

TYPICAL APPLICATIONS

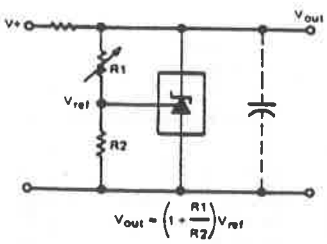


FIGURE 16—SHUNT REGULATOR

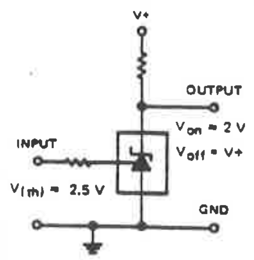


FIGURE 17—SINGLE-SUPPLY COMPARATOR WITH TEMPERATURE-COMPENSATED THRESHOLD

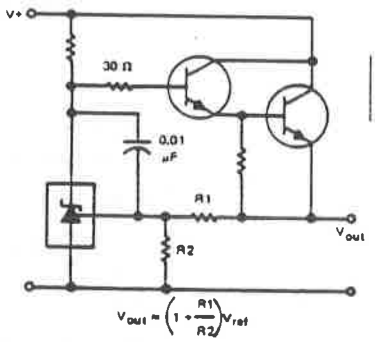
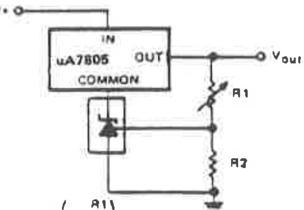


FIGURE 18—SERIES REGULATOR

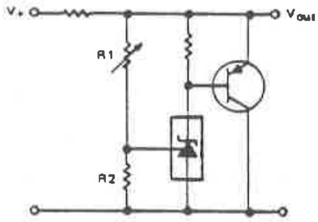
TYPICAL APPLICATIONS



$V_{out} = V_{ref}\left(1 + \frac{R1}{R2}\right)$

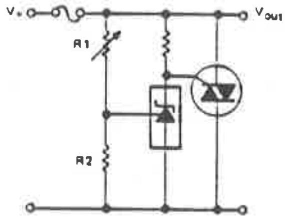
Min $V_{out} = V_{ref} + 5\ V$

FIGURE 19– OUTPUT CONTROL OF A THREE-TERMINAL FIXED REGULATOR



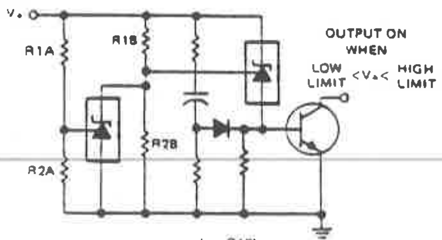
$V_{out} = \left(1 + \frac{R1}{R2}\right)V_{ref}$

FIGURE 20–HIGHER-CURRENT SHUNT REGULATOR



$V_{limit} = \left(1 + \frac{R1}{R2}\right)V_{ref}$

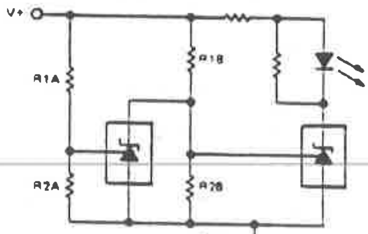
FIGURE 21–CROW BAR



Low limit $= V_{ref}\left(1 + \frac{R1B}{R2B}\right) + V_{BE}$

High limit $= V_{ref}\left(1 + \frac{R1A}{R2A}\right)$

FIGURE 22–OVER-VOLTAGE/UNDER-VOLTAGE PROTECTION CIRCUIT

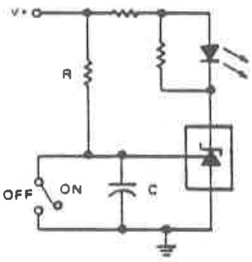


Low limit $= V_{ref}\left(1 + \frac{R1B}{R2B}\right)$

High limit $= V_{ref}\left(1 + \frac{R1A}{R2A}\right)$

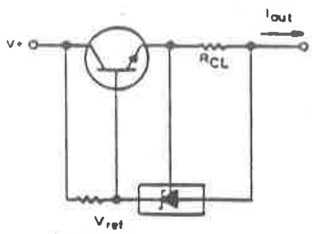
LED ON WHEN LOW LIMIT < V+ < HIGH LIMIT

FIGURE 23–VOLTAGE MONITOR



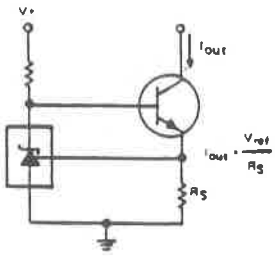
$\text{Delay} = R \cdot C \cdot \ln \frac{V+}{(V+) - V_{ref}}$

FIGURE 24–DELAY TIMER



$I_{out} = \frac{V_{ref}}{R_{CL}}$

FIGURE 25–CURRENT LIMITER OR CURRENT SOURCE



$I_{out} = \frac{V_{ref}}{R_S}$

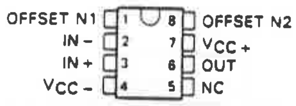
FIGURE 26–CONSTANT-CURRENT SINK

TYPES OP-07C, OP-07D, OP-07E
ULTRA-LOW-OFFSET-VOLTAGE OPERATIONAL AMPLIFIERS

D2757 OCTOBER 1983

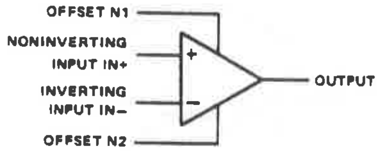
- Ultra-Low Offset Voltage . . . 30 μV Typ (OP-07E)
- Ultra-Low Offset Voltage Temperature Coefficient . . . 0.3 μV/°C Typ (OP-07E)
- Ultra-Low Noise
- No External Components Required
- Replaces Chopper Amplifiers at a Lower Cost
- Single-Chip Monolithic Fabrication
- Wide Input Voltage Range
  0 to ±14 V Typ
- Wide Supply Voltage Range
  ±3 V to ±18 V
- Essentially Equivalent to Fairchild μA714 Operational Amplifiers
- Direct Replacement for PMI OP-07C, OP-07D, OP-07E

D, JG OR P DUAL-IN-LINE PACKAGE
(TOP VIEW)



NC – No internal connection

symbol

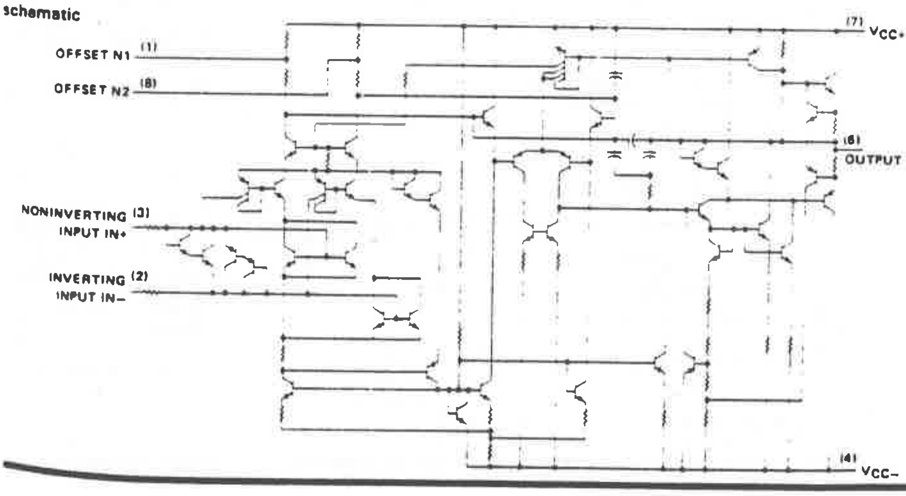


description

These devices represent a breakthrough in operational amplifier performance. Low offset and long-term stability are achieved by means of a low-noise, chopperless, bipolar-input-transistor amplifier circuit. For most applications, no external components are required for offset nulling and frequency compensation. The true differential input, with a wide input voltage range and outstanding common-mode rejection, provides maximum flexibility and performance in high-noise environments and in noninverting applications. Low bias currents and extremely high input impedances are maintained over the entire temperature range. The OP-07 is unsurpassed for low-noise, high-accuracy amplification of very-low-level signals.

These devices are characterized for operation from 0°C to 70°C.

schematic



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage V_{CC+} (see Note 1)	22 V
Supply voltage V_{CC-}	−22 V
Differential input voltage (see Note 2)	±30 V
Input voltage (either input, see Note 3)	±22 V
Duration of output short circuit (see Note 4)	unlimited
Continuous total dissipation at (or below) 25 °C free-air temperature (see Note 5)	500 mW
Operating free-air temperature range	0 °C to 70 °C
Storage temperature range	−65 °C to 150 °C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: JG package	300 °C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: P package	260 °C

NOTES: 1. All voltage values, unless otherwise noted, are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at the noninverting 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 either power supply.
5. For operation above 25 °C free-air temperature, refer to Dissipation Derating Curves in Section 2. In the JG package, these chips are glass-mounted.

electrical characteristics at specified free-air temperature, $V_{CC\pm} = \pm 15$ V (unless otherwise noted)

	PARAMETER	TEST CONDITIONS†		OP 7C MIN	OP 7C TYP	OP 7C MAX	OP 7D MIN	OP 7D TYP	OP 7D MAX	OP 7E MIN	OP 7E TYP	OP 7E MAX	UNIT
V_{IO}	Input offset voltage	$V_O = 0$, $R_S = 50\ \Omega$	25°C		60	150		60	150		30	75	μV
			0°C to 70°C		85	250		85	250		45	130	
α_{VIO}*	Temperature coefficient of input offset voltage	$V_O = 0$, $R_S = 50\ \Omega$	0°C to 70°C		0.5	1.8		0.7	2.5		0.3	1.3	μV/°C
	Long term drift of input offset voltage	See Note 6			0.4			0.5			0.3		μV/mo
	Offset adjustment range	$R_S = 20\ k\Omega$, See Figure 1	25°C		±4			±4			±4		mV
I_{IO}	Input offset current		25°C		0.8	6		0.8	6		0.5	3.8	nA
			0°C to 70°C		1.6	8		1.6	8		0.9	5.3	
α_{IIO}	Temperature coefficient of input offset current		0°C to 70°C		12	50		12	50		8	35	pA/°C
I_{IB}	Input bias current		25°C		±1.8	±7		±2	±12		±1.2	±4	nA
			0°C to 70°C		±2.2	±9		±3	±14		±1.5	±5.5	
α_{IIB}*	Temperature coefficient of input bias current		0°C to 70°C		18	50		18	50		13	35	pA/°C
V_{ICR}	Common mode input voltage range		25°C	±13	±14		±13	±14		±13	±14		V
			0°C to 70°C	±13	±13.5		±13	±13.5		±13	±13.5		
V_{OM}	Peak output voltage	$R_L \geq 10\ k\Omega$	25°C	±12	±13		±12	±13		±12.5	±13		V
		$R_L \geq 2\ k\Omega$		±11.5	±12.8		±11.5	±12.8		±12	±12.8		
		$R_L \geq 1\ k\Omega$			±12			±12		±10.5	±12		
		$R_L \geq 2\ k\Omega$	0°C to 70°C	±11	±12.6		±11	±12.6		±12	±12.6		
A_{VD}	Large signal differential voltage amplification	$V_{CC\pm} = \pm 3$ V, $V_O = \pm 0.5$ V, $R_L \geq 500\ k\Omega$	25°C	100	400			400		150	400		V/mV
		$V_O = \pm 10$ V, $R_L = 2\ k\Omega$	25°C	120	400		120	400		200	500		
			0°C to 70°C	100	400		100	400		180	450		
B_1*	Unity gain bandwidth		25°C	0.4	0.6		0.4	0.6		0.4	0.6		MHz
r_i*	Input resistance		25°C	8	33		7	31		15	50		MΩ
CMRR	Common mode rejection ratio	$V_{IC} = \pm 13$ V, $R_S = 50\ \Omega$	25°C	100	120		94	110		106	123		dB
			0°C to 70°C	97	120		94	106		103	123		
k_{SVS}	Supply voltage sensitivity ($\Delta V_{IO}/\Delta V_{CC}$)	$V_{CC\pm} = \pm 3$ V to ± 18 V, $R_S = 50\ \Omega$	25°C		7	32		7	32		5	20	μV/V
			0°C to 70°C		10	51		10	51		7	32	
P_D	Power dissipation	$V_O = 0$, No load	25°C		80	150		80	150		75	120	mW
		$V_{CC\pm} = \pm 3$ V, $V_O = 0$, No load			4	8		4	8		4	6	

†All characteristics are measured under open loop conditions with zero common mode input voltage unless otherwise noted

NOTE 6 Since long term drift cannot be measured on the individual devices prior to shipment, this specification is not intended to be a guarantee or warranty. It is an engineering estimate of the averaged trend line of drift versus time over extended periods after the first thirty days of operation.

*These parameters are guaranteed but not tested

operating characteristics at specified free-air temperature, $V_{CC\pm} = \pm 15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†		OP-7C MIN	OP-7C TYP	OP-7C MAX	OP-7D MIN	OP-7D TYP	OP-7D MAX	OP-7E MIN	OP-7E TYP	OP-7E MAX	UNIT
V_n	Equivalent input noise voltage	$T_A = 25°C$	$f = 10$ Hz		10.5	20		10.5	20		10.3	18	nV/√Hz
			$f = 100$ Hz		10.2	13.5		10.3	13.5		10.0	13	
			$f = 1$ kHz		9.8	11.5		9.8	11.5		9.6	[illegible]	
V_{NPP}	Peak-to-peak equivalent input noise voltage	$f = 0.1$ Hz to 10 Hz, $T_A = 25°C$			0.38	0.65		0.38	0.65		0.35	0.6	μV
I_n	Equivalent input noise current	$T_A = 25°C$	$f = 10$ Hz		0.35	0.9		0.35	0.9		0.32	0.8	pA/√Hz
			$f = 100$ Hz		0.15	0.27		0.15	0.27		0.14	0.23	
			$f = 1$ kHz		0.13	0.18		0.13	0.18		0.12	0.17	
I_{NPP}	Peak-to-peak equivalent input noise current	$f = 0.1$ Hz to 10 Hz, $T_A = 25°C$			15	35		15	35		14	30	pA
SR	Slew rate	$R_L \geq 2$ kΩ, $T_A = 25°C$		0.1	0.3		0.1	0.3		0.1	0.3		V/μs

†All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified.

TYPICAL APPLICATION DATA

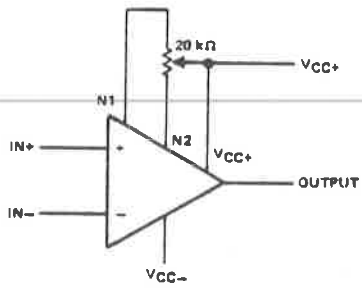


FIGURE 1—INPUT OFFSET VOLTAGE NULL CIRCUIT

PNP POWER TRANSISTORS

COMPLEMENTARY TO THE TIP31 SERIES

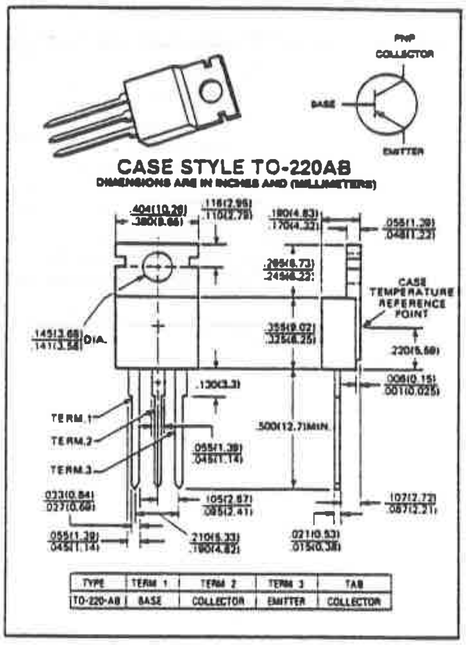
TIP 32 Series

-40 ~ -100 VOLTS
-3 AMP, 40 WATTS

The TIP32 Series power transistors are designed for use in general purpose amplifier and switching applications.

Features:

- Designed for complementary use with TIP31 series
- 40W at 25°C case temperature
- 3A continuous collector current
- 5A peak collector current
- Minimum f_T of 3 MHz at 10V, 0.5A
- Customer-specified selections available



maximum ratings (T_C = 25°C) (unless otherwise noted)

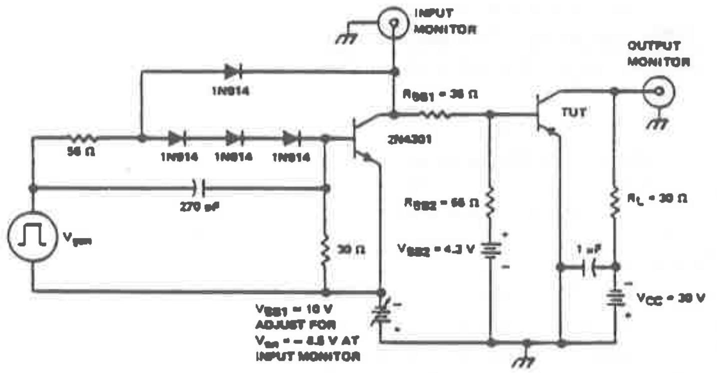
RATING	SYMBOL	TIP32	TIP32A	TIP32B	TIP32C	UNITS
Collector-Emitter Voltage	V_{CEO}	-40	-60	-80	-100	Volts
Collector-Base Voltage	V_{CBO}	-80	-100	-120	-140	Volts
Emitter Base Voltage	V_{EBO}	-5	-5	-5	-5	Volts
Collector Current — Continuous Peak	I_C I_{CM}	-3 -5	-3 -5	-3 -5	-3 -5	A
Base Current — Continuous	I_B	-1	-1	-1	-1	A
Total Power Dissipation @ T_A = 25°C @ T_C = 25°C	P_D	2 40	2 40	2 40	2 40	Watts
Operating and Storage Junction Temperature Range	T_J, T_{STG}	-65 to +150	-65 to +150	-65 to +150	-65 to +150	°C

thermal characteristics

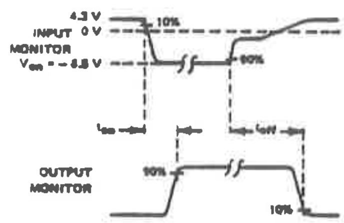
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.125	3.125	3.125	3.125	°C/W
Maximum Lead Temperature for Soldering Purposes: ⅛" from Case for 5 Seconds	T_L	250	250	250	250	°C

electrical characteristics (T_C = 25° C) (unless otherwise specified)

CHARACTERISTIC		SYMBOL	MIN	TYP	MAX	UNIT
off characteristics						
Collector-Emitter Breakdown Voltage (I_C = -30mA)	TIP32 TIP32A TIP32B TIP32C	V_{CEO}	-40 -60 -80 -100	— — — —	— — — —	Volts
Collector Cutoff Current (V_{CE} = -30V) (V_{CE} = -60V)	TIP32, TIP32A TIP32B, TIP32C	I_{CEO}	— —	— —	-0.3 -0.3	mA
Collector Cutoff Current (V_{CE} = -80V) (V_{CE} = -100V) (V_{CE} = -120V) (V_{CE} = -140V)	TIP32 TIP32A TIP32B TIP32C	I_{CES}	— — — —	— — — —	-0.2 -0.2 -0.2 -0.2	mA
Emitter Cutoff Current (V_{EB} = -5V, I_C = 0)		I_{EBO}	—	—	-1	mA
second breakdown						
Second Breakdown with Base Forward Biased		FBSOA	SEE FIGURE 3			
on characteristics						
DC Current Gain (I_C = -4A, V_{CE} = -1V) (I_C = -3A, V_{CE} = -4V)		h_{FE}	25 10	— —	— 50	—
Collector-Emitter Saturation Voltage (I_C = -3A, I_B = -375mA)		$V_{CE(sat)}$	—	—	-1.2	V
Base-Emitter Voltage (I_C = -3A, V_{CE} = -4V)		$V_{BE(on)}$	—	—	-1.8	V
switching characteristics						
Turn-on Time	R_L = 30Ω, I_C = 1A, I_{B1} = I_{B2} = 0.1A, $V_{BE(off)}$ = 4.3V	t_{on}	—	0.3	—	μs
Turn-off Time		t_{off}	—	1	—	



TEST CIRCUIT



VOLTAGE WAVEFORMS

NOTES: A. V_{gen} is a 30-V pulse into a 50 Ω termination.
B. The V_{gen} waveform is supplied by the following characteristics: $t_r \leq 15$ ns, $t_f \leq 15$ ns, Z_{out} = 50 Ω, t_w = 20 μs, duty cycle ≤ 2%.
C. Waveforms are monitored on an oscilloscope with the following characteristics: $t_r \leq 15$ ns, $R_{in} \geq 10$ MΩ, $C_{in} \leq 11.5$ pF.
D. Resistors must be noninductive types.
E. The d-c power supplies may require additional bypassing in order to minimize ringing.

FIGURE 1. RESISTIVE-LOAD SWITCHING

STATIC FORWARD CURRENT TRANSFER RATIO
vs
COLLECTOR CURRENT

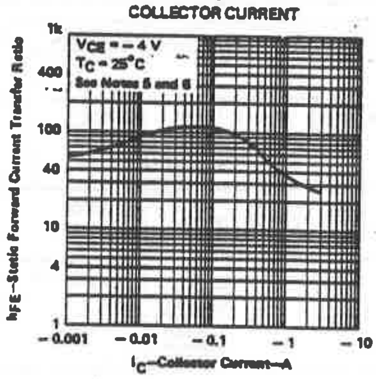


FIGURE 2. TYPICAL CHARACTERISTICS

NOTES: 5. These parameters must be measured using pulse techniques, t_w = 300 μs, duty cycle ≤ 2%.
6. These parameters are measured with voltage-sensing contacts separate from the current-carrying contacts.

FORWARD-BIAS SAFE OPERATING AREA

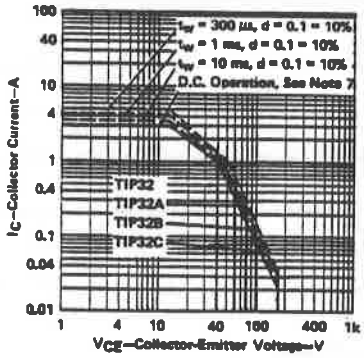


FIGURE 3 MAXIMUM SAFE OPERATING AREA

NOTE 7: This combination of maximum voltage and current may be achieved only when switching from saturation to cutoff with a clamped inductive load.

DISSIPATION DERATING CURVE

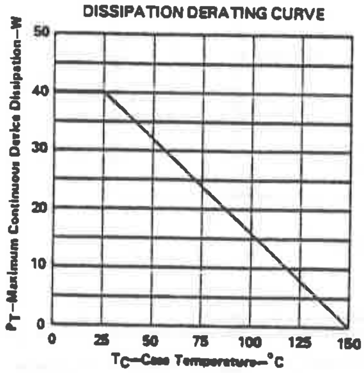


FIGURE 4 THERMAL INFORMATION

SERIES uA7800
POSITIVE-VOLTAGE REGULATORS

BULLETIN NO. DL-S 7612386, MAY 1976

- 3-Terminal Regulators
- Output Current up to 1.5 A
- No External Components
- Internal Thermal Overload Protection
- Direct Replacements for Fairchild μA7800 Series and National LM340 Series
- High Power Dissipation Capability
- Internal Short-Circuit Current Limiting
- Output Transistor Safe-Area Compensation

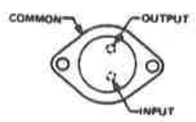
NOMINAL OUTPUT VOLTAGE	−55°C TO 150°C OPERATING TEMPERATURE RANGE	0°C TO 125°C OPERATING TEMPERATURE RANGE
5 V	uA7805M	uA7805C
6 V	uA7806M	uA7806C
8 V	uA7808M	uA7808C
8.5 V	uA7885M	uA7885C
12 V	uA7812M	uA7812C
15 V	uA7815M	uA7815C
18 V	uA7818M	uA7818C
24 V	uA7824M	uA7824C
packages	KA	KA and KC

description

This series of fixed-voltage monolithic integrated-circuit voltage regulators is designed for a wide range of applications. These applications include on-card regulation for elimination of noise and distribution problems associated with single-point regulation. One of these regulators can deliver up to 1.5 amperes of output current. The internal current limiting and thermal shutdown features of these regulators make them essentially immune to overload. In addition to use as fixed-voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents and also as the power-pass element in precision regulators.

KA PACKAGE

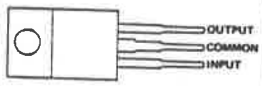
(TOP VEIW



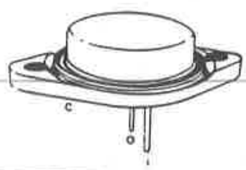
TO-3

KC PACKAGE

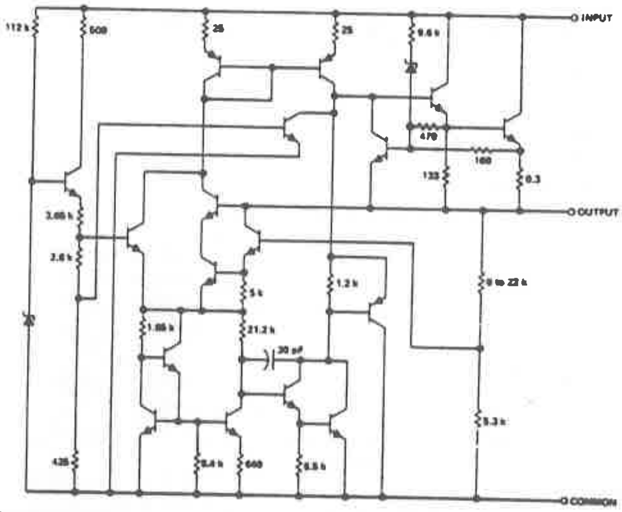
(TOP VIEW)



TO-220AB



schematic



Resistor values shown are nominal and in ohms.

absolute maximum ratings over operating temperature range (unless otherwise noted)

		uA78__M	uA78__C	UNIT
Input voltage	uA7824M, uA7824C	40	40	V
	All others	35	35	
Continuous total dissipation at 25°C free-air temperature (see Note 1)	KA (TO-3) package	3.5	3.5	W
	KC (TO-220AB) package		2	
Continuous total dissipation at (or below) 25°C case temperature (see Note 1)		15	15	W
Operating free-air, case, or virtual junction temperature range		−55 to 150	0 to 150	°C
Storage temperature range		−65 to 150	−65 to 150	°C
Lead temperature 1/16 inch from case for 60 seconds	KA (TO-3) package	300	300	°C
Lead temperature 1/16 inch from case for 10 seconds	KC (TO-220AB) package		260	°C

NOTE 1: For operation above 25°C free-air or case temperature, refer to Dissipation Derating Curves, Figure 1 and Figure 2.

TO-3 AND TO-220AB FREE-AIR TEMPERATURE DISSIPATION DERATING CURVES

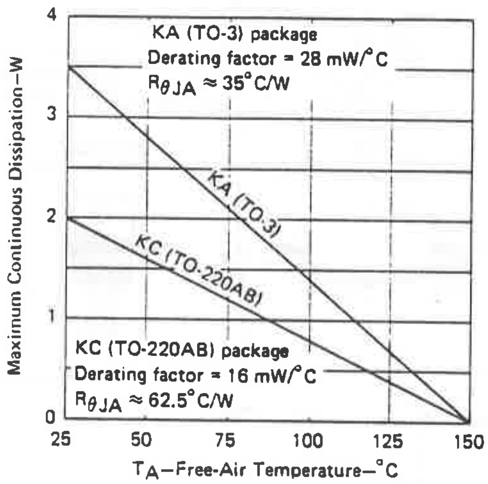


FIGURE 1

TO-3 AND TO-220AB CASE TEMPERATURE DISSIPATION DERATING CURVE

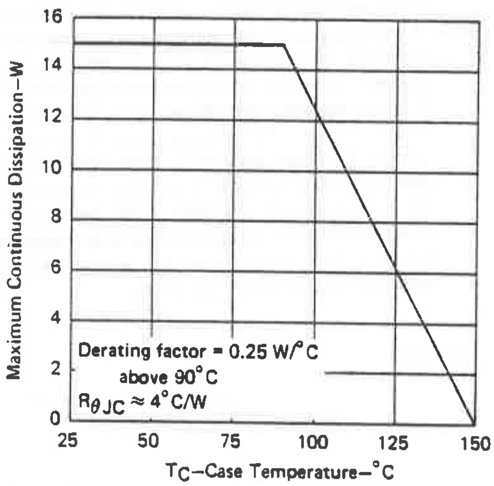


FIGURE 2

recommended operating conditions

		MIN	MAX	UNIT
Input voltage, V_I	uA7805M, uA7805C	7	25	V
	uA7806M, uA7806C	8	25	
	uA7808M, uA7808C	10.5	25	
	uA7885M, uA7885C	10.5	25	
	uA7812M, uA7812C	14.5	30	
	uA7815M, uA7815C	17.5	30	
	uA7818M, uA7818C	21	33	
	uA7824M, uA7824C	27	38	
Output current, I_O			1.5	A
Operating virtual junction temperature, T_J	uA7805M thru uA7824M	−55	150	°C
	uA7805C thru uA7824C	0	125	

uA7805M, uA7805C electrical characteristics at specified virtual junction temperature, V_I = 10 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS†			uA7805M			uA7805C			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
Output voltage			25°C	4.8	5	5.2	4.8	5	5.2	V
	I_O = 5 mA to 1 A, $P \leq 15$ W	V_I = 8 V to 20 V	−55°C to 150°C	4.65		5.35				
		V_I = 7 V to 20 V	0°C to 125°C				4.75		5.25	
Input regulation	V_I = 7 V to 25 V		25°C		3	50		3	100	mV
	V_I = 8 V to 12 V				1	25		1	50	
Ripple rejection	V_I = 8 V to 18 V, f = 120 Hz		−55°C to 150°C	68	78					dB
			0°C to 125°C				62	78		
Output regulation	I_O = 5 mA to 1.5 A		25°C		15	50		15	100	mV
	I_O = 250 mA to 750 mA				5	25		5	50	
Output resistance	f = 1 kHz		−55°C to 150°C		0.017					Ω
			0°C to 125°C					0.017		
Temperature coefficient of output voltage	I_O = 5 mA		0°C to 150°C		−1.1					mV/°C
			0°C to 125°C					−1.1		
Output noise voltage	f = 10 Hz to 100 kHz		25°C		40			40		μV
Dropout voltage	I_O = 1 A		25°C		2.0			2.0		V
Bias current			25°C		4.2	6		4.2	8	mA
Bias current change	V_I = 8 V to 25 V		−55°C to 150°C			0.8				mA
	V_I = 7 V to 25 V		0°C to 125°C						1.3	
	I_O = 5 mA to 1 A		−55°C to 150°C			0.5				
			0°C to 125°C						0.5	
Short-circuit output current			25°C		750			750		mA
Peak output current			25°C		2.2			2.2		A

†All characteristics are measured with a capacitor across the input of 0.33 μF and a capacitor across the output of 0.1 μF and all characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \leq 10$ ms, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.