ELECTRONICS IN PHOTOGRAMMETRY

DISSERTATION

FOR THE M.E. DEGREE OF THE ROORKEE UNIVERSITY

BY

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UNDER THE GUIDANCE OF :

SHRI H.L. OSWAL

PREFACE.

I have great pleasure in submitting this dissertation in completion of the requirements for qualifying for the M.E. Degree in Photogrammetric, Engineering.

Shri H.L. Oswal kindly accepted to guide me in my dissertation. I gratefully acknowledge the benefit I received from his valuable guidance.

The College of Military Engineering, Poona, The Concrete Association of India, Bombay and the Institution of Engineers, Bombay Centre, kindly allowed me to have the benefit of reading the relevant books from their libraries. I thank them for their kindness.

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SYNOPSIS

This dissertation on "Electronics in Photogrammetry" is restricted to information regarding use of electronic devices in photogrammetry. It does not cover either the technical aspects of electronics or the details of instrument design.

After explaining in Chapter II the advantages of the use of electronic devices in photogrammetry, some important electronic systems and their components are described in Chapter III. Devices for time control, light control, position control, and servomechanism are mentioned as the principal control systems. In chapters IV and V use of electronic devices in ground control and photo flights is described. Chapter VI deals with use of electronics in photography and processing for prints. In the last chapter i.e. Chapter VII automatic plotting, rectification and map compilation are dealt with.

CHAPTER 1.

INTRODUCTION

1.1 Photogrammetry is the 'science or art of obtaining reliable measurements by means of photography and it obviously includes the study of operations and instruments for taking of photographs and intepreting them in three dimensional measurements with the desired precision. The photogrammetric instruments were devised for the accuracy required but the use of these instruments, till the last war, involved tedious adjustments and operations and the work, by no means, could be done expeditiously. With the introduction of electronic devices in all fields of applied sciences, photogrammetry has made rapid progress, because of the ease and speed of the operations made possible by electronic instruments. The astonishing speed of operations and adaptability to varying conditions is perhaps the most significant difference between electronic and non-electronic devices.

1.2 The use of electronic instruments has increased in the last few decades, to the point where one finds it difficult to name any branch of science where electronics is not at work gathering data for man's information. The time has long since passed when electronic instruments were employed chiefly by electrical engineers for the study of electrical circuits. In the - industrial world, today the electronic instruments find a place in the measurement of almost any quantity one might think of e.g. acceleration, velocity, displacement, stress, strain, thickness of any material, mass and weight, pressure and vacuum, temperature, light intensity and colour, the frequency and intensity of sound, radio - activity, chemical quantities and medical and biological measurements. Electronic systems are also used in the devices employed for ensuring safety and in those used for inspection or detection. It may be said that they have immeasurable uses. The science of measurement by electronics is by no means confined to measurements on our planetary or to our island universe. The modern radio telescope, as a matter of daily routine probes the secrete of the clouds of - intergalactic matter, while the luminous stars tell the photomultiplier tube of an expanding universe. Just as remarkable is the electronic computer that stands ready to draw conclusions from data in a few hours, which only a few decades ago, many a man life times would have been insufficient to reach.

1.3 One can get a glimpse of the fascinating and exciting possibilities of electronic instrumentation by the use of ready-made equipment available on the market. But the calls on electronic devices for measurement and computation are so varied that the scientists must be prepared to design their own instruments suitable to the problem in hand.

1.4 This dissertation gives information about electronic devices used in photogrammetry. As a preliminary to the understanding of electronic devices, electrical instruments of photogrammetry are also included. Possible future development of electronic instrumentation in photogrammetry is also indicated.

1.5 Details of instrument building and technical aspects of electronics are highly specialised lines beyond the purview of a photogrammetric engineer and are not covered by this dissertation.

CHAPTER 2.

WHY ELECTRONIC INSTRUMENTS?

2.1 This is the age of automation. We find that electronics has found application in almost all scientific disciplines. In the following chapters we will see how electronics helps us in different phases of work in Photogrammetry and what promise it holds for us in this field. In this chapter we shall try to briefly answer the logical question, "What can electronic - instruments do for Photogrammetry".

2.2 It is to be admitted that the number of measurements which can be made only by the - electronic instruments and not otherwise is very small. Moreover a good electronic instrument may not necessarily be more accurate and yet it may be more expensive than the devices working on other systems. Yet the choice of electronic instruments is justifiable because of their particular advantages over other instruments viz. versatility, speed or response, adaptability to various difficult conditions of measurements and in most cases ease and convenience which result in saving intime and saving of personnel. They may also give more accurate results and might prove to be more reliable.

2.3 The immense speed of operation is perhaps the most important reason in most cases for preferring the electronic instruments to the non-electronic ones. This is mainly because of the low mass of the electron, which permits it to be accelerated to extremely high velocities in extremely short times. Consider the case of a radar where we use radio waves. (This is explained later). The time taken by a radio wave to reach a distant target and return to the radar, after being reflected by the target, is of the order of a few micro-seconds. It is practically impossible to measure such a short duration of time with the help of our presently available mechanical indicators, whereas it is very easy to measure such short durations of time by an electronic instrument.

2.4 Versatility is another valuable feature of electronic instruments. Take a basic electronic counter for example. The same instrument with minor changes in the input circuit can be made to record either events per unit time or time interval. Such an instrument in collaboration with certain other instruments like the crystal controlled clock, the photo-tube, etc. can be used for the measurement of various other quantities. The result may be displayed in a variety of ways, as the application may demand, making the versatility almost unlimited.

2.5 Another outstanding feature of electronic instruments is their adaptability to the control systems. Before anything can be controlled it must be measured. And if the measuring system is made to deliver an output in the form of an electric signal, it can be adapted to automatic control function. Any servomechanism may be regarded as an instrumentation problem if one desires to take that point of view.

2.6 Automatic control is one very obvious example of a feed-back though that is by no means the - only application of electronic instrumentation. In addition to minimising the error between the input and output signals of a system, the feed-back may be used to control the input and output of various quantities.

2.7 The possibility of using electronic instruments as telemetering systems in dangerous and inaccessible places is fairly obvious. There are many glamourous examples, such as research rockets, unmanned satelites, spy planes, etc.

where it is convenient and at times obligatory to use remote indicating and remote controlled instruments.

2.8 Till late most of the devices were of the 'open loop' type. Their action went only in one direction, so to say. As long as everything operated correctly, they were fine. But in case of failure or error in any part of the mechanism, the mechanism was incapable of discovering and remedying it. In modern automation, we use a feed-back system which tells the mechanism when it makes mistakes or otherwise gives it instructions and in case no correction is possible, orders the machine to stop.

2.9 These particular advantages go to show how necessary and helpful the electronic instrumentation is to the technician and why Photogrammetrists have switched over to electronics and in fact opened a new age, 'the age of electronics'.

2.10 Now we shall see how electronics helps us carry out the work in Photogrammetry. It can be said with confidence that electronics helps us in every phase of our work. The following paragraphs give us an idea as to what instruments use electronics. The details about them, i.e. their principle of working, importance, etc. will be dealt with in the forthcoming chapters.

2.11 The first phase of the Photogrammetric work is providing control by ground survey. This means fixing points with known position and elevation in the area to be photographed. Formerly this was done by ground survey methods such as triangulation, levelling, traversing, etc. But the recent developments in electronics slowly outmoded these methods and electronic instruments like Tellurometer, Geodimeter, Air borne profile recorder, Santoni's Solar Periscope, etc. came into vogue. They speed up the work and increase the accuracy. The electronic computers help the calculation work of geodetic and topographical computations.

2.12 Next comes planning and execution of Photo-flights. Formerly many of the instruments on the pilot's indicator panel were non-electronic. They did not give the accuracy required for photogrammetric work. Moreover the aircraft was not very steady or stable. The effect of all this compelled the Photogrammetrist, many a times, to order re-photography of the area and the result was a great loss of finance, labour and time. Now-a-days instruments like radar, radar altimeters, wireless units, shoran, decca and other navigation systems, auto pilots, fire detectors, etc. make an accurate and safe flight feasible.

2.13 In the actual photography and processing for negatives and prints the Photogrammetrist is aided by instruments such as exposure meters, intervalometers, automatic winders and shutters, camera stabilising mounts, electronic printers, spool tank developers, electron image tube etc. They minimise the possibility of error and render prints of a good quality and speed up the work.

2.14 In the last stage of work, i.e. map compilation, the Photogrammetrist uses the instruments like terrain data translators, automatic map compilation system, steromat, co-ordinatographs, automatic rectifiers, safety devices as caution signal in autographs etc. The digital computers in fact can be used in all the phases. All of these are electronic instruments.

CHAPTER 3.

SOME ELECTRONIC SYSTEMS.

3.1 One of the chief differences between man and the other animals is that the other animals rely solely upon muscular strength to satisfy the needs of existence, whereas man takes advantages of and utilises many forces of nature to accomplish his desires. The primitive man domesticated some animals to aid him in his work. Later centuries saw utilisation by man of the force of wind and water in such devices as crude wind mills, water wheels and the sailing ships. The 19th Century witnessed the harnessing of the energy of steam and the beginning of the internal combustion engine. The first half of the 20th Century brought the development of electricity as a flexible source of energy for light, power and communications. The second half of the century is seeing a great advance in automation through the medium of electronics in new electrical and mechanical self-deciding and self-controlling devices.

Components and Circuits:

3.2 The marvellous achievement in the field of electronics and automation is made possible by the use of many components, circuits and devices. Several of these components, circuits and devices may be employed in combination to achieve the desired result. The electronic equipment may be classified as shown below (13).

1. * Vacuum-tube amplifiers.
2. Vacuum-tube oscillators.
3. Saturable-core reactors.
4. Series impedance transformers.
5. Peaking transformers.
6. Phase-shift circuits.
7. Free-wheeling circuits.
8. * Rectifiers.
9. * Filters.
10. Voltage dividers.
11. * Time-control circuits.
12. * Constant-voltage circuits.
13. Non-linear resistors.
14. * Electronic switches.
15. Long-tailed pair.
16. * Light control devices.
17. Temperature-control devices.
18. * Position-control devices.
19. * Rotary amplifiers.
20. Antihunt circuits

The asterisked ones are of use in Photogrammetry.

Principles of Circuit Systems:

3.3 Simple control systems involve some manual actions which determine the operation of a machine. The system may be of the on-and-off type forming a simple switch or may be of an automatic push button type forming a starter. These starting or stopping devices are simple controls. Other type of controls may be of the regulator type to check the speeds of machines etc. In the last type a transformer circuit along with amplifiers is used to do the job. Here an expenditure of a small amount of energy is used to control the delivery of a much greater amount of energy, e.g. Auto-pilot mechanism.

/. Another form of control system is a closed cycle type system in which there is a mechanical or an electrical circuit interlock between the final controlled unit and the primary controlling unit. In electrical terminology this means a closed circuit and a feed-back, e.g. Electronic Printer.

Some Electronic systems and their Components:

Vacuum-Tube Amplifiers:

3.4 The vacuum triode, tetrode and pentode are amplifying tubes. Associated with suitable circuits, they constitute one type of amplifier and they have revolutionized the art of electrical communications, measurement and control. The function of a magnifier is to increase or magnify a very weak signal until it is capable of controlling sufficient electric power for producing light, sound or mechanical work. An amplifier does not create any energy but controls sources of electric energy to give outputs that follow the original input signals with fidelity. The amplification may be in one or in a series of stages or steps. The amount of amplification that can be attained for some application is limited by various factors. The discussion about these - factors is out of the scope of this dissertation. Electronic Printer, Cloud height data analyser, etc. use vacuum tube amplifiers.

Time Control Devices:

3.5 The timing of various types of operations may be controlled by electric circuits, magnetic devices and mechanical devices. The time required for the transient current and the voltage changes in the inductances and the capacitances is made use of here. e.g. Intervalometer, - Spool tank developing units, etc.

Light Control Devices:

3.6 The electronic components that function under changes in light are the phototube, the electron multiplier and the photovoltaic cell. The phototube or a photoelectric cell is a tube, may be gas-filled or with vacuum inside, containing a cathode and an anode as parts. The cathode is a half-cylindrical sheet of metal covered on the inner side with a thin layer of photoemissive material (often cesium oxide on silver) while the anode is a coaxial wire of low photoemissivity. The phototube is best adapted to applications requiring exactly the same response at all times to the same radiation, quick response to very rapid changes in the radiation or in circuits in which the voltage impressed upon the tube might reach high values. The vacuum-phototubes are used for light-measuring and light relay devices and the gaseous phototubes for (i) facsimile transmission of pictures, (ii) as an'electric eye' in photometric measurements, (iii) for control of artificial illumination and many other applications. The photovoltaic cells are used in measuring the light change but are not very responsive. The electron multiplier can be used as a combined photoelectric pick-up and amplifier for minute light variations, for sound reproduction of films and in television.

Position-Control Devices:

3.7 The function of the position-control devices is to transmit motion by electrical means between two points that cannot be readily connected - mechanically. This function can be accomplished through the use of either a direct or an alternating current. The Selsyn system also called Synchro system for transmitting motion electricity is used for indicating the positions of all kinds of remote mechanical equipment and also for the remote control of such equipment. They are made in a variety of sizes and with different accuracies to fit the application. SEG V - rectifier, Camera Mountings use these devices.

Servomechanism:

3.8 This is a term appearing quite frequently in electronics. It comprises a class of automatic regulators whose purpose is to keep a regulated quantity matched to a reference quantity. Usually the quantities regulated are the speed, position or change in the rate of speed of some machine. Thermostats that control the temperature of a body and hydraulic governers that control the speed of a turbine are but a few examples of simple servomechanism. Many operate electrically or electronically; others are mechanical, hydraulic or gas operated. At times some of these types of servomechanisms are used in combination.

3.9 For keeping the regulated quantity matched to a reference quantity, the servomechanism should possess the following four important characteristics, viz :-

1. Fast response,
2. High accuracy,
3. Unattended control,
4. Remote operation.

A Servomechanism consists of three basic elements. Those are : (1) an error detecting-device, (ii) an amplifier, and (iii) an error-correcting device. The error detecting device determines when the regulated quantity differs from the reference quantity. It then sends out an error signal to the amplifier, which in turn supplies power to the error correcting device. With this power, the error correcting device changes the regulated quantity so that it matches the reference quantity. The closed loop composed of the error detector, the amplifier, the error corrector and the regulated quantity are characteristic of all servomechanism devices.

3.10 Any quantity can be regulated and can also be used as a reference quantity. Moreover the regulated quantity and the reference quantity need not be the same if the proper detecting device is employed; but the measuring units within the error-detecting and error-correcting device must be the same for even dissimilar quantities, e.g. the temperature of a room and the speed of the blower for the room should both be measured in terms of voltage and so on. e.g. Auto Pilot systems, SEGV Rectifier, etc.

3.11 The error corrector of a servomechanism system actually does the work of regulating. The error detecting device and the amplifier serve only as a means of controlling the error corrector so as to make the regulated quantity match the reference quantity.

3.12 There are many forms of servomechanism systems; but their fuller description has been omitted here on account of the limited scope of this Dissertation.

CHAPTER 4.

ELECTRONICS IN GROUND CONTROL

4.1 Photogrammetric construction of maps necessitates the establishing of horizontal and vertical values in the form of co-ordinates, of certain photographic image points for the use in subsequent operations leading to map compilation. These image points are commonly known as photo control points and the survey made to establish the same is known as ground control survey.

4.2 Control points are points of known plan-position and elevation. The number of control points and their required accuracy depends upon the accuracy of the required mapping, scale of mapping, extent of the area to be mapped and methods of ground survey employed.

4.3 Fixing the control points is the basic requirement for all plotting operations. For plotting by graphical methods, like the radial line method or the slotted templet method, control points are necessary for the purpose of restitution of scale of the plotted area and for orienting the plotted area with respect to the co-ordinate system in use. For controlled mosaics or photomaps rectified photographs are required to be used. In the process of rectification, control points plotted on a sheet and marked on the photograph are used for orienting the negative in the rectifier. Plotting instruments like Wild Autographs etc. use the control data for orienting the dispositives or photographs in the photo carriers. Even in contouring by simple means like the parallax bar, a set of control points helps us to determine the corrections in heights obtained from the measured parallaxes. These examples prove the - indispensability of control points.

4.4 Electronics has made rather a dramatic entrance in the work of laying of ground control. This was solely due to the development of distance measuring systems and altimeters based on propagation of low frequency radio waves. Most of them were first developed for air and sea navigation, the more accurate ones were then used for surveying.

4.5 In the days when electronics was not known or was not much in use, ordinary ground survey methods had to be used. These methods involved a huge amount of work and they were time-consuming;

this ultimately increased the cost of work. For vertical control we have to determine accurately the heights of control points. For determining the heights of points on hills a faster way is tachometry but it is not an accurate method. Then the only way remaining is to run a levelling line which is a very difficult task in hills and is time-consuming. If the points are chosen from the photographs, then some of them might also be inaccessible. It will then be difficult to get their accurate height. Electronic instruments like the airborne profile recorder and the radar altimeter give us the heights of points - without occupying them. The time required is also very short. In ordinary surveying where we use instruments like theodolites, levels, etc. we have to depend much on atmospheric conditions. Mist, fog, haze make the work impossible. Electronic instruments like tellurometer, aerodist and others based on the same principle can be used with advantage in such cases. They use - radio waves which are not affected by varying atmospheric conditions. In ordinary surveying, as we have to depend on the observer's capability of getting good intersection, the maximum - length of a line covered in one shot is only a few miles. The measurement of long lines involves measurement in small parts and a good number of stations have to be occupied. This involves a large amount of labour and takes time. For fixing position of unknown points with respect to known points we use triangulation, wherein we measure one side and two angles of triangles. This is because measuring all the sides is difficult. In Triangulation a small error in the angular measurement causes a considerable error in the co-ordinates of the points, the position of which is to be fixed. With modern electronic instruments this job is quite simple. For fixing co-ordinates of unknown points instead of triangulation trilateration can be used where three sides of the triangle are measured. The method is more accurate and faster.

4.6 The modern tendency is towards the use of such instruments as render fast work and exclude the human element as much as possible. The electronic equipment has all these advantages. The sources of errors in electronic distance measurement are :

i) Error in the measurement of time interval giving distance.

ii) Error in recording the time interval.

iii) Errors in allowance for the time taken in transmission through the electrical circuits.

iv) Changes in velocity of waves owing to changes in atmospheric pressure, temperature, humidity, etc.

The first three are errors in the determination of time and are independent of the length of the line but the fourth is in general, proportional to the length of the line. The error in the measurement of the time interval is inherent in the apparatus and it depends upon the degree of accuracy to which time can be read. The exact point of starting of the pulse is difficult to ascertain; to reduce errors it is necessary to measure the time interval by various operators. Of course the final accuracy can easily be increased by taking a large number of sets.

4.7 It has been stated that the change in the velocity of waves affects the accuracy. The variations in the velocity are due to variations in value of the atmospheric refractive index which in turn depends upon the atmospheric - pressure, temperature and density. The velocity generally varies from about 186,208 miles/ sec. to 186,248 miles per second. According to Clark

$$V = \mu C$$

where

V = velocity of transmission,

μ = Index of refraction for the atmosphere,

C = a constant represented by the velocity of transmission of waves in free space,

where μ may be calculated from the formula of England, Crawford and Mumford asgiven below :-

$$(\mu - 1) \times 10^4 = \frac{p}{2T}\left[2\cdot 11 + \frac{100}{p}w\left(\frac{101\cdot 59}{T} - 0\cdot 00293\right)\right] ,$$

where

T = absolute temperature Centigrade.

P = total atmospheric pressure in mms. of mercury.

W = partial pressure of water vapour in mms. of mercury.

This formula, however, would be inconvenient for computing a mean velocity for the path, so a number of approximate formalae assuming normal atmospheric conditions are in use. The simplest one is based on the assumption that

where $\mu_h = \mu_0 \left(1 - \frac{h}{4R}\right)$

μ_h = index of refraction at h feet above sea level.

μ_0 = index of refraction at sea level

R = mean radium of the earth in feet for the area

under consideration.

then v the mean velocity along the path,

$$v = v_0 \left(1 + \frac{H+h}{8R} - \frac{L^2}{64R^2}\right),$$

where

v_0 = velocity at sea level under normal atmospheric conditions.

L = Approximate slant distance ($v_0 \times t$)

H = Height of the point to which the distance is measured above sea level.

h = Height of instrument station above sea level.

4.8 Some of the electronic distance measuring devices are given below :-

i) Radar (Radio Detection and Range) - This uses radio energy in pulse form. It falls in non-co-operative category. It has a range of about 50 miles and is mainly used for navigation.

ii) Loran (Long Range Navigation) - This navigational aid uses continuous waves. Its day time range is about 250 miles at high altitudes and increases to 1400 miles at night (Ref. 10).

iii) Shoran (Short Range Navigation) - As the name suggests, this has a short range as compared to a Loran, the maximum range being 300 miles. It uses radio energy in pulse form.

iv) Hiran (High Precision Shoran) - It is on the same principles as the Shoran but is more accurate. It has a range from 100 miles to 500 miles.

v) Gee - H - This is a British system and is much used by Britishers. It uses pulse form of radio energy and has a range of about 450 miles.

vi) Oboe - This is the same as Shoran; the only difference is that the transmitter is in the moving vehicle like an aircraft or a ship, the distance of which is to be measured from a known point.

vii) Decca - This aid uses continuous waves. A set of two Decca Stations define a system of hyperbola with respect to which navigation is done. This aid was invented by the Britishers. It can be used upto 300 miles but the reliable range is only 100 miles.

viii) Geodimeter - This instrument uses pulsating polarised light waves. This has a very short range and the measurements can be done in total darkness only. Atmospheric agents affect results obtained with this to a considerable extent; so it has many limitations.

ix) Tellurometer - This aid uses continuous waves and is found to be very useful for distance measurements in survey work. It has a range of 150 miles.

4.9 All these devices use radio waves. Radio waves are waves generated by converting electricity into waves that radiate freely through vacuum or atmosphere and to a certain extent penetrate through solid matter and produce - electrical effects. In practice radio energy is used as continuous waves or pulsating waves. A pulsating wave has fluctuating density whereas a continuous wave has a constant density.

4.10 The systems used for distance measurement are of two types -- Co-operative and non-co-operative. In non-co-operative system the waves are reflected directly from the object or station whose distance is being measured. This form of measurement, commonly used in conjunction with directional wireless to determine the rough bearing as well as the rough distance, is employed for military purpose in the detection of alien aircraft or for anti-aircraft gunnery; but its accuracy is not so great as that of the co-operative system, and its range is more limited. In the co-operative form, a special receiving instrument receives the signals at a different point and, after a short delay of known duration,

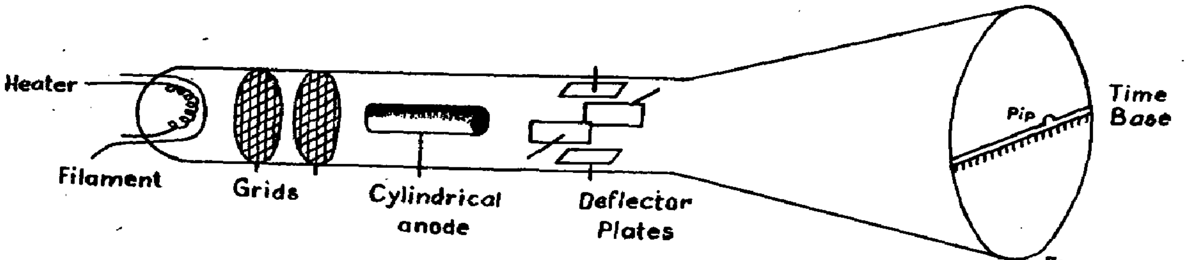


Figure 1

Sketch No.1

Cathode ray tube.

re-transmits them on a different frequency to the sending station, generally boosting up the strength of the signal in the process. The main transmitting and receiving apparatus may either be in the aircraft or at the ground station. Consequently the co-operative system is preferred.

4.11 Of all the systems the radar system is the oldest and may be taken as the basic system. The other systems involve more or less the same principle of working, but differ in certain other characteristics and in accuracy and range. Radars, Shorans, E.P.Is. use short intense pulses of radio energy while in Decca, Loran, Tellurometer continuous waves are transmitted. Gee H system is like Shoran; so is the Oboe system except that the transmitter in the latter system is on the ground and not in the vehicle, the range of which is to be measured. Some of these systems (e.g. Decca, Loran, Lorac, etc.) measure the difference between the distances from the navigating vehicle to two or more fixed points. Others measure the full direct distances. The measuring or indicating devices used include a cathode ray tube (vide sketch No.1) in each case, in the Radar, the Shoran, the E.P.I. and the

Tellurometer. In the other systems like the Decca and the Loran, phase-meters with calibrated dials and printers are used for measuring the phase difference between the different incoming waves, on the hyterodyne principle. In the use of these electronic instruments for survey, it is necessary to use high frequency waves, i.e. of short wave length as against those used for ordinary radio broadcasting - wherein waves of comparatively low frequency are used. In the ordinary radio transmission we are not much bothered about the path of travel of the waves. A wave ordinarily travels but a short distance beyond the limits of visual observation. Long distance reception therefore almost depends upon the waves received after reflection from the ionosphere a layer of negatively changed ions surrounding the earth's atmosphere at heights from 60 to 180 miles above m.s.l. As actual paths of such waves are not definitely known, they prove to be useless for survey purpose.

4.12 Another factor which makes the short wave transmission preferable is that the rate of growth of the pulse depends upon the frequency of transmission that the short waves give a sharper and narrower impression of the pulse on the recorder than long waves do and that a more accurately defined commencement of the pulse front is obtained from which measurements can be taken. The Decca, the Shoran and the Tellurometer, as they use short waves, are more - suitable for survey purposes. These are briefly described later in this chapter. The Decca system is mainly used for Hydrographic surveys, and the Shoran system mainly for ground surveys. The Tellurometers measure comparatively short distances, but they measure them very accurately, on the ground.

4.13 Before describing any of these systems, we will first take note of the Radar, which is the basis of all these systems. This will be of help in describing the other instruments later on.

4.14 In the Radar, a powerful pulse of high-frequency carrier wave travels froma transmitter, hits an object like the fuselage of an aeroplane or a ship and is reflected in all directions including the direction in which the transmitter is situated. A receiver is situated near the - transmitter (in fact one and the same aerial acts both for the transmitter and the receiver). The receiver measures the very minute interval of time taken by the pulse in travelling the distance from the transmitter to the object (target) and back to the receiver. A little time after the reflected pulse reaches the receiver, another pulse starts from the transmitter. If instead of the intermittent pulse, a continuous transmission occurred, it would not be possible for the receiver to measure the time of travel of the energy from the transmitter to the receiver via the target without using co-operative system. Furthermore since the energy is transmitted in intermittent pulses, it is possible to pack a lot of energy in each pulse. This is necessary because even though it is possible to concentrate the transmitted energy into a beam, the reflected energy gets widely diffused and the receiver receives a very small portion of the transmitted energy especially when the reflecting qualities of the target are poor.

4.15 The main component of the receiver is a - cathode ray tube which in collaboration with other components and circuits measures the very short time taken by the pulse energy to travel from the transmitter to the target and back. This distance which is double the distance of the target from the receiver, be '2d'; then the distance of the target from the receiver will be'd'.

If the time interval between the emission and the reception of the pulse be '2t', taking 'v' the velocity of radio waves (as 186,000 miles/sec.) we have d = v.t. If the two way distance be 100 miles say, then t = 1/1860 secs. At - present the instruments are capable of measuring upto one millimicrosecond (10^{-9} seconds) which means that the unreliability of the measured distance is ± 2 inches.

4.16 Shoran (7) was designed by Mr. S.W. Seeley of the Radio Corporation of America. It works on a freqnency of 210 to 260 megacycles/sec.

4.17 Shoran system falls in the co-operative category. Here a transmitter is placed in a moving vehicle i.e. the aircraft in aerial survey. The target instead of being a mere responder is a transponder. The geographical positions of these targets are accurately found. The two transponders are distinguished by the names 'Drift' station and the 'Rate' station respectively. The position of the required point is determined by finding out its distance from the rate and the drift stations. In case there is a difference in the altitude in the stations, their heights above the M.S.L. should be known. This will be useful both for determining the position of an aircraft or a point

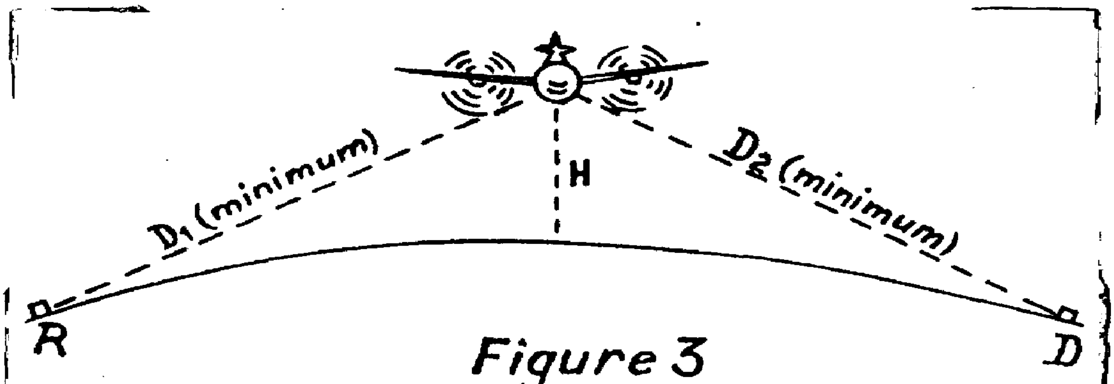


Figure 3

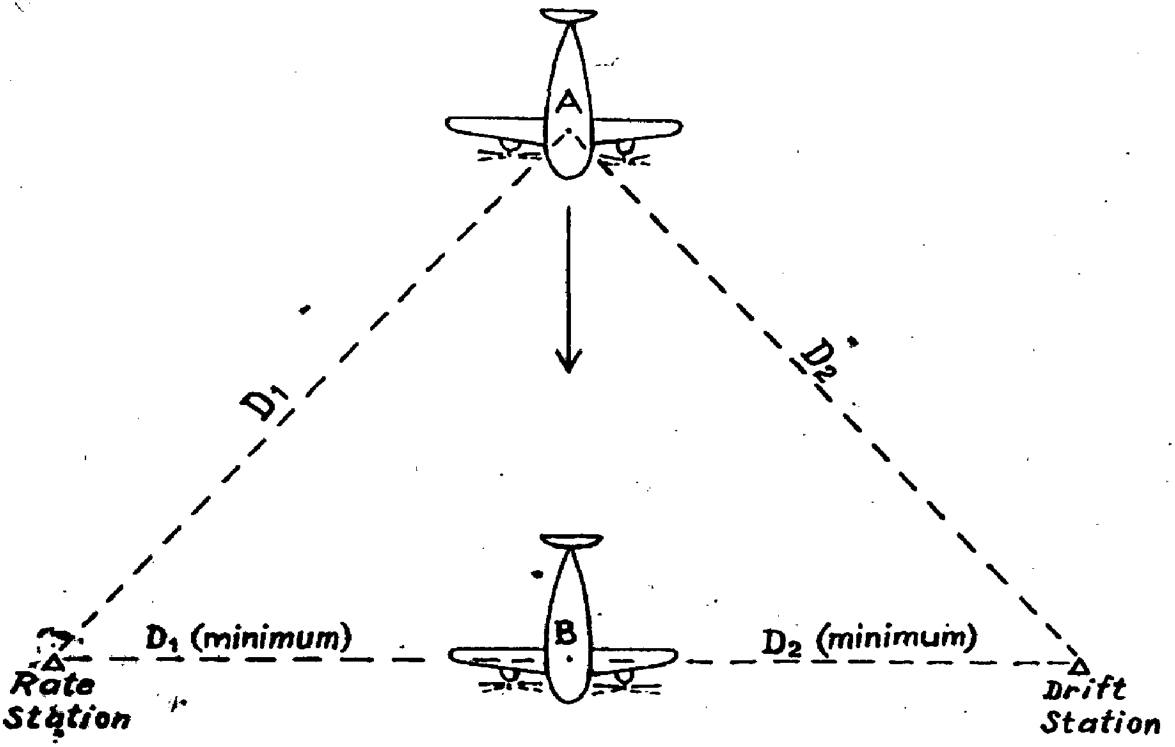
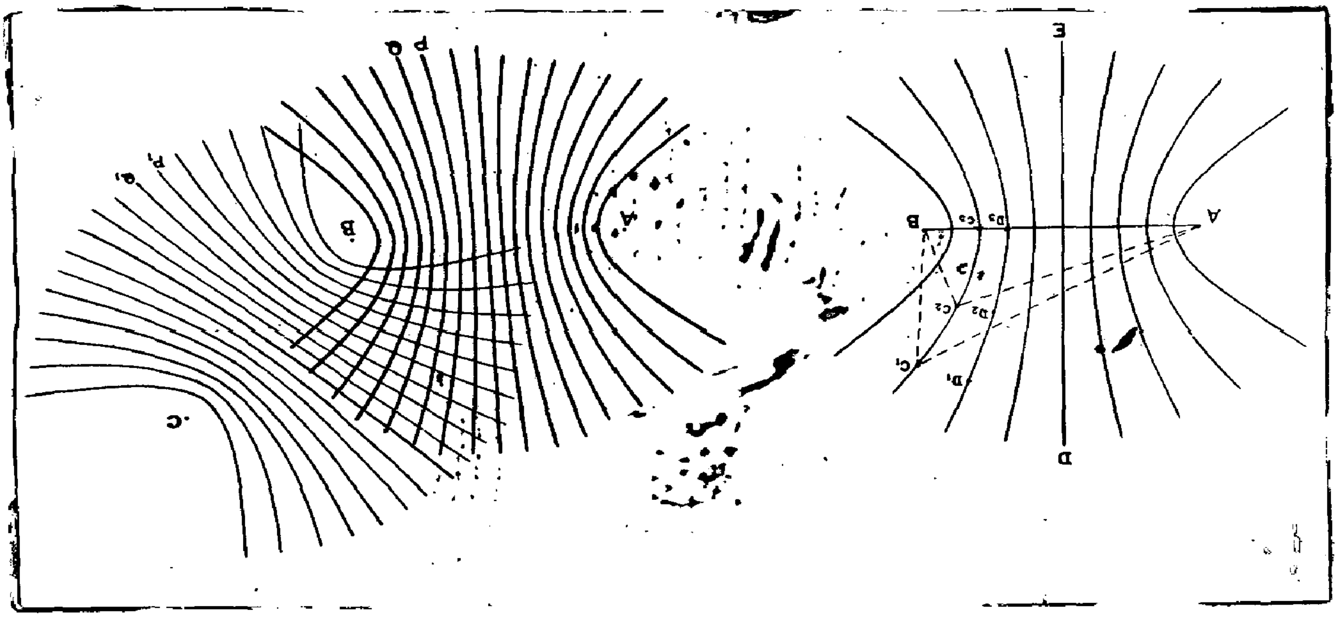


Figure 2

$D_1 = D_2$; $D_1 + D_2$ is least when aircraft is at position B.

Sketch No.2 -

Line Crossing Technique.



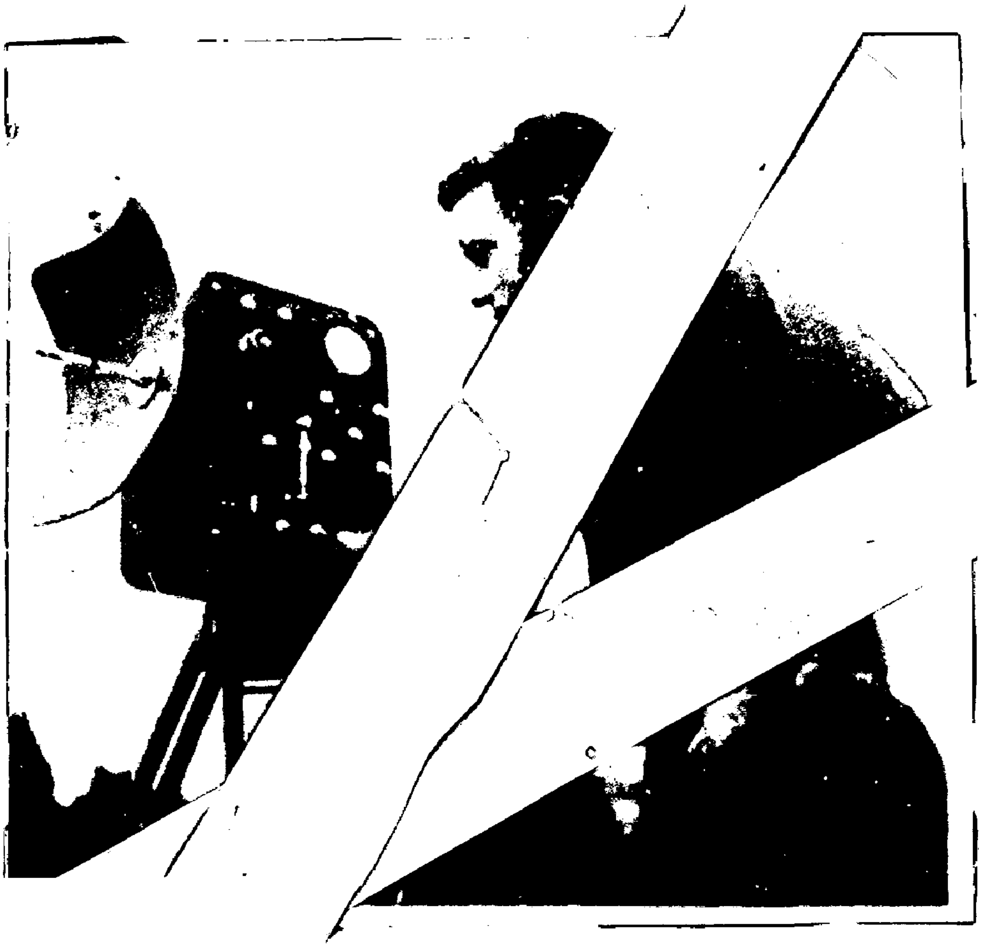
Sketch No.3

Hyperbolic position lines generated by Decca System.

4.19 In the Decca system the co-ordinates are in a hyperbolic form. In electrical terms, each family of hyperbola is made up of lines of equal phase difference as between the signals received from a pair of transmitting stations situated at the focal points, the continuous wave transmission being synchronized or "phase-locked" and assumed to travel at a constant speed.

4.20 Thus a comparison of the phase of the signal at the point of reception - the basic function of the Decca receiver - will locate the receiver on a hyperbola along which, by definition, all points have a constant distance difference from the two stations. The indicated hyperbola thus forms a navigational line of position. In practice one station is called the "Master station" (vide sketch No.3). For fixing the geographical position of the observer at a point, with - reference to groundstations, two sets of position lines are required. These are obtained by - generating two hyperbolic patterns, using one master station with two other slave stations. The special feature of this system is that several observers can use the system at the same time.

4.21 Another device, the Tellurometer (15) was invented by Mr. L. Wadley, a Scientist on the



Sketch No.4

lurometer 'Micro-Distancer'.

Staff of the South African Council for Scientific and Industrial Research. It also employs - micro-waves and is of co-operative type. A set of the equipment consists of two portable units, one placed at each end of the line to be measured, each powered by an ordinary automobile storage battery. Operators can maintain contact by means of built-in telephones (vide sketch No.4).

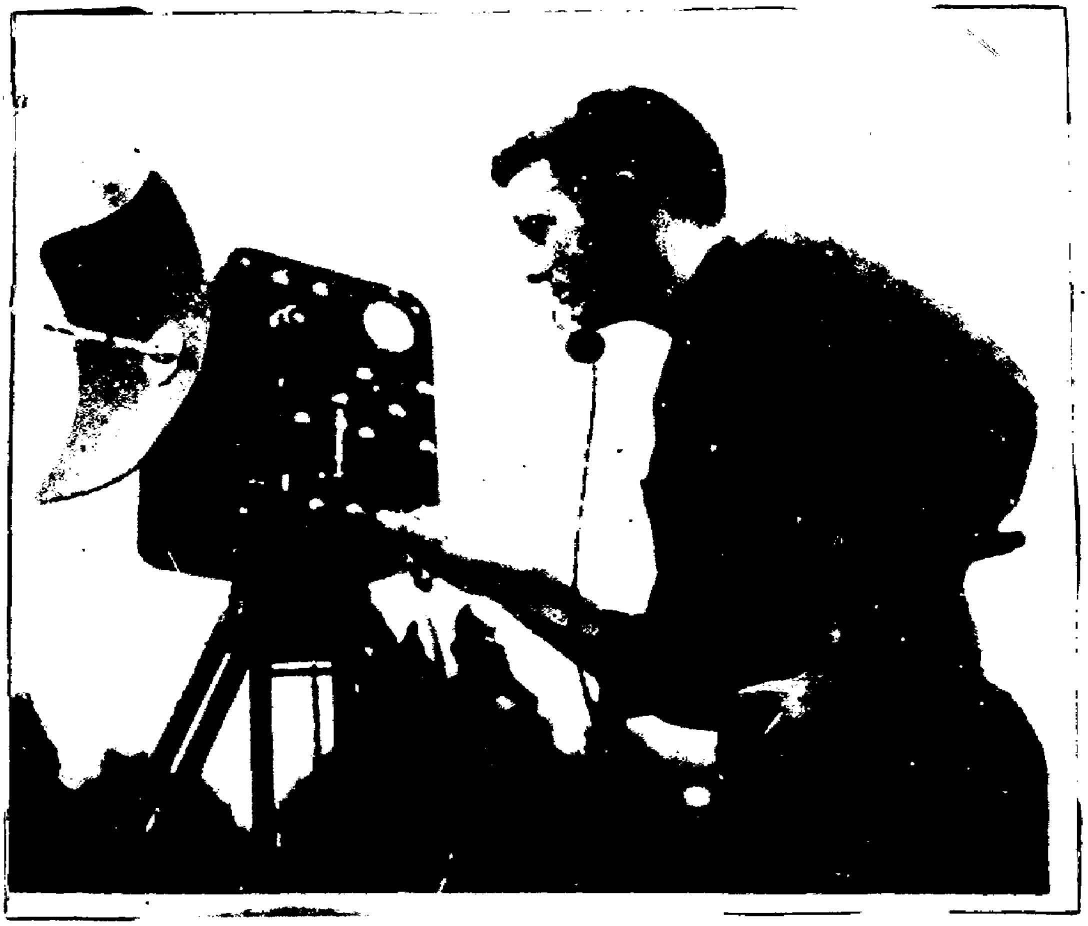
4.22 The electronics involved is simple. A continuous wave of about 10 cms. in length - 3000 Mc (Megacycles) per second is radiated from the master unit. This carrier wave is modulated by measuring frequencies of 10 Mc/sec. and others of similar order and is received and re-radiated by the remote unit. The return wave intercepted by the master unit and the phase shift between the outgoing and the incoming - modulations is indicated by a cathode-ray tube. This phase shift gives the measure of the elapsed time and is indicated by a small break in a trace adjacent to a circular scale. Four - measuring frequencies are used and the same scale serves for all. For the sake of simplicity, the propagation velocity used in computation is half the actual value, so that the distance is deduced directly. The velocity of the microwaves varies a little with atmospheric pressure and humidity, and small corrections are required to be made for these variations. Therefore the operators carry a wet-and-dry-bulb thermometer and a barometer for measuring the meteorological conditions.

4.23 To avoid the necessity of a clearing line between two stations in forest terrain, Dr.A.G.Mungall of the Division of Applied Physics, National Research Council, U.S.A., devised a means of separating the antenna, the actual source of radiated waves, from the main body of the circuitary and elevating it on a mast so that the instrument can "see" over the tops of the trees. The retracting mast can be run up as high as 40 ft. above the instrument. The crew can then clear the usual line, a few feet in width, for sighting purposes, and the distance can be measured over, rather than through, the timber.

4.24 As to the advantages of the instrument, two men, one with the transmitter and the other with the receiver can measure any distance from 500 feet to 40 miles in 10 minutes. Only 10 minutes suffice for unpacking, setting up, demounting and re-packing the instrument. It produces accuracies of 1 part in 300,000 ± 3 inches or greater by individual calibration. Users have obtained an accuracy of 1 in 5000 on lines 500 to 1500 ft., 1 in 10,000 on lines 1500 ft. to 1 mile and 1 in 25000 on lines 1 to 40 miles. Federal Agencies, State Highway Engineers and Private Firms of America have reported 40% - saving in the cost of establishing horizontal control by using Tellurometers.

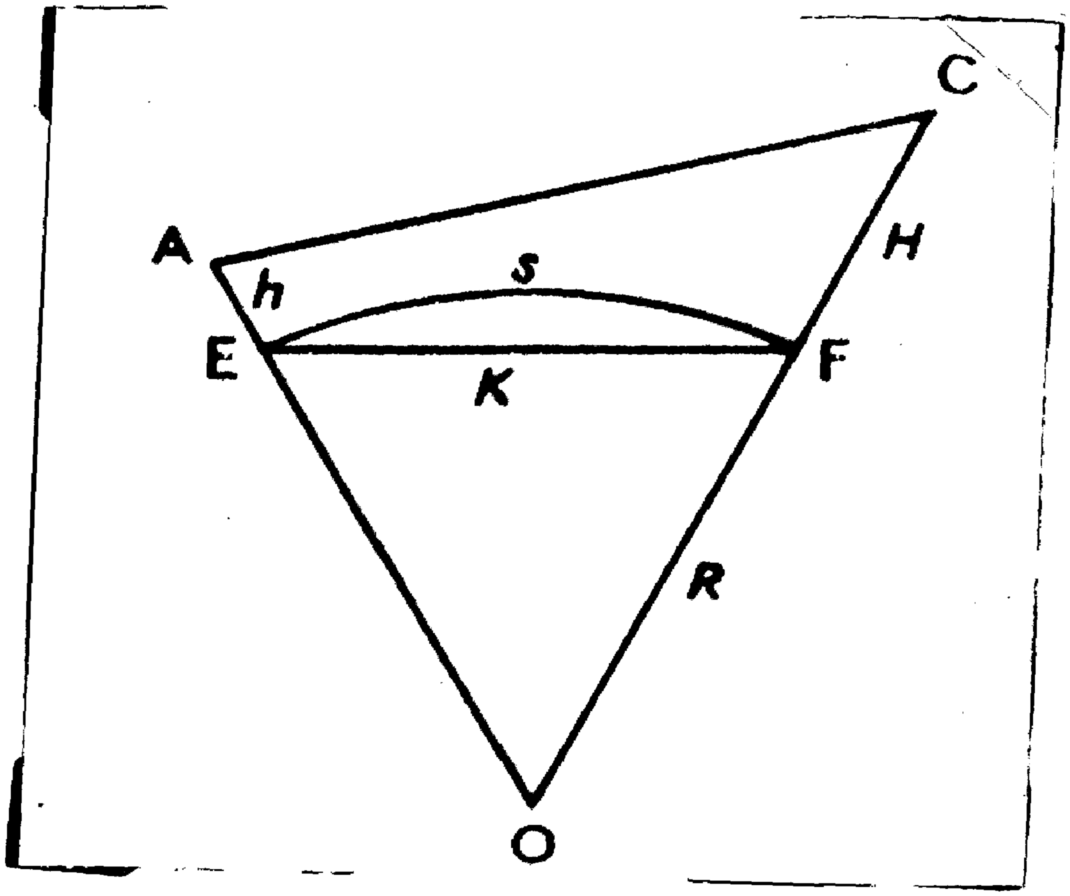
4.25 Geodimeter, another electronic instrument developed for distance measurement, uses polarised light waves instead of radio waves. The measurement of distance by the Geodimeter is a function of time required by the light waves to travel from the transmitter to the target and back. The time is measured electronically as in the Tellurometer. But this equipment is heavy and bulky. Moreover it can only be used at night and in total darkness for long lines. Even twilight or moonlight precludes the polarised light waves used by Geodimeters. Rain, mist or fog also can block the line and prevent work. Due to all these disadvantages the instrument has not become very popular.

4.26 The latest addition to the Tellurometer family is the Hydro-Dist. and the Aero-Dist.(6).



Sketch No.4

New Tellurometer 'Micro-Distancer'.



Sketch No.5

Reduction of Slant Distances.

The Hydro-Dist. introduces a technique for measuring distances across water from shore stations to points on the water. The Aero-Dist. is the new airborne Tellurometer system. This can be used for distance measurement by the "line crossing" technique. It fills the gap between the Tellurometer-Micro Distancer and the Hiran system and has an operating range of from 40 to 150 miles.(It is to be noted that the lower limit of the Hiran system is about 100 miles.)

4.27 All the distances measured by the electronic instruments are direct distances between the transmitter and receivers. As the elevations of points from the sea level may be different, the distances may be inclined. They have to be reduced to surface distance. Reference is made to Clark (10) (vide sketch No.5).

4.28 In the figure if A and C be two points, the distance between which is being measured say L, and if their elevations from sea level be h_1 and h_2 and if o be the centre of the earth and R the radius, then the chord length EF = K, say, then

$$EF = K = \sqrt{\frac{[L-(h_2-h_1)][L+(h_2-h_1)]}{\left(1+\frac{h_1}{R}\right)\left(1+\frac{h_2}{R}\right)}}$$

and the required arc length EF will be :

$$\text{Arc EF} = K + \frac{K^3}{24R^2} + \frac{3K^5}{640R^4} + \cdots\cdots$$

If the slant distance is to be converted to geodetic distance, tables can be used giving arc distances at sea levels from recorded time of transmission; or else it can be calculated from one of the many formulae. As an example (10) assuming arbitrary calibration velocity 186,218 miles,

$$A = \frac{2.152}{10^8} M (H+h) + \frac{1.794}{10^8} \times \frac{(H-h)^2}{M} - \frac{0.2477}{10^8} \times M^3$$

where

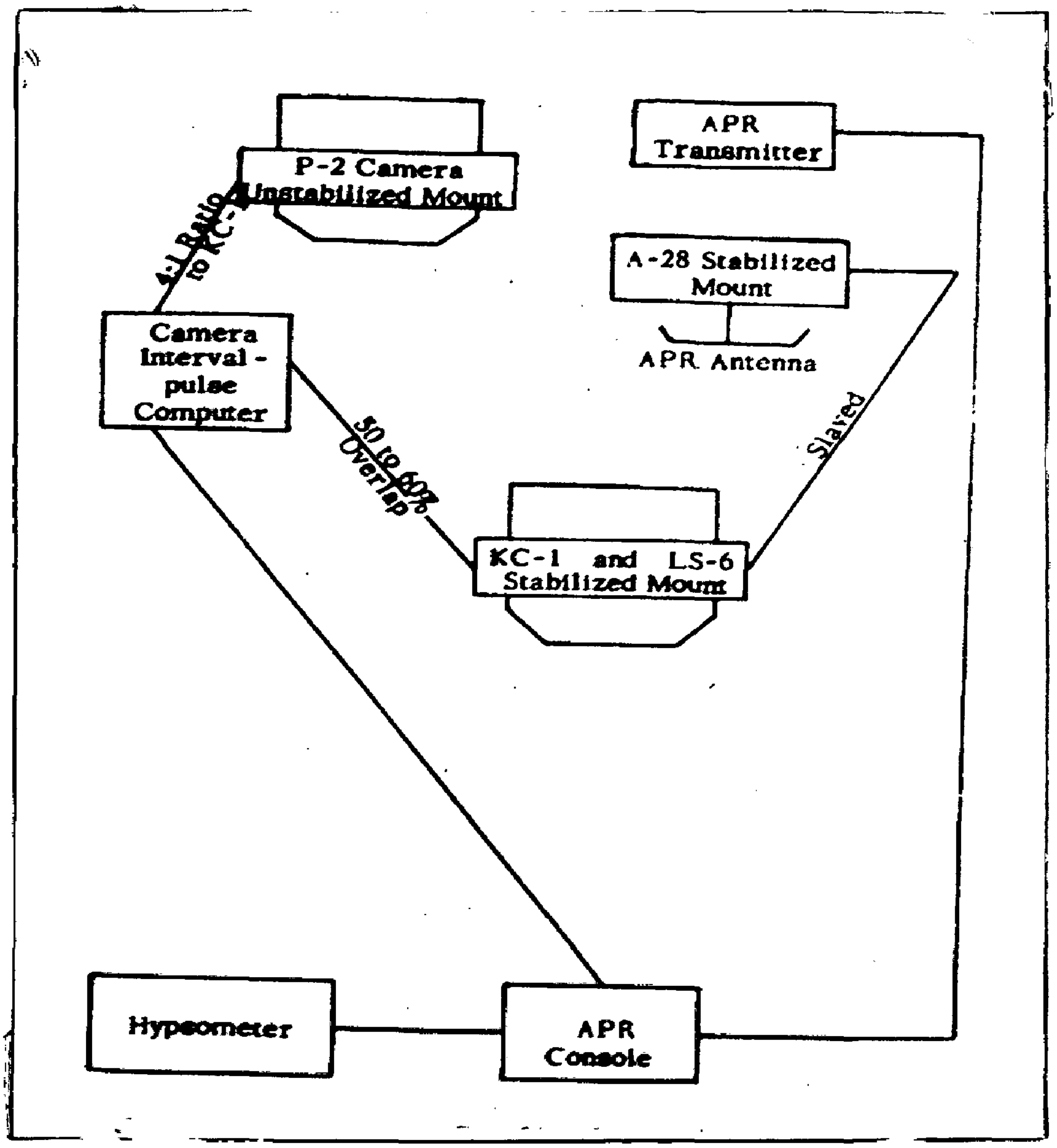
A = slant distance minus arc distance in miles.

M = approximate arc distance in miles (say recorded slant distance, true slant distance, chord distance or arc distance).

H = Height of station, the distance of which is required above sea level.

h = height of ground station above sea level.

4.29 Up till now we have studied the equipment and methods for the laying of horizontal ground control. For providing vertical control, an instrument known as Terrain Profile or more commonly as Airborne Profile Recorder is used (5). It helps us to determine the relative heights of ground points along the flight line,



Sketch No.6

Block diagram of the Airborne Profile Recorder System.

from the aircraft itself.

4.30 The basic Airborne Profile Recorder system consists of the following six units (vide - sketch No.6), viz.

(i). Console Assembly - This assembly consists of an aluminium cabinet which contains a dual-pan recorder, timing circuits, monitor circuits, power supply circuit, and the operator's controls.

(ii). Transmitter Receiver - This unit includes a microwave hybrid duplexer, crystal detector, magnetron and hydrogenthyratron pulse modulator, modulator driver stages, high voltage power supply, and five stage video amplifier.

(iii.) Transmitter-receiver Mounting Tray - This is a standard 4 point shock mount assembly.

(iv). Inverter - A Jack and Heintz F16-4 inverter is used. It is capable of converting the aircraft's 28 V.D.C. supply to closely regulated 400 cps 115-V alternating current which is used for the power supply and for servo-motor excitation.

(v). Hypsometer Head - This is a cylindrical glass-lined container partly filled with toluene. It includes a thermistor, resistor, condenser and electrical connectors for attaching the cables to the back panel of the console and to the static lines of the aircraft.

(vi). Antenna Assembly - This assembly consists of a double dipole in a parabolic reflector. The antenna is fed from a Type RG-52/U wave-guide which terminates in a choke coupling.

4.31 The Airborne Profile Recorder as a whole consists of two distinct measuring systems, namely a highly accurate radar altimeter to measure - terrain clearance and a sensitive pressure-altimeter to measure variations from level flight. The terrain clearance as measured by the radar - altimeter and the terrain as provided by the difference between the radar and pressure altimeter readings are simultaneously and continuously recorded on a paper chart in the instrument. The clearance record is used to determine the photographic scale; the profile record provides vertical control for topographic purposes. The record data are correlated to geographic positions by using simultaneous vertical mapping photography.

4.32 Thus it is possible to provide the vertical control on photographic missions, in areas where it is impracticable or at times impossible to adopt ground survey methods for control. This method proves economical both in time and money.

4.33 The recorder under proper use, both in flying and data reduction, can be considered a first order surveying instrument to obtain vertical control for all types of mapping and charting.

4.34 In the test conducted by the Lockheed Aircraft Corporation for Wright Air Development Centre (5), with altitude 3000 ft. over terrain, which progressed from flat to rolling to mountainous on maps with large scale - 10 feet contours, American National Standard Accuracy Maps - the elevations were correct within ±2.5 ft.

4.35 It is also found that the recorder gives most accurate results for photography with a flying height varying between 6000 ft. to 10,000 ft.

4.36 By proper use of the auxiliary date such asweather, altitude, etc. recorded at the same time as of the readings, the relative height of points can be established within sufficient accuracy for 1/50,000 mapping and under optimum conditions for 1/25000 mapping.

4.37 Before concluding this chapter we shall recapitulate the benefits of using electronic instruments for establishing the ground control. They are greater accuracy, economy of time and money and efficient in conditions wherein other methods fail. We are no doubt very much - advanced now in the methods of laying horizontal control. But for vertical control we still do not have instruments that can give us the height differences between two points on the ground keeping the instrument at any one of them. In future, such instruments will definitely be available which then can be used in ground surveying also. It may involve measurements of vertical angles to a higher degree of accuracy and of the direct distance, by electronic means.

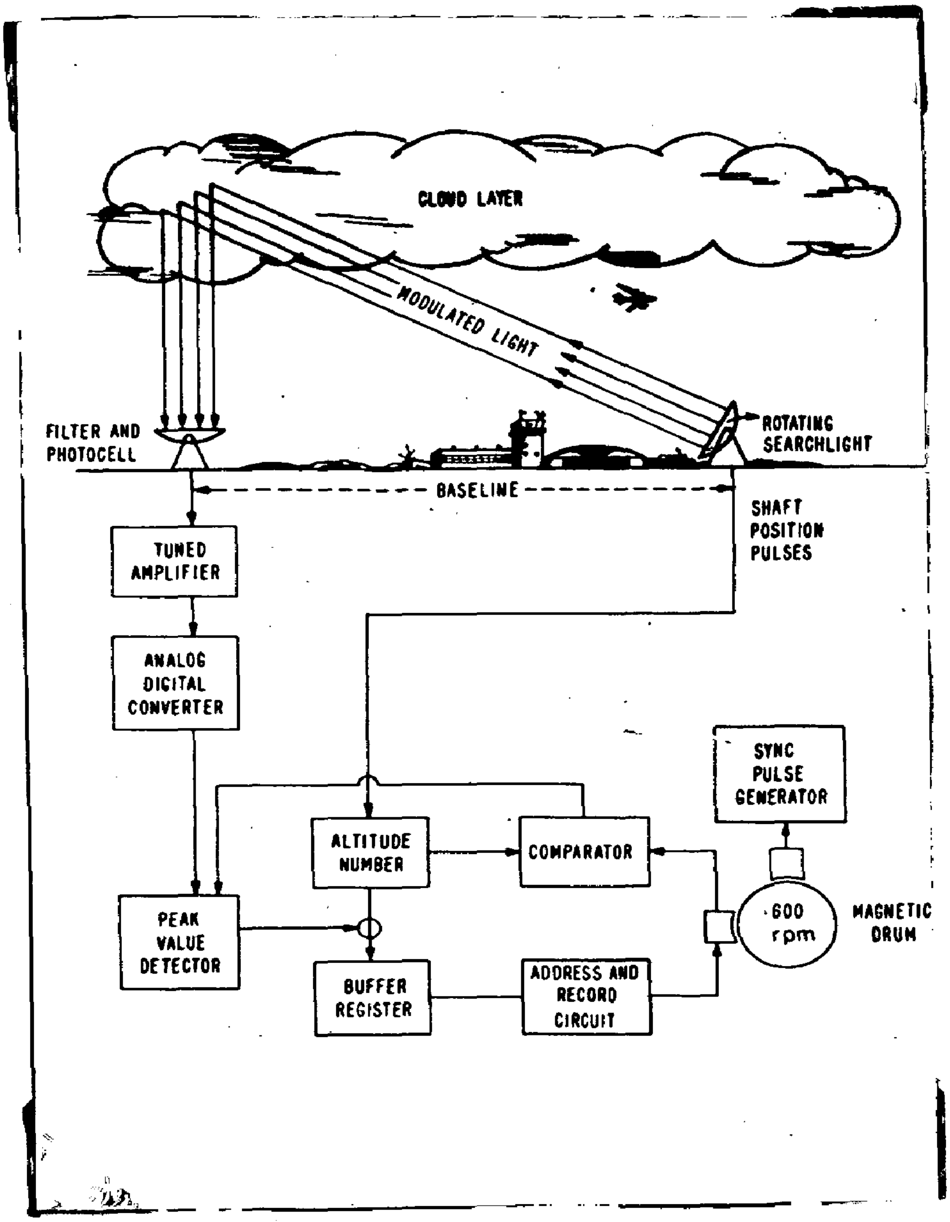
CHAPTER 5

ELECTRONICS IN PLANNING AND EXECUTION OF PHOTOFLIGHTS.

5.1 In this chapter we will go through the use of electronics in planning and execution of our flights conducted for photographic missions. The part concerned with the actual photography will be dealt with in the next chapter.

5.2 The success of a photoflight solely depends on its proper planning. This includes choosing the proper day, time, equipment including the type of aircraft, and pre-determination of the flying height, speed, etc. It will be interesting to know how electronics has crept into this field also.

5.3 As regards choosing the time and day, we have to totally depend on the weather bulletins published by the Weather Forecast Bureau, as is done for any flight. In our planning we decide the speed, flying height, flight line, spacing, etc. - as said before. All these are decided from the type of camera, the scale of mapping, accuracy required; but the conditions existing in the field are many a times not favourable for our work. The effect of clouds is considerable. It is



Sketch No.7

Ceilometer.

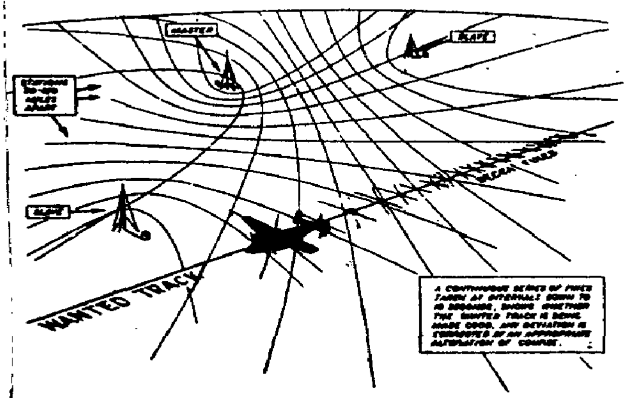
quite difficult to anticipate the cloud height much in advance. The electronic instrument used for this purpose is the Ceilometer (19), also called the Cloud Height Indicator (vide sketch No.7).

5.4 This instrument can measure the height of the clouds from the ground upto about 10,000 ft. A light beam from the search light is reflected by the clouds and is received by a photocell placed at a known horizontal distance from the search light. Either the light or the photocell is rotated through an angle of 90°. The cloud height is calculated by simple triangulation using the angle at which the reflection from the cloud is received and a known base line. The light source is modulated by a rotating shutter and the photocell operated in conjunction with a filter and tuned amplifier to discriminate against the ambient light. The ceilometer scans the cloud 10 times per minute. The instrument along with other accessories is used to analyse the cloud data for meteorological purposes. It can also measure the thickness of the clouds. Other weather instruments used for forecasting the weather have been omitted here although their value to photogrammetry, even if indirect, is not negligible. When the aircraft takes off and starts flying - electronics plays an important role in helping the crew to man the aircraft. We will see now how it does.

5.5 The radar installed on the aircraft - presents a picture of the weather conditions for the next few miles. As soon as the photography begins all the flying has to be manually controlled. Excepting during the take off and landing operations and piloting at the time of actual photography, the pilots and the crew can take rest or relax say, by switching over to the autopilot control. Even when the flight lines are quite long, the autopilot cannot be used at the time of photography as it is not capable of correcting very minute changes in the flight direction (less than 3 degrees) etc., and also is not capable of controlling the drift of the aircraft. The autopilot works on servomechanism, When there is a small change in the element for which the autopilot is set, a small current is generated in the mechanism, which works the servometer and provided the necessary correction. When the changes are too small, such as a change of a few minutes of an arc in the direction, the current generated will be too feeble and incapable of working the servometer. In photoflights we cannot allow any irregularities of this type. In general flying navigation is very much aided by modern instruments, though the sextant is still used for getting the astronomical fixes along with the equipment like the radio compass, Decca and other navigator systems. The Decca navigator system isalready described in the last chapter. Here we will see how it can be used for Navigation (14).

5.6 One of the principal functions of a radio aid to a survey is that of tracking or controlling straight and parallel flight lines. Visual methods have to be resorted to, only under peculiar conditions like flying over undeveloped terrain and for large scale mapping where a small mistake in tracking may result in missing the object of photography and consequently in a very heavy wastage of survey effort. Depending on the scale of mapping, the maximum permissible deviation from the wanted track may range from about ± 300 yards to ± 30 yards.

5.7 The two methods of Decca tracking can be used with advantage to fulfil our needs under normal conditions. They are :

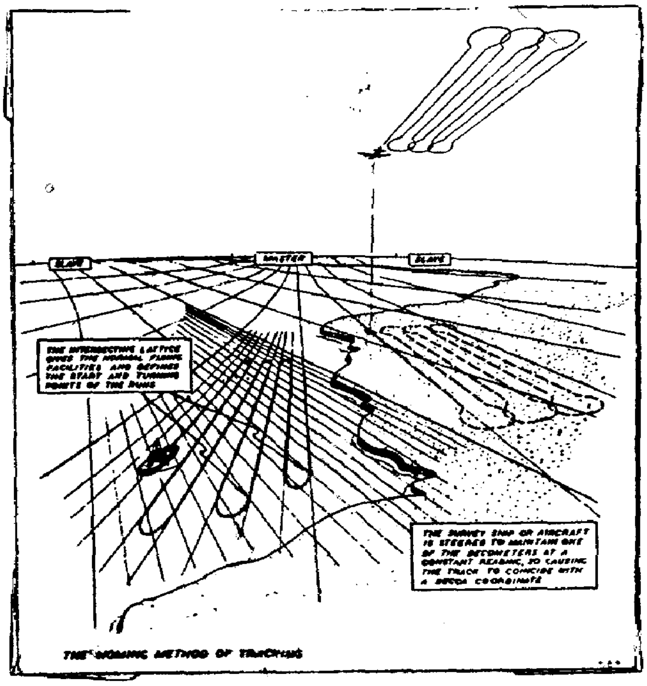


A CONTINUOUS SERIES OF FIXES TAKEN AT INTERVALS DOWN TO 10 SECONDS, SHOWS WHETHER THE WANTED TRACK IS BEING MADE GOOD. ANY DEVIATION IS CORRECTED BY AN APPROPRIATE ALTERATION OF COURSE.

THE TRACK-GRAPH METHOD OF STRAIGHT FLYING

Sketch No.8

Straight Line Tracking
on Decca System.



THE INTERSECTING LATTICE GIVES THE NORMAL FLYING FACILITIES AND DEFINES THE START AND TURNING POINTS OF THE RUNS

THE SURVEY SHIP OR AIRCRAFT IS STEERED TO MAINTAIN ONE OF THE DECOMETERS AT A CONSTANT READING, SO CAUSING THE TRACK TO COINCIDE WITH A DECCA COORDINATE

THE HOMING METHOD OF TRACKING

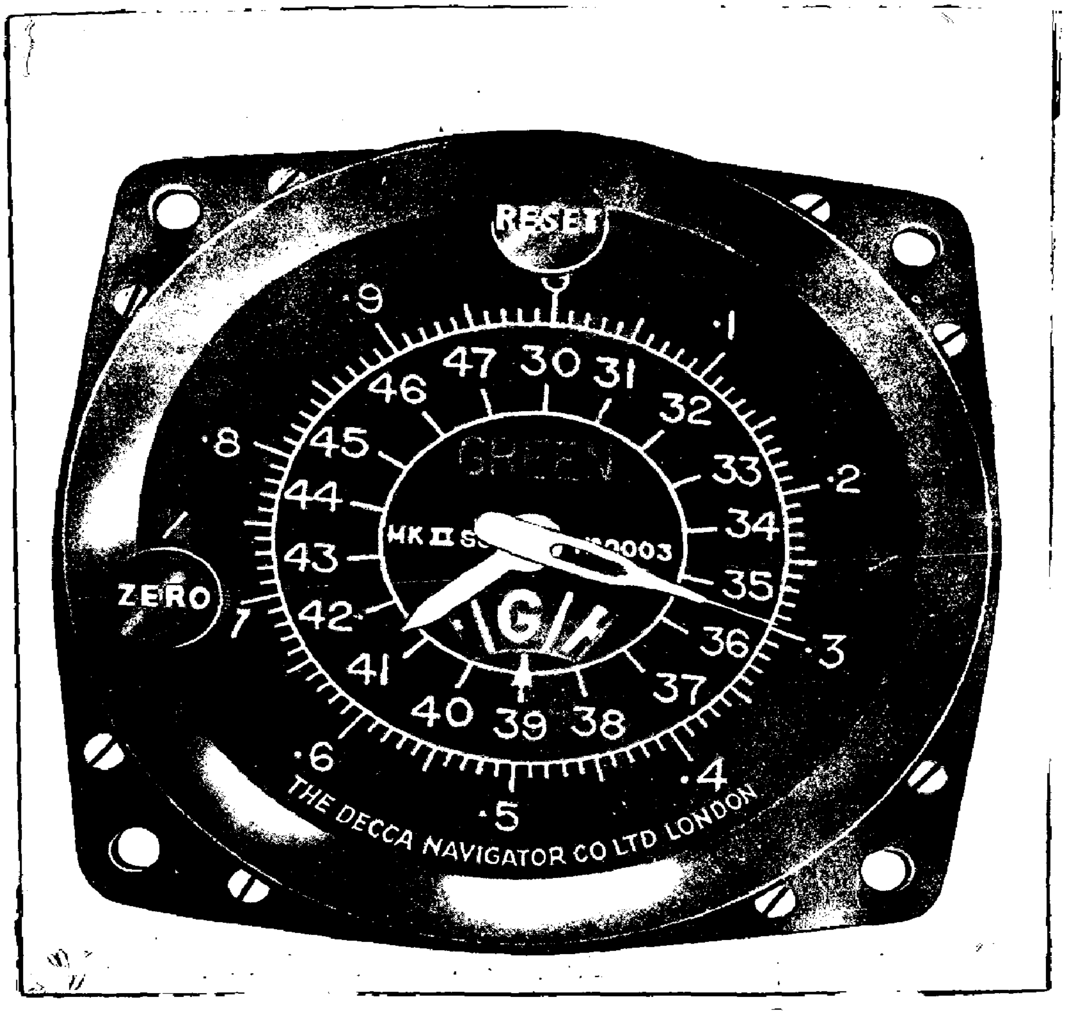
Sketch No.9 -

Homing method of Tracking
on Decca System

(1) Straight line tracking
(vide sketch No.8)

(2) Homing method of tracking
(vide sketch No.9)

5.8 In the straight line method of tracking, straight flight lines of any desired orientations can be flown by Decca, irrespective of the disposition of the hyperbolic patterns in the area to be surveyed. The method involves drawing the direct flight lines on a Decca Chart and keep the course along them with reference to a series of Decca fixes plotted on the same chart. The fixes are obtained either by manual plotting or by means of the flight log. In the manual plotting, an observer passes course corrections to the pilot on the interphone system and in the latter case, the flight log system which is - housed on the dashboard does the work. The latter assures a higher standard of plotting as its operation is continuous. It saves the crew efforts and gives a full record throughout the flight. The manual method needs minimum equipment and can generally be accepted on large plotting scales. The choice thus depends on various factors such as scale, installation space, crew potential, availability of equipment, etc.



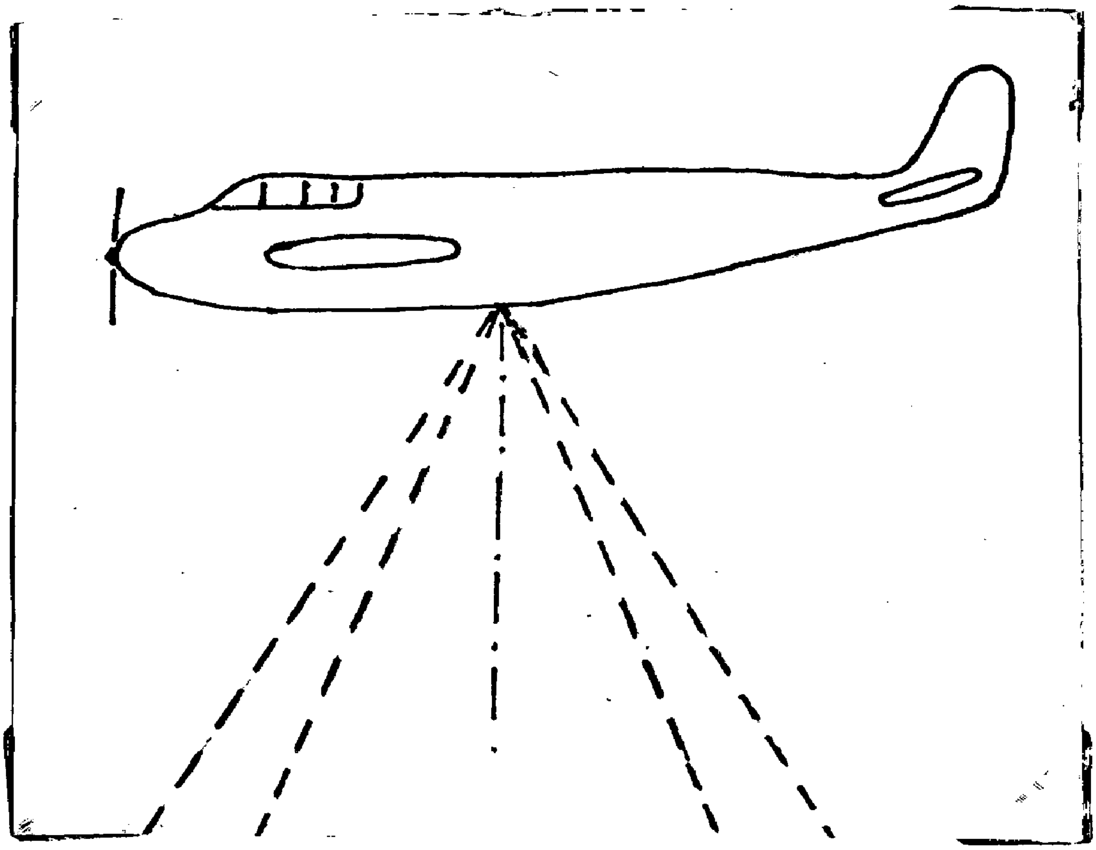
Sketch No.10

Decometer.

5.9 In the homing method of tracking, we use a decometer. It is already said that each family of hyperbola generated by a pair of transmitting stations situated at the focal points, is made up of lines of equal phase difference. The decometer or phasemeter (vide sketch No.10) is an instrument in which a pointer rotates and indicates the position of the plane, being at zero when we are on a hyperbolic position line. With a suitably positioned decometer installation, the pilot can maintain his course along such a line. It is thus possible to house the aircraft along such a line or on fractional hyperbola by maintaining the decometer needle in any fixed position. The lines though curved can be assumed to be straight over small areas and for large scales like 1/2500 etc.

5.10 For ordinary navigation in case of general flying all information required for navigation can be plotted previously on the charts and flying is done with the help of flight logs or small scale track graphs.

5.11 The homing method is more accurate as - compared to the straight tracking method. Results show only 20 yards off track flying at a scale of 1/2500 and flight line spacing of 200 yards.



Sketch No.11

Beams of Radio Waves as radiated
in Doppler System.

5.12 The system commonly used these days and which finds favour with theIndians in particular is the Doppler system of navigation.

5.13 Fig.11 shows an aircraft emitting two pencils of radiation downward which are reflected back to the aircraft. The Doppler principle states that when a source of radiation of frequency f.c.p.s and of wavelength λ cms. moves towards an observer with a velocity of v cms. per second, the frequency measured by the observer is $(f + v/\lambda)$c.p.s. This change in frequency of v/λ due to relative motion is referred to as the Doppler frequency shift.

5.14 The Doppler system radiates a pair of beams of radiowaves as shown in Fig.11. The difference between the emitted signal freqnency and the – received signal frequency from the forward and backward looking pair of radiation beams is – measured. This difference is porportional to the aircraft's ground speed. If we use four beams radiating symmetrically to the aircraft's axis, covering the ground in an x shaped pattern, the Doppler frequency shift between from the two diagonal pairs of beams can be compared. If the frequency shifts differ the antenna radiating the beams is not aligned with the actual path being flown. This means the aircraft is drifting. The frequency difference found on comparison is used to actuate a servo mechanism which rotates the antenna aligning the radiated beams with the actual path being flown. The angle through which the antenna rotates is the angle of drift. Accuracies of 0.1° have been obtained in the measurement of drift, angles on the Doppler systems. The important advantage of the Doppler system is that all measurements are made in the aircraft without any assistance from ground stations.

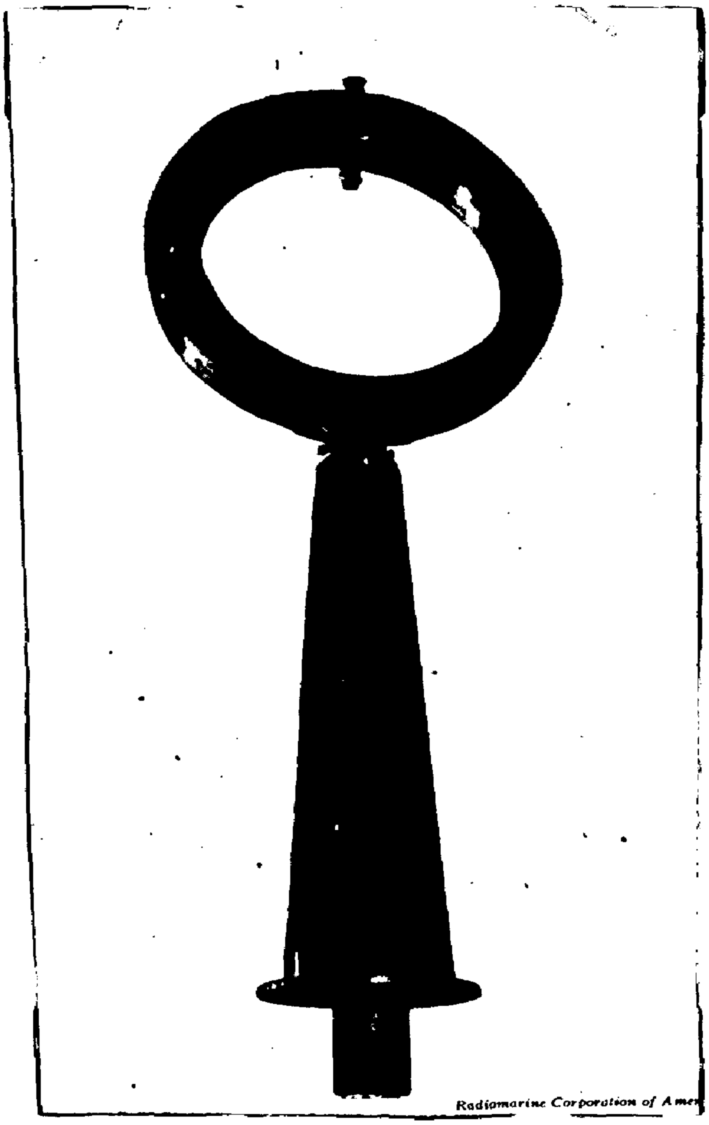
5.15 The Aero Service Corporation of England owns and operates the RADAN, a commercial model of Doppler System used for survey navigation. The Radan consists of a transmitter, an antenna, a receiver, a gyrocompass and a special computer which determines continously the distance travelled as well as the lateral deviation from the pre-selected track. All this information is available in digital form to the pilot and the data compiler. These data are exactly those that are required for the photogrammetric purpose.

5.16 Experiments (44) have proved that distance accuracies within 0.2% or better can be obtained with Doppler navigation. This is well within photogrammetric requirements.

5.17. In a test flight with Aero Services Radan, a 9 in. x 9 in. camera was triggered by the Doppler computer at equal intervals. The plane was flown along a straight railroad track. The actual exposure intervals were then checked by photogrammetrically measuring the ground distance between the nadir points of the photographs. The maximum error was 9 ft. for a 1500 ft. base i.e. 0.6%.

5.18 With the help of such accurate systems it will be very easy to reduce the side laps or lateral overlaps in the actual photography and the danger of leaving gaps due to poor navigation will not at all exist. This will help us reduce the number of flight strips and ultimately the total number of photographs. This will mean a lot of saving in the cost of photography. If distance between successive ground stations is accurately known as is given by Doppler computer, aerial bridging will be much easier.

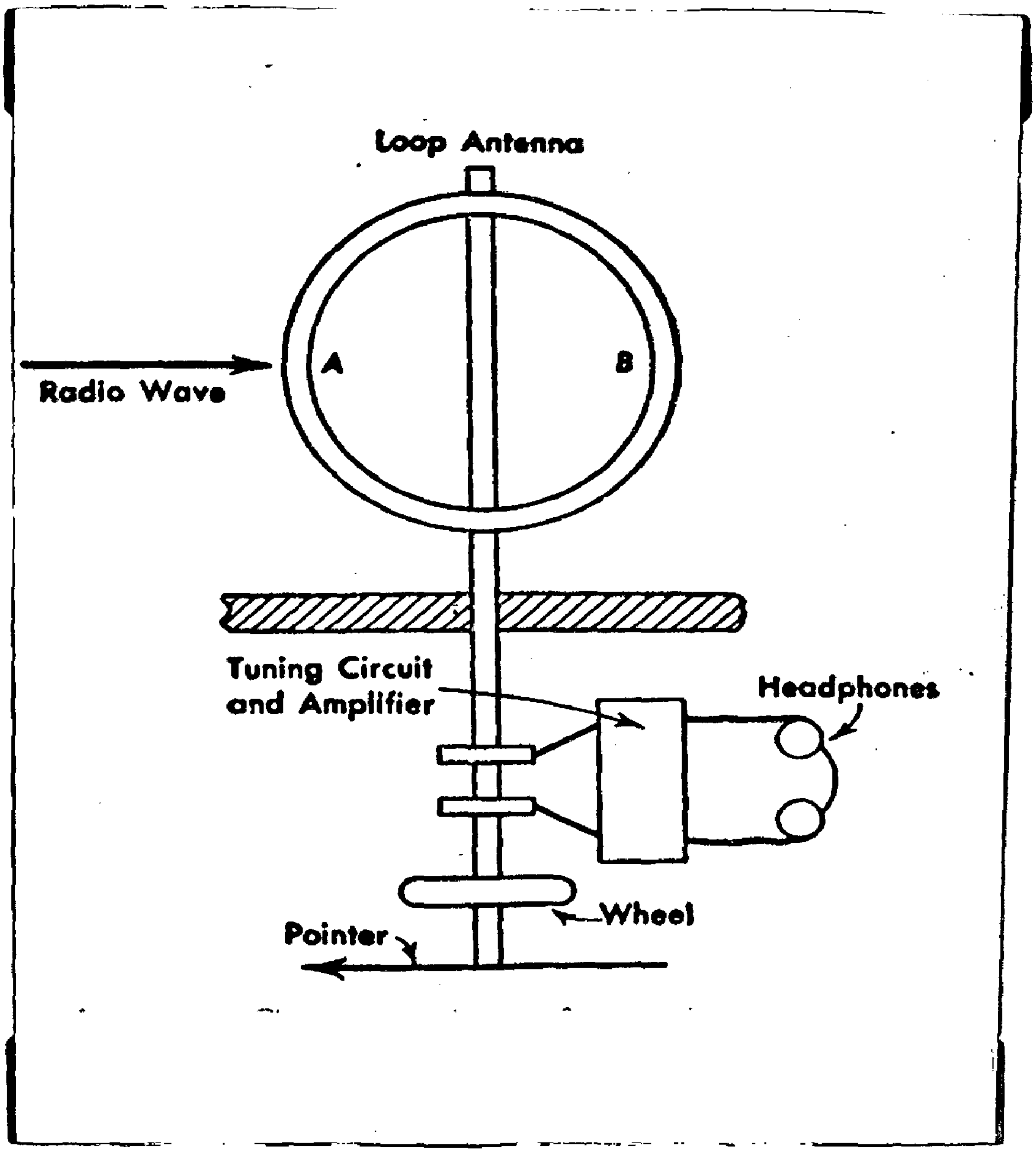
5.19 Doppler can be used at any altitude down to 400 ft. and at speeds upto about 105 knots. It can also be used on turns with angles of bank upto 30°.



Radiomarine Corporation of Ame

Sketch No.12

Loop Antenna



Sketch No.13

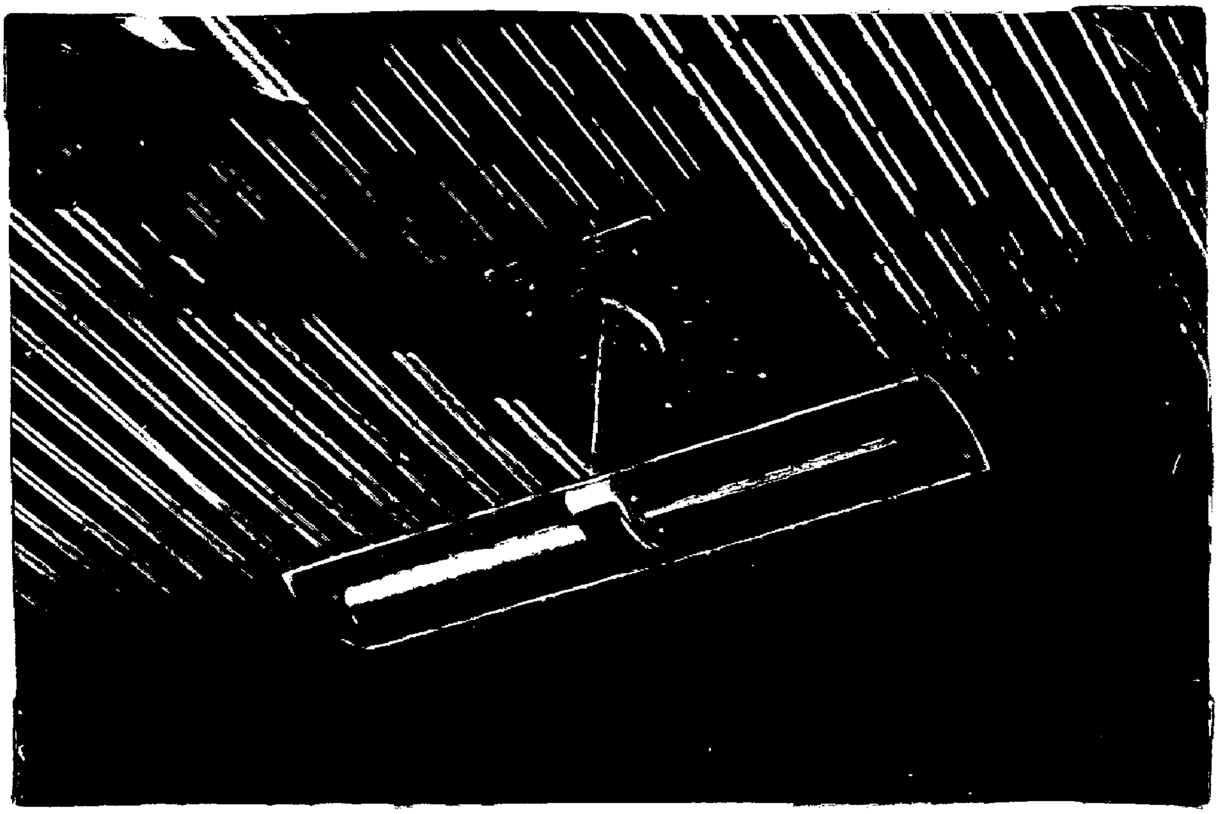
Construction of the Radio Compass

5.20 Now we describe the radio compass (12). This instrument is used to find out the direction of the signal being received. Certain stations from all over the world transmit a particular type of signal. The different stations and their particular signals are known to the operators of the wireless. These station signals give us the bearing of the stations from which it is very easy to plot the position of the aircraft, by using simple geometry.

5.21 The simplest type of radio compass is the loop antenna (12). It consists of a coil, about 15 or 20 inches in diameter, of several turns of insulated wire; (vide sketch No.12 & 13). The coil is mounted on a shaft so that it (the coil) may be turned in any direction. The terminals of the coil are connected through a tuning circuit, to a vacuum tube amplifier leading to a pair of head-phones. This type of antenna receives the maximum signal when the plane of the coil points towards the radio beacon and receives a zero signal when the plane of the coil is perpendicular to the intercepted radio wave. The first difficulty that arises in the application of this device is the "180 degrees ambiguity". With the use of this instrument we can fix the path of travel of the radio wave but cannot fix the direction definitely. In other words, on board an aircraft one could not tell whether the radio wave from a particular radio beacon is coming from east or west but can only say that their path of travel is east-west. When employing the maximum response - method one solution of this problem involves the addition of a vertical antenna in the shaft of the loop antenna. The output of the vertical antenna may be combined or 'coupled' with the output of the loop antenna, so that the combined signal will be maximum when the radio waves come from the left, say. Then when the coil is - turned through 180° the signal will be weaker. In this manner the path and the direction of the waves can be determined, by making this improvement. Under conditions of negligible local noise or static the direction of the radio beacon may be determined more accurately with the minimum than with the maximum response. This is called the "null method".

5.22 On the aircraft the loop antenna is usually located underneath the fuselage and is turned from the cockpit. The effects of static due to higher speed are reduced by enclosing the coil with a non-magnetic sheath containing a short circumferential airgap by housing the coil in a streamlined enclosure. With this equipment, the pilot of an airplane may either fix his position, aided by a compass, with respect to two radio beacons on land or sea, or turn the loop antenna for maximum or minimum response.

5.23 These days most of the airports and modern aircraft too are provided with equipment for "blind landing". The pilot in an airplane, arriving within a few miles from the airport,may make a landing in the densest fog under the guidance of this equipment. For this a - visual radio compass points the way towards one of the runways at the airport, while another pointer informs the pilot whether he is flying over or below the radio beam which rises gradually into the air from a radio beacon, located at the far end of the runway. Approach markers at the end of the landing strip send up aural or visual signals when the aircraft crosses the outer boundary of the airport and when the aircraft crosses the approach end of the landing strip. Such systems have been so perfected as automatically to take over the



Sketch No.14

Close up of one of the Sending and Receiving Antenna, for Radar Altimeters.

control of an aeroplane as it approaches the airport, fly it on 'on the beam' and land it without any assistance from the pilot.

5.24 The radar altimeter which was referred to in the last chapter in the description of the Airborne Profile Recorder, is another important aid to navigation. It indicates the height of the aircraft above the ground point which lies directly below it. It works on the same principles as that of the radar and uses the microwaves (Vide sketch No.14). It helps the pilot to keep clear of the mountains which might in some places rise higher than the aircraft level itself.

5.25 All these instruments and devices aid the crew in carrying out their jobs accurately; but the efficiency of the crew depends on their physical condition also. For this reason we have to make the condition in the aircraft more comfortable. The effect of high altitudes is reduction in atmospheric pressure and temperature. Due to these, the crew gets exhausted very soon. In photoflights the pilots cannot switch over to the autopilot mechanism and have to man the plane themselves for a long time. This strain tells upon their performance.

In order to keep up their efficiency, the modern aircraft is pressurised and temperature-controlled. We have in the beginning studied a few electronic control circuits. The same type of circuits, with a few modifications are used for temperature and pressure control. Their details would call for a separate and specialised study and that would be out of the scope of this dissertation.

5.26 Now comes the problem of the safety of the aircraft. As the aircraft uses high octane petrol, there is always the danger of the aircraft catching fire. When a fire breaks out in an aircraft engine it must be detected and quenched within a few seconds to avoid serious damage or possible loss of life. Moreover some survey flights cannot be repeated at will, for example the photography of an enemy territory. The best care should therefore be taken against possibilities of fire. The American National Bureau of Standards, has developed a reliable fast acting electronic fire detector (16). The investigation which led to the invention was undertaken for the Wright Air Development Centre by W.F. Roeser and C.S. McCamy of the Bureau's Fire Protection

Laboratory. The details of the system are not available as this is still under experimentation and is not yet in commercial use. But the principle was the outcome of the studies of the flame characteristics. The results brought out the difference between the characteristics of the flame and those of the sunlight, lightening, gunfire or beacons. On the basis of these a detector was designed for detecting the occurence of fire alone.

5.27 Other electronic detectors working on - similar principles are provided for other purposes and a panel with indicator lights assures the proper working of different instruments and machinery.

5.28 All these aids ensure accurate and safe flying, which is the basic requirement for carrying out the main part of photogrammetric work namely the photography. The instruments also help us to reduce the number of personnel required for flights. Flying is quite safe in peace times but in war times during reconnaisance flights over enemy areas the life of the whole crew is at stake. At present we need the pilot at least. We should try in future to exclude the pilot even, for such flights by adapting remote control mechanism. This is definitely within realisation. When we can launch satelites in space and even bring them back to earth the problem of pilotless survey flights is one, the solution of which is not distant in the future.

CHAPTER 6

ELECTRONIC PHOTOGRAPHY AND PROCESSING FOR PRINTS.

6.1 As emphasized in the last chapter, the taking of photographs is no doubt the work of vital importance in photogrammetry. In fact the term photogrammetry has been derived from the word photography. Without an accurate and clear photography, accurate mapping can never be possible. By a clear photograph we mean a photograph of uniform density between 0.3 to 1.5 giving an image which is sharp and well defined and having a resolution of — 20 lines/cms. or better. Now in this chapter we will see how instrumentation in the processing field has helped us to achieve good results.

6.2 The quality of the photographs depends largely on the type of the camera used. The lens is the main part and must be very properly designed. The American Bureau of Standards has developed a computer routine to assist in the design of optical lenses. The method called Lenstar was developed by D.C. Friedman of the Data Processing System Laboratory.

6.3 This routine was developed to locate the plane of best focus for a lens after the initial part of the problem has been run on a computer. The computer traces the rays - through a lens to produce a set of punched cards giving the co-ordinates of the ray at six chosen planes behind the lens. The references planes are to bracket the expected plane of best focus. At this stage the Lenstar programme can help us to determine the location of the optimum image plane which may lie somewhere between two computed reference planes. Choice of the optimum plane is usually a matter of human judgment, since no lens can produce a perfect image. Lenstar however makes it possible for the lens designer to select what seems to him the best of several images after actual visual comparison.

6.4 As the different objects in an image possess different hues in a wide diversity, a particular film filter combination will not be efficient for adequately separating the different objects. So the type ofthe film filter combination to be used will have to be determined with reference to the hues of the objects of primary interest in the image. A choice of film filter combination all too often has had to depend upon the guess work as to the special reflectance properties of the subjects to be photographed. Present practice makes use of about eight film filter combinations of which several are — sensitive in the same general spectral region. The Perkin Elmer Corporation have built a — "portable reflectance spectrometer" (4). Its major components are largely production items. The motor generator set, for instance, consists of a standard two cycle air cooled gasoline engine coupled with an electric generator. The lamp is a high pressure Zenon arc lamp. Other parts are, signal amplifier, recorder and recorder amplifier, the photo-multiplier, high voltage source, the wave length drive motor, etc.

6.5 Now, we may examine how electronics has helped making better aerial cameras and their accessories. Since long we have started the use of the automatic cameras. They are all electrically operated. The exposure and rewinding of films, and even the change of film magazines are done electrically (9).

6.6 The control for the automatic operation of cameras consists of a small box fitted in the operator's cockpit showing four dials and push buttons as follows :-

(1) Turning button to set apparatus in motion.

(2) Indicator lamp showing whether the shutter is being wound and when set ready for exposure.

(3) A counter showing the number of exposures made.

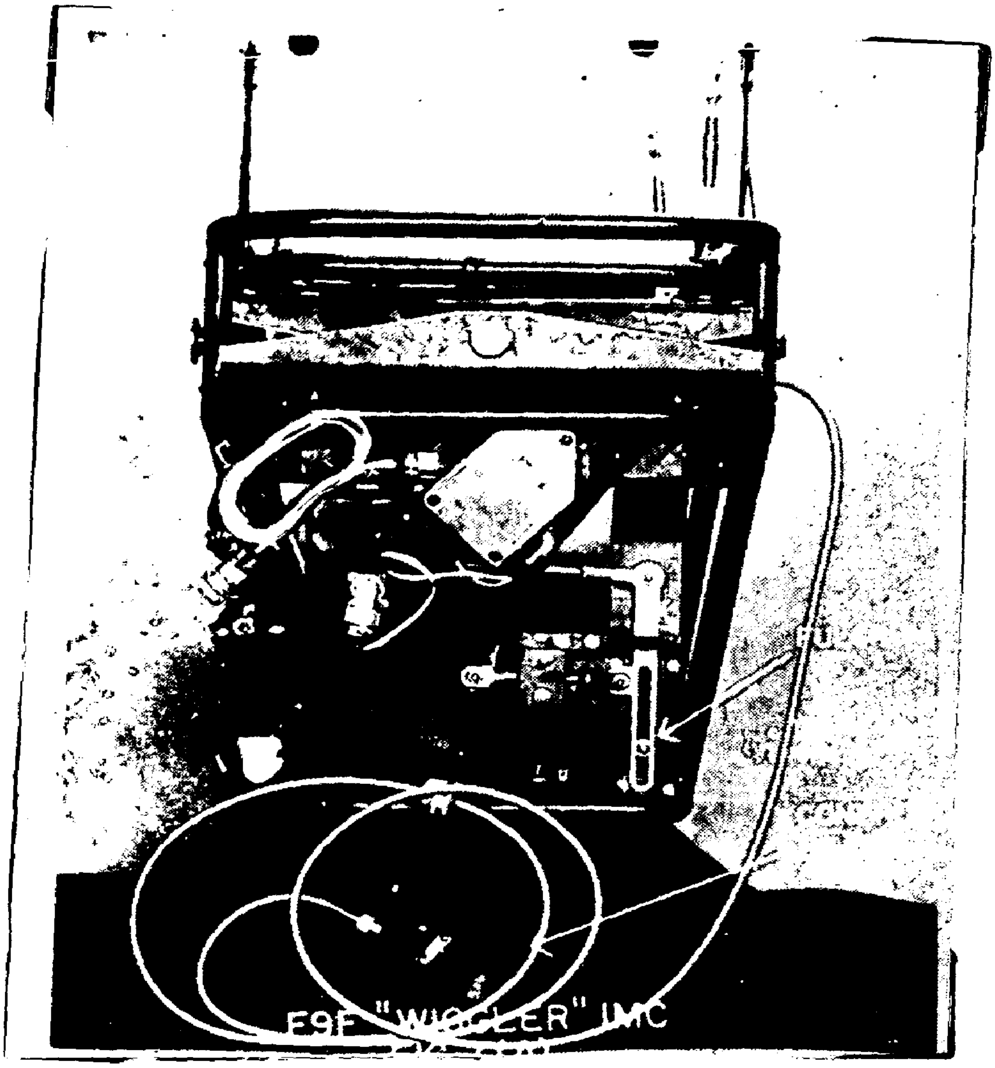
(4) A timing switch with two hands. One hand is set by a turning knob by the operator to the time interval of exposure required, whilst the second operates on electric clockwork mechanism, indicating the number of seconds between exposure. When both coincide in position, a contact is made and an electric motor works and operates the shutter.

(5) A push button enables the exposure to be made whenever required and does not interfere with the automatic operation of the camera by the time switch.

A motor also operates the camera gear box to effect the winding of film. In many cameras, a protective device is also provided so that in case of a jam the device slips and prevents mechanical damage to the parts of the camera. Another motor is provided which effects the change of magazines. All these devices work on the electric supply from the aircraft and use is made of transformers for voltage adjustments.

6.7 These devices relieve the operator of many of his responsibilities and makes him free to attend to other jobs like guiding the pilot to follow the pre-determined path, determine the crab and orient the camera properly, start and stop the taking of exposure, adjust the overlap, if required, etc., by observing the view finder. The control can also be connected with signal lamps arranged so that both pilot and cameraman can observe the instant of exposure. The device of the signal is also used for giving a warning, before an exposure is made, so that the pilot canlevel off and the cameraman can level up his camera. Thus the signal apparatus can be utilised for bringing about better team-work between the pilot and the cameraman. ('This is regarding an 'Eagle' camera. Other cameras may have a slightly different arrangement but the principle is the same in all cases.)

6.8 It is a fact that the aircraft can never be kept perfectly horizontal. A very small amount of tip and tilt is always present. This is considered negligible in general flying; but the needs for photogrammetry are of a very high precision. In the past many types of mounts have been designed for the camera. The latest fully automatic mounts are remote controlled and can thus be placed even in an inaccessible



Sketch No.15

Wiggler Device to overcome
Image-motion.

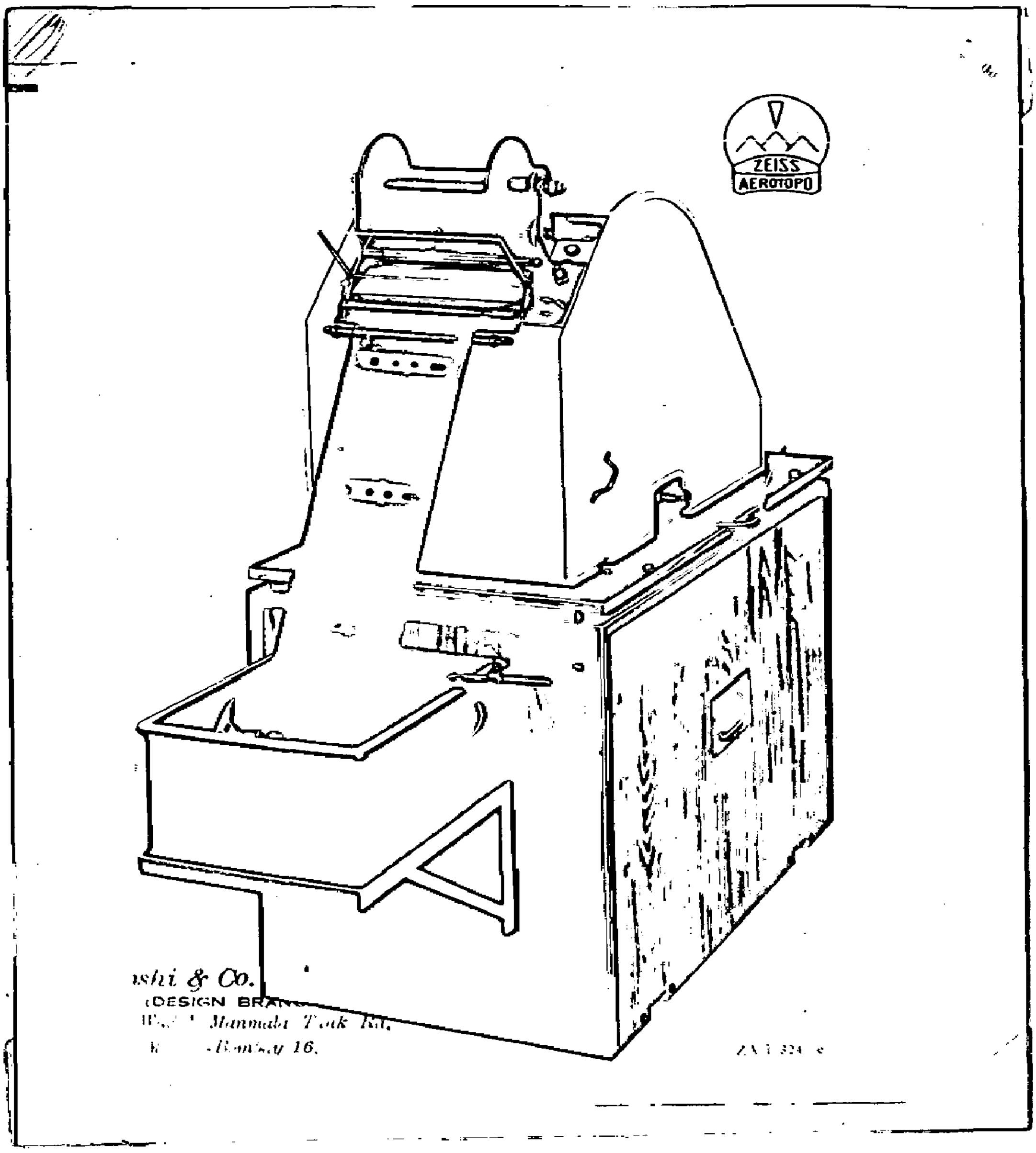
place. As an example, an aircraft doing reconnaissance work over enemy territory can mount the camera in the bomb bay or on a wing. The remote controlled mechanism can do away with a cameraman. Such aircraft must be able to climb out of range of anti-aircraft fire quickly and to fly fast enough to outrun enemy airplanes. This calls for reduction of unnecessary weight. With the automatic camera mounts, the aircraft can be stripped of all excess weight, such as armament and the weight of a cameraman, to give it its maximum efficiency.

6.9 The reconnaissance planes need high speeds. As a result of this, the image shows what is known as the 'image movement'. So the image irregularities present a problem. To reduce the irregularities we use the best available shutter mechanisms and reduce the exposure time. But certain amount of image movement does show. To overcome this, a mechanical panning system was developed by the U.S. Navy personnel of Experimental Project Branch Overhaul and Repair, California, and was named the 'Wiggler' (vide sketch No.15). It is meant for use with the conventional serial cameras that are flown in jet aircraft (2). It accomplishes image movement compensation through camera oscillation, which was formerly manually done in the old panning system first tried by Mr. Losee. The panning system was one of the simplest methods for stopping image movement. In the panning system the camera was moved along with the moving object and the picture was snapped when the camera and the image in the view-finder appeared to be moving at the same speed. This method was first tried by Mr. Losee when taking vertical photographs of timber in Canada for the purpose of inventory. The success of this method entirely depended on the operator's skill. In 'Wiggler' system the pilot has complete control over the instrument for the varying altitudes and ground speeds. In operation an electrical impulse energizes a drive motor in the 'Wiggler' which oscillates the camera. The Planning method needed an operator and kept him busy through the flight, whereas the - 'Wiggler' is operated by the pilot himself and he does not have to look after it once he sets it on. Of all the systems devised to overcome image movement, the 'Wiggler' has proved to be the least expensive and the simplest to build and maintain.

6.10 All these developments are very interesting but we are still left with the major problem of getting more accurate information on the negative and of being able to reproduce this information in the photographic print or plate in such a form as to increase the accuracy and speed of measurement. The devices that have been discussed up till now have assured us of a 'good' latent images on the film. Now we have to get accurate negatives and prints from them. A negative is the basis of all our work. Any deformations or defects in the nagative cannot be corrected and the only solution that remains, in case we come up with bad negatives is to do the photography again which involves great loss of time, labour and finance. Further, even after getting a good negative if the prints do not record the maximum details to utmost accuracy, the whole plotting will be affected and inaccurate maps will be the result. It is beyond doubt that in every stage, printing, reduction or enlargement, etc. there is definite loss of detail. This increases our responsibility still more. To ensure a very careful and efficient treatment of the

Sketch No.16

Film Developing Outfit.



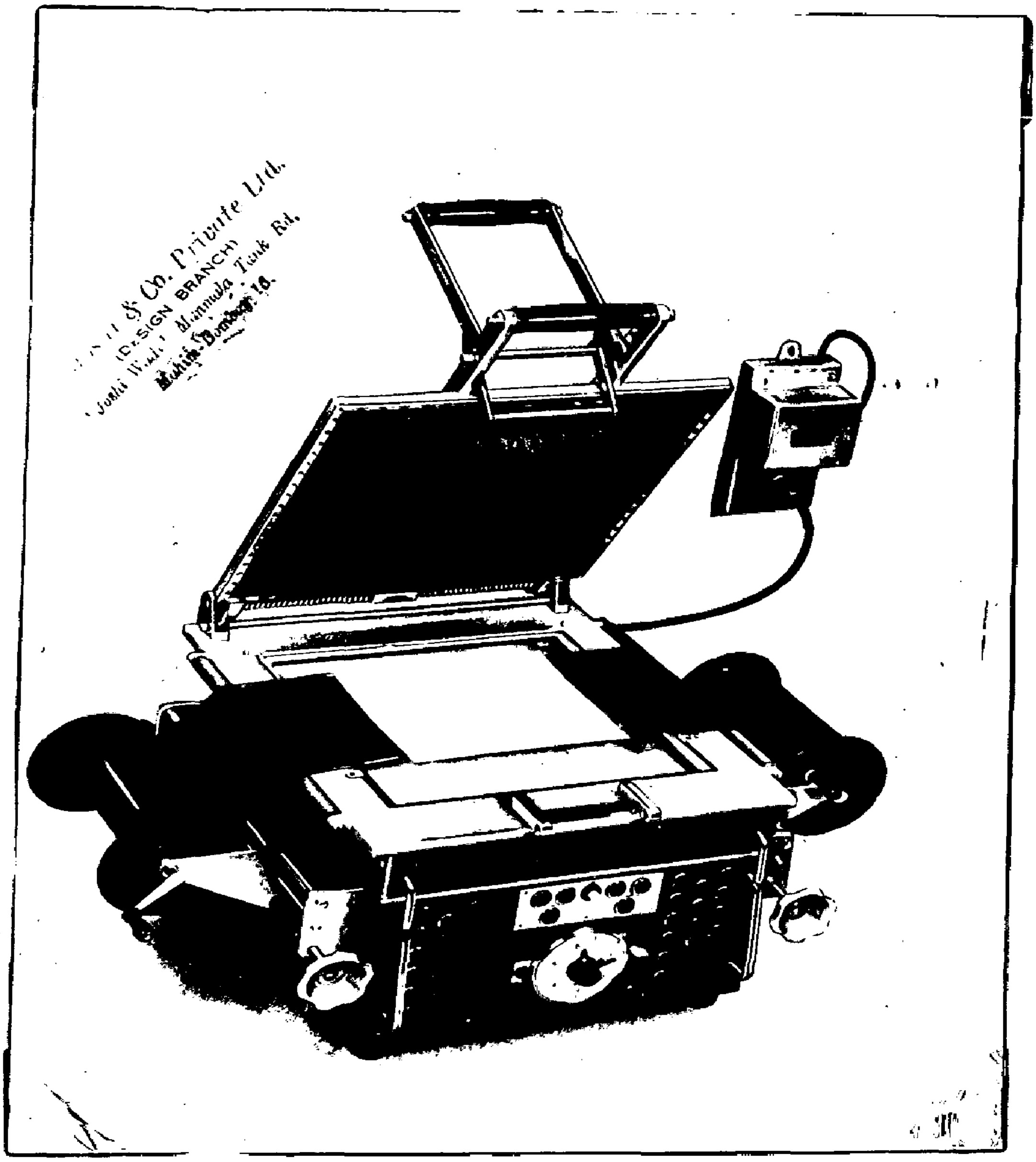
Sketch No.17

Film Dryer.

negatives and prints, it is advisable to exclude human element and work with the electronic equipment. We will study the equipment now.

6.11 The electric film developing outfit consists of three metal tanks, a removable twin processing assembly with re-wind mechanism and the clip-on auto-reversing electric motor drive (vide sketch No.16). The three tanks are of nesting type, one each for developing, fixing and washing. They are provided with drains at the bottom. A special attachment permits winding the exposed film directly from the take up spool of the magazine to the reel assembly. The reels can take 400 ft. of film 9" wide. The upper part of the reel assembly accommodates the re-wind mechanism. An electric motor drive is built into a watertight encasement. Hand cranks are also provided to operate in case of electricity failure. The speed is controlled by a rotary resistance. This permits uniform action of the developer solutions on the film irrespective of its length.

6.12 The wet film has then to be dried. This is done on an electric dryer (vide sketch No.17). It comprises a plastic drain tank from where



Sketch No.18

Contact Printer.

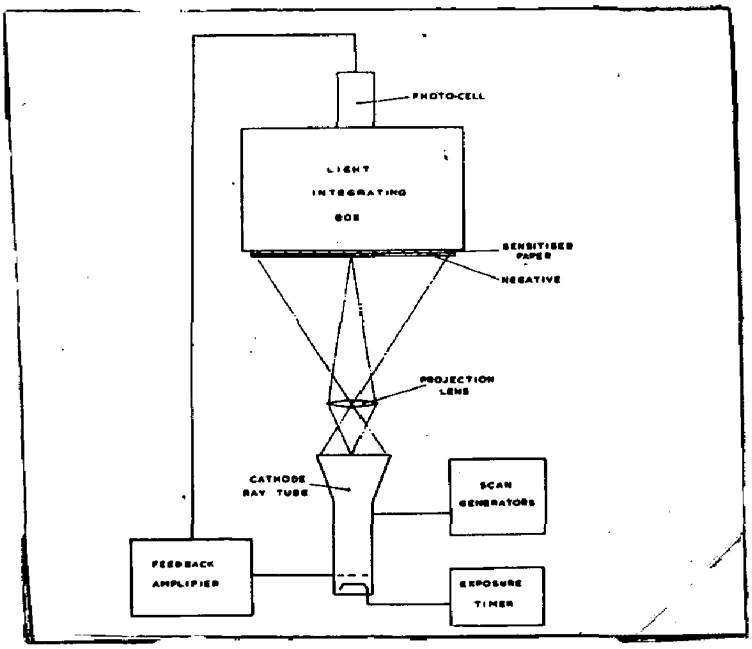
film is led to the drying drum with emulsion inward. A nozzle gives out compressed air from an electric compressor and blows out water drops. The interior of this drying drum — features a radial blower. Fresh air drawn by the blower passes through a filter and an — electric heater where it can be preheated for fast work. A thermostat controls its temperature to a desired value. A red signal lamp is provided to indicate that the heater is on. The sense of advance of the film can also be reversed by means of a switch. A safety overload clutch stops the motion in case the take up reel gets overloaded. It processes a 9" wide film, 400 ft. length in 2½ hours at normal temperature and 45% humidity.

6.13 Then the dried rolls go for printing. Here a big lamp bank helps us give an illumination as is described (vide sketch No.18). It takes a film 12"x 12". The timer can be set from 0.1 to 6 seconds or 1 to 60 seconds. The procedure is :

(1) Check the negative material in special bulbs provided.

(2) Preparation for exposure by putting on the necessary lamps.

(3) Exposure.



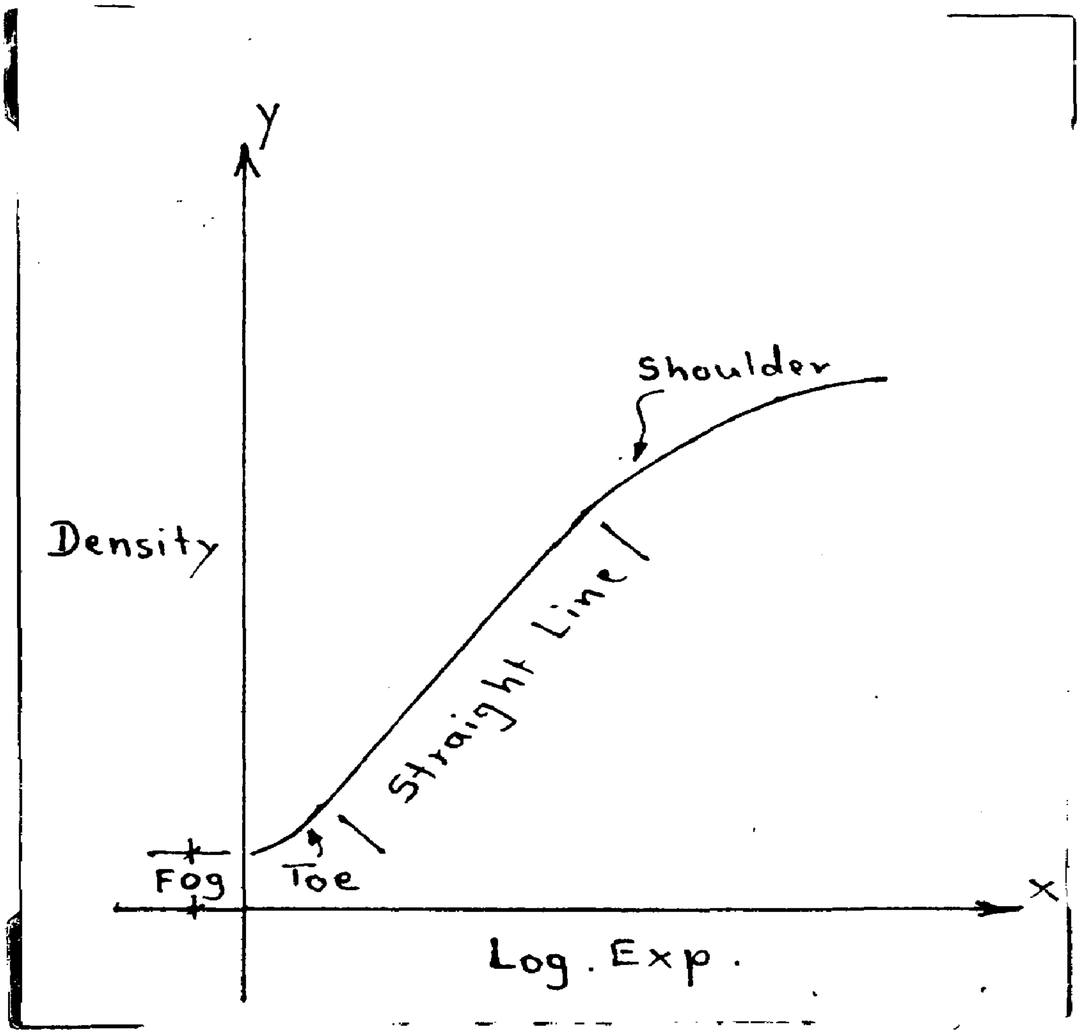
Sketch No.19

Block Schematic Diagram of the Electronic Printer.

6.14 The electric dark room equipment discussed above is of great use. Mechanical damages like scratches, deformations on account of excessive strains, dust precipitations during the drying process are carefully avoided. This guarantees clean films and assures convenient and safe - working. The operations are more reliable, time saving and simple.

6.15 It is rather unfortunate that even with the present day printing material, we are not able to get all the details of good negative in one print without some loss of detail in bright light and shadows. It is also unfortunate that the shadow detail is generally of a much lower contrast. Even with the 'good negative', it is still necessary to resort to some form of shading during the printing process. A good negative exhibits uniform contrast, sharp and well defined images, resolution of 40 lines mm. The best available means of contrast control is the electronic contact printer (8). The principle involved was first used in the production of television pictures. Then in 1949 Simmons in the United States first adopted the principle in photographic process (vide sketch No.19).

6.16 In the electrical printer, the light source is a cathode ray tube which produces a small spot of light due to the bombardment of a phosphor screen by an electron beam. The intensity of this spot light can be varied by the application of a modulating voltage to one of the control electrodes. This spot is made to scan an area of the face of the tube in a series of lines by applying suitable deflecting wave-forms to the cathode ray tube. The light from this scanning spot is projected on to the negative and paper, at a suitable magnification, so that each small area of the paper receives a brief exposure each time the spot scans the negative. The light is diffused by passage through the paper and is then collected by a photocell placed some distance from the back of the paper. The voltage generated by the photocell is of course inversely porportional to the mean density over the area covered by the spot and after suitable magnification is fed back to the cathode ray tube in such a way as to reduce the intensity of the spot as lower density areas are scanned. By controlling the amount of amplification of the photocell voltage, it is possible to vary the amount of feedback and the density in the



Sketch No.20

Characteristic Curve

negative can be reduced to any desired value. This is important as we photogrammetrists say that we should always try to work in the straight line region ofthe characteristic curve for every film. When a photographic emulsion is exposed in a sensitometer and the densities obtained after development are plotted against logarithms of exposure a curve is produced - which is called a characteristic curve. Fig. 20 shows a typical characteristic curve. In the straight line region the exposure varies directly as density and as a result a linear relationship is maintained between the logs of image brightness and the corresponding densities. If the density is different and the difference be too much, then a uniform exposure to the whole of the photograph will over-expose some portion and under-expose some portion of each such photograph. Generally under-exposed portions show low contrast and lose some shadow details while over-exposed portions are dense and may lack in highlight details. As we keep very short shutter opening to reduce the image movement, we have to use fast films. Fog is more in fast films than in slow films. The fog raises the general density and hence the graininess of the image and reduces contrast in the darker tones of the subject. An electronic printer helps to achieve better resolution, uniform density and better contrast from even a bad negative. This is very important as the cost of aerial photography and the amount of labour put in for the same is very high and it is very difficult to re-photograph an area in case the photography is below the standard. With the help of electronic printers, we will be able to enhance the detail and thus be able to obtain good results from slightly bad photography. One difficult problem is thus solved.

6.17 The more difficult problem we have to face is verticality. With all the modern equipment it is practically impossible to avoid a very small deviation from verticality. By the modern gyroseopic controls it is eventually possible to confine the amount of tilt to about 15 minutes.

6.18 The effect of tilt is most noticeable where elevation data are determined from aerial photographs. Even planimetric maps of flat terrain cannot be traced from aerial photographs without making some adjustment for the effect of tilt.

6.19 The scale of tilted photograph changes in a regular manner through the picture. If the scale near the centre is correct then the scale is smaller on the side that is tilted upward and bigger on the side tilted downward.

6.20 The tilt also causes image displacements. Due to the tilt images are displaced radially towards the isocentre on the lowerside and away from the isocentre on the upper side. Along the axis of tilt there is no displacement - relative to an equivalent untilted photograph.

6.21 Because of the change in scale and displacement of images, the shapes of areas on tilted photographs are not similar to the - corresponding shapes on the map or an equivalent untilted photograph. Thus in laying mosaics areas near the edge of one photograph will not have the same size and shape as on an adjoining photograph. In graphic compilation of map details from photographs, a photogrammetrist is restricted to tracing images near the centres of photographs where image displacement and scale differences are small.

6.22 In radial plotting we assume that the angles subtended by the photographic images at the radial centre are equal to the corresponding angles on the ground. This holds good in case of vertical photographs only, where the principal point which is also the nadir is used as the centre. In case of flat terrains, the isocentre can be used as radial centre for tilted photographs also. Relief when present also causes image displacement as the scale changes due to relief. These displacements are radial from the nadir. Displacements due to tilt and due to relief are entirely independent. So in the case of radial plotting from tilted photographs of a terrain with relief neither the nadir nor the isocentre can be chosen as radial centre and radial plotting can only be accomplished after duly rectifying the photographs.

6.23 Tilt thus poses a serious problem. The modern plotting machines can deal with tilted photographs for the purpose of plotting. Rectification (which is dealt with in the next chapter) also helps us to reduce these errors to a certain extent. For getting exact values of tilt-deformation the tilt has to be calculated. Calculation of tilt deformations is an uphill task. These calculations are too difficult and time consuming to be undertaken without the help of modern electronic computers.

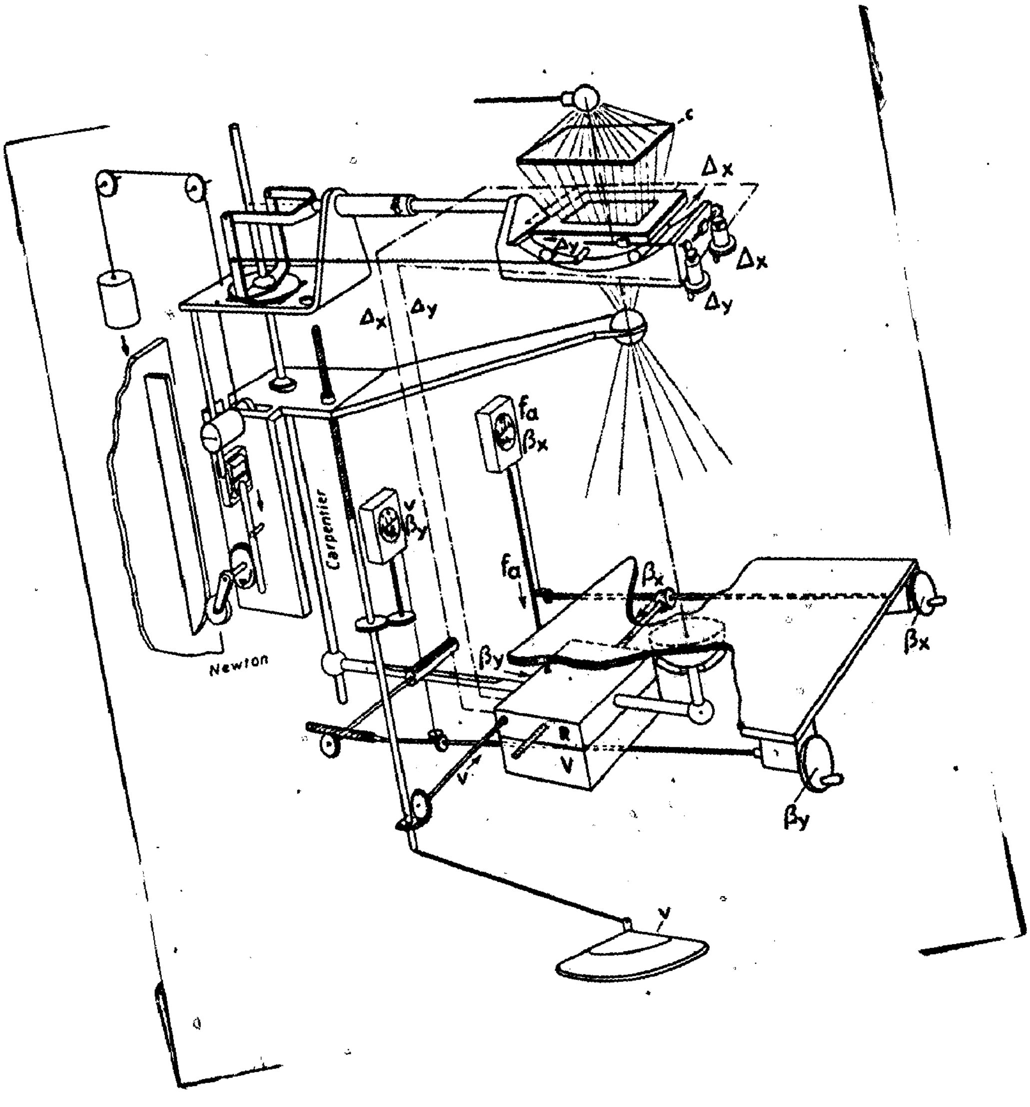
6.24 In the forthcoming years, no pains should be spared to find methods for taking absolutely vertical photographs or atleast for measuring the tilt accurately at the time of exposure. The angle at the air station subtended by the principal point and the nadir point gives us the amount and the direction of the resultant tilt. So if we can accurately record the nadir along with the principal point on the photograph at the time of photography, calculation of tilt will be much simpler and radial plotting or mosaicing will be much facilitated.

CHAPTER 7.

ELECTRONICS IN RECTIFICATION, AUTOMATIC PLOTTING AND MAP COMPILATION.

7.1 Plotting and printing are the last stages of the work in photogrammetry for mapping. Mapping from photographs is equally accurate and very much quicker in comparison with - mapping by ordinary survey methods, if proper photogrammetric equipment is used and proper care is taken.

7.2 It is a well accepted fact that no aerial photographs can be truly vertical but are only nearly vertical. For converting a tilted photograph into one having no tilt a photographic procedure called Rectification is - adopted. A photograph that is reproduced by rectification is equivalent geometrically only to one taken from the original camera station with the lens axis directed in a - different direction. If we have to effect any change in the scale also a camera having a different focal length can be used for rectification.



Sketch No.21

Automatic Rectifier SEG V

7.3 Photographs are very commonly used for preparing mosaics and photomaps. A controlled mosaic or photomap is necessarily restituted for scale, tilt, etc. ; hence it needs rectified prints. For drawing contours or determining spot heights from photographs by simple methods, like parallax bar method, if a rectified photograph is used, no — corrections for tilt deformations are needed and the work becomes simpler. In case of providing control by graphical methods like the radial line method or the slotted templet method, the accuracy increases considerably, if rectified photographs are used. This proves the importance of rectification in photogrammetry. The Zeiss Automatic Rectifier SEGV is described below.

7.4 The Zeiss Auto-focussing Rectifier SEGV is fully automatic and has a vanishing point control (23). Fig.21 shows the details of its construction. In a normal rectifier the conditions to be satisfied are as below :-

(i) Distance condition - that the product of the distance of the image plane and that of the projection plane, must equal the square of the effective focal length. This is known as the Newton's Lens equation.

(ii) Schiempflug condition - that the lens plane, the image plane and the plane of projection must intersect in one common line.

In addition the SEGV satisfies the vanishing point condition which says "contrary to the condition prevailing at the moment of exposure, the optical axis of the rectifying lens is not at right angles to the image plane. Furthermore the focal length of the taking camera will not usually be identical with that of the projection lens. Therefore the rectifying pencil of rays will not be congruent with the taking pencils of rays in the camera". In order to satisfy this condition the aerial photograph has to be displaced by a certain distance with reference to the optical axis at the rectifier. In the automatic rectifier all these are automatically satisfied without any delay. The distance condition is satisfied by means of a cam inversor. By means of the pedal disc, the lens carriage is moved in a vertical direction by gears and lead screw. At the same time the negative carrier and illumination system are set in accordance with the distance condition by means of a contact on the inversor cam. The Schiempflug condition is satisfied by a special carpentier inversor based on the principle of gnomonic reciprocal projection. The vanishing point condition is satisfied by extensive use of electronic means. In - accordance with the enlargement ratio and the two tilts as well as the respective focal - length of the aerial camera, potentiometer contacts are set mechanically in conformity with certain mathematical relations. The respective bridge connections would be - balanced i.e. null if the potentiometer contacts dX and dY. viz. the displacement to be given to the negative carrier, were correctly set. As long as this is not the case, an electrical current continues to flow through an electronic amplifier and is used for driving servomotors which displace the cross-slides of the negative carrier until a balance in voltage has been reached. By this method the vanishing point condition is satisfied automatically. This instrument is very accurate, convenient for the operators to work and also saves a lot of time.

7.5 As seen above the present optical rectifiers do perform a satisfactory transformation of the oblique copy to a rectified print. In order to handle a complete range of photographs from various cameras and the tilt angles and scales involved, a large number of rectifiers is required for any complete installation. Moreover unusually long focal length cameras require a special rectifier for high tilt angles.

7.6 Captain Ross of Rome Air Development Centre, New York and Dr. Lavine of Fair-Child Graphic Equipment, New York, have brought out the design of a Universal Photogrammetric Electronic – Rectifier. The very fact that it can accept photographs from cameras of all focal lengths and all tilt angles and give rectified prints goes to show that electronic methods increase the range and the efficiency of the rectifiers.

7.7 In the meantime a copy is placed on the transparent cylindrical copy carriage at the left of the machine with the principal line parallel to the axis of the copy carriage. The transparency is illuminated by curved blue flourescent tube underneath the copy carriage. Scanning is accomplished by an oscillating mirror placed above and on the axis of the copy holder. As the oscillating mirror scans a line, the copy carriage advances and thus the entire photograph is scanned line by line. A lens focuses the copy image on an aparture plate in front of a photo multiplier tube and the light energy is converted into an electronic signal. An amplifier modifies the signal as required. The greater the amount of light passing through the copy at any given point, the greater will be electrical signal output from the photo-multiplier. The signal actuates an ultrasonic light modulator mounted on a carriage, which moves parallel to the axis of a recording cylinder where a photo sensitive paper is exposed to give a rectified print.

7.8 The design specifications of the Universal Electronic Rectifier are as below :-

i) Camera focal length 3" to 100"
ii) Tilt angles 0° to 80°
iii) Tip angles 0° to 15°
iv) Resolution 500 lines per inch.
v) Copy size upto 9" x 18"
vi) Maximum reproduction size 36" x 48"
vii) Change of scale range 1/3 to 3 times
viii) Recording material - Standard photographic paper.

7.9 Because of the accelerated development of the parts of the earth the demand for maps of all scales is increasing considerably. During the mapping a terrain a photogrammetrist has often to satisfy a number of conditions that may be contradictory such as a maximum precision, completeness and speed at minimum cost. Precision can be increased by increasing the density of control. Completeness and speed can be increased by enlarging the scale of photography. This ultimately increases the cost.

7.10 Horizontal and vertical control can be provided by ground survey methods. Planimetric position of control points is fixed by triangulation and the heights by levelling. The accuracy of this control is one of the factors upon which the accuracy of the final map depends.

7.11 When we are concerned only with planimetric details we can use the graphical methods of aerial Triangulation such as radial line method or slotted templet method. In these methods we plot on a grid, the points the co-ordinates of which are known. Those are used for the restitution of scale. The positions of points chosen as pass points and the photoprincipal points are then fixed by graphical procedures and they render a network of triangles which is used as a control network for plotting of planimetry. If spot heights and contours are also required from the photographs, then we have to use spatial methods..

7.12 For the purpose of plotting, determining spot heights and contouring from a stereoscopic pair of photographs, the minimum requirement is five points of known elevation and position so that corrections for most of the errors, such as errors due to tilt, film defects, etc. can be made. When we have to do mapping of a big area, we photograph the area in strips. Normally we do not have five control points in every overlap. In order to facilitate accurate plotting and contouring we have to supply a control to each overlap. For this the available control is extended to the area where little or no control exists. When we have control available at the ends of the strip and extend it to the portion in between, the method of extension is called "bridging". When control is available only at one end and is extended, the method of extension is known as the cantilever method.

7.13 Until fairly recently the most accurate method of extension of vertical as well as horizontal control was aerial triangulation of strips on plotting machines, followed by the transformation of the obtained strip co-ordinates to the map projection system. Since the beginning of photogrammetric mapping, analytical aerial triangulation has been considered a potential method. In this method the co-ordinates of points are measured on the photograph. The map co-ordinates are derived from these photoco-ordinates by computation only. Till recently the analytical triangulation was not practicable for two reasons. First no precise stereocomparators were available to read the co-ordinates and secondly the required computations were time consuming. The new comparators and electronic computers have made analytical aerial triangulation a practical possibility. A method of analytical aerial triangulation - developed by the National Research Council of Canada is given below as illustration.

7.14 In this method first the co-ordinates of corresponding points from a stereopair of photographs are read on a stereocomparator. These are first referred to the principal point as the origin of rectangular co-ordinate system. Then corrections are obtained for several types of errors like film distortion, radial and - tangential distortion, refraction and effect of earth's curvature. On a tape are printed all the instructions for correcting the plate co-ordinates, computing the relative orientation, scaling, computing strip co-ordinates and transforming them to map co-ordinates. The printed tape is then fed into an electronic computer where it is stored. Another tape containing plate co-ordinates and other relevant data is then fed in. The machine then goes through all computations and printed results are delivered out. (Electronic computers are - described in detail later).

7.15 Analytical triangulation has a number of advantages over triangulation on plotting - machines. A greater accuracy can be achieved because the measured co-ordinates can be corrected for all determinable errors in position. In instrumental methods accuracy cannot be achieved to this extent and no corrections can be given for irregular distortions.

7.16 Analytical triangulation is not restricted by any limitations like those in the instrumental aerial triangulation. The bundle of rays defined by image points from a photograph at the time of taking is not reproduced to mathematical precision in an instrument. Hence the model is always slightly distrorted in instrumental methods. On the other hand in the analytical method the bundle of rays is defined by a formula and the accuracy depends on the comparator accuracy which is quite high these days and also on the number of decimal placed used in computations.

7.17 In instrumental triangulation the accuracy depends on the ability of the operator to remove parallaxes and thereby orient the photographs. In analytical orientation a correct orientation of the camera is automatically achieved. In the instrumental method any slight inaccuracy in centering the photograph in the plate holder results in distorting the bundle of rays.

7.18 The higher accuracy of analytical triangulation makes it possible to reduce the number of ground control points and thus the cost of field surveys. The number of photogrammetric operations is also less when this method is used.

7.19 The analytical aerial triangulation thus proves to be superior to the instrumental triangulation and eventually is being more widely used for aerial triangulation. This will have a great impact on the present plotting instruments like Wild Autograph A7 and A9 or Zeiss Stereoplanigraph C8 etc. At present these instruments do aerial triangulation and provide control and feed work for about eight plotters like Wild A8. The importance of these Wild A7 and A9 Autographs etc. will considerably go down in the years to come.

7.20 The report of the aerial triangulation done in Vorarlberg, Austria,carried out by the Federal Office of Weights and Measures, Vienna, proves the use of these computors. They used the I.B.M. punch card computers according to the method of Roelofs and Van der Weele. On comparison of the co-ordinates of control points determined by terrestrial means with the transformed and compensated Autograph A7 co-ordinates, the mean square errors were dx = ± 4.8 cm. dy = ± 6.0 cm. The method and the use of computers assured a saving in time and proved - suitable for bridging over 4 to 6 models keeping the error of position within the drawing accuracy.

7.21 The solution of a large number number of scientific and engineering problems is possible only after detailed numerical computations. Such computations frequently present formidable practical difficulties. The latest and the most advanced elegant methods of electronics and automatic control engineering have made it possible to bring into use the high speed automatic computing machine known as the Electronic Computers.

7.22 Electronic computers are classified as analogue computers and digital computers. The analogue computers are of purely scientific use.

7.23 The digital computers as the name indicates, deal with digits. Most of the digital computers work with digits in the binary scale, in which all digits are in either zero or one. The presence of a pulse represents one and the absence zero. In general the system consists of five basic portions as mentioned below :-

i) Input unit - This can take a variety of forms and most commonly is in the form of punched cards, punched paper tape or magnetic tape. The input is generally automatic and the information is printed or punched by -

(a) Photoelectric scanning
(b) Fluorescent ink spots
(c) Magnetic recording
(d) Magnetized spots
(e) Magnetic ink character sensing.

(The description of all these is out of the scope of this dissertation.)

ii) Arithmetic Unit - It is here that the actual calculations and logical discussions are made. The logical discussions depend upon arithmetic discussions of equality and greatness. The unit works in a series of pulses and the flow of these pulses is controlled by gates. These gates are switches in the form of relays or valves or transistors.

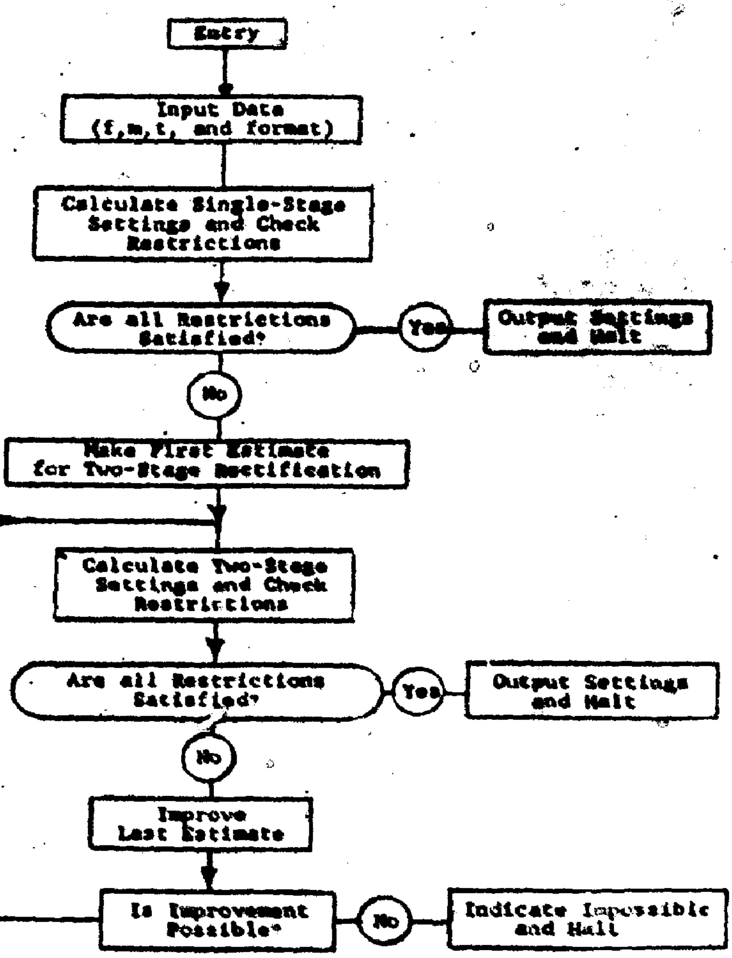
iii) Memory - This portion does the work of storing the information it has received and information upon which it may be in the course of working.

iv) Control Unit - This portion controls the operation of the whole system. A computer has to be told precisely what is required to be done and when; instructing the computer in this manner is known as programming. This unit is thus concerned with extracting the order to be obeyed, interpreting its function and generally overseeing the mechanism. It consists of storage and switching circuits throughout the machine.

v) Output unit - This is where results are produced and can either be shown by punching cards, paper tape or writing on magnetic tape or printing direct from the computer.

7.24 In the analogue computers physical quantities such as voltage, shaft rotations, etc. are made to obey mathematical relations comparable to those of the original problem. They are of different types viz. mechanical, electrical, electromechanical, etc. The adaptability of a particular type depends on the availability of computing elements to establish the desired mathematical relation.

7.25 In comparison with digital computers, Analogue computers are less accurate but are less expensive and often easier to construct. They are thus very useful in applications requiring accuracies between 0.5 to 5.0%. The advantages brought in by the introduction of these machines are more speed, less effort, greater accuracy (an important point when clerical standards are tending to fall), legibility, more readily available information for

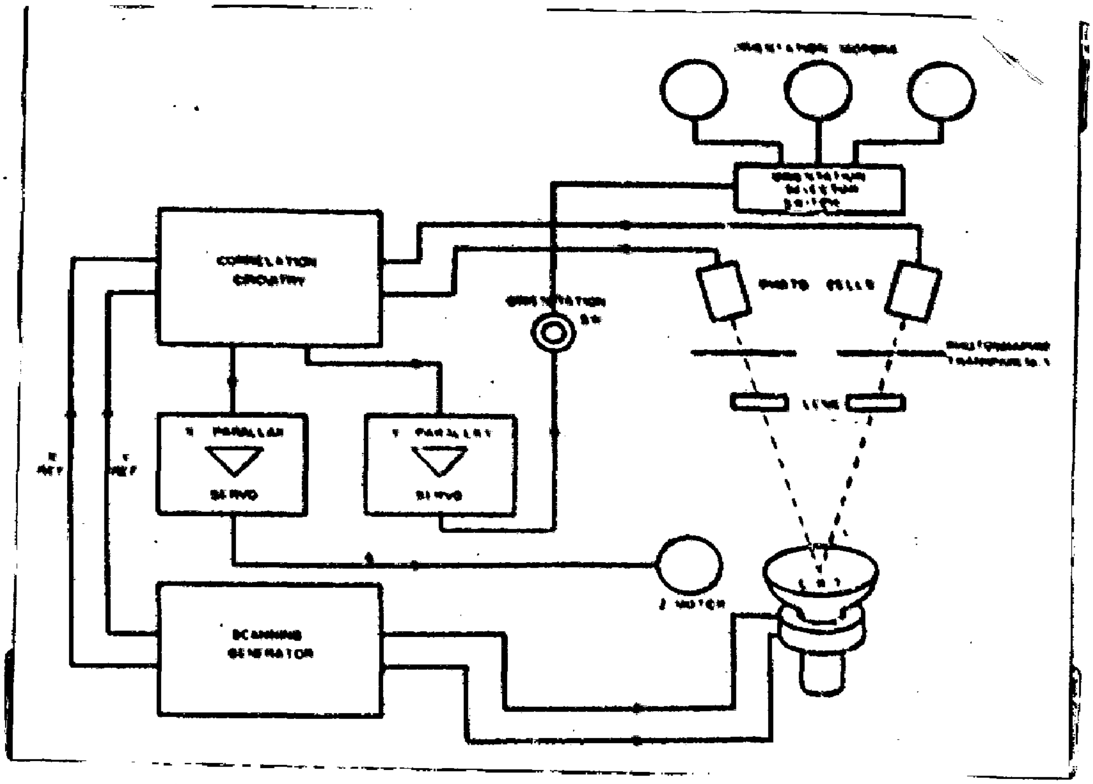


Sketch No.22

Flow Diagram for the Computer
Programme.

management control. The shortcomings are less flexibility, investment, not forgetting the construction of initial outlay and special - stationary. It requires a trained staff and any mechanical breakdown may cause serious - effect such as very wrong results. It requires less staff and is very useful as the modern trend is towards reduction of human element from work. The use of medium size Digital computer systems (5) for the solution of rectification problems is also emphasized by - Mr.C.W. Hanson of the Broadview Research Corporation, Washington, D.C. The method of solution uses an iterative procedure and is used to calculate the settings for photo-rectification equipment. The restrictions on the settings are imposed by the projective characteristics of the photography and the mechanical and optical limitations of the rectification equipment (vide sketch No.22). This method though cumbersome for manual use is well suited to automatic computing machinery.

7.27 In the process of plotting, clearing of X and Y Parallax is the basic operation. A few years ago, Mr. D.N. Kendall, the President of the Photographic Survey Corporation, Toronto, Canada, gave support to and provided funds for a research project at automatizing this -



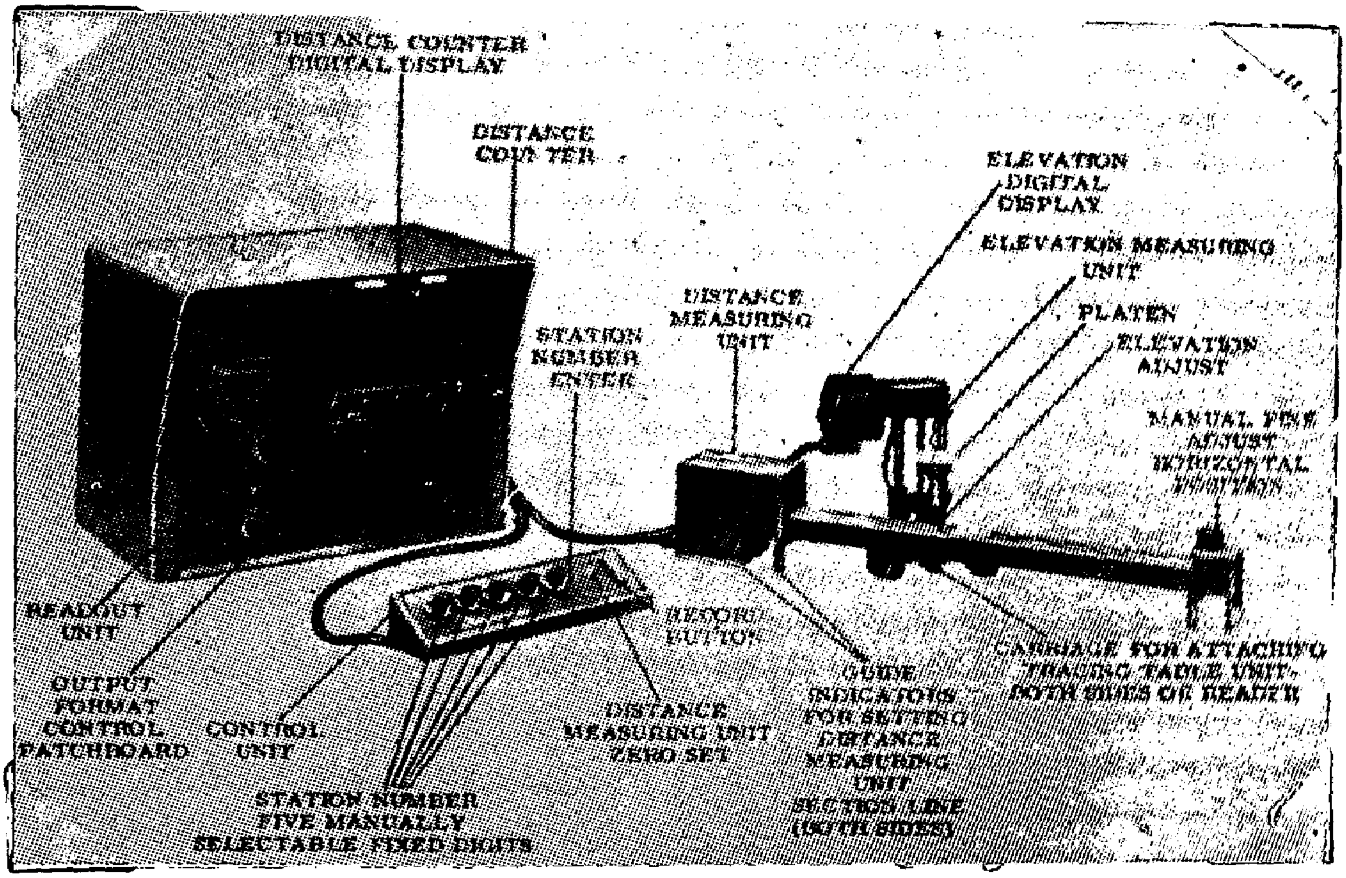
Sketch No.23

Block Schematic Diagram of the
Stereomat.

operation of clearing parallax and driving the floating mark to produce profiles or contours automatically. The systems devised for this purpose by the Benson-Lehner Corporation of Los Angels, is named as 'Stereomat' (5). It takes the form of an attachment to a conventional stero plotter and provides necessary motions to the projectors and the floating mark, for relative orientation and location of the - terrain surface respectively (vide sketch No. 23).

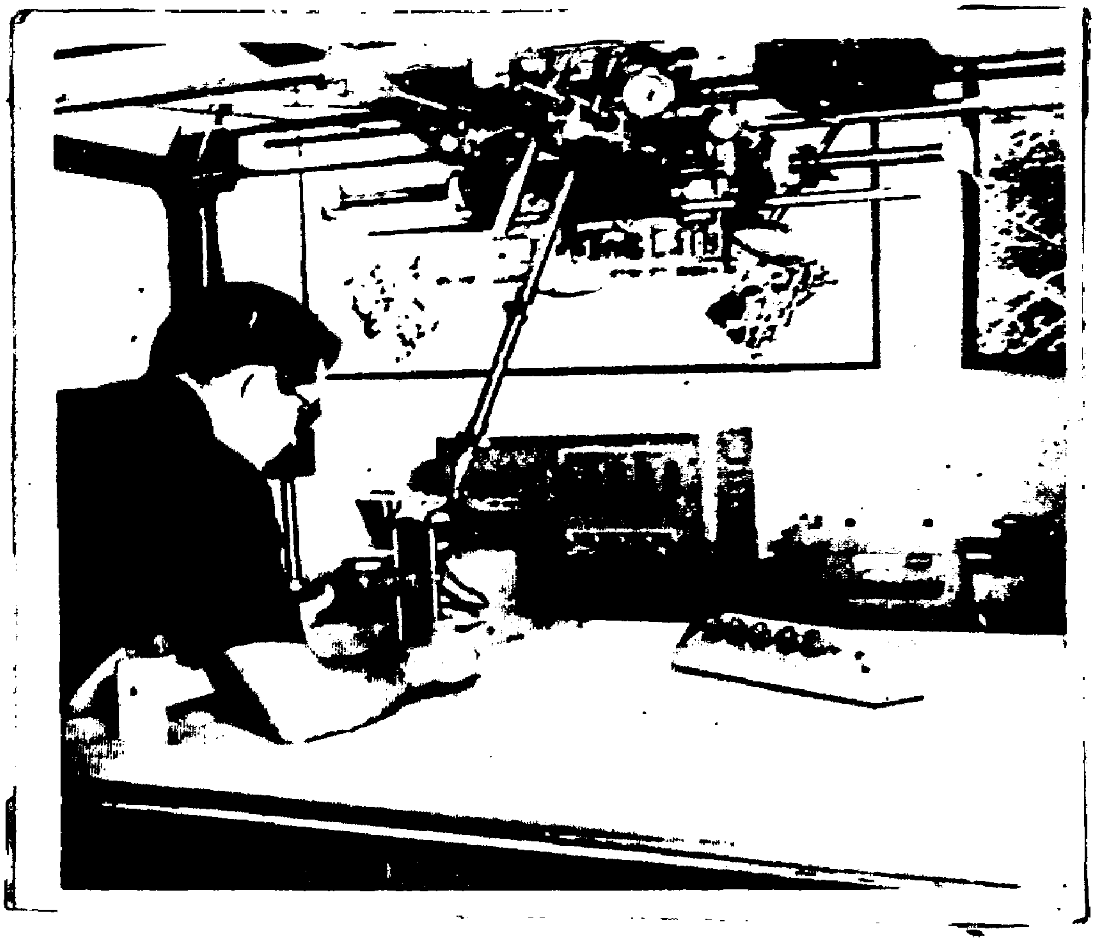
7.28 The clearing of parallax between two - images requires that the corresponding points in the images be identified and located with respect to each other. Stereomat uses the method of 'flying spot' scanning i.e. scanning a small area by a spot light moving in a - random pattern. Here a cathode ray tube light-source and photoelectric cell-sensing means are employed. The spot of light produced by the electron beam striking the fluorescent screen in the cathode ray tube, may be moved about the screen area in response to the voltages applied to coils which deflect the electron beam from its normal central position. The amount of light reaching the photocells will be a function of image densities at any instant. As the spot image moves over the photographs, the light reaching the photocells varies, producing thereby electrical signals responsive to the image density variations from point to point. Separate photo cells are provided for each photograph. If there is a difference in densities of the images produced on the two photocells, the photocells drive servomotors and execute corresponding movements on the surface of photographs so that the image densities coincide and thus the parallax between the two images is automatically removed. The stereomat is at present applied to plotters of the Kelsh type using optical mechanical principle, but it is also applicable to stereoplotters of other types, including first order machines and the accuracy of the machines is not affected thereby. An external recorder can also be coupled to a Stereomat to produce a profile of the terrain.

7.29 A new photogrammetric measuring device known as the Terrain Data Translator (2) has recently been developed and field tested by the Bensor-Lehner Corporation of Los Angels. Its primary purpose is to provide ground -



Sketch No.24

Components of the Terrain-Data Translator System (less type and key punch)



Sketch No.25

Terrain Data Translator System as used in conjunction with a Projection type Plotter.

cross-section and profile in digital form - directly from the stereo model as viewed in the double projection or Kelsh type stereoplotter, or directly from a topographic map sheet. The record of the terrain data can be obtained in any form viz. typed records, punched cards, or punched paper tape of combinations of these. The system is easily installable and requires no special skill or training on the part of the operator. Other applications of the Data - Translator involve volume determination of coal piles, borrow pits, etc. and reservoir areas. It is also useful for measuring the ground surface subsidence around mines and oil fields. It permits increased accuracy and significant savings in terms of both time and money.

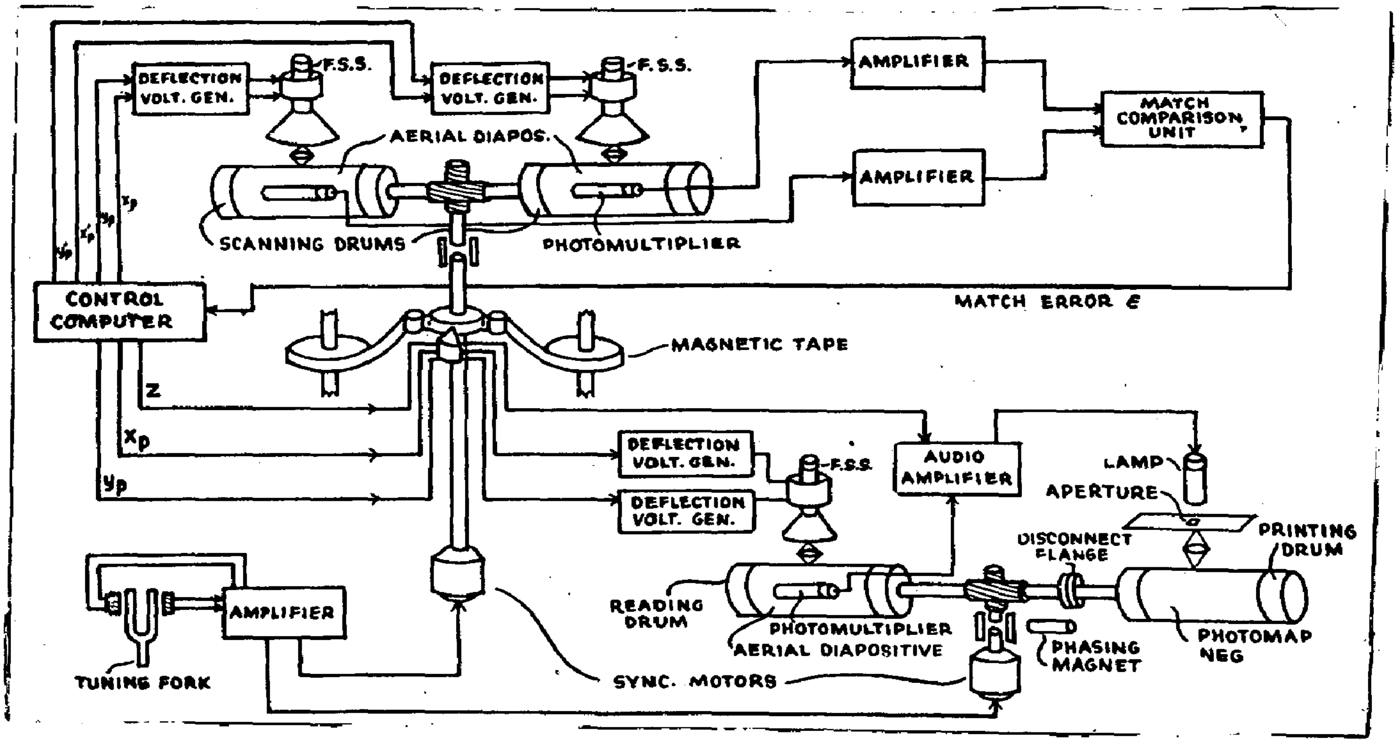
7.30 The sketch (vide sketch No.24 & 25) shows the main components of the Terrain Data Translator system without the typer and key punch.

7.31 The instrument consists of a distance - measuring unit and the elevation measuring unit consisting of a modified Bausch and Lomb tracing table which can be attached to the distance - measuring unit. The control unit is mounted within convenient reach of the operator and actuates the readout. The combined Distance

Counter and Readout Unit provides a visual display on the decade counters of distances 'left' and 'right' from the centre line. It provides means to feed the digital computer also. The elevation reading at each point, together with the distance right or left of the centre line, is automatically recorded when the operator presses a button located at the control unit. Gearing arrangements exhibits true heights and distances with common scale range. Its price, design and flexibility allow for the calculation of a nominal amortization figure without undue threat of a large loss arising from early obsolescence.

7.32 Currently under development is the — Automatic Map Compilation System (2), designed to produce a true orthographic photomap from each conjugate pair of aerial diapositives without establishing a stereo-model. Groups of such outputs assembled together make a composite photomap, corrected for relief aircraft tilt, scale change, adjustment to control etc.

7.33 The system operates by scanning electronically those conjugates points on the two dispositives which correspond to points along a line in the stereo model. The scanning is



Sketch No.26

Block Schematic Diagram of the Automatic Map Compilation System.

controlled by a high speed digital computer and the resulting picture co-ordinates and ground elevations are tape-recorded. The recorded numbers then control a rectifying print-out to produce the orthographic photomap. The operation is fully automatic and assures saving in time. The test results have proved its satisfactory working.

7.34 The symbolic and block diagram of sketch No.26 shows the major components, the main - information flow and the control connections of the automatic map compilation system, currently constructed and which is being further developed.

7.35 The heart of the system is a computer in which most of the control signals originate. It not only solves the equations, but provides timings and programme for all other operations.

7.36 The whole system can be divided into two parts viz. (1) the scanning and matching section and (2) the printing section. In the scanning and matching section a straight profile is cut through the model (x held constant) by automatically scanning and matching the corresponding conjugate profile points on the two dispositives. In the printing section the dispositive is again scanned along the irregular line made up of recorded (x_1 , y_1) values and simultaneously the video signals are printed out along a straight line on a photomap.

7.37 The manufacturers are at present testing the instrument and a test result says that the results were quite encouraging when a map was prepared from 1/40,000 photography and the terrain which was highly undulating with abrupt elevation changes and containing no cultural features and sparse topographical detail.

7.38 In many instances, electronics though at our service is not noticed at all. The higher order plotting instruments are very delicate and sensitive. When their X and Y carriages move out beyond a certain limit so as to cause damage to the instrument, an electric caution signal rings, informing the operator to reverse movement. The signal thus protects the instrument and is of great importance. In the Zeiss Stereoplanigraph C8, certain innovations were recently made (25), with special attention to the new semi-numerical methods; lefthand and righthand miniature motors with reduction gears are now provided for a long convenient setting of tip and tilt corrections in any position.

They are controlled by special knobs and their range is limited by overload clutches. To eliminate the inconvenient change from base in to base out and vice versa hitherto required in case of aerial triangulations a small electric motor with magnetic clutch is provided; this facilitates setting. The retracting and releasing of the drawing pencil of the plotting table is operated by an electro magnet. An electric switch near the foot of the operator works the magnet. It is easy to operate.

7.39 Even in the map printing office in the wet plate process, the machinery used for making the wet plates (Centrifuger) works on an electric motor. All the printing machines are of rotary type. They also work on electric motors.

7.40 Thanks to electronics which helps us throughout in all the stages of our work.

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CHAPTER 8

SUMMARY

(Ref. 1.1 to 1.5) - With the introduction of electronic devices in all fields of applied sciences, photogrammetry has made rapid progress, because of the ease and speed of operations made possible by electronic instruments. The extreme speed of operations and adaptability to varying conditions is perhaps the most significant difference between electronic and non-electronic devices.

(Ref.2.1 to 2.14) - The choice of electronic instruments is justifiable because of their particular advantages over other instruments, viz. versatility, speed of response, adaptability to various difficult conditions of measurement and in most cases ease and convenience which result in saving in time and saving of personnel.

(Ref. 3.1 to 3.12) - Time devices, light control devices, position control devices and servomechanisms are the important electronic systems in photogrammetric instrumentation. Fast response, high accuracy, unattended control and remote operation are their main characteristics.

(Ref.4.1 to 4.37) - In the work of laying of ground control in photogrammetry the introduction of electronic instruments using Microwaves, e.g. the tellurometer, decca navigator system and airborne profile recorder have outdated the old survey instruments and older survey methods because of their greater accuracy and economy of time and money and efficiency of measurement in difficult working conditions.

(Ref.5.1 to 5.28) - Modern navigation systems like the decca navigator system and doppler system and equipment like autopilot, fire detector, etc. have made photoflights accurate and safe. They also help to reduce the air crew.

(Ref. 6.1 to 6.24) - The devices like Wiggler help us overcome image motion which is otherwise a serious problem. The electronic dark room equipment like the electronic printer, electric film, developing and printing outfit, etc. help us avoid mechanical damages like scratches, deformations on account of excessive strain etc.

(Ref. 7.1 to 7.40) - The automatic rectifiers have made rectification easier and more accurate. The electronic computer facilitates the calculations of aerial triangulation to a great extent. The development of the spot scanning technique and automatic parallax removal technique made it possible to design automatic - plotting and contouring equipment. In every phase of work in photogrammetric mapping - electronic equipment has an immeasurable - importance.