*Advanced Radar Map Compilation Equipment**

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ABSTRACT: *The utilization of radar photography for purposes of making maps has been studied and tested for the past several years. New impetus has been added to the study program with the advent of the coherent side-looking radar and the presentations obtained therefrom. As these high resolution radars continue to be developed and improved, the long sought hopes of mapping from these presentations have also become more of a reality. With this in mind, the Photogrammetry Division of GIMRADA has launched a program to develop a ground data reduction sub-system as part of an advanced radar map compilation system for the U. S. Army. The ultimate goal is to permit mapping from radar photography to a scale of 1/250,000 meeting national map accuracy standards.*

Studies have been completed which prove the feasibility of this system and equipment has been fabricated to carry out the program. Currently being tested are the prototype side looking radar presentation restitutor and the prototype side looking radar viewing and measuring instrument.

IMAGINE if you will, a giant pair of dividers (Figure 1) with electronic legs being pulled across an unmapped area through cloud cover, haze, smoke, fog or darkness, continuously making accurate measurements up to hundreds of miles. If you can envision this, you can understand and appreciate the advantages of mapping with side-looking radar. Unfortunately, it is not quite so simple. The problems of obtaining a workable side-looking radar mapping system are numerous.

The utilization of radar photography for purposes of making maps has been studied and tested for several years at the U. S. Army Engineer Geodesy, Intelligence and Mapping Research Development Agency (GIMRADA) Fort Belvoir, Virginia. New impetus has been added to this study program with the advent of the coherent side-looking radars and presentations obtained therefrom. Advanced concepts for mapping from radar photography are based on the integration of an airborne mapping system and a ground data reduction system; an integration we hope will permit the compilation of high accuracy planimetric maps.

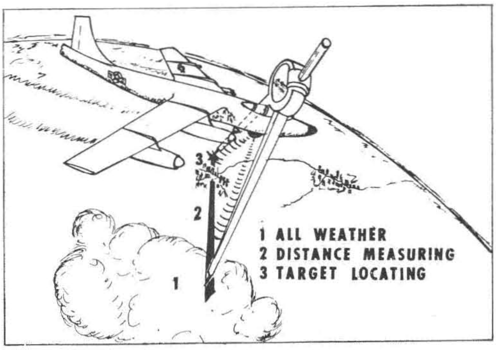

FIG. 1. Side looking radar mapping system.

The ideal side-looking airborne radar mapping system elements are as follows:

a. A slant-range sweep over a plane earth.
b. A record of the aircraft elevation above the terrain.
c. A record of the aircraft elevation above sea level.
d. Navigational positions of the aircraft in latitude and longitude.
e. Film-speed correlated to aircraft ground speed.
f. Provision for altitude delay.

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g. Range marks on the film.
h. A 9.5-inch format.

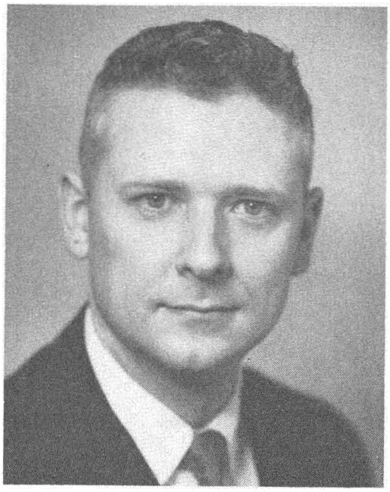
Generally, radar presentations do not yield geometrically correct plan-position information suitable for planimetric mapping or measurements. This is especially true of side-looking radars as compared to PPI radars, particularly those which generate a slant-range sweep. The apparent distortion of the radar presentations is attributed to several factors, and it is necessary to correct these distortions before the information contained on the photography can be properly utilized.

First to be described is the ground data reduction system being developed by GIMRADA to correct for these distortions, and then a brief explanation of the actual operation of two of the prototype instruments presently under test. The ground-handling equipment will consist of a viewing and measuring instrument, a restitutor and an electronic computer. (Figure 2)

The radar photography will first be processed through the viewing and measuring instrument. Presentations from the two adjacent flight lines will be viewed simultaneously to select conjugate image-points in the overlap areas of the two transparencies. Measurements will then be made to these image-points from the indicated flight path on each transparency to obtain the radar measured distances between adjacent flight-lines. Periodic radar distance ties of this type will then be made at various intervals along the flight direction. These measured distances, together with navigational distances established between and along the line of flight, form the basis for the flight-line network adjustment which will be performed by the computer.

The computer (Figure 3) to be used for the adjustment will be a general-purpose digital computer of the Fieldata type. It will be programmed to accept radar measurement data obtained from the viewing and measuring instrument, and the tape containing the airborne navigational data from the airborne radar equipment. Measured distances will be converted from slant to ground-range, navigational distances between and along the flight paths will be computed, the flight line network adjustment will be made, and the flight path correction data will be output on tape for use as input to the restitutor.

The unrestituted film will feed into the



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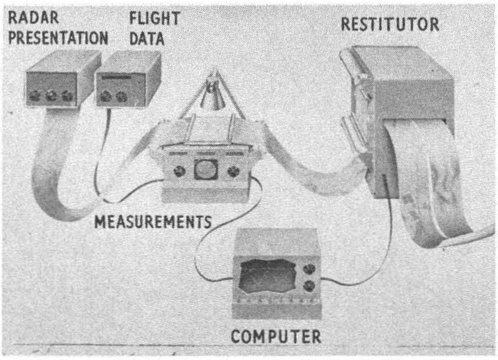

Fig. 2. Advanced radar compilation equipment.

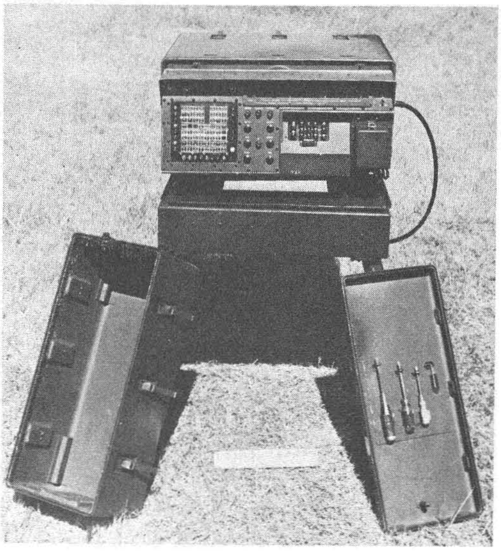

Fig. 3. Field artillery digital automatic computer (FADAC).

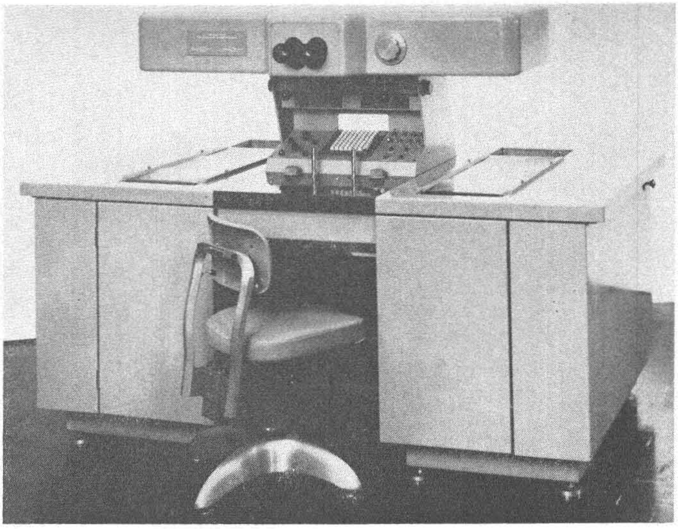

FIG. 4. Side looking radar presentation viewing and measuring instrument.

restitutor simultaneously with tapes containing the airborne auxiliary data and the adjustment data for correcting the flight line. The restitutor which has the capability of automatic, semi-automatic, and manual operation will then correct all imagery with respect to the adjusted flight lines. A moving aperture will continuously scan the unrestituted 9.5-inch film and by optical mechanical means, reproduce a geometrically correct radar presentation on another roll of 9.5-inch film. This results in a plan position presentation suitable for planimetric mapping.

Because side-looking radar photography is analogue to Sonne or continuous strip photography and because a great many measurements across and along the line of flight must be made for the adjustment program, it was desirable to build a mensuration instrument capable of making these measurements and one that could handle long rolls of 9.5-inch film.

The viewing and measuring instrument is designed to accept two 9.5-inch width films, wound on standard spools up to 390 feet in length. The two rolls represent opposite sides of adjacent flight lines and are mounted so they will provide a simultaneous view of the same area when viewed through the optics. This simultaneous viewing is important for radar because of the various shapes a target displays when obtained from different aspect angles.

The viewing and measuring instrument (Figure 4) is basically composed of two independent assemblies; namely, the base section and optics section. There are six systems and related controls in these assemblies as follows: film transport, alignment, measuring and printout, viewing, lighting, and electrical

The supply and take-up spools are connected to drive motors through magnetic friction clutches which maintain tension on the film. Direction of film transport and speed of the film drive is determined by relative electrical currents supplied to each of the clutches. A vacuum system holds the film flat against a glass plate during the measuring operation but is automatically released during film transport.

Before measurements can be taken, the film must be aligned with the coordinate axes of the instrument. In order to align the instrument to the film flight-line, the entire measuring and lighting system must be rotated with respect to the film. A dual-projection reticle system (Figure 5) is provided for this purpose. These reticles consist of two identical line patterns about seven inches apart and located at the outside edge of each viewing area. When the patterns are properly aligned with the flight line of the film, the latter is then parallel to the axis of the instrument, and measuring can be started.

Measurements are made by back projecting a measuring crosshair into the plane of the film. The reticle projector is located beneath the film, and is pulled over a glass plate by steel tapes wrapped around invar drums. The angular position of the drums is read by shaft encoders to give the x and y coordinate posi-

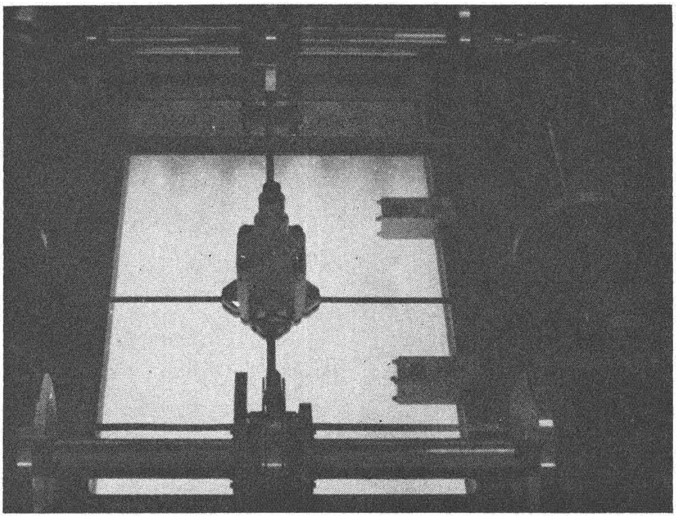

FIG. 5. Projection reticle system.

tion of the reticle. The reading from the encoders can then be displayed visually or printed on paper tape through controls located on the instrument control panel. (Figure 6)

Motion of the reticle is controlled by two joysticks, one for each side, through a dual-range servo-drive system. Speed of the drives can be varied from 0.05 to 50 inches-per-minute. Measuring on a point-to-point or cumulative basis in either direction to an accuracy of one mil is possible with this instrument by utilizing the zero reset button and/or changing the direction of the measurement switch.

All electrical supply and control components are housed in chassis which are accessible through the rear doors. The two side sections are identical and contain the reticle drive servo-amplifiers and fluorescent tube ballasts, digitizer data processor and zero reset units, and the *X*, *Y* digitizer equipment. The center section contains the power supplies and the digitizer readout control unit.

The viewing and scanning systems (Figure 7) are contained in the upper portion of the instrument. Three magnifications of approximately 0.5×, 1.5× and 4.5× may be selected by rotating a large knob to the right of the eyepieces. The fields of view are approximately 10×10, 3×3 and 1×1 inches respec-

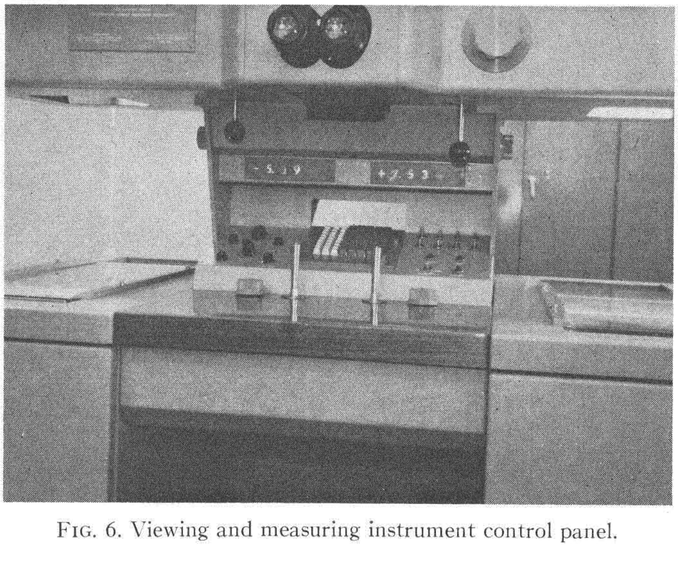

FIG. 6. Viewing and measuring instrument control panel.

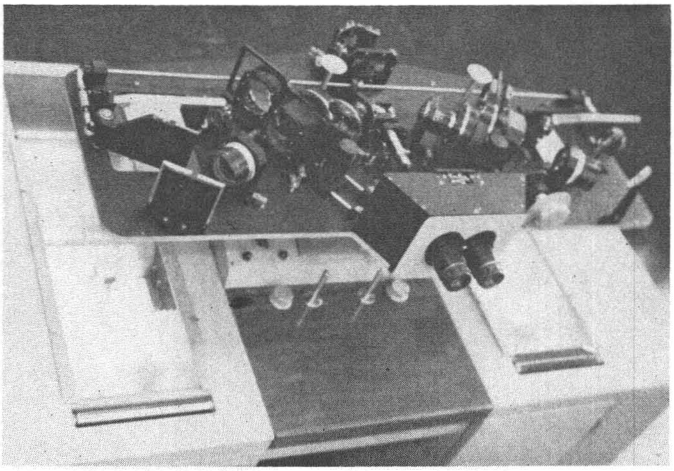

FIG. 7. Viewing and measuring instrument optics assembly.

tively. Each eye receives a simultaneous view of the two films appearing side by side in a vertical plane.

At the low power a reticle consisting of two concentric squares can be seen in the field. These represent the fields of view for the intermediate and high powers and can be moved about the field to selected areas by means of the scanner controls projecting from the bottom of the optics section. The selected area can be brought under closer observation by either of the two higher powers.

A bank of fluorescent tubes on either side of the instrument provides illumination of the film. Provision is made for varying the light intensity.

The radar-viewing and measuring instrument was built by Boller and Chivens, Inc., of South Pasadena, California, and is presently being tested for adherence to specifications.

The prototype side-looking radar-restitutor is a far more complicated device, and is believed to be the first instrument of its kind designed to rectify a side-looking radar photograph.

The characteristics on which the design of the restitutor was based are as follows:

a. The uncorrected radar information will be available on the film transparencies.
b. The presentation for each side will be 9.5 inches in width and up to 250 feet in length.
c. The maximum ground-range from the aircraft will vary from 3 to 50 miles.
d. The presentation will have sweep traces eight inches in length.
e. A flight line will be displayed on the film to indicate the start of the sweep.
f. The presentation will contain calibrated slant-range markers at the beginning of each roll.
g. The aircraft altitude will range from 1,000 to 50,000 feet.
h. Sweep delay will vary from 0 to 40,000 feet.
i. The aircraft velocity will vary from Mach 0.2 to Mach 2.0.

The requirements (Figure 8) for the restitutor are that it automatically corrects for errors caused by the following:

a. *Slant range*—Any point along a sweep trace will be corrected from its slant-range position to the equivalent ground-range position. The correction will take into account the average variation of terrain elevation from sea level and the curvature of the earth.
b. *Systematic distortion*—Correct for minor systematic distortions such as non-linearity of the sweep, lens distortion in the recording camera and curvature of the scope face.
c. *Sweep delay*—Correct for any operator introduced sweep delay.
d. *Flight line*—Correct the flight line track caused by a deviation in the intended flight path.
e. *Line of flight*—Correct for line-of-flight deviations due to non-correlation of the film-speed to ground-speed.

The range correction will be such that any position along a sweep-trace will be accurate to within 0.006-inch of its true ground-range

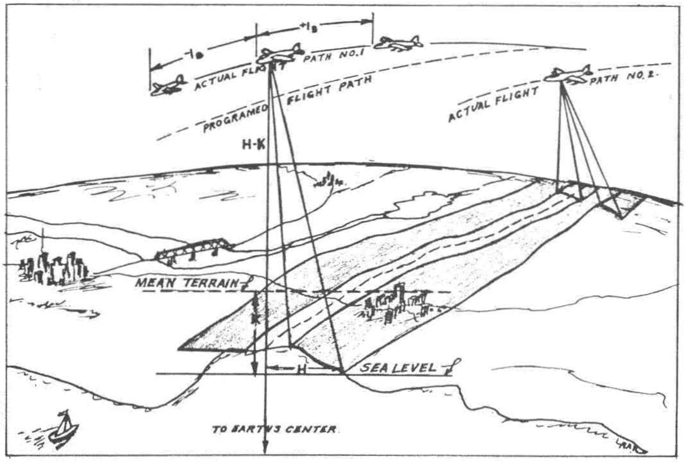

FIG. 8. Airborne radar system and geometric relationship.

position at presentation scale assuming the auxiliary data are correct. The flight-line correction will position the flight-line plot within a resultant accuracy of 0.002-inch at presentation scale.

The side-looking radar presentation restitutor is an instrument composed to two units; the electro-mechanical restitutor and the control console. The restitutor (Figure 9) is composed of the following sub-assemblies: Restituted film magazine, unrestituted film magazine, light sources, copying lens, marginal data projection system, cams, servomotors, constant speed drive-motor, scanner, and associated gears and shafting. The control console contains the tape reader and winder, digital to analog converter, amplifiers, system logic, power supplies, and control elements. All the restitutor components and sub-assemblies are mounted on a 4×8 foot cast-iron surface plate to minimize and isolate vibration.

Two independent optical systems are provided on the unit. The main optical system is composed of a 14-inch focal-length, f:9 apochromat, artar lens and two light-tight bellows extending from the lens to each film carriage. The bellows permit lens adjustments and minor alignment without disturbing the film. The marginal data optics are housed within the main system and are not externally visible. This system is used to transfer data recorded in the margin of the unrestituted to the restituted film. If desired, the operator may view the marginal data through a beam splitter viewing tube.

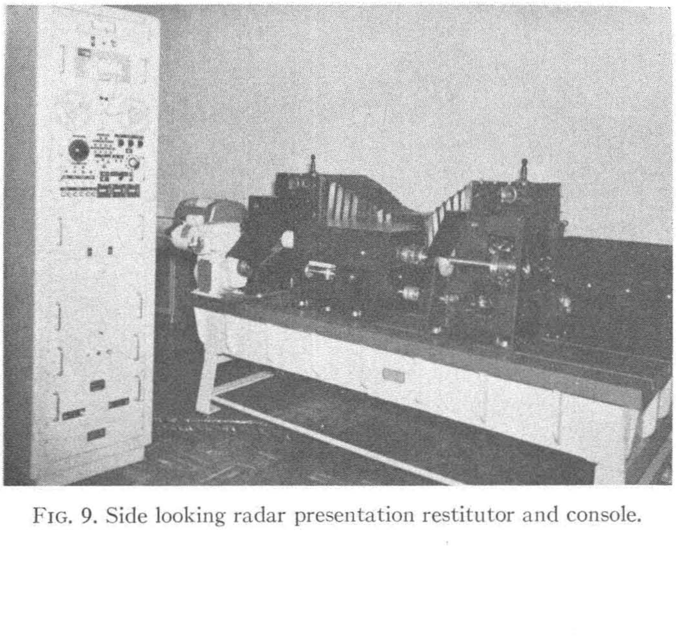

FIG. 9. Side looking radar presentation restitutor and console.

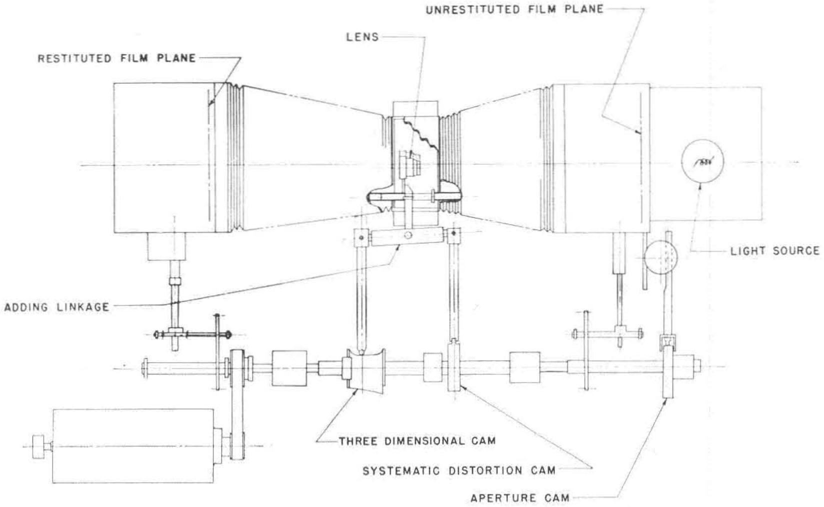

FIG. 10. Side looking radar presentation restitutor (plan view).

The main cam shaft (Figure 10) is attached to a one-half horsepower motor by a belt drive and lies along a line parallel to the main optical system. This shaft supports the three cams and drives the unrestituted and the restituted film.

The unrestituted film magazine consists of an inner and outer housing. The film is mounted in the inner housing and can move laterally with respect to the outer housing by activating a servo which corrects for altitude and sweep delay.

Mounted to the film magazine is a miniature dual element photo voltanic null indicator for tracking the flight line. If the film drifts, a voltage is induced across one element which drives a servo and corrects for the drift. The servo for correcting altitude, sweep delay and film drift is located on the side of the outer housing. The amount of inner carriage travel is displayed on dials which can be read to the nearest 0.001-inch. In addition to the dials, the servo consists of two 10-watt motor-tachometers, a follow-up pot, magnetic clutch, limit switches, connector and phase shifting networks. All system servos are Class I, tachometer damped with potentiometer feedback.

The unrestituted film is scanned with a 0.005×0.050 inch aperture which scans eight inches of film plus a slight overtravel on each stroke. A positive action shutter controls the scanning by opening on the forward stroke and closing on the return. Micro-switches at the beginning and end of the scan set up the logic circuit.

The aperture is translated by gearing set up between the aperture cam, the cam follower, and a multiplier assembly. The aperture cam profile is divided into four sections or angles with each section being defined by a separate mathematical function. The scanning function is parabolic to reduce the three dimensional cam accelerations while the remaining three return sections are polynomial. The aperture cam follower accelerations do not exceed 2 G's, with the motor running at 50 rpm. However, due to relatively high accelerations at low displacements, a captive type needle-bearing follower is employed.

One unique feature of the aperture cam is the micropositioning device which is used in the initial alignment of the instrument to exactly zero the 3-D and aperture cams. The hub of the latter contains a worm which mates with a gear cut in the cam shaft. The worm shaft contains a screwdriver slot which when rotated changes the angular position of the cam relative to the proper alignment of the two cams at the zero position.

The three dimensional cam (Figure 11) is mounted on the cams same shaft and phased to the aperture cam. (The figure shows a replica of the actual cam.) This cam basically solves the slant-to-ground range triangle, introduces an earth curvature correction factor and is compensated by altitude or sweep-delay corrections. The axial distance corresponds to altitude above terrain (H-K) and the circumferential surface corresponds to the slant-range from the initial target. The basic equation for the cam contour is determined by three variables: Altitude above terrain, the cam angle in radians and the cam rise. This equation is a hyperbolic function while the transition is again defined by polynomials. The earth curvature factor which is a function of aircraft altitude and mean terrain is introduced as a constant and computed at 25,000 feet.

The cam is mounted on a ball spline which forms a part of the main shaft. Axial freedom is provided by this design which in turn represents altitude above the terrain. The *H-K* servo positions the cam in this direction and receives the same input as the sweep-delay servo. Dials again read inches of travel which corresponds to altitude scaled to inches. The cam is enclosed in an aluminum frame supported by bearings on the ball spline frame housing. The frame is filled with oil to provide lubrication for the 3-D cam. The lead screw driven by the (*H-K*) servo positions the frame and in turn positions the cam.

The systematic distortion cam is used to correct the small distortions in the system and is made up of an adjustable cam assembly which rotates freely at shaft speed. A metal strip wrapped around adjustable segments actually shapes the cam, which is preset to correct for minor distortions. The systematic distortion adjustments are made with two other cams set at the zero position. The follower outputs of the 3-D and systematic distortion cam terminate at the adding linkage. This linkage output translates the main copy-lens which in turn provides the final corrections.

The restituted magazine is similar to the unrestituted magazine in that it also contains an inner and outer housing. The inner housing which carries the raw film, is positioned by the flight-line servo or "*B*" servo as it is frequently called. This servo works from the adjusted flight-line input data and positions the flight path perpendicular to the aircraft track. When a deviation of 0.5 inch is reached, the servo repositions to zero producing an offset.

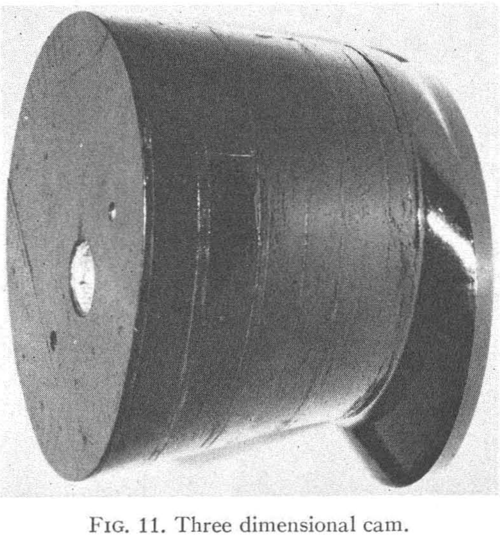

FIG. 11. Three dimensional cam.

Tensioning, magazine shift, clutch and contact assemblies are the same as on the unrestituted magazine. Additional features are the alignment micrometer for use in aligning the systematic distortion-cam and a rear access door.

In-flight errors are caused by non-correlation of aircraft speed to ground speed. These errors are corrected by a digital stepping motor and gear train coupled through a differential to the film drive. The motor is energized by pulse input and advances or retards film movement in 0.001 inch increments. The drive-motor is a one-half horsepower, 110-volt, 60-cycle variable speed motor with speed variation accomplished by a ribbed V-belt and dual variable pitch pulley mounted on parallel shafts. Manual speed controls are incorporated, and the ratio between the mounted output shaft and the cam shaft is approximately 1.5 to 1.

In the condensing system, (Figure 12) the light source produces a virtual image approximately 24.5-inches behind the Fresnel lens. This lens is positioned in such a way that the image it forms utilizing the virtual object falls at the front surface of the copy-lens.

All circuitry is contained in the control console which is composed of two compartment relay rack type construction. The lower compartment contains all the DC power supply except the logic while the upper compartment contains all control and digital circuitry.

The tape reader is located in the upper section of the console. It is designed for use with one-inch, eight-channel insulating tape for Fieldata code and will read blocks of up to 12 lines. Each code hole contact is made up of three wire brushes composed of palladium-platinum gold alloy. A common collector plate of nickle-rhodium is hinged over the brushes. The brushes retract when the collector plate is raised. The reader is powered by a 1/40 HP inductive motor. A V-belt connects the motor shaft to the output shaft of the clutch, and is connected to a sprocked wheel to drive the tape. Momentary application of 28 VDC current engages the clutch for one revolution for advancing the tape one block. The clutch then disengages automatically. The tape winder takes up to 700 feet of perforated tape which feeds to the reader, then

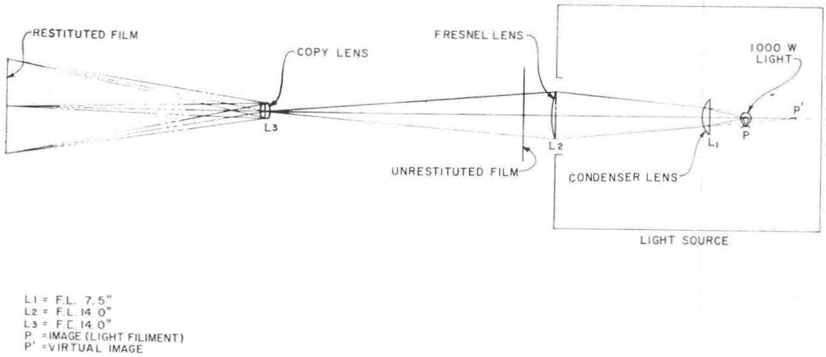

FIG. 12. Side looking radar restitutor projection system.

rewinds. The tape may also be advanced manually.

The digital logic performs all the logic manipulations required for operation of the system. It is composed of printed card circuits. Test points found along the base of the card file allow various signals to be monitored. The digital-to-analogue converter converts digital information to analogue servo voltages.

Although the equipment is designed to operate manually, the manual mode will not be used except for the initial set-up of the equipment. The semi-automatic mode of operation is also seldom used except for single flight lines or overlapping flights where the navigational input is absolutely accurate and no adjustment to the flight line is required. The automatic mode generally speaking will be the only method of restitution because theoretically, automation is the final end product for all advanced mapping systems.

Belock Instrument Corporation of College Point, New York, built the restitutor under contract to GIMRADA and delivered it for test in May of 1962.

The title of this paper, "Advanced Radar Map Compilation Equipment," is somewhat of a misnomer. Let us say that radar map compilation equipment has been advanced but that this is only the beginning of what the author hopes will someday be the Advanced Radar Map Compilation System.

Mapping from radar is still very much in its infancy. How long it will be before it can take that second significant step forward depends largely on the order of priority and the urgency for its need in defense mapping.

Photogrammetry as an aid to radar mapping research has proved to be invaluable. At the same time, radar has advanced the science of photogrammetry. Just as dividers are the tools of the draftsman, so should radar presentations be the tools for the cartographer. The author feels it is only a matter of time before radargrammetry will be as much of a common term in the mapping field as photogrammetry is today.

*Radar Network Adjustment**

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THE Strategic Systems Division of the United States Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) is currently working on a task "Utilization of Radar Presentations for Topographic Mapping." The objective of this task is the development of a radar mapping system to provide the

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* Presented at March 24–30, 1963 ASP-ACSM Convention, Hotel Shoreham, Washington, D. C.

EDITOR'S NOTE: The Abstract for this paper is on page 484 of the 1963 YEARBOOK.