INFRARED EMITTERS, DETECTORS, AND INSTRUMENTATION

A DISSERTATION

Submitted in Partial fulfilment to the
requirements for the award of the Degree
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in
Elcetrical Engineering
(Measurement & Instrumentation)

by

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CERTIFICATE

Certified that the dissertation entitled "INFRARED EMITTERS, DETECTORS AND INSTRUMENTATION" which is being submitted by Shri Pradeep Kumar Tandon in partial fulfilment for the award of the Degree of Master of Engineering in Electrical Engineering (Measurement and Instrumentation) of University of Roorkee, Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is to further certify that he has worked for 8 months from Feb. 1, 1978 to Oct. 7, 1978 for preparing this dissertation at this University.

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ABSTRACT

Among the many new techniques which have become of significance in applications beyond the laboratory is the INFRARED technique. The term infrared is generally applied to devices which depends for their basic information upon the electromagnetic energy of wavelength between 0.7 and 1000 um, which is reflected from, absorbed by, or emitted by objects of interest.

The present dissertation is a critical review to the infrared theory and its applications. Different types of infrared sources, targets and backgrounds are discussed; fundamental physics and optics are discussed; this discussion leads to the design of basic infrared instruments and systems. The choice of detectors is one of the most critical part of infrared instrument or system. Characteristics and applications of various types of detectors; thermal type, quantum type and nonconventional types, are discussed.

An analyser for infrared detectors has been developed which has got three major advantages : firstly, no additional preamplifier is required from outside; secondly, it can measure cell resistance from $10\,\Omega$ to $1\ M\Omega$; and thirdly, it is very inexpensive as the costly wave analyser has been replaced with a built in electronic filter.

One of the most useful advantage of infrared techniques is remote sensing of temperature. An infrared temperature scanner, which can scan approximately 400 points in one second has been developed by the author. This has the advantage that thermal maps of heated bodies can be obtained.

In addition, a scheme of great interest to the manufacturers and users of large rotating machines for scanning temperature of stator bore surfaces has been proposed.

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1. INTRODUCTION :

During the last million years, man has been successful in increasing his abilities and in enlarging his understanding of the world where he lives in. The tool responsible for such progress is an outstanding computer (usually called the brain), which receives the outside information through senses, compares it against the stored information (experience and/or knowledge), and makes decision and orders their implimentation. Contrary to the general behaviour of living beings, man has shown no patience and no willingness to keep himself within the original limitations of the human system as described above. In his unrelenting drive for progress, he has been constantly striving to widen the range of his capabilities and performance.

First came the improvement in the action of area (i.e. with his fare hands, man made tools, and with the tools he made devices capable of expanding greatly the range of physical performance); then came the effort to improve the decision making mechanism and recently man has attacked the third area; expanding the input information acquisition. It seems logical that the widening of the limits of human senses, or the addition of new ones, should enable the brain to receive more information for a more complete evaluation of the out side world.

Among the latest advances in this area has been the development of senses to detect and measure infrared radiation and the capability of presenting this information in a way that is understandable to the human mind.

With the help of infrared techniques and systems developed so far, now it is possible to perceive the infrared radiation emitted by all physical matters. The amount of information that infrared radiation can yield is tremendous and possibly a sizeable fraction of it is yet to be understood. The present day research in the field of infrared radiations is to measure these radiations more and more accurately and with higher and higher sensitivities, and to give meaning to every detail of this measurement. The aim of present dissertation is to review the uptodate developments in the infrared detectors sources and instrumentation and to develop a few instruments with an aim of making an humble contribution in the advancement of knowledge and tools in this field.

A review of the laws governing the infrared physics is made in Chapter II. The next five chapters are devoted to a deep study of the engineering aspects of the elements that comprise the infrared system. In Chapter III sources are discussed in detail. Chapter IV and V cover the infrared sensors, thermal, quantum and the nonconventional sensors, the thermal and quantum types being the major ones.

The instrumentation aspects are discussed in Chapter VI briefly. Some of the important applications of infrared systems are discussed in Chapter VII. An exhaustion list of the application is also included.

The author has developed two schemes : analyser for infrared detectors, and the infrared temperature scanner. Although, analysers are already available, the scheme developed by author has three advantages, firstly, if a cell (thermistor, photoconductive, bolometer, etc.) type detectors is to be tested and if its cell resistance is in between $10\,\Omega$ - $1\,M\Omega$, the analyser is able to tell this information. Secondly, no additional preamplifier is required from outside, which is a significant provision. The analyser available always need different type of preamplifiers for different detectors, but here this problem is solved. Thirdly, the cost of analyser is appreciably reduced because the expensive electric wave analyse is not needed. A simple electronic band pass filter is used for this purpose. The scheme is discussed in detail in Chapter VIII.

The second instrument, namely the temperature scanner, developed by author has one major advantage that here by using a strip-chart recorder or any other recorder, thermal mapping in two dimensions can be done. The scheme has got other advantages also which are discussed in detail in Chapter IX along with the scheme.

In Chapter IX, one scheme is proposed for measuring the stator and bore surface temperature which is a current problem faced by many manufacturers and users of large and rotating machines.

In Chapter X, the future trends and the scope of using infrared radiations is discussed. In short, it can be said, the final infrared world has not been spoken, the final work has not been performed, and the final goal is not achieved. Infrared as a new technique just starts here. The little progress done so far is almost nothing when compared with the future developments anticipated in this new field.

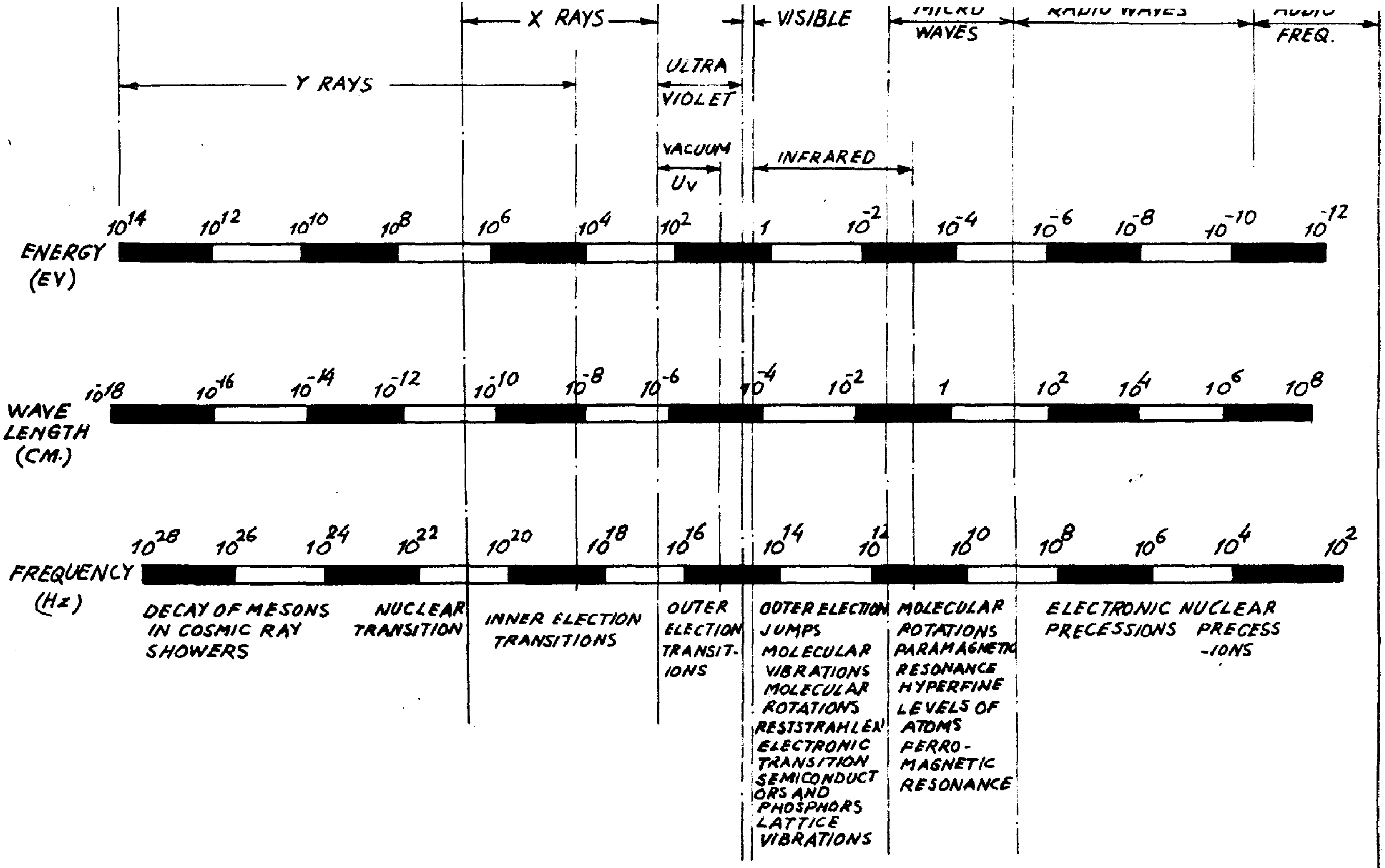


FIG.2.1 THE ELECTROMAGNETIC SPECTRUM

2. REVIEW OF BASIC CONCEPTS :

2.1 INFRA RED SPECTRUM[1,2] : Fig. 2.1 shows the spectral distribution of electromagnetic radiation starting at the right end with so called audio frequencies, it progresses through the radiowaves (long, medium, short, VHF, UHF, XHF, and milimetre waves) to infra-red regions. There is an overlap between the shortest frequencies of the infra-red spectrum and the higher frequency end of milimetre waves. At the high frequency end of the infra-red region, there is a visual radiation (light), next ultra-violet, and then as the energy contained increases, X-rays, γ-rays, and cosmic rays.

These radiations are different in a way they are generated : by electromagnetic generators (alternators) at the low-frequency end, all the way to nuclear radiations and mesons decay at high frequency end. Infra-red radiation is reduced by the rotational and vibrational movements of the atomic and sub-atomic particle of which physical matter is made. Since atomic and subatomic particles are always in motion, infra-red radiation is always emitted by physical matter, at frequencies corresponding to resonant constants of the oscillator. Since there is a great variety of different particles, different frequencies are generated in great variety, covering the range of what is known as infra-red spectrum.

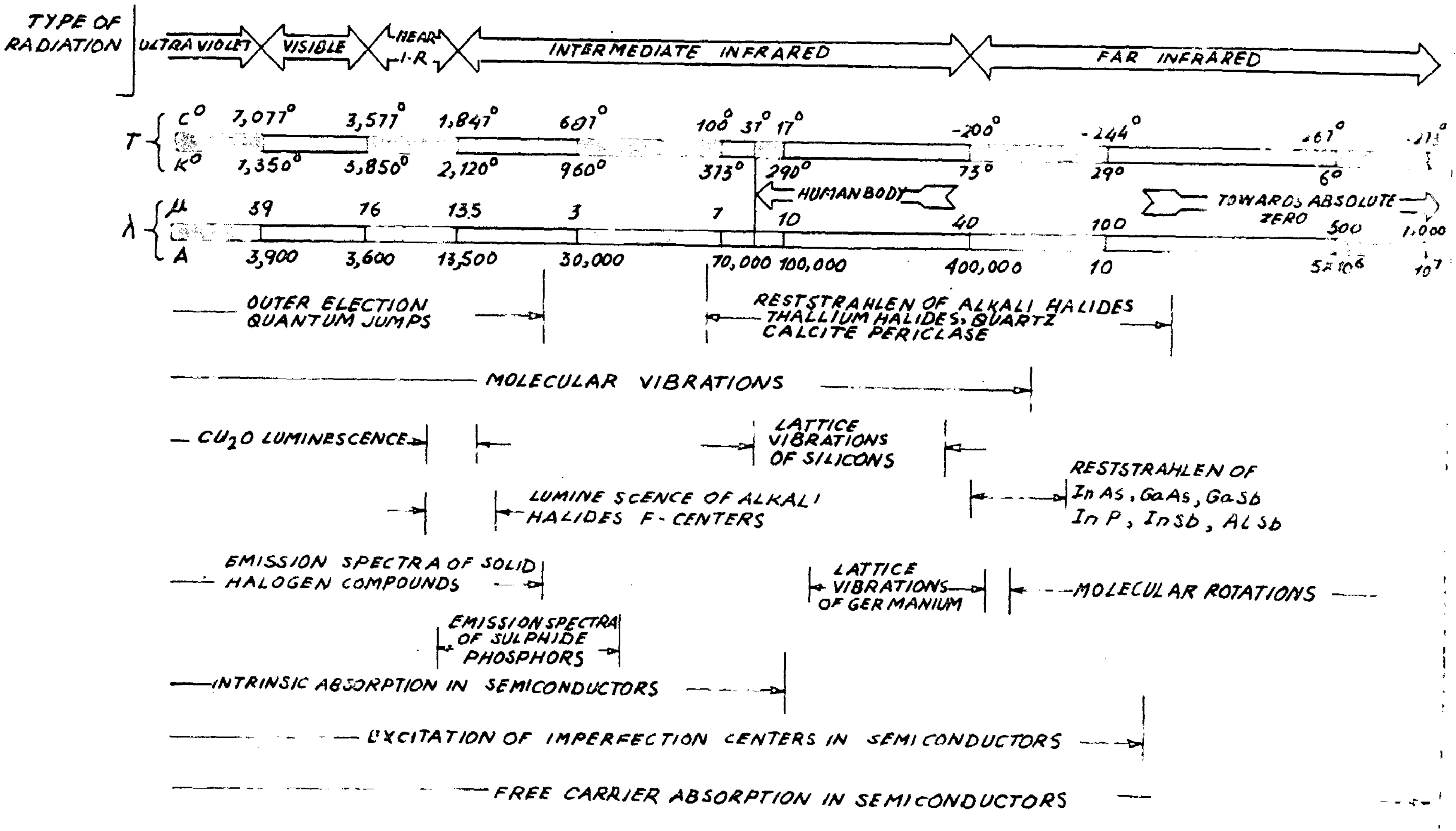


FIG. 2.2 VISIBLE AND INFRARED SPECTRUM

Fig. 2.2 shows the detailed infra-red spectrum. The total spectrum is divided into three areas : the near infra-red, the intermediate infrared and the far infra-red. Although at the present time there does not seem to be real need for dividing the infrared band in any number of sub-areas. On the basis of mass, infrared radiators (sources) are divided into three groups:

(i) Sub-atomic particles , whose 'jumps' supply most of the radiation in the near infrared region.

(ii) Atomic particles whose movements produce radiation in intermediate infrared region.

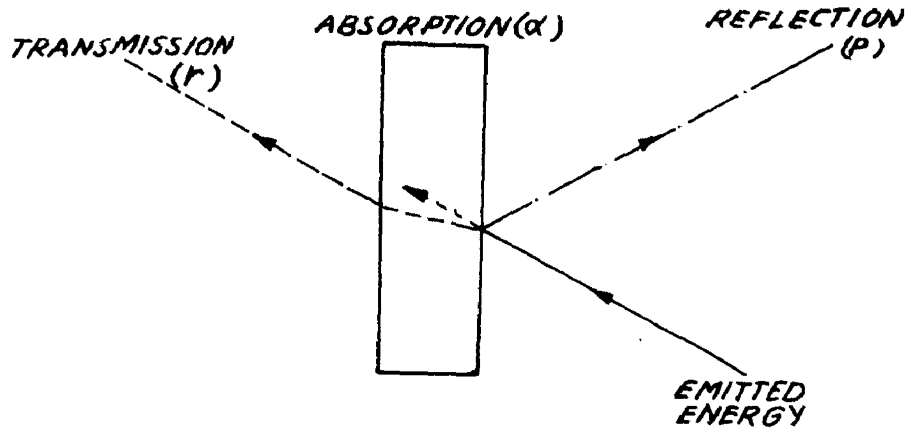
(iii) Molecules whose vibrations and rotations generate radiation in far infrared region.

In Fig. 2.2 elements of interest are the sources of infrared radiations and the spectral areas covered by them. By the science of spectroscopy it can be understood as to how molecule of certain types have their resonant frequencies limited to certain areas. Every molecule has its own resonance profile, a string of different frequencies i.e. unique, since it is generated by the elementry particles of which molecule is made. The frequencies generated by a particular molecule is like a finger print, and by spectroscopic analysis these finger prints are recognised, thus identifying the chemical composition of the substance under examination.

2.2 INFRA-RED - TEMPERATURE RELATIONSHIP[1]: One more element of interest in Fig. 2.2 is the temperature scale. Temperature is defined as the measure of level of heat contained in a physical body. And heat is energy, kinetic energy of basic elements of which physical matter is made; molecules, atoms, sub-atomic particles. On the basis of definition of heat the temperature can be defined as the level of agitation of these particles (molecule almost atomic particles). The greater the agitation the higher will be the energy contained and the heat level of temperature. Also for larger agitation, the greater the variations of electromagnetic field generated by these oscillators. In other words, the higher the temperature, the greater the power emitted by radiations. Furthermore, the greater the agitation, the higher the frequency of peak of the emitted radiation band.

2.3 BLACK BODY : Before defining black body it is necessary to understand three terms which are commonly used[1,2,3,4, & 5.] :

(i) Reflectivity (ρ): It is a measure of an object's ability to reflect incident energy.



FIG·2·3 TRANSMISSION, ABSORPTION & REFLECTION OF INFRARED ENERGY

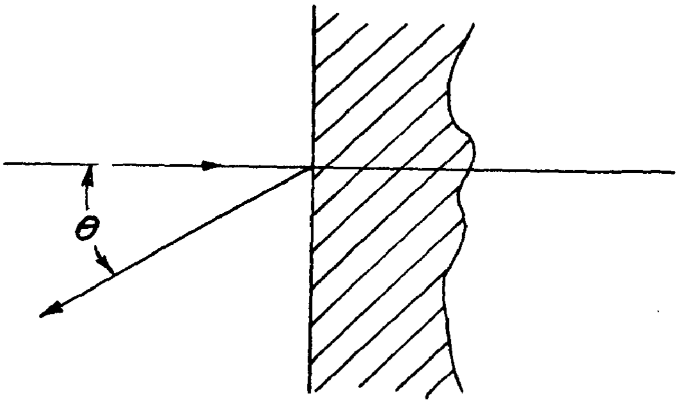
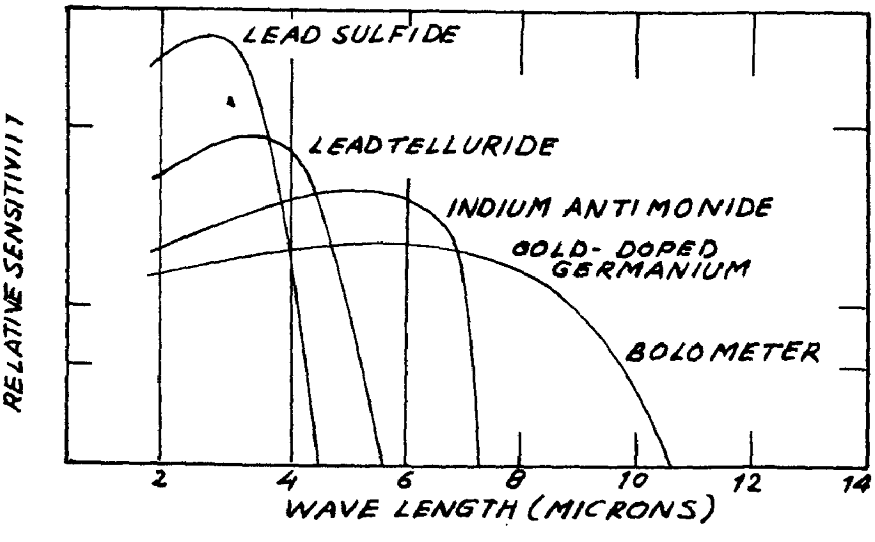


FIG 2·5 ANGLE OF RADIATION



IG·2·6 RESPONSE CURVES FOR VARIOUS INFRARED DETECTORS

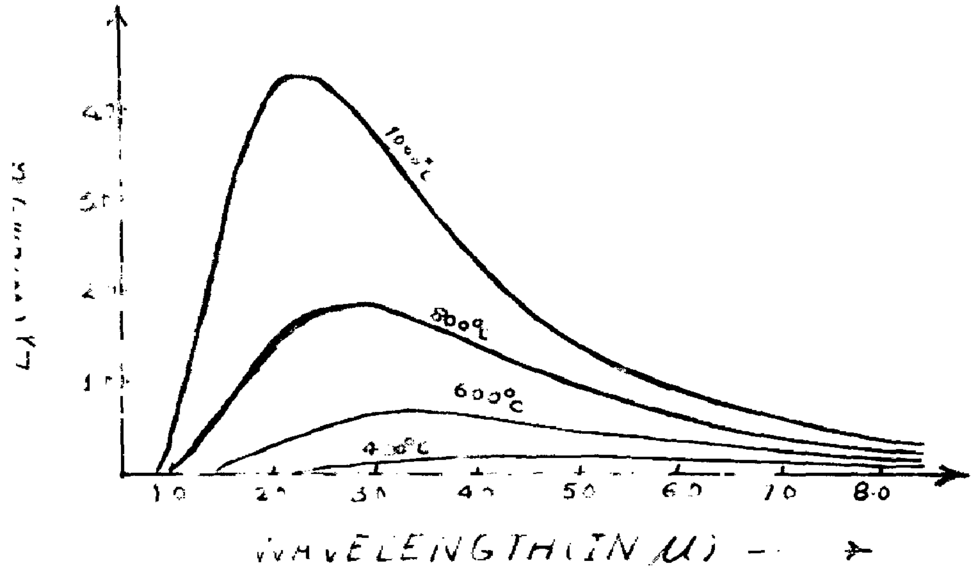


FIG 24 BLACK-BODY
RADIATION

(ii) Absorptivity (α) : It is a measure of an object's ability to transmit incident energy.

(iii) Transmissivity (τ) : It is a measure of an object's ability to transmit incident energy.

Transmission, reflection, absorption of infrared energy are shown in Fig. 2.3.

The sum of absorption reflection, and transmission must be equal to 100% of the total incident energy, i.e.

$$1 = \rho + \alpha + \tau \qquad \ldots (2.1)$$

(iv) Emissivity (ϵ) : It is a measure of ability, or ease, with which an object, or surface emits infrared radiation.

Emissivity is the ratio of radiant energy of a body at $T^{o}K$ temperature to the radiant energy emitted by a black body at the same temperature T^{o} K. This may be written as :

$$\epsilon = \frac{W_o}{W_{bb}} \qquad \ldots (2.2)$$

where, W_o = total energy emitted by an object at a given temperature $T^{o}K$

W_{bb} = total energy emitted by a black body at the same temperature $T^{o}K$

A perfect mirror will have a reflectivity of 1.0, a perfect absorber will have an absorptivity of 1.0, there is no ~~a~~ perfect absorbers reflectors or transmitters found in nature.

Consider a physical body having infinite number of different particles whose natural or resonant frequency are different in such a way that the spectrum emitted out from that is covering the whole infrared spectrum. This imaginary body is known as 'Black-body' Black body, in chart, is the ideal absorber which emitts ~~units~~ every frequency. In the Fig. 2.4 black body radiation is shown on logarithmic ordinates. From Fig. 2.4, the following is concluded :

(i) The radiation amplitude is different for every frequency and its envelope (the radiation curve) shows continuity, with one single peak where the intensity is maximum.

(ii) For every temperature of the emitting body there is a single emission curve corres-ponding to it.

(iii) No curve ever intersects any other curve, but for increasing temperatures, every curve runs above all the curves corresponding to lower temperature

(iv) As temperature increases the peak of the radiation curve moves towards shorter wavelengths

(v) As temperature increases, the amplitude of emitted radiation increases according to an exponential law.

2.4 BASIC RADIATION LAWS[1,3,4] :

2.4.1 Kirchhoff's Law : When the object is at thermal equilibrium, the amount of absorption (or absorptivity, α) will equal to the amount of emission (or emissivity,). This may be written as : $\alpha = \epsilon$ ... (2.3)

and by substituting from eq. (2.1)

$$= 1 - (\rho + \tau) \qquad \text{... (2.4)}$$

2.4.2 Emissivity : already discussed in 2.3

2.4.3 Stefan Boltzmann's Law : The hatter an object becomes the more infrared energy it emits. The total energy emitted by an object and its temperature relationship is :

$$W = \epsilon\sigma T^4 \qquad \text{... (2.5)}$$

where,

W = energy in watts/sq.cm.

ϵ = emissivity factor

σ = Stefan Boltzmann's constant (5.67×10^{-12} watt per cm sq. per $(^{\circ}K)^4$)

T = temperature in $^{\circ}K$

If two objects are placed near each other then the amount of radiant energy emitted from the hotter object to the colder object is proportional to the difference of the fourth power of their absolute temperatures, i.e.

$$W = \epsilon \sigma (T_1^4 - T_2^4) \qquad \ldots \qquad (2.6)$$

where, T_1 = temperature of hotter body in ^{o}K

T_2 = temperature of colder body in ^{o}k

2.4.4 Weir's Displacement Law : As the temperature increases, the wavelength, at which the maximum amount of energy is radiated, becomes shorter, i.e.

$$\lambda_{max} = \frac{2.89 \times 10^{-3}}{T} \mu m \qquad . \qquad (2.7)$$

where,

λ_{max} = max. wavelength in μm

T = temp. in ^{o}k

Spectral emissivity is the emissivity value of an object for a given wavelength ϵ_λ or wave length interval $[\epsilon(\lambda_1 - \lambda_2)]$. It is also noted that for some materials, emissivity also varies with temperature.

2.4.5 Planck's Equation : The relationship between spectral emission, temperature, and radiant energy is given by Planck's equation :

$$W_\lambda = \frac{\epsilon_\lambda c_1}{\lambda^5 (e^{c_2/\lambda} - 1)} \qquad \ldots (2.8)$$

where,

W_λ = Radiation emitted by an object at a given wavelength (λ) .

= Emissivity of the object at the same wavelength (λ)

C_1 = Planch's first radiation constant (3.75×10^{-12} W-cm^2)

C_2 = Planch's second radiation constant (1.38 cm in $^\circ$k)

= Wavelength in μ

= base of natural logarithm

T = Temp. in $^\circ$k

2.4.6 Lambert's Law : The amount of radiant energy from a given surface varies with the cosine of angle from which it level that surface, Fig. 2.5 :

$$W_\theta = W \cos \theta \quad \ldots \qquad (2.9)$$

where,

W_θ = energy emitted at angle θ

W = energy emitted at normal (right angle) to the surface ($\theta = 0$)

θ = Angle between the direction of energy being emitted and the normal ($\perp$) of the surface from which the energy is being emitted.

Stefan's Boltzmann's Law and Planch's equation are for the total amount of energy emitted by a surface (of a given area into a solid angle of π steradian (the total hemisphere of space surrounding that surface). Now let I, the intensity of radiation emitted by a surface, is the radiant energy per steradian normal to the surface, i.e.

$$I = \frac{W}{\pi} \quad \ldots \quad (2.10)$$

and by substituting from eq. (2.5)

$$I = \frac{\epsilon \sigma T^4}{\pi} \quad \ldots \quad (2.11)$$

2.4.7 Inverse Square Law[2] : The intensity of radiation emitted by a Point source varies as the inverse square of the distance from that point source. The flux density (F) of radiation from a surface at a distance (D) is amount of radiant energy passing ~~th~~through an area perpendicular to the line of right of the emitting surface. Mathematically, this may be written as

$$F = \frac{WA}{\pi D^2} \quad \ldots \quad (2.12)$$

From equation (2.5)

$$F = \frac{\epsilon \sigma T^4 A}{\pi D^2} \qquad \ldots \quad (2.13)$$

Again from eq. (2.10)

$$F = \frac{I_A}{D^2} \qquad \ldots \quad (2.14$$

where,

F = Flux density

A = Area of emitting surface

D = distance from the emitting surface to the receiving surface.

The equations 2.5, 2.6 and 2.8 can also be expressed in terms of photon flux. The photon distribution is given by :

$$\theta\lambda = \frac{\epsilon_1 C_1}{\lambda^5 (e^{C_2/\lambda T} - 1)} \qquad \ldots \quad (2.15)$$

whereas, θ_λ is the photon flux emitted by an object at a given wave length (λ), and all other symbols are the same as those used in figure (2.8).

When the function θ_λ is integrated over the total spectral region from zero to infinity, the total number of emitted photons becomes,

$$Q = \epsilon\ T^3\ \frac{1.52 \times 10^{11}}{S} \qquad \ldots \quad (2.16)$$

where,

Q is the total number of emitted photons per sec.

2.5 OPERATING PARAMETER OF INFRA-RED DETECTORS[2,3]

(i) Signal(S) : The signal is the voltage generated by an infra-red detector that is related to the infrared energy striking the detector. The signal generated by an infrared detector may vary with detector size, temperature, bias, and time constant.

(ii) Responsivity (R_v) : Responsivity is the ratio of signal O/P to the incident radiant flux. It is expressed as volts/watt and may be written as :

$$R_v = S/J$$

where,

R_v = Responsivity,

S = r.m.s. voltage from detector

J = r.m.s. value of energy flux striking the detector.

(iii) Noise (N) : Noise is the voltage generated by an infrared detector as a result of its resistance, temperature, band width and bias. There are five following sources of electrical noise that occur in infra-red detector.

(a) Johnson Noise (or Thermal Noise) : Noise caused by thermal fluctuations in the electron within a resistive element. Johnson noise is independent of frequenc

(b) Current Noise : It is produced by the fluctuations in a resistive element caused by current. Current noise is inversely proportional to the frequency and is sometimes referred to as 1/f noise.

(c) Photon Noise : This is caused by fluctuations in the rate at which photon arrive at the sensitive area of the detector. Photon noise is frequency dependent and follows the same curve as the frequency response of the detector.

(d) Shot Noise : Caused by random emission of electrons. Shot noise is frequency dependent and is proportional to the responsivity of detector.

(e) Background Noise : Radiation originating from the detector environment includes background radiation noise. The extent of background radiation noise is dependent on temperatures, emissivities and the geometry of such of elements of detector wall, window, and media as seen by detector elements.

(iv) <u>Signal-to-Noise Ratio</u> (S/N) : The S/N ratio is the ratio of signal to noise. The higher the (S/N) ratio, the better the detector.

(v) <u>Noise Equivalent Input</u> (NEI) : The noise equivalent input is the amount of incident radiation (measured in watt per cm^2) on an infrared detector that will produce a signal to noise ratio of 1 (unity), i.e.

$$NEI = \frac{JN}{S} \qquad \ldots \quad (2.17)$$

where,

J = r.m.s. incident energy flux

N = r.m.s. noise voltage

S = r.m.s. signal voltage

(vi) Noise Equivalent Power (NEP) : The NEP is similar to NEI except the incident energy is measured in watts rather than $watts/cm^2$ i.e.

$$NEP = \frac{JNA}{S} \qquad \ldots \quad (2.18)$$

where,

A = area of detector element.

(vii) Detectivity (D) : The detectivity is the reciprocal of NEP or

$$D = \frac{1}{NEP} \qquad \ldots \quad (2.19)$$

The detectivity D^* (called D - Star) is called a figure of merit used to determine the quality of infra-red detector. D^* is normalised to unit areas and unit band width. It is measured in cm/watt, i.e.

$$D^{*}_{+} = \frac{(A\ F)^{\frac{1}{2}}}{NEP} \qquad \ldots \qquad (2.20)$$

where,

ΔF = Noise band width in Hertz. Detectivity is sometimes expressed as D* (500 K, 90 ,: 1) where, 500 K is the black body temperature used to measure D*, 90 is the frequency at which the infra-red radiation was modulated and 1, the band width used to measure noise (in Hertz).

(viii) Spectral Response ($\sigma\lambda$) : The different types of infra-red detectors respond differently to various wavelengths of incident radiation. In Fig. (2.6), typical spectral response curve for some of popular infra-red detectors are shown.

3. INFRA-RED SOURCES, TARGETS & BACKGROUNDS :

3.1 BLACK BODY TYPE SOURCES : These are widely used for the absolute calibration of infrared equipment. A black body represents a theoritical concept, i.e., it is an ideal thermal radiator to which all other thermal radiators can be compared. Practically, an ideal black body source can not be constructed (having emissivity of unity). The black body type sources used for calibration purposes have an emissivity somewhat less than unity (and probably independent of wavelength) and should thus be called gray bodies or, perhaps, black body simulators[3].

3.1.1 Theoritical Principles : In 1860 Kirchoff sta ed that the radiation within an isothermal enclosure is black body radiation; therefore if a small hole is cut through the wall of the enclosure, the radiation leaving this hole should closely simulate that from a black body. Neither the geometrical form of the enclosure nor the material of which it is constructed affect the result. The important point is that the area of the hole should be very much less than that of the internal surface of the enclosure. The difficulty in applying this idea lies in determining the relationship between the relative size of the hole and the accuracy with which the emergent radiation simulates that from a black-body. The accuracy of simulation is called 'effective emissivity'.

This is a function of the size of hole, the shape and constructional material of the resulting cavity, and the extent to which the cavity departs from a true isothermal condition.

The best known analysis of the black body design problem is that by GOUFFE. On the assumption that the walls are diffuse reflectors, Gouffe finds that the effective emissivity of a cavity is

$$\epsilon' = \frac{\epsilon\ (1 + K)}{\epsilon\ (1 - A/S) + A/S}$$

where,

ϵ' = effective emissivity of the cavity

ϵ = emissivity of the cavity walls

A = area of the opening through which radiation leaves the cavity, m^2

S = total surface area of the cavity, including that of opening, m^2

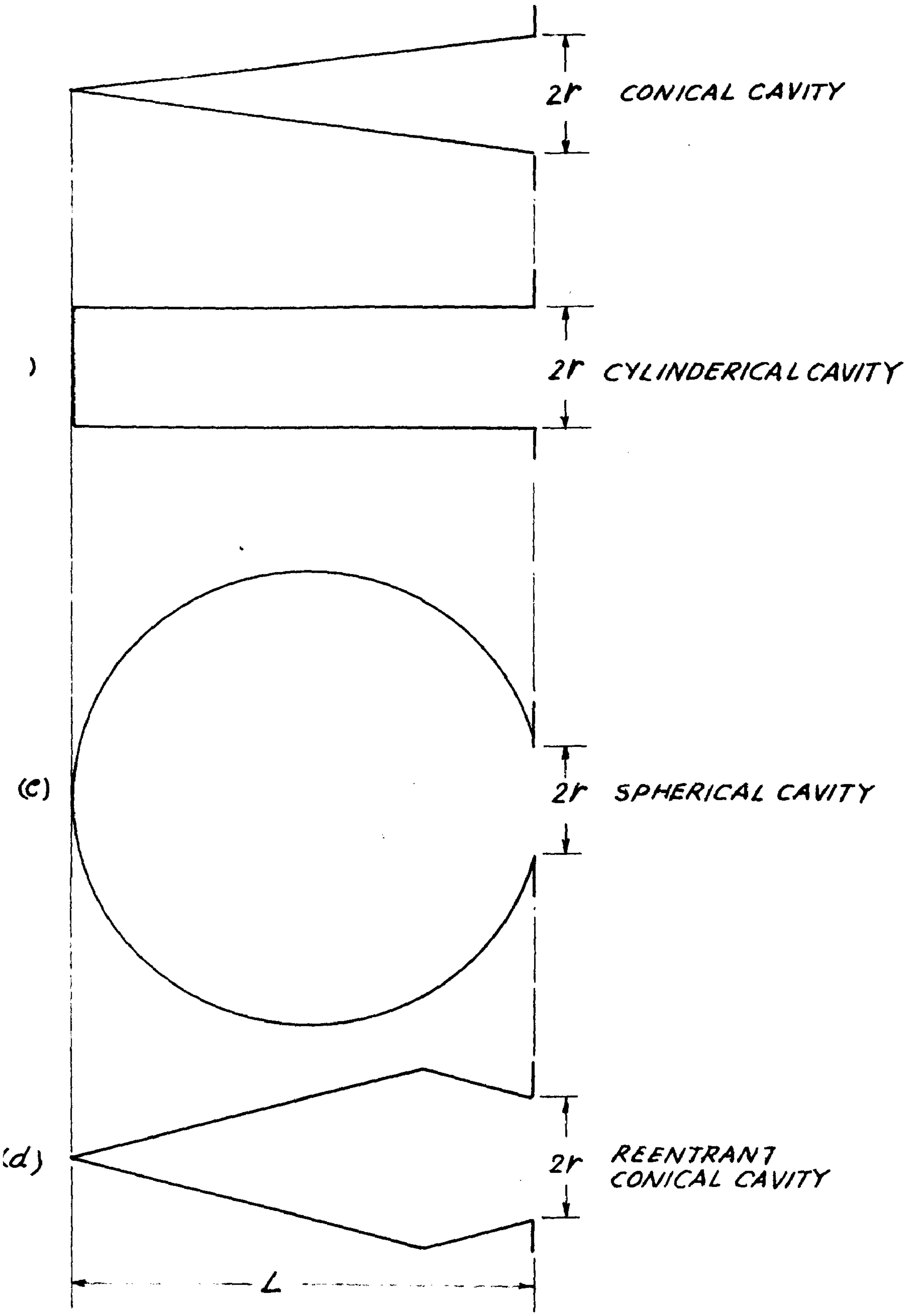
K = $1 - \epsilon/(A/S - A/S_o)$ ... (3.1)

So = surface area of sphere whose diameter is equal to depth of the cavity (measured from the plane of the opening to the deepest point of the cavity).

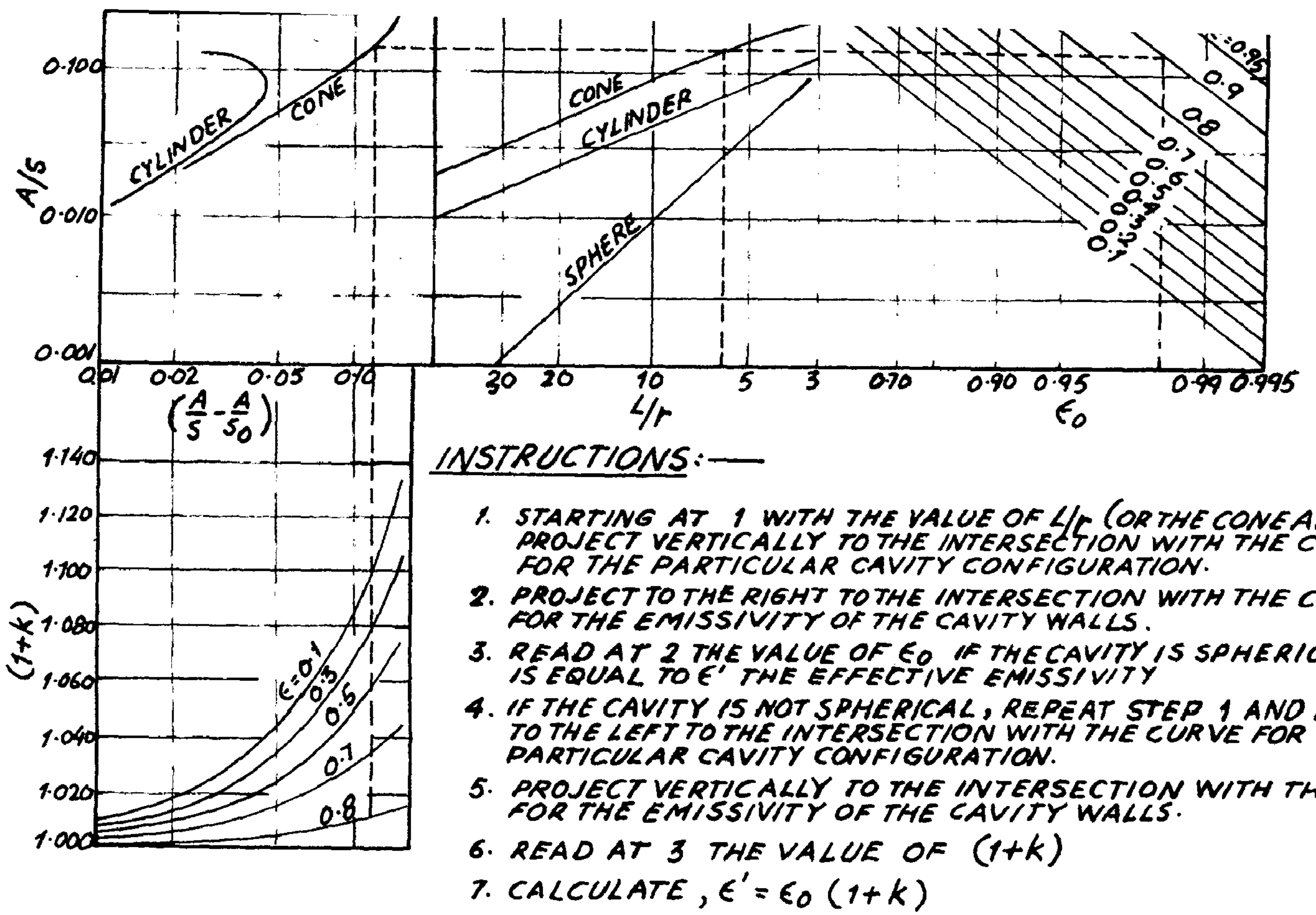
for convenience eq. (3.1) is written as -

$$\epsilon' = \epsilon_o (1 + K) \qquad \ldots \qquad (3.2)$$

The numerical value of K is small i for a spherical cavity K = 0 i.e. $\epsilon' = \epsilon_o$



3·1 TYPICAL CAVITY CONFIGURATIONS FOR BLACK BODY TYPE SOURCES



INSTRUCTIONS:—

1. STARTING AT 1 WITH THE VALUE OF L/r (OR THE CONE ANGLE) PROJECT VERTICALLY TO THE INTERSECTION WITH THE CURVE FOR THE PARTICULAR CAVITY CONFIGURATION.
2. PROJECT TO THE RIGHT TO THE INTERSECTION WITH THE CURVE FOR THE EMISSIVITY OF THE CAVITY WALLS.
3. READ AT 2 THE VALUE OF ϵ_0 IF THE CAVITY IS SPHERICAL ϵ_0 IS EQUAL TO ϵ' THE EFFECTIVE EMISSIVITY
4. IF THE CAVITY IS NOT SPHERICAL, REPEAT STEP 1 AND PROJECT TO THE LEFT TO THE INTERSECTION WITH THE CURVE FOR THE PARTICULAR CAVITY CONFIGURATION.
5. PROJECT VERTICALLY TO THE INTERSECTION WITH THE CURVE FOR THE EMISSIVITY OF THE CAVITY WALLS.
6. READ AT 3 THE VALUE OF $(1+k)$
7. CALCULATE, $\epsilon' = \epsilon_0 (1+k)$

FIG. 3.2 NOMOGRAM FOR COMPUTING THE EFFECTIVE OF A CAVITY BY THE METHOD OF GOUFFE

Some typical configuration are shown in Fig. 3.1. for design purpose, rather than making calculations for each of these configurations, it is simpler to use the nomogram shown in Fig. 3.2. Directions for using nomogram are also given therein[2].

For most commercially available blackbody type sources and those built in laboratory, the values of L/r are usually greater than 6 and the wall emissivities usually exceed 0.85. Under these conditions one can not depend on the present theories to predict the effective emissivities of such sources to an accuracy of better than ± 1 per cent. As a result, it is not presently possible to have a primary standard blackbody type source whose radiating characteristics are known to an accuracy commensurate with those of other primary physical standards.

3.1.2 Construction of a black-body type source[2,4] :

Most of the black body type sources used for calibration of infrared equipment are of the cavity type, have an opening of + 1.75 cm or less, and operate in the temperature range of 400 to 1300 °K. The design problem of such sources include the choice of a cavity configuration, the means of achieving an iso-thermal condition in the cavity, theprovision of a high wall emissivity, and the means for ensuring that the cavity is maintained at a known and stable temperature. The choice of cavity configuration usually involves consideration of a cone, sphere, cylindrical or a reentrant conical cavity. Although for a given L/r ratio the spherical cavity has the highest effective emmissivity, but it is difficult to fabricate and to heat it uniformly. A cylindrical one is easy to fabricate but too difficult to heat uniformly. A conical shape is the best shape among the three but the greatest heat loss occurs near the open end of a cavity and it is generally recommended that the number of heater turns be inserted in this area so as to increase the heat input. The reentrant conical cavity (Fig. 3.1 D) is often used because of it is less susceptible to excessive cooling at its open end and probably has a higher effective emissivity than does a simple conical cavity.

For temperatures upto 1400° K the core is usually made of metal; above 1400° K graphite or a ceramic is used. Copper is the ideal metal for this purpose, but because of unstable oxide layer formed because of heating (continually scales off at temperature above 600° K), the strainless steels in 18-8 series are used.

The core is heated by a nicrone wire. To improve the uniformity of the cavity temperature, the designer can vary the outer contour of the core so that the cross sectional area of metal at any point is constant. If the heater winding is uniform, each turn has a constant volume of metal to heat. Alternatively, an arbitrary outer contour can be used with a non-uniform heater winding adjusted so that each turn heats a constant volume of metal. Still another precaution is to plac a thermally isolated limiting aperture in front of opening in the cavity.

To increase the emissivity of the cavity walls, a rough machined finish should be specified, and no attempt should be made to smoothen and polish it. For 18-8 series of stainless steel, heating to 600° K causes the surface to tarnish and increases its emissivity to 0.5. Treating the surface with cronic and sulfuric acid results in an emissivity of 0.6. Heating the surface to 1000° K will form a stable oxide film having an emissivity of 0.85. If the operating temperature is not higher than 100° C, the cavity may be coated with a black enamel, such as Sicon-black[2], to give a wall emissivity of 0.93.

To sense the core temperature platinum resistance thermometer is used. Ideally, the thermometer should sense the cavity temperature rather than that of the core. This difficulty can be overcome by adjusting the set point of the temperature controller with reference to a percisely calibrated thermocouple into the cavity (but not so as to touch the walls).

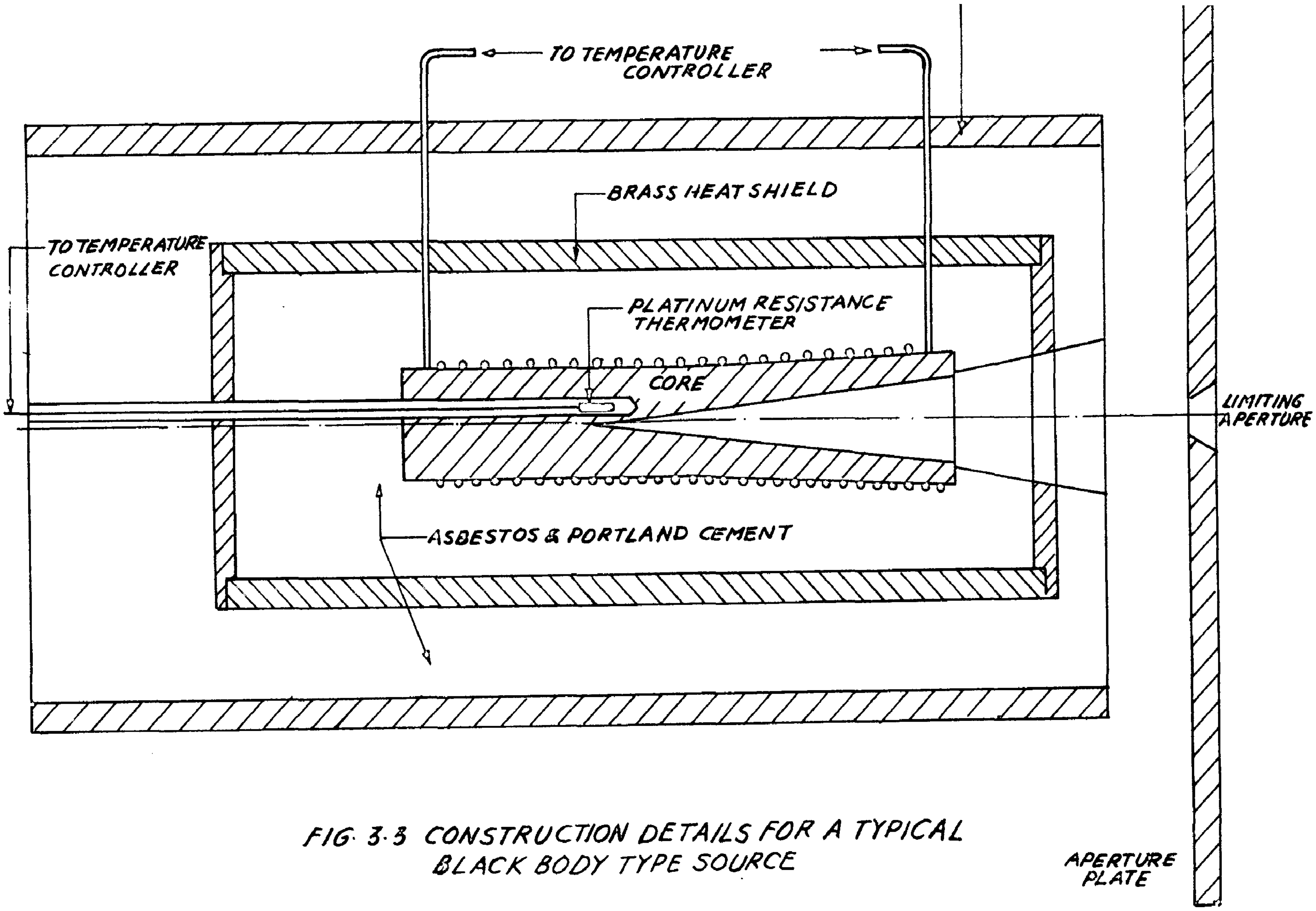


FIG. 3.3 CONSTRUCTION DETAILS FOR A TYPICAL BLACK BODY TYPE SOURCE

A complete blackbody type source that can be built is shown in Fig. 3.3. The type 18-8 stainless steel core is about 0.1 m long and has a conical cavity for which the value of L/[illegible] is equal to 8 (an included cone angle of about 15°. The constant pitch heater winding (michrome wire) is insulated from the core by a thin sheet of asbestos. If one value has happy disposition, he should be sure to anneal the michrome wire prior to winding the core (passing enough current through the iro to bring it to a red heat will anneal it). The heater requires an input power of about 125 W in order to maintain the cavity at a temperature of 800° K. Under these conditions it is estimated that the temperature variations in the cavity do not exceed 5°C. Most of this variation is near the open end of the core and is effectively eliminated by the limiting aperture placed in front of the source. If the source emissivi of the cavity walls is assumed to be 0.85, the effective emissivity of the cavity is 0.995. For convenience, most black body type sources used for calibration contain a series of apertures. The area of the apertures are found by an optical comparator and the accuracy of the aperture is checked radiometrically[1,2].

3.2 STANDARDS FOR SOURCES OF RADIANT ENERGY :

In 1967 the National Bureau of Standards (NBS) United States made a standard. The black bodies cores are heated by immersion of core in a bath of molten metal held at the temperature of the freezing point of the metal. Since the freezing point of most metals are known to a small fraction of a degree, this arrangement offers a convenient means of holding black body core at a precisely known temperature. Other dimensions for core etc., are also specified by N.B.S.

The N.B.S. has developed four types of incandescent lamps for use as standards[1,2,4].

1. The standard of thermal radiation
2. The standard of spectral radiance
3. The new standard of spectral irradiance, and
4. The new standard for total irradiance

The standard of thermal Radiation was developed in 1913 by Coblentz for those who wanted to measure visible light in absolute physical units. It is a seasoned 115 V carbon-filament lamp calibrated in terms of the irradiance, produced at a distance of 2 m. The original lamps were calibrated against a black body type source operated at temperatures between 1270° K and 1420°K. The estimated experimental errors in these measurements are 0.5 per cent.

The standard of spectral Radiance is a lamp with a tungsten ribbon filament and was first available in 1960. The values of spectral radiance are given at intervals of 0.05 μm from 0.250 to 0.750 μm and at intervals of 0.1 μm from 0.80 to 2.6 μm.

The new standard of spectral irradiance was introduced in 1963 and it is a 200 W quartziodine lamp with a coiled-coil tungusten filament. The values of the spectral irradiance are given for the interval from 0.25 to 2.6 m. The estimated uncertainties in the calibration of both lamp range from 3 per cent at the long wavelength 0 to 8 per cent at the short wavelengths.

The new standard of total irradiance was introduced in 1966. It is a tungsten filament lamp and is available in three sizes (100, 500 and 1000 W). The new standards appear to be in close agreement with the original Coblentz lamps.

3.3 COMMONLY USED SOURCES :

The French Electrical Heating Committee has suggested that the artificial infrared sources can be divided into three, depending upon the peak wavelength of their spectral emission curve.

1. Short wave infrared sources - below 2 μm
2. Medium wave infrared sources - between 2 to 4 μm.
3. Long-wave infrared sources - above 4 μm.

These limits may seem arbitrary, but in fact they do correspond quite well to certain marked differences in the mode of operation and manufacturing technique of different sources.

Analytical instruments most commonly used are a Nernst glower, a Globar, incandesent wire sources (lamps), flames, lasers etc.[2,4,5,6]

3.3.1 <u>Nernst Glower</u>[2,6] : A Nernst glower is made from rare earth oxides. It is generally shaped as a cylinder upto a few millimeters in diameter and a few centimetres long, and is fitted with platinum leads. Thus, it is conveniently shaped for focusing efficiently on a monochromator entrance slit. It generally operates in the 1400 to 1600° K range. Except for a deficiency in its emissivity below 5 µm, which is partly compensated by the proximity to its peak radiance, the Nernst glower is an efficient radiator. In utilizing a Nernst glower one must take into account its large negative temperature coefficient of resistance. At room temperature its resistance is so high that it is not feasible to heat it by passing a current through it. Instead, instruments employing Nernst glowers provide an indirect means of pre-heating the glower to a dull red temperature, after which the direct heating takes over. Nernst glowers do not deteriorate on exposure to the atmosphere but are subject to mechanical distortion, which is their most severe practical limitation.

3.3.2 <u>GLOBAR</u>[3,4] : A globar is made ffom silicon carbide or carborundum. It operates generally ina slightly lower temperature range rather than a Nernst glower.

For wavelengths shorter than about 7 μ it has a significantly higher emissivity than a Nernst glower. Beyond this the two are comparable except for a drop in the Globar emissivity between 10 and 14 μ. Globars are not troubled by the negative temperature coefficient and the susceptibility to mechanical distortion of the Nernst glower. The most serious problem in working with Globars is that large thermal gradients are produced around the electrical contacts which frequently necessitates water cooling to avoid arcing problems. In some cases Globars have been made with a large diameter in the vicinity of the contacts and a smaller cross-section in the area radiating to the slit. This minimises the problem and in some cases reduces the requirememt for water cooling to more convenient air cooling. In addition, it should be noted that Globar rods are generally of larger diameter than Nernst glowers, thus requiring a larger electrical power input for a given radiant energy through the entrance slit. However, the larger diameter of a Globar makes it easier to illuminate wider slits uniformly with a Globar than with a Nernst glower.

3.3.3 Incandescent lamps : For all practical purposes the radiation from tungsten has without doubt been more thoroughly investigated than the radiation produced by any other metal. The spectral mission curves of tungsten have more or less the same form as those for the black body, but

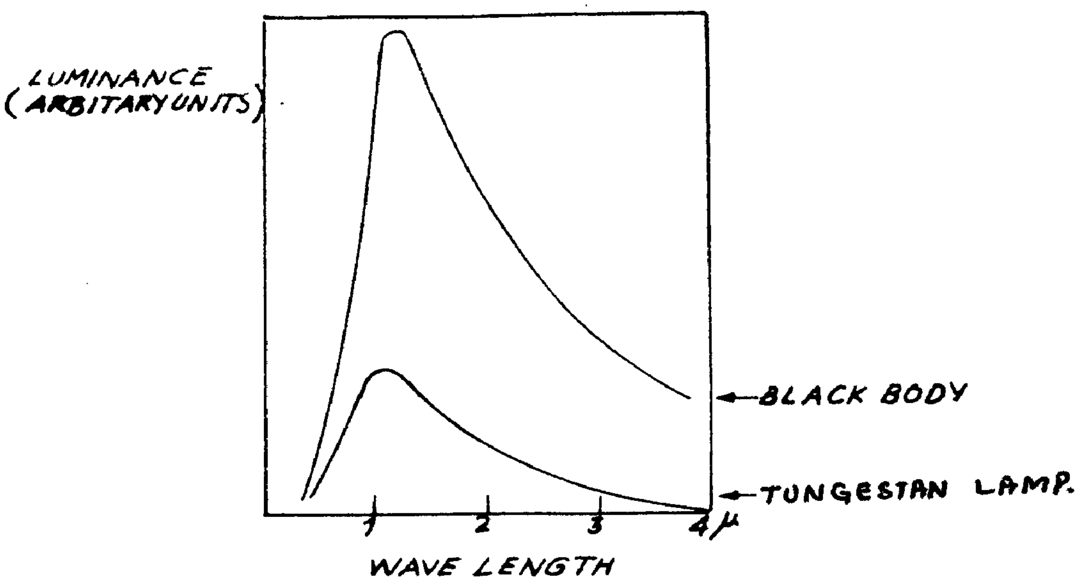


FIG. 3.4 SPECTRAL EMISSION CURVES OF THE BLACK BODY AND TUNGSTEN AT 2450°K

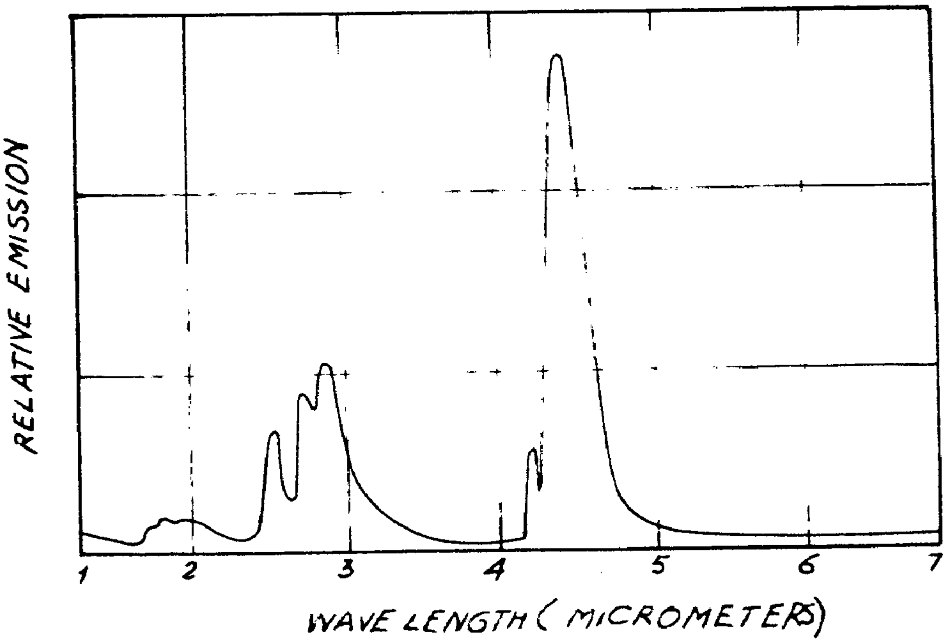


FIG 3.5 EMISSION OF NATURAL GAS FLAME

the emission factor of tungsten steadily decreases as the wavelength increases. Fig. 3.4 shows the emission curves for tungsten and for black body both at 2450° K.

It is clear from Fig. 3.4 that the tungsten lamps can be used as infrared source but only for near infrared since the glass envelop does not transmit radiant energy beyond 4 μm. These lamps provide a solution, although not always a satisfactory one to the problem of finding a suitable source for field calibration of near infrared equipment. Since the radiant emittance changes rapidly with changes in filament current, it is imperative that this current be closely monitored during measurements.

In tungsten lamps 10 of the input power to a typical 100 W household lamp is radiated beyond the bulb as visible light, 70% is radiated in the near infrared, and 20% is absorbed by the gas in the lamp and by its glass envelope. The glass envelope can readily reach a temperature of 150° C. As a result, equipment operating in the intermediate and the far infrared may receive strong signals from tungsten lamps. It is important to note that the signals are from the heated envelope and not the filament, since the spectral distribution is quite different for the two[2,3,4,5,6 & 7]

3.3.4 <u>Xenon Arc Lamp</u> : The Xenon arc lamp has been used in near infrared communication system. Its particul advantage is the ease with which the output can be modulated by varying the current supplied to the lamp. Most of the energy from the Xenon arc is radiated in visible and ultra-violet, but there is a useful output in the near infrared, extending to a wavelength of about 1.5 µm.

3.3.5 Laser : The laser, an aeronym for 'light amplification of stimulated emission of radiation", represents an entirely new family of quantum electronic devices. Lasers provide coherent sources of extremely high radiance in the portion of the spectrum extending from the ultra violet to microwave lasers emit energy at specific wavelenths. The wavelength at which a laser emits is dependent upon the active medium used by the laser.

A carbon-dioxide (CO_2) laser emits energy at 10.6 µ.m. Ten watt CO_2 lasers are readily available. Some CO_2 lasers emit more than 1000 Watts at 10.6 µm.

Another commonly used infrared laser is the neodymium doped yttrium aluminum garnet[3] (Nd : YAG). The Nd: YAG lasers emit about 10 watts of energy at 1.06µm. Most other lasers emit visible radiation.

3.3.6 Flames : When hydrocarbon fuels are burned in the atmosphere, or with oxygen, two of the combustion products produced are water vapour and carbondioxide. Both of these products emit energy in infrared spectrum. H_2O at 2.7 um and CO_2 at 4.45 µm. There are numerous other weak bands between 1 and 24 µm.

The effective emittance of the flame depends upon its thickness, temperature and pressure at which the exhaust gases escape. Fig. 3.5 shows the emission characteristics of a natural gas flame. Other flame emissions may vary slightly but the strong emission at 2.7 and 4.45 µm will always be apparent.

3.3.7 <u>The Sun</u> : The sun approximates a black body at a temperature of about 5500°C. Over 5 % of the solar radiation is in the infrared portion of the electromagnetic spectrum. The sun's peak energy is emitted at about 0.5 micrometer. The solar constant (the irradiance from the sun measured outside the earth's atmosphere at the mean solar (earth to sun) distance). Value is 0.140 W cm^{-2} (or as it is usually stated, 2.00 gm cal cm^{-2} min^{-1}). The irradiance at the surface of the earth is about two thirds of this value, or, 0.09 W•cm^{-2}. Since many infrared systems are designed to detect targets that produce an irradance of 10^{-10} W cm^{-2} or less, an inadvertent look at the sun may seriously overload or even permanently damage these systems.

3.3.8 <u>P-N junction infrared emitters</u> : If the P-N junction results from a diffusion in gallium arsenide (GaAs), the radiant energy in infrared with a typical peak at 0.9 um. This ideally matches the response of silicon photodiodes and photo transistors.

The energy emitted from visible LEDs and IR emitters is spontaneous or noncoherent (random in phase and direction). If the level of current flowing through a Ga As PN junction is increased beyond a certain threshold, a lasing action takes place, in which the spontaneous emission stimulates an increase in the radiant power. The light amplification by the stimulated emission of radiation (LASER) is something similar to an avalanche effect. The resultant output from a solid state laser is invisible and is not as coherent as that produced from a ruby, gas, or dye laser, but the device is much more compact. Output radiant powers from 1 to 65 W are possible from single-diode lasers when pulsed for 0.2 μ Sec. with current from 10 to 250 A.

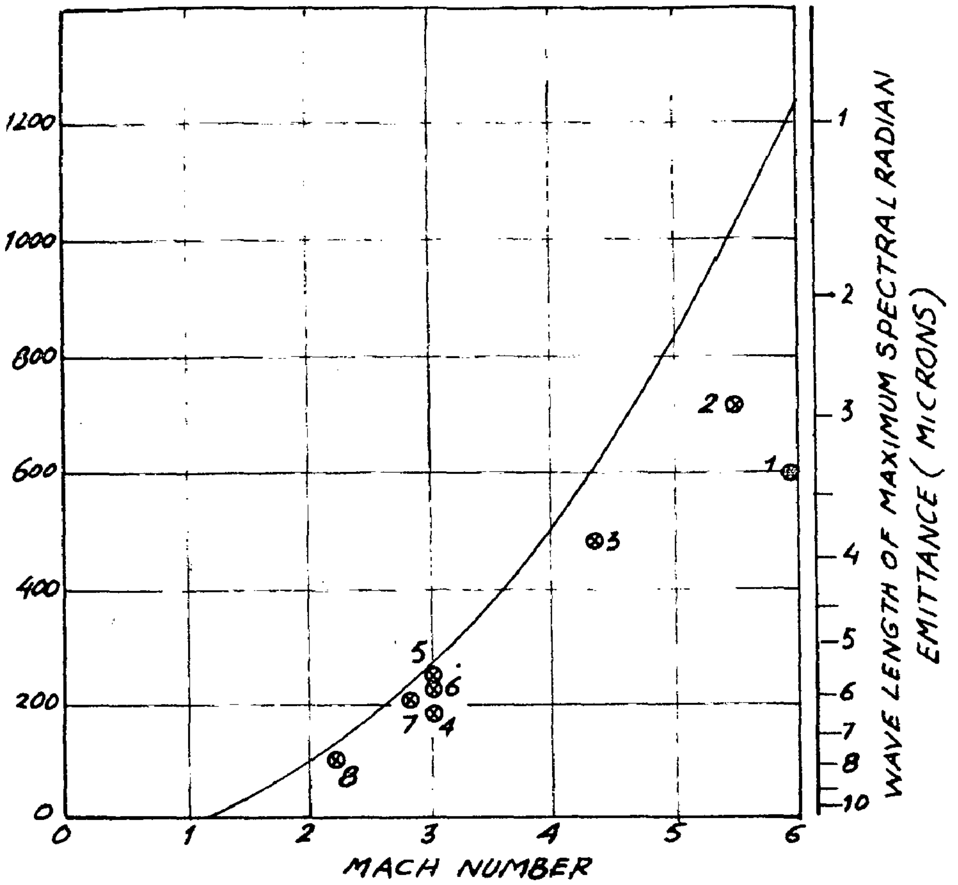
3.3.9 Carbon Arc : A low intensity carbon arc has been used as a spectrometry source when a greater radiance than that of the Globar or Nernst glower was needed. A source temperature of about 3900°K is reached. A five fold decrease in emissivity occurs as the wave length increases from 2 to 10 μ.

The high intensity carbon arc, which operates at 5800 to 6000°K is used in solar stimulators. The arc current is three or more times greater than that of the low instensity arc and the operating life of the electrodes is proportionately less.

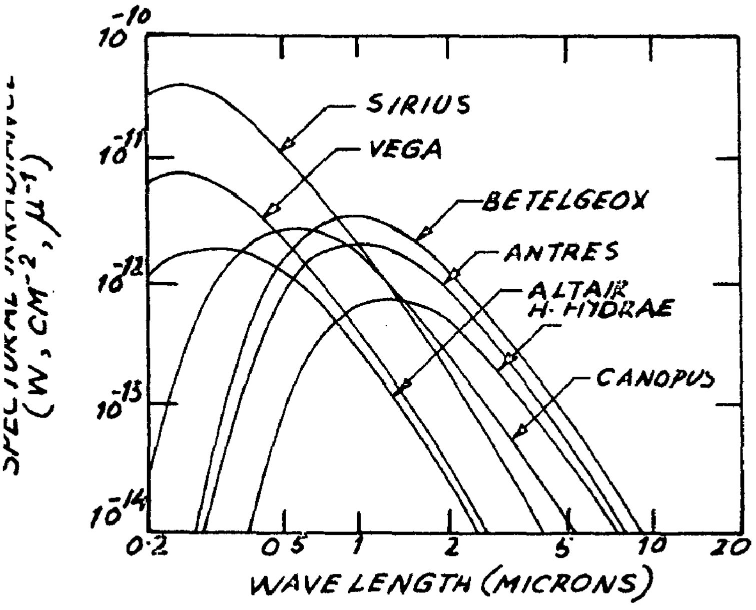
3.4 TARGETS :

3.4.1 Turbojet engine[2,4,5] : From turbojet there is considerable radiant energy because of large quantity of heat developed in combustion process. Measurement of the radiation from military turbojets and civilian turbojets is important for security and other view points. There are two sources of radiation from a turbo engine : the hot metal tail pipe and the stream of exhaust gases, often known as the plume. For engineering calculations, a turbojet engine can be considered as a gray body with an emissivity of 0.9, a temperature equal to the EGT (exhaust gas temperature), and an area equal to that of the exhaust nozzle. It has been proved that the plume radiance depends on the number and temperature of the gas molecules in the exhaust stream. These values depend, in turn, on fuel consumption, which is a function of air craft flight altitude and throttle setting. It is found for a particular turbojit engine that the radiance of its plume at an altitude of 35,000 ft is about one half of ~~its--plume-at-an-altitude~~ the value at sea level.

Similar results can be concluded for the turbofan



G·3·6 EQUILIBRIUM SURFACE TEMPERATURE CASUED BY AERODYNAMIC HEATING



IG·3·7 SPECTRAL IRRADIANCE AT THE TOP OF THE EARTH'S ATMOSPHERE FROM SELECTED STARS engine, Boeing ,the ramjet ,the rocket engine, and so on.

3.4.2 Aerodynamic Heating[4,5] : An object moving at high speed through the atmosphere becomes heated. At speeds above Mach 2, the resulting high temperatures produce sufficient radiation to be of interest to the infrared system designer. This happens to be the same speed regime in which ram air compression starts to reduce the temperature of the exhaust gases from the after burning turbojet. Fig. 3.6 shows equilibrium surface temperature caused by Aerodynamic heating (for altitudes above 37,000 ft and laminar flow). Space vehicles ree~~e~~ntering the earth's atmosphere convert an enormous amount of kinitic energy into heat, resulting in surface temperatures of 2000° C or even more[2].

3.4.3 Personnel : The emissivity of skin is very high, averaging 0.99 at wave lengths longer than 4 μ. It is interesting to note that the value is inddpendent of skin colou human skins are equally black beyond 2 μ. Thus human skin is another excellent example of the inadvisability of estimating the emissivity of a surface on the basis of its visual appearance.

Skin temperature is a complex function of radiation exchange between the skin and its surroundings. When human skin is exposed to severe cold, its temperature can drop to as low as 0°C. In a normal condition, with air temperature of 31°C, the temperature of the exposed skin of the face and hands is about 32°C. In order to calculate the radiance from a nude human body, it is necessary to know the radianting area of the body. For analytical purposes, an average male by an assemblage of cylinders having a surface area of 1.86 m^2. On the assumption that the skin is a perfect diffuse radiator, the effective radiating area is equal to the projected area of the body, or about 0.6 m^2. With a skin temperature of 32°C, the radiant intensity of an average nude, male (assuming him to be a point target) is 93.5 W_{sr}^{-1} . At a distance of 1000 ft (if atmospheric absorption is ignored), he produces an irradiance of 10^{-7} W cm^{-2}. About 32% of this energy lines in the 8 to 13 µm region and only 1% in the 3.2 to 4.8 µm region. The presence of clothing reduces these values since both the temperature and emissivity of clothing are lower than those of the exposed skin.

3.4.4 <u>Surface vehicles</u> : Surface vehicles may radiate sufficient energy to be of interest as target. The paint used on such vehicles usually has an emissivity of 0.85 or greater; weathering and natural deterioration of the paint as well as accumulations of dust and dirt tend to increase the emissivity. Because of their high temperature, exhaust pipes and mufflers may radiate several times as much energy as the rest of the vehicle does. In recent years, deginers

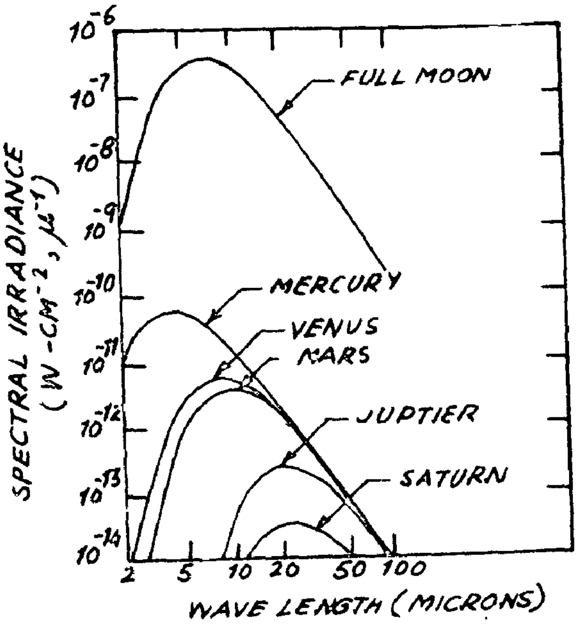


FIG. 3·8 SPECTRAL IRRADIANCE AT THE TOP OF THE EARTHS ATMOSPHERE FROM THE MOON & PLANETS

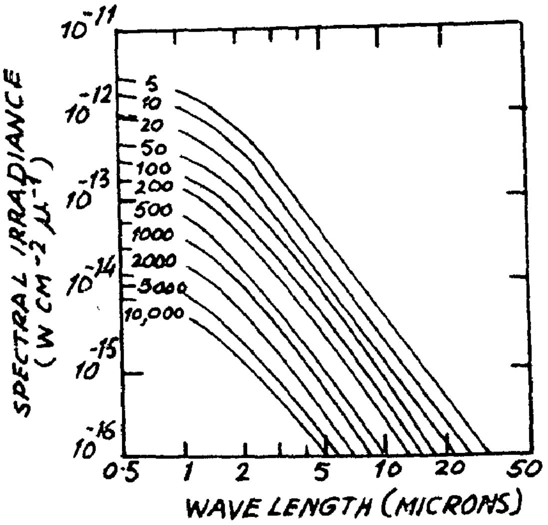
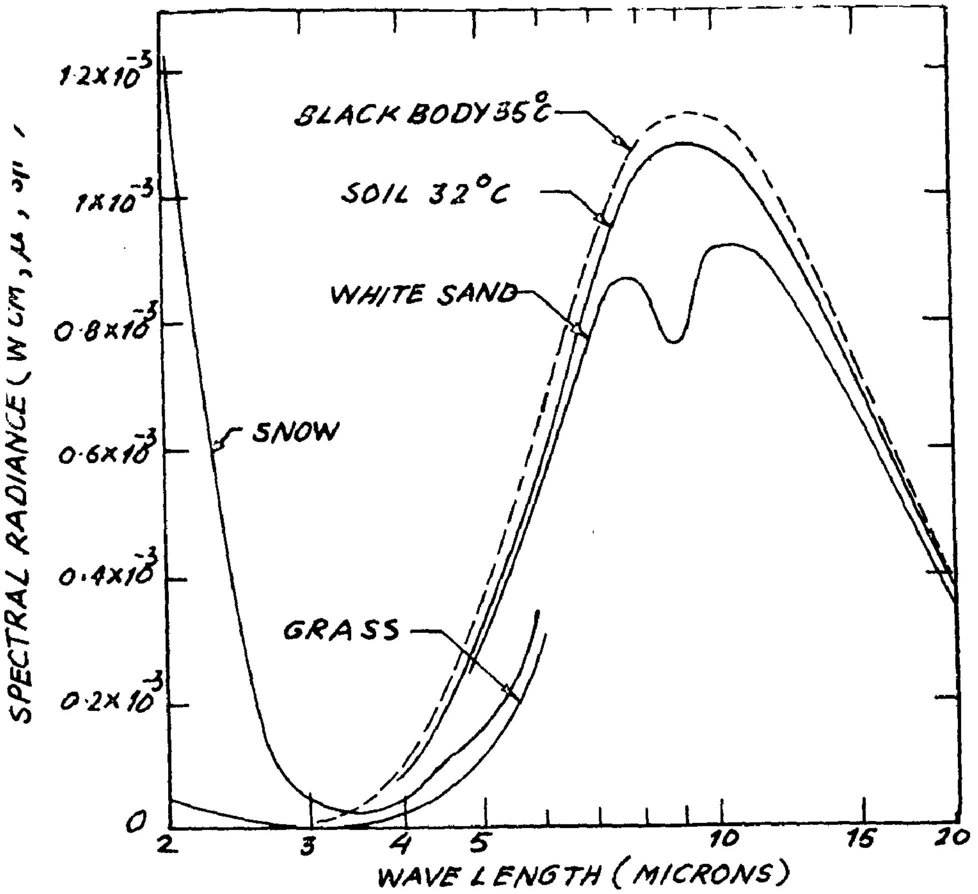


FIG. 3·9 THE NUMBER OF STARS GIVING A SPECTRAL IRRADIANCE AT THE TOP OF THE EARTH'S ATMOSPHERE GREATER THAN A SELECTED VALVE have learnt the importance of keeping mufflers and exhaust pip well hidden beneath vehicles to limit their detection by infra-red systemss

3.4.5 Stars and Planets[4,5] : Most of the brighter stars are best detected by systems working in the visible or near infrared portion of the spectrum. Fig. 3.7 ~~Fig.~~ adapted from the extensive data of Ramsey shows the spectral irradiance at the top of the earth's atmosphere from some of the brighter stars. Fig. 3.8 shows the spectral irradiance from the moon and planets. It includes only self emitted thermal radiation and not reflected sunlight. Information on the number of stars giving an irradiance above a certain level is found in Fig. 3.9.

3.5 BACKGROUNDS[1,2,4,5] :

Targets are most likely to appear in front of some sort of background that will complicate the detection process. Of particular interest are a few backgrounds such as the earth the sky, the outer space, the stars and the planets etc. There is a little agreement on the most effective means of describing a background. One might use an infrared or thermal picture in which the brightness (more properly, the luminance) at any point in the picture is related to the radiance at that point in the scene. But it is difficult to obtain a good differentiation of fine detail with a short



FIG·3·10 SPECTRAL RADIANCE OF TYPICAL TERRAIN MATERIALS OF OBSERVED DURING THE DAY TIME

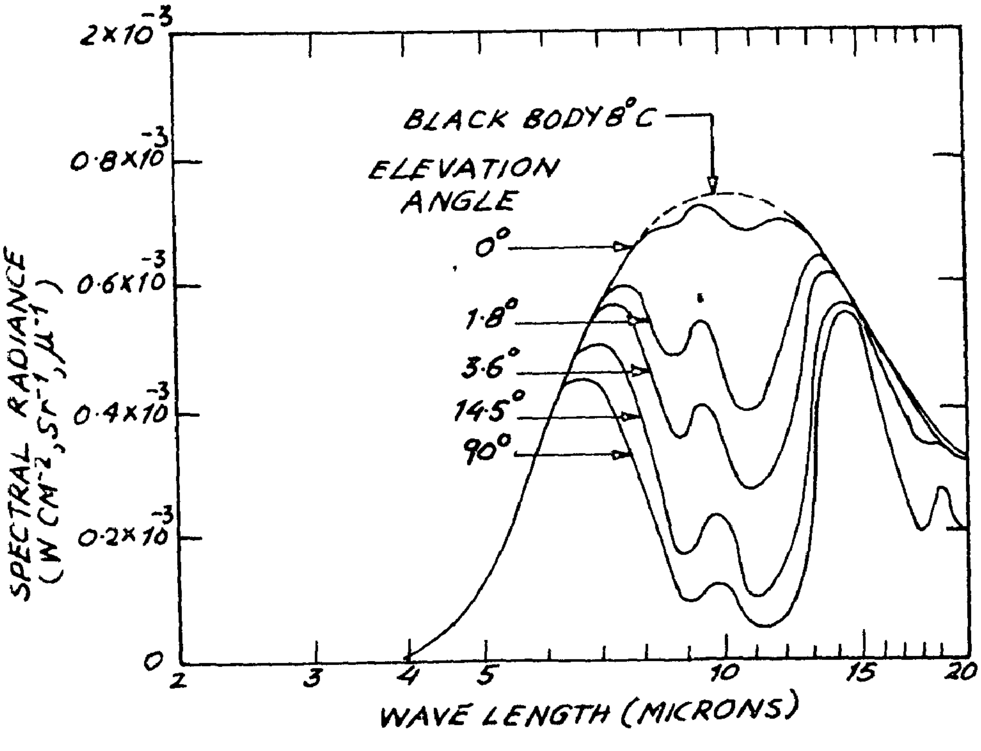


FIG 3·11 SPECTRAL RADIANCE OF A CLEAR NIGHT SKY exposure time, an accurate correlation between brightness and radiance, and coverage of wide range of temperatures on a single picture. The second method may be that one could present a series of single-line scans across the scene showing sense radiance as a function of azimuthal angle. And hence by plotting a series of isoradiance contours superimposed on an ordinary photograph of the sense, the effect of background is known.

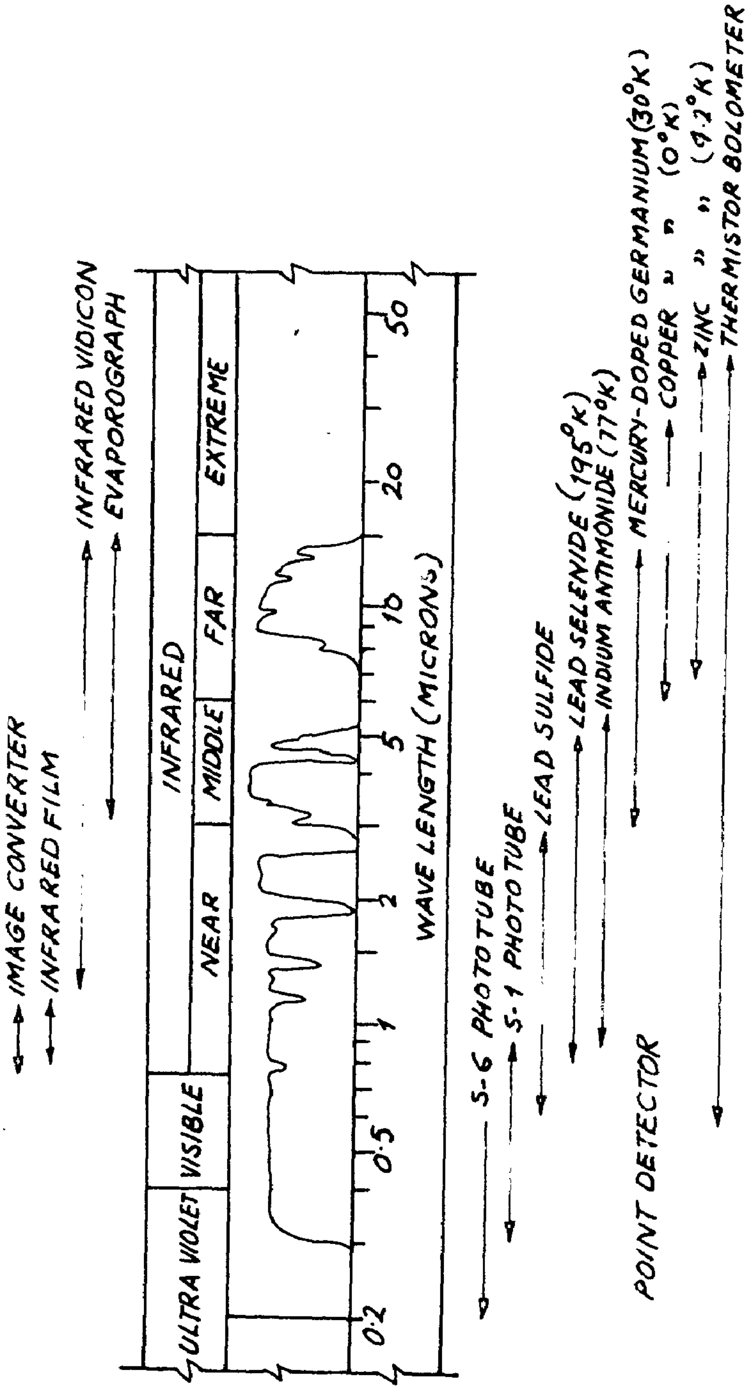
3.5.1 The Earth : During day time the radiation from earth surface is a combination of reflected and scattered sunlight and the thermal emission from earth itself. The maximum spectral radiance from the sun occurs at 0.5 μ; that of earth, radiating as a gray body at 280°K, occurs at about 10 μ. Thus two peaks are there in spectrum; one short wavelength is due to sunlight and long wavelength is due to thermal radiance from the earth. Fig. 3.10 shows the spectral radiance of snow, grass, soil and white sand. The spectral distribution of earth changes as it is viewed from a high altitude. This information is important for satellites, turbojets, rockets etc.

3.5.2 The sky : The spectral radiance of the sky is approximately similar that from earth, i.e. scattered sunlight below 3 μ and thermal radiation beyond. ~~The~~

The emissivity of the path through atmosphere depends on the amount of water vapour, carbon dioxide, and ozone along the path. Thus both the temperature of the atmosphere ~~of the~~ and the elevation angle of the line of sight must be known in order to calculate the sky radiance. Fig. 3.11 shows the spectral radiance of a clear night sky and its change with the elevation. It is clear from the figure that as the elevation angle increases the path through the atmosphere becomes shorter and at wavelengths where the absorption is lower the emissivity becomes lower. The spectral radiance curve of an overcast sky matches with black body. Most overcasts occur at relatively low altitudes, a few hundred to a few thousand feet, and their temperatures are usually within a few degree of the air temperature at the surface of the earth .

3.5.3 <u>Outer Space</u> : Infrared systems operating outside the earth's atmosphere will view a background of cold space. To a first approximation, the temperature of this background is absolute zero. More accurately, integration of the radiance of the space background over whole of outer space (including all of the stars) indicatds that the effective temperature is about 3.5°K.

3.5.4 <u>Stars and Planets</u> : When considered as backgrounds stars and planets are of interest because they may be mistaken for targets. Fig. 3.9 shows the number of stars that wil produce a spectral irradiance at the top of earth's atmosphere in excess of any selected value. If for instance, a particular infrared sensor will respond to a spectral irradiance of 10^{-14} W cm^{-2} μ^{-1} at 2 u, there are about 1000 stars that it will see. If this system had the same response, but at 5 μ, there are only about 50 stars that it would have to contend with.



7·1 THE DETECTORS(DETECTORS OPERATING TEMPERATURE IS 300°K UNLESS OTHERWISE NOTED

4. INFRA-RED DETECTORS - Thermal & Quantum Types

An infrared detector is simply a transducer of radiant energy, which converts it into some other measurable form; this can be an electrical quantity, a change in some physical property of the detector, or the blackening of a photographic plate.

Two groups of detectors are shown in Fig. 4.1. Those in the upper part of figure are imaging detectors and those in the lower part are point or elemental detectors. This grouping is convenient when the objective is a system yielding a picture-like rendition of a scene. An imaging detector, such as photographic film, yields the picture directly. With a point detector, however, it is necessary to build up the picture by sequentially scanning the scene. The point detector, when placed at an image plane, responds to the average irradiance at that particular point in the image. In short, the imaging type responds continuously to the entire image, but the point type must examine it sequentially.

The other basis of classification, which is more widely accepted, is the physical mechanism involved in the detection process. In one group called thermal detectors, the heating effect of the incident radition causes a change in some electrical property of the detector. In the other group, called the photon or quantum detectors, there is a direct interaction between the incident photons and the electrons of the detector material. Therefore the response of the thermal detector is proportional to the energy absorbed, whereas that of photon detector to the number of photons absorbed.

4.1 THERMAL DETECTORS :

The thermal detectors are distinguished as a class by the observation that the heating effect of the incident radiation causes a change in some physical property of the detector. Since most thermal detectors do not require cooling, they have found almost universal acceptance in certain field and space borne applications in which it is impracticable to provide such cooling. Because (theoretically) they respond equally to all wavelengths, thermal detectors are often used in radiometers. However, the practical limitations of availabl blackening materials often force one to modify the simple assumption that the detectivity of thermal detdctors, is independent of wavelength. The time constant of thermal detectors is usually a few miliseconds of or even longer. Hence these detectors are not used in search systems or in any other application where high data rate is required.

4.1.1 Thermocouples[1,2,4,5,8]: One of the most practical means of sensing the increase in temperature due to the radiation of energy is the thermocouple, a junction between two metals that have a large difference in their thermo-electric power. Most commonly used combinations are bismuth-silver, copper-constantan, platinum-rodium and bismuth-bismuth tin alloy. Fine wires of the two metals, having 3 to 4 mm length and about 25 μm in diameter, are joined at one end to form thermoelectric junction. This junction is fastened directly to blackened receiver, which defines the sensitive area of the detector. Quartz fibers are used to give additional mechanical strength to the device.

Because of low resistance (1 ohm to 10 ohm only), it becomes difficult to couple these detectors with tube amplifiers. However, transistorized amplifiers are well suited for this purpose. Because of their large time constant (few miliseconds to several seconds), the chopping frequencies are limited to 10 Hz or less.

The time constant of thermocouple can be expressed as :

$$\tau = \frac{C}{\Omega} \qquad \ldots \quad (4.1)$$

where, C = thermal capacity of junction and receiver

Ω = Rate at which the assembly loses energy.

Therefore a low time constant requires a low thermal capacity and an efficient coupling of the detector to a heat sink.

4.1.2 Thermopiles[1,2,8,9] : Several thermocouples can be connected in series to form a thermopile. The advantage of such construction is that the voltage developed at each junction adds so as to increase the responsivity. Similarly, the series connection increases the resistance of the detector and make it easier to match it to an amplifier. Since the time constant of most of thermopiles is several seconds, it is impractical to use a chopper with them.

The thermopiles can be made by evaporating overlapping films of antimony and bismuth. Because such a construction is much more rugged than that of the traditional thermopile, These are used in space applications. The overlapping areas that make up the junctions are formed on a thermally insulating layer set in the middle of one face of an aluminum block. The reference junctions are formed where the evaporated films contact the aluminum block. Because of low thermal capacity of junction, the time constant of the device can be made as low as 10 miliseconds. By evaporation technique the thermopiles can be made in any shape, size and arrangement of junctions.

4.1.3 Bolometers[2,4,8,9] : The detectors, those change their electrical resistance because of incident radiation are called bolometers.

(a) Metal Bolometers : The metals used for bolometers usually have temperature coefficient of resistance of about 0.5 per cent per degree centigrade. A blackened strip defines the sensitive area of the detector. It is a wheatstone's bridge so that any change in its temperature unbalances the bridge. A typical bolometer consists two identical elements. One, called the active element, is allowed to expose to the incident radition, and the other element, called the compensating element, is carefully shielded from the incident radiation. By this arrangement slow changes in the ambient temperature will not affect the bridge balance.

(b) Semi Conductor Bolometers : In these bolometers the element used is thermistor, which has temperature coefficient of resistance as high as 4.2 per cent/ per degree centigrade. The elements used are thin flakes formed by sintering a mixture of metallic oxides. These flakes are mounted on an electrically insulated substrate which also acts as a metallic heat sink. Therefore by selecting substrates of different thermal characteristics it is possible to change the time constant of the detector from 1 to50 miliseconds. Semiconductor (thermistor) bolometers are rugged (as compared with metal bolometers), they require no cooling, and also their high resistance makes it easy to match them to an amplifier. Because of these qualities these detectors have found wide application in space vehicles. Since the thermistor materials are not absorber, they must be blackened during manufacture.

It is known that the detectivity varies inversely to the square root of the detector area. Thus a reduction of detector area, while maintaining full collection of radiation, will improve performance. This can be achieved by "optical immersion" of the detectors.

(c) Superconducting bolometers[1] : These bolometers are based on the principle that the tremendous change in the resistance occurs in the transition of certain metals and semiconductors from their normal to super conducting state. In transition range, which is only a fraction of degree wide, the temperature coefficient of resistance is about 5000 per cent per degree centigrate. At this temperature (that for Niobium nitride is 15° K) the resistance variation becomes sharply nonlinear with relation to the impinging thermal energy, thus the bolometers acquires extremely high sensitivity.

Because cryogenic capabilities enable attaining very low temperatures, the use of super conducting bolometers is possible, although the problem of precisely holding the transition state temperature makes it difficult to obtain precise and repeatable measurements.

(d) Carbon Bolometers : These have been used for spectroscopic investigations in the extreme infrared range. The sensitive element is a slab cut from a carbon resistor and cooled at 2.1° K. Its D* is at least an order of magnitude greater than that of a thermistor bolometer.

(e) <u>Germanium bolometer</u> : It is a single crystal of gallium doped germanium cooled to 2.1° K. Its D* is nearely two orders of magnitude greater than that of a thermistor bolometer, and since its spectral response extends beyond 1000 μ, it is equally suitable for detecting either infrared or microwaves.

(f) <u>Ferroelectric bolometers</u> : Certain dielectric compounds, called ferroelectric materials, exhibit a spontaneous polarization, whose magnitude varies with temperature. When these materials are subjected to heating, their crystalline structure undergoes a rapid change at the so called Curie temperature. At this point, their polarization disappears and their dielectric coefficient varies sharply.

It is obvious that a capacitor utilizing a ferroelectric dielectric will undergo a large change in capacitance when the temperature changes near the Curie temperature. A number of ferroelectric components are known which cover a wide range of 260° C to 570° C.

Because ferroelectric bolometer is essentially a capacitor, it is immune from the danger of thermal runaway, which is always present in the operation of thermistor bolometers, and which forces their use at a point located below the maximum efficiency point[8,9].

4.1.4 Pyroelectric detector : In this detector ferroelectric material is used, ~~specially~~ specifically triglycine sulfate (TGS) crystal. A spontaneous polarization (electric charge concentration) is exhibited by this material, and this phenomenon is temperature dependent. In practice, a very small capacitor is fabricated, which has TGS crystal as the dielectric sandwitched between two metal plates. As infrared radiant energy is absorbed by the dielectric, a voltage appears at the two poles of the capacitor, proportional to the magnitude of the impinging radiation.

A major advantage of this detector is that it does not need a bias voltage, with consequent absence of self generated low-frequency noise which otherwise would be unavoidable.

4.1.5 Pneumatic or Golay Detector : This detector is based on the principle of the gas thermometer. It consists of a radiation absorber placed in a gas chamber. The absorber is in essence, a broad-band radio antenna designed to match the impedance of the free space. It is heated by the incident radiation, which in turn heats the gas in the chamber. The resulting increase in pressure is observed optically by the deflection of a small flexible mirror. These detectors come within a half order of magnitude of the theoretically ultimate detectivity. They are, however, extremely fragile and are essentially useless for field applications.

4.1.6 Calorimetric detector : This was developed by Eisenman~~and.~~ and ~~It~~ is a black radiation detector, which is used as a ~~bal~~ blackness standard for determining the spectral response of other detectors. It is a fast responding miniature calorimeter built in the form of a conical cavity. The emissivity and hence the absorption of the detector is probably greater than 0.995 from the visible to 40 u.

4.1.7 Problems of blackening thermal detectors : The materials which are used to form a thermal detectors are not good absorbers, therefore they are blakened by applying an absorbing coating. An ideal black coating must have -

1. Uniformly high absorptance at all wavelengths,
2. Negligible thermal capacity,
3. High thermal conductivity, ~~and~~
4. No adverse effect on the electrical properties of the detector element.
5. It must be possible to apply this coating without exposing the element to an undue danger of breakage.

A thin layer of soot from a candle flame or burning camphor is effective from 0.5 to 10 μ only. The gold black has a relatively low electrical conductivity and therefore can be applied only to low resistance detectors. For high resistance detectors the most satisfactory blackening is done by black paints and lacquers[2].

One of the assumed advantages of thermal detector is that its detectivity is independent of wavelength (though this condition is rarely achieved). Now-a-days photon or quantum detectors are more in use because thermal detectors do not have high detectivity and low time constants simultaneously. Since blackening increases the thermal capacity of the detector, the manufacture must tread the narrow path between a thin coating which reduces both the time constant and the detectivity and on every thick coating that increases both quantities.

4.2 PHOTON OR QUANTUM DETECTORS[1,2,3,4,8,9,10] : Most photon detectors have a detectivity that is one or two order of magnitude greater than that of thermal detectors. Because of the direct interaction between the incident photons and the electrons of the detector material, the response time of the detectors is very short, most have time constant in few microseconds or even less as compared with few miliseconds of the thermal detectors. The spectral response of photon detectors varies with variations in wavelength. Also, many photon detectors will not function unless they are cooled to cryogenic temperatures.

When photon impinges on semiconductor material of which the detector is made, electron hole pairs are produced; this effect is known as a photo effect.

To separate an electron from a 'hole' the photons must have enough energy to accelerate the electrons to such a speed that will rip them off their orbits around the atom's nucleus, thus turning them into "free electrons", which are able to move about, following the prevalent electromagnetic field. When a photon splits the electron hole pair, its energy is absorbed by the electron, which raises to the higher energy level called "~~corner~~ carrier band" where it remains in a free state until the end of its 'carrier life-time' when it recombines with a hole, losing in the process the excess energy that was keeping it with the carrier band. The energy so liberated is in the form of a photon, and the radiation composed of these photons is called recombination ~~radiation composed of these photons is called recombination~~ radiation because of the physical process by which it was generated.

The energy region located between the valence band and the carrier band is called the "forbidden gap" of the semiconductor to indicate that neither electrons nor holes can remain in this region as long as the semiconductor material is absolutely pure. Because of this region every quantum detector has a long wavelength limit beyond which the incoming radiation produces no effect. When a photon impinges on a semiconductor material there may be following effects.

When the incident photon transfers its energy to an electron inthe detector material, this electron may have sufficient energy to escape from the surface. This is called the photoemissive effect. Since it is observable beyond the confines of the detector material, it can be classed as an external photo effect. For wavelengths longer than about 1.2 microns, photons do not have sufficient energy to free an electron from the surface. There are, however, a number of internal photo effects in which the energy transferred from the photon raises an electron from a nonconducting to a conducting state and, in so doing, produces a charge carrier. If the material is an intrinsic, or pure, semiconductor, the photon produces an electron-hole-pair. If the material is an extrinsic, or impurity, semiconductor, the photons produces charge carriers, of single sign, either positive or negative.

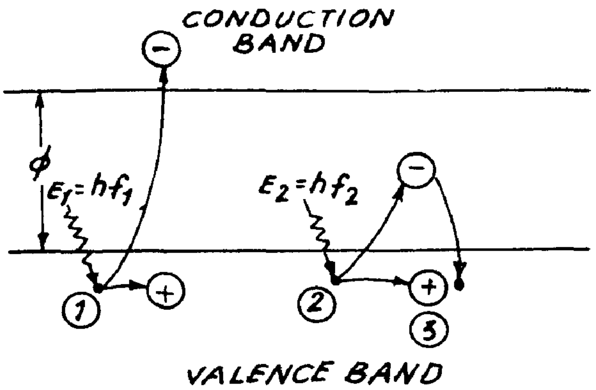


FIG. 4.2 SHOWING THE PHOTOEFFECT IN A SEMICONDUCTOR
(THE SEMICONDUCTOR CRYSTAL ENERGY STRUCTURE IS REPRESENTED BY THE VALENCE AND CONDUCTION BAND

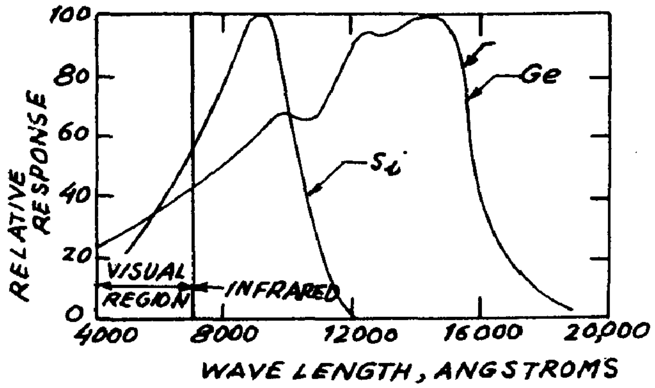
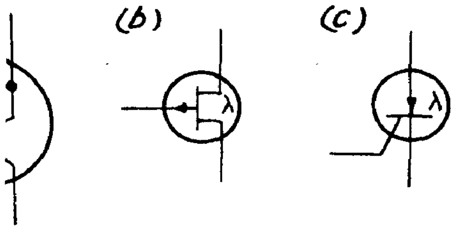


FIG. 4.3 CURVES SHOWING THE SPECTRAL RESPONSE OF Si & Ge PHOTOSENSORS COMPARED WITH THE VISIBLE REGION



4.4 SYMBOLS OF A PHOTO DARLINGTON

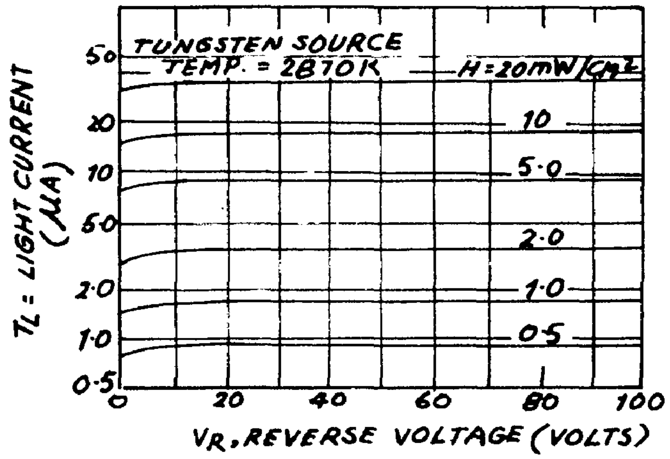


FIG. 4.5 IRRADIATED VOLTAGE CURRENT CHARACTERISTICS FOR PHOTO DIODE

Now if an electric field is applied by biasing detector changes in the number of charge carriers will vary the current flowing through the detector. This is called the photo conductive effect.

If the photon produces an electron-hole pair in the vicinity of a p-n junction, the electric field across the junction will separate the two carriers to give a photovoltage. This is termed the photovoltaic effect. No external bias suppl is required for a photo voltaic detector since it is, in effect furnished by the p - n junction.

When electron hole pairs are formed near the surface of a semiconductor, they tend to diffuse deeper into the materialin order to reestablish electrical nutrality. During this process the charge carriers can be separated by a strong magnetic field so as to give a photo voltage. Thisis known as the photcelectromagnetic effect. Some of the photon detectors are discussed below :

4.2.1 Photoconductive detectors -

(i) Bulk type photoconductive cells[9,10] : Consider a photo stricking the surface of a semiconductor (FIG. 4.2). If its energy, $E_1 = hf_1$ is greater than the energy gap between the valence and conduction energy bands of the semiconductor, sufficient energy will be imparted to an electron to raise it to the conduction level, leaving a hole in the valence band.

This electron hole pair is free to serve as current carriers, so that conductivity of the material increases, with the increase irradiance and area.

Since bulk type cells changes their resistance as the irradiance changes, these are also known as photo resistors. The spectral response of photoconductive cells depends upon the basic material used, Some of the materials are discussed below[3].

(a) Lead Sulfide : The lead sulfide (PbS) detector is perhaps the most common of all infrared photoconductive detectors. Lead sulphide detectors may be chemically deposited or evaporated onto a subtrate (usually quartz). Lead sulfide detectors may be operated at room temperatures or may be cooled to increase their S/N ratio.

(b) Lead Selenide : Lead selenide (PbSe) detectors are photo conductive and may be produced in much the same way as lead sulfide. But these are not in much use.

(c) Indium Antimonide : Perhaps the most versatile of all infrared detectors, indium antimonide (InSb) may be used as photo conductive, photocoltaic, or photoelectromegnatic detector. In-Sb detectors may be cooled or used at room temperature.

(d) Doped Germanium : A sensitive, long wave length photo conductive detector may be made using Germanium as the host semiconductor and copper or mercury as the impurity atoms.

Copper doped germanium (Cu : Ge) detectors must operate at temperatures below 10°K. Mercury doped germanium (Hg : Ge) may operate at temperatures upto 40°K. Germanium may also be doped with gold (Au : Ge), Zinc (Zn : Ge) and cadmium (Cd : Ge).

(e) Mercury Cadmium Telluride : Mercury cadmium telluride (HgCd Te) detectors are photoconductive and operate at a temperature of 77° K.

(ii) <u>Junction type Photoconductive detectors</u>[8,9,10] :

The mechanism of current control ~~through rad~~iation is similar to that for the photoconductive cell, whereby photons create electron hole pair on both sides of the junction. With no light applied, the reverse current is the reverse saturation current due to the minority carriers, holes in the N-type and electrons in P-type. When light is switched on, the photoinduced electrons the conduction band of P-type will move across the junction down the potential hill with the thermally generated minority carriers. Similarly, holes produced in the valence band of the N-type (by electrons being photoexcited into the conduction band) are available to add to the current flow by moving across the junction to the P side. The spectral response of the diode to wave lengths is shown in Fig. 4.3. These can operate at frequencies of the order of 1MHz or even higher.

(b) PIN Photodiodes[10] : Although the PN photodiode provide a much higher frequency response than bulk type photoconductive devices, an even faster response may be achieved in PIN photodiode. This consists of adding a layer of intrinsic silicon between heavily dopped ~~deppod~~ P and N type silicon materials. By providing an additional layer of silicon the transit or diffusion time of photoinduced electron hole pairs reduces. That is, carriers created by photons incident on the middle of the depletion region have to travel lesser distance than if generated at one side or the other of the depletion layer. The relatively thick layer (2.5 μ) of high resistivity intrinsic silicon ensures the absorption of most of the incident photons. It is found that the signal generated by the PIN photo diodes is relatively lower than PN photo diodes. However, the response time of the PIN photodiodes is ultrafast, with a switching speed of typically 1 n sed.

(c) Avalanche Photodiode : Current sensitivity may be increased from 30 to 100 times by operating a photodiode in its reverse break down region. In the avalanche photodiode, the construction is such as to provide a very uniform junction that exhibits the avalanche effect at voltages between 30 to 200 V. The dark current is typically 10 μA. The electron hole pairs that are generated by incident photons are accelerated by the high electric field to 'kick' new electrons from the valence to the conduction band. In this way, a typical photomultiplication of 50 is obtained, so that photo current may be 0.5 to 1 m.A. It is further noted that this mechanism does not reduce the fast response as found in PN photo diodes. The avalanche photo diodes can be operated at a modulation frequency of 2 GHZ with an excellent signal to noise ratio. The only disadvantage with this device at present is their expense[10].

(d) NPN photoduo diode : The current flow in the photodiode is small. The NPN photoduodiode is high current device, which is inexpensive also. To fabricate photoduodiode another junction is added. This device resembles with transistor; only difference being 10 time wider base. This device has typical sensitivity of 20 u A/mw/cm^2, roughly 10 times higher than the previous devices. The main advantage with this device is that they can be fabricated in very small sizes (typically 0.082 inch in diameter and 0.4 inch long). Therefore these are well suited to punched cards and tape read out applications[8,10].

(e) NPN phototransistor : The phototransistors can be used as an infrared detectors of higher radiation sensitivit because it has inherent current amplification. Any bipolar transistor is affected by photons on its collector base junction, and for this reason transistors are encased in photon tig (or light tight) packages. However, photo transistors are constructed to optimize their photon activating characteristics and often have a lens built into the package to focus radiation on the collector base junction. The photoinduced current of this junction (like that in a photodiode), I_λ , serves as the base current of the transistor. The amplification or current gain of the transistor then results in a collector current of $I_c = (h_{fe} + 1) I_\lambda$.

The transistor is connected in a conventional manner, so that the collector-base junction is reversed biased. The base lead may be provided in some packages and may be left floating or used to bias the transistor into some area of operation[9,10].

(f) <u>Other phototransistor types</u>[10] : By photo transistors typically the sensitivity of detectors varies from 0.02 to 0.8 m.A /m.W/cm^2. More economically higher sensitivity ranging from 1 to 4 m.A/m.W/cm^2 can be obtained by using a photo darlington amplifier. This contains a photo transistor and a direct coupled transistor amplifier stage. Symbol is shown in fig. 4.0. The disadvantage of this device is higher switching time.

The photo-FET, ~~THOUGH~~ through a new device to this field, but it has a high power gain and fast response. The device has 3-times more gm when it is cooled to 198° C (in liquid nitrogen), and its rise time is only 30 n sec.

For controlling very high power photo SCRs are used. The speed is relatively lower than the previous devices. A pulse of photons is enough to trigger the photo S.C.R. in 'ON' state from 'OFF' state but one the device is 'ON' its looses control of current through it.

4.2.2 Photo voltaic sensors[8,9,10] : Suppose a specimen of semiconductor has been populated with impurities that yield mobile electrons (or dopped n type), and this is joined to a sample containing hole yielding impurities (dopped p-type). The excess electrons will diffuse into the hole bearing material and conversely the excess holes will diffuse into the electron bearing sample and the two parts will take up, respectively, a positive and negative change, giving a small region of high electric field of the order of $10^5 - 10^6$ Vm^{-1} at the interface. In photovoltaic detector the photon flux is allowed to fall on the surface of the junction bearing material and the excited ~~corners~~ carriers diffuse to the near by junction. If each arm of the junction is connected to an external circuit a current will flow. Provided the external resistance as a resistance considerably smaller than that of the junction then most of the excited carrier flux will appear in it. The photovoltic effect can be also understood if the characteristics of photodiodes are examined, it is found that

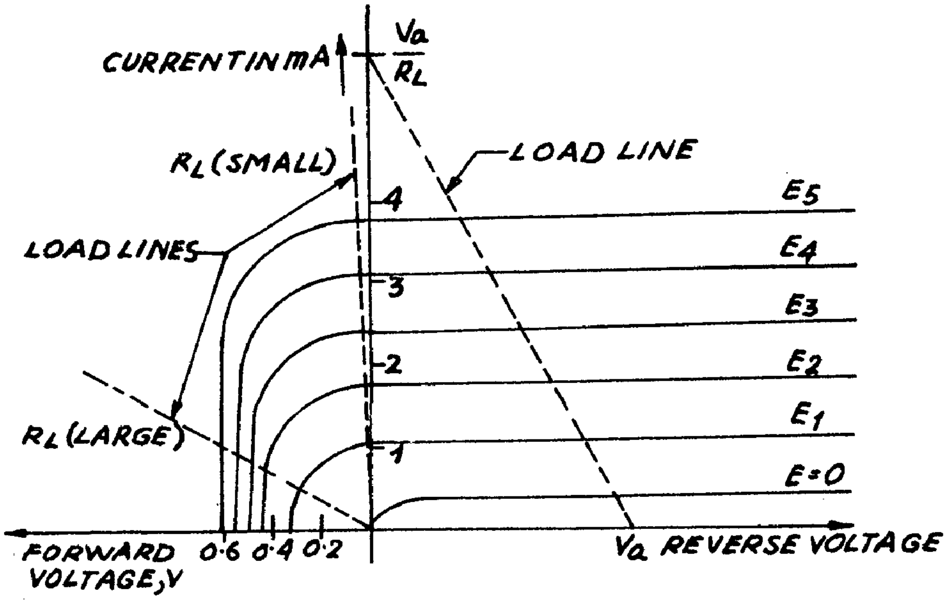


FIG. 4·6 SHOWING THE PHOTOCONDUCTIVE AND PHOTOVOLATIC QUADRANTS OF OPERATION PHOTODIODE

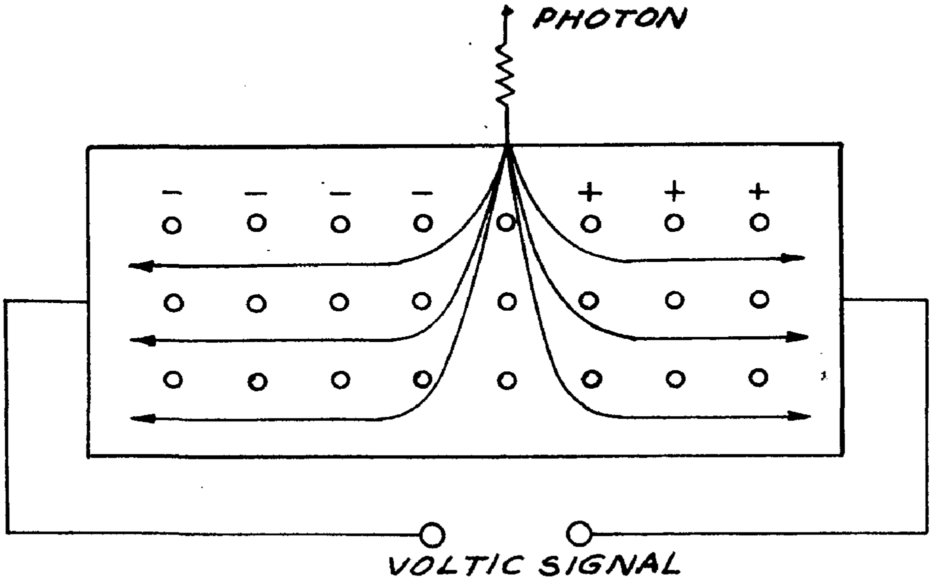


FIG. 4·7 PHOTO ELECTROMAGNETEC CELL

the curves (Fig. 4.5) do not pass through the origin but are shown terminating on the current axis. If the curves were continued to the 'left' for fordward voltages, they would have the form Fig. 4.6. This describes a hotovoltaic or photogenerative quadrant of operation in which the device can work without any applied voltage. That is, the junction generates a voltage and/or current depending upon the illumination and the load. This mode of operation is very useful when a sensor is required to detect very low levels of radiation since under complete dark conditions the current is zero. (This is not true in the reverse biased mode, where the dark current may be comparable to that generated by the radiation being detected).

Under short circuit conditions (or R_L very small), the photovoltaic effect is very sensitive to radiation and generates very little noise. Photovoltaic devices employing diffused junction in the indium antimonide and operating at liquid nitrogen temperatures can be used to detect radiation from the visible range of 6 microns. It is found that silicon is the best material for infrared detection purpose, its efficiency is about 14% (Efficiency n = Output power/ input) which is quite high.

4.2.3 <u>Photoelectromagnetic Cell</u>[2,3,9] : The photoelectromagnetic detector (P.E.M.) is unusual, but not unique among the devices. It requires an external magnetic field of its operation (Fig. 4.7). Suppose photon flux is falling on one face of detector. The current which is diffused is due to both by holes and electrons. This current will decay due to recombination of the excited carriers as it moves into the device. This current is deflected by megnetic induction towards the sides of the device giving a lateral current.

A photo electromagnetic detector consists of a wafer cut from a slab of intrinsic semiconductor material and a magnet. In short, incident photons produce electron-hole pairs, and these are separated by the externally applied magnetic field. Such detectors show response to 7 μ without requiring cooling and have very very short time constants. They have enjoyed little popularity and are rarely used, principally because their detectivity is relatively low compared to that of photoconductive and photovoltaic types.

4.2.4 <u>Photomissive detector</u>[2,8] : The energy of photon is given by

$$E = h\nu = hc/\lambda$$

where h = Plank's constant
ν = frequency of photon
λ = wave length of photon
c = velocity of photon.

When a photon collides with an electron in a metal, it may transfer its energy to the electron. If it does, the electron acquires all of this energy and the photon ceases to exist. This acquired energy may be sufficient to enable the electron to penetrate the potential barrier at the surface and to escape from the metal. Penetration of this barrier requires an amount of energy that is a characteristics of the material is called the work function. Therefore, the kienetic energy of the photoelectron as it leaves the surface is the difference between the energy gained from the photon and that used to over come the work function.

$$[\text{illegible}] = \frac{mv^2}{2} = h\nu - \Phi = \frac{hC}{\lambda} - \Phi$$

where m is the mass of the electron and v is its velocity. Since the energy of the photon varies with frequency or long wave length time beyond which this energy is less than that required to overcome the work function. The wavelength at which this occurs, called cut off wave length, is

$$C = \frac{1.24}{\Phi}$$

where Φ is in electron volts, of the elements that are photoemissive, the lower work functions are found among the alkali metals. Cesium with a work function of 1.9 e.V. is the lowest and has a cut off wavelength 0.65 μ. Surfaces compounded of more than one material may have still lower work function. The lowest value, 0.98 e.V, is observed with a silver oxygen cesium surface. This is commonly called an S-I surface and its cut off wave length is $1.2\ \mu$. Hence the response of photoelectric detectors extents only a shots way into the near infrared, and they are rarely used in the infrared systems.

In its simplest form a photoelectric detector consists of a photoemissive cathode and a plate, both housed in an evacuated glass envelope. An ~~extremely~~ externally applied voltage maintains this plate at about 400 V. positive with respect to the cathode, so that essentially all of the photoelectrons are collected by the plate. Photoemissive surfaces with very low work functions also emit electrons by thermal excitation. Since these electrons are indistinguisable from photoelectrons, they ultimately limit the minimum detectable signal. The number of themmally emitted electrons can be reduced by cooling the photoemissive surface.

4.2.5 <u>Detector arrays</u> : Infrared detectors may be constructed in linear arrays or matrices using hundreds of individual detectors closely spaced and in a wide variety of configurations.

Bicells or quadcells, causing of two or four sections, are used for position-sensing application. The signal out of such an detector is related to the position of incident radiation relative to the center of the cell[1,5].

Linear arrays may be used for single line infrared scanning systems. Area arrays are commonly used for two dimensional scan techniques. No moving optics are needed when the detector arrays are used making scanning system more rugged and reliable. Area arrays of infrared detectors may be used to make infrared vidicon tubes for infrared television systems.

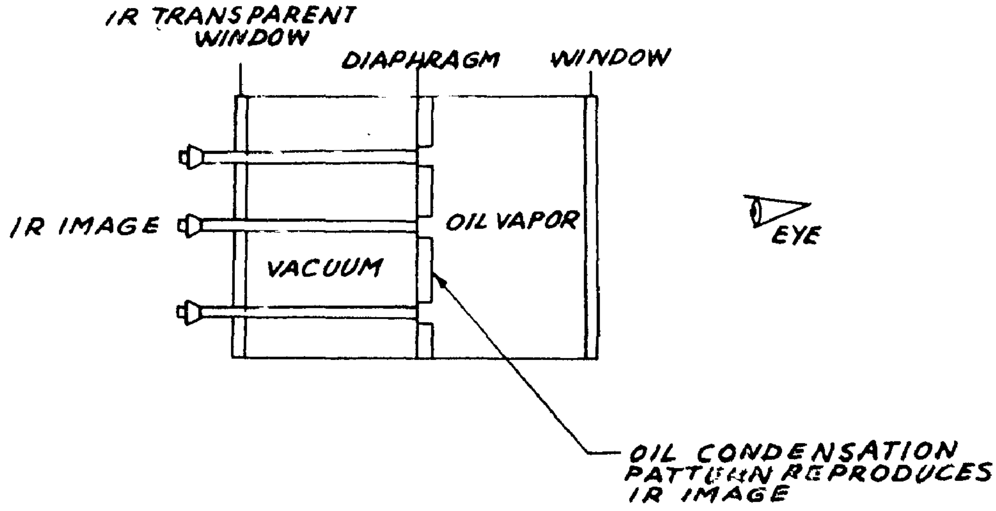


FIG. 5.1 BASIC EVAPORAGRAPH

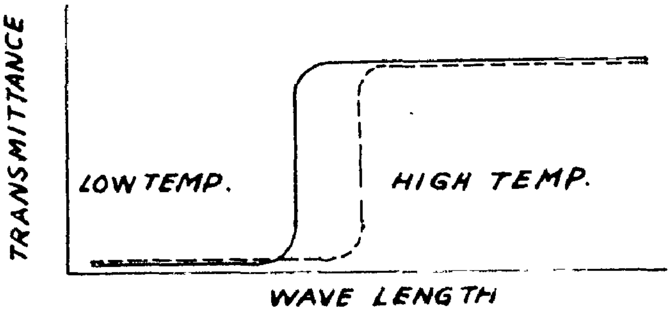


FIG. 5.2 VARIATION IN SEMICONDUCTOR FOUNDAMENTAL DESORPTION WAVE LENGTH WITH TEMPERATURE

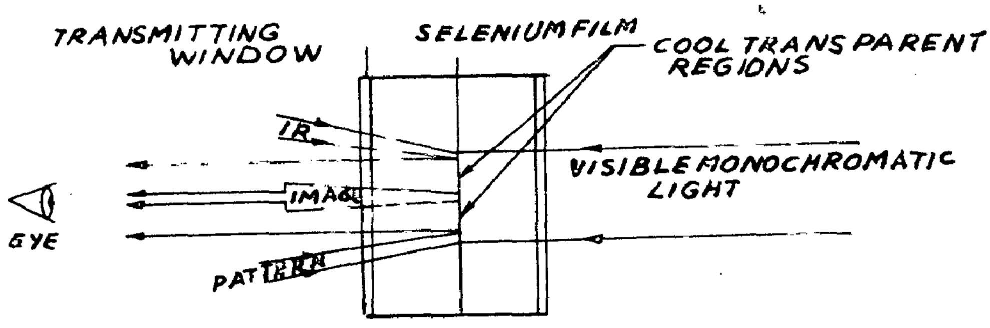


FIG. 5.3 SCHEMATIC OF ABSORPTION-EDGE IMAGE CONVERTER

5. INFRA-RED DETECTORS : UNCONVENTIONAL TYPE :

The devices described in this section cannot fit into the two major families of thermal and electronic detectors that have been examined so far.

5.1 THE EVAPORAGRAPH (OR EIDOPHOR)[11] :

The evaporagraph is used to convert a pattern of infrared radiation into a visible picture without the intermediaries of detector, amplifier, and display system. The instrument consists of a sealed chamber separated into two parts by a plane membrane. The space on one side of the membrane contains oil-vapour while that on the other side is evacuated. The infrared image is focused onto the side of the membrane facing into the evacuated space and causes a temperature pattern corresponding to the infrared image to be formed. Those parts of the membrane at higher temperatures will allow less oil-vapour condensation than other, cooler, regions and so a pattern of oil disposition builts up reproducing the radiation pattern, and, if the oil is illuminated with white light, then interference colours depending on the oil thickness, will make the pattern visible (Fig. 5.1). Modifications of this basic idea yielding faster, more sensitive systems have been prepared and examined practically. A more sophisticated technique places an opaque grid in the radiation pattern. Corresponding to the windows in the grid will be a pattern of comparatively isolated regions of higher temperature oil in which the surface tension is lower than that of the surrounding oil and, because of this, those areas, those areas deform into dimple like shapes. Clearly where no radiation is falling there will be no temperature variation between the oil undder window and that under the bars of grid, therefore the surface will remainflat. This surface pattern is observed by a 'Schlieren' system wherein the oil film is illuminated and light reflected from it observed, using an optical system which obscures all light save that coming from regular arrays of dimples, where they exist. Although the response of this type of instrument is slow, it produces a good optical image with a mechanically simple and robust apparatus.

5.2 ABSORPTION-EDGE IMAGE CONVERTER[8,11] :

The transmission of visible radiation in a semi-conductor is usually large at long wavelengths and falls abruptly, at a certain critical wavelength λ_c to a low value which is maintained for a shorter wavelength. The value of is temperature dependent, usually becoming longer with λ_c increasing temperature (Fig. 5.2). Suppose now a plate of such material has light of wavelength just longer than λ_c

falling on it, then most of this visible light will be transmitted through the plate. If now infrared radiation falls on the element the temperature will rise, λc will increase, and light will no longer be transmitted. In practice this absorption edge image converter has been made by supporting a thin film of ~~selemina~~ selenium, in an evacuated enclosure to avoid convection currents, and focusing the image of an evacuated enclosure to avoid conmection currents, and focussing the image of an infrared scene onto it through a suitably transmitting window. This heat pattern reproduced as an opacity pattern in the selenium, was made visible by shining monochromatic sodium light through the film, so giving a 'negative' image of the infrared pattern, areas of intense radiation appearing dark and vice versa (Fig. 5.3). The device yielded recognisable pictures of kettle at 60° C and a human head, presumably at a lower temperature. The respanse speed is about 0.5 sec..

5.3 FREQUENCY CONVERSION[1,8] :

Another way to detect infrared radiation is turn to turn it into a visible signal : this frequency conversion can be achieved in several ways, by taking advantage of different physical phenomena, such as :

1. Luminescence of phosphor compounds, further subdividdd in (i) Photolumenescence and (ii) Electro-lumenescence.

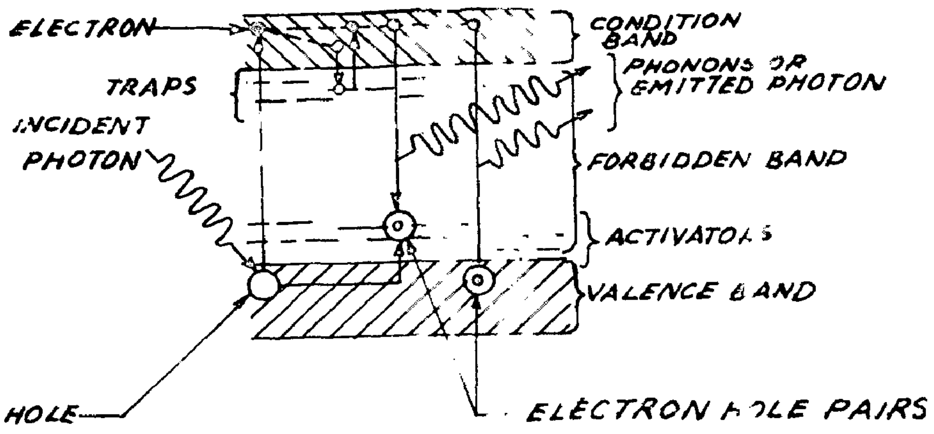


FIG. 5.4 ENERGY STRUCTURE OF PHOSPHORS

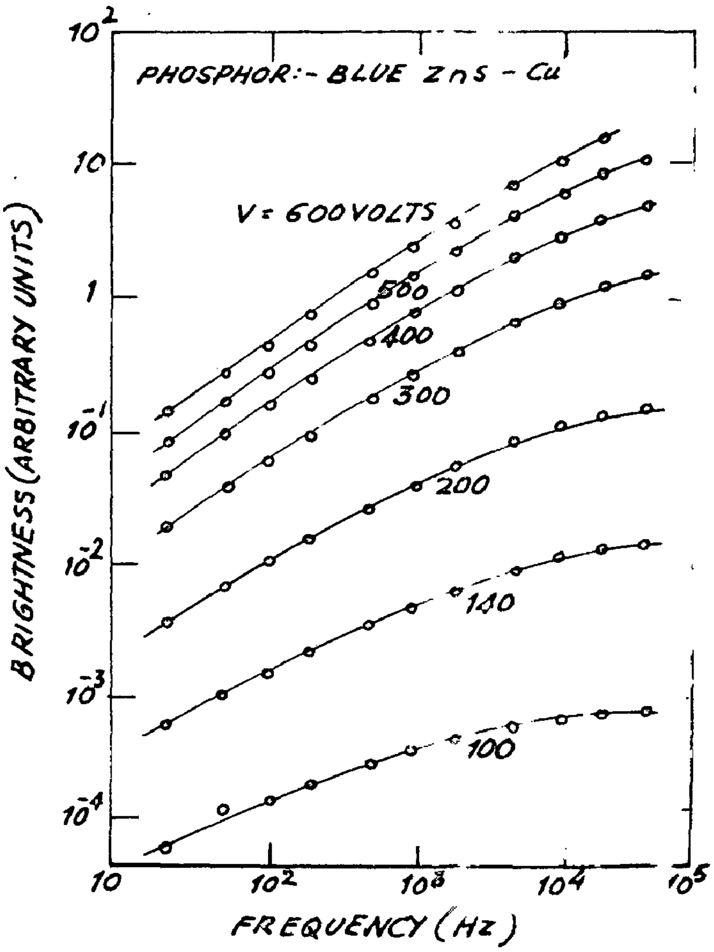


FIG. 5.5 FREQUENCY DEPENDENCE OF THE BRIGHTNESS OF A BLUE-EMITTING ELECTROLUMINESCENT ZnS·Cu PHOSPHOR FOR VARIOUS APPLIED VOLTAGES

2. Secondary emission of photons from primary impinging radiation.
3. Refractivity changes in cholesterol compounds

5.4 PHOSPHOR LUMINESCENCE[1] :

The light emission by phosphor compounds is a recombination radiation phenomenon. 'Phosphor' is the general designation for certain dielectrics made of a crystalline structure, dopped by impurities whose energy levels are located within the forbidden energy gap. Fig. is an ample of this condition, the energy levels just above the condition : the energy levels just above the conduction band are called activator levels, while those located just under the conduction band are called trapping levels. When the radiation of adequate energy content (usually blue or ultraviolet light) impinges upon a phosphor compound, electron hole pairs located in the valence band are separated and the electrons are brought to the higher energy level of the conduction band. At the end of their lifetime, they recombine into the valence band, after having lost their excess energy either by transfer to another particle or by emission of a photon, in which case electromagnetic radiation of radiation of wavelength corresponding, to the photons energy is emitted. When wavelength falls within the visible light range, the phenomenon takes the name photoluminescence.

The impurities located at energy levels within the forbidden gap can affect the photolumenescence phenomenon i two ways : (a) those at activator levels contribute free electrons when struck by lower energy impinging photons, (b) those at trapping levels act at intermediate energy steps for electrons that are degrading from the conduction to the valence band, thus reducing the energy level of the photons emitted at each step. In this way the wavelength of the emitted radiati-on is shifted out of the visible spectrum. This is called "quenching effect" and for a certain group of phosphors is produced by impinging infrared radiation.

The opposite effect is called "phosphor stimulation." It takes place for certain phosphor when external excitation is removed. At this point, a number of electrons remain trapped at the tfapping levels, and impinging infrared radiation raises their energy enough to liberate them, so that they can decay to the valence band, releasing photons in the visible spectrum.

By careful choice of the doping elements, phosphor can be produced that will exhibit quenching or stimulation by infrared within well defined thermal limits.

5.5 ELECTROLUMINESCENCE[1] :

Phosphor excitation that will produce visible luminescence can also be achieved by means of an alternating (i.e. a.c.) field imposed across phosphor layer. In this instant, doping is not required, since the presence of

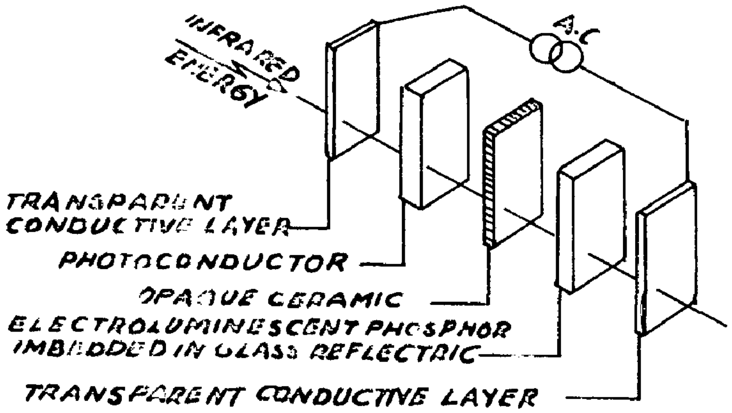


FIG. 5.6 IMAGE CONVERTER FOR NEAR-INFRARED RADIATION

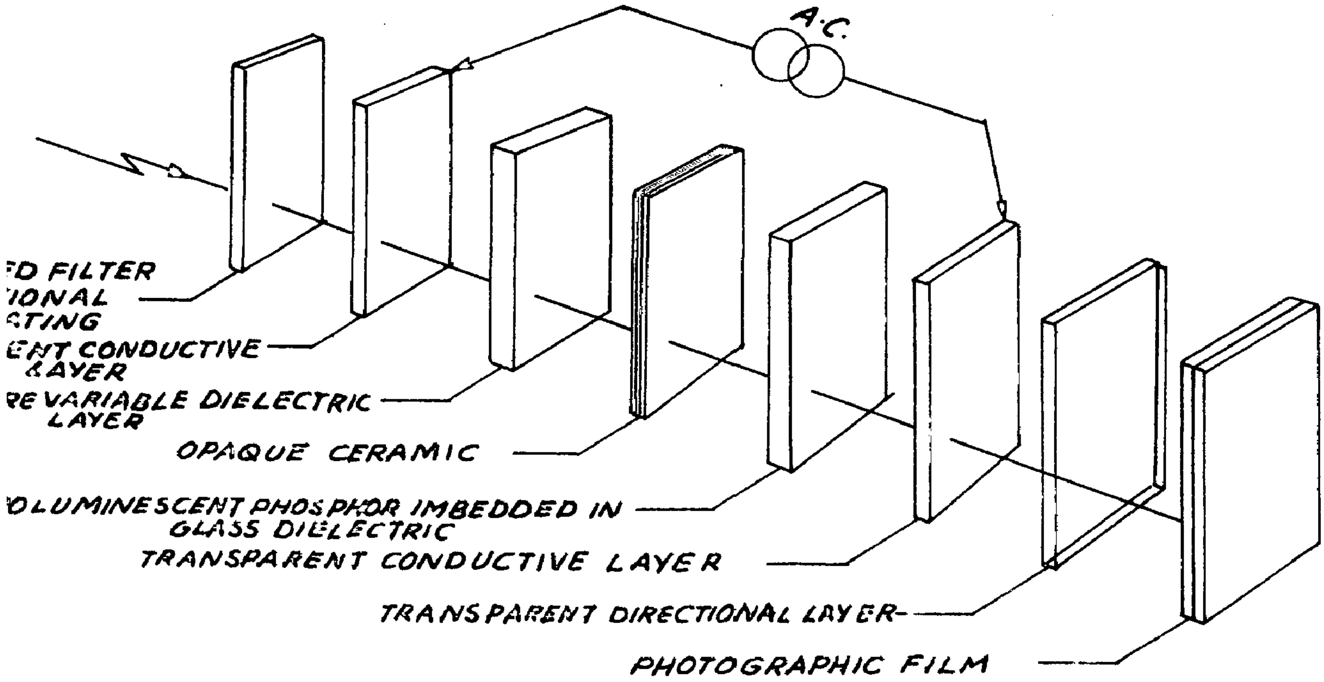


FIG. 5.7 FERROELECTRIC IMAGE CONVERTER FOR FAR INFRARED RADIATION

activator and trapping levels is unwanted. The energy needed to rise the electrons from the valance to the conduction band is supplied by the external a.c. field, and the brightness of the luminescence is proportional to the voltage of the applied field and to its frequency (Fig. 5.5).

Electroluminscent panels can be used as infrared to visible converters when an infrared image is focused onto a surface capable of modulating point by point the strength of the a.c. signal applied across phosphor layer.

On converter is shown in Fig. 5.6. It makes use of a photoconductive layer to modulate a.c. excitation at every point of the phosphor's surface. Modulation takes place because the photoconductors d.c. resistance varies inversely with the strength of the impinging infrared radiation. Thus for every point of the surface where the infrared is focused, the resistance variations of the photoconductor cause inverse variations of the a.c. field applied, to that same point. This in turn cause inverse variations of the induced luminescence of the phosphor, so that the visible image faithfully reproduces the infrared image focused on the opposite side of the converter.

A photographic film applied onto this surface can record the image in a permanent way, and can also store the low level light emitted during a long exposure if its instantaneous level is too low.

The thermal range of operation for this type of converter is dependent on the characteristics of the photoconductor used. It is very difficult to cool the photoconductor to cryogenic temperature. Therefore, photoconductors operating at ambient temperature are used, and therefore the converter is only sensitive to the near infrared.

5.6 FERROELECTRIC CONVERSION[1,2,8] :

To operate in the far infrared spectrum, modulation of the a.c. voltage can be achieved by replacing the photoconductive with a ferroelectric layer. In this case, the modulation takes place by capacitance variation, instead of resistance variation, but the resistance is similar. The ferroelectric layer is a compound of barium litanate and istrontium titanate in such proportions as to make its capacitance variations highest in the desired temperature range. Fig. 5.7 illustrates the arrangement that solves the problem of long wave image conversion.

5.7 INFRARED VIDICON[1,8,11] :

The signal storage capability upon which is based the operation of the vidicon tubes is especially useful in

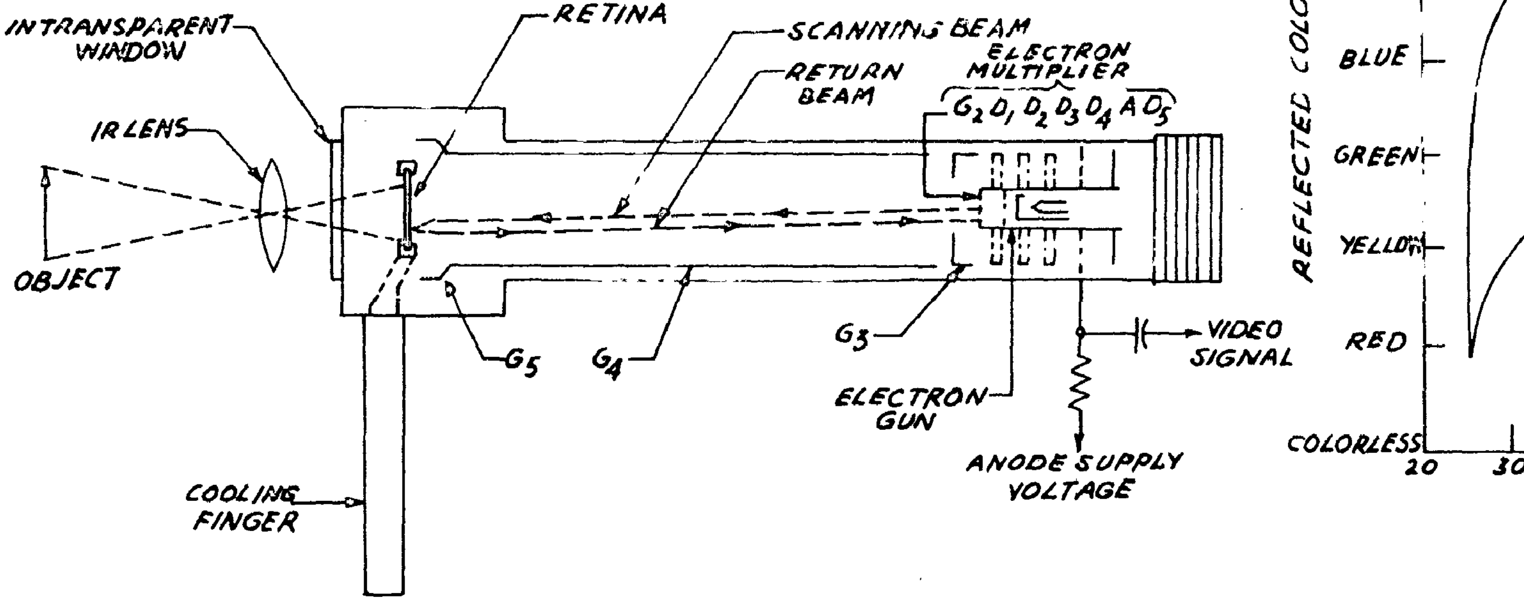


FIG. 5.8 SCHEMATIC DIAGRAM OF INFRARED VIDICON

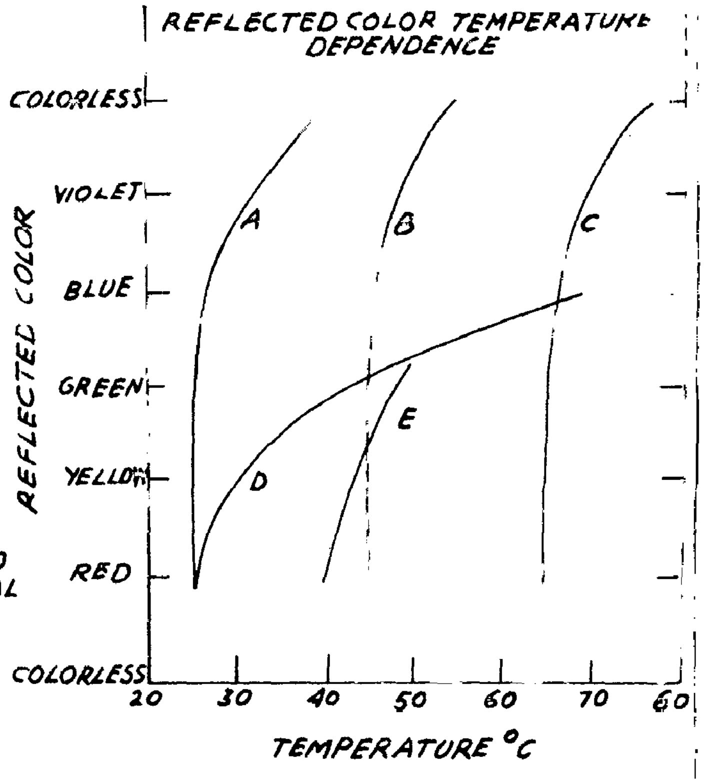


FIG. 5.9 TEMPERATURE DEPENDENCE OF LIGHT SCATTERING FOR MIXTURE OF CWOLESTEROL ESTERS

the infrared range, where the energy content of the radiation emitted by the target becomes prograssively lower as the wavelength increases. Fig. 5.8 shows a schematic diagram of vidicon tube. The video information is generated by the current variations occuring in the scanning electron beam when it reaches the area of the ratina that have been partially discharged by leakage through the photoconductive material of which the ratina is made, focussing an infrared image on the front surface of the ratina creates different d.c. resistance values for every point, in inverse proportion to the intensity of the impinging radiation. An optical system of reflective or refractive elements is located in front of the vidicon tube. The incoming radiation passes through the infrared transparent window and is focussed on the front surface of ratina. This surface is kept at a positive potential with respect to the cathode and as long as no infrared radiation falls onto it, the photoconductive material of which the ratina is made constitutes a barrier between this positive-charged surface, and the back surface , which is negatively charged by the electron seanning beam emitted by the cathode. When radiation falls on the ratina electrical leakage between front and back of ratina takes place, in direct proportion to the amount of infrared energy impinging on every elementary area of ratina. Consequently, the electron scanning beam on its next passage will deposit on tho depleted area just enough negative charges to reestablish the cathode potdntial. As a result, the strength of electron beam that returns to the anode G_2D_1 surrounding the electron gun will vary in inverse proportion to the infrared energy that illuminates every point of the ratina.

The path of the electron beam from the cathode to the ratina and back is shown in dotted lines with arrows pointing the direction of travel, focussing, alignment and deflection coils are wound around the tube's neck, but are not shown in illustration. Grid G_5 slows down the incoming electrons for better landing characteristics, while G_3 serves to control the path of electrons emitted by D_1 and approaching D_2. The remaining dynodes are D_3, D_4, and D_5, which together make the electron multiplier of the return signa At every dynode stage, several electfons are ejected for every impinging electron, for the well-known principle of secondary emission, until finally at the last dynode stage, the amplified electron beam current travels the tube, via tho anode. Viedosignals, or variations in beam current correspondigg to infrared radiation on the vidicon target, ~~us~~ are also amplified and are capacity coupled into a pre-amplifidr.

The amplification provided by the electron multiplier maintains a high signal to noise ratio and permits the use of a lower gain preamplifier. Optimum performance is obtained when the output noise of the tube, composed of the random noise of the electron beam amplified by the electron multiplier, exceeds the preamplifier input noise. Cooling of photoconductive material is done by liquid nitrogen in the crygonic container located at the front end of the tube. This tube is sensitive in the intermediate infrared spectral region and its performance specifications are classified.

5.8 LIQUID CRYSTALS[1,2,3,11] :

Certain organic compounds, while in liquid form, exhibit optical anisotropy typical of crystalline solids. This behaviour is characterized by a difference in the speed of light propagating along two different directions, so that reflection and refraction take place according to the laws of birefringence. The phenomenon is due to the fact that the molecules are aggregated in orderly configurations of groups or layers, where they are all stacked parallel to each other. Though many organic compounds exhibit liquid crystal properties, only those producing dicromism have been used to convert temperature into colour information. The phenomenon used for this conversionis the unequal absorption

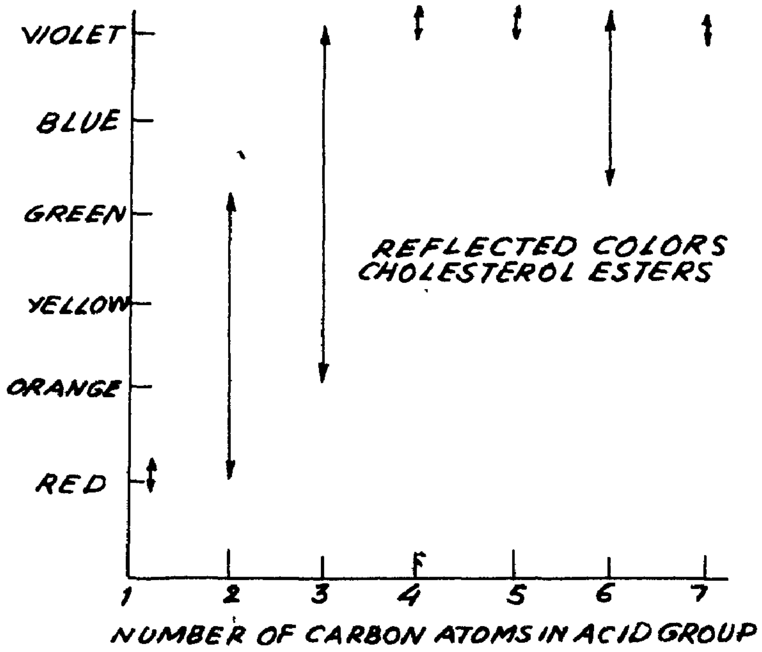


FIG. 5.10 LIGHT SCATTERRING AS A FUNCTION OF CHOLESTEROL ESTER STRUCTURE

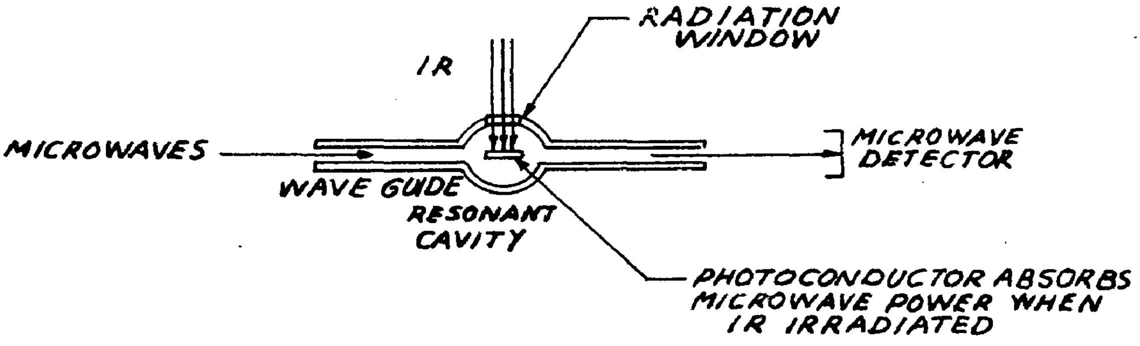


FIG. 5.11 SCHEMATIC OF MICROWAVE BIAS PHOTODETECTION

coefficient for the two polarized light beam into which the impinging rays are split. The nonabsorbed polarized beam is either transmitted or reflected, after having rotated a certain angle, whose magnitude depends on the temperature of the compound. This produces various colours in the visible spectrum, which are indicative of the temperature of the surface on which compound is adhering. The derivatives of cholesterol, called esters, exhibit the above mentioned phenomenon to a high degree. It is found that the molecules of such organic compounds are stacked together, while the molecules axis are progressively rotated always the same angle from one layer to next. This configuration in turn produces a rotation of polarization plane of the incident light. or example, at 20^{o} C, 1 mm section of quartz will rotate light of a wavelength of 6560 A^{o} (red) 17.25 degrees, while the same sample will rotate blue light (wavelength 4480 $\overset{o}{A}$) by 39.24 degrees. Fig. 5.9 shows temperature dependance of different cholesterol esters mixtures. ~~Fig. 5.16 shows temperature dependance of different cholesterol esters mixtures. Fig. 46~~ Fig. 5.10 shows the colour range of the reflected light varies with the number of carbon atoms contained in acid group of the cholesteric molecule.

Due to the fact that the colours are produced by reflection and not by transmission, these compounds should be deposited onto black surfaces. Since a layer 10- μ thick is sufficient to produce accurate colour display, a single gram of mixture dissolved in adequate volume of solvent can cover 1000 cm^2 of surface. A good liquid crystal changing its hue by 1000° A for a temperature change of one degree and taking a few tenths of second to do so. The working temperature of liquid crystals is conveniently around room temperature and much of their use has so far been in the direct observation of an liquid crystal film painte over a machine or component in order to show up the temperature distribution.

5.9 MICROWAVE BIASED PHOTOCONDUCTORS[11] :

It is known that the difficulty in increasing the signal by increasing the voltage applied to the photoconductive sample arises from the free carrier recombination at the contacts. A higher electrical field merely drove holes and electrons more quickly into close proximity at the contacted ends of the device where they rapidly recombined and quenched the signal. To overcome this difficulty impurities are added which from traps immobilizing either all free holes or all free electrons. But these impurities show the discharge of carriers from the traps giving a current long after the radiation signal had ceased.

The dilemma of choosing speed or sensitivity was resolved by sommers and Teutsch. By them, even without the one-carrier trapsl excessive recombination at the contacts could be avoided if the electric field being applied were reversed just before the cloud of photo-excited carriers reached a contact. The velocity of the excited carriers and the detector dimensions required the field reversal to take place some 10^{10} times a second which is a frequency in microwave region. Now microwaves, that is the electromagnetic radiation having a wavelength falling between a millimeters and tens of centimeters, do not require the conventional circuitry of low frequency practice, with wires attached to contact regions on the photoconductor specimen. It is possible to pass power directly into the specimen merely by holdigg it in a microwave beam which will produce within it the high frequency field required. There is a limitation on the microwave based (M.W.B) photoconduction system which is imposed by the rapidity with which the free-carrier population in the detector can respond to external field reversals. This response rate is controlled by the dielectric relaxation time of the material, equal to the ratio of the permitivity to the electrical conductivity.

In actual system a beam of microwaves is led through a tube or guide into a resonant chamber where the photoconductive specimen is holding in a position of maximum electric field. The currents set up in the specimen absorb power from the microwave beam and remaining power is now radiated, then the consequent fall in conductivity will ease it to absorb even more microwave power and the through put of the resonant chamber will decrease (Fig. 5.11).

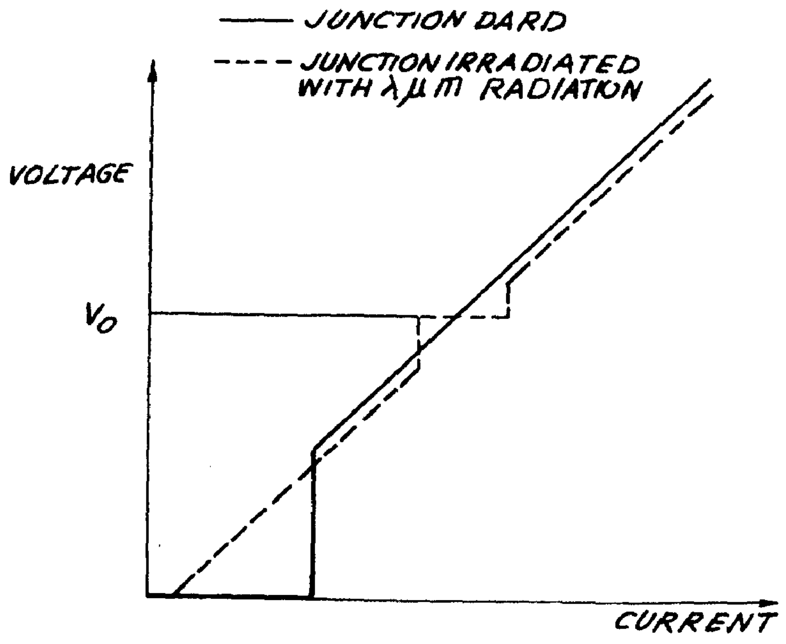
It is this variation that is used to absorbe the presence of infrared radiation on the detector.

This system of microwave guide and resonant chamber also acts in the manner of an electrical transformer increasing the voltage that finally appears in the microwave detector circuit. Over that appearing across the photoconductive itself, by a factor of ten or more in practical systems.

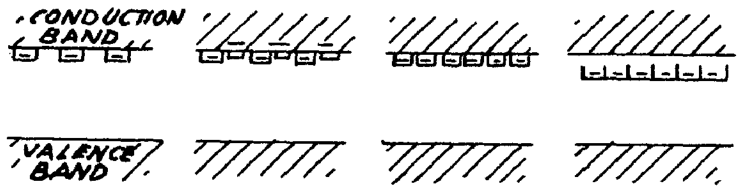
This system has been most intensively developed using room temperature photoconducting material sensitive to 1.5 μ m radiation, but 10 μ m wavelength radiation has been detected by a system operating at very low temperatures.

5.10 THE JOSEPHSON JUNCTION DETECTOR[9, 11] :

It consists of two superconducting electrodes separated by some 10 Å ? of insulator. Pairs of electrons can tunnel from electrode to electrode through the insulator without doing work. This means, microscopically, that a finite current can flow across the junction without an applied

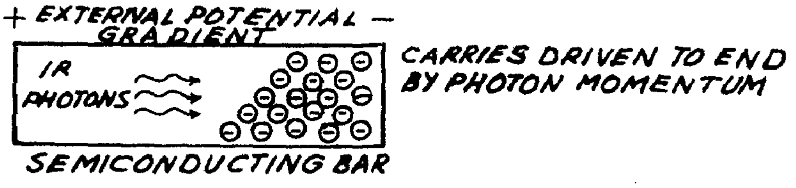


FIG·5·12 CURRENT-VOLTAG CHARACTERISTICS OF JOSEPHSON JUNCTION



(a) FEW IMPURIT-IES PHOTO-DETECTION IS INEFFICIENT (b) WITH MORE IMPURITIES ENERGY LEVEL BECOMS & DEFUSE & SOME ELECTRONS SPILL INTO CONDUCTION BAND (c) WITH MAGNETIC FIELD APPLIED IMPURITIES ENERGY LEVELS ARE CONFINED TO NARROW REGION (d) WITH STRONC MAGNETIC EIELD ENERGY LEVEL IS MOVED AWAY FROM CONDUCTION BAND

FIG. 5·13 USE OF IMPURITY CENTERS IN INFRARED PHOTODETECTION



FIG·5·14 PHOTON -DRAG DETECTOR

voltage difference and it behaves as if has no electrical resistivity. If the current through junction is increased beyond a certain critical value then the bond between the electron pair fails and the junction behaves as a simple ohmic resistance. If now electromagnetic radiation of frequency f falls on the junction then the current voltage relationship will show a normal ohmic resistance until a voltage V given by $hf = 2\ Vq$ is reached when the bond reforms. (Here h is planks constant.) At this voltage a sudden increase in current appears giving another region of zero resistivity (Fig. 5.12). It is now clear that by monitoring the appropriate region of current voltage characteristic shown by the junction the presence of incident radiation can be detected. Although the Josephson junction was first used for millimetric wavelengths it seems possible that it may be used to detect radiation with a wavelength as short as 200 µm. The device response time is less than 10^{-9} second and will probably be limited always by the time constant of the electrical circuit in which it is used. Radiation with a power of less than 10^{-11} watt has been detected by a junction using niobium superconducting arms held at a temperature of 3.1° K. This operating temperature draws attention to the practical disadvantage in using what is a fast and sensitive infrared detector. The necessary super conducting state is achieved only at a very low temperatures.

5.11 MAGNETICALLY TUNED INFRARED DETECTOR[9,11] :

Another long wavelength detector using indium antimonide at very low temperatures works on a more conventional basis in which low energy photons free carriers from impurity levels which are, energetically, close to the conduction band. This sounds so standard a mechanism as to be out of place in a chapter devoted to the less orthodox device but the interest lies in the reconciliation of sensitivity and wavelength response. If only a few impurity centres are added to the compound then the probability of exciting carriers from them with any given radiation flux is low. Now by increasing the number of centres this probability becomes larger and it would be expected that the sensitivity would do so as well but, unfortunately, the energy level of the centers now begins to spread and may finally reach right to the conduction band. The desired ~~situated~~ situation with a discreating well defined impurity level can be restored by the presence of high magnetic field leading to a sensitive long wavelength or small photon energy, detector. The effect of the magnetic field is not only to compress the band of energies that the impurities show but also to move it slightly with relation to the conduction band (FIG. 5.13). This allows different wavelength radiations to be preferentially detected as the magnetic field is varied and so the detector is said to be tunable.

5.12 THE PHOTON DRAG DETECTOR[9,11] :

The moment for a flux of photoms can be used to drive free carriers down to one end of a semiconducting bar with the consequent voltage gradient along the semiconductor in the direction of the incident radiation (Fig. 5.14). This effect is not to be comfused with simple photoconduction where the energy of the photon frees a charge carrier for subsequent manipulation by an external electric field. Here it is the moment of the photon that pushes along carrier that are already free. The sensitivity of these 'photon-drag' detectors is low, since the momentum associated with a photon is very small even when its energy is reasonably large. It may appear perverse to use momentum effects when the much larger energetic phenomena are available but the response speed of the photon drag detector is very great and probably incommensurable since, in any complete detector system, some other component will ~~am~~ almost certainly be slower and hence from the limiting factor. This fast, insensitive device is used cheifly for monitoring the output of lasers operated in very brief pulses as, in this situation, much radiation power is available. Commercial devices develop a signal of a few microvolts for an incident radiation power of a watt and respond in less than 10^{-9} second.

5.13 M.O.M. DETECTOR[11] :

This device detect radiation with wave length lying in the 10-2 μm range to which it responds in less than 10^{-13} second. Designated as M.O.M., or metal-oxide-metal detector, the construction is simple, at least to describe, consisting typically of a short, pointed tungsten wire pressed against a nickel or steel block. The length of tungesten does not seem to be critical 2-3 mm being satisfactory but the diameter of the proble must be approximately 10% of the radiated wavelength, say 2 μm. This probe resonates with radiation and the metal-oxide-metal contact at the nickel rectifies the consequent induced currents. In fact the metal probe may be regarded as a very high frequency dipole receiving aerial. The normal mode of use is to place the probe assembly in a microwave beam so that when the infrared radiation falls on it, the excited condition of the device affects the microwave propagation.

The characteristics and the applications of detectors, discussed in Chapter 4 and 5 are summarised in Table 1.

S. No.	Type	Operating Mode	Operating temperature	Useful wave length range	Time constant (u Sec.)	Applications
	(a)	(b)	(c)	(d)	(e)	(f)
1.	Thermo-couple	Thermo-electric	Room temperature	1 - 40	25000	For spectrometers and other similar instruments. As a laser detector for space instrumentation (using thin film on high thermal conductivity substrate).
2.	Thermo-piles (Evaporated)	-do-	-do-	-do-	5000	
3.	Thermister Bolometer	Bolometer	Room	0.2 - 40	2000	Can be used in radiometers. Not in much use because of high noise signal.
4.	Ferro-electric Bolometer	Bolometer	Room	1 - 12	-	Can be used in radiometer but expensive.
5.	Golay cell	Gas expansion	Room	5 - 1000	20000	Extremely fragile and are essentially useless for field applications.

(x)	(a)	(b)	(c)	(d)	(e)	(f)
6.	Niobium nitrate bolometer	Super conductivity	16° K	-	550	The problem of precisely holding the transition state temperature makes it useless for practical applications. Find uses in research work.
7.	Carbon bolometer	Bolometer	2.1° K	40 - 100	10000	Find uses in laboratory .
8.	Germanium bolometer	Bolometer	2.1 K	5 - 2000	400	Find much uses in laboratory work and suitable for detecting either infrared or microwaves.
9.	Silicon detectors	Photo-voltaic	Room	0.5 - 1.05	100	Radiometers
10.	Lead sulfide detector (PbS)	Photo conductive	Room	0.6 - 3.0	50-500	Radiometers.
11.	Indium arsenide detector (In As)	Photo-voltaic	Room	1. - 3.7	$\simeq 1$	Fast scanning radiometers.

	(a)	(b)	(c)	(d)	(e)	(f)
18.	Lead selenide (PbSc)	Photo-conductive	195^o K	0.5 - 5.1	30	Mostly used in Radiometers
19.	Indium antimonide (InSb)	Photo-conductive	195^o K	0.5 - 6.5	≃1	Fast scanning radiometers.
20.	Lead sulfide (Pbs)	Photo-conductive	77^o K	0.7 - 3.8	500-3000	Radiometers
21.	Indium arsenide (InAs)	Photo-voltaic	77^o K	0.6 - 3.2	≃ 2	Fast scanning radiometers
22.	Tellurium (Tc)	Photo-conductive	77^o K	0.7 - 4	60	Not in much use
23.	Lead tellunide (PbTc)	-do-	77^oK	1 - 5.4	≃ 5	Radiometers.
24.	Indium antimonide (InSb)	photo-voltaic	77^oK	0.6 -5.6	≃1	Fast scanning radiometers

	(a)	(b)	(c)	(d)	(e)	(f)
25.	Indium antimonide (InSb)	Photoconductive	77° K	0.7 - 5.9	1 - 10	Fast scanning radiometers
26.	Gold dopped germanium (P-type)	-do-	77° K	1 - 9	$\simeq 1$	--do--
27.	--do- (N type)	-do-	77° K	1 - 5.5	50	Not used
28.	Mercury cadmimum tellunide	Photovoltaic	77° K	6 - 15	0.01	Ultra fast scanning radiometers.
29.	Zinc dopped germanium silicon alloy (Ge-Si:Zn)	Photoconductive	48° K	2 - 15	$\simeq 1$	Fast scanning radiometers
30.	Merucry dopped germanium (Ge : Hg)	--do--	30° K	3 - 14	$\simeq 1$	--do--

	(a)	(b)	(c)	(d)	(e)	(f)
31.	Cadmium doped germanium (Ge:Cd)	Photo-conductive	28^{0} K	6 - 24	≤1	Fast scanning radiometers
32.	Copper doped Germanium (Ge:Cu)	-do-	4.2^{0} K	6 - 29	≤ 1	--do--
33.	Zinc doped germanium (Ge:Zn)	-do-	4.2^{0} K	7 - 40	≤ 0.01	Ultra fast scanning radiometers.
34.	Pyroelectric	Pyro-electric effect	Room	Visible to 1000 u	< 1	TGS detectors best for high performance but ceramic or polymer film detectors useful where maximum robustness and simplicity required radiometers having ultra fast scanning.
35.	Photo drug Ge	-	Room	Depends on free carrier absorption.	≤ 10^{-4}	Super fast, robust monitors of high power lasers.

	(a)	(b)	(c)	(d)	(e)	(f)
36.	Metal oxide metal junction	-	Room	10-20	$<3 \times 10^{-8}$	Useful as hydrocyne detector frequency mixer and harmonic generator.
37.	Josephson junction	-	$4^{o}K$	200-2000	10^{-3}	-

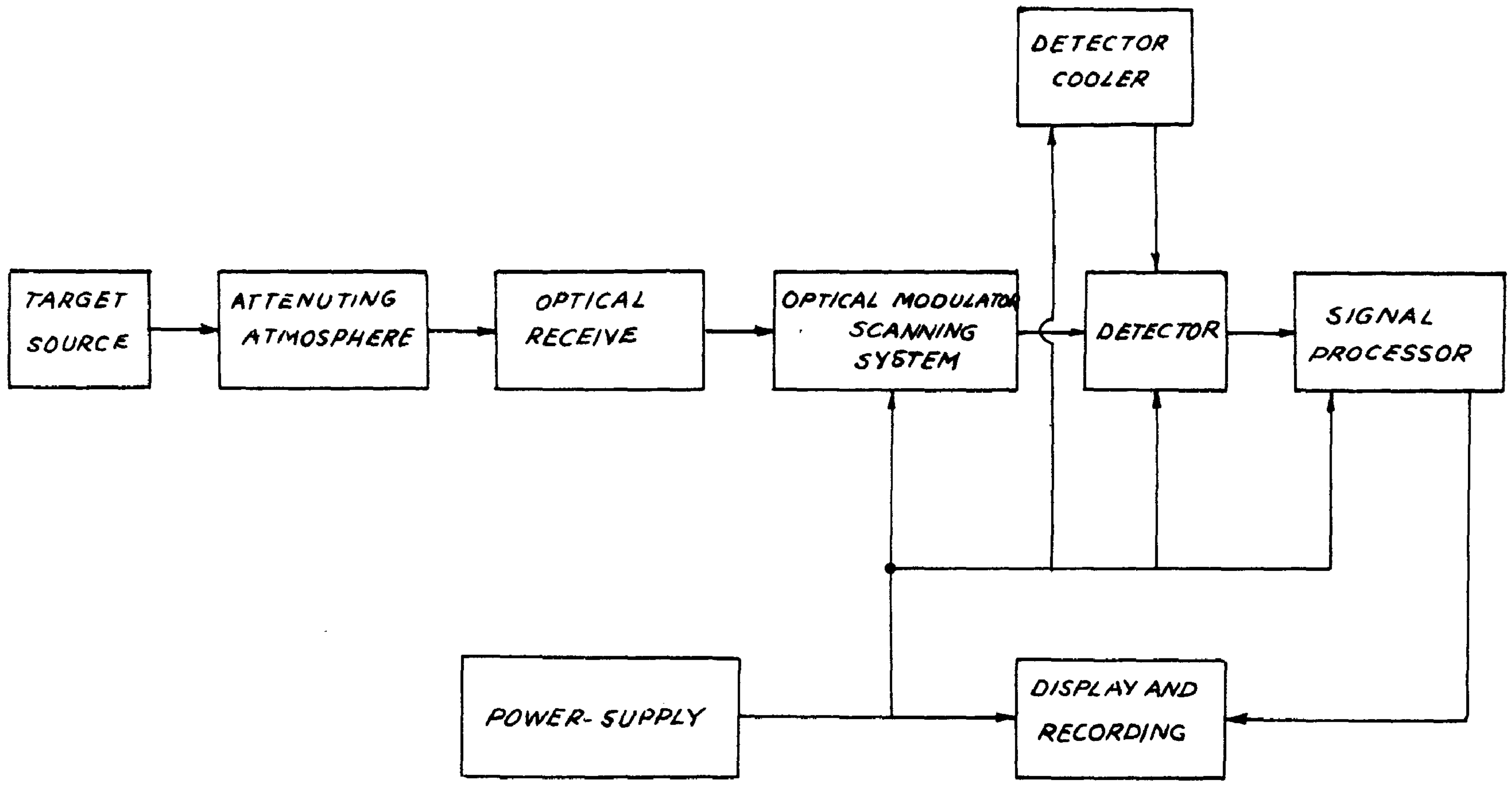


FIG. 6.1 ELEMENTS OF INFRARED SYSTEM

6. ELEMENTS OF INFRARED INSTRUMENTATION :

The common elements of infrared systems are shown in the block diagram of fig. 6.1. The target is the object of interest and it radiates energy somewhere in infrared portion of the spectrum. The system may be designed to detect the presence of the target, to track it as it moves, to glean information leading to its indentity, or to measure its temperature. If the radiation from the target passes through any portion of the earth's atmosphere, it will be attenuated because the atmosphere is not perfectly transparent. In case if a known radiation from source is projected to some matter under test, the radiation attenuation depends upon matter. The optical receiver, which is closely analogous to a radar antenna collects some of the radion from target (or the source radion which is passed through matter) and delivers it to a detector which converts it into useful electrical signal. Before reaching the detector, the radiation may pass through an optical modulator where it is coded with information concerning the detection of the target or information to assist in the differentiation of the target from unwanted details in the back ground. Since some of the detectors must be cooled, one of the system elements may be means of providing such cooling. The electrical

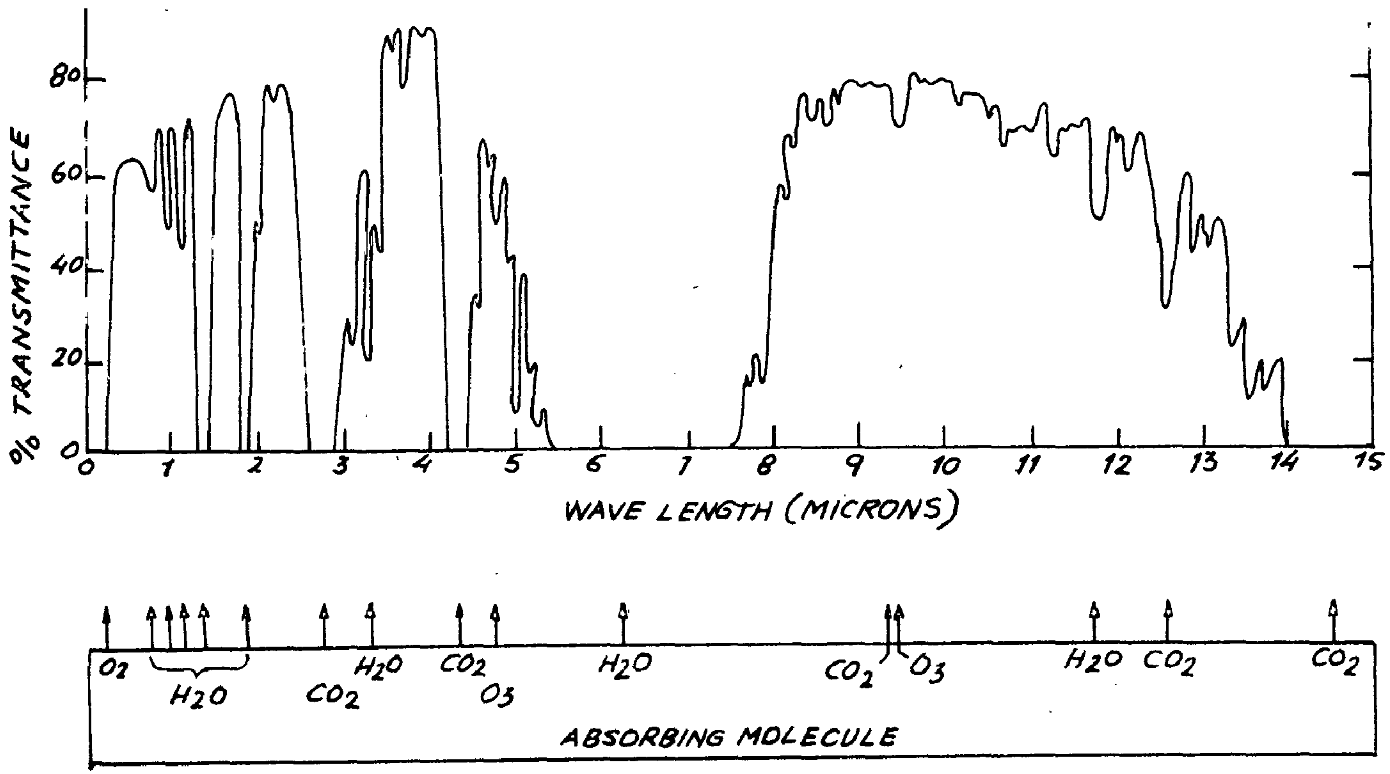


FIG. 6.2 TRANSMITTANCE OF THE ATMOSPHERE FOR A 6000 ft. HORIZONTAL PATH AT SEA LEVEL

signal from the detector passes to the processor where it is amplified and the information about the target or matter is extracted. The final step is the use of this information to automatically control some process or to display the information for the interpretation by a human observer.

The targets and sources are already discussed in chapter 3 and detectors are discussed in chapter 4 & 5. In this chapter optical receivers, detector coolers, attenuting atmosphere, signal processor, and display and recorder are discussed.

6.1 ATTENUTING ATMOSPHERE : The most of the infrared systems view their targets through earth's atmosphere. Before it reaches the infrared sensor, the radiation flux from the target is selectively absorbed by several of the atmospheric gases, is scattered away from the line of sight by small particles suspended in the atmosphere and, at times, is modulated by rapid variations in some atmospheric property. The general process by which radiant flux is attenuated in passing through the atmosphere is called extinction. The spectral transmittance measured over a 6000ft. horizonal path at sea level is shown in fig. 6.2. The molecule responsible for each absorption band either water vapour, carbondioxide, or ozone, is shown in lower part of figure.

The curve can be characterized by several regions of high transmission called atmospheric windows seperated by inverting regions of high absorption.

Fogs and clouds are strong scatterers and are, in effect, opaque to infrared radiation. As a consequence, infrared systems can not be considered to have a true all-weathercapability. On the other hand, transmission through rain is surprisingly good and should not be overlooked in trade off studies of the usefulness of radar and infrared sensors. Reference 2 deals with this aspect in detail.

6.2 OPTICAL RECEIVER :

6.2.1 OPTICAL GAIN SYSTEMS (OR MICROSCOPIC AND TELESCOPIC SYSTEMS) :

The function of optical receiver is to shape, direct, orand modify the infrared radiation before it reaches the infrared detector from target or source. The optical system, used in infrared system, collect and focus the incoming radiation onto an infrared detector. In fact the optical system magnifies the receiving area of a bare detector yet maintain the noise level equivalent to that from a detector of small receiving area. Thus the effective "optical gain" is the ratio of the optical requiring

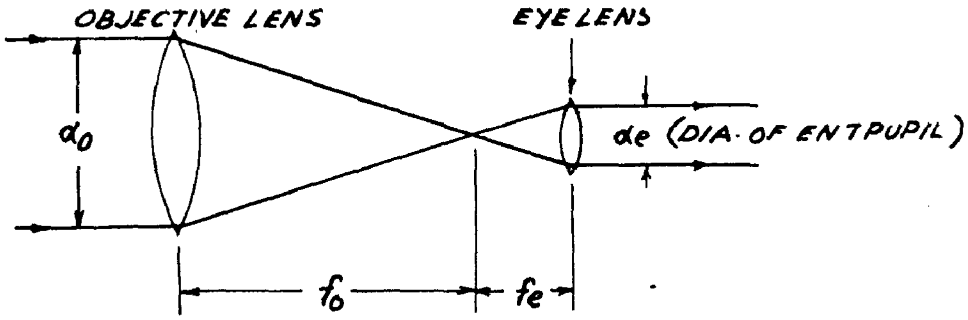


FIG. 6.3 GENERLIZED TELESCOPE

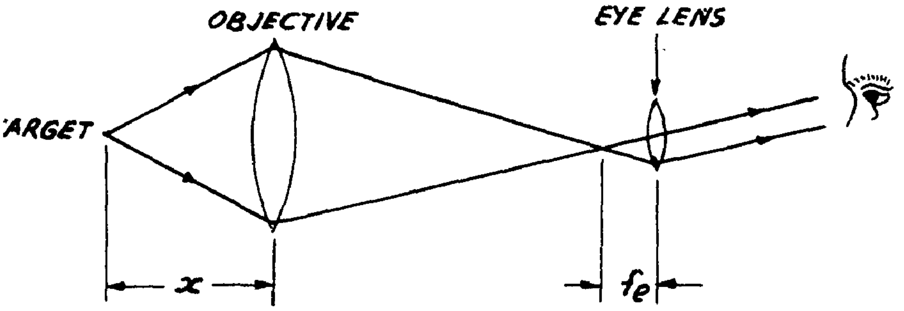
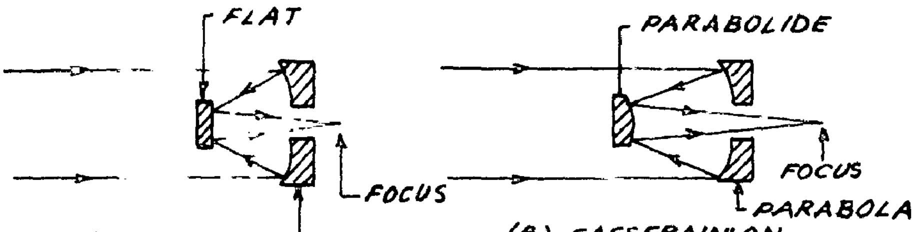
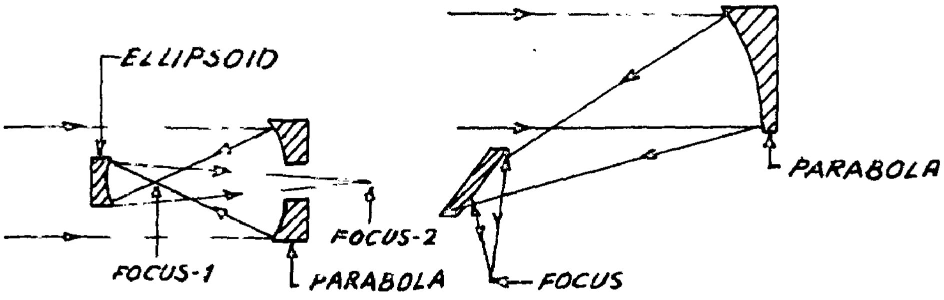


FIG. 6.4 GENERALIZED MICROSCOPE

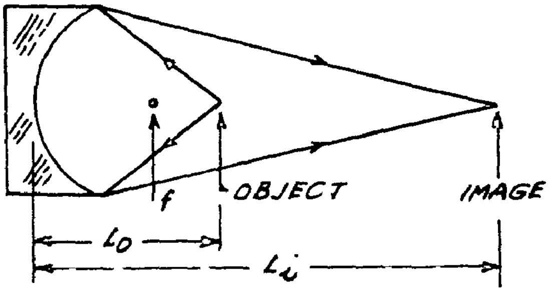


(A) FOLDED (B) CASSERAINIAN

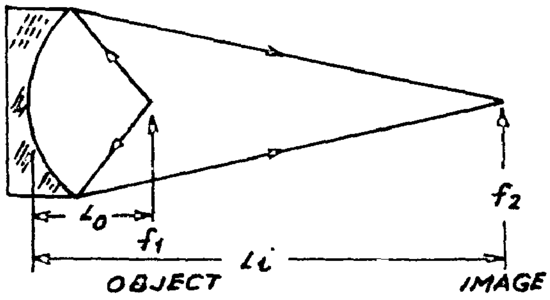


(C) GREGORIAN (D) NEWTONIAN

FIG. 6.5 TYPICAL REFLECTING TELESCOPE OBJECTIVES



(A) PARABOLOID



(B) ELLIPSOID

$$\frac{L_i}{L_o} = \text{LINEAR MAGNIFICATION} = \frac{\text{IMAGE DISTANCE}}{\text{OBJECT DISTANCE}}$$

FIG. 6.6 TYPICAL REFLECTING TELESCOPE OBJECTIVES area to the detector area.

Infrared systems can be categorized into telescopes and microscopes, schematically represented (refractive type) in figures 6.3 and 6.4 for each case it is seen that a generalized "objective" forms an image of the source which is then viewed by some collecting element - an element which transfers radiant energy to the infrared detector. This collecting element, in evegy case, is actually - a collimating element which has the objective focused source at its focal point. The goal of optical design is to fill the detector with collimated radiation which has been increased in angular density by the objective[1,2,4,5].

Typical reflecting telescope 'objectives' are shown in Fig. 6.5. These systems are also known as catoptric systems. For perfect imagery, all utilize a primary element which is a parabola, while the parabola suffers from astigmatism off axis, for collimated radiation it forms the theoretically perfect image. No other simple mathematically surface has a single focal point for all rays, which are parallel to the axis. Examination of the previous system considerations shows that overall system performance depends upon focal length. Thus the variations of Fig. 6.5 demonstrate techniques for modifying focal length, while maintaining element diameters constant for practical package designs. The Fig. 6.5(D) i.e.

Newtonian utilizes a simple flat mirror to devote the focussed rays. Several flats could be used to achieve folding such as Fig. 6.5(A).

The Gregorian, long focal lengths can be achieved with theoretically perfect performance for axial rays by utilizing a folding ellipsoid. The ellispsoid, a surface with two focal points, is suated so that one focal point coincides with the focal point of the primary parabola. A modification of this technique is that of the cassegrain, which utilizes a hyperboloid instead of an ellispoid. Theoretically perfect performance is achieved for axial rays[1,2,3,4].

Fig. 6.6 illustrates typical reflecting microscope designs. In as much as linear magnification, is the ratio of image to object distance, surfaces which allow ready attainment of such real distances while permitting theoretically perfect performance, must be used. In the first example a parabolide is used with the object just outside the focus. Unfortunately, astigmatism results when the parabola is used because of the incident angles. However, the astigmatic aberration can be minimized by utilising slow optical systems. The problem because of astigmatism is overcome by utilizing an ellipsoid with source and image at conjugate foci. Again it a mathematical surface which

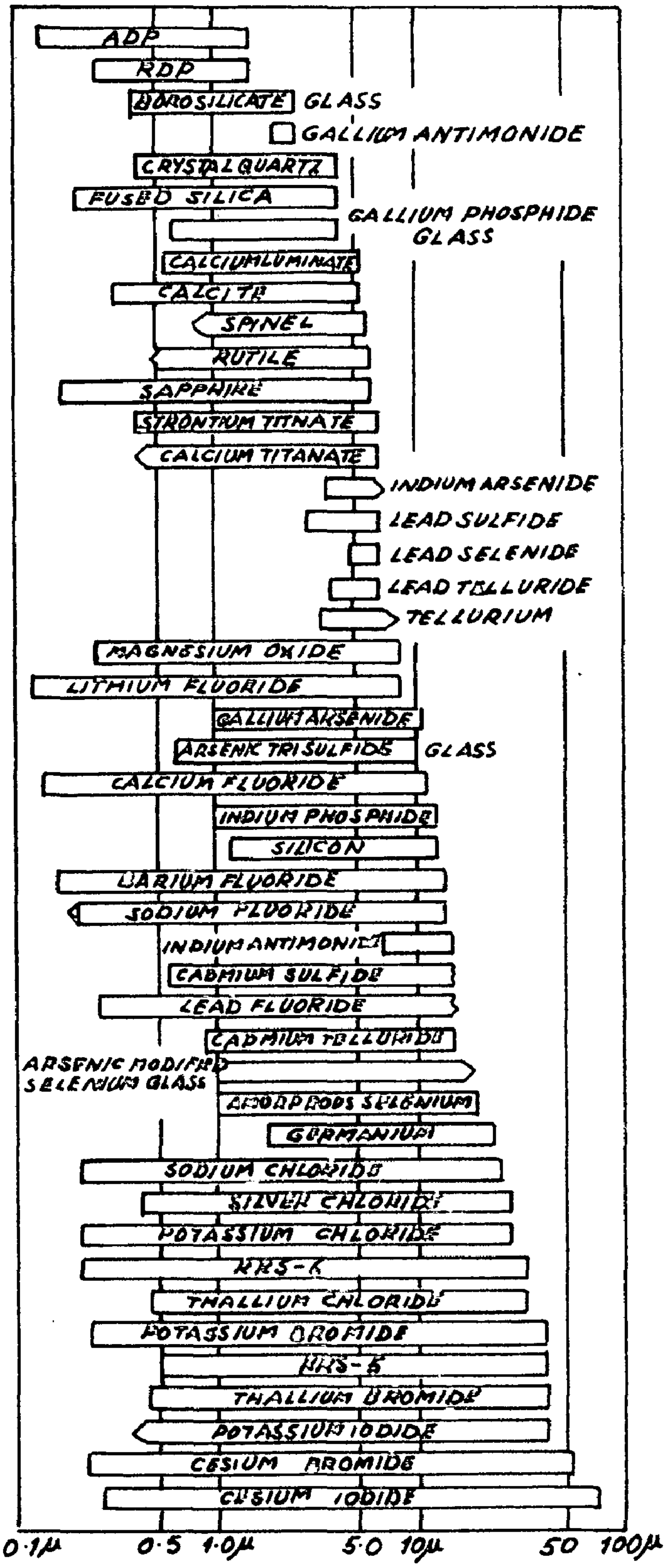


FIG. 6·7 MATERIAL FOR LENS

inherently possesses desired optical properties complished by a collimator of appropriate design, ~~or~~ the detector can be placed at ~~the~~ its focus directly.

Reflecting demands are preferred by virtue of their achromatic properties and their relative ease of fabrication. Reasonable image quality - if not theoretically perfect - can be achieved with minimal design effort. Advantages and disadvantages of optical system made of reflective and of refractive elements are summarized in table - 2. (Page 95).

Refractive systems can be used for narrow spectral bands, or when chromatic aberration can be disregarded and transmission losses can be afforded. Many materials having good transmission to infrared radiation are available to the manufacture of lenses (Fig. 6.7). Among the most widely used are KRS-5, germanium, silicon, sapphire, barium flouride, and arsenic trisulphide.

In case of refractive systems it is interesting to note that the distance of the target does not affect the detector reading, as long as the field of view is contained within the limits of target[1].

S. No.	Image degradation	Optical system.	
		Surface Reflective	REFRACTIVE
1.	Chromatic aberration	None	Unavoidable. Requires compensation.
2.	~~Chromatic aberration~~ Transmission Losses	None	Wave length - dependent. Thickness - dependent. Losses as high as 50% are not uncommon for thickness of just a few millimeter.
3.	Reflection losses	2 to 5% coating helps to reduce these losses	20 to 30% for two surface coating helps to reduce these losses.
4.	Obscuration	Upto 10% due to presence of holes for the passage of the optical field.	None
5.	Coma	Present. Can be completely compensated in special systems	Present. Can be in part compensated.
6.	Spherical aberration.	Present Can be completely eliminated.	Present. Can be in part compensated.

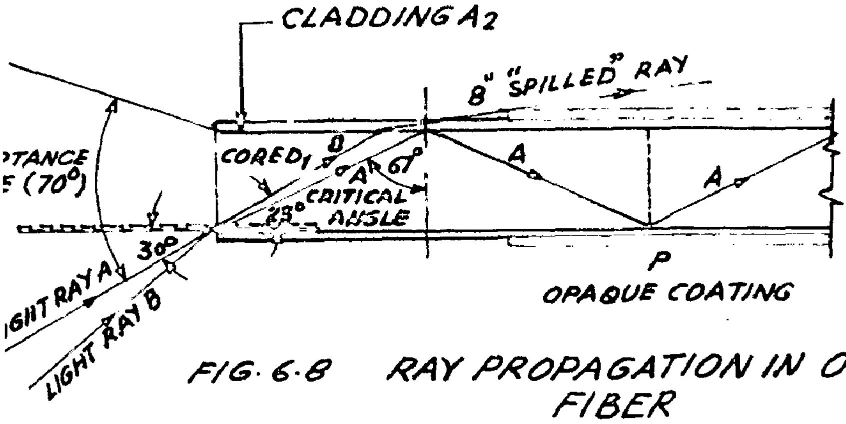


FIG. 6.8 RAY PROPAGATION IN OPTICAL FIBER

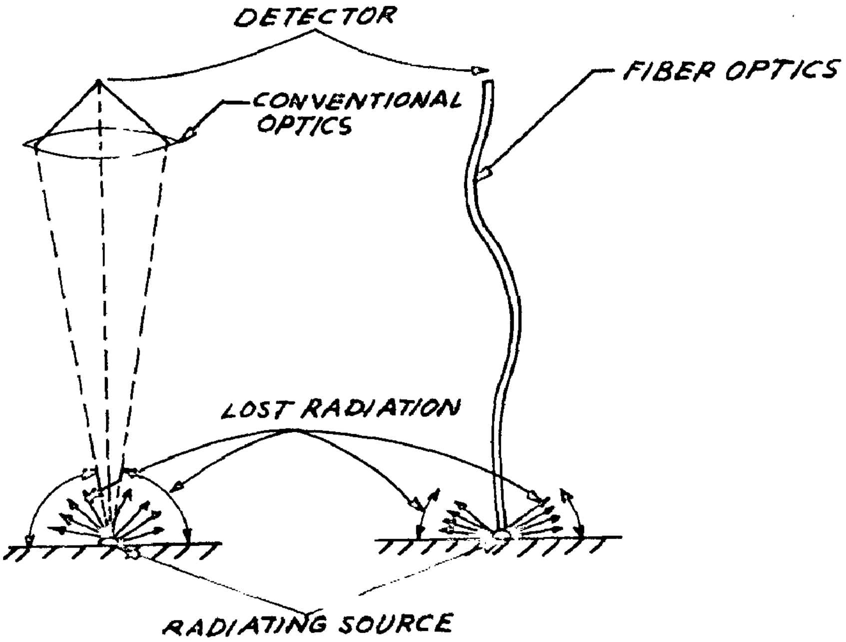


FIG. 6.9. CAPTURE OF RADIANT ENERGY TELESCOPE FIBER OPTICS

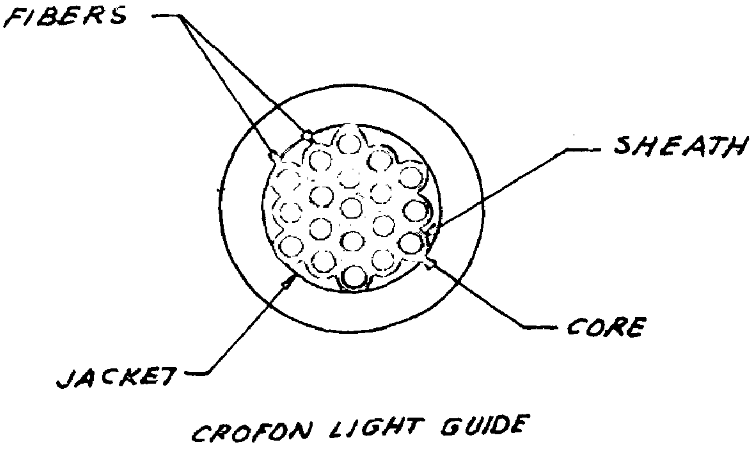


FIG. 6.10 END VIEW OF FIBER BUNDLE

All the optical systems of the type described so far have limitation of physical nature, due to their material size, weight, alignment, optical finish of the surfaces, and such that they all must comply with the requirement that the infrared detector have a direct, unimpeded view of the target - no opaque obstacles in between, no surrounding envelopes, no hiding around corners. Unless the detector can view the object, it cannot measure its radiation, light, and the term includes infrared radiation, travels only in a straight line, and the detector can not look around corners or through solid obstacles. This problem can be overcome by using optical fibres.

6.2.2 OPTICAL FIBERS[1,13, 14,15,16] : Optical fibers are transparent linear elements inside which light propagates by total internal reflections. Fig. 6.8 shows the physical principle on which the fiber operation is based. Most of the fibers presently available are made of glass.

In Fig. 6.8 all light rays that, after entering the front surface, acquire an inclination smaller than critical angle are totally reflected inside the fiber, and keep travelling in this fashion until they reach the opposite and or are totally absorbed, whichever coming first for a fiber having critical angle 67°, Fig. 6.8 shows an acceptance angle of 70°, which means that all rays incident onto the fiber's front surface at 35° angle or less with its axis will be trapped inside the fiber by total internal reflection. On the other hand the rays entering the fiber with an inclination larger than 36° angle will leave the fiber at the first contact with its surface. This behaviour is commonly called "spilling".

The critical angle is a function of the ratio between the reflective indexes n_1 and n_2 of the glass of which fiber is made and of the medium surrounded it. Therefore, by changing n_1/n_2 ratio acceptance angle can be changed to get special performance characteristics.

To get the permanent n_1/n_2 ratio cladding is used. Cladding consists of coating the fiber with a layer of solid material (usually a different type of glass) having the desired index of refraction. Without this coating, two fibers touching each other would 'spill' light into each other, since they have the same refractive index. Common material combination is lead glass for the core and borosilicate glass for the cladding.

Fig. 6.8 shows a fiber which is enveloped by a layer of cladding ~~whose out-layer of material~~. This will prevent stray rays, coherent once have the same identical geometrical distributio of the fibers at the two ends. Therefore the radiation distortion picked up at the front end is exactly duplicated. at the output, with only degradation resulting from (a) the transmission losses and (b) the resolution allowed by the size of the individual fibers and the spacing in between.

The incoherent fiber bundles, instead, have a random distribution of the fiber at the two ends, and no imag is transferred from one end to the other, Only light is available at the output is quantity proportional to the total light input, minus the transmission losses.

In the transmission of images through coherrent fiber bundles, the capability of controlling the acceptance angle can be used to enhance resolution. It is already seen how by reducing the difference between the refractive indexes of the core and of the cladding it is proportionally reduce the acceptance angle at the fiber front end. In this way, every fiber see only what is in front of it, ~~which~~ with consequent finer resolution capability.

6.2.3 <u>Filters</u>[3,5] : Many infrared systems require selection of certain wave lengths, spectral filtering techniques can be used to observe specific wavelength regions or reduce background radiation. The most common such as those surpassing the critical angle (for example, where the fiber makes a curve) from spilling out, the outer coat will merely absorb them. Also, at a curve, radiation cannot get into the fiber from outside, and every change of interference with the rays travelling along the fiber is eliminated. The ratio of the band radius to the fiber diameter tells how tight a curve can a fiber make without spilling away most of the trapped radiation and this should be above 40. The total number of internal reflections are dependent on the average inclination of rays entering its front end. And this inclination is a function of the n_1/n_2 ratio. The smaller will be angle made by the entering rays with the fiber's axis, lower will be the number of internal reflections per unit length. Core size is also directed by total number of internal reflections. For conventional acceptance angle around 30° from the fiber axis, about 500 reflections per inch of length will be the average for thick fibers (250 μ in diameter). For thin glass fibers (about 20 μ in diameter) as high as 4000 reflections per inch is probably a realistic average.

Besides their capability to carry light around corners and through an air tight walls, optical fibers can provide quite large acceptance angles for incident radiation;

thereby making them comparable to 'fast' conventional optical systems i.e. system having large numerical aperture (NA).

$$NA = n_1^2 - n_2^2$$

n_1 refractive index of fiber

n_2 refractive index of coating

This NA is the numerical aperture number of an optical system, and it is a measure of its ability to accept incident light rays. This, of course, is the function of the limit angle of acceptance. The large is NA, the larger the cone of radiation entering the optical fibers, transmitted along its length and out of its output end.

It is illustrated graphically in Fig. 6.9 that optical fibers can capture appreciably higher radiation power. For material selection and their transmission spectrum please see reference 1.

<u>Fiber Bundles</u>[14,15] : A fiber bundle is an assembly of a number of fibers, anywhere from just a few to several hundreds, lined inside a containing pipe that can be either rigid or flexible. The ends of the flexible bundles are made rigid to hold firmly in plate the terminations of all the fibers. Fig. 6.10 shows the geometrical representation of an end surface of a fiber bundles which are devided into two groups : coherent & incoherent. The

coherent once have the same identical geometrical distributio of the fibers at the two ends. Therefore the radiation distortion picked up at the front end is exactly duplicated. at the output, with only degradation resulting from (a) the transmission losses and (b) the resolution allowed by the size of the individual fibers and the spacing in between.

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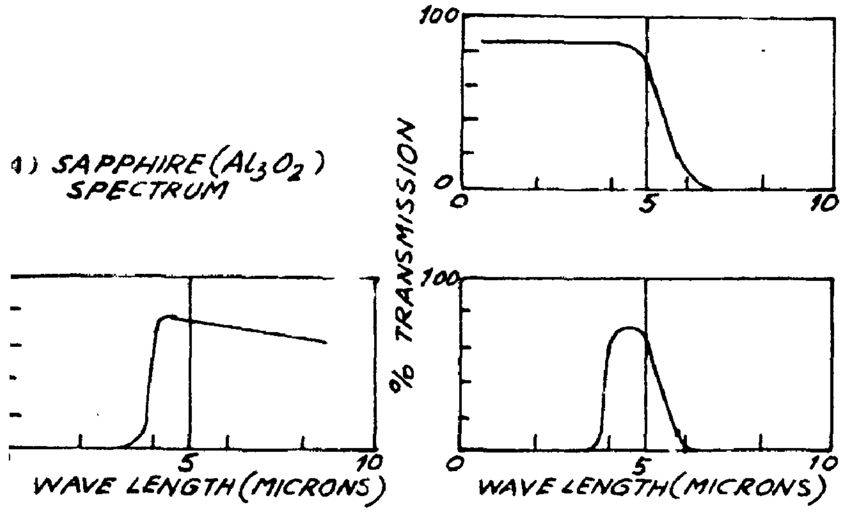
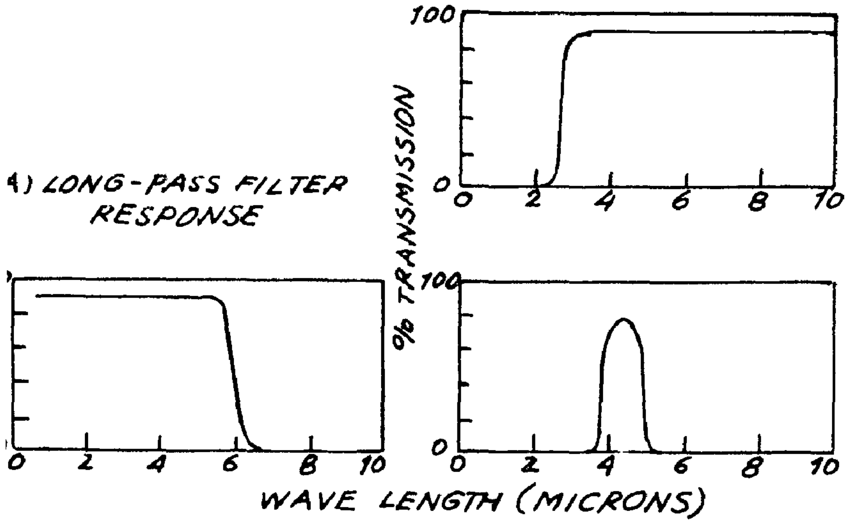


A) SAPPHIRE (Al_3O_2) SPECTRUM

DIUM ARSENIDE SPECTRUM

(C) COMBINED SPECTRA OF (A) & (B)

FIG. 6.11 TRANSMISSION SPECTRUM OF COMBINED MATERIALS



A) LONG-PASS FILTER RESPONSE

SHORT-PASS FILTER RESPONSE

(C) BAND-PASS FILTER RESPONSE

FIG. 6.12 RESPONSES OF SPECTRAL FILTERS

types of spectral filtess are the absortion filters and the interference filter. In some précise instruments (such as spectro-scopes) reflective and refractive dispursion type filters are used.

The absorption filter combines the natural transmission characteristics of two or more optical materials. Fig. 6.11 shows the transmission spectrum obtained by combining sapphire and indium arsenide.

The interference filter is made of multiple layers of dielectric materials of alternately high and low ~~are~~ refractive indices. Accurate control of the substrate material, absorption characteristics of the coatings, and number of layers can provide filters for almost any desired spectral response. Spectral filters may be long pass, short pass, or band-pass as shown in Fig. 6.12. Narrow band pass filters are sometimes called spike filters.

Reflective and refractive dispurtion type filters are discussed in chpater 7 in the section of spectfoscopes.

6.3 OPTICAL MODULATOR AND SCANNING :

An optical modulator is used provide directional information for tracking and to suppress unwanted signal from backgrounds. The optical modulator can assume many forms, but basically each can be described as a pattern~~s~~ of alternately clear and opaque area carried on as suitably transparent substrate. It is common practice to call the optical modulator ~~as a~~ the chopper^2.

6.3.1 OPTICAL MODULATOR: The infrared detector in a radiometer normally looks at a target that has a constant or slow-changing temperature. This results in a very-slow level d.c. signal from the detector which is difficult to amplify. Detector outputs of a few microvolts (10^{-6} volts) are common.

A chopper blade may be used to modulate the incoming radiation at a fixed frequency. This produces an a.c. signal which is easier to amplify. The maximum frequency that should be used is determined by the time constant of the detector and may be expressed as $f_{max} = \frac{1}{2\pi t}$

where f_{max} = maximum operating frequency in Hz
t = time constant of the detector, which is to be used, in seconds.

The chopper disc is normally placed between the collecting optics and the detector. The chopper disc can be at a minimum size by placing it as close to the detector as possible.

A variable or synchronous motor is generally used to rotate the chopper blade. The number of blades (or openings) on the disc and the speed of the motor determines the chopping (or modulation) frequency. Mathematically,

$$f_{ch} = \frac{\text{r.p.m. x No}}{60}$$

where f_{ch} = modulation frequency in hz
R.P.M. = revolutions per minute of motor
No = Number of openings in chopper disc.

The selection of the best chopping frequency, which allows the highest sensitivity of the system, is done by detectors characteristics. For thermistor bolometers of current design, the chopping frequency can be as low as 10 Hz or as high as 100 Hz. For photo detectors, the frequency is at least one order of magnitude higher, due to their much faster time response.

For high chopping frequencies, tuning forks have lately been replacing the driving motor-slotted wheel assemblies. The chopping action is performed by appropriately shaped vanes attached to the end of the fork's times, whose excursion can be 2 cm. An electronic oscillator drives the fork at its resonance frequency, which can be any where between 30 and 25,000 Hz.

The advantages of tunning forks are small size, light weight, great accuracy, long term stability, very low power drain, and negligible heat generation.

6.3.2 SCANNING SYSTEM : When discrete measurement ~~is~~ of radiation emitted by different areas of a two dimensional target ~~must~~ is to be made, some way of scanning the target must be implemented. This can be achieved in one of the following ways[1].

1. Linear raster scan similar to the TV picture system.
2. Spiral scan similar to industrial TV imaging system
3. Point to point scan following a pre determined pattern that can be any configuration.

The scanning can be implemented by[25] :

1. Moving the detector
2. Moving the target
3. Moving the optical field
4. A combination of the systems, stated above.

The first one can be used only for slow speed operation and has the drawback of subjecting the detector to vibration that can increase the noise content of the output signal.

The second one can only be implemented for only small targets : here too, the scanning speed is limited.

The third one is usually achieved with the use

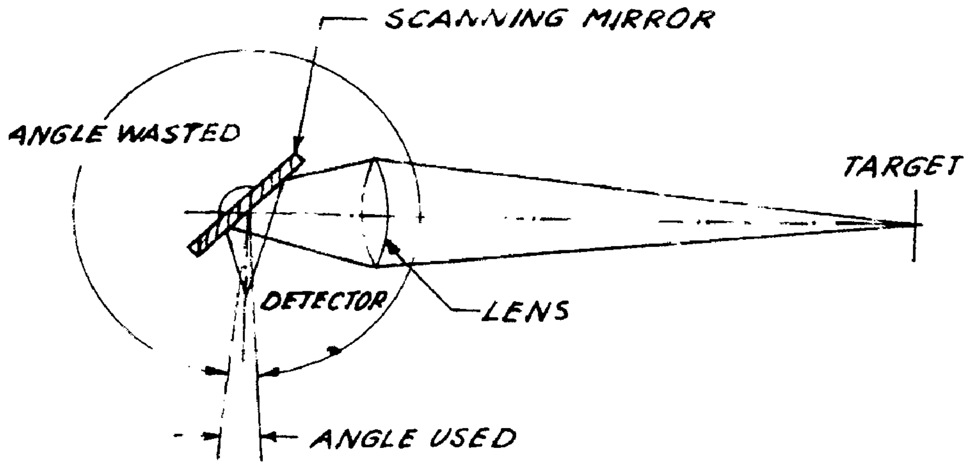


FIG. 6.13 ROTATING SCANNING MIRROR

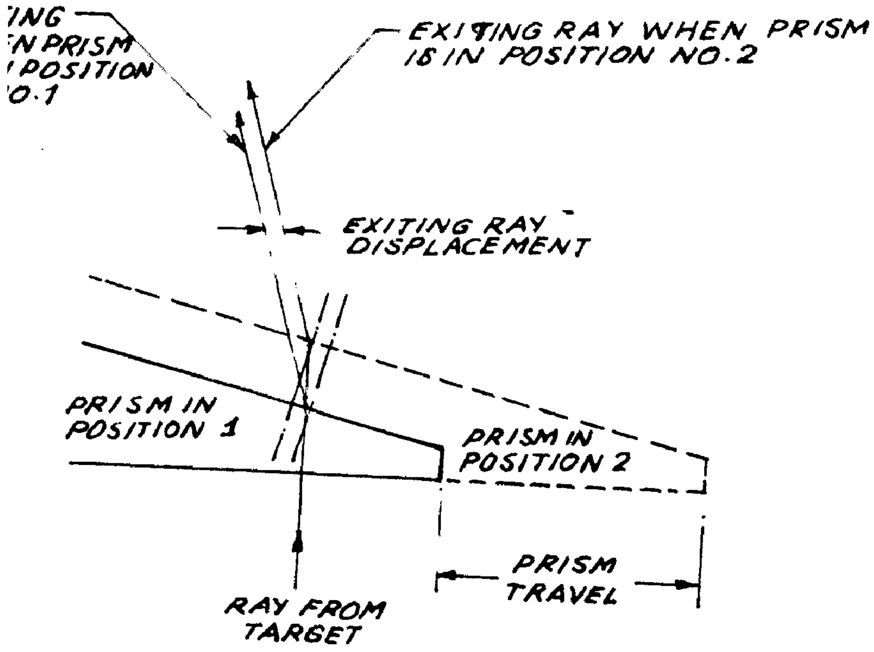


FIG. 6.14 RAY DISPLACEMENT THROUGH PRISM MOVEMENT

of oscillating or rotating mirrors that are located along the axis of the optical field. High speed can best be attained with rotating mirrors, although their efficiency is low, since during most of the rotation cycle the mirror reflects into the detector the surrounding back grounds, as shown in Fig. 6.13.

For linear, TV-like rasters, one single mirror, rotating and tilting at the same time, has been used with satisfactory results.

(b) The optical fields can also be displayed by moving transparent prisms or "wedges as shown in fig. 6.13 if the chromatic aberration, the reflection, and the variable transmission losses can be either tolerated or compensated for. Fig. 6.14 shows a wedge system capable of scanning a surface in the x and y direction: If the speed ratio of the two ~~walls~~ wheels can be varied, the system will have capability of varying the number of lines per frame. Prisms can be translated, as in the illustrations or rotated in a full circle or in oscillating fashion. The last two modes are also typical of mirrors: the full rotation has the drawback of low efficiency, as already seen, since it consists of accelerating, linear, and decelerating motions, seperated by two riversals of directions. Since only the linear position can perform scanning at even rate, acceleration,

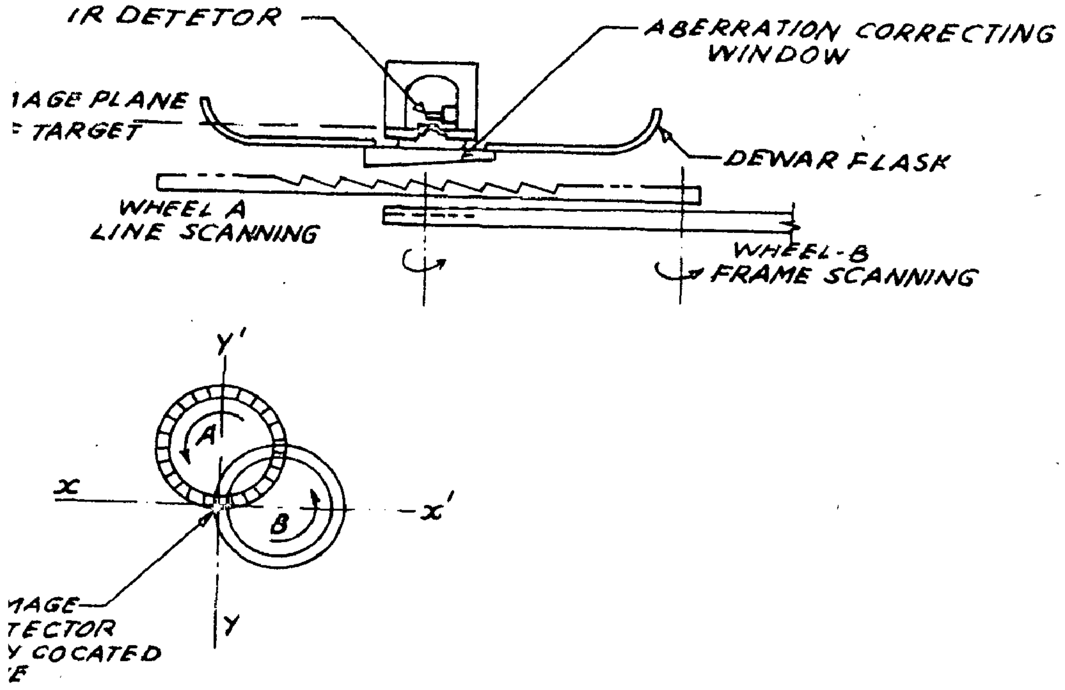


FIG. 6.15 PRISMATIC SCAN SYSTEM

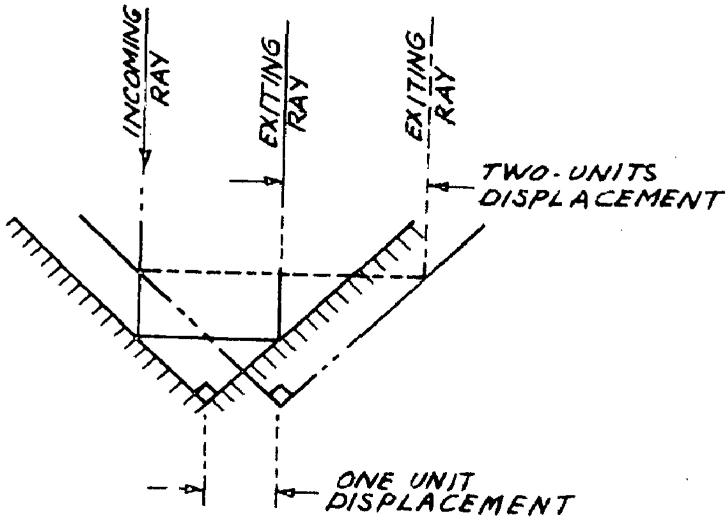


FIG. 6.16 CONVENTIONAL CORNER REFLECTOR

deceleration, stop, and return must be blanked out, thus greatly reducing the efficiency of the oscillating mode.

CORNER REFLECTOR SYSTEM:

Using reflective system, the scanning motion having linear motion and almost no losses can be achieved. This system is known as 'corner reflector'. In its conventional configuration, this system is composed of two flat mirrors rigidly tied together at 90° angle. It can be seen from Fig. 6.15 that horizontal motion of this pair of mirrors by one unit in length produces a two unit displacement of the outgoing ray, without any changes in optical path length (i.e. without shift of the focal plane). Such an optical arrangement could be used in a scanning system, but of course, in this configuration, it would have all the efficiency losses typical of the alternating motion. However, all these losses can be eliminated with the solution shown in figure 6.16, where the corner reflector is formed by the shaded area of two helicoidal surfaces. The pitch of these helics equals the displacement that the mirrors of Fig.6.16 must travel to a complete the scanning motion. The two helics are rotating at uniform speed and in perfect synchromism and are pushed in such a way that two 'steps'

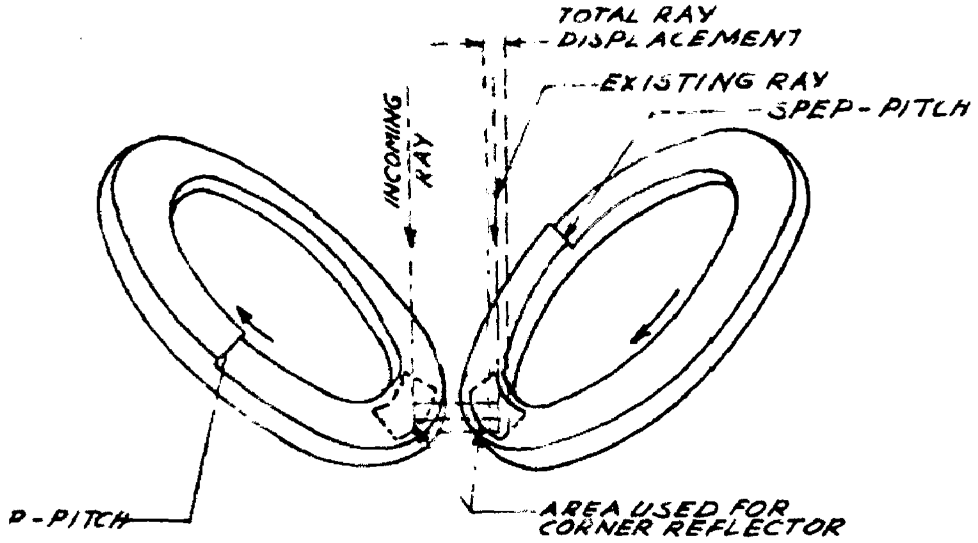


FIG 6.17 MODIFIED CORNER REFLECTOR

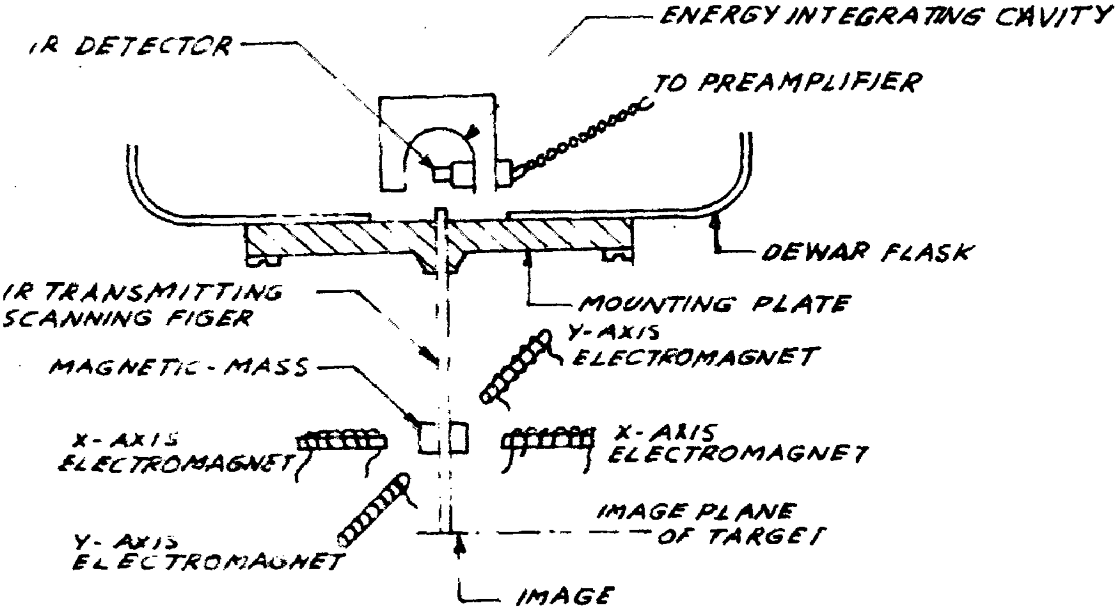


FIG 6.18 INFRARED TRANSMITTING FIBER SCAN SYSTEM

face each other at every turn.

If one observe the displacement of the reflecting surfaces in the plane passing through the axis of rotation of both helics, one notice that for every turn (starting from the position where the two steps are facing each other) the two reflecting surfaces move in the X direction at uniform speed and at the end of a 360° revolution of the helics they fly back in no time to the starting position.

This solution achieves a perfect saw tooth displacement of the incoming optical ray, with linear speed and zero return time. If the incoming optical field is composed of many rays instead of single one, the time lost for the return is equal to that ~~part~~ fraction that it takes for the step in the helical surface to cross the whole optical field.

The amount of distortion can be largely compensated by locating the two helics in such a way that the outside rim of one faces the inside rim of the other, and vice versa. Extensive calculations of the residual amount of distortion left in the system under this configuration have been made and they show that this quantity is controlled by the ratio between the pitch of the helics, the diameter of the wheels and the area intercepted by the optical beam[1].

THE SCANNING OPTICAL FIBER :

This system has got an advantage that it can be used for very small targets. This composed of a single optical fiber (or fiber bundle depending upon the size of the target), made of infrared transparent glass. The front end of this fiber, a light guide, scans the target, or, better yet, the image of the target in its focal plane. The infrared energy entering the front end travels through the length of the fiber and exits at the opposite end towards the detector. Due to the possibility of choosing any convenient size for the target image, the area resolution that can be achieved can vary within very wide limits.

Figure 6.18 describes the fiber scan system. In the illustration, the fiber motion is achieved by means of two electromagnetic fields at 90° to each other, acting on a magnetic mass located near the tip of the fiber.

COMPUTER CONTROLLED SCANNER :

Perhaps the most exacting requirement for a scanning system designer to yield perfectly repeatable infrared signatures is the constant scan speed. Should this requirement not be met, the raster would be composed of lines of varying length, spaced at varying intervals from each other, and the location of the points of the target would correspondingly change in any type of output display. For imaging devices, this would result in a loss of detail. Much more serious instead is the condition for those systems where the analog signal from the detector is turned into digital information. In these systems the data are taken at preaddressed points, called 'window', located along the scan line in correspondence of those elements of the target that are of interest. THis approach greatly simplifies the signal processing by drastically reducing the number of points to be mounted. In the case of electronic printed board assemblies, for instance the window's will be located in correspondence of the center of every component part of the assembly. In this way, only the information about these component parts is processed, while all nonessential data related to the mounting board, wires, and such are ignored. Of course,~~its~~ to obtain repeatable results with this approach, it is necessary to assure perfect coincidence between the point to be monitored and the corresponding window. Whenever this was not assured, serious difficulties were encountered due to the fact that the speed of scanning elements was not perfectly constant.

The problem was solved in the inspect system where the computer that opens the 'window' also controls the scanning elements by means of a shaft encoder mounted on the mirror's rotating axis. In this way, perfect coincidence between points to be monitored and windows is assured and signature repeatability is consistent.

6.4 COOLING DEVICES[2,4,17] :

Many of the applications require detectors sensitivity i the spectral region comprised between 5 and 15 μ.

Quantum detectors able to meet this requirement must be cooled to temperatures approaching absolute zero. This is due to the fact that the forbidden energy gap must be small enough to allow the impinging low-energy photons to cause electron transitions from the valence to the carrier band. Therefore, the overall thermal energy content of the detector must be brought low enough to avoid self generation of these transition because of the detector's own temperature. Otherwise, self saturation occurs, and sensitivity to low-energy radiation impinging from outside would be lost.

For instance, the Ge:Au detector needs cooling to 77^{o} K for a D*' peak at 5 μ while Ge:Cu has to be cooled to 40^{o} K for a D* peak at 22 μ.

To read these low temperatures, extensive use is made of various liquified gases, utilized at their boiling point. The most used among these gases are nitrogen, neon, hydrogen and helium, although several others cover the same thermal area, as shown in table below :

Boiling points of some of the gases
used in cryogenic systems :

Table-3

GAS	Temperature in ^{0}K
Helium	4.4
Hydrogen	20.5
Neon	27.1
Xenon	65.9
Nitrogen	77.2
Argon	87.3
Oxygen	90.0
Krypton	120.7

To cool the detectors with liquid gases, Dewar flasks are used. These are similar to thermos bottles with the difference that they are often made of metal, and they can be of a two-stage design, that is one thermos bottle is contained inside a large thermos bottle. The two-step thermal gradient thus obtained when the inside bottle is filled with a colder liquid while the enveloping bottle holds a less cold liquid ensures better insulation of the inner area and reduces its thermal losses. Longer operation is thus ensured since the gas eveporation takes place at a slow rate. A double Dewar flask that allows an

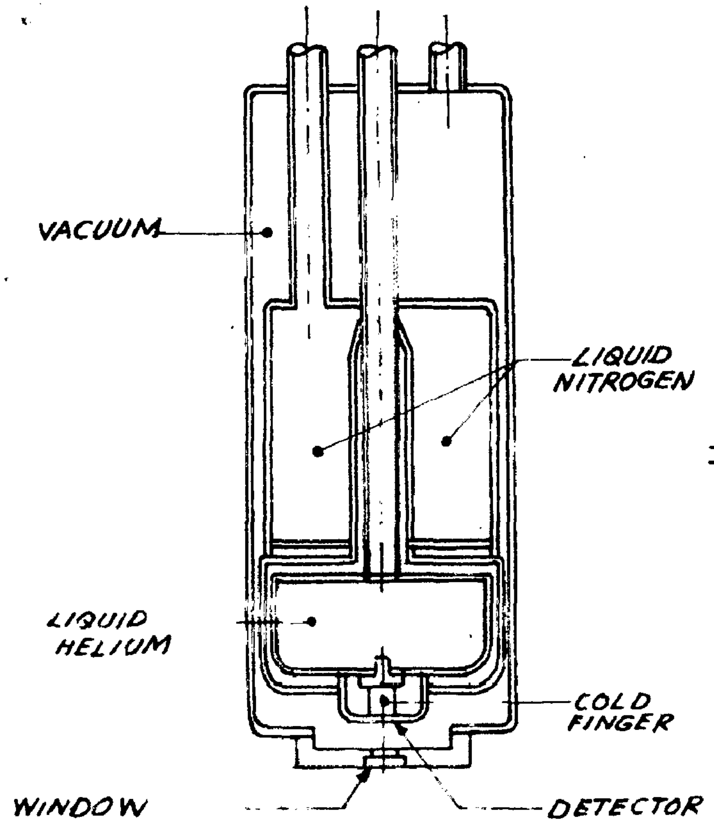
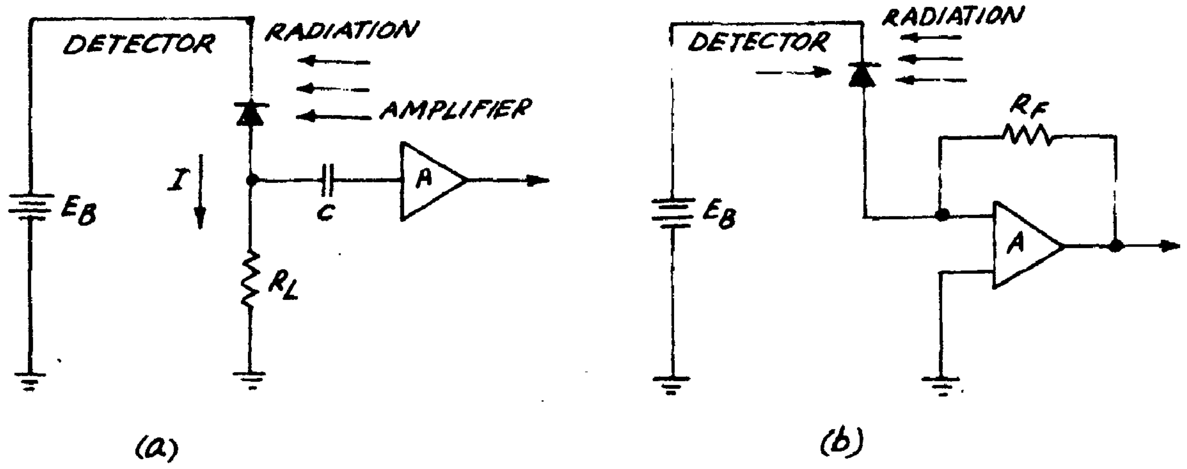


FIG. 6.19 DOUBLE DEWAR FLASKS



(a) VOLTAGE MODE
(b) CURRENT MODE

FIG. 6.20 ELECTRICAL CONFIGURATIONS FOR PHOTO DIODE DETECTOR uninterrupted working period of about 8 hours when the inside container is filled with liquid helium while the outside chamber holds liquid nitrogen. (Figure 6.19). The infrared detector is mounted on the so called 'cold finger' protruding from the inner container, which is practically at liquid Helium temperature, and operates in a vacuum. The impinging radiation enters through a hermetically sealed window located just in front of the detector.

A variation of the double - Dewar concept is the gas shield unit. In this case only one liquid gas is used, and the gas developing from its boiling condition is made to circulate through the enveloping chamber of the double Dewar, before being discharged to the outside atmosphere. Thermal insulation of the liquid contained in the inner chamber is thus achieved by its own gas, eliminating the complications connected with the use of two different liquified gases.

Another method of cooling detectors to temperatures as low as 30° K is to use one of the many cryogenic refrigerators designed for infrared cooling. There are several closed-cycle coolers using Jule-Thomson expansion values, or expansion engines, to reach low temperatures; but one recent development that has done much to make detector refrigeration more practical is the availability of coolers based on the stirling cycle.

6.5 SIGNAL PROCESSOR :

The raw signal yielded by the detector must be amplified and appropriately processed for adequate display of the desired information. To this effect, the following elements must be considered[1,2].

1. "Electrical biasing of detectors.
2. Noise characteristics and filtering methods
3. Signal Band width
4. Amplifier characteristics

6.5.1 ELECTRICAL BIASING OF DETECTORS : For a detector there will a optimum biasing condition where that detector will give the maximum signal to noise ratio. In chapter 8, methods for obtaining optimum bias are discussed. Also same devices can be used in both models : current mode and voltage modes.

Fig. 6.20 shows the common connections for photoconductive type detectors. Fig. 6.20(a) shows the voltage mode type of operation. A D.C. bias supply is connected across the detector and load resistance R_1. The impedance of the detector is much higher than that of R_1. The signal in a.c. coupled off the load resistor and connected into and amplifying system. Radiation impinging on the detector changes its resistance and current is produced through R_1.

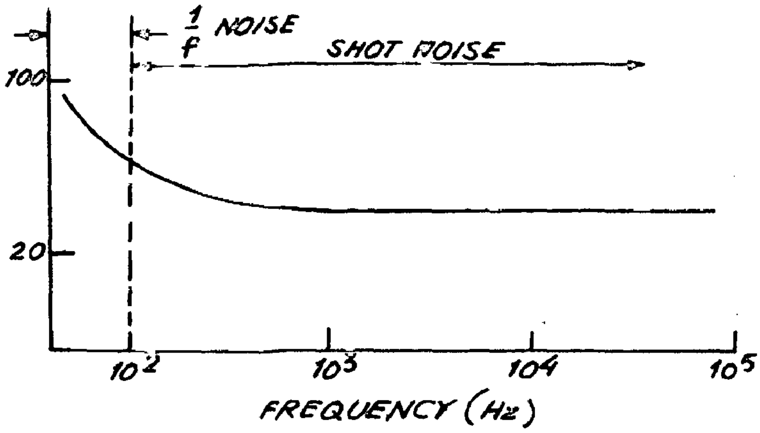


FIG. 6.21 TYPICAL DETECTOR NOISE SPECTRUM

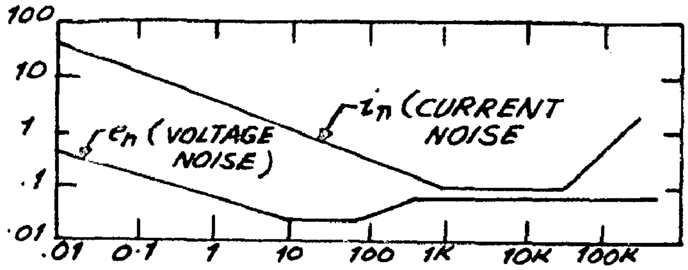
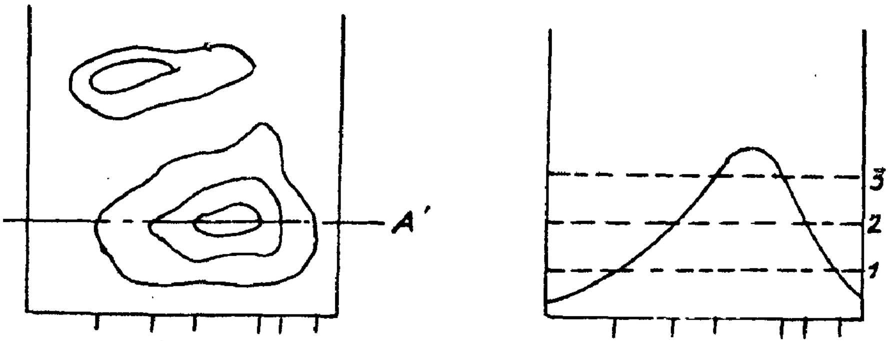


FIG. 6.22 AMPLIFIER NOISE



(a)

(b)

FIG. 6.23 CORRELATION BETWEEN ANALOG AND ISOTHERMAL DISPLAYS

(a) TYPICAL ISOTHERMAL MAP

(b) ANALOG SCAN TRACE ALONG LINE A-A'

The input impedance to the amplifying system must be much higher than R_1. The choice of R_1 is decided by considerations of desired frequency response, tolerable noise level and desired gain. Now its equivalent circuit is drawn to calculate frequency response and expected noise voltage.

Fig. 6.20(b) shows a current mode configuration. Signal current produced by impinging radiation is coupled directly to a transimpedance amplifier. THE input impedance is $Z_i = \frac{R_f}{A}$. The Z_i can typically be as low ~~as lest~~ as 10Ω At such a low impedance level the effective signal band width can be larger than in the voltage mode and noise levels at the amplifier input can be significantly lower. Also for some detectors the current mode produces better stability in the detector operating point and produces a signal much lower in harmonic content.

6.5.2 NOISE CONSIDERATION : The major noise contributers in the system are as follows[3,11].

1. Detector noise
2. Bias supply noise
3. Amplifier equivalent noise
4. Resister thermal noise

Detector noise is principally shot noise above 100 Hz, and below 100 Hz the 1/f noise (also called flicker noise) predominates (Fig. 6.21).

Bias supply noise is supply rectifier ripple and varia tion with line and load. Obviously, in low signal applications, the bias supply contribution to noise must be controlled consistent with an acceptable signal to noise ratio. To overcome the ripples problem d.c. batteries can be used. Amplifier noise is shown by typical curve in Fig. 6.22. The region from d.c. to 10 Hz for the voltage curve is the 'flicker region'. The region above 10 Hz is 'shot noise' dominated. The i_n curve in Fig. 6.22 is dominated by flicker noise upto about 800 Hz. This level selection after the flicker region is shot noise. The increasing region above 10 KHz is noise current due to the noise voltage divided by the capacitive reactance due to the amplifier input capacitance. A particular amplifier will have different noise characteristics from that shown in Fig. 6.22[1] and therefore the selection of a proper amplifier must be determined by the constraints of the problem at hand.

For white noise [shot noise and Johnson (thermal noise) are both white noise], the spectral density, e_n is constant. The r.m.s. white noise in a given band width, E_n, can be calculated as $e_n\sqrt{f_2 - f_1}$. Flicker noise can be calculated as $e_n = K\sqrt{e_n(\frac{f_2}{f_1})}$, where K is the value of e_n at 1 Hz.

Resistor noise contributions are generated in detector load resistors and in first stage amplifier feed back resistors.

All the above described noise sources must ~~not~~ be r.m.s. summed and used to determine effects on system performance. Typical design techniques to improve signal to noise ratios are as follows[2,4]:

1. Chop the infrared radiation at a fixed frequency and pass the signal through a narrow band filter centered at the chopping frequency.
2. Design a gated integrator that samples the during the gate time and integrates samples to enhance the signal and average out the noise.
3. Select a signal frequency that utilizes a low noise region of the detector and amplifier characteristics.

6.5.3 BAND WIDTH CONSIDERATIONS : The applications dictates the band width required. For instance, in a scanning application, the spatial resolution required coupled with the scanning speed will determine the upper limit of frequency response required. This limit is usually below 1 KHz for thermal detector since their response does not exceed 1 msec. For quantum detectors used in fast scanning systems, the high frequency response might exceed 100 K Hz. Low frequency cut off is usually determined by the repetition frequency of the signal. System band width should be kept as narrow as is feasible.

6.5.4 AMPLIFIER CHARACTERISTICS : In addition to low noise, amplifier systems must provide :

1. Gain
2. Linearity
3. Width dynamic range

Solid-state amplifiers using discrete and integrated circuits are available having a broad choice. Amplifier linearity can be assured by using high feed back factors in amplifier design to make gain characteristics independent of amplifier open loop nonlinearities.

To minimize stray signal pick up and cable loss the preamplifier must be located very close to the detector. When even impedance matching between detector and preamplifier is a problem, an emitter follower (or buffer stage of operational amplifier) unit can be used. The preamplifier drives a power or shaping amplifier that must provide the usual amplifier characteristics of large dynamic range, adequat band width, and the like. Its noise characteristics are, however, not as critical. It must also provide the interface match with the desired display medium and measures for attenuation in systems having very wide signal input variations.

6.6 DISPLAY AND RECORDING SYSTEMS :

6.6.1 DISPLAY SYSTEMS[1,2,4] : This is an area where a variety of techniques is applied. The major ones are as follows :

1. Oscilloscope trace display
2. TV picture display (black and white, or colour)
3. Photographic imaging (black and white or colour)
4. Digital conversion and print out display.
5. Digital conversion and generation of iso-thermal map.

First four methods mentioned above are in common use in electric instrumentation so they will not be discussed here.

Iso-thermal Map[1,2] : The concept here is the same as in geographical maps or weather map, only the quantity to be plotted is temperature instead of altitude or barometric pressure. The contour lines in this case are called 'iso-thermal' and they connect all the points having the same temperature.

An isothermal map can easily be displayed on the face of CRT, such as the one shown in Fig. 6.22(a) while the CRT trace of the scan line AA' is shown in Fig. 6.22(b). The analogy with the geographical map is complete, if only altitudes are replaced by different voltage levels.

It will suffice here to say that every one of these systems tries to solve the problem of displaying the electrical output of the detector with the approabh best suited for the evaluation of the thermal behaviour of the chosen target. In general, this involves the problem of representing on a two dimensional display a three-dimensional function that might even vary with time, hence the great variety of solutions, none of which is totally satisfactory.

6.6.2 RECORDING SYSTEMS : The most common recording devices used within infrared instrumentation are as follows :

1. Chart recorders (Pen recorders, visicorders, electrocorders).
2. Magnetic tape recorders
3. Photographic recorders
4. Facsi~~i~~mile recorders
5. Digital print out equipment
6. Punched tape recorders

Again here, the choice is dictated by the system's performance characteristics, chart recorders are used for point detectors or for slow scanning systems, while high scanning speed requires the use of magnetic tape recorders or special photographic systems. Punched tape facsimile and print out equipment all require preliminary conversion of the analog output into digital information.

7. INFRARED SYSTEMS AND THEIR APPLICATIONS :

7.1 INFRARED SYSTEMS : Infrared systems are classified as follows :

1. Search, track and range type systems
2. Radiometer (or radiometry)
3. Spectroscope (or spectroradiometry)
4. Thermal imaging
5. Reflected flux systems
6. Cooperative source systems.

It is assumed that the target radiates at least some of its flux in the spectral region of interest. Infrared equipment has the potential capability of detecting the presence of the source, determining its direction with respect to some reference, and determining its distance. Hence the first system is called 'search, track and range system'. Infrared equipment can also measure the flux from the target in a broad spectral interval, an operation designnated as 'radiometry' in the system classification, or it can measure the flux in a narrow spectral interval, which is called 'spectroradiometry'. If the target is an extended source, the infrared equipment can also be used to determine the geometrical or spatial distribution of the flux, which is called 'thermal imaging'.

If the target is poor radiator in the spectral region of interest, perhaps because of its low temperature or low emissivity, the infrared equipment can respond to the flux that the target reflects from an auxilary source of illumination. A photographic system, for instance, responds to the sunlight reflected from a scene. THe system responding to this scene is called 'reflected flux system. As a final alternative, one can place a source at the target, at the observer, or at both locations and arrange to have the infrared equipment sense such things as the motion or the modulation of one or more of the sources. Examples of such a mode of operation include tracking systems in which a beacon is placed on the object to be tracked, and communication systems. The function is designated as a cooperative source.

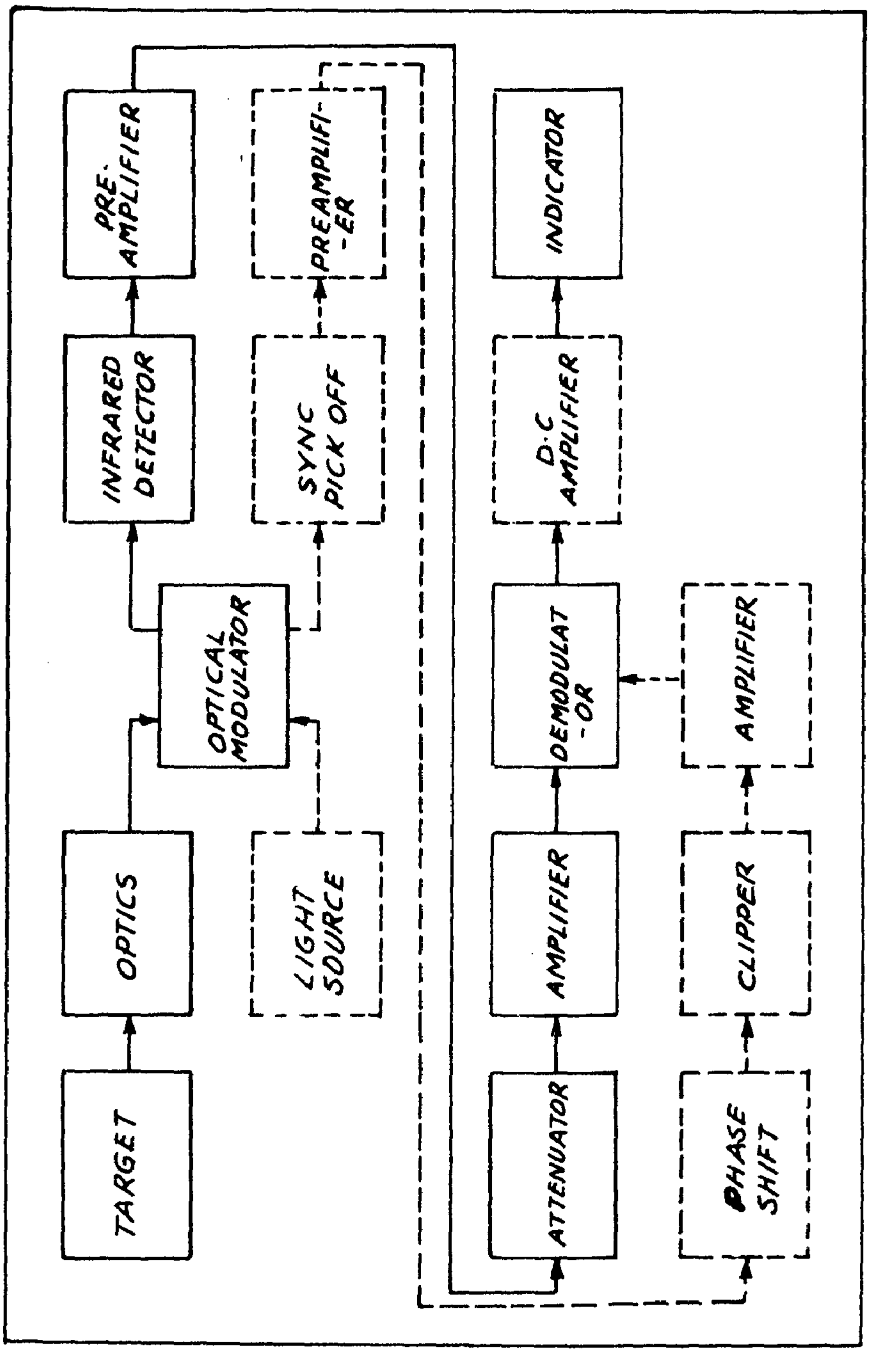
Generally speaking, all infrared equipment can be classified in two classes : SPECTROMETERS and RADIOMETERS. The spectrometers are capable of measuring the direct energy content of the radiation emitted by the target at every frequency of spectral band; the radiometers instead measure the total energy contént of the radiation emitted by the target within a predetermined spectral band.

7.1.1 <u>RADIOMETER</u> : Radiometers are those systems whose output can yield either absolute or relative measurement of the magnitude of the infrared radiation emitted by the area viewed by the detector. The output signal is usually an analog function, whose value can be precisely measured either directly or through translation into digital information.

Radiometers can be divided in various groups or classes, according to their principle of operation, the mode of viewing the target, and the optics type. Table 2 shows the major groupings.

Table 4 - Classification of infrared Radiometers[1]

Radiation detector	Field of view	Optics type	Description
Incoherent	Stationary	Telescope	Point detector
	-do-	Microscope	Infrared microscope
	-do-	Single optical fibr~~ous~~er	Point detector
	Line scan	Telescope	Line scanner
	Surface scan	-do-	Raster scanning radiometers.
	-do-	Microscope	Scanning microscope.
Two frequencies	Stationery wide field.	Telescope	Imaging device
	Stationery area	-do-	Two wave length radiometer.
	-do-	Fiber optical bundle	Small area detector.
Recombination	Stationary area	Single optical fiber.	Point detector



FIG·7·1 BLOCK DIAGRAM OF INFRARED RADIOMETER

The above classified radiometers can be equipped with cooled or uncooled detectors of various types and they all have a sophisticated optical system, either using conventional optical elements or fiber optics. The spatial resolution, that is the ability to resolve two adjascent elements emitting different levels of infrared radiation, varies between very large areas to a few microns.

The thermal resolution requirements are dictated by the smallest temperature gradient to be detected. Also, in view of the fact that radiometers measure infrared radiation and not temperature, therefore emissivity factors must be taken into account. Temperature resolution varies from a small fraction of 1° C (for targets around 300° K) to several degree centigrade for infrared monitors.

Lastly, the time response requirements are dictated by the speed of the thermal transients to be detected, which for semiconductors can be very fast. Further requirements are set, for scanning systems, by the scan speed, which in the fastest systems might reach 1600 lines / sec. The limiting factor, in the time response of systems using quantum detectors is to be found in the processing ~~d~~electronics.

Fig. 7.1 shows a simplified block diagram of a typical radiometer. The solid block in FIG. 7.1 indicate the components or circuits, required for a basic radiometer be added to increase the instrument's overall abilities.

(i) Infrared Point Detector : A point detector, sometimes called a 'staring' detector, is the simplest radiometric system. It is a small portable instrument, battery operated and provided with a built in 'light spot' finder that usually points out the area viewed by the detector. A single reflecting optical element, typically 5 cm. in diameter, is the collector, and a thermistor bolometer is used as the sensor, with ambient temperature compensation provided by a twin shielded element . It is battery powered, and its smallest spot size is 0.25 cm at 25 cm. distance (approximately). Emissivity correctly located on the side of the instrument. Scanning a number of elements can be carried out by sequentially pointing on them the light beam of the unit, and by recording the meter's indication for each of them. Typically, by this instrument accuracy of 2% of full scale reading can be obtained. A better accuracy can be achieved by improving the electronics, but then the instrument will not be that much portable.

(ii) Point detector with Mov~~e~~able target : In this system the detector is stationary, while the target, mounted on an X-Y table, is moved in the horizontal plane according to programme punched on a control tape, and designed to bring into the area viewed by the detector every element of interest, as a predetermined sequence.

This system has got following advantages over the system discussed previously[1,2,4] (i.e. infrared point detdctor) :

1. Fixed focus : for a particular planar target the focal distance is always the same, since every point is moved into the same viewing area.
2. No detector time wasted looking at back ground or at areas between components.
3. Visually identifiable target area : a spot of visible light is projected onto it during the operation.
4. Viewing the components can be programmed in any desired sequence : for instance, a most desirable scanning sequence is one where the radiation level steadily decreases (or increases) from the first of the last element . This distribution make it easy to detect defective, since the uniformity of the detector output pattern is broken.
5. Possibility of manual, or of fully automated operation.

~~The~~ Essentially, the system contains the following major subsystems[1,2] :

1. The Radiometer containing the infrared detector, optics, and signal amplifier.

2. The equipment track containing all output equipment, controls, and power supplies.
3. The scanning system containing the tape reader, positioning table and servo circuits.

There may be following four devices available at the output :

1. A logarithmic scale voltmeter calibrated above ambient.
2. An X-Y recorder which records temperature in a bar chart formed thus generating an infrared signature for each circuit.
3. A set of go, on-go lights indicating whether the temperature reading falls between the pre-programmed minimum and maximum for the particular point or components.

As an alternative, the output equipment can be modified by the addition of a digital pointer which replaces the X-Y recorder as the display medium.

(iii) Line-Scanner[3,4] : Instruments of this type move the detector field of view back and forth along a stationary line. Most of the timd they are used to monitor moving targets, such as rabbon of material (paper for example) moving along rollers. In some applications the

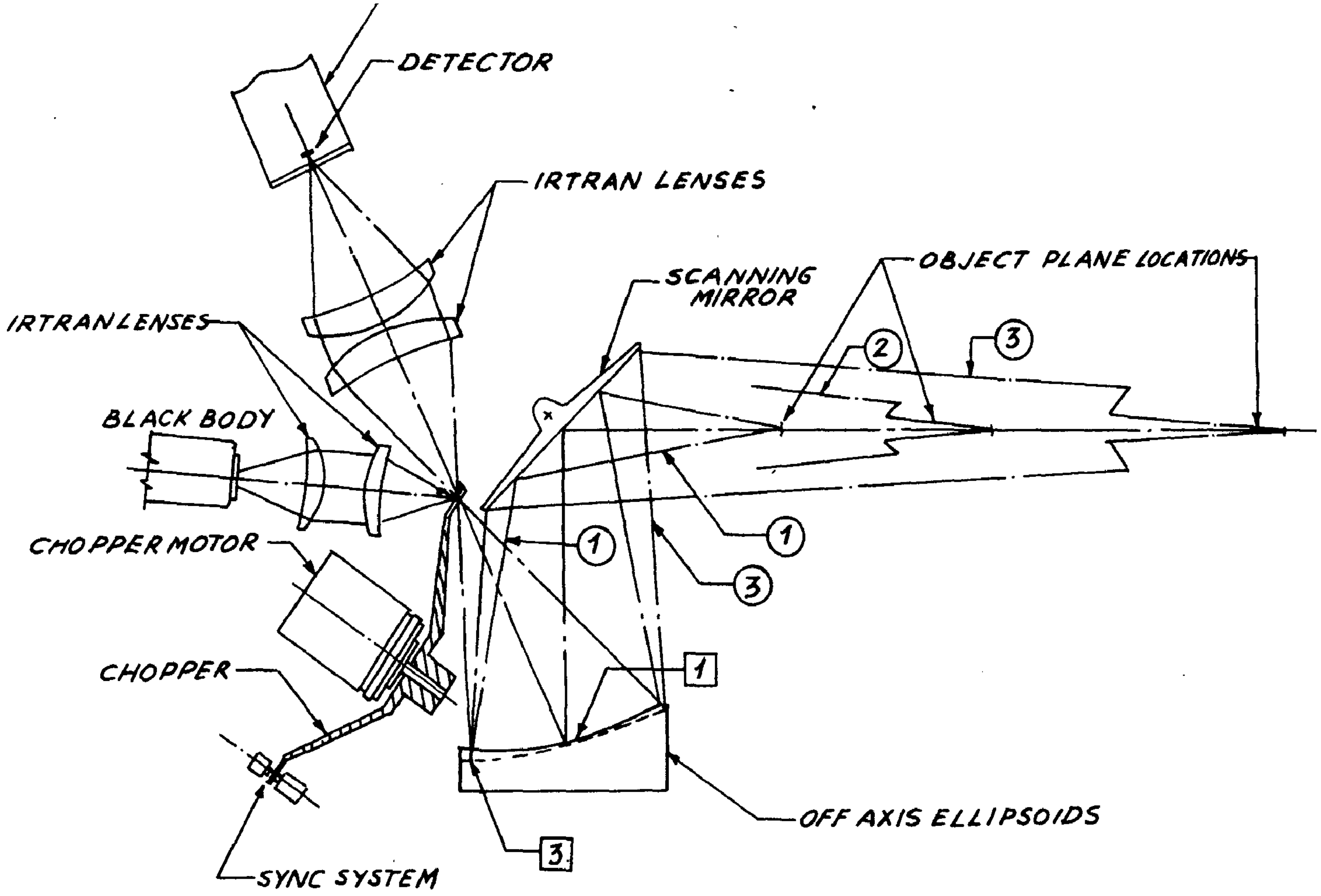


FIG. 7.2 OPTICS SCHEMATIC FOR LINE SCANNER

radiometer itself is moved either linearly or radially to allow converage of a two-dimensional target. These can be designed and developed for special purposes. Fig. 7.2 shows its optical schematic : the radiation from the target is collected by the off axis elliptical mirror after having been folded by the scanning plane mirror. This radiation is chopped by an element rotating at 4000 Hz at the primary focal point, from where it is transferred by a 1:1 relay lens system to the infrared detector. When the chopper is in such a position as to block the radiation from the sample, it reflects the radiation from the black body reference source. In this manner the detector continously compares the target's radiation with the reference.

The optics have three interchangable off-axis ellipsoidal mirror which allow focussing targets located at a distance of 6, 10 and 17 inch. The spot size is correspondingly 0.6, 1.0 and 1.7 mm in diameter, while the scan line length is 0.35, 0.59 and 1.0 inch, respectively (typically).

The scanning mirror rate is 100 lines/sec. obtained by oscillatory exclusion of 3° of the mirror at its resonant frequency : this makes it possible to use relatively low power for the motion (about 200 mW), in spite of the fact that the physical size of mirror is rather large (2.5 inch diameter). The detector is a gold dopped germanium photo conductive detector cooled to liquid nitrogen temperature inside the Dewar flask. The noise equivalent temperature of the system is 0.5° C with a target temperature of 50° C.

(iv) Raster scanning Radiometer : Raster scanning Radiometers find a wide range of applications in medicine, earth sciences, night reconnaissance materials, and electronics evaluation. The system shown in FIG. 7.3. is remarkable for its fast scanning speed for the use of a silicon polygon whose rotation performs the line scan, and for the use of refractive optics in addition to reflective elements. As shown in figure the detector is an InSb cell housed in a 4-hour Dewar for liquid nitrogen. The focus can be adjusted anywhere between 20 inch and infinity. Scanning in the vertical direction is performed by the front mirror Y, oscillating 16 times/sec., while the radiating silicon prism x Scans 1600 lines/sec. The combined action thus yields 16 full frame shaving 100 lines each. The optical resolution is about 100 points per line.

The video signal generated by the system is forwarded to a C.R.T. viewing system where an intensity modulated display is generated, either as a black and white, or a coloured picture of the target, or a quantized thermal map.

Typical characteristics of the equipment are as follows :

Field of view	$11^{\circ} \times 11^{\circ}$
Temperature resolution	0.2° C
Thermal range	Max. sensitivity 1° C and Min. sensitivity 200°C
Target thermal range	$- 30$ to $+ 200^{\circ}$ C

Capability of super imposing isotherms onto the C.R.T. modulated display.

(v) <u>The infrared microscope</u>[3] : When physical size of the target is very small, such as in the case of the semi-conductor 'chips' on which transistors and integrated circuits are deposited, the spatial resolution of the radiometers so far described becomes inadequate, and a change in the optics must take place, from telescope to microscope.

The reduction in surface of the elementary area upon which the detector is being focused, causes a corresponding reduction of the infrared signal reaching the detector.

An infrared microscope consists of two major elements: The detector unit, which includes the microscope, substage, detector cell, and coolant reservoir, and the control unit, which contains all of the ~~soil~~ solid-state circuitry

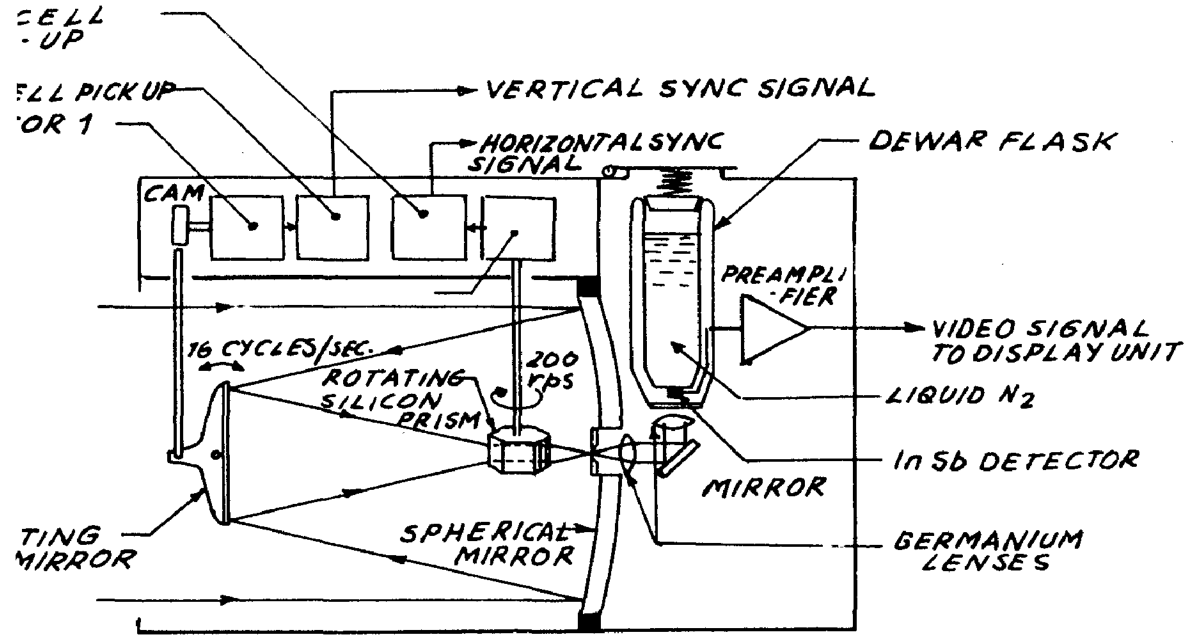


FIG. 7.3 RASTER SCANNING RADIOMETER

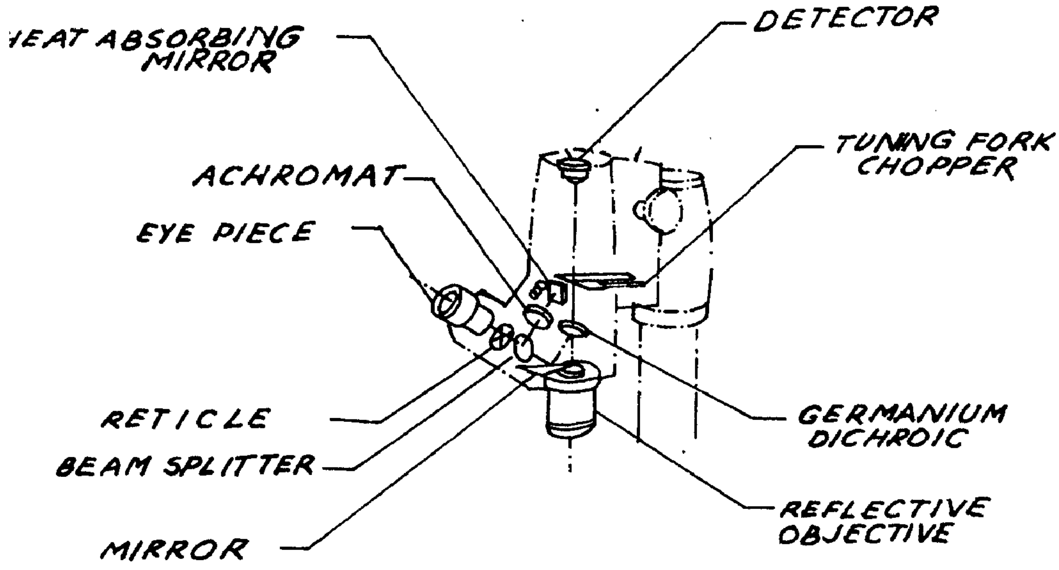


FIG. 7.4 OPTICAL DIAGRAM OF MICROSCOPE

for amplifying, filtering and demodulating the signal from the detector and displaying it on a meter.

The infrared detector is an indium antimonide cell mounted in a Dewar flask which has a liquid nitrogen capacity sufficient for 12 hours of operation without refilling. The instrument is capable of operating continously for an indefinite time, requiring only periodic refilling of liquid nitrogen reservoir. The reservoir may be refilled without interrupting operation.

The reflective optical system permits visual observation and focusing of the object with the aid of a built-in vertical illuminator. Reflective objective lenses with nominal resolution of 0.0014, 0.0007 and 0.0003 inch are available. Fig. 7.4 shows the optical diagram of a similar instrument, equipped with a noncooled detector, namely, a thermistor bolometer[1].

The solid state control unit provides external connections for an X-Y plotter, strip chart recorders or oscilloscope. The target is mounted on a micrometric substage whose operation can be manual, semi, or fully automatic. Since the microscope is

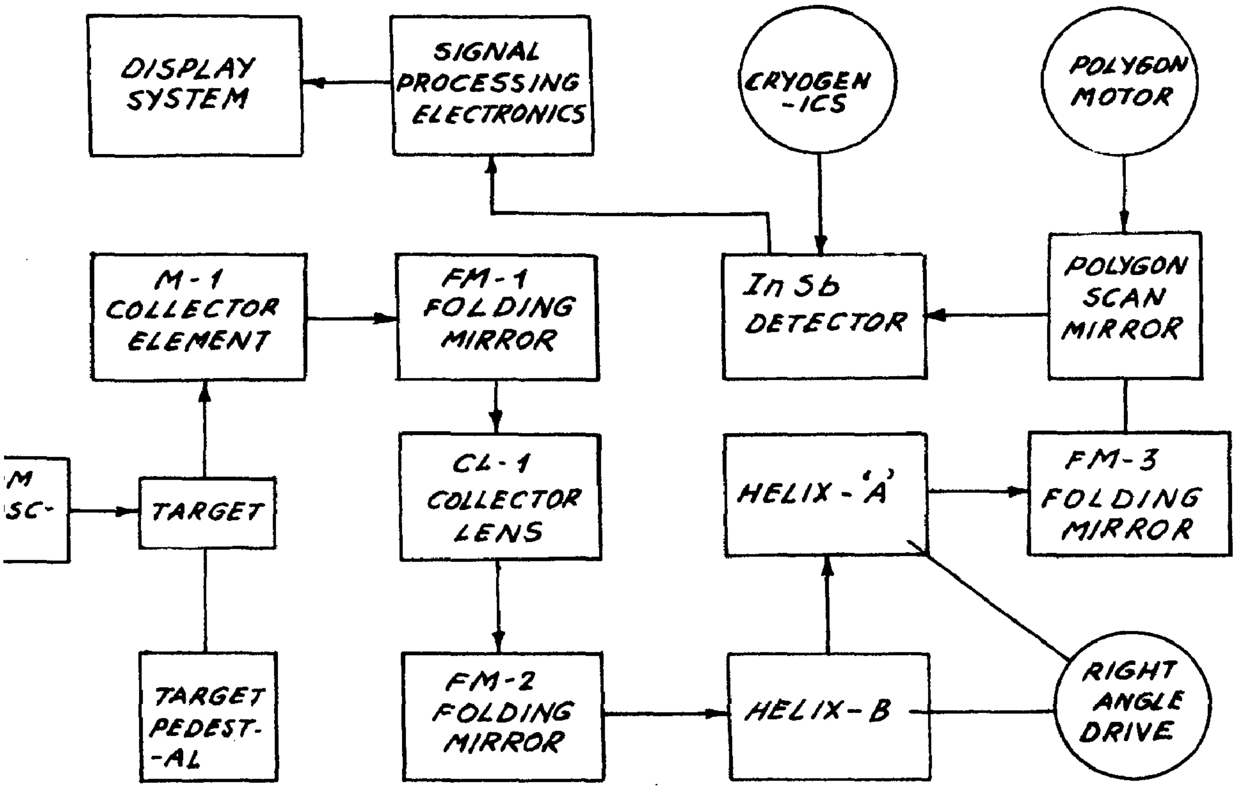


FIG. 7.5 FUNCTIONAL DIAGRAM OF FAST SCAN MICROSCOPE

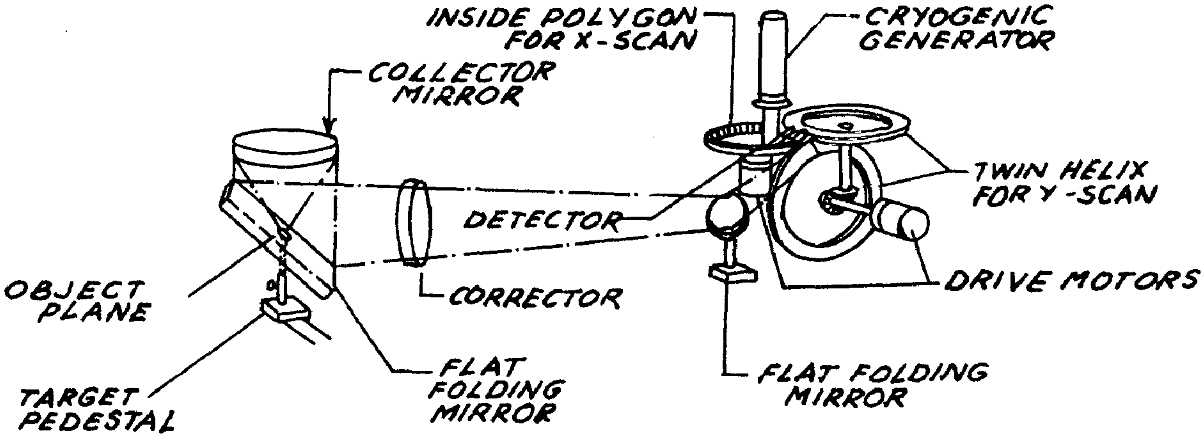


FIG. 7.6 OPTICS SCHEMATIC OF FAST SCAN INFRARED MICROSCOPE

essentially a point detector, the scanning taking place by moving the target, turning the micrometers controlling the X and Y position of the substage.

(vi) Fast-scan microscope[3,4] : Beyond a certain speed, physical movement of target can not be achieved without the danger of damage to it. But, the extremly close spacing of the active elements deposited on a semiconductor chip make it desirable to scan the target during warmup time, before thermal interaction between these elements takes place It is at this point in time that electrical, physical and mechanical properties of each and every component of an integrated circuit can best be evaluated by infrared, while thermal contrast is still good. After the heat emitted by the power dissipating elements has thermally flooded the unit, much detail disappears and only the major gradients are still visible.

Fig. 7.5 is the block diagram of the instrument and Fig. 7.6 outlines the optics and the scanning elements. An approximate magnification ratio 1:8 is obtained through the use of a single as-pherical reflecting element of special design. The maximum performance specifications of the instrument are as follows :

Area resolution : 100 μ

~~Number of scan lin~~es
~~per frame~~ : ~~Variable upto 200~~

Temperature resolution	20° C
Number of scan lines per frame	Variable upto 200
Number of frames per second	Variable upto 4
Area viewed in one frame	1 mm^2
Detector response speed	$<1\ \mu$ sec.

The design of the instrument had to reach the very limits of the state of the art in the area of optics scanning efficiency and detector sensitivity. As a result the optics are diffraction limited the scanning employs the unique system described in chapter 6 under heading 'Modified corner reflector system'that reaches close to 100% efficiency. The detector is an In-Sb cell cooled to 77° K by an 8-hour supply of liquid nitrogen.

To eliminate the incomveniences connected with the use of liquid coolants, an optical feature of the instrument is a cryogenic system equipped with a Ge-Hg detector whose sensitivity approximates very closely the performance requirements in the themmal range of interest. The use of the instrument is thus simplified, since the detector cooling takes place automatically by simply turning the a.c. power switch on. The system's output is an analog signal composed of frequencies as high as 100KHz and having a dynamic range o 60 db, complete with line and frame sync. pulses.

(vii) Two-wave length radiometer[1,3,4] (or two-colour radiometer) : Single wavelength (monochromatic) and total radiation infrared radiometers measure the energy emitted by an object and are subject to errors due to unknown or changing emissivity values and environmental effects such as smoke or haze. Also, the target must be completely resolved by the radiometer field of view for accuracy.

A-two colour (two wavelength) radiometer can reduce or eliminate the effect of target emissivity and the transmission characteristics between the target and radiometer.

A black body energy distribution curve for an object is shown in fig. 7.7. Also shown in the distribution curve for an object at the same temperature having an emmissivity 0.5.

If one is to measure the energy emitted at two given wavelength (λ_1 and λ_2) ~~we~~ one ~~could~~ can find that a 1008 F black body suits 0.71 $W/cm^2/\mu m$ at 2.5 μm (λ_1) and 0.11 $W/cm^2/\mu m$ at 1.8 μm (λ_2). Now consider the ratio between these two energy levels.

$$R_t = \frac{W_{\lambda_1}}{W_{\lambda_2}}$$

where R_t = Ratio (apparent temperature)

W_{λ_1} = energy emitted at λ_1

W_{λ_2} = energy emitted at λ_2

$$Rt = \frac{0.11}{0.31} = 0.355$$

$1000^{\circ}F$

If the/source were not a black body, but had an emissivity value of 0.5 then the energy emitted at λ_1 would be 0.055 $W/cm^2/\mu m$ and the energy at λ_2 would be 0.155 $W/cm^2/um$ However, the ratio between λ_1 and λ_2 would still be 0.355. The same ratio would also be measured if there were some attenuation ~~attemptati~~ of energy due to the transmitting media.

As the temperature increases, the slope of the distribution increases and the ratio between W_{λ_1} and W_{λ_2} will increase.

Both wavelengths selected for a two colour, or ratio radiometer must be in the same slope of either side of the energy distribution curve.

Fig. 7.8 shows a simplified optical diagram of a ratio radiometer. It should be noted that the ratio radiometer depends upon the emissivity, or transmission, being constant at all wavelengths, Unfortunately, thisis not always true; many materials, or transmitting medium, have emissivity values that vary with wavelength. This variation in wavelength will affect the ratio measured and result in an error in apparent temperature.

7.1.2 SPECTROSCOPE : A spectroscope is an optical instrument which produces a complete spectrome by separating light or infrared radiation into individual wavelengths. The spectroscope may use prisms, gratings, or interferometers to produce the spectral separation. Prisms provide wavelength separation by refractive dispersion, while grating work by diffractive dispersion.

Prism-type spectroscopes are most common and typically, resolve wavelength of 10^{-4} micrometers at 1.0 micrometer. Gratings provide about 10^{-5} micrometer resolution and interferrometric technique can provide upto 10^{-6} micrometer resolution at 1.0 micrometers.

They are many types and variations ~~of~~ in spectroscopes. Some are discussed in the following :

(i) Spectrometer[3] : A spectrometer is an instrument that measures the angular deviation of light as it passes through a prism or grating. Wavelength is usually determined by the angular position of the prism or grating. A dial connected to the prism/grating base can be calibrated directly in wavelength.

Recording spectrometers automatically rotate the prism or grating and record relative signal intensities directly onto chart paper which may be calibrated in wavelength.

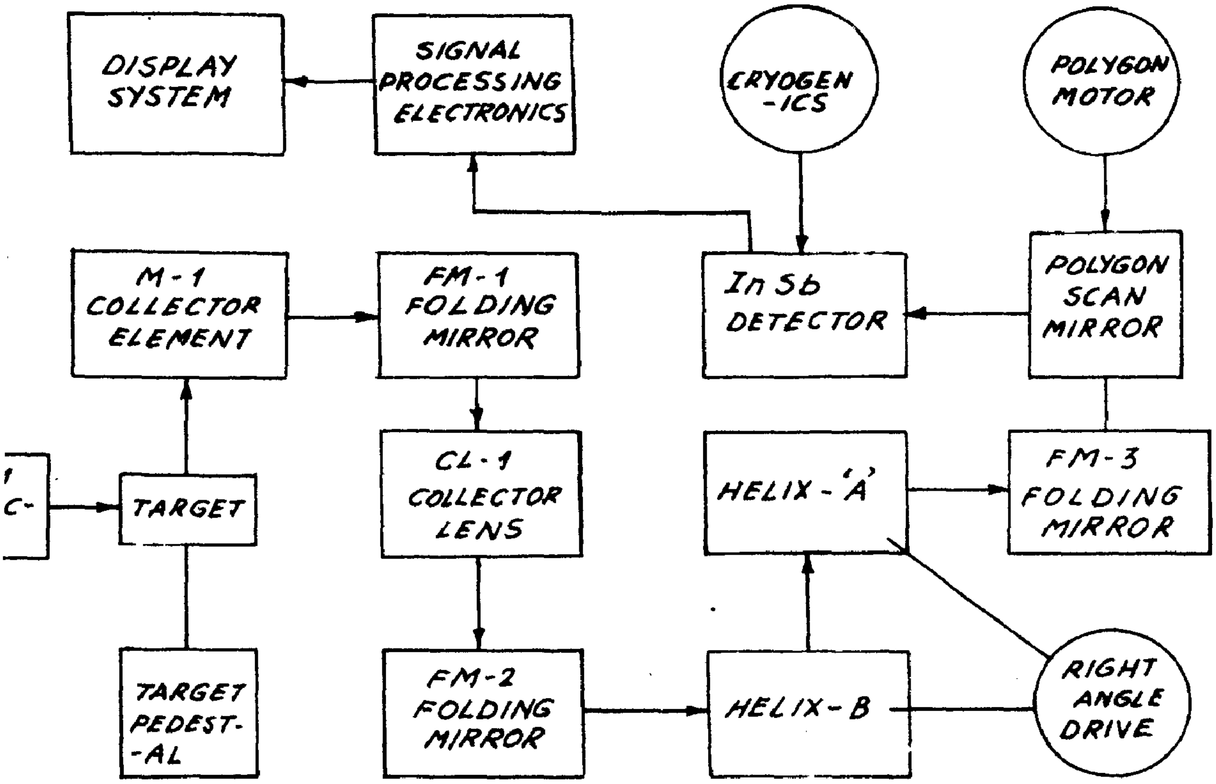


FIG. 7.5 FUNCTIONAL DIAGRAM OF FAST SCAN MICROSCOPE

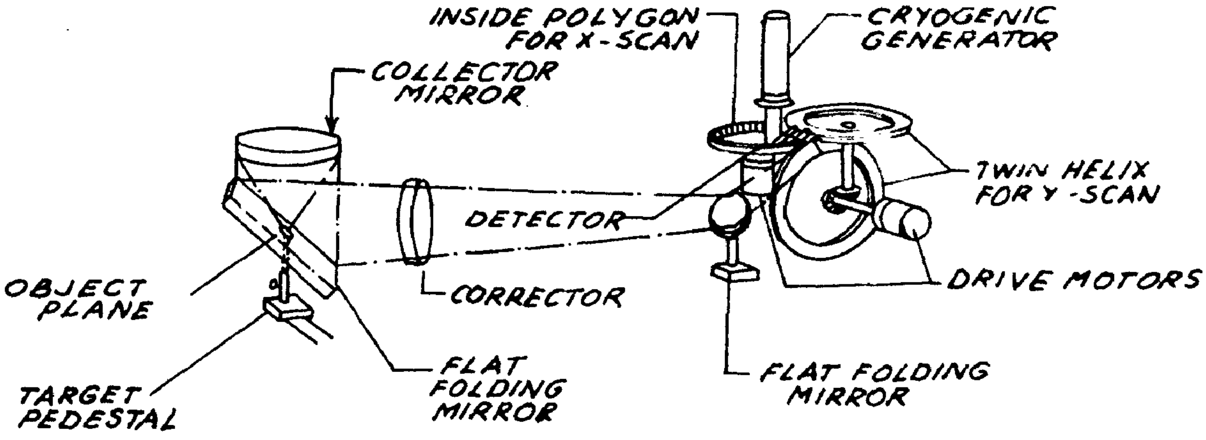


FIG. 7.6 OPTICS SCHEMATIC OF FAST SCAN INFRARED MICROSCOPE

(ii) <u>Spectrophotometer</u>[1, 3, 18] : A spectrophotometer is an instrument that compares the intensity of a reference beam to the intensity of a sample beam at the same wavelengths. Fig. 7.9 shows a simplified optical schematic of a typical spectrophotometer using prisms[3].

The infrared source is modulated at 11 hertz and deflected into two directions by the chopping mirror. The resulting reference beam and sample beam are recombined and directed to the entrance slit.

If a detector is placed at the enterance slit it would :

1. Measure no a.c. ~~sing~~ signal (at 11 Hz) if there is r sample or obstruction placed in the sample beam.
2. Measure a maximum a.c. signal if the sample beam (or the reference beam) is completely blocked.
3. Measure an a.c. signal with an amplifier related to optical attenuation of the sample beam;

The recombined beam is directed through a prism P_1, where it is dispersured and reflected back through the same prism and redirected to another slit.

The optical components between the entrance slit and the fixed slit from a monochrometer, which selects narrow positions of the spectrum. The beam is then focused onto a thermocopule ,

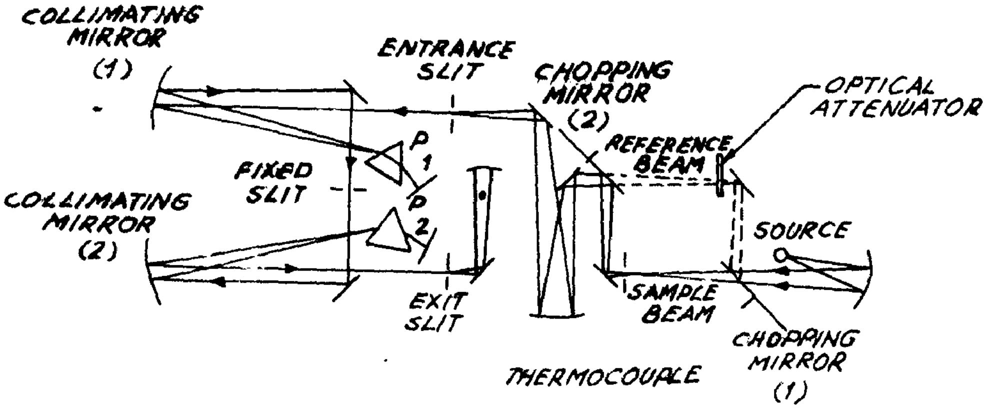


FIG. 7·9 SPECTROPHOTOMETER (USING PRISMS)

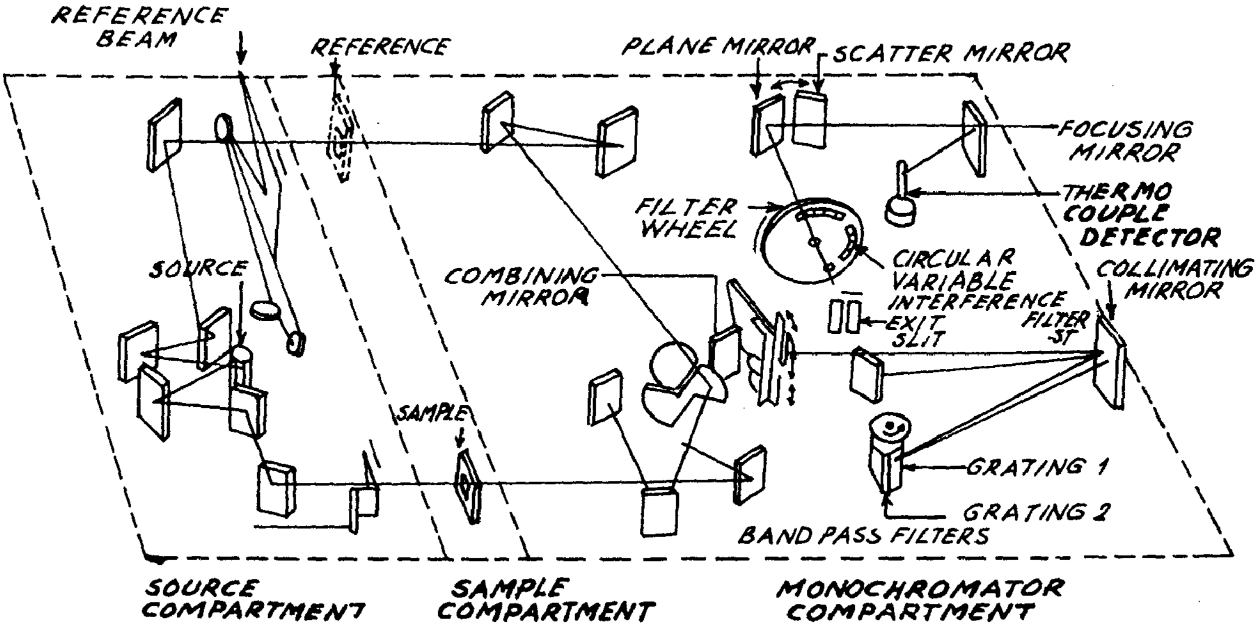


FIG. 7·10 SPECTROMETER (USING GRATING)

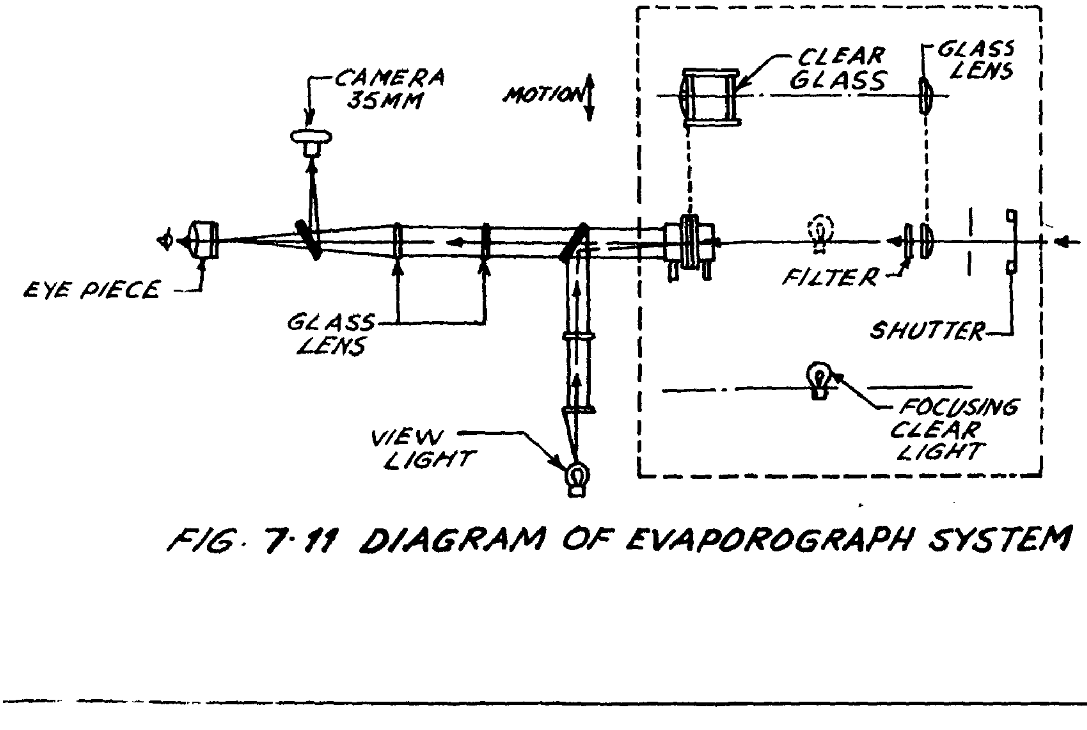


FIG. 7·11 DIAGRAM OF EVAPOROGRAPH SYSTEM

The signal from the thermocouple is amplified and used to position the optical attenutor in the reference beam path. The optical attenuator is constantly being positioned so that the reference beam path. The optical attenuator is constantly being positioned so that the radiation energy from the sample beam.

The position of optical attenuator is related to the percent of transmission through the sample beam. The position is used to plot per recording of transmission versus wavelength. Wavelength is determined by the position of prism P_2.

The same purpose can be solved, but at a higher precision, by the use of grating in place of prism. IR-20 spectrophotometer[18] manufactured Backman specification by optical coating laboratory. Fig. 7-10 shows the optical schematic of the same. In the source compartment, radiation from a Nernst glower is split into two equal beams. These are directed along parallel paths through the sample compartment. Here the front beam passes through the sample the ~~compa-~~ rare beam passes through the reference (e.g. air, cell filled with solvent).

In the monochromator compartment, the rotating chopper, mirror recombines the beams, throughout the reminder of their traverse they follow a common path. The combined beam passes through one of three band pass filters and then through entrance the slit. A collimating mirror now reflects the beam onto gratings, which are mounted back to back to rotate about a common axis.

The dispursed beam is directed back to the collimating mirror and onto the exit slit. The emergent beam passes through either (a) one of two circular variable interference filters (400 to 600 cm^{-1} range), or (b) an open aperture (600 to 250 cm^{-1} range.). The rotating wheel moves the filters through the beam in synchronization with the grating, at every given angular position, the corresponding filter passes the appropriate frequency but rejects all others.

The now essentially monochromatic beam is reflected from a polished plane diagonal mirror (replaced by a rough ground scatter mirror for the 600 to 250 cm^{-1} region) to a focusing mirror and onto the detector. The incident beam consists of alternate pulses of optical energy, which contribute opposite pulse component to the 10 Hz detector output signal. In response to this signal, the electro-optical servoloop continuously adjusts the reference beam attenuator to maintain optical null balance. The amount of reference beam energy absorbed by the sample. The recorder pan is mechanically coupled to the reference beam attenuator, to provide a read out linear in % T.

The above instrument can also be used in single beam operation mode. In single beam mode, the reference beam is blocked and does not contribute to the detector output signal. Since beam counterpart of the double beam reference signal is electrically generated 10 Hz component of proper phase. The servoloop continuously adjusts the reference voltage to maintain the electrical null balance with respect to the sample signal components. The balancing signal is applied by a potentiometer mechanically coupled to the recorder pen, to provide a read out linear in % T.

(iii) Spectrograph[3] : A spectrograph is an optical instrument that photographically records the spectral lines emitted by a source. The resulting photograph, or record, is known as a spectrogram.

(iv) Spectroheliograph[3] : A spectroheliograph is a special camera desgined to take solar photographs. The spectroheliograph allows energy at a single wavelength to expose ~~expre~~ the film. The resulting photograph, is called a spectroheliogram.

7.1.3 THE THERMAL IMAGING (or the Evaporograph)[1,4] : The radiant power accumulated during a certain length of time can be used when a relative, instead of absolute, radiation measurement is desired. Just as in photography the duration of the exposure controls the average tone of the picture, so in the evaporagraph the length of the time exposure controls the colour of the display picture, which is the conversion, in the visible range, of the infrared image of the target.

The colour, however, do not bear a univocal correlation to the radiation of each point or target, since the duration of the exposure has also an effect on their formation. In other words, the same object always having the same radiance, will appear in different colours in the visible display, according to the length of exposure. However, radiance gradients will appear as colour differences, and whenever absolute values are not required, the evaporograph will display these gradients in bright colour.

When infrared radiation falls on thin film of oil, a pattern is formed according to infrared radiation impinging on it. In the same way that on 'oil slick' on water reflects different colours of spectrum according to the thickness of the oil layer, the evoporograph's oil membrane, when illuminated by white light, reflects different colours related to the thickness of the oil film left on it after the partial evaporation produced by the infrared image focussed upon it.

The operation of instrument is shown in Fig. 7-11.

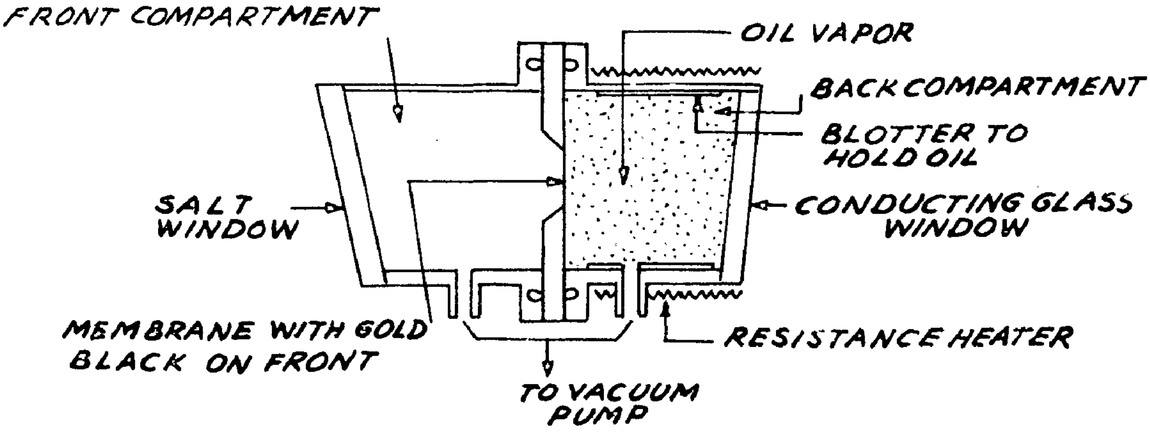


FIG. 7.12 THE EVAPORAGRAPH CELL

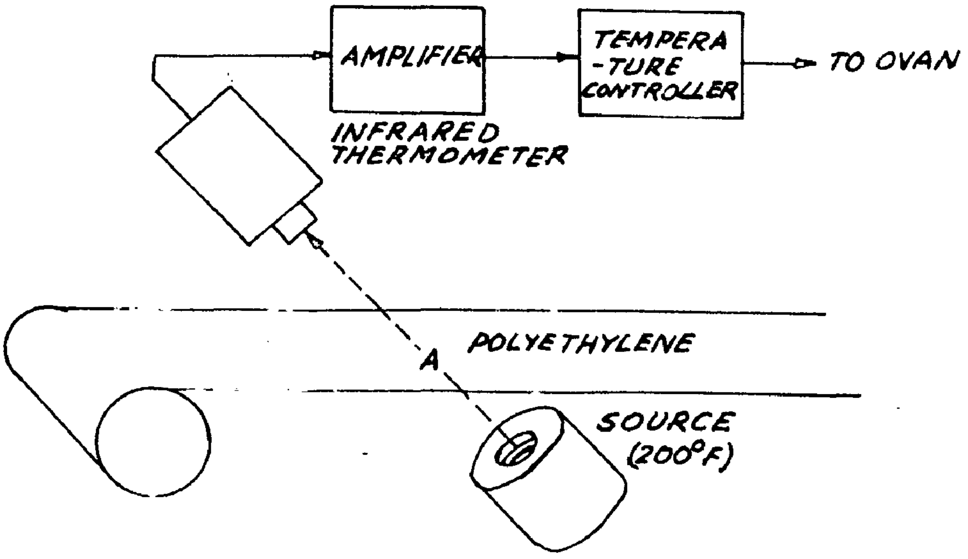


FIG 7.13 LAYOUT TO CONTROL POLYETHYLENE TEMPERATURE

The opticalsystem gathers infrared radiation from the field of view and focused as image of the field on the membrane. A special coating on the front surface absorbs this radiation and changes temperature from point to point in accordance with amount of radiation received by each portion of the membrane. Thus temperature difference are into differences of oil thickness, which cause while light to be converted into interference patterns of different colours, giving a visible coloured thermal image of the entire field of view.

Fig. 7-12 shows the heart of instrument, the evoporagraph cell, which is described in the 5th chapter. The performance characteristics of the instrument vary with the lens used and with other fabrication details : The fastest model meets the following specs :

Optics	...	2.25 inch diameter, f/1.5 germanium.
Detector	...	Evacuated 'membrane' cell
Readout	...	Optical viewing of 35 mm black and white or coloured transparencies.
Minimum detectable temperature difference		0.5° C for black body at 25° C
Angular resolution	...	1.0 m rad.
Maximum time to obtain Thermal image	...	20 sec.
Maximum spatial resolution	...	10 lines/mm with a 10° C difference at 6 inch distance from the lens.

TABLE -5

INFRARED APPLICATIONS MATRIX

users stem	Military	Industrial	Medical	Scientific
Search, track, and range	Intrusion detection Bomber defense Missile guidance Navigation and flight control Proximity fuses Ship, aircraft, ICBM, and mine detection Fire control Aircraft collision warning	Forest fire detection Guidance for fire-flighting missiles Fuel ignition monitor Locating hidden law violators Monitoring parking meters Detect fires in aircraft fuel tanks	Obstacle detection for the blind	Satellite detection Space vehicle navigation and flight control Horizon sensors Sun followers for instrument orientation Studies of the optical structure of the horizon
Radiometry	Target signatures	Detection of hot boxes on railroad cars Noncontact dimensional determination Process control Measurement of the temperature of brake linings, power lines, cutting tools, welding and soldering operations, and ingots	Measurement of skin temperature Early detection of cancer Monitor healing of wounds and onset of infection, without removing bandages Remote biosensors Studies of skin heating and temperature sensation	Measurement of lunar, planetary, and stellar temperatures Remote sensing of weather conditions Study of heat transfer in plants Measurement of the earth's heat balance
Spectro-radiometry	Terrain analysis Poison gas detection Target and background signatures Fuel vapor detection Detection of contaminants in liquid oxygen piping	Detection of clear-air turbulence Analysis of organic chemicals Gas analysis Determination of alcohol in the breath Discovery of leaks in pipelines Detection of oil in water Control of oxygen content in germanium and silicon	Detection and monitoring of air pollution Determination of carbon dioxide in the blood and in expelled air	Determination of the constituents of earth and planetary atmospheres Detection of vegetation or life on other planets Terrain analysis Monitor spacecraft atmospheres Zero-G liquid level gauge Measurement of magnetic fields

Contd. ...

4.	Thermal imaging	Rec on s The e Subm Det n p w f Dama	Earth resource surveys Locate and map the gulf stream Detect forest fires from satellites Study volcanoes Detect and study water pollution Locate crevasses Sea-ice reconnaissance Petroleum exploration
5.	Reflected flus	Nig Car Int Area Cam Sta Doc	Detection of forgeries Determine thickness of epitaxial films Determination of the surface constituents of the moon and the planets Gem identification Analysis of water quality Detection of diseased crops
6.	Cooperative source	Ter Comm w Cou s Rang Dro Int	Space communications Understand the mechanism of animal communications Peripheral input for computers Study the nocturnal habits of animals Terrain illumination for night photography

Size, optical head complete ... 18 x 14 x 11 inch^3
Weight, optical head complete;. 48 lb
Power ... 800 W
Supply voltage ... 115 V a.c. supply

Search, track and range instrument system is basically a radiometer, which has a facility of programming also.

Inflected fux type systems an infrared source and a radiometer or spectrascope is utilized to make the system. More known radiation is projected on a body under study and the reflected radiation is measured by either radiometer or by spectroscope.

Cooperative sources are infrared source of high intensity. These are mostly used for communication purposes.

From above, it is clear that any infrared system uses radiometer, spectrocope, or source or any combination of these three.

7.2 <u>APPLICATIONS OF INFRARED</u> : Infrared applications are summarized in Table 5. Across the top of this table are listed the potential users of such techniques. These are grouped into four categories that include the military, industrial, medical, and scientific users. At side of table and inducated the kinds of functions for which infrared

4.	Thermal imaging	Reconnaissance and surveillance Thermal maping Submarine detection Detection of underground missile silos, personnel, vehicles, weapons, cooking fires, and encampments Damage assessment	Nondestructive testing Inspection Locating piping hidden in walls and floors Inspection of infrared optical materials Detect and display microwave field patterns Study efficiency of thermal insulators	Early detection and identification of cancer Determination of the optimum site for an amputation Localization of the placentral site Studies of the efficiency of Arctic clothing	Earth resource surveys Locate and map the gulf stream Detect forest fires from satellites Study volcanoes Detect and study water pollution Locate crevasses Sea-ice reconnaissance Petroleum exploration
5.	Reflected flus	Night driving Carbine firing Intrusion detection Area surveillance Camouflage detection Station keeping Docking and landing	Industrial surveillance and crime prevention Examination of photographic film during manufacture Detection of diseased trees and crops Travelling matte photography Automatic focusing of projects	Measurement of pupilary diameter Location of blockage in a vein Monitoring eye movements Study the nocturnal habits of animals Examination of the eye through corneal opacities Monitoring healing processes	Detection of forgeries Determine thickness of epitaxial films Determination of the surface constituents of the moon and the planets Gem identification Analysis of water quality Detection of diseased crops
6.	Cooperative source	Terrestrial communications Command guidance for weapons Countermeasures for infrared systems Range finding Drone command link Intrusion detection	Intrusion detection Automobile collision prevention Traffic counting Radiant heating and drying Data link Intervehicle speed sensing Aircraft landing aid Cable bonding	Ranging and obstacle detection for the blind Heat therapy	Space communications Understand the mechanism of animal communications Peripheral input for computers Study the nocturnal habits of animals Terrain illumination for night photography

equipment is peculiarly well adapted.

Most of the applications discussed below are industrial one. Some important applications of the field of Medicine, Military and Science are also ~~induced~~ included here.

7.2.1 <u>TEMPERATURE MEASUREMENT</u> : Temperature measurement and control by infrared techniques is used in virutally every industrial process. Infrared radiometers provide quick, remote temperature measurement without affecting the temperature of the object being observed.

Operation of the radiometer is simple. Just aim the unit, like a camera, and read the temperature. Most radiometers have an emissivity adjustment for absolute temperature reading. Radiometers generally have a recorder output for pen recorders or for temperature controllers.

Usually, infrared thermometers are restricted to measurement of opaque surfaces. However, special combinations of electro-optical components provide a means of noncontact measurement of many transparent materials.

~~Normally, infrared thermometers are restricted~~

Normally, when an infrared thermometer observers a transparent object it not only senses the infrared energy but the energy emitted by the surface directly behind it also.

The resultant integrated temperature will be different from that of the transparent object.

(i) Temperature Measurement of glass[3] : Glass does not emit infrared energy uniformly at the wavelengths. It is desirable, therefore, to measure the radiant energy only at the longer wavelengths, beyond 45 micrometres to measure the glass temperature.

Most of the optical parameters operate at 0.65 micrometers, where glass is highly transparent. Some infrared thermometer look only at wavelength shorter than 4.5 micrometres, while others look at wavelengths, above and below 4.5 µm, giving false glass temperature indications.

By the help of interference filters, infrared radiation absorption take place beyond 4.5 micrometres. By combining the proper interference filter with a long wavelength detector, glass temperature variation of 0.2 per cent which occur for short duration can be detected and recorded. One per cent accuracy is possible with careful calibration techniques.

There is essentially no transmission of infrared energy through glass beyond a 45 micrometre. This means hot sources such as ovens, behind the glass cannot influence the temperature reading in any way.

(ii) Flame Temperature Measurement[19] : when hydrocarbon fuels are burned in the atmosphere or with oxygen ratio of the combustion products produced are water vapour and carbondioxide. Both of these products emit energy in the infrared spectrum : H_2O at 2.7 micrometers and CO_2 a t 4.45 micrometers. The width of the emission bar depends some what on the temperature and presence at which the exhaust gases escape. Also transmission of the flame depends on its thickness.

The termo couple's can not be used because of the extremely high temperatures and relatively fast contamination of the thermocouple itself. Infrared techniques offer a distinct advantage of permitting temperature measurement without disturbing the combustion process or influencing the temperature in any way.

(iii) Temperature Measurements of Plastics[19] : Plastics temperature (such as polyethylene temperature) may be measured at 3.5 micrometres or by use of a total infrared thermometre and black body radiation source.

Use of the black body is more applicable for control applications varying thickness or changes in the infrared transmission of the transparent material will not affect the control accuracy.

Let us assume that we want to control the temperature of the polythene during extrusion and that the temperature must be maintained at 200° F. Fig. 7-13 shows a typical geometrical layout of to control polyethylene temperature. In order to maintain the temperature at point A, the black body source must be set at 200° F and radiometer is sighted into its cavity. Now the voltage output shown by the radiometer is say x when nothing is placed in between the radiometer and black body. The polyethene has an emissivity value of 0.3 in the spectral region used at 200°F. The voltage generated by radiometer be again x. This can be shown mathematically [illegible] that the transmission factor of the polyethylene has no effect on the voltage output when the temperature of the transparent material is equal to the temperature of the black body. Since transmission is determined mostly by the thickness of the material, thickness will not affect the control voltage in any way. In actual practice the source is set at the desired control temperature.

The output will not follow the desired set point, however, the controller is not interested in the accuracy of temperatures above or below its set point. An error voltage related to the offset temperature will provide the controller with reliable control temperature information.

7.2.2 Component part evaluation[1,19,20] : Electric components and circuits performance can be judged beautifully with the help of infrared techniques. An infrared microscope having adequate area and temperature resolution would be able to solve this problem. Conventional test equipment can only supply information related to the overall operation of the electronic components or circuits. But with the help of infrared techniques one can detect hidden anomalies that can make the component or circuit unreliable and likely to become an early failure.

The components under normal operating conditions give a particular radiation ~~in-case-of-any-fault~~ spectrum. In case of any fault change in radiation can be measured by radiometer or by infrared thermal map technique. The programme or chart of a sound circuit is already available and at each stage the output from infrared tester and programme, is compared to detect the fault in the circuit. This method is very useful for large scale integration (LSI) circuits and small scale integration (SSI) circuits, otherwise it is not possible to check the performance of each active element with the help of conventional method, because of the impossibility of reaching them through the outside connection.

In short, when applied to semiconductor ddvices, infrared techniques must be divided in two areas :

1. Information related to the radiation of thermal origin.
2. Information related to the recombination radiation

The data under step 1 carrie~~s~~s infor ation about electrical power dissipation and about mechanical characteristics related to the performance of the semiconductor devices. It~~is~~s usefulness can be broken down in the following areas[1,2]:

1. Engineering design evaluation : The ability to measure the true operating temperature of each and every element of the circuit enables the design engineer to determine the electrical operating characteristics of trans~~m~~isters and diodes, which are heavily temperature dependent. With this information, actual stress levels and de~~f~~rating factors can be disclosed and corrected.

2. Reliability Calculation : Knowledge of the actual operating temperature of components enables the relibility engineer to obtain the true failure ratios for all components, so that the reliability calculations can be trusted as being really representative of the unit under evaluation.

3. Manufacturing quality control : SO far the following defects have been detected through infrared measurements : poor chip-to-header bonding; defective metalization; reduced ~~cor~~ cross section of conducting elements; hot-spots capable of including breakdown conditions; excessivo

or insufficient power dissipation by junctions or by resistors. Investigation is still proceeding in other areas of interest, such as semiconductor cracks and quality of the bond between the chip and elements attached to it (wire bond) deposition onto it (resistors and metal interconnect).

The data obtained under step 2 carries information about electrical characteristics (other than power dissipation) by junction or by resistors. Investigation is still proceeding in other areas of interest, such as semiconductor cracks and quality of the bond between the chip and elements attached to it (wire bond) deposited onto it (resistors and metal interconnect).

The data obtained under step 2 carries information about electrical characteristics (other than power dissipation) Such as waveform and current magnitude of the signal flouring through the junction of transistor and diodes. It also contains information about carrier lifetime, crystal doping, and degree of uniformity of current density along the junction. Such data is especially useful to :

1. The design engineer who can find how the signal travels through the circuit and it gets modified in waveshape and amplitude as it proceeds from point to point.

2. The quality control engineer who can verify how well the process keeps within the upper and lower control limits established as a result of the recombination radiation measurements. Of course, this refers not only to the electrical characteristics of the signals, but also to the uniformity of current flow density along each junction.

3. The failure analyst who will be able to investigate the circumstances and the effects related to the faulty condition under examination.

4. The physicist who will be able to actually 'see' on the oscilloscope display the ~~carner~~ carrier lifetime characteristics and other physical qualities of the semiconductors that are the object of his study.

7.2.3 MECHANICAL BOND Q UALITY EVALUATION[19] : Most of the mechanical bonds used today's space-age handwave are as follows :

1. Fusion bond (solder, brazed, welds)
2. Adhesion bond obtained through the use of chemical or mechanical bond agents.
3. Bonds obtained through electrical deposition of metallic materials (plating, motelizing).

4. Bonds obtained through vaccum disposition of elements or compounds (motalization in semi-conductor devices).

5. Compression bonds, obtained through application of pressure at the interface of metals to be joined. The pressure can be steady or intermittent (hamming, ultrasonic) and the temperature of the metals can be ambient or raised to a convenient thermal level.

According to the applications, one of the following systems is used :

1. Flooding the surface of the target with radiant heat and mapping the temperature at every point of it. This discloses how the heat diffuses through the material located under the surface, thus yielding information about the presence of hidden anomalies along the diffusion path.

2. Soaking the target in an oven-like environment at a higher than ambient temperature, and mapping the thermal distribution on the surface, after removal from the oven. Physical characteristics along the heat flow path from the core to the outside surface will be reflected in a corresponding thermal distribution that can reveal hidden anomalies.

3. Introducing a thermal differential between two points of the target chosen in such a way that the heat flow between them will be affected by the characteristics of the element under evaluation. Thermal mapping of the surface between the two points will depict how the heat flow takes place, thus disclosing the presence of any anomaly hidden under the surface. The temperature differential can be introduced by heat injection at one point, or along a line conveniently chosen.

4. Developing heat due to friction generated in the unbounded region. Thermal mapping of the outside surface of the ~~location where the~~ target will show a warm area in correspondence to the location where the fraction takes place.

7.3.4 TRANSMISSION LINE REPAIR[3,19] : Defects in power line, transmission insulators or connectors and poor splices can be detected before electrical service is interrupted or costly repairs are needed. Any resistance to current through the transmission cable will cause power to dissipate at the point of resistance, which will cause an increase in temperature. This temperature increase can easily be detected by infrared radiometers.

7.2.5 INFRARED PHOTOGRAPHY[1]: Near-infrared energy may be detected by photographic means. Photographic emulsions are available that allow to 'see' wavelengths as long as 1.4 micrometers. A major use for infrared film is aerial photography, since the longer wavelengths penetrate the atmospheric haze with less attenuation.

Comparison of infrared photographs with normal photographs can be used to identify certain objects or detect comouflaged items. The comparison of photographic information at two different wavelengths can yield much information concerning landscapes, printings, and other documents.

Any camera can be used to take infrared photographs. All that is needed is some infrared film and a special filter. The filters are used to attenuate all, or most of the visible energy striking on film.

7.2.6 FOREST FIRE DETECTION[2,19] : Infrared techniques appear to be attractive for the early detection of forest fires A simple scanner placed on a high point in the local terrain could continuously scan many square miles of forest. The time required for one complete azimuthal scan need only be of the order of tens of minute. The use of integrated circuritary would permit operation from batteries that are rechargable by solar cells. A comparison transistorized transmitter would alert a central monitoring facility if a fire was discovered.

conditions. Infrared survillance of earth horizon ~~clod~~ Could coverage and hot air masses can aid in the forecasting of rain, snow, thunderstorms, and huricanes.

Infrared radiometers abroad satellites have measured the surface temperature of Mars and Jupiter. The Mariner 6 satellite, for example, measured the surface temperature in the equatorial region of Mars at + 20° C. It also absorved a temperature of - 120° C at a latitude of 77° south. Infrared technique also helps in the evaluation of the mineral content below the surface of a distant planet.

7.2.8 <u>MILITARY APPLICATIONS</u>[2,3] : Military uses of infrared techniques are numerous. Some important are as below :

Infrared communications are ideal for military use. They are wireless, relatively compact, and vary directional, which ensures private communications. Infrared communication system were first used in the World War II.

Infrared imaging systems containing of the snooper scope and sniperscope were also used in World War II. Newer, more sophisticated imaging systems convert periscopes and telescopes for use at night distinguish between natural and comoflaged objects; and map target area at night.

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Since infrared guide missiles find a fire to be a very attractive target, it is not surprising that some thought have been given to having such missiles carry a fire suppressing payload.

Infrared equipment is used for the early detection and rapid extinguishing of fires in air craft fuel tanks. Ruggedized load sulphide detectors mounted inside each tank detect any flame and actinate an extinguishing system. The detonation time of fuel air mixture is from 3 to 8 m sec. and typical infrared actuated extinguished system record in 1 to 3 m sec.

7.2.7 SPACE TECHNOLOGY APPLICATIONS[1,2] : Infrared radiometers are used with telescopes to track the sun, moon, and stars for positioning astronomical instruments for observations and measurements. The detection and tracking of celestial objects is important for space navigation.

Setellites use the earth as a reference for position and altitude control. The carbon dioxide layer around the earth produces a corona that makes wisual observation inaccurate Infrared radiometers operating at about 12 micrometers greatly incrdase the accuracy of earth horizon.

The TIROS (television and Infrared observation Satellite) satellite has been successfully used to plot and forecast weathe conditions. Infrared survillance of earth horizon ~~clod~~ could coverage and hot air masses can aid in the forecasting of rain, snow, thunderstorms, and huricanes.

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Infrared technology. Infrared horning missiles such as the Navy's sidewinder and the AIR Forces Falcon have been operational for many years. The guidance systems in these air-to-air missile provide continuous target position information to constantly aim the missile on a collision course. Most airborne targets generate large amounts of infrared energy provide strong signals for the infrared-sensing missiles to 'home-in' on.

Infrared radar systems are used for early warning of aircraft and ballistic missiles. Passive radar systems do not transmit signals that may be detected and indicated its position. Infrared radar systems also provide search, aquisition and tracking information for gun fire control.

7.2.8 INFRARED SIGNATURE[19] : Every physical object, from the simplest to the most complex one, from the smallest to the longest one, has a visible shape and its surface exhibits visible colours. A coloured picture of it will unequivocally identify it, the only limitation is the impossibility of differentiating between identical copies of the object.

The same is true with infrared. Instead of visible radiation, infrared radiation is the parameter being monitored. As long as the object exhibits a different radiation level than the background, its picture 'signature' or 'pattern' or 'profile' will define its surface thermal distribution, as affected by its surface emissivity, and will be consistently the same for identical thermal conditions. For any system, its infrared signature can be recorded and used as a standard, typical of that assembly during proper operating conditions. All identical units operating in the same mode will exhibit an infrared signature that matches the standard. Some of the intelligent use of infrared signature for electron circuits, LSI and MSI are listed below :

1. Electrical design verification
2. Product design evaluation
3. Component stress analysis
4. Reliability calculation
5. Inspection, test, and trouble shooting
6. Detection of hidden failure conditions
7. Detection of secondary overstresses
8. Novel maintenance policy

7.2.9 MEDICAL USES OF INFRARED[1,3,21] : Infrared imaging techniques promise to enhance the already proven roles of electronics in medicine. Within a short time, infrared instrumentation will be as valuable a tool to doctors and hospitals as the X-ray machine is today.

The medical profession has used infrared photography for a number of years. This method, however, is limited by the fact that the film emulsions are sensitive primarily to reflected energy at the very near infrared wavelengths.

New thermal imaging devices detect emitted radiation and 'see' further into the infrared spectrum. These devices enable the medical examiner to observe and record skin temperature differentials without physical contract with the patient.

Infrared scanners have been used for clinical studies in ~~the~~ many countries. These 'cameras' have been utilized experimentally as a basic research tool for the detection of breast cancer ~~carrier~~, determining the degree of skin burns and frostbite, and for numerous other cliniccal studies.

Human skin at temperature 37° C emitts more than 50 per cent of its energy between 5 to 14 micrometres. The maximum energy is emitted at approximately 9.3 micrometres.

The infrared emissivity of human skin, redardless of colour, very closely approaches unity (~~t~~ = 1). This one fact means that reliable, remote plotting of skin-surface temperatures can be made regardless of skin colour, visible light conditions, or ambient temperatures and its further insures a high degree of reproductivity.

It is also important to know that the heat generated by an illness or reaction must occur on or near the surface of the skin, in order to be detected by infrared methods.

The term (thermography) is used to describe the technique involving infrared scanning cameras. The word 'thermography' generally is used to describe the final picture. On the thermograph, black to white represent about 1° C.

It has found that the identical symmetrical areas of the body surface are almost always within ~~always-with~~ 1° C unless there is a derangement of the vascular supply or some pathological progress to explain it.

Medical detectors have recognised that breast cancer provokes varying degrees of local inflammatory reactions associated with an increased blood and lymphatic supply. Tests show that average temperature rise is either the area of the tumor or ipsilantleral aerala is 2.27° F. No temperature rise has been associated with cysts or fibroa denomata.

More than a hundred patients, each having a lump in one breast, were investigated in Landon. All cases showing a rise more than 1° C over the contralateral normal area were designated as 'hot' while the others were 'cold' group contained degenerative lesions, such as cysts and duct stasis.

The values of infrared diagnosislies in its early detection of symptoms.

Theyroids also have been studied. It has been observed that overactive toxic gosters are extremely hot and therefore emitt more infrared radiation than underactive ones.

More accurate and earlier evaluation of burn injuries can also be made by infrared techniques. Destroyed or devitalized skin limit the amount of infrared radiation emitted as compared with partially burned skin.

Healthy adult dogs have been used to test the usefulness of infrared techniques for detection of degrees of skin burns.

An increase in skin temperature over the appendix has been seen to occur several hours before the white blood count rose, indicating a possible use of infrared in the earlie diagnosis of appendicitis.

Since any inflamation is associated with heat and therefore has an increased infrared emission, successful treatment becomes obvious by the reduction of heat.

Infrared imaging also may be of great ~~assistance~~ assistance to doctors in the study of congenital defects, vascular inflammations, drug reactions, and circulatory diseases.

7.2.10 <u>INSTRUMENTATION LANDING</u>[1,10] : When the atmosph becomes foggy or/and cloudy u to such a extent that the air strip is not visible from aeroplane from a height of about 300 metres than aeroplane is landed with the help of instruments. This job can be done by either with the help of microwave systems or with the help of infrared system. Infrared techniques, are new comers to this field. With the help of infrared techniques landing method is more safe.

In microwave method information is sent from control rooms to the aeroplane and then by that information the plane is landed manually. But in case of infrared technique which has got a property that radiation region can be restricted in direction and air length both, the landing becomes fully automatic.

7.2.11 <u>INFRARED HEATING</u>[47] : Infrared heating is adgantageous in following ways :

1. directional effect
2. Intensive effect
3. Loss thermal inertia
4. Cleanliness and safety
5. Speed
6. Penetration of radiation (very much advantageous particularly in thick layers).

Some of the applications for infrared heating are discussed below :

(i) For Paint Drying[4] : The object of infrared heating is to increase the temperature of paint so as to accelerate the polymerization of the resin base giving a macromolecular structure which ~~reduces~~ renders the film of paints particularly touch. Examples for the drying of paint are as follows :

1. The drying of enamelled metal plate (enamel) before stoving. If the objects are dried in a tunnel, they can be kept much free from dust, and are not liable to damage resulting from manual handling.
2. The drying of anti-dust warnish and various other protective layers.
3. The drying of insulating varnish in electrical equipments.
4. It has been found that the insulating properties are improved in this way, because the drying is more through than other methods.

(b) In TEXTILE INDUSTRY[7]:

In some cases, in which a large amount of water has to be removed from the fabric,the use of infrared heating is advantageous, and very good results are obtained. The qualities inherent in the infrared drying allow very uniform treatment, and the quality of the sizing is improved so that there are ~~finer~~ fewer breakages on the loom. Other applications are the drying of flax after setting and the drying of textile after bleaching and dyeing.

At present, however, the applications of infrared in textile industry seems to be mainly concerned in the field of plastic treated textiles and synthetic fibres. There are many other special applications in textile industry such as polymerisation on paper making, felts, vulcanisation of rubber coating and the drying of adhesive priming on the canvass for automobile tyres.

(c) THE PAPER INDUSTRY[7]:

The drying problems are not with at all stages in paper industry : during the manufacture, coating, printing gumming, stitching, glazing, etc. ~~THIS~~ These problems do not only occur with printing paper, but also with wall paper, card board etc.

A related problem in the drying of photographic paper for photographying paper , and copying by the irradiation of thermosensitive paper.

(d) IN FOUNDRY WORK[2] :

The sand used for making moulds, must be dried to a depth of 10-15 mm, to prevent instantaneous vaporisation when the metal is run in, which could give rise to flaws in casting of surface temperature of around 60° C is used for this purpose. In this case the uniformity of drying is achieved only by infrared heating.

(e) PLASTIC INDUSTRY[3,7] :

In short infrared heating has got following applications :

1. The conditioning of gramophone records blanks.
2. Heating sheets of plastics to soften them before cutting shaping or stamping.
3. The treatment of plastics coating on textiles.
4. The drying of plastics adhesives
5. The heating of plastics granular or pill form, before moulding.

In some countries infrared heating is used on a large scale in the manufacture of synthetic leather.

(f) IN FOOD INDUSTRY[4]:

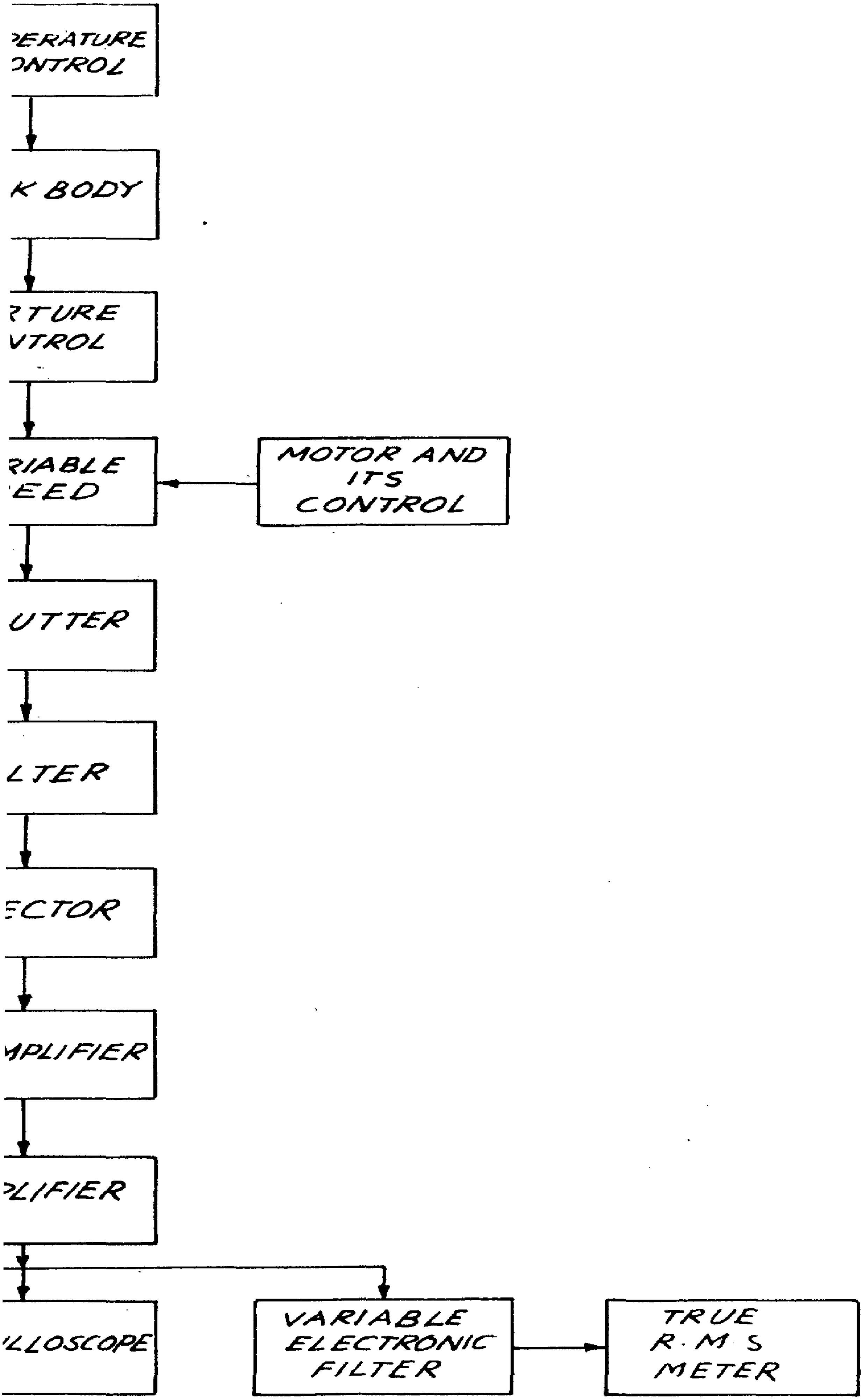
Where electric cooling is economically justified, the use of an infra red oven will give its usual advantages. Because of penetrating and uniform heating property of infrared the quality of product is often improved. In several countries including India, such ovens are used for the manufacture of biscuits, breads, etc. Infrared lamps have been tried with success. For such purposes as the cooking of fish, drying of coffee and cocoa, drying of grains, etc.

To keep the food hot, infra-red ovens are in general use. The infrared heating is preferred for processing the packaging in which food is sold.

(g) Miscellaneous applications[7] :

The following examples illustrate the vast range of industrial applications of infrared heating in various fields :

1. The drying of metallic objects by electroplating.
2. The drying of explosives
3. The drying of paint on glass (mirrors)
4. Heating of grains, etc. to kill parasites
5. The drying of glue applied to woolen objects.



BLOCK DIAGRAM OF ANALYSER

8. AN ANALYSER FOR DETECTORS :

The growing demand for infrared detectors has created a need for improvement in production techniques and better quality control. for the better function an analyser detectors have been developed here. It checks and records quickly and accurately all of the important operating parameters of an infrared detector.

The various figures of merit used to describe the performance of a detector were discussed in Chapter 2. For convenience they are summarised in table 8. Inspection of this table shows that only five quantities need to be known in order to calculate these figures of merit; the signal voltage, the noise voltage, the equivalent noise bandwidth of the measuring circuit, the blocking area of the detector, and the irradiance. ~~Infrared~~-In practice the experiment-or measures additional quantities in order to determine other characteristics of the detector. One may also beinterested in recording certain details describing the physical nature of the detector and the condition of measurement.

8.1 BLOCK~~ING~~ DIAGRAM FOR ANALYSER :

A block diagram of the components needed to make up a typical detector analyser test set as proposed in the references (2 & 3) is shown in Fig.9.1. The description

Figure of Merit	Equation	Units
Responsivity	$R = \frac{V_s}{HA_d}$	VW^{-1}
Noise equivalent power	$NEP = HA_d \frac{V_n}{V_s}$	W
Noise equivalent irradiance	$NEI = \frac{NEP}{A_d}$	$W\ cm^{-2}$
Detectivity	$D = \frac{1}{NEP}$	W^{-1}
D-star	$D^* = \frac{(Ad\ \Delta f)^{\frac{1}{2}}}{NEP}$	$cm\ (H_z)^{\frac{1}{2}}\ W^{-1}$

A_d = Detector area, cm^2

H = Irradiance, $W\ cm^{-2}$
(rms value of the fundamental component)

V_n = rms noise voltage

V_s = rms signal voltage
(fundamental component)

Δf = Equivalent noise bandwidth, H_z.

of each block is given below :

(i) Black body radiator &: Temperature controller The design, construction, and calibration of these units are already covered in chapter 3. Most of the measurements are done at a black body temperature of 500° K to 900° K. After proper calibration incandescent lamps can also be used as a source in place of black body radiator.

(ii) Limiting Appertures: These are used to provide an accurately known radiating area for the black body source. Several aperture sizes are available, ranging from 0.25 to 5 mm in diameter.

(iii) Variable speed modulator : These were discussed in Chapter 6. For getting variable speed the use of a d.c. motor is ideal.

(iv) Frequency meter : Used to measure and monitor the chopping frequency.

(v) Shutter : An opaque shutter is used to block the flux from the black body in order that the noise from the detector can be measured in the absence of an input signal.

(vi) Detector : The principle requirement here is a means of holding the detector during test. Such items are usually custom made to fit the specific needs of the experimenter. It is particularly convenient if the detector mount can be moved either toward or away from the black body source. In this way detectors can be so positioned that the distance from the limiting aperture to the plane of the responsive element remains constant and one calculation of irradiance is valid for all measurements.

(vii) Variable bias supply : It is a variable stabilized d.c. supply and is used to get the optimum biasing condition for a detector under test.

(viii) Preamplifier : The preamplifier is one of the most critical components in the entire test set. Unfortunately, no single preamplifier can provide optimum performance with all of the variable detectors. The primary requirement is for noise figure that is so low that the noise from the detector is the limiting source of the noise inthe system. A low output impedance is desirable in order to permit the use of low-impedance connecting cables. Most designers prefer to built their own preamplifiers.

(ix) Shielded enclosure : At the very minimum, this enclosure should be a light tight box painted black on the inside so as to shield the detector from the ambient illumination. In some test sets the black body source and chopper are also placed within this box. However, for proper shielding, individual workers will have to find experimentally just how much shielding is required in their particular location.

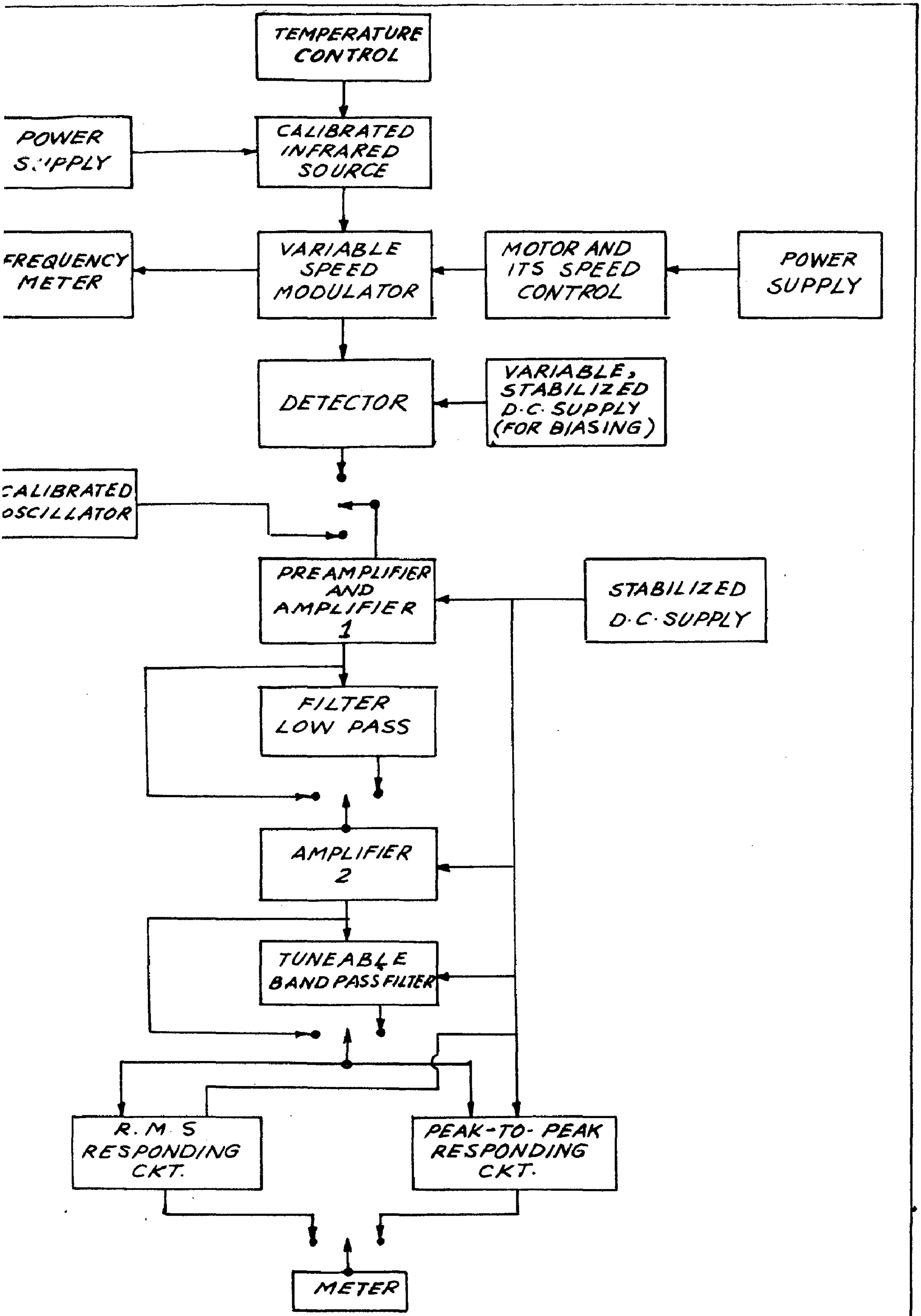
(x) Calibrated attenuator and audio oscillator : These provide a calibrating voltage of known amplitude and frequency for determining the voltage gain between the detector and the output indicating device.

(xi) Amplifier : The level of the signal from the preamplifier is usually too low for direct application to the final read-out device. Since most chopping frequencies lies in the audio range, any good audio amplifier can be used.

(xii) Oscilloscope : This is used to ensure that no overloading occurs at any position in the test set. Any general purpose oscilloscope is suitable.

(xiii) Wave analyser : This is a narrow band width voltmeter tunable from 20 Hz to 50 KHz. The equivalent noise band width varies with manufacturer but it is usually about 5 to 6 Hz. Since this instrument is not true r.m.s. responding, the correction factor must be applied when noise voltage are read.

(xiv) Variable electronic filter : It is often convenient to be able to select a particular bandwidth for the measuring circuit so that the noise can be measured in



G.8.2 BLOCK DIAGRAM OF THE ANALYSER DEVELOPED BY AUTHER

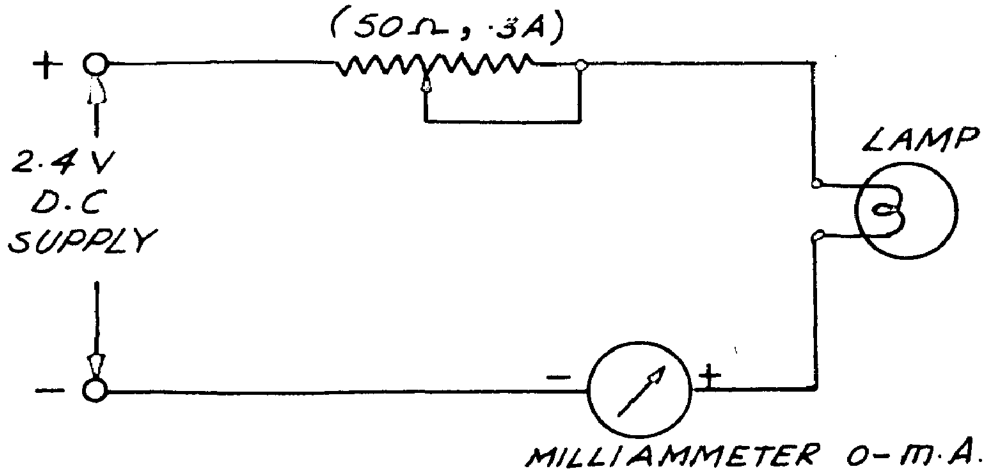


FIG. 8·3 TEMPERATURE CONTROL OF INCANDESCENT LAMP

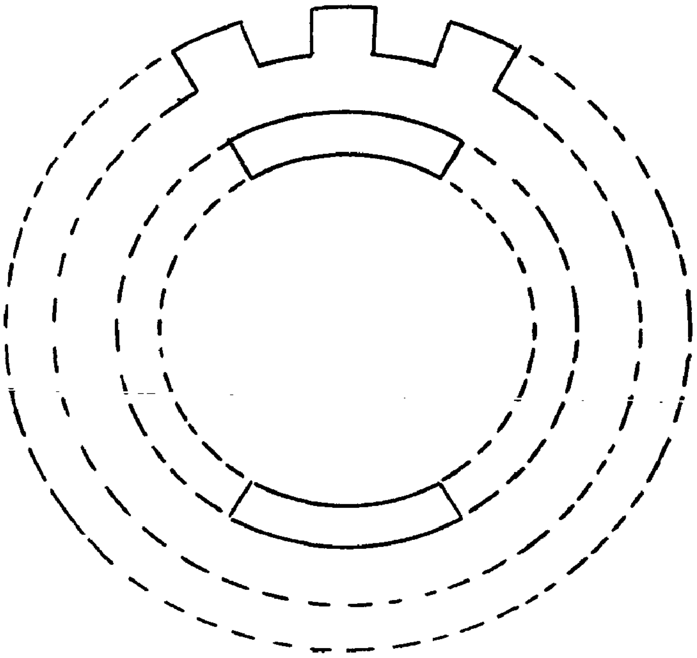


FIG. 8·4 CHOPPER DISC

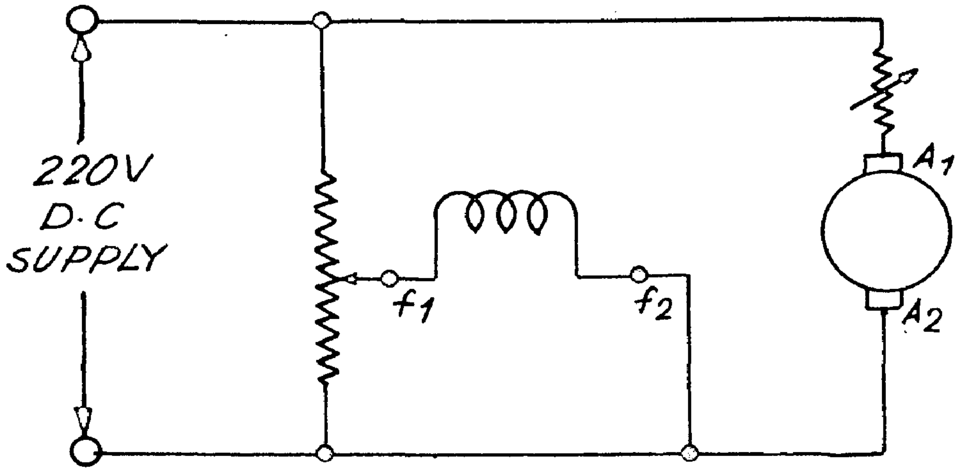


FIG. 8·5 SPEED CONTROL OF MODULATOR USING A D·C MOTOR a band width approximating that of the final system. Such control of the band width can be had with the amplifiers, or w with variable electronic filter.

(xv) True r.m.s. meter : This meter is used to measur both signal and noise.

(xvi) Refrigerator : Many types of detectors must be cooled. Refrigerators are discussed in chapter 3.

8.2 SCHEME OF ANALYSER :

The block diagram of the analyser developed by the author is shown in figure 8.2. Details of each block, including design are discussed below individually.

8.2.1 TEMPERATURE CONTROL & SOURCE : THe incandescent lamp of 2.2 V, having a lens and a reflector is used as an infrared source. A calibration of incandascent lamp is done by optical pyrometer. In lamp the different temperatures are obtained by changing the current through it (Fig. 8.3).

8.2.2 MODULATOR : Opital modulator systems are already discussed in section 6.3.1. Here a chopper disc, having 36 slots in one position and two slots in second position, is used to modulate the infrared radiation. The chopper disc used is shown in fig. 8.4.

Variable speed control of modulator is done by using a d.c. shunt motor; The speed control circuit for d.c. motor

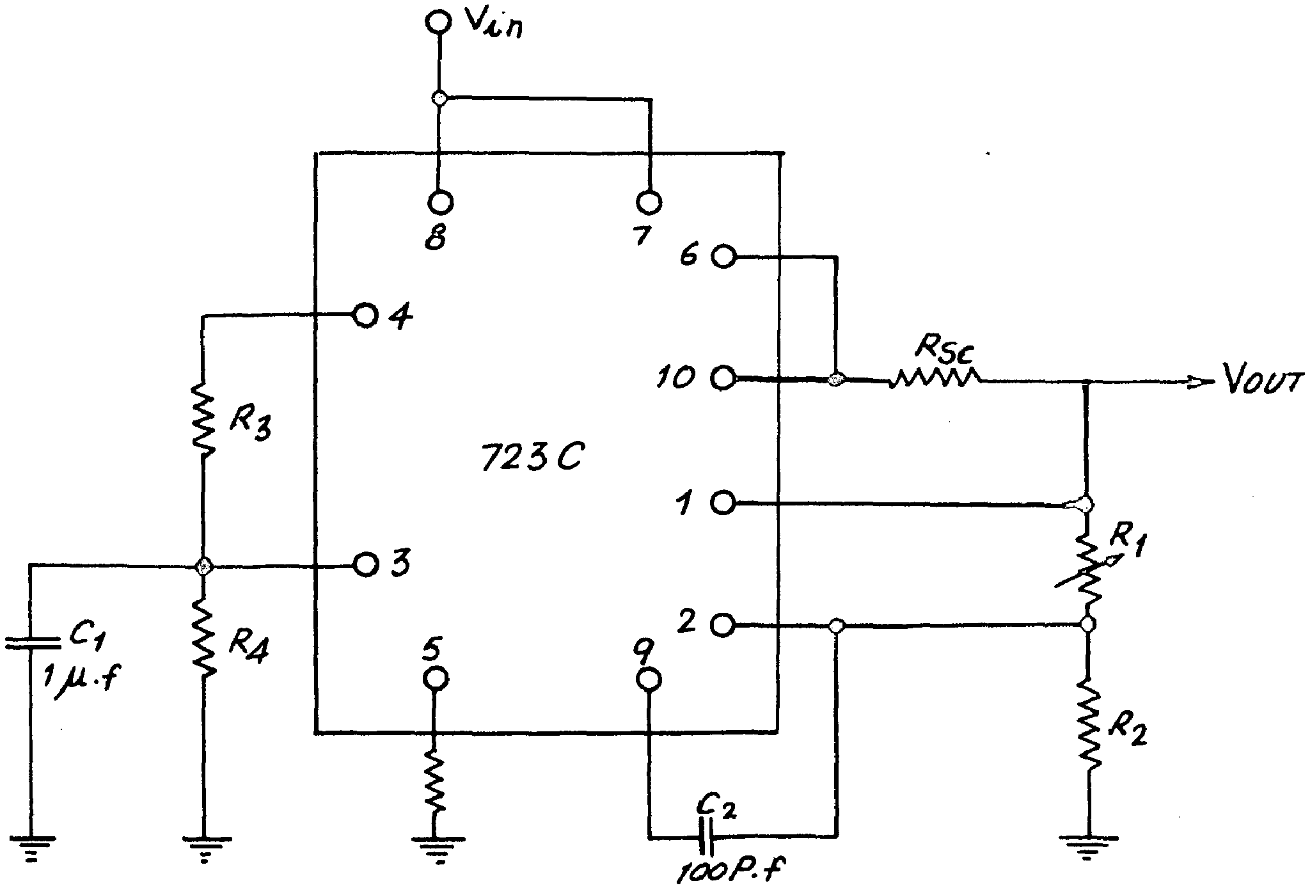


FIG. 8.6 VARIABLE STABLIZED D.C. SUPPLY USING IC 723C

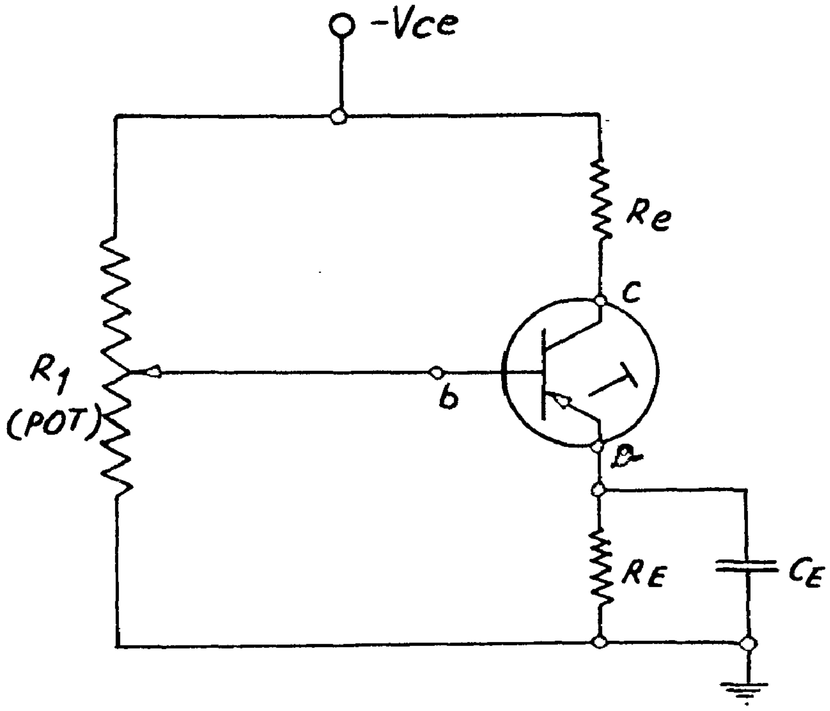


FIG. 8.7 PRE-AMPLIFIER FOR PHOTO-TRANSISTOR

is shown in Fig. 8.5. Speeds higher than the rated are obtained by decreasing field current, and speeds lower than the rated are obtained by decreasing the armature current. A variation of 150 r.p.m. to 4000 r.p.m. in speed is obtained by the motor, which gives a chopping frequency variation of 10 Hz to 25 KHz.

8.2.3 <u>REGULATED D.C. SUPPLY</u> (For Biasing) : The fixe d.c. supply, which is input to the voltage regulator is 12 V battery. The circuit diagram for variable stabilised supply using IC 723 is shown in Fig. 8.6.

<u>Design</u>: (From Fig. 8.6)

V_{zener} (given) = 7 V

Variation required = 2V - 12 V

Short circuit current I_{sc} = 30 mA

Take V_{ref} = 1.0 V

From Fig. (8.6)

$V_{ref} = 7 \times R_4/(R_3 + R_4)$

or $1.0 = 7 \times \dfrac{R_4}{R_3 + R_4}$

Take $R_4 = 1\ K\Omega$

Therefore

$R_3 + 1 = 7$ or $R_3 = 6\ K\Omega$

R_{SC} (Short circuit resistances) = $\dfrac{V_{BE}}{I_{SC}} = \dfrac{0.6}{30 \times 10^{-3}}$

$$\therefore \; R_{SC} = 20\,\Omega$$

where,

V_{BE} = Voltage drop across base to emitter.

$$V_{out} = V_{ref} \times \frac{(R_1 + R_2)}{R_2}, \quad R_2 = 7\ K\Omega \text{(say)}$$

where $R_1 = 0$; $V_{out} = V_{ref}$

$$V_{out} = 1.0\ V$$

When $R_1 = 10\ K\Omega$ $\quad V_{out} = 1.0 \times \dfrac{10 + 1}{1}$

$$= 11\ V$$

Therefore, the final values are :

$R_1 = 10\ K\Omega$ Pot.; $R_2 = 1\ K\Omega$; $R_3 = 5.6\ K\Omega$; $R_4 = 1\ K\Omega$

$C_1 = 5\ \mu F$ and $C_2 = 100\ pF$.

8.2.4 PREAMPLIFIER AND AMPLIFIER : It is stated in section 8.1 that preamplifier is one of the most critical component in the entire test set. Every detector should have its own preamplifier[2,3].

The author has provided two preamplifiers, one for photo transistors type detectors, and other for cell type detectors (such as photo conductive, thermistors etc.), having impedances 10 Ω to 1 MΩ approximately.

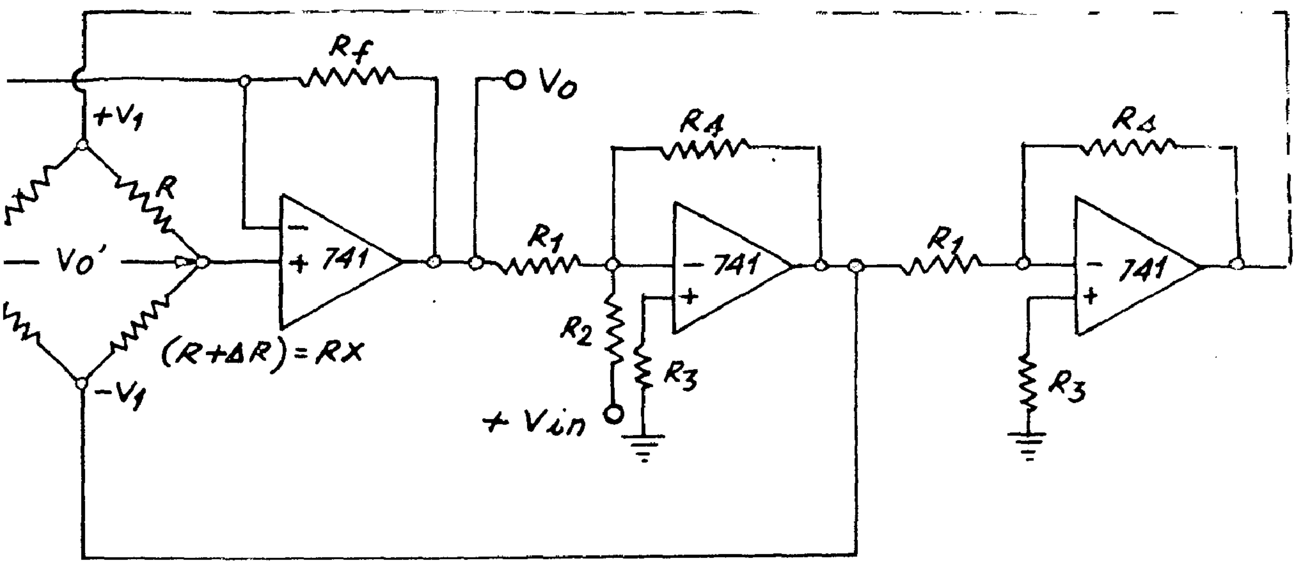


FIG. 8.8 LINEARIZED BRIDGE CIRCUIT

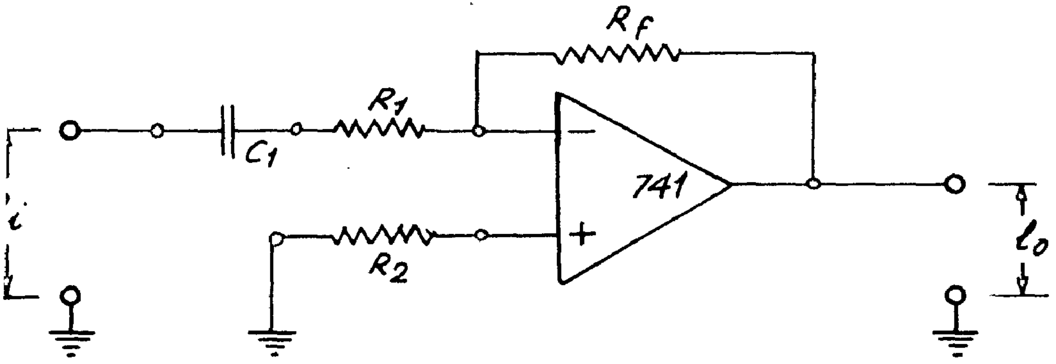


FIG. 8.9 A.C. AMPLIFIER

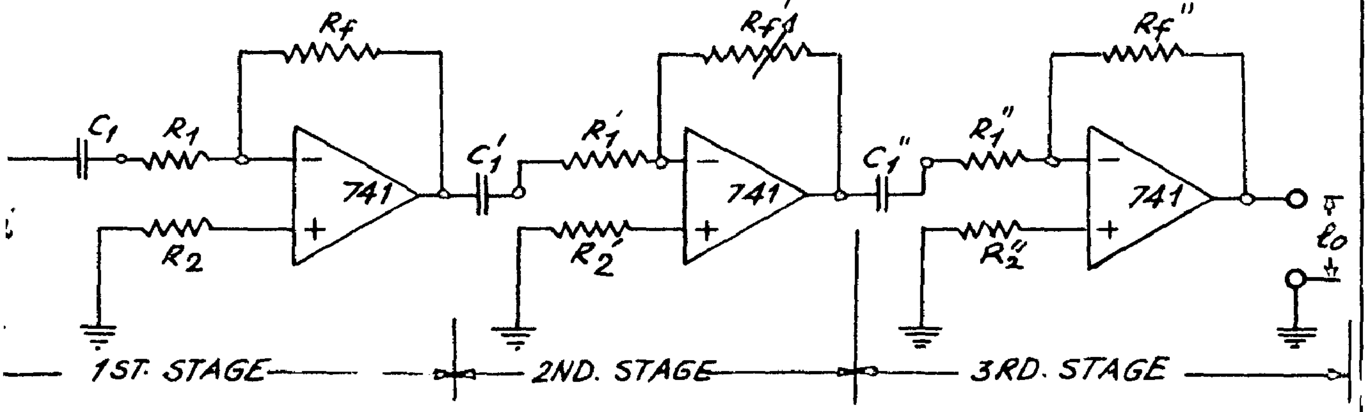


FIG. 8.10 A.C. AMPLIFIERS IN CASEADER

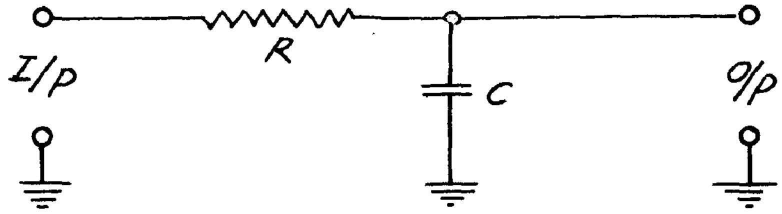


FIG. 8.11 LOW PASS FILTER

The preamplifier used for cell type detectors is basically a bridge circuit. The arrangement is in such a way that the out of balance voltage from bridge becomes the measure of cell resistance. This bridge works as a preamplifier also for cell, under test.

(a) Pre-amplifier for photo transistor type detectors :

Consider Fig. 8.7

Take load resistance R_c = 10 K Ω

Voltage of point = − 3 V

Supply voltage = − 10 V

Therefore, current through R_c under saturation condition is $= \frac{(-10 + 3)V}{10 \times 10^3 \Omega} = 0.7$ m.A.

Therefore $R_E = \frac{3V}{0.7 \text{ m.A}} = 4.3$ K Ω

Take R_E = 4.7 K Ω

Also take pot R_1 = 10 K Ω Minimum frequency at which the transistor can be applied for operation is 100 Hz.

$$\text{Therefore} \quad C_E \gg \frac{1}{2 \pi f R_E} = \frac{1}{2 \times 3.14 \times 100 \times 4700}$$

$$= \frac{10^{-5}}{6.28 \times 4.7}$$

$$C_E \gg 0.034 \ \mu\text{.f.}$$

Take C_E = 10 μ.f.

(b) Bridge Circuit for Cell type detectors[22]

Bridge circuit for cell type detectors is shown in

$R_f = 1\ M\Omega$, $R_1 = 10\ K\Omega$, $R_2 = 10\ K\Omega$, $R_3 = 4.7\ K\Omega$ and $R_4 = 10\ K\Omega$. By using these values practically good results are obtained when Rx is varied from 100Ωto 1 MΩ.

(c) Amplifier :

The amplifier is essential so as to drive the final output displays devices or recorders, because preamplifiers output is too low.

A simple a.c. amplifier using one operational amplifier is shown in fig. 8.9. The value of C_1 is decided by the cut off frequency and the resistance R_1[12] i.e.

$$C_1 \geqslant \frac{1}{2\pi f_c R_1} \quad \text{where, } f_c = \text{cut off frequency}$$

For getting higher amplification two or more stages of such amplifiers are used in cascade (Fig. 8.10).

Design : From FIG 8.10

1st stage : Cut off frequency = 100 Hz

take gain = 10

and R_1 = 33 KΩ

Therefore, $R_f = R_1 \times 33 = 330\ K\Omega$

$$\text{and } R_2 = \frac{R_1 \times R_f}{R_1 + R_f} = \frac{33 \times 330}{330 + 33} = \frac{33 \times 330}{360}\ K\Omega$$

$$\simeq 30\ K$$

Fig. 8.8. With an additional of feed back circuit, the output voltage of standard resistance bridge can be made to vary linearly for a change in bridge resistance. The feedback circuit provides good sensitivity for a wide range of bridge resistance variations, while maintaining the full scale linearity of the bridge output voltage within 0.1%. Furthermore an a.c. or d.c. voltage may be used to excite the bridge[11].

The output of the bridge remains zero as long as its four resistance arms are equal to each other. One arm of the bridge is variable from this resistance null.

$$R_x = R + \Delta R$$

Where, ΔR represents the change in bridge resistance, Now for standard bridge

$$V_0' = V_1 \quad R/(2\,R + \quad R)$$

This is not a linear relationship, since ΔR appears in the denominator. Now by applying feedback the bridge excitation voltage changes in such a way that the relationship between output voltage and R becomes linear (Appendix - 1).

For best results R_x can be varied from 0 to 2 R. The author has taken the values of $R = 470\ K\Omega$, Take $R_2 = 33\ K\Omega$

Now $e_1 \geqslant \frac{1}{2\ f_e\ R_1}$

$$\geqslant \frac{1}{2 \times 3.14 \times 100 \times 33 \times 10^3}$$

$$\geqslant \frac{10^{-5}}{6.28 \times 33}$$

$$\geqslant 0.048 \times 10^{-6} = 0.048\ \mu.f.$$

Take $C_1 = 0.44\ \mu.f.$

2nd stage : It is a variable gain stage.

Take $R'_1 = 10\ K\Omega$ and take gain = 100

Thereforé $R'_f = 100 \times R_1$ or $R_f = 1\ M\Omega$ (Pot)

$$R'_2 = \frac{R'_1 R'_f}{R'_1 + R'_f} = \frac{10 \times 10^3}{10 + 1000}\ K\Omega$$

$$\simeq 10\ K\Omega$$

Take $R'_2 = 10\ K\Omega$

$$C'_1 \geqslant \frac{1}{2\ \pi f_c R'_1}$$

$$\geqslant \frac{1}{2 \times 3.14 \times 100 \times 10^4}$$

$$\geqslant \frac{10^{-6}}{6.28}$$

$$\geqslant 0.16\ \mu.f.$$

Take $C'_1 = 0.44\ \mu.f.$

3rd Stage : Take $R''_1 = 10 K\Omega$ and gain = 100

$$\therefore \quad R''_f = R''_1 \times 100 = 10 \times 100\ K\Omega$$

$$= 1\ M\Omega$$

$$\therefore \quad R''_2 = \frac{R''_1 \times R''_f}{R''_f + R''_1} = \frac{10 \times 10^3}{10 + 1000}\ K\Omega$$

$$\simeq 10\ K\Omega$$

Take $R''_2 = 10\ K\Omega$

$$C''_1 \geq \frac{1}{2\pi f_e R''_1}$$

$$\geq \frac{1}{2 \times 3.14 \times 100 \times 10^4}$$

$$\geq \frac{10^{-6}}{6.28}$$

$$\geq 0.16\ \mu.f.$$

Take $C''_1 = 0.44\ \mu.f.$

2.8.5 <u>LOW PASS FILTER</u> : To measure the signal, noise must be filtered out. For this purpose all frequency appearing above 2.5 K Hz must be filtered out. Fig. 11 shows a simple passive filter, By cascading these filters effective filtering (selectivity becomes higher) can be done.

Design : Max. frequency = 2.5 KHz

$$\therefore \quad \text{Time constant} = \frac{1}{2.5} \times 10^{-3}\ \text{Sec.}$$

$$= 0.4\ \text{m.sec.}$$

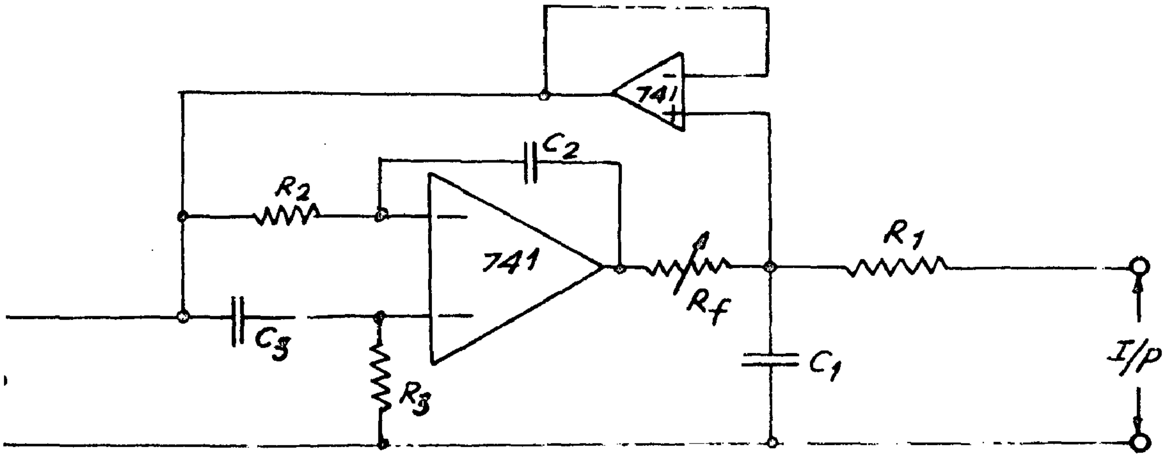


FIG. 8. 12 TUNEABLE BAND PASS FILTER

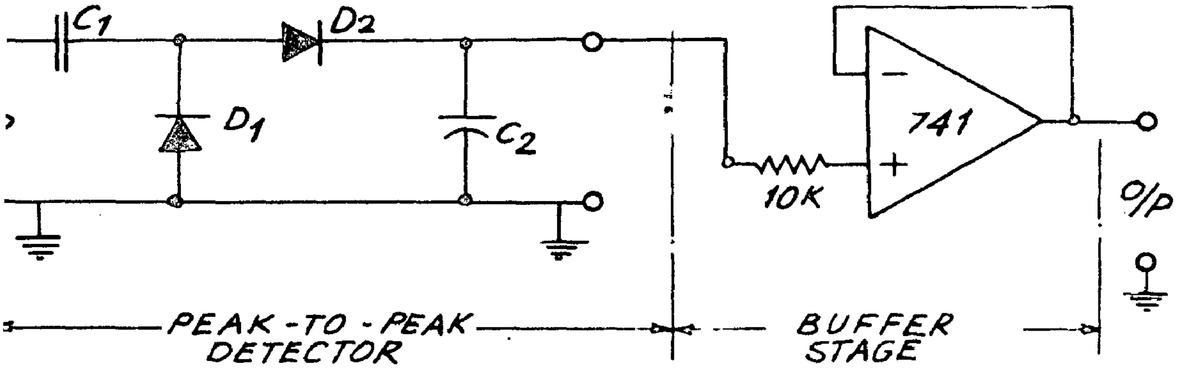


FIG. 8.13 PEAK-TO-PEAK DETECTOR

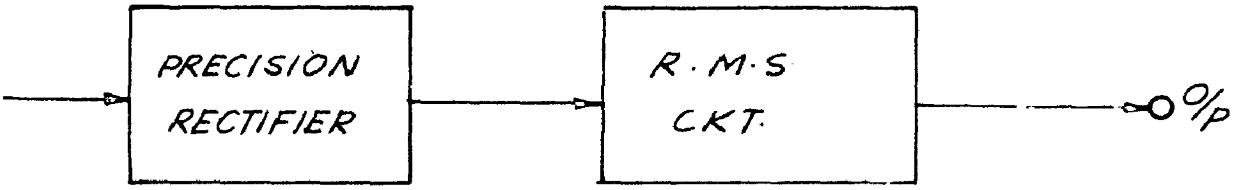


FIG. 8. 14 BLOCK DIAGRAM FOR R.M.S. RESPONDING CKT.

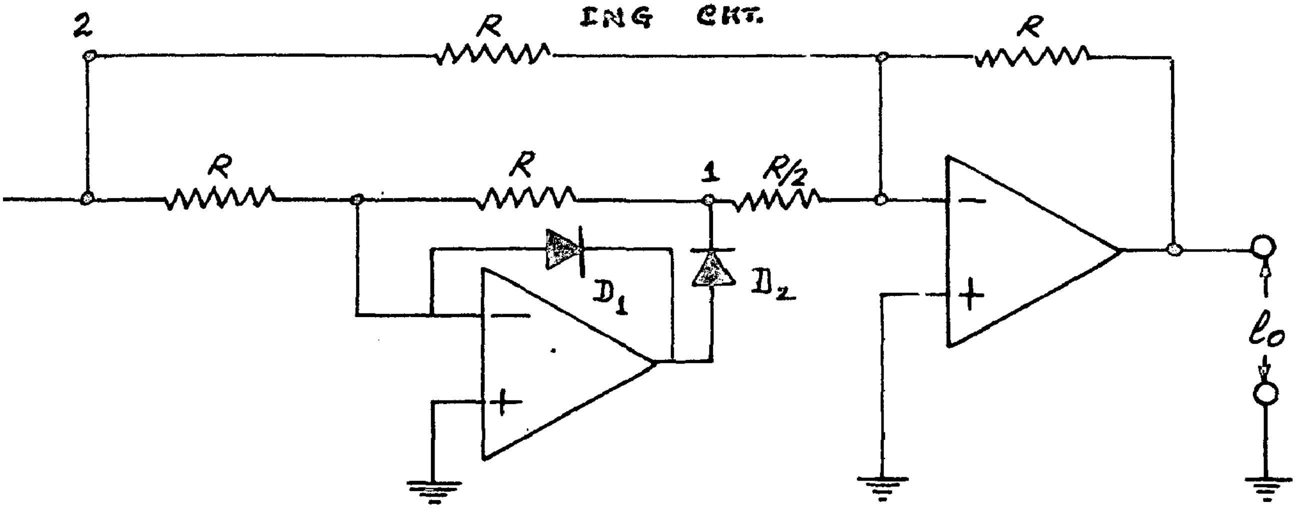


FIG. 8.15 PRECISION RECTIFIER CKT.

Take C = 0.1 μ.f.

Therefore R~~e~~c - time constant

$$\text{or} \quad R \times 0.1 \times 10^{-6} = 0.4 \times 10^{-3}$$

$$\text{or} \quad R = 4 \times 10^{3} = 4\ K\Omega$$

Take R = 4.7 KΩ

For high selectivity author has used three such filters.

Next stage to filter is an amplifier . The amplifier used here by author is having a gain of 6 approximately.

2.8.6 TUNABLE BAND PASS FILTER[22]

It is desirable to plot noise spectrum of the detector under test. For this purpose a tun~~e~~able band pass filter is used by author. The circuit diagram for such filter is shown in Fig. 8.12.

Design . Design equations are

$$K_1 = (R_f\ C_1 R_2 C_2)^{\frac{1}{2}} = \frac{1}{2\pi f_o}$$

$$K_2 = R_1 C_1 = \frac{1}{2\pi\ BW}$$

$$K_3 = (R_f C_1 / R_2 C_2)^{\frac{1}{2}}$$

$$= \left[\left(\frac{V_{oS}}{e_{o\ max}}\right)^2 - 1\right]^{\frac{1}{2}}$$

Now filters time constant can be computed as

$$R_1C_1 = K_2$$

$$R_2C_2 = \frac{K_1}{K_3}$$

$$R_fC_1 = K_1K_3$$

$$R_f/R_1 = \frac{K_1K_3}{K_2}$$

where, f_o = ~~control~~ central frequency = 100 Hz

V_{os} = Output voltage swing of operational amplifier = 20 V pk - pk

$e_{o\ max}$ = maximum output voltage = 1V pk - pk

B.W = Band width = 5 Hz

Therefore, $K_1 = \frac{1}{2\ f_o} = \frac{1}{2 \times 3.14 \times 100}$

$$= 1.59 \times 10^{-3}$$

$$K_2 = R_1C_1 = \frac{1}{2\ BW} = \frac{1}{2 \times 3.14 \times 5}$$

$$= 3.18 \times 10^{-2}$$

$$K_3 = \left(\frac{V_{os}}{e_{o\ max}}\right)^2 - 1^{\frac{1}{2}} = \left(\frac{20}{1}\right)^2 - 1^{\frac{1}{2}}$$

$$= (399)^{\frac{1}{2}} = 19.99$$

and $R_1C_1 = K_2 = 3.18 \times 10^{-2}$

$$R_2C_2 = K_1/K_3 = 7.76 \times 10^{-5}$$

$$R_fC_1 = K_1K_3 = 3.18 \times 10^{-2}$$

$$R_f/R_1 = K_1K_3/K_2 = 1$$

Take $C_1 = 0.1\ \mu.f.$

Therefore $R_1 = \dfrac{3.18 \times 10^{-2}}{0.1 \times 10^{-6}} = 3.18 \times 10^{5}$

$= 318\ K\Omega$

Take $R_1 = 330\ K\Omega$

Therefore, $R_f = 1 \times R_1$

$= 330\ K\Omega$

Take $R_f = 470\ K\Omega$ (Pot)

Take $C_2 = 0.001\ \mu.f.$

Therefore $R_2 = \dfrac{7.96 \times 10^{-6}}{0.001 \times 10^{-6}}$

$= 7.96\ K\Omega$

Take $R_2 = 8.2\ K\Omega$

final values are : $C_1 = 0.1\ \mu.f.$
$R_1 = 330\ K\Omega$
$R_2 = 8.2\ K\Omega$
$C_2 = 0.001\ \mu.f.$
$R_f = 470\ K\Omega$ pot

8.2 PEAK TO PEAK RESPONDING CIRCUIT[23] : Circuit is shown in Fig. 8.13.

Input impedance of buffer stage is 1 M Ω = Rin

Input frequency minimum = 10 Hz

$R_{in} C_2 > 1/10$

or $C_2 \quad \frac{1}{10 \times 10^{-6}} = 0.1$ μ.f.

Take $C_2 = 1$ μ.f.

and C_1 should be $> C_2$

Take $C_1 = 10$ u.f.

also, take diodes D_1 and D_2 as SR 204.

8.2.8 R.M.S. RESPONDING CIRCUIT : R.M.S. responding circuit has two parts namely : precision rectifier and r.m.s circuit.

(a) Precision Rectifier[12] (Appendix - 2)

Design from fig. 8.15

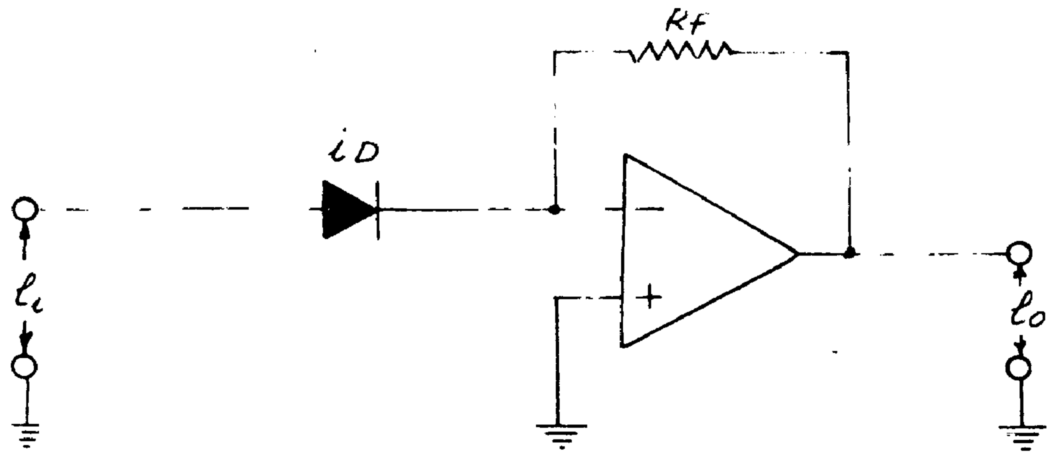
Take R = 1 K Ω

Therefore R/2 = 500 Ω take this as 470 Ω

Diodes : SR 204

Operational amplifier = 741 C

With the help of the circuit shown in Fig. 8.15 voltage above 0.2 V are rectified if germanium diodes are used. Still batter rectification i.e. for the rectification of lower voltage than the 0.2 V, a gain in last stage operational amplifier is provided.



(a)

FIG 8.16 R.M.S. RESPONDING CKT.

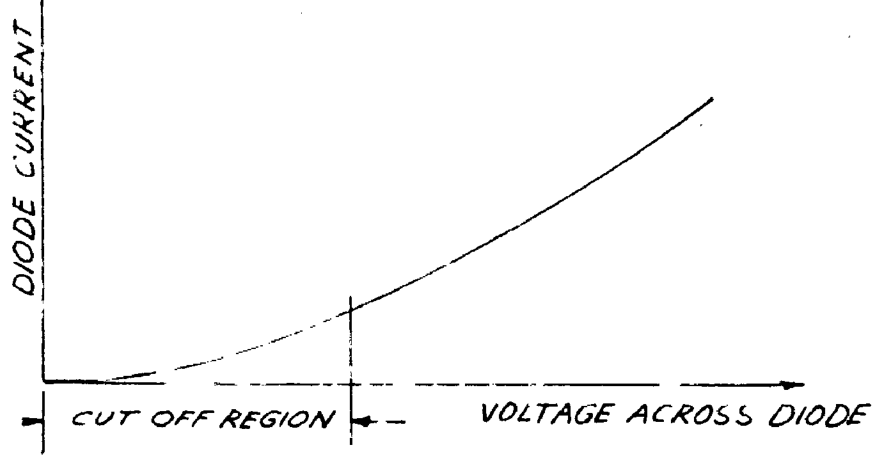


FIG 8.16(b) DIODE CHARACTERISTICS

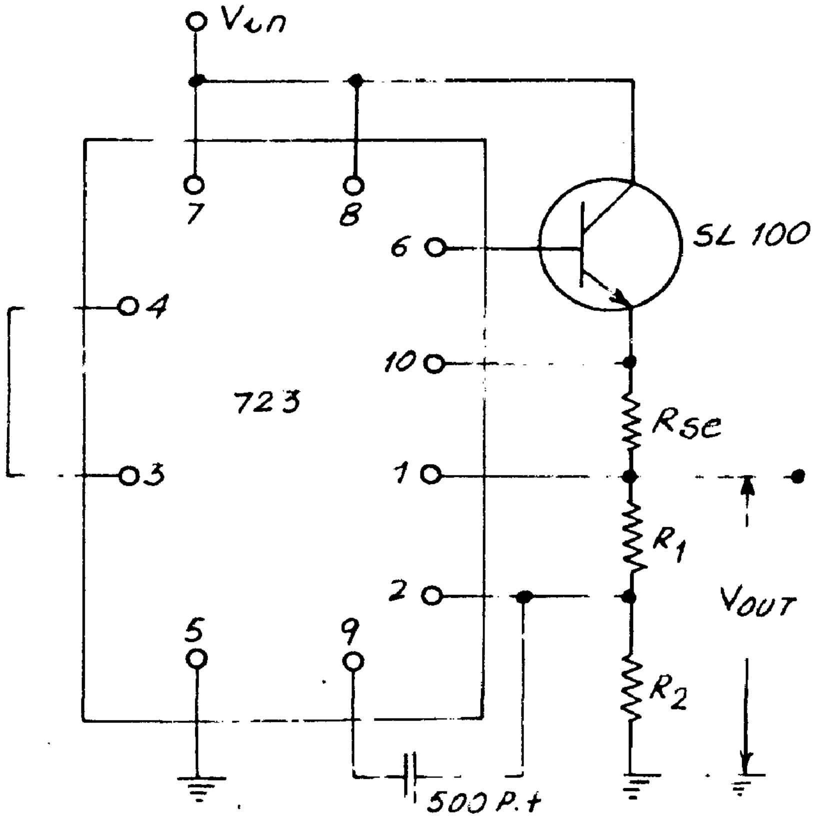


FIG 8.17 STABILIZED POWER SUPPLY USING 723 VOLTAGE REGULATOR

(b) R.M.S. Circuit[12] :

Consider the forward biased diode characteristics shown in Fig. 8.16(b). In cut off region the diode gives sq uare Law characteristics. This is utilized in r.m.s. responding circuit (Fig. 8.16 a). Operational amplifier is used as a current to voltage converter. When e_i voltage is applied at the input the current through diode (i_D) will have relationship :

$$i_D \propto e_i^2$$

$$\text{and} \quad e_o \propto i_D$$

$$\text{i.e.} \quad e_o \propto e_i^2$$

The e_o is fed to a moving coil meter for indication purpose.

8.2.9 STABILIZED POWER SUPPLY : A d.c. stabilized supply of ± 14 V is required for operational amplifiers. For this purpose two voltage regulators (723) are used.

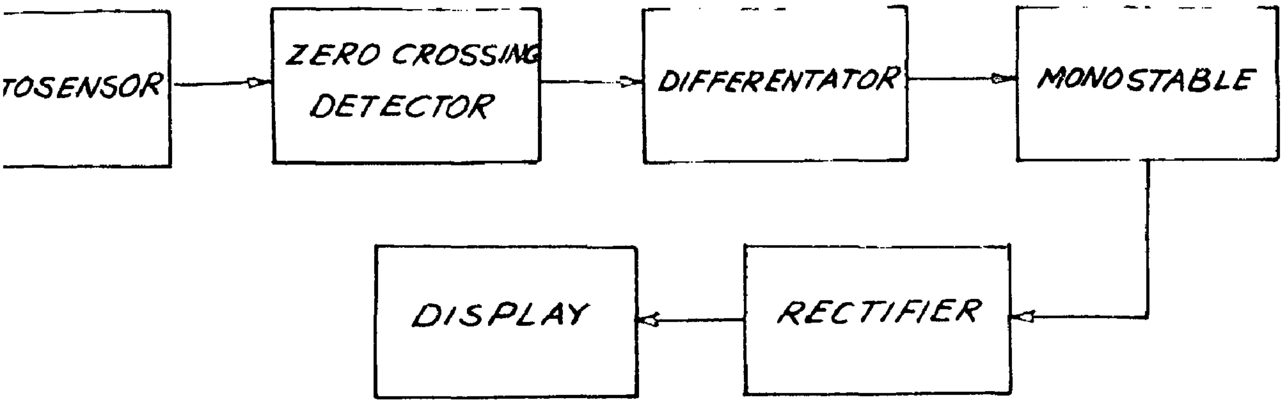
Design : Circuit diagram using 723 regulator and SL 100 transistor is shown in Fig. 8.17.

$$V_{out} = V_{ref} \times \frac{R_1 + R_2}{R_2} \qquad V_{ref} = 7 \text{ V (given)}$$

$$V_{out} = 14 \text{ V}$$

$$14 = 7 \times \frac{R_1 + R_2}{R_2}$$

or $2 R_2 = R_1 + R_2$ or $R_2 = R1$



·8·18 BLOCK DIAGRAM FOR FREQUENCY METER

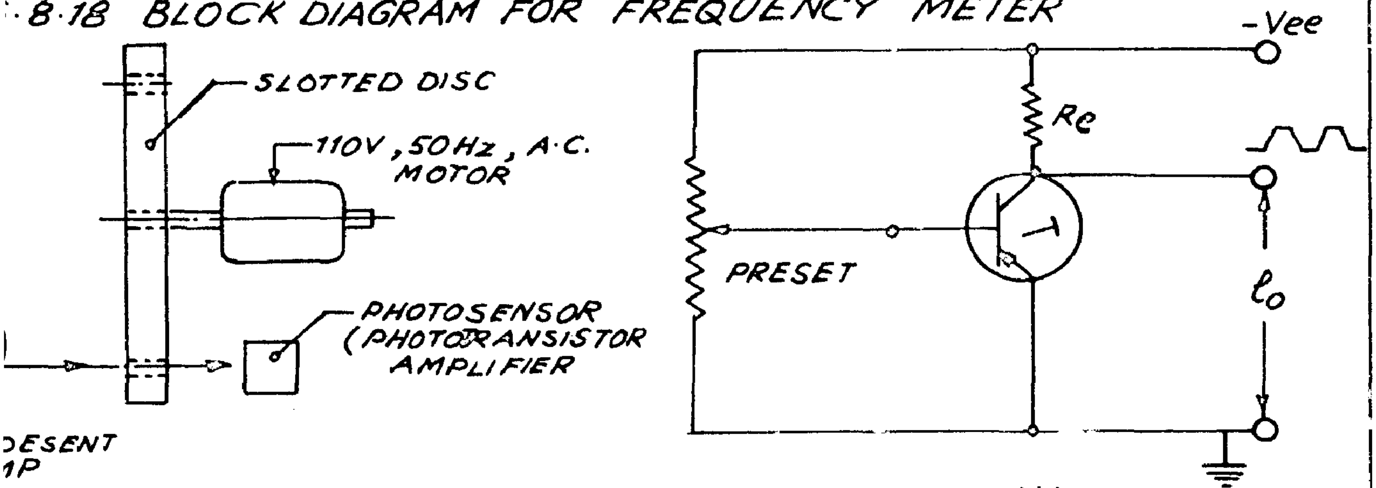


FIG. 19(a)

FIG. 8·19 (b)

FIG.19 CHOPPER FREQUENCY SENSING BY PHOTO METHOD

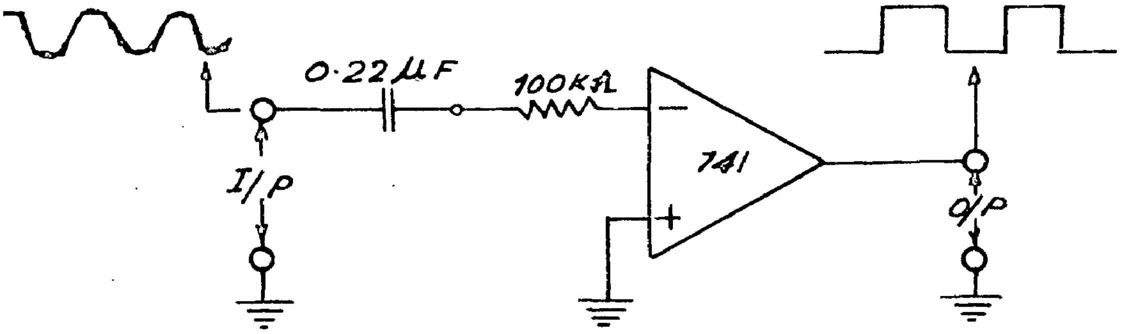


FIG. 8·20 ZERO CROSSING DETECTOR

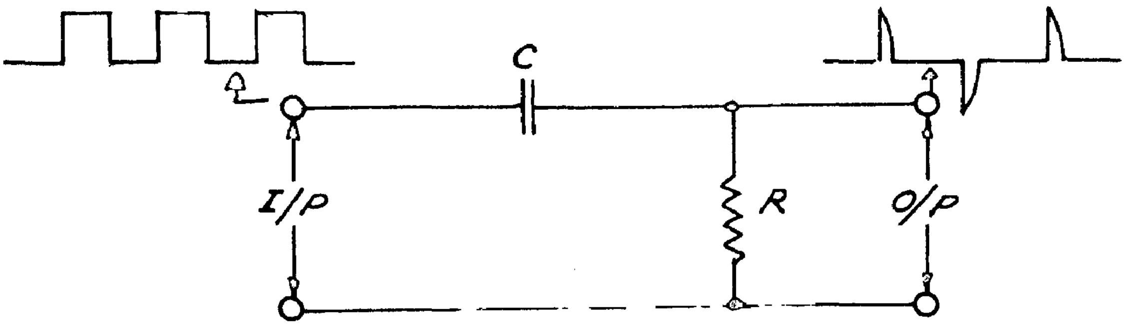


FIG. 8·21 DIFFERENTIATOR

Take $R_2 = R_1 = 1\ K\Omega$

Let short circuit current $I_{Sc} = 200$ m.A

$$\therefore\ R_{Sc} = \frac{V_{BE}}{200\ m.A}$$

$$= 0.6/200 \times 10^3 = 6/2\ \Omega = 3\ \Omega$$

Transistor used is SL 100.

8.2.10 FREQUENCY METER :

To measure the chopper frequency of optical modulator an electronic frequency meter is used. Fig. 8-18 shows the block diagram for frequency meter.

(i) Photo sensor :

A photo sensor is used to sense the presence of absence of slots. The arrangement is shown in FIG. 8-19(a). In this arrangement photo transistor is used to sense the presence or absence of light.

Fig. 8.19(b) shows a photo transistor used as a switch, when light is present, than e_o is zero and when light is absent e_o is - 15 V. A preset is used to bias the base and to limit the current through transistor a resistance R8 is placed. Let the current through transistor under saturation condition is 1.5 m.A. Therefore,

$$R_c = \frac{15\ V}{15\ m.A} = 10\ K\Omega \text{ when supply voltage}$$

is - 15 V.

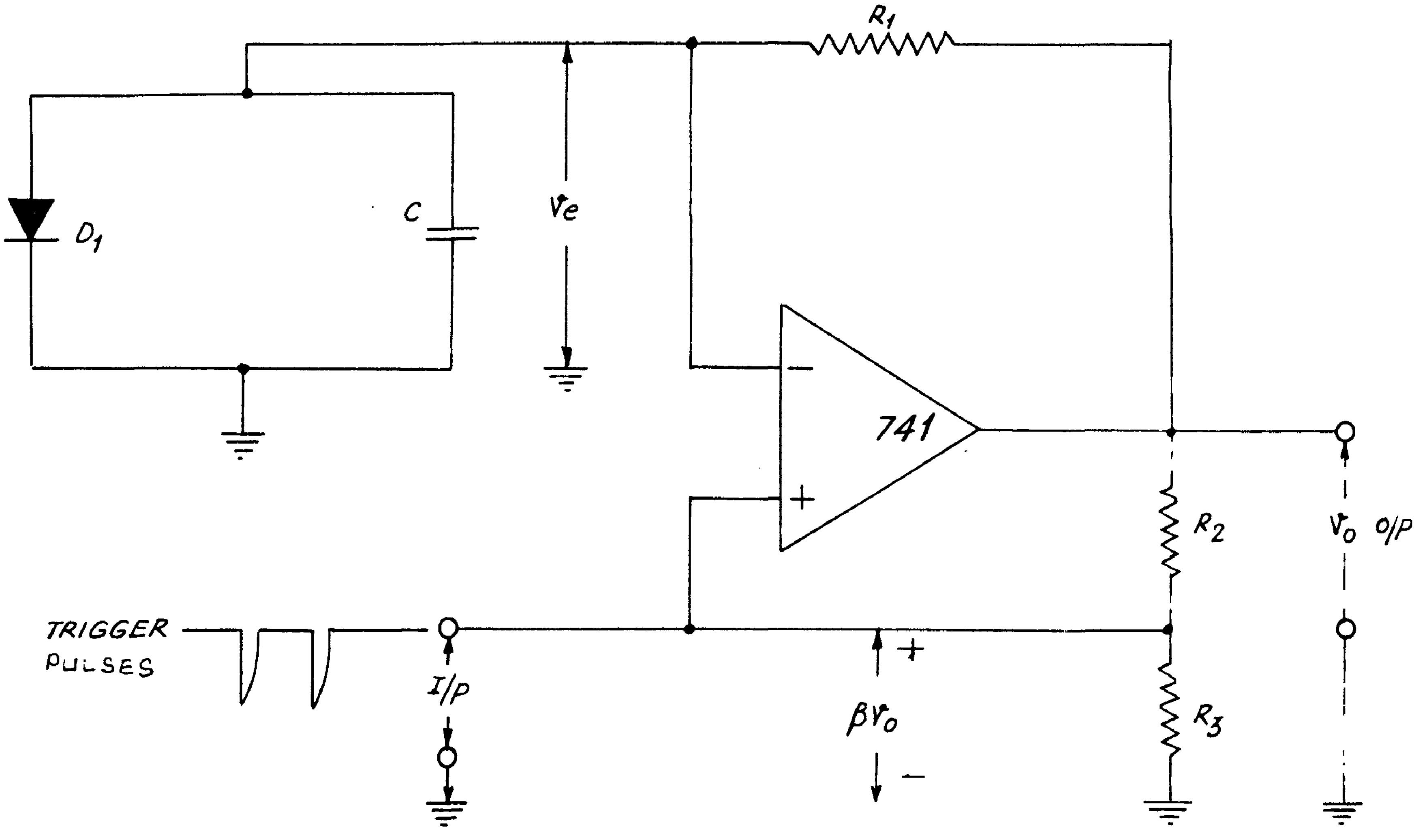


FIG. 8.22 (MONOSTABLE)

(ii) Zero crossing detector :

The output from photo sensor is not perfect square and to shape the waveform of photo sensor a zero crossing detector is used. Fig. 8.20 shows circuit diagram for the same using one operational amplifier 741.

(iii) Differentiator :

To drive monostable negative pulses are required. The output of zero crossing detector is differentiated and to get only negative pulses a diode is used to block the positive pulses. ~~Fig.~~

Design : From Fig. 8.21.

$R_{\phi}C < 1/2.5$ K Hz — Because max. chopper frequency is 2.50 K Hz

$$\text{or } R_{\phi}C < \frac{10^{-3}}{2.5}$$

$$\text{or } R < \frac{10^{-3}}{2.5 \times 10^{-7}}$$

Take C = 0.1 μ.f

$$\text{or } R < \frac{10^{+4}}{2.5}$$

or $R < 4$ K

Take R = 1 K

(iv) Monostable Multivibrator[24] :

Monostable multivibrator circuit is shown in Fig. 8.22.

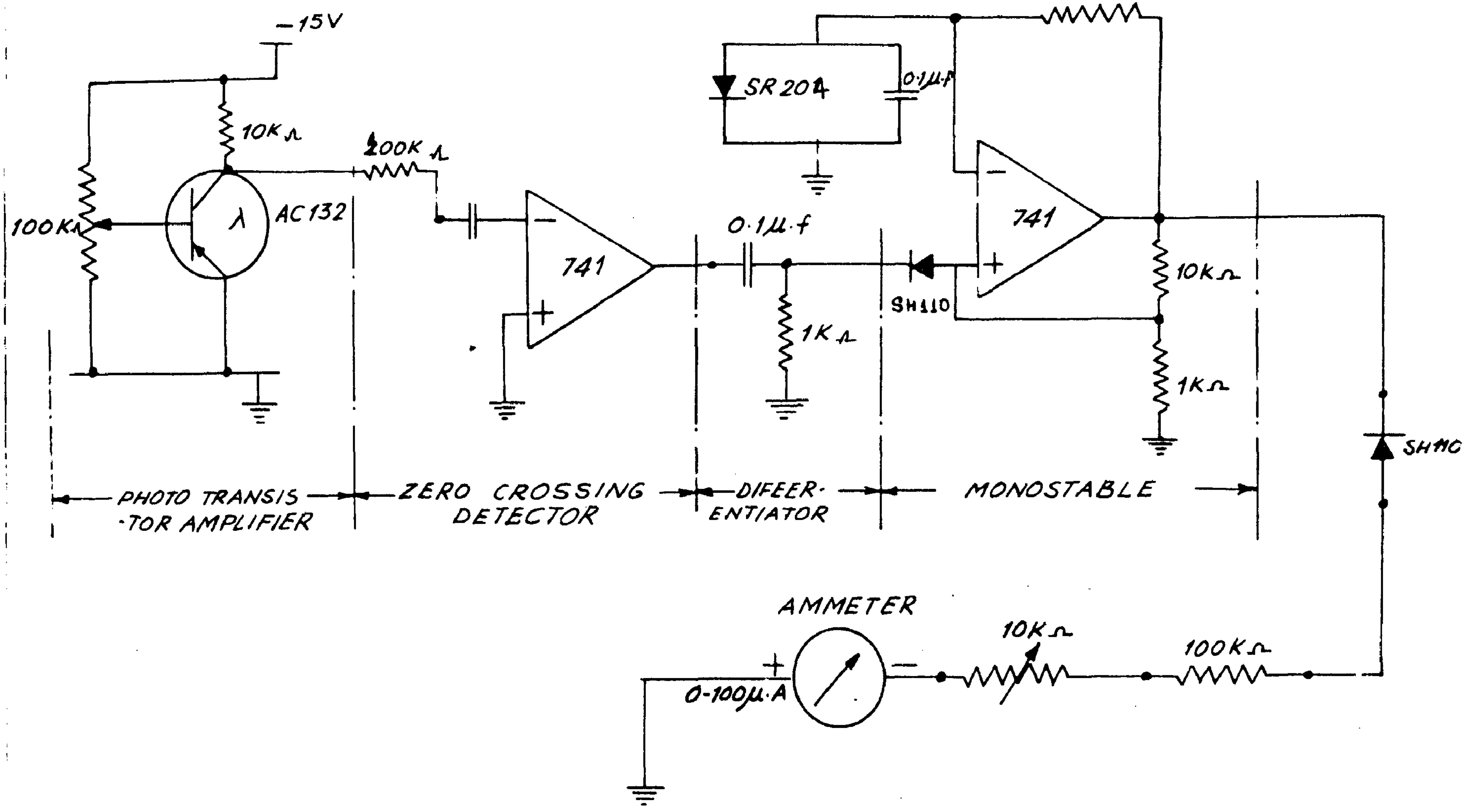


FIG. 8.23 CIRCUIT DIAGRAM FOR FREQUENCY METER

Design :

Take operation amplifier $=$ 741

Diode D_1 $=$ SR 204

$\therefore$ $V_c = 0.2$ V (Since SR 204 is germanium diode).

In the stable state the output of monostable is + 12 V and the capacitor is clamped at

$$V_c = V1 \simeq 0.2 \text{ V.}$$

Pulse width of monostable T is given by

$$T = R'C \ln \left[\frac{(1 + V1/Vo)}{1 - \beta}\right]$$

Take $R_2 = 10\ K\Omega$

$R_3 = 1\ K\Omega$

$$\therefore \quad \beta = R_3/R_2 = 0.1$$

Take C = 0.1 μ.f.

$$\therefore \quad T = R' \times 0.1 \times 10^{-6} \ln \left[\frac{1 + (\frac{0.2}{12})}{0.9}\right]$$

$$T = R' \times 10^{-7} \ln \left(\frac{1.02}{0.9}\right)$$

$$= R' \times 0.122 \times 10^{-7}$$

Take $T = 1.22 \times 10^{-4}$ sec

$$R' = \frac{0.122 \times 10^{-7}}{1.22 \times 10^{-4}}$$

$$= 10^{-4}/10^{-8} = = 10 \text{ K}$$

Complete circuit for frequency meter is shown in Fig. 8.23.

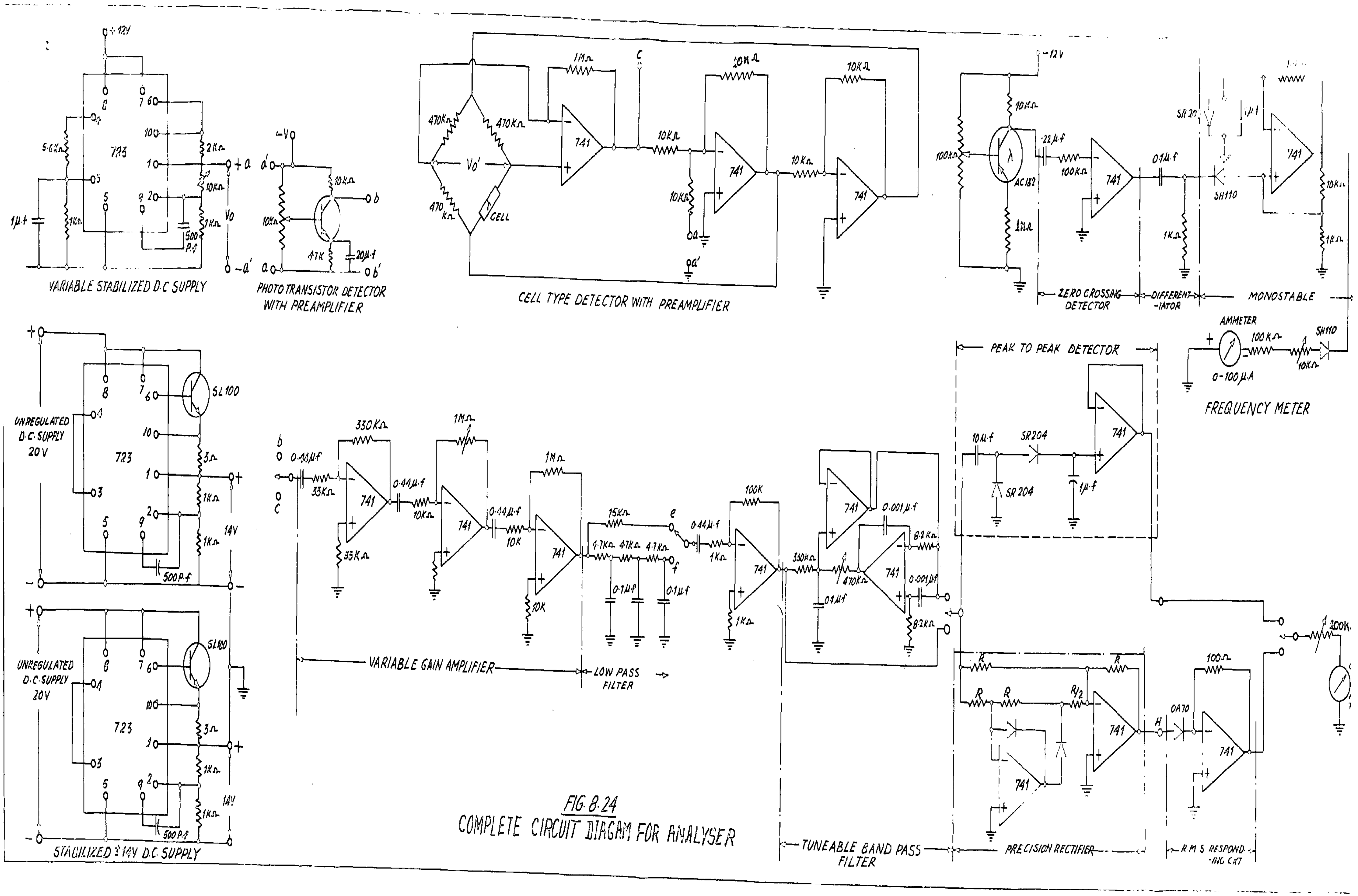


FIG. 8.24
COMPLETE CIRCUIT DIAGRAM FOR ANALYSER

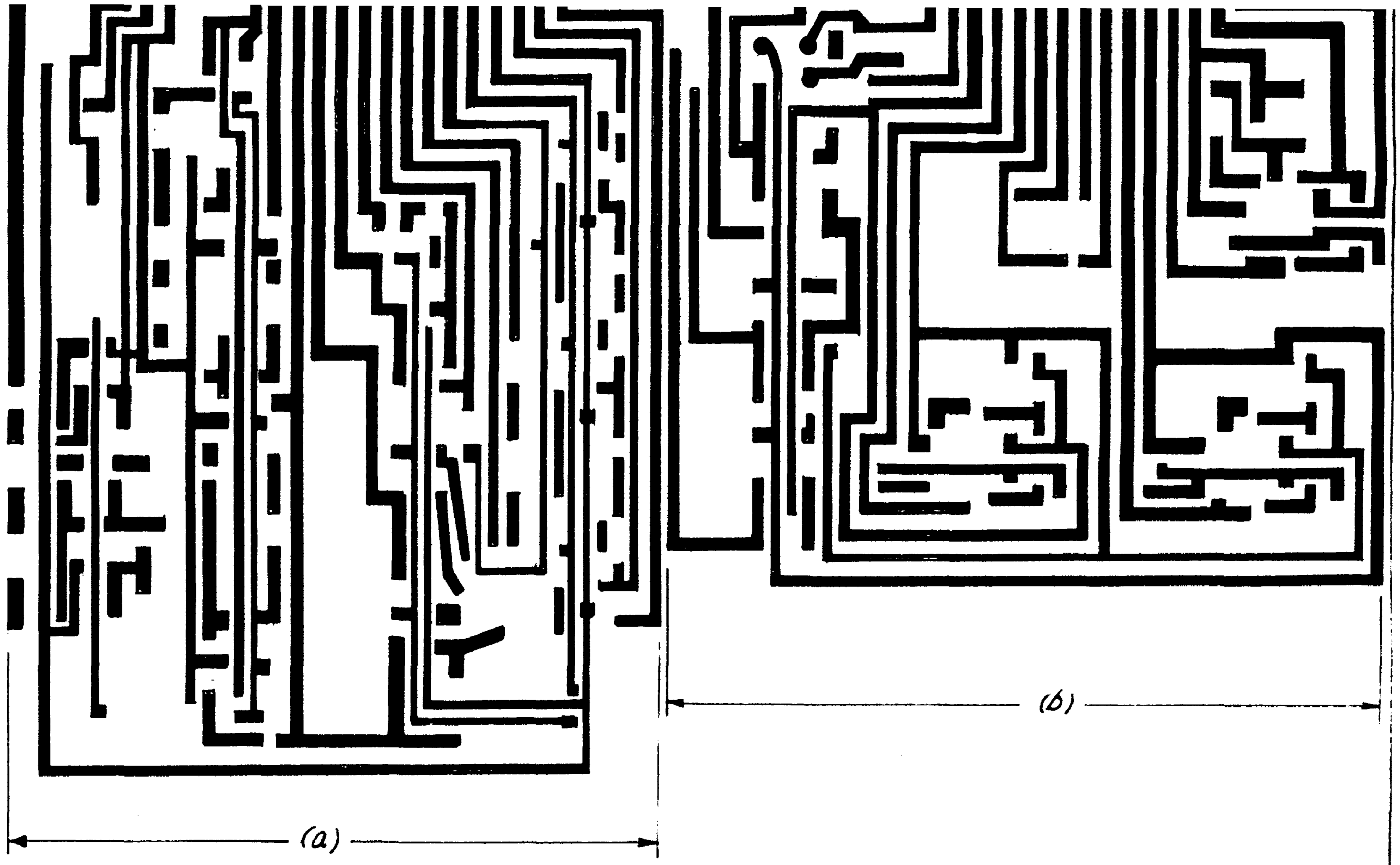
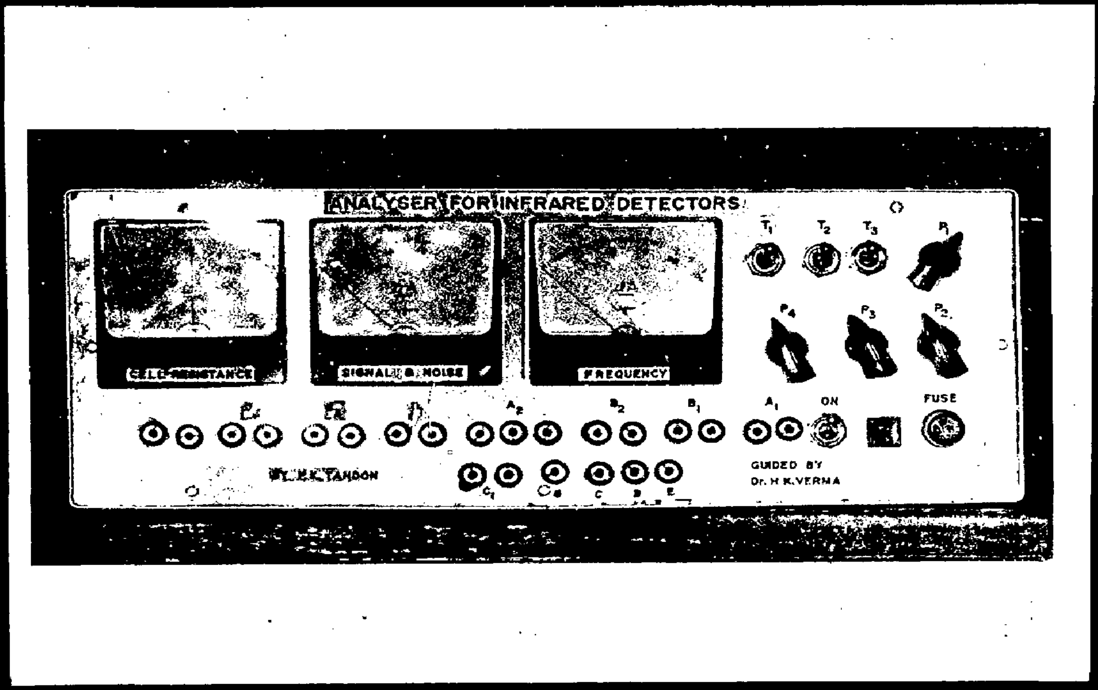
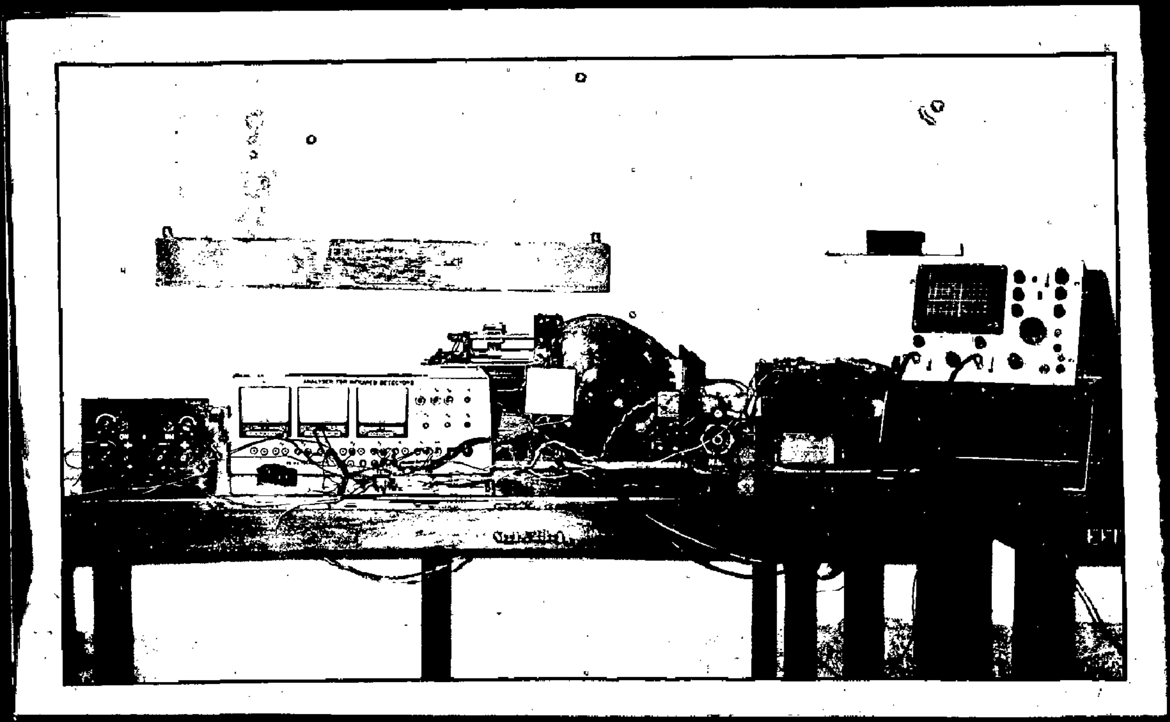


FIG. 8·25 P.C.B. LAYOUT FOR ANALYSER



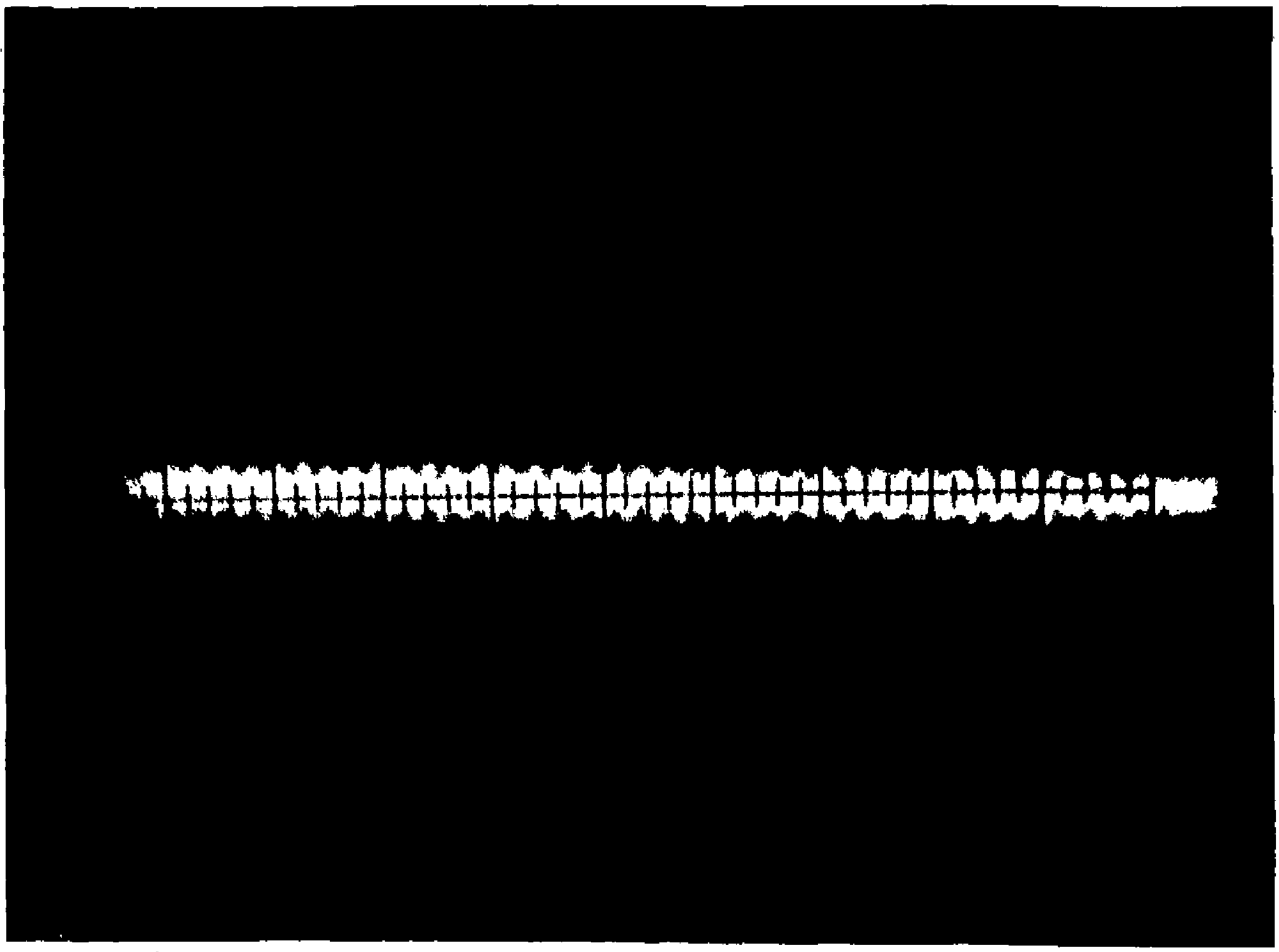
Photograph - 8.1

Analyser Developed



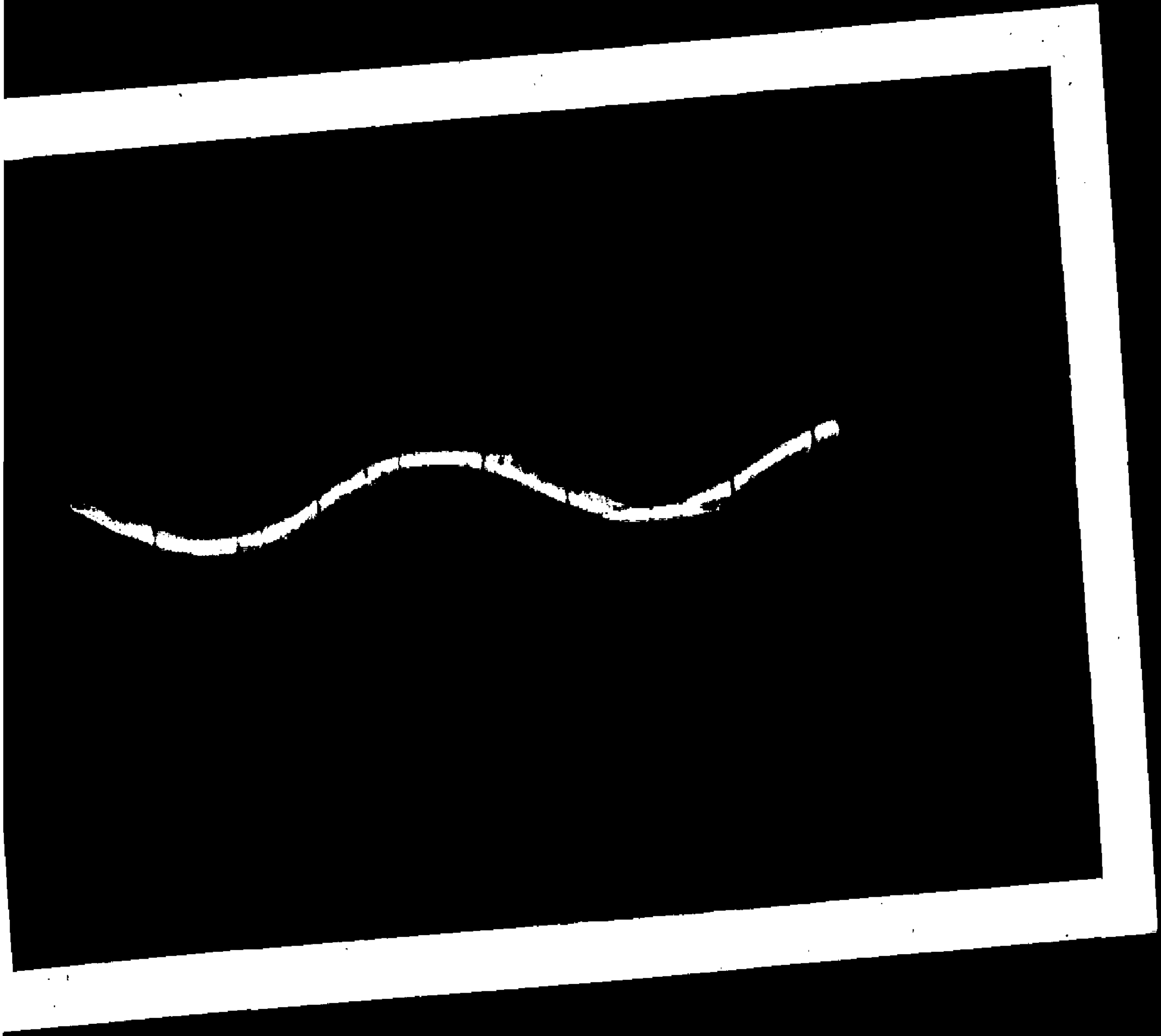
Photograph - 8.2

Analyser System (that includes the analyser, chopper, d.c. power supplies and C.R.O.)



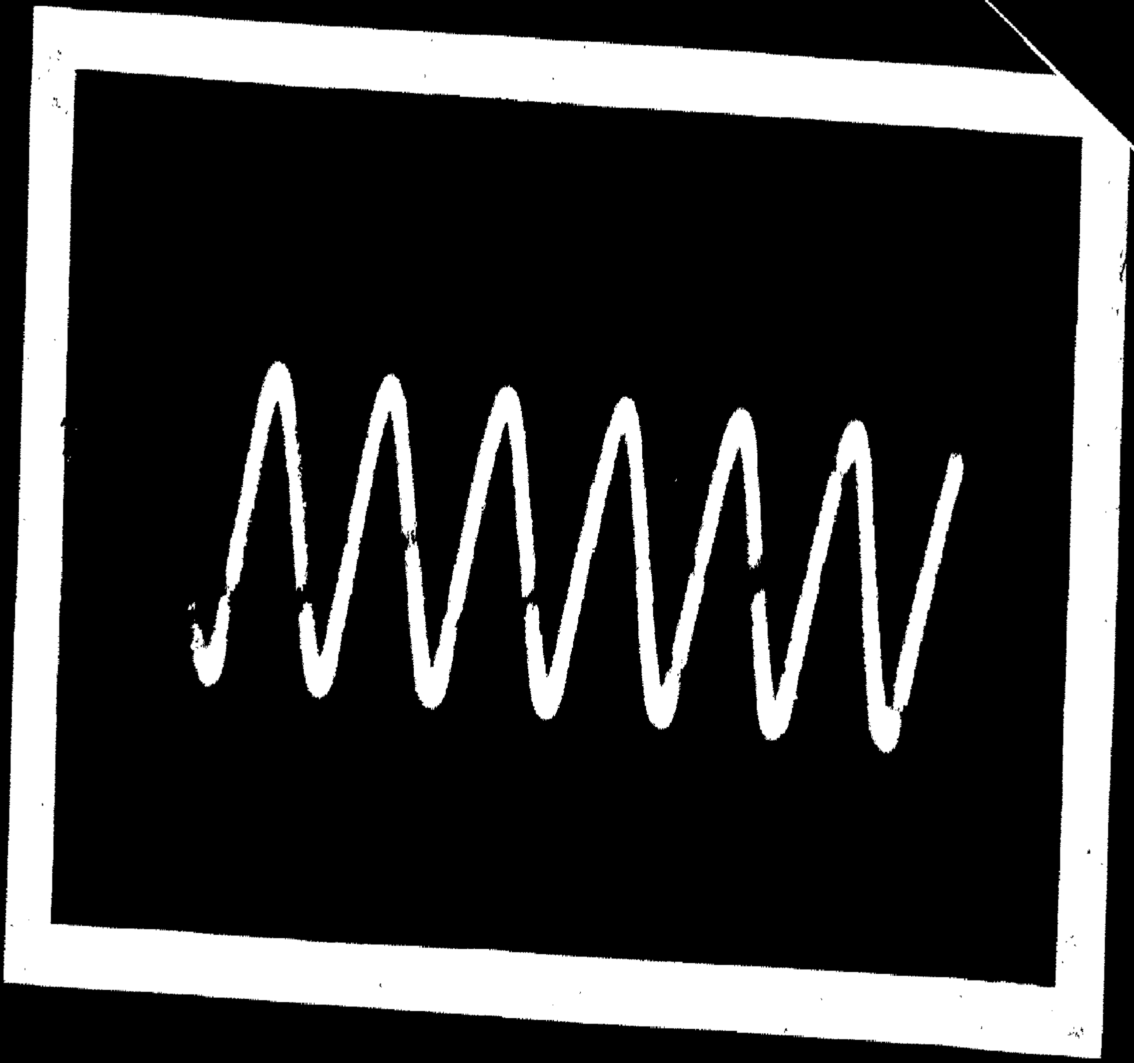
Photograph - 8.3

Noise wave shape of phototransistor A.C. 132



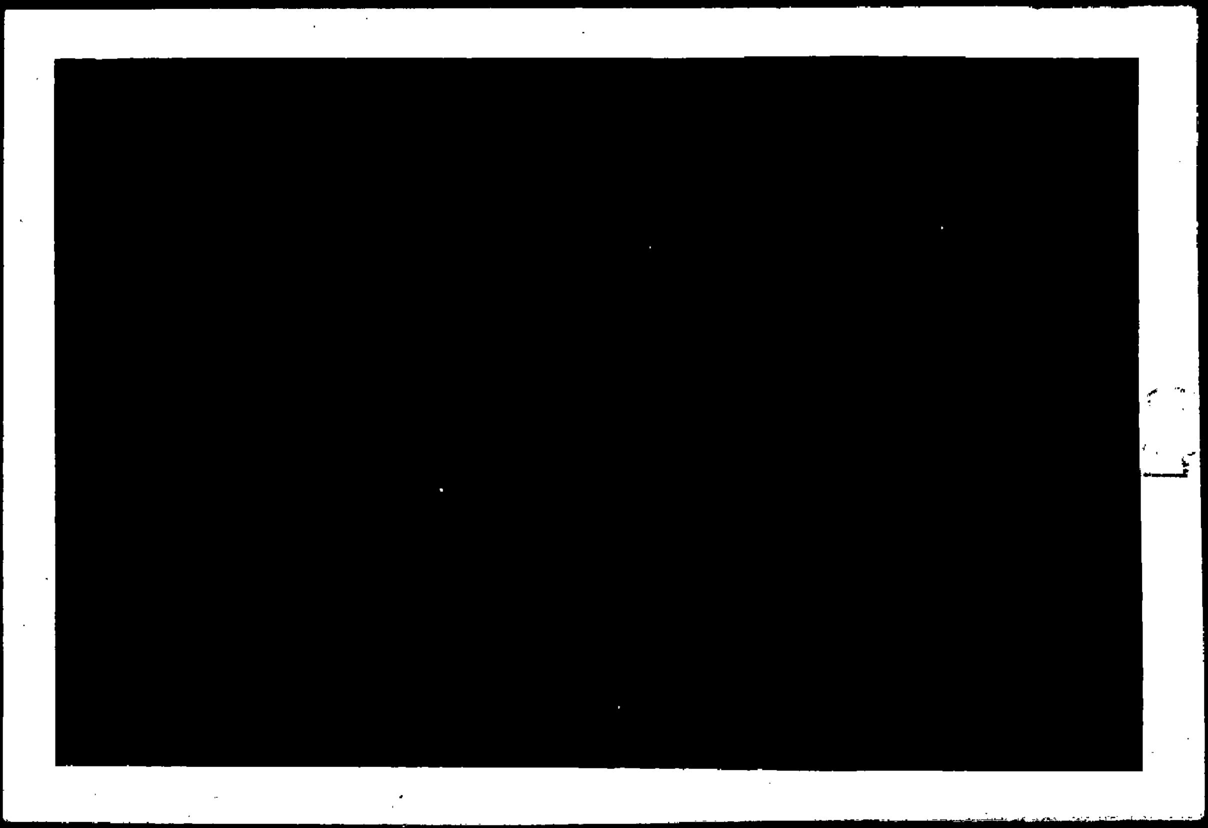
Photograph - 8.4

Output of low pass filter



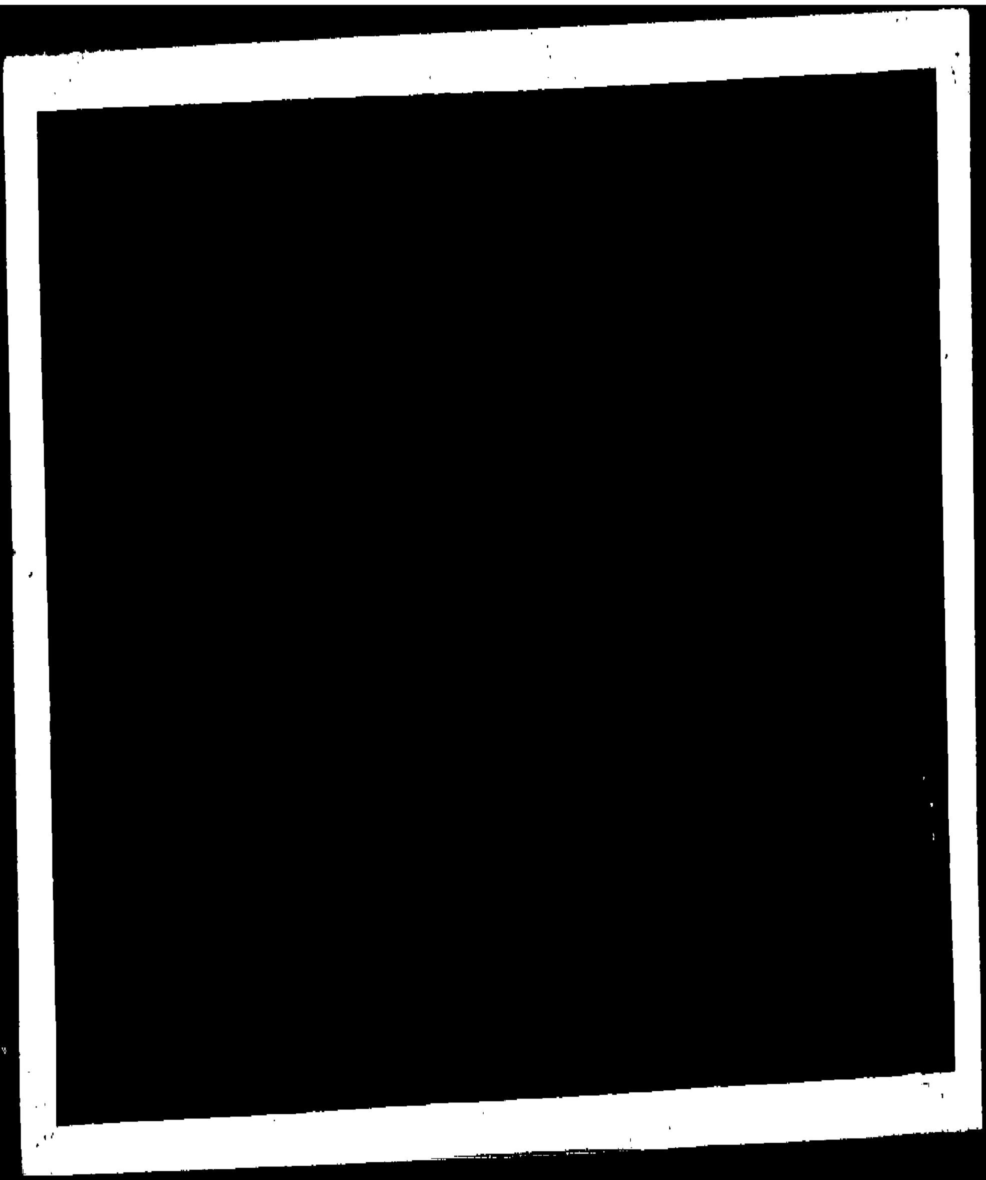
Photograph - 8.5

Output of tunable band pass filter at 10 KHz



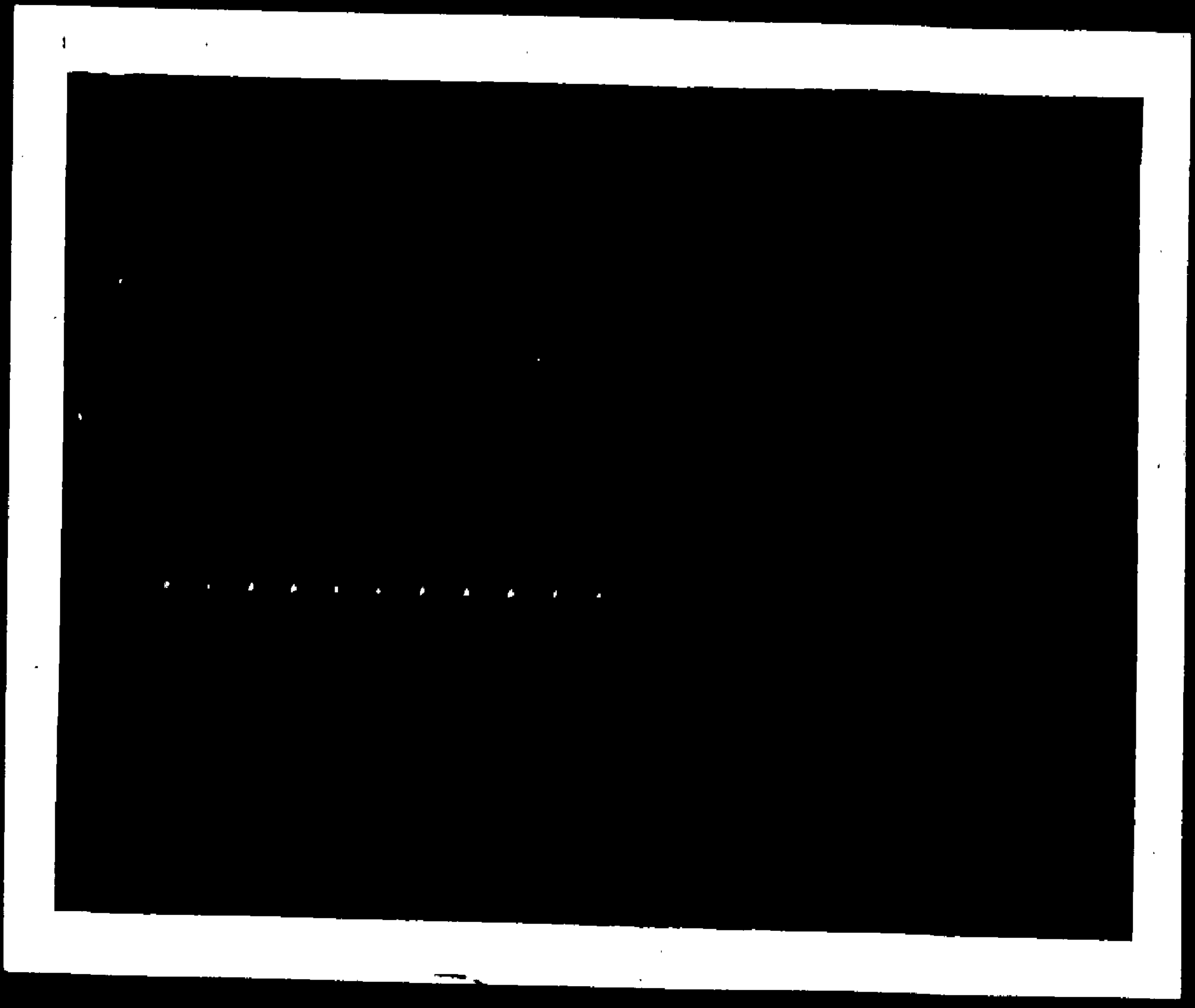
Photograph - 8.6

Output of tunable band pass filter at 5 KHz



Photograph - 8.7

Wave shape after precision rectifier
(high voltages at input)



Photograph - 8.8

Wave shape after precision rectifier
(Low Voltage at input)

8.2.11 COMPLETE CIRCUIT DIAGRAM : Complete circuit diagram for analyser, developed is shown in fig. 8.24 and plan for this circuit on printed circuit board is shown in Fig. 8.25.

8.3 RESULTS :

Photograph 8.1 shows the analyser developed for infrared detectors and photograph 8.2 shows the complete analyser system that includes the analyser, chopper, d.c. power supplies and C.R.O.

The photographs 8.3 to 8.8 shows the wave shapes obtained on C.R.O. after different blocks of the analyser for a phototransister AC 132, which was under test. Photograph 8.3. shows the noise wave shape and photograph 8.4 is output of low pass filter. It is clear from the photograph 8.4 that noise compo ents of high frequency are filtered out and very low frequency components of noise are present. The output of tunable band pass filter is shown in photograph 8.5 and 8.6 for two different settings of centre frequencies namely 10 K Hz and 5 K Hz respectively. Photographs 8.7 and 8.8 shows the wave shape after precision rectifier. The waveshape shown in photograph 8.7 is perfect whereas that in photograph 8.8 is distorted. In the later case, the two peaks are unequal as the rectifier is not able to rectify the voltages less than about 0.2 V perfectly.

The requirement was to select between photodiode SI 100 and Photo transistor AC 132 as the detector temperature scanner scheme, which is discussed in chapter 9. The chopping frequency in temperature scanner scheme is kept 420 Hz. SI 100 and AC 132 have given following results, while the chopping frequency of the analyser was kept 420 Hz.

S. No.	Current through incandesant lamp.	SI 100			AC 132		
		Noise (N)	Signal (S)	S/N	Noise (N)	Signal (S)	S/
1	175 m.A	0.855 mV	4.5 mV	8.16	0.145mV	8.5mV	58
2	180 m.A	0.055 mV	6.0 mV	10.90	0.145mV	10.0mV	6.
3	190 m.A	0.055 mV	9.0 mV	16.40	0.145mV	13.5mV	9.
4	200 m.A	0.055 mV	13.5 mV	23.30	01145mV	18.0mV	11.

It is clear from the above table that photodiode SI 100 will be a better choice because of higher S/N ratio. ~~#~~$_2$0 Also in expression of D* window area of detector~~s~~ appears. It was found that the photo diode SI 100 has got smaller window area than the photo transistor AC 132. Accordingly, SI 100 has been selected for the temperature scanner.

8.4 ADVANTAGES of Analyser developed by author over the previously existing analysers :

(i) No additional preamplifier is required. The analysers available requires different preamplifiers for different type of detectors under test. But in the developed scheme this problem is approximately removed.

As stated previously also the analyser developed by author has two pre amplifier;one for phototransistor type detectors and other for cell type detectors. Phototransistors can be tested and their characteristics can be plotted at a load of 10 KΩ.

For cell type detectors, a bridge circuit is used. By using simple feed back principle and using the operational amplifiers a sensitive bridge is made.

(ii) Cell resistance, if it is from 1 MΩ to 10 Ω can be measured by this analyser, which is a important provision.

(iii) For plotting noise frequency stectrum a costly electric wave analyser is replaced by a simple electronic filter (tunable band pass filter), which uses only two operational amplifiers. With this provision the cost of analysor is considerably reduced.

(iv) Signal voltage is directly measured, this could be achieved by using a filter after third stage. When signal is to be measured, the filter is connected in the circuit and when noise is to be measured it is disconnected by the circuit. For this purpose a toggal switch is used.

Limitations of the Analyser :

(i) Because of non-availability of optical filters a spectral response can not be plotted.

(ii) NEI, NEP and D* are also can not be calculated because of nonavailability of instruments.

(iii) Maximum chopper frequency obtained is 2.5 KHz, while detectors are supposed to be tested upto 10 KHz. This limitation can be overcome by using a chopper of higher speed.

(iv) In optical modulator disc, slots are made in two positions, for getting low and high chopping frequencies respectively. Therefore, to test a detector source and detector both should be transferred from one position to other for different chopping frequency tests while it is desirable not to touch the source once it is fitted in the analyser set up, and if it is touched, then it should be calibrated again.

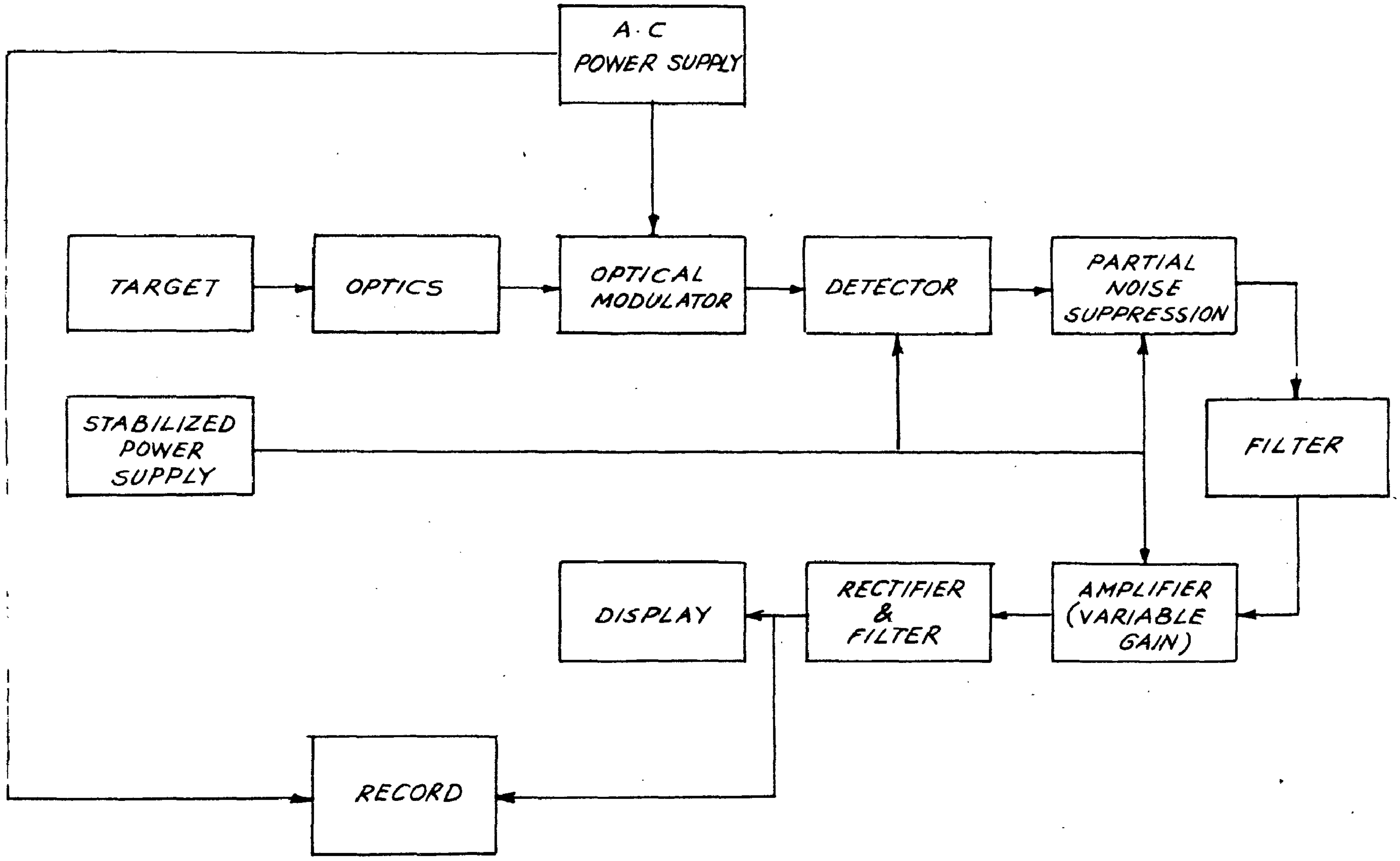
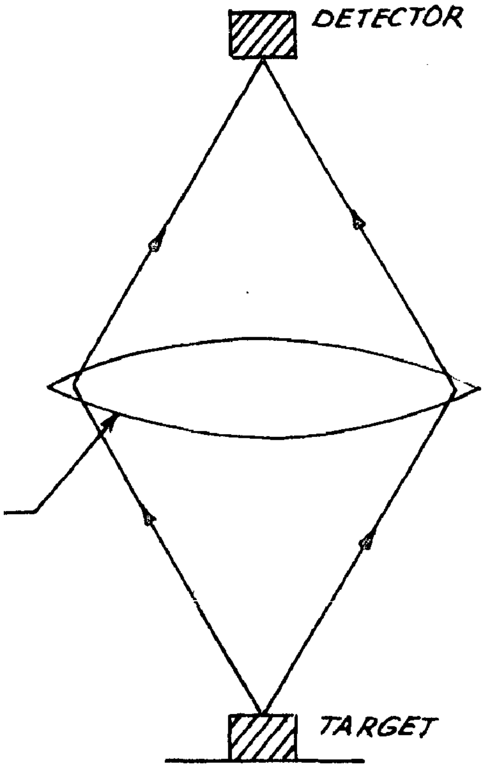


FIG 9·1 BLOCK DIAGRAM FOR TEMPERATURE SCANNERSCHEME



9.2 FOCUSING ARRANGEMENT USINGA DOUBLE CONVEX LENS

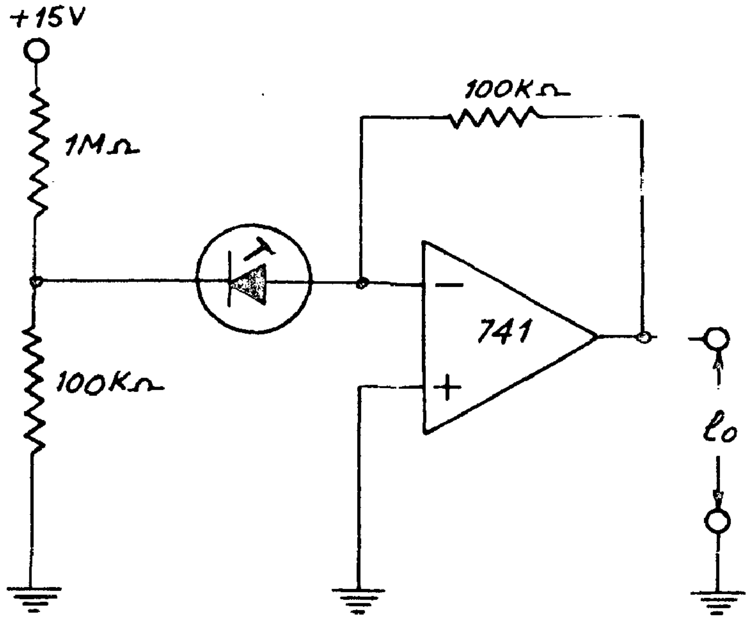


FIG 9.3 **DETECTOR**

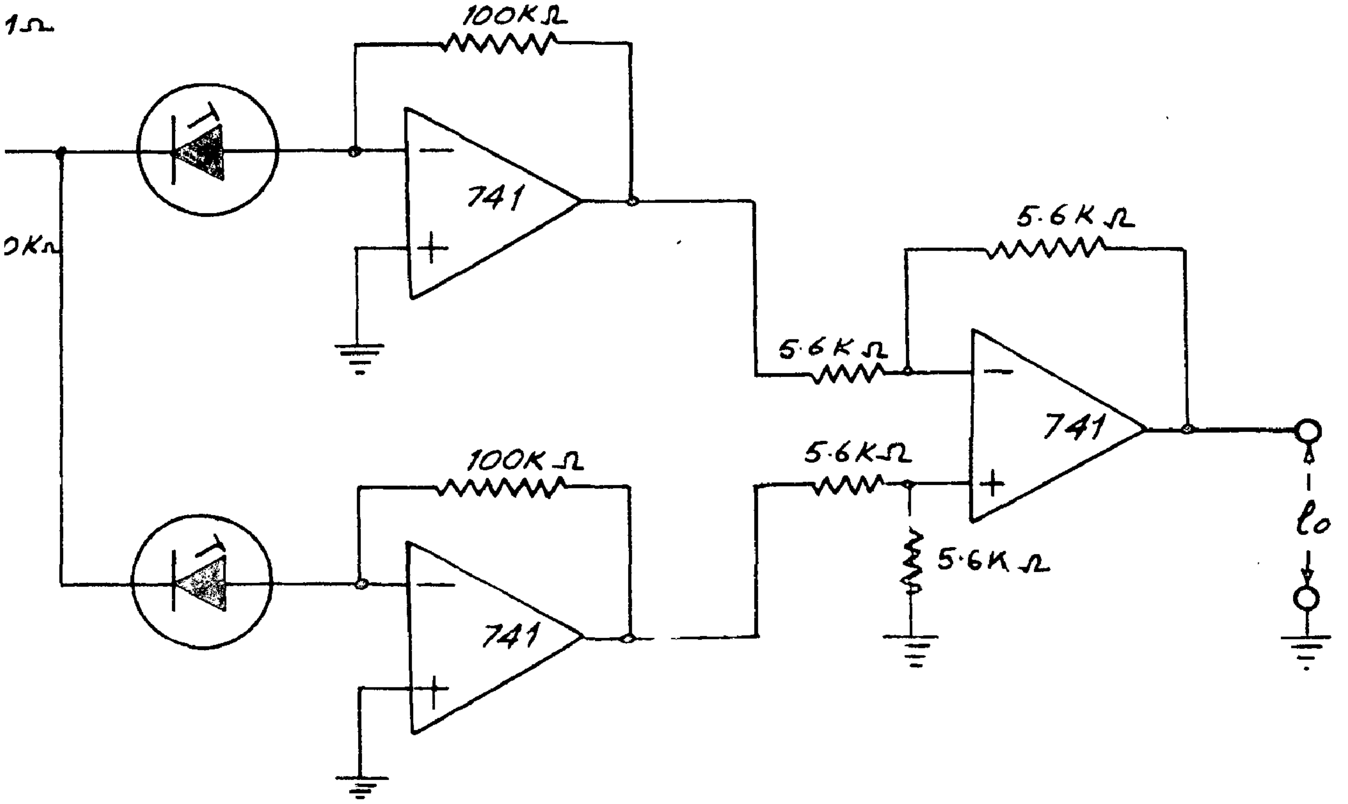


FIG. 9.4 PARTIAL NOISE SUPPRESSION

9. INFRARED TEMPERATURE SCANNER :

9.1 SCHEMATIC : Block diagram for temperature scanner developed by author is shown in Fig. 9.1. Each block is discussed below.

9.1.1 OPTICS : To focus the image of target at the detector optics is used. There can be number of arrangements for focusing. Here focusing is done by using a double convex glass lens (Fig. 9.2). Since glass works as opaque above 3 μm wavelength radiations, the corresponding temperature at 3 μm wavelength radiation is 700° C approximately, this scanner would be able to detect the temperature above than the 700° C.

9.1.2 OPTICAL MODULATOR : A slotted disc having 18 slots, diven by an 110 V, 50 Hz a.c. supply having 400 r.p.m. is used as optical modulator. Therefore, the chopping frequency will be = 420 Hz.

9.1.3 DETECTOR : A photo diode is used as a infrared detector to sence the temperature. As radiation falls on junction, reverse leakage current increases and the same becomes the measure of radiation, i.e. ~~become~~ the measure~~s~~ of temperature (Fig. 9.3). In Fig. 9.3 as the radiation falls on photo-diode, leakage current of photo ~~transistor~~ diode changes; an operational amplifier is used to convert this current into proportional voltage. SI 100 photo-~~transistor~~ diode is used as a

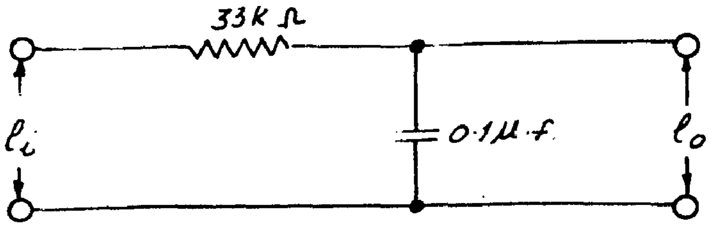


FIG. 9.5 FILTER

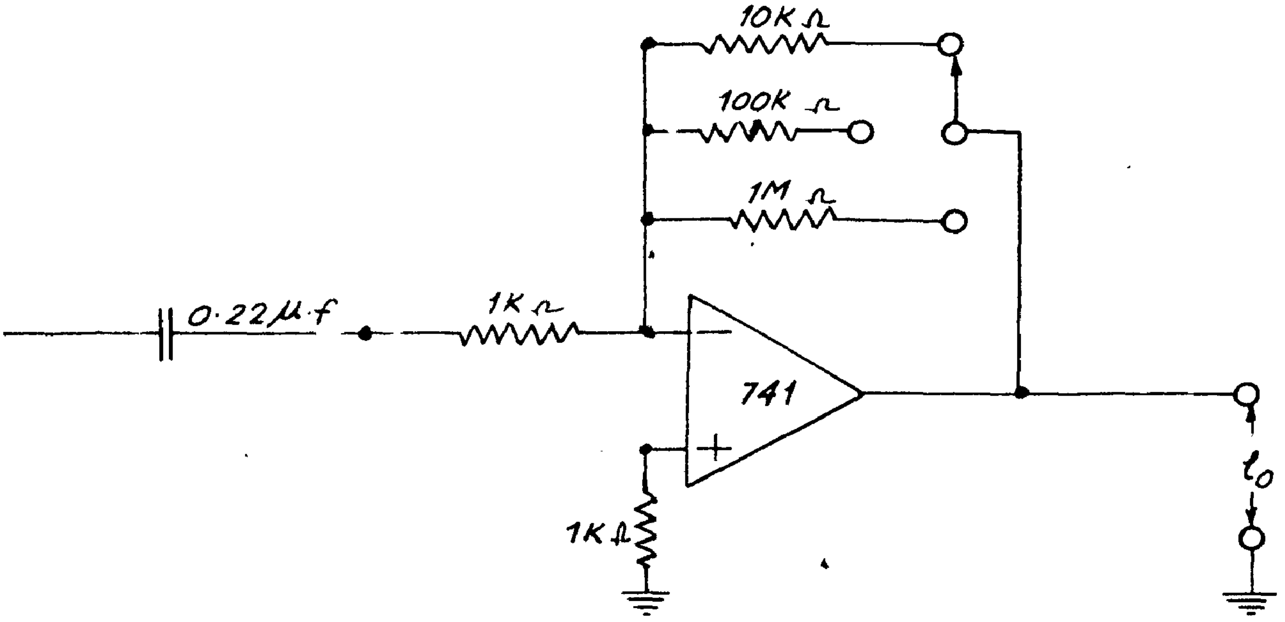


FIG. 9.6 AMPLIFIER

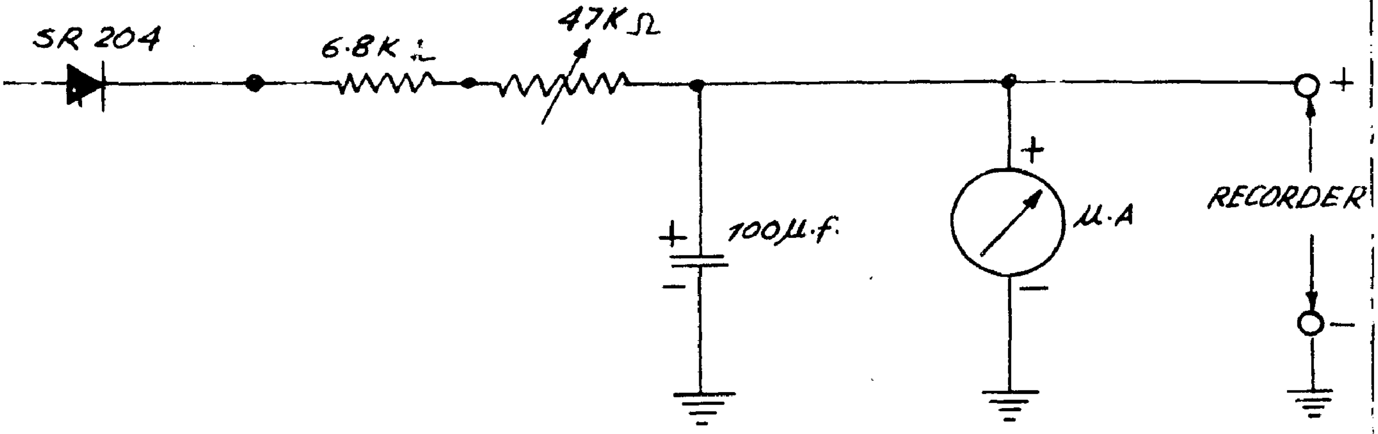


FIG. 9.7 RECTIFIER & FILTER

detector. ∴ feedback resistance of 100 K Ω is used in operational amplifier.

9.1.4 PRE-AMPLIFIER : Consider Fig. 9.4, here an identical photo~~transistor~~ diode is used to suppress the noise. The gain of differential amplifier is kept unity. Because two similar photodiodes will produce same type of noise, the noise is cancelled out because of differential amplifier stage.

9.1.5 NOISE SUPPRESSION : Though most of the components of noise are suppressed by using ~~noise suppression block~~ pre-amplifier but than even some noise is still present. A low pass filter is used to filter out the remaining noise, having higher frequency components than 420 Hz.

Time constant for filter = 1/420 Sec. = 2.4×10^{-3}

From Fig. 9.5, RC = 2.4×10^{-3} Sec.

$$\text{or} \quad R = \frac{2.4 \times 10^{-3}}{C} \ \cancel{\text{Sec.}}$$

$$\text{Choose} \quad C = 0.1\ \mu\text{f.}$$

$$\therefore \quad R = \frac{10^{-3} \times 2.4}{10^{-7}} = 2.4 \times 10^{3}$$

$$= 2.4\ \text{K}\Omega$$

$$\text{Take,} \quad R = 2.2\ \text{K}\Omega$$

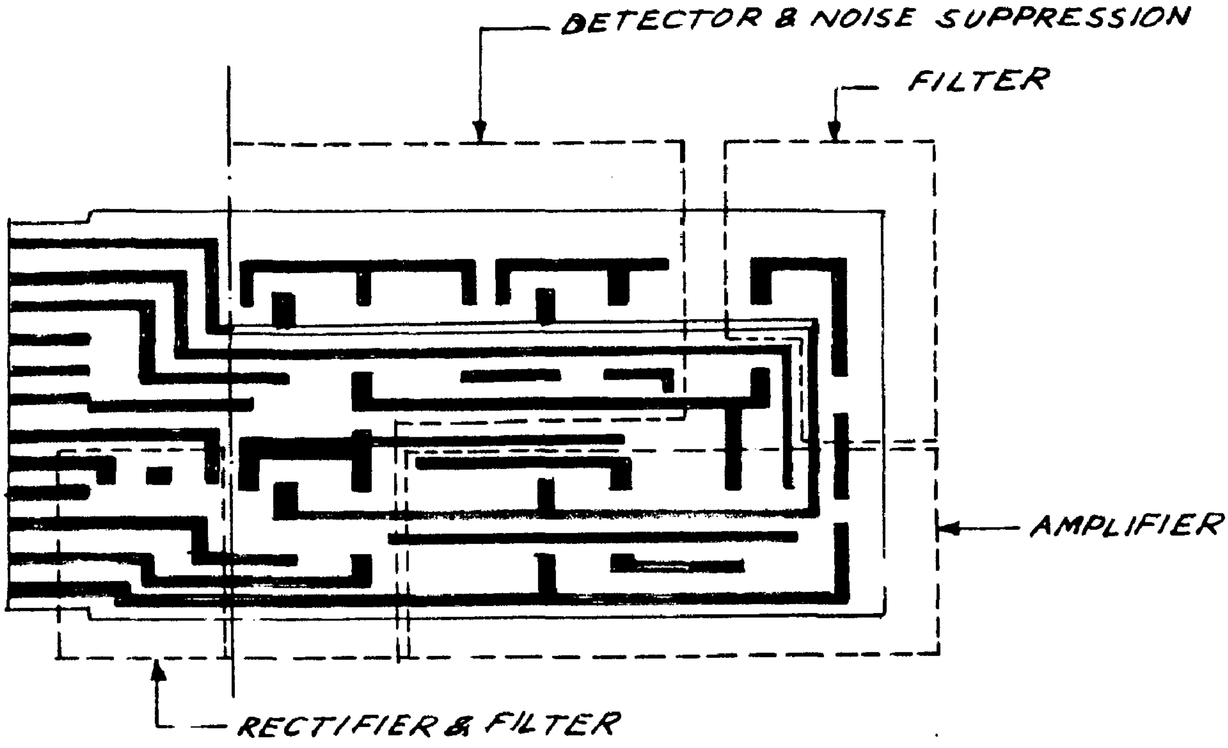


FIG. 9.9 PRINTED CIRCUIT BOARD LAYOUT FOR TEMPERATURE SCANNER

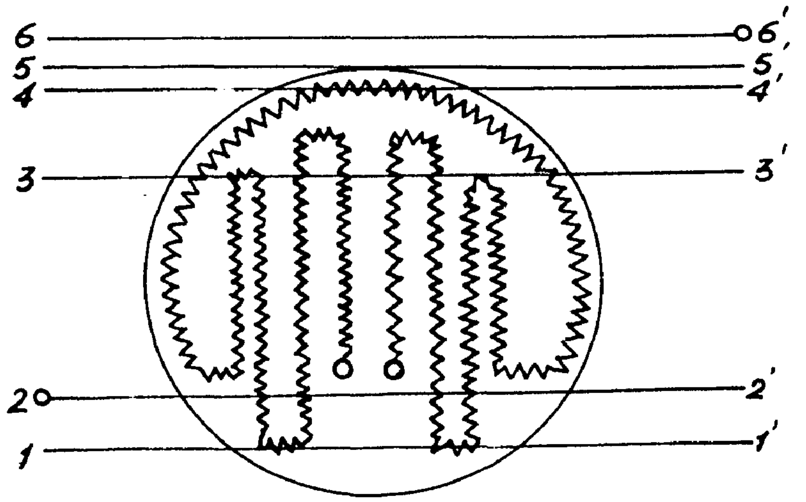


FIG. 9.10 HEATER USED FOR TEMPERATURE SCANNING

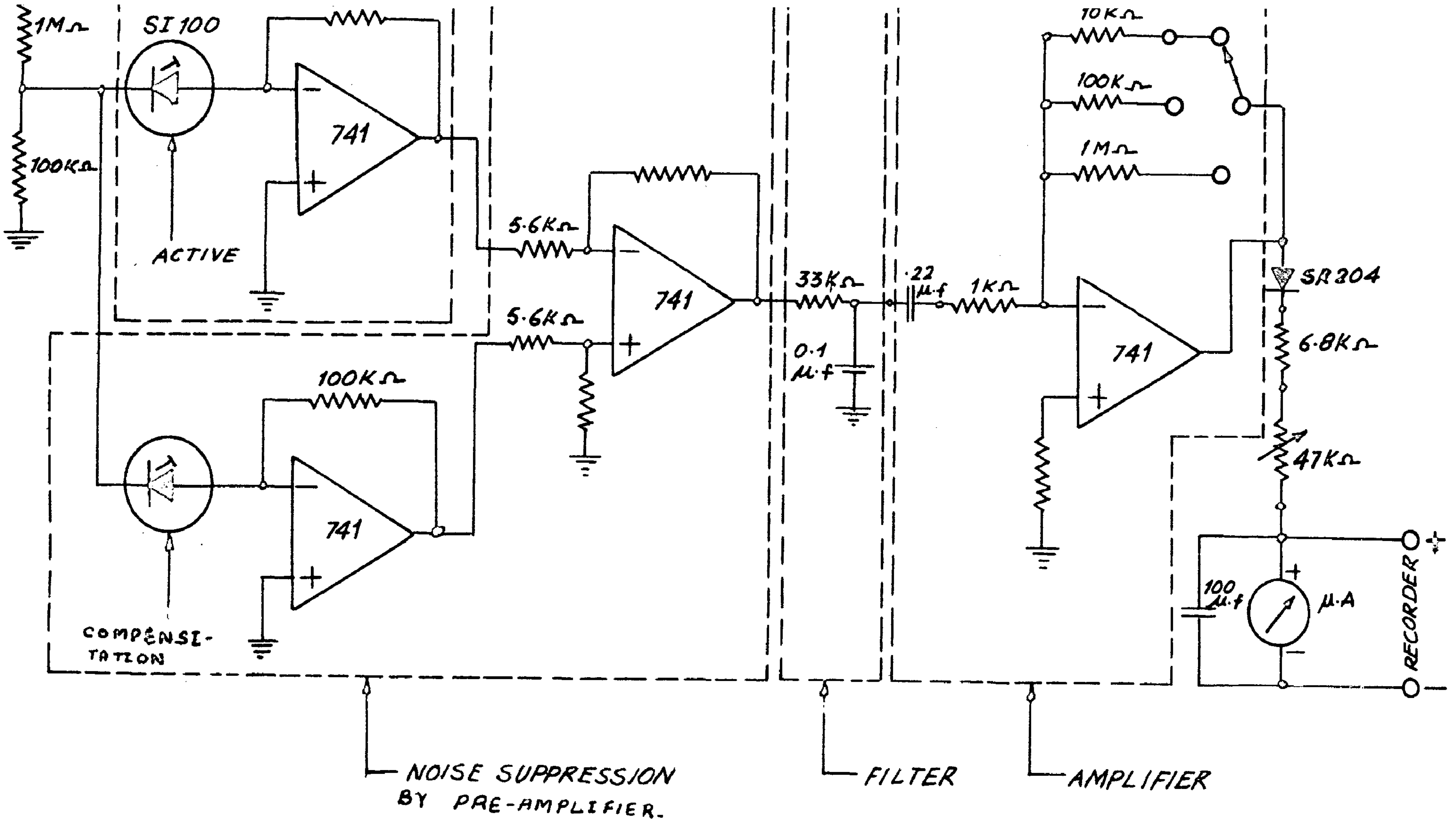


FIG. 9·8 COMPLETE CIRCUIT DIAGRAM

9.1.6 AMPLIFIER : The output after low pass filter is not sufficient to drive the output i.e. or display device or recorder. Therefore an a.c. amplifier is used to amplify this signal. The amplifier used, in the developed scheme, has got three ranges (Fig.9.6)

Three feed back resistance are : 10 KΩ, 100 K Ω and 1 M Ω.

$$\text{Take, } R_1 = 10\ K\ \Omega\ ;$$

$$R_2 = 10\ K\ \Omega .$$

$$\text{Now, } C = \frac{1}{2\pi f\ \ R_1} \qquad \text{where } f = 420 \text{ Hz.}$$

$$= \frac{1}{2 \times 3.14 \times 420 \times 10^4}$$

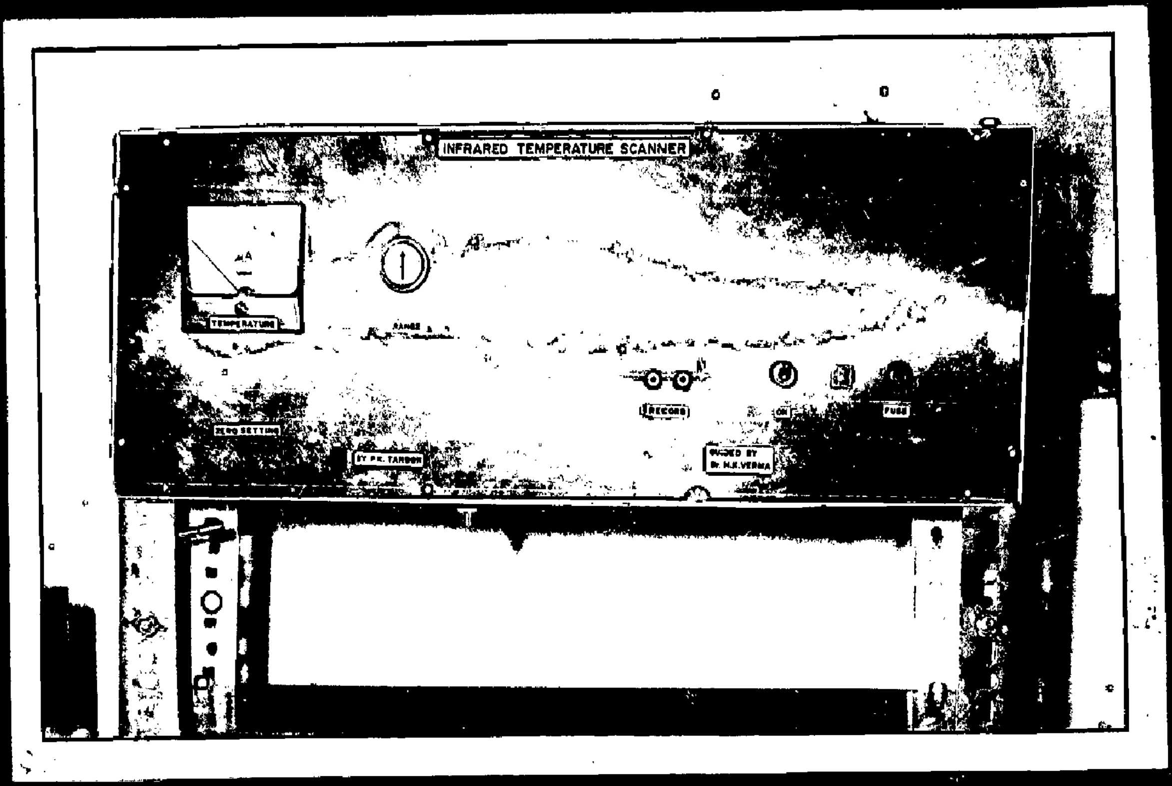
$$= \frac{10^{-6}}{6.28 \times 4.2} = \frac{10^{-6}}{26.4}$$

$$= 0.038 \text{ u.f.} \qquad \text{Take, } C_1 = 0.22 \text{ u.f.}$$

9.1.7 Rectifier and filter : The rectification is done by a single diode SA 204 and for smoothing the output a capacitor of 100 μ.f. is used (Fig. 9.7).

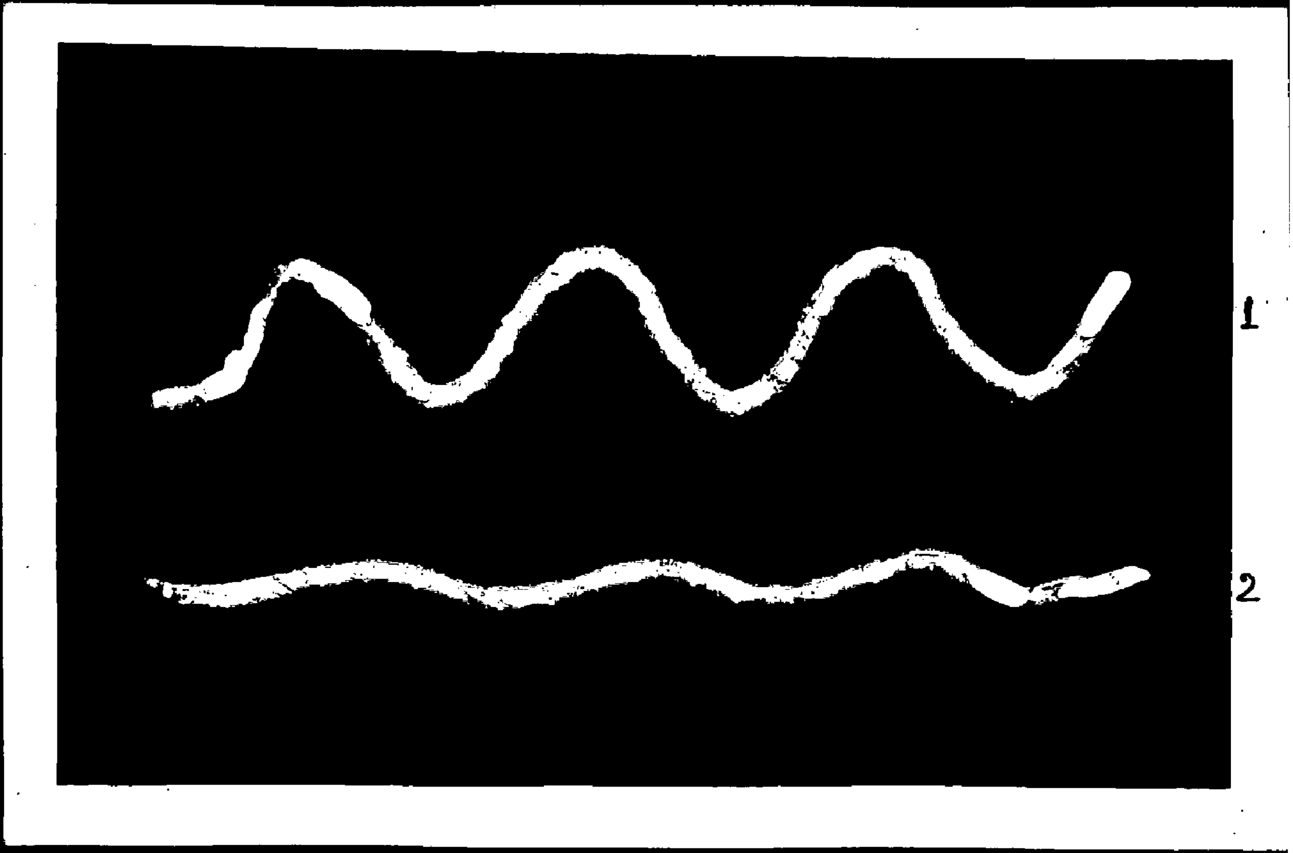
9.1.8 COMPL ETE CIRCUIT DIAGRAM : Complete circuit diagram is shown in Fig. 9.8 and plan of printed circuit board for the scheme is shown in Fig. 9.9.

9.1.9 DISPLAY AND RECORD : Temperature is displayed on moving coil meter and recording is done by a strip-chart-recorder.



Photograph - 9.1

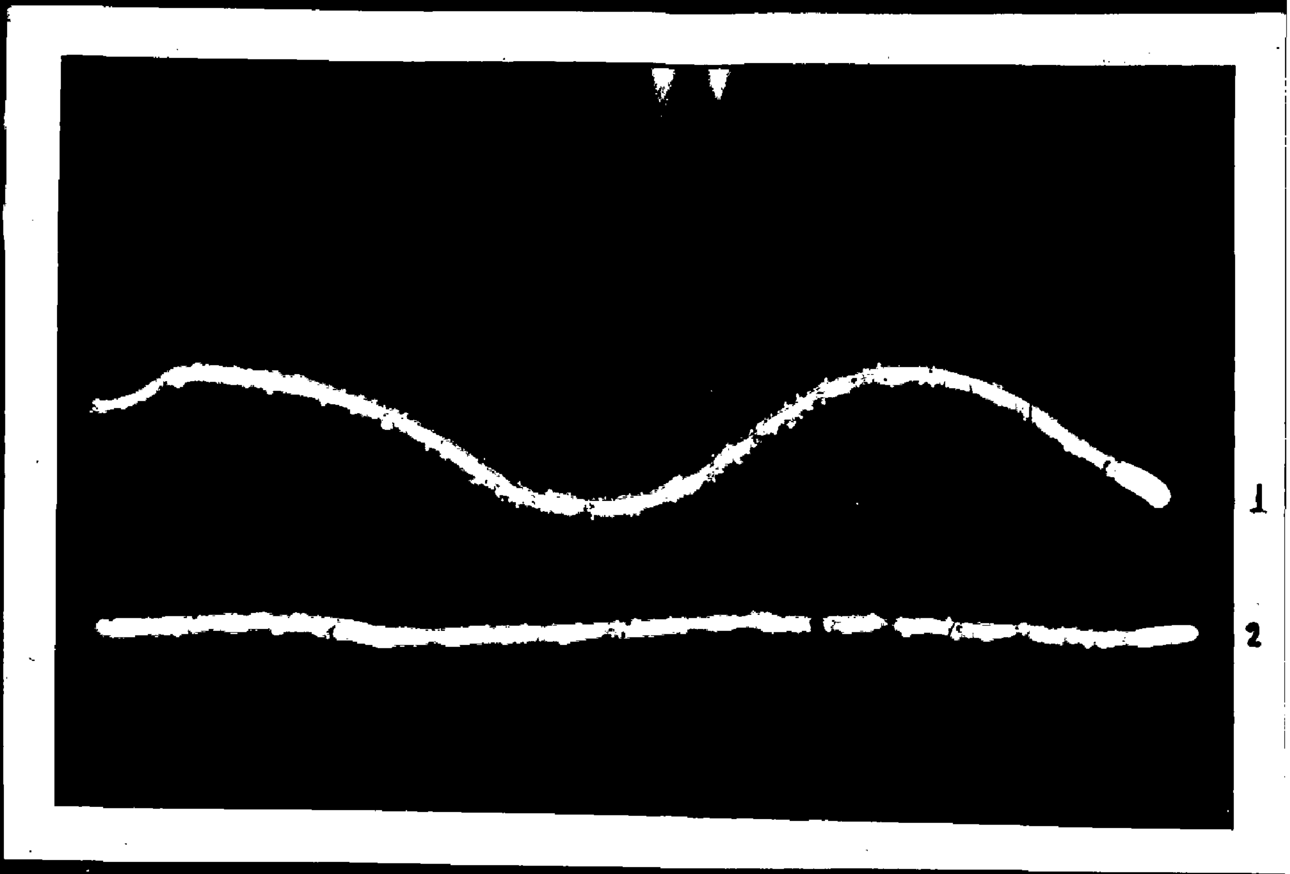
Temperature scanner developed



Photograph - 9.4

Wave - 1 : Noise of measuring detector

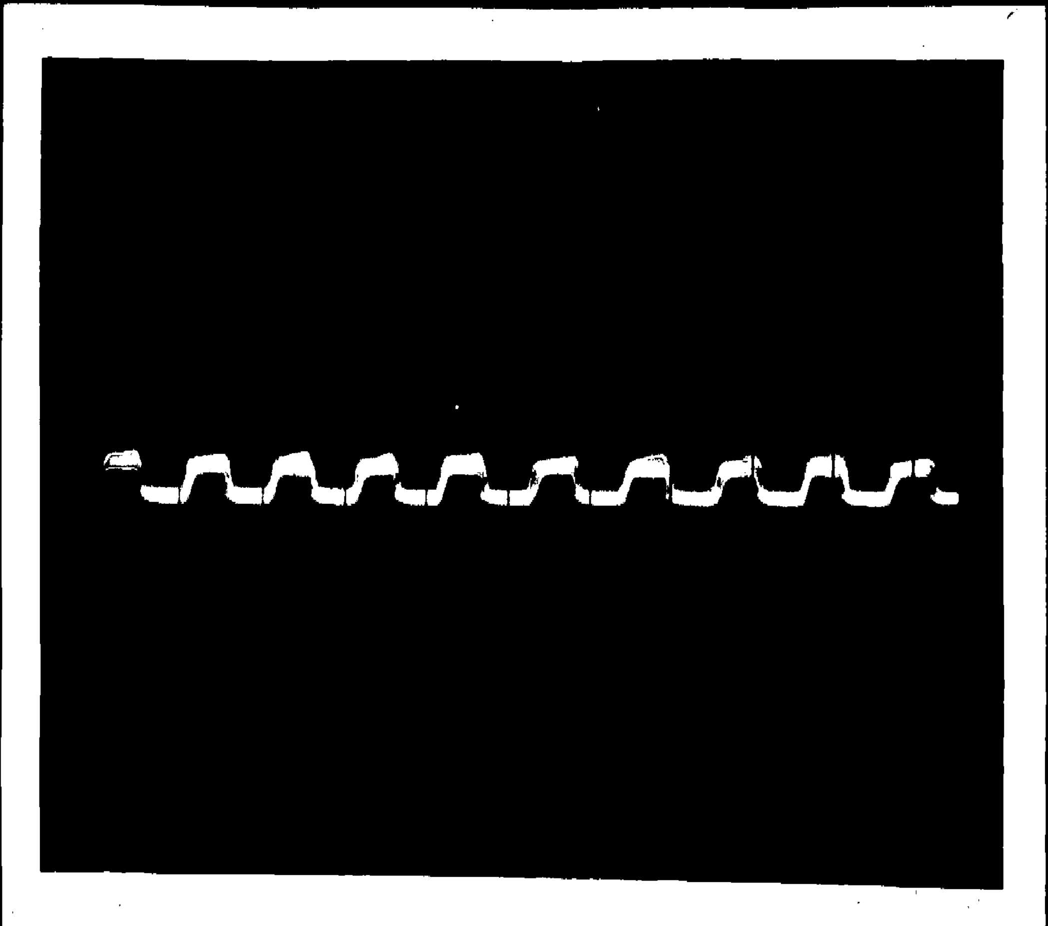
Wave - 2 : Output of differential amplifier



Photograph - 9.5

Wave - 1 : Output of differential amplifier

Wave - 2 : Output after low pass filter



Photograph - 9.6

Output scanner after amplifier when heater is under test.

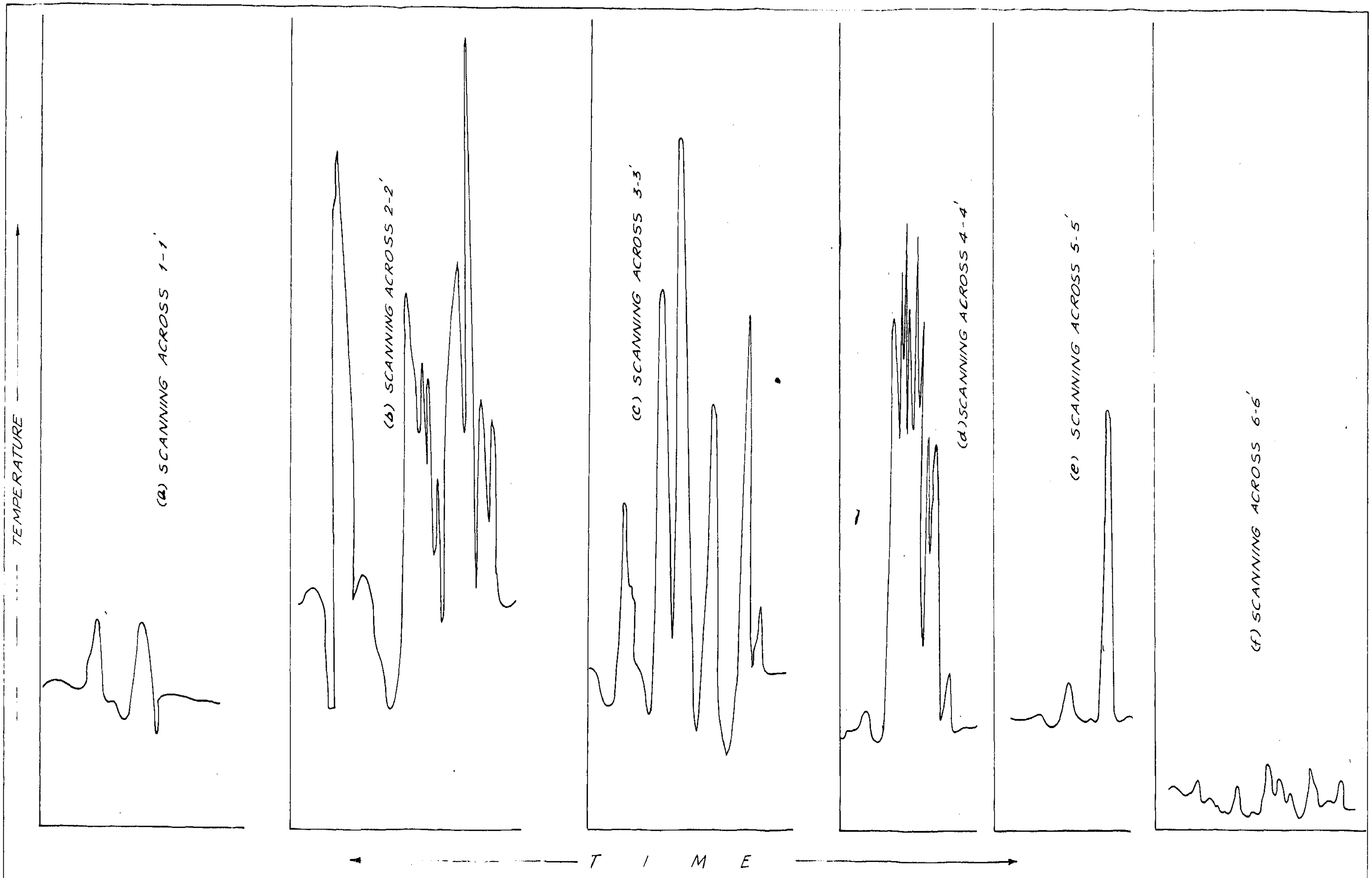


FIG. 9.11 THERMAL MAP OF HEATER

9.2 TEST RESULTS :

Photograph 9.1 ~~to 9.6~~ shows the temperature scanner developed by the author; and photograph 9.2 shows the temperature scanner with strip chart recorder with a room heater under test.

Photographs 9.3 to 9.6 show outputs of the different blocks of the temperature scanner as recorded on C.R.O. The photograph 9.3 shows the noise produced by the two detectors(each ~~a~~ photo diode SI 100) measuring detector and detector. In photograph 9.4 wave -1 is the noise of the measuring detector and wave-2 is the output of the differential amplifier. The wave-2 in photograph 9.4 shows how noise is cancelled out by differential amplifier stage. In photograph 9.5 the wave-1 is the output of differential amplifier stage and wave-2 the output after the filter stage.

Photograph 9.6 shows the output of scanner after amplifier stage when heater is under test.

Thermal mapping of heater (Fig. 9.10) is done by the temperature scanner and results as taken with a strip chart recorder are given in Fig. 9.11.

The scanning curves for the heater (Fig. 9.10) are shown in Fig. 9.11. The two peaks appear~~ing~~ in Fig. 9.11(after scanning the heater along 1-1' because across 1-1' line because one coils is crossed, i.e. two times high temperature appears and rest of places the temperature is low because of absence of ~~no~~ coil. Similarly Fig. 9.11 (b) to (f) can be explained.

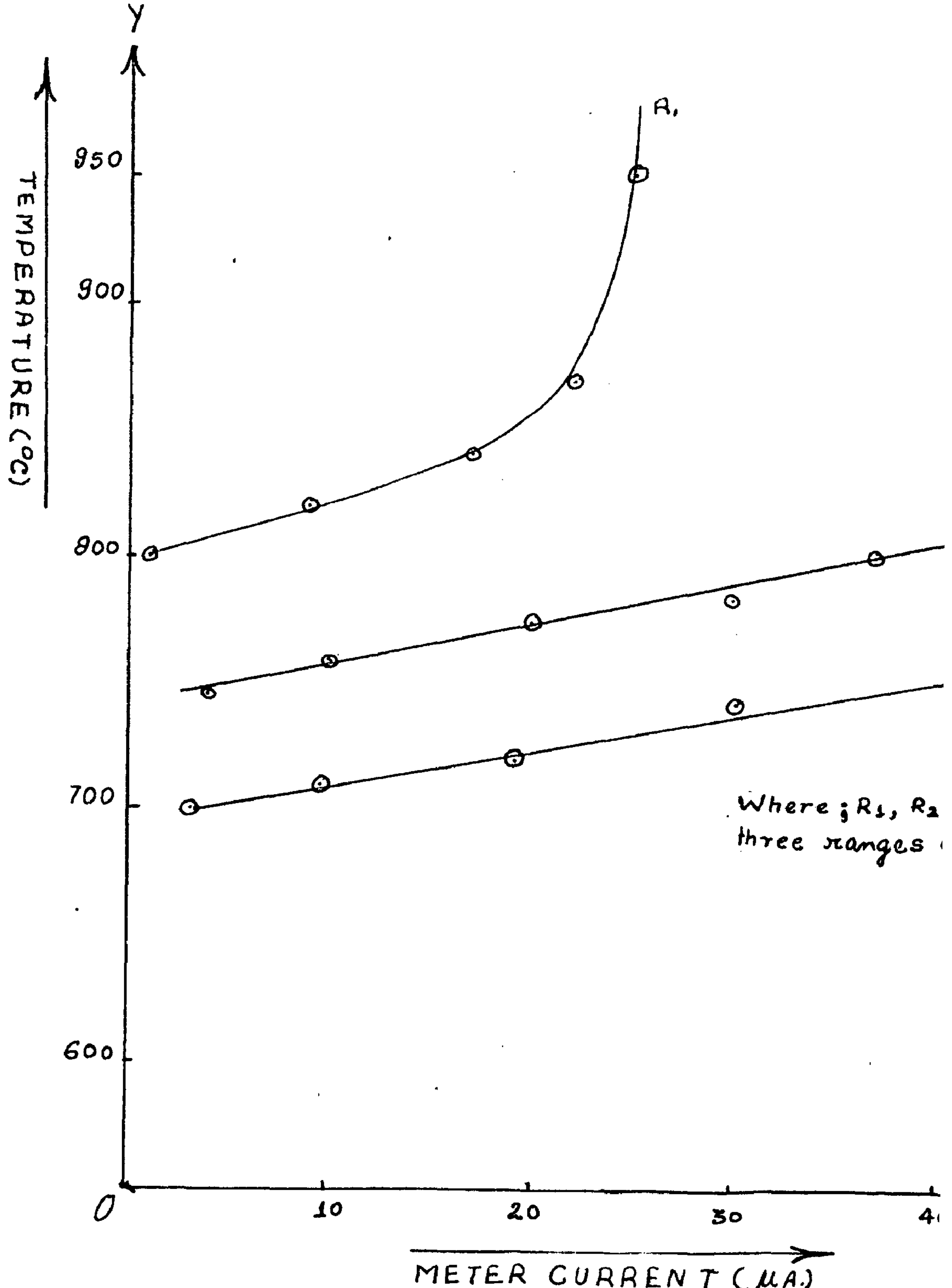
9.3 ADVANTAGES :

1. With the help of the temperature scanner degeloped thermal mapping is possible.
2. Temperature measured by this method can be measured with a higher accuracy as compared with any other non-contacting method e.g. thermocouple, pyrometer etc. By proper design the accuracy upto 1° C is possible.
3. The calibration of the scanner is not affected by the distance of the object from the detector under practical limits.
4. Maximum object size that can be scanned is 55 cm x 25 cm x 25 cm.
5. By applying a moveable plain mirror this system can be converted into line scanner$^{2}=_{2}$.

9.4 LIMITATIONS :

1. The scanner could not be calibrated accurately because of non availability of thermocouple or an accurate pyrometer. Therefore expected accuracy

CALIBRATION CURVE FOR TEMPERATURE SCANNER



Where ; R₁, R₂
three ranges

Fig 8.12.

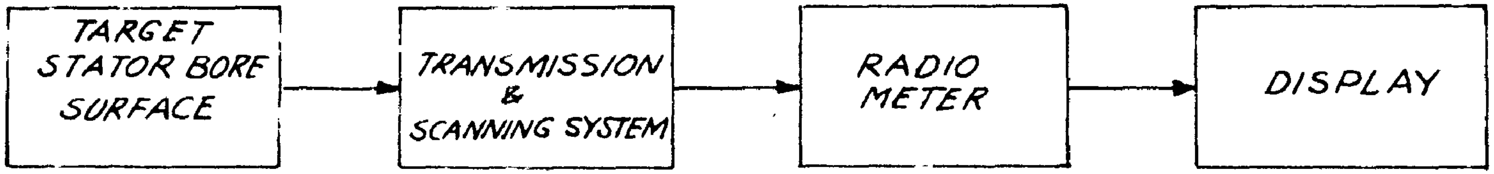
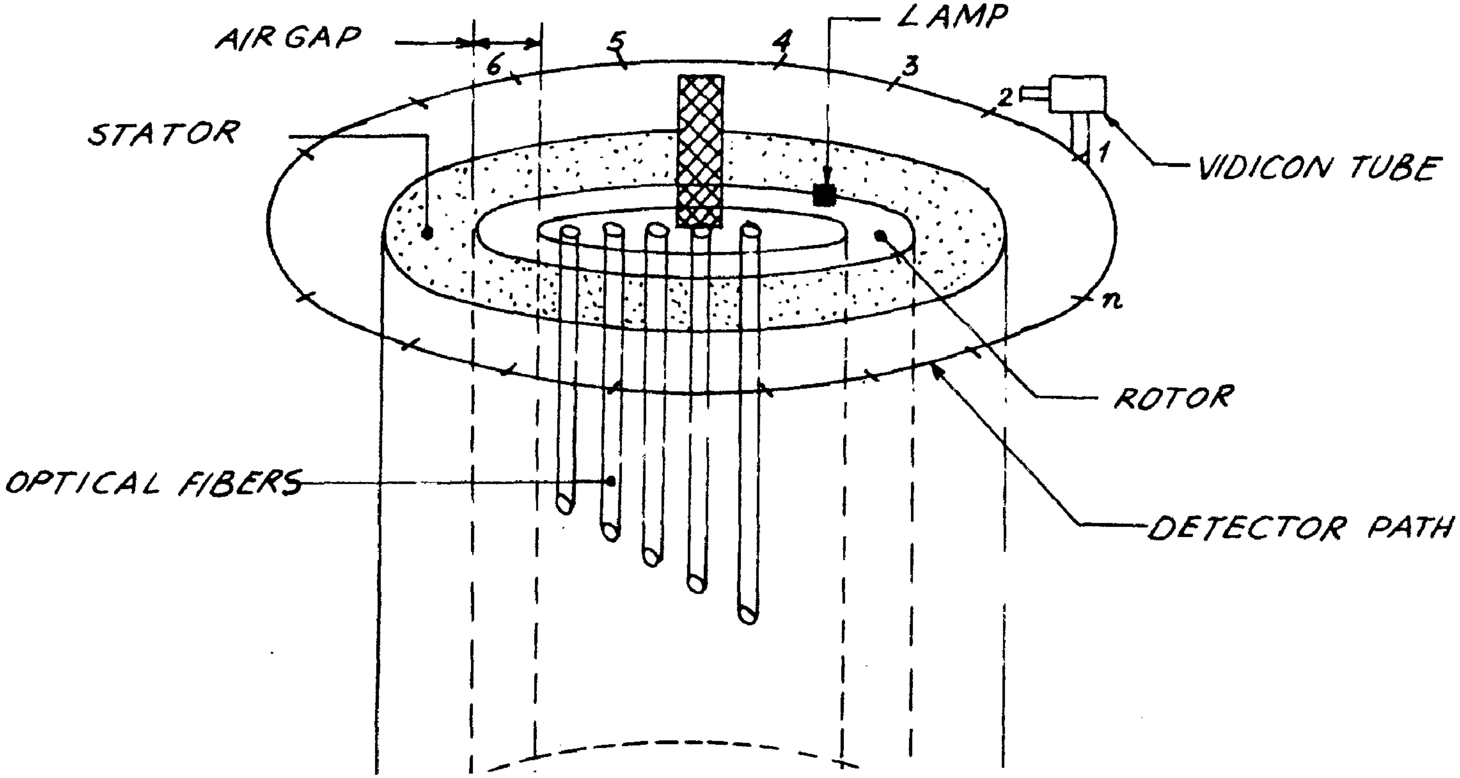


FIG. 9.13 BLOCK DIAGRAM FOR STATOR BORE SURFACE TEMPERATURE MEASUREMENT



could not be achieved by the developed temperature scanner. However, the calibration curve obtained with the available pyrometers is shown in Fig. 9.12

2. Scanning is done manually. Therefore, the object speed cannot by maintained constant. To overcome this problem automatic scanning can be included[1].

3. The system cannot scan temperatures lower than 700°C because glass lenses are used here to concentrate the radiations emitted from object to the detector; and below 700° C the radiations emitted are having higher wave lengths than 4 µm (Fig. 2.2). Glass became opaque above 4 µm. wavelengths.

To overcome this problem lenses of other materials (discussed in chapter6) can be used.

9.5 SCANNING STATOR BORE SURFACE TEMPERATURE :

A scheme that can be used for scanning bore surface temperature is shown in Fig. 9.13. Each block is discussed below.

(a) Target : Here target is stator bore surface of which temperature is to be measured. The bore surface temperature varies from 100° C to 200° C and at this temperature th corresponding infrared radiation is emitted by surface at 7µm wavelength.

(b) Transmission and Scanning System : The infrared radiation from the bore surface of stator is collected by optical fibers, which are having property that even if the tangent is not in the line of sight of detector, these are able to concentrate the radiations emitted by the target on to the detector, while this is not possible with the conventional optical methods.

The optical fibers are placed on the rotor in such a way that one end is facing to the stator bore surface and other end is in the line of site of detector (Fig. 9.14). The fibers of different length are placed throughout the periphery of the rotor in such a way that they cover whole axial length of the stator.

Now let detector be fixed at point 1. As the rotor moves, detector will detect the radiation coming out from each fiber i.e. at position 1 a strip is scanned having length equal to the stator bore depth and strip width depends upon the distance of fiber from the stator bore surface. Now, as the detector moves from point 1 to 2 another strip will be scanned in the same way. In this way if detector moves through out the periphery of the stator whole of the stator bore surface area is scanned.

As the strip in one position is scanned, a synchronizing signal is given to detector to move it to scan the second strip and so on. This synchronizing signal can be given only by placing a lamp which gives a very high intense signal to detector and the detector will saturate. A level detector is placed to detect this and accordingly a signal is given to the detector-movement controlling devi-ce to move it to next position.

(c) Radiometer and display : Radiometer includes optical system, detector, amplifidr and signal processor unit. Here vidion tube is one of the best detectors[1] and discussed in detail in chapter 4. Other quantum detectors can also be placed along with appropriate arrangement.

If a vidicon tube is used, then it gives a vedio signal at its output, which can be displayed after proper processing of signal[1,2].

10. CONCLUSIONS AND FUTURE TRENDS :

10.1 CONCLUSIONS :

In this dissertation the author has attempted to discuss several elements of the relatively new engineering technology of infrared instrumentation. The physical laws, feasible studies, current applications and theoretical foundations applied to infrared techniques have been dealth with at length.

The author has developed two schemes : an analyser for infrared detectors and a temperature scanner. The developed analyser, though similar type already existing, has three measure advantages which have been discussed in chapter 8. With this analyser photo transistor AC 132 and photo-diode BI 100 have been tested successfully. Because of nonavailability of few instruments, D*, NEI, NEP, and L could not be measured. However, the requirement was to get the best detector for temperature scanner (which is the second instrument developed by author), and which could be solved with this analyser.

The second scheme, namely temperature scanner, has been successfully developed and has given required result The temperature range which could be measured by this scanner 700° C to 1300° C. The instrument available to caliberate this scanner was only pyrometer. The scanner developed has got a higher sensitivity and a higher resolution than the pyrometer.

By using strip chart recorder or any other recorder, the thermal mapping of any target can be done in two dimensions with the developed temperature scanner.

Author has also proposed one scheme for measuring the stator bore surface temperature which is a current problem faced by many manufacturers and users of large rotating machines.

10.2 FUTURE TRENDS AND SUGGESTIONS :

It is clear from the previous chapters that infrared techniques are one~~s~~ of the most powerful tools in the evolution of the materials, electronics, etc. There are areas, for instance, where feasibility has not even been tried inspite of the fact that both theory and common sense tells that the idea should work. One of these areas for instance, is the detection of wave guide malfunction.

Radio frequency losses in microwave guides manifest themselves as heat sources. A study should be conducted to determine how to use infrared detecting equipment to locate the area of radio frequency loss and its magnitude.

These techniques could be used both for the evolution of new designs and for the control, test, and trouble shooting of production equipment.

Effective shielding of the radio frequency detector against radio frequency interference is a pre-requisite for proper infrared measurements in the application.

Another application of infrared may be to detect the hidden stresses caused by vibrations, in electronic and mechanical equipments. It is known that during vibration test, resonance is developed at different points, while the vibration frequency is being varied, but many of these resonance go undetected, unless they are visual, or so distructive that as to cause a failure. With the help of infrared techniques, however, these defects may be detected[1].

Though much work is done on optical fibers but in infrared it has got very small applications so far. The image transfer capability of coherent fiber bundles can be of immense significance in the conventional radiometers designed for thermal measurements of close targets. Conventional optical systems are based on the principle of reconstructing an image in a focal plane. Also because of the critical requirements of alignment, focusing, aiming, and the like, the conventional systems can work only if the target can be directly viewed by the object, but in case of optical fibers there is no such limitation; the target may not be directly visible to the detector.

Another advantage of optical fiber is that it reduces the scanning requirements from two dimensions (area scan) to one dimension (line scan), which is of great significance.

In infrared microscopy the optics can be replaced by a coherent fiber assembly of which one single fiber, located in the centre of the bundle, is made of infrared transparent materials.

In U.S.A. instrument landing of air crafts is successfull-y done, but it still requires some modification. So far, very little work is done in the field of infrared communication for industrial use, though military is using infrared communication in many of its applications after the World War II.

The infrared techniques for trouble shooting, tracking, guiding and for collecting many useful informations from space craft has also started recently.

REFERENCES

1. Riccardo, Vanzetti : "PRACTICAL APPLICATIONS OF INFRARED TECHNIQUES", Wiley - Inter Science Publication, Canada, 1972 & 1977.

2. Hundon (Jr.), Rechard, D. : "INFRARED SYSTEM ENGINEERING" Wiley Inter Science, New York, 1969

3. Bernard, Burton : "ABC's OF INFRARED", W. Foulshan And Co. Ltd., England, 1971.

4. Jamieson, John A.; Mefree, R.H.; Plass, G.N.; Grube, R.H., and Rechards, Robert G. : "INFRARED PHYSICS AND ENGINEERING", McGraw-Hill Book Company, Inc., New York, 1963.

5. Hotter, M. R.; Nudelman, S.; Suits, G.H; Wolfe, W.L.; Zissis and George, J. : "FUNDAMENTALS OF INFRARED TECHNOLOGY", The Machillan Company, New York, 1962.

6. Walker, S. and Straw, H. : "SPECTROSCOPY", Vol. 2, Champman and Hall Ltd., and Science Paperbacks, Britain, 1970.

7. Toison, M.La. : "INFRARED AND ITS THERMAL APPLICATIONS", N. V. Philips Glocilampenfarbieken, Eindhoven, Netherlands, 1964.

8. Putley, E.H. : "MODERN INFRARED DETECTORS", Physics in Technology, Vol. 4, Dec: 1973, pp 202 to 222.

9. Hudson (Jr.), R. D. and Hudson, J. Wordsworth; (Editors) : "INFRARED DETECTORS", Dowden, Hutchinson and Ross, Inc., U.S.A., 1975.

10. Foltershead, Allen : "ELECTRONIC DEVICES AND CIRCUITS", Prince Hall of India Private Ltd., New Delhi, 1976.

11. Wright, H. C. : "INFRARED TECHNIQUES", Oxford University Press, Ely House, London, 1973.

12. Gream, J. G. ; Tobey, Gene E.; Huelsman, L.P. : "OPERATIONAL AMPLIFIERS : DESIGN AND APPLICATION", McGraw-Hill, Kogakusha, Inc., Japan, 1971.

13. Kapany, N.S. : "OPTICAL FIBERS". Academic Press, New York, 1967.

14. Vanclooster, R and Pharisean, P. : "LIGHT PROPOGATION IN FIBER BUNDLES" Physica, Vol. 49, No. 4, November 1970 pp 493-501.

15. Snyder, A.W. : "RADIATION LOSS DUE TO VARIATION OF RADIUS ON DIELECTRIC OR OPTICAL FIBERS", IEEE Trans. on microwave theory and techniques, Vol. 18, No.9, Sept. 1970, pp 608-615.

16. Tideken, R. : "FIBER OPTICS AND ITS APPLICATIONS", Focal Press Ltd., London, 1972.

17. Crouch, J. N. "Cryogenic Cooling for Infrared", Electro-Technology, Vol. 75, May 1965, pp 96-100.

18. "MANUAL OF I.R. - 20 SPECTROMETER" Backman & Co.

19. Herchil, F.:"APPLICATION OF INFRARED IN INDUSTRY", McGraw-Hill Kogakusha, Inc., New York, 1978.

20. Ballard, Douglas W. "COMPUTER BASED TERMOGRAPHIC DISPLAYS AND REAL TIME TECHNIQUES" IEEE Trans. on Indurial Electronics and Control Instrumentation, Vol. - 20 No. 4, November 1973, pp 200-205.

21. Guha, S.K. : "INTRODUCTION TO MEDICAL ELECTRONICS" Bharat Bhawan, Patna, 1969.

22. Weber, Samuel (Editor) "CIRCUITS FOR ELECTRONICS ENGINEERS", Electronics Magizine Book Series, McGraw-Hill, Inc., New York, 1977.

23. Oliver and Cage : "ELECTRONIC MEASUREMENT AND INSTRUMENTATION" McGraw-Hill Book, Inc., New York, 1971.

24. Millman, J. and Halkias, Christors C.: "INTEGRATED ELECTRONICS : ANALOG AND DIGITAL CIRCUITS AND SYSTEMS" McGraw-Hill Kogakusha, Inc., Japan, 1972.

APPENDIX - I

Consider Fig. 8.8

$$Vo = \frac{Vo'}{2} = \frac{V_1 \Delta R}{2R + \Delta R}$$

From Fig. 8.8 it is clear that $V_1 = V + Vo$

$$= \frac{(V + Vo)\Delta R}{2R + \Delta R}$$

Here for calculation purposes take

$$R_f = R$$

or $$Vo = \frac{V \Delta R}{2R + \Delta R} + \frac{Vo \Delta R}{2R + \Delta R}$$

or $$Vo \left(1 - \frac{\Delta R}{2R + \Delta R}\right) = \frac{V \Delta R}{2R + \Delta R}$$

or $$Vo (2R + \Delta R - \Delta R) = V \Delta R.$$

or $$Vo = V \frac{\Delta R}{2R}$$

which is linear relation between output voltage and change in resistance RX.

APPENDIX - II

In precision rectifier circuit (Fig. 8. 15), the high open-loop gain of the operational amplifier is used to reduce the effect of the diode non-linearity and temperature sensitivity. The operation of the circuit can be analysed by the usual techniques except that the relationship of current and voltage in the diodes must be taken into account.

Consider first operational amplifier : when $e_1 > 0$ diode D_1 will become forward biased and therefore the voltag at point 1 will be zero. At point 2 there will be e_1 voltage appearing, operational amplifier - 2 is acting as a adder and the voltage appearing at points 1 & 2 are added.

Therefore $e_o = e_1 + e_2$

or $e_o = 0 \times \left(- \frac{R}{R/2} \right) + e_1 \times \left(- \frac{R}{R} \right)$

or $e_o = -e_1$

where

e_1 = voltage at point 1

e_2 = voltage at point 2

Now if $e_1 < 0$, D_2 will become reverse biased and D_2 will bo forward biased. Therefore, the voltage at point 1 will be

$$e_1 = - e_1(- R/R)$$

$$= e_1$$

and voltage at point 2 is :

$$e_2 = - e_i$$

Therefore, $e_o = e_1 \times \left(- \frac{R}{R/2} \right) + e_2(- R/R)$

$$= - 2e_1 - e_2$$

$$= - 2(e_i) - (- e_i)$$

$$= - 2 e_i + e_i$$

$$= - e_i$$

Hence, circuit shown in Fig. 8.15 works as a precision rectifier.