Construction & Operation
of
Mod 2B Radar Optic
FEI

Developed by

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Mr

This F.C.I. system was ~~des~~ designed and developed at A.P.G.C. as a unit which ~~x~~ could be built, operated and maintained by ~~field &~~ operational units with suitable shop facilities. It is a new and simplified design of a radar optic scoring system developed here. ~~A working~~ A prototype was built and ~~spent~~ operated ~~to~~ to run down as many bugs as possible as well as to determine operating procedures. Ideas to further simplify this unit have been constantly appearing up ~~to~~ thru the time of writing and they will undoubtably continue to do so. The unit appears to be relatively bug free however for the total maintenance ~~to~~ during some 12 or

15 missions has been the replacement of 1 fuse which was underated.

All items used except one are stock and are listed. The one is exception is a camera since the Air Force has no ~~decent~~ suitable motor driven 35 mm camera available. ~~The~~ Camera used is a Model 4 c mfg and sold by Flight Research Corp., Richmond Va. This camera is almost ideal for the job and little difficulty should be experienced ~~obtained~~ obtaining them. Any motor driven 35 mm camera with frame rates of 20 to 50 pers second would be suitable with slight modifications to the A scope combining system. At present, work is under way here in the Photo Optic

Lab to fit the A-1 to this installation.

Theory of operation of this ~~form~~ method of scoring ~~runs,~~ simplified, runs as follows. A motion picture record is made of ~~the~~ rockets path past the target by a camera in a chase plane flying through a firing run in formation with ~~the~~ firing aircraft. Concurrently with ~~the~~ strike camera record a record is made of a radar A scope presentation on which is displayed both rockets and targets ~~range~~ ~~from~~ relative range. When ~~the~~ range of pattern centroid is coincident with target range ~~the~~ a corresponding photograph is taken from the strike record. Miss distance is obtained from this ~~film~~ frame of film by comparing miss distance of centroid to target length.

In this ~~Mod. 2 b~~ ~~scoring~~ F.E.I. functions of strike camera and scope camera are combined to eliminate difficulties of synchrozizing camera, assessment problems and others. A modified 4" Baltar lens is removed from its lens barrel and screwed into ~~the~~ an adapter ~~[illegible]~~ Drawings # 4 & 7 — ~~[illegible]~~ These lens are focussed individually at the factory so it will ~~no~~ be neccessy to refocus them on the modified barrel by screwing ~~the~~ lens proper onto ~~the~~ modified barrel in ~~the~~ correct position and pinning it there. This can be accomplished on ~~an~~ optical bench or more simply on a camera with a ~~borsight~~ boresight tool. The 4" lens images ~~the~~ strike information on the film while a 2" lens set in the adapter images through

~~[Drawing 4 & 5]~~ 5

a mirror onto one edge of frame aperture A scope information. In order to place this ~~O~~ cathode ray tube in a ~~practtal~~ practical posistion it was neccessary to use a mirror mounted on the camera (Drawing 4 & 5) This scope lens leaves something to be desired in speed as it is only f 4.5 max ~~and~~ for this reason the shutter opening on this image portion ~~of the~~ is increased (Drawing 8)
It is ~~absolutely~~ mandatatory to use a 3 J P 11 tube for the much higher actinic value of its phosphor. At these writing speeds light from a green phosphor P-1 will not produce an acceptable trace. Class L film is also used to gain a slight speed advantage.

See drawing ~~(~~ 4 & 6) for mounting detail of cathode ~~rad~~ ray tube. Power for this tube is from a high voltage supply used in pilots presentation of ~~F-86-D~~ F94C

To ~~prov~~ provide neccessary voltages for an 'A' presentation on the 3JP-11 a sweep and video circuit simple to the point of crudity is used. It ~~fitt~~ is entirely adequate however. ~~Two~~ All power plus trigger and video pulses are obtained from a G-30. This unit is constructed on ~~an~~ aluminum chassis, Drawing 3, which fits the same type shock mount as ~~the~~ voltage regulator of the G-30. Video amplifier (Fig 14 to 18) is a straight R.C. coupled pentode receiving video information from the video jacks on G-30 range computer and power supply. ~~R-20 is~~ R-20 is kept ~~small~~ low to to maintain time rise of ~~the~~ pulses. It fist appeared that some form of peaking network would be ~~neccos~~ neccessary to keep ~~the~~ out put ckt 'fast' enough ~~and yet~~ with a reasonable gain however this ~~was~~ is not neccessary if all leads are kept short and good high frequency practice is followed in construction. ~~A~~

A negative trigger pulse ~~from the mo~~ from the G-30 R.T. unit initiates sweep and unblanking functions. Drawings 14 & 15 this trigger is coupled thru a diode V_1* to ~~the~~ the normally non-conducting plate of a univibrator — ~~the~~ Current is drawn by this trigger causing ~~or~~ conduction in this ~~tro~~ triode while the other is cut off. This state remains until enough charge has leaked off C_3 and C_4 for the circuit to return to its normal state. Output of this circuit is a large negative pulse which may be varied in duration from ~~one to~~ 3 to 15 micro seconds. This negative pulse gates the sweep and intensifier ~~ckt~~ circuits through C_5 and R_9

* this tube has later been replaced by two 1N34A diodes in series.

To keep screen burning and other undesirable effects down, ~~the beam of~~ Cathode ~~Ray~~ ray tube beam is turned on only during sweeps. A negative gate is applied to ½ of V_3 which is conducting heavily causing the tube to cut off ~~with~~ Diagrams 14 & 16. An almost square pulse is then applied to the grid of V_6 (3JP11) ~~turning~~ allowing beam current to flow for pulse duration.

To generate necessary sawtooth voltages for sweep a negative gate is applied to clamp tube V_3 cutting it off and allowing plate voltage to rise Diagrams 15+17. This rising ~~grid~~ voltage is applied ~~to~~ directly to the grid of ½ of V_4 - This ~~tube~~ triode has a large amount of feedback from plate to grid thru C_6 + R_{14} ~~[illegible] variational [illegible]~~. The resulting lenearly increasing voltage is ~~fed~~ coupled to a horizontal deflection plate of ~~3JP~~ V_6

thru c_{16} and a portion is applied to ~~the~~ grid of the other triode of V_4 which is a paraphase inverter. This tube inverts the sawtooth which is now applied to the other ~~pt~~ deflection plate of V_6 thru c_{16} —

~~It~~ Circuitry is simple and straightform. There is room for improvement in layout especially high voltage components. To set this circuit up a scope ~~such as~~ with most excellent highfrequency response ~~should~~ be used. ~~Couple~~ A T.S. 239 should be adequate. Through a high impeadance probe ~~&~~ couple the plate of V_1 to the scope and apply a negative trigger of about 25 volts to J-302 - This trigger ~~can~~ should be the trigger pulse of a G-30 but may be synthetic. Adjust R_7 until the pulses ~~form~~ is 'locked in' with the trigger. This can be determined by removing the trigger which should ~~also remove the~~ stop the pulse. Too high a setting of this control will result in inability to trigger the circuit while to low a setting will cause the circuit to run free without triggering. Correct setting is ½ way between these points.

9. Next move the probe to ~~plate~~ pin 2 of V_3 where a square positive pulse will appear. Width of this pulse controls ~~width of~~ range displayed on the A scope. Scale factor is 490'/micro-sec. C_4 should be adjusted until desired range is obtained. Settings of 5 to 7 micro seconds are normal.

~~Next~~ Display positive sweep on the scope by going ~~to~~ to pin 5 of V_4. C_6 must be adjusted for proper sweep rate. Too fast a rate will result in a ~~rise to a~~ sawtooth rising to a maximum and becoming flat for the remainder of the pulse while to slow a rate will mean a decreased amplitude. Correct setting is ~~between the~~ just beyon the point~~s~~ where flatness ends and where decreased amplitude is noticable.

With a little experience all of these adjustments may be made by merely watching A scope presentation.

The G-30 is strictly stock with only tubes V ______________________ being removed to decrease power drain. T.O.'s apply completely except for bench checks to the range and other circuits disabled by removal of tubes. ~~there is one other exception when the~~

Cable diagrams for this installation are given ~~in~~ Dig #[12 + 13]

Primary power wiring in plane and tank are given ~~in~~ # [10]

In order to eliminate any possibility of interference with firing aircraft system, ~~the~~ primary of the magnetron H.V. supply is connected only ~~during~~ a few seconds before and during firing.

Power for ~~the~~ scope power supply

is taken from any convenient point on the 115 V 400~ supply through a 1 amp fuse. This is not shown on these diagrams. Ships wiring is given in Drawg. 11. A single point push to make ~~tot~~ switch is placed in the tank for convenience in preflight. This ~~$~~ operates camera and radar.

To prevent an overload on G-30 component since additional filament and plate power is drawn from it tubes ~~# V~~ tubes in the range computer section which are not used in this circuit should be removed ~~are removed~~. Other than this it is unmodified.

① Set A.G.C. threshold until AGC volt is -1. If gain is insufficent this may be reduced. Do ~~Not~~ Not connect the trigger cable from R.T. unit to ~~the~~ Range Computer as this will operate a dunking circuit that obscures the ~~fo~~ first portion of the trace.

Construction and mounting details are given in Drwg. # 1, 2, 3, 4, 5 & 6. These are detailed enough to be self explanatory.

¶ This report was hurridly assembled and there are undoubtably blank areas however we have readily available any additional information neccessary.

prove ~~the~~ feasibility of this system as a method suitable for field use. a ~~separ~~ complete system including radar, cameras, and A scope was assembled. ~~A~~ the R.F. unit of a G-30 was housed in a 120 gal M-116 napalm tank along with an A scope presentation which was photographed by a 35 mm camera whose shutter openings were synchronized with those of another 35 mm strike camera ~~which served as a strike camera~~ equipped with a 4" ~~lens~~. This unit was ~~and~~, suspended from an 86 F, hurriedly assembled, and without preliminary tests taken to Yuma A.F.B. where ~~a~~ ~~intensive rocket~~ a large number of firings were being made. During the week ~~there~~ ~~8 successful~~ 8 firings were ~~made~~ chased by this 86 with all 8 being successfully recorded. ~~The this~~ This Instrumentation in spite of its hurried design and construction and unnecessary complexity ~~performed f~~ required no maintenance.

~~Results were all~~ ~~Results were extremely gratifying.~~ ~~Severa~~ Several hits were recorded ~~whic~~ thus affording a check against instrumentation accuracy which proved to be excellent. This was the first instance of a firing error indicator functioning successfully in the field. Several conferences were held with ~~people in~~ members of Air Defence and Training Commands as to the most ~~usefuls~~ satisfactory configuration of this system and it was decided that a chase plane equipped with this F.E.I. offered more advantages ~~primarily~~ than any others.

A ~~simple,~~ unit was then designed using, with one exception, stock A.F. items which is simple enough to be reproduced by any ~~well~~ Air Force installation equipped with machine shops and facilities

This scoring method is extremely versatile requiring ~~on~~ a basically only two sources of data, radar video information and photographic data from a strike camera. We have built a series of these ~~sco~~ Radar-Optic ~~sco~~ F.E.I.s ~~hire~~ using various configurations. They have fallen into roughly two ~~f~~ classes - ~~#~~ units ~~systems~~ mounted on the firing craft and using system's radar for video and those mounted on a chase plane with it's own radar. The system ~~describe~~

~~the sys~~

~~described~~ described in the following is the Model 26 which was designed for field use. It consists of an unmodified G-30 radar feeding a 4 tube sweep and vide chassis ~~which~~ whose output is an 'A' presentation on a 3SP11 cathode ray tube. A modified lens combines the image along one edge of ~~the~~ 35 mm film ~~along~~ with strike ~~on~~ photographs. A 40 ~~fps~~ frames per second camera is used. Housing for the unit is ~~an~~ an M-116 napalm tank with neccessary changes ~~to~~. Weight is approximately 125 pound and drag is only slightly higher than a normal tank. The chase plane flies a fairly tight formation with firing craft and during the last ~~ten secon~~ few second ~~two~~ of a firing run radar* and camera are turned on for ten or 15 seconds.

* ~~High~~ Voltage is ~~only~~ applied to the magnetron only during this period to eliminate possibility of interference

for maintaining an 'E' system. A prototype of the unit was assembled and tested here and will be given to Yuma for further tests. ~~this~~ Complete details of construction and operation of this ~~unit~~ FEI are given in the attached appendix.

Since the concept of 'tracking' ~~rock~~ missiles with pulsed radar is relatively new and ~~##~~ opens a realm of possibilities in the missile field in general its specific application ~~to~~ as a practical for E system scoring A.C.I. ~~system~~ will be described in some detail. TF Restating the problem of photographic scoring: Ranging of ~~missiles from missiles miss~~ of rockets miss by motion picture photography is easily accomplished by stadiametric technique if ~~the correct a~~ and only if a rocket is in ~~or near~~ a perpendicular plane normal to the longitudinal axis of the strike camera ie a plane ~~through~~ through the target

insert Paragraph on MZ b

paralell to the camera's film plane. ~~Accuracy~~ First order accuracies are determined soley by the ~~correctness~~ errors in detecting the cutting of target plane by ~~the~~ rockets and relation of this to the strike camera film. ~~a~~ Positional errors thus become a function of time errors as the target is in continous, ~~or~~ linear motion. ~~set conditions~~

An example will illustrate. Assume that ~~the~~ a single ~~strike~~ rocket ~~or centroid of a pattern~~ crosses ~~the~~ a target plane, ~~whose~~ at some given time missing ~~short~~ the target aim point by ~~[illegible]~~ 50 ft ~~left~~ lead in azimuth. ~~Suppose that~~ Suppose that a photograph is taken ~~some~~ $1/20$ of a second later and ~~data is taken~~ miss distance is assessed from this photograph. ~~Errors in azimuth will now vary directly as the speed of th target speed. Elevation errors~~ Elevation errors are neglegible since vertical target velocity is zero and vertical rocket velocity relative to the firing aircraft ~~is t~~ arises only from gravity acceleration which is on the order of ~~70 ft/sec~~ 700 ft/sec at this point. Errors in azimuth will now vary directly as target speed. ~~In this~~ In this case ~~the with target will will have~~ the missile will appear to have ~~to~~ passed ~~it~~ closer to the target by ~~the~~ distance ~~the to~~ of target travel in 1/20 sec. With a target speed of 300'/sec ~~this~~ error in azimuth ~~wout~~ would be 15' against an elevation error of 3.5'. It is obvious that the relation

Error in ~~distance~~ assessing miss distance in azimuth (ft) = target velocity (ft/sec) × error in determining time of crossing rocket plane (sec)

holds for this specific case.

Other much smaller errors are present in ranging technique but this time function error predominates. This of course leads to a ~~more fundamental~~ another problem. Since rockets are fired during a relatively long period of

* should be footnoted *

time* (approximately 1.25 secs for an 89D, ~~#~~ .084 sec. for 86D and .168 sec for ~~8~~ F-94 for full salvos) ~~so~~ the rocket pairs must be followed separately and ~~the time of crossing~~ crossover time ~~to~~ recorded ~~under~~ for each pair or one ~~rocket~~ pair must be chosen and the time of only this pair's crossover be recorded. The first procedure is ~~for~~ neccessary for extremely accurate work in engineering tests. For evaluation of system accuracy it is enough to know where the so called strike rocket or pattern centroid goes for it is this rocket which is theoretically designed to hit ~~target center~~ target aim point. Since neither missiles or ~~syst~~ fire control system is perfect it is neccessary to add rockets ~~befo~~ fired before and after the strike rockets to bring kill probability to a reasonable figure. It is ~~so~~ the centroid which is scored with the system being described

*

32 by interpolation

although it is possible to score other rockets

~~Since~~ ~~Since time~~ Radar ~~without~~

sets used to determine range coincidence

~~have~~ is ~~the~~ avg ~~G-30~~ AN-APG-30, an

airborne, low power, X band set with ~~5 KW peak p~~

commonly used for range data on A series

sights. It would be desirable to have a

set with more power or ~~at least~~ an antenna

of smaller beam angle but this is more

than offset by such factors as small size,

light weight, simplicity and ease of maintenance.

Range information is displayed on a 3"

scope in an 'A' presentation. In this

presentation the scope beam is started, coincident with transmitter output pulse, at one

edge of the tube and is swept linearly

across ~~the face~~, ~~thus~~ along X axis ~~If~~ Return pulse

information is displayed along ~~the~~ Y axis the resulting ~~pattern~~ in ~~range~~ scale ~~giving~~ ~~range~~ on which ~~range of objects~~ distance of objects from the set may be determined. ~~Absolute range is~~ Relative not absolute range is of primary interest here.

Since extremely short ranges are ~~used~~ ~~of int~~ neccessary here some complications arise since the sets are designed for much longer ranges. Radar range factor is approximately 490 ~~per~~ micro sec ~~[illegible]~~ thus the .4 micro sec pulse of a G-30 covers 196 feet in space thus Objects closer together than this cannot be separated on ~~a~~ a presention. Ideally ~~the~~ pulse length would approach zero with position of ~~an~~ each scanned object appearing as a single narrow line. Unfortunately practical limitations prevent this. ~~so that~~ ~~Rockets~~ A salvo of rockets appears as a single ~~pulse~~ lengthened pulse and the target as another relatively wide pulse. After a little experience ~~pulse can~~ time of crossover for the centroid can be determined by inspection to within one frame of film run at 40 frames per sec even though ~~the~~ pulse width occupies a relatively large amount of trace width.

~~Once correct~~ At forty frames per second the maximum azimuth time error is less than 1/40 second ~~x~~ X tow speed. At present tow speeds this is on the of 7 feet. Elevation error ~~ty~~ is neglegible Once ~~the~~ ~~moment~~ instant of crossover of the centroid is found it is ~~only~~ neccessary only to ~~choose~~ select the ~~centroid~~ centroid ~~and~~ of the pattern from strike photographs and determine magnitude of miss ~~from~~ stadiametrically. For use with present targets a slide projector would be desirable but not neccessary. Experience here has shown that pattern centroid is extremely close to the center of a circle which encloses all but obviously wild rockets. Choosing this point becomes simple after ~~comparing~~ observing several strike films. One this point is chosen magnitude of miss is determined by comparison of ~~opps~~ ~~it is only neccessary to compose it its distance from aimpoint* with target length to determine image miss distance to~~ image distance of centroid from ~~magnitude of miss.~~ aimpoint* to image distance of target.

~~Advan~~ This system ~~approximates~~ has much to reccomend it. Indeed it is difficult to conceive ~~of of an~~ another system~~s~~ with the advantages of no target limitations, ~~at ver~~ simple data reduction~~s~~, and a ~~record of photographic~~ record of ~~the~~ firing passes realistic enough to ~~evaluate~~ offer incentive to a pilot to study his performance. To ~~to~~ accurately evaluate a pass with any form of FEI it is neccessary to have a record of pilots perfomance to determine errors introduced from steering.

~~Strant~~ As mentioned before ~~the app~~

* aim point on a non reflective banner with corner reflectors attached is of course the reflectors. It will vary with reflective targets.

the use of radar to obtain range data from missiles has many applications. It should be an extremely valuable tool in ballistics studies of ~~velocit~~ velocity, acceleration, and pair dispersion. As an F.P.I. system its ~~is~~ value is obvious. Many possibilities exist for its immediate utilization. ~~Most str readily avai~~ There is no reason why the Model 26 F.P.I. as described in the appendix should not be immediately reproduced for use at bases where firing programs are being conducted. At present it seems impractical to equip individual fighters with this system even though it would involve only a simple 'black box' and a camera. ~~A~~ Such an installation would be far simpler than the Radar equipment which is presently ~~being vast~~ scheduled for installation. It would be of vastly more use. ~~A~~ Value of an F.C.I. system needs no further justification.

~~Development~~ Use of this system should have far reaching effects on to targets. Now instead of having to use banners as a crude attempt at scoring, its only function of a target need be provision of a radar target with realistic performance. A logical target configuration would be a radar reflector enclosed in a streamlined structure offering small drag. Once drag is reduced to a low figure it is possible to reduce cable size weight and drag as well as reduce tow reels ~~to~~ size weight and complexity. With this reduction in size weight and drag the next logical ~~sto~~ step is use of fighter craft to obtain realistic performance. ~~That~~ Work has been done toward developing small low drag, radar reflective targets by a least two companies one of whose targets has the added feauture of frangibility which should be extremely attractive for training use. A protype of a high speed target was recently constructred here and prelimary tests of it are under way. ~~A~~ Drag of such targets are ~~in the m~~ approximately 50 lbs at 300 knots T.A.S. ~~Height~~ while weight is 20 lbs. or less. Radar reflector area is equivalent to a 3' diameter conventional round reflector. ~~It~~ there are commercially available nylon fishing lines which have adiquate strength to tow these targets. With small cable, reel sizes can be cut to reasonable figures. It is a relatively minor problem to design a reel such that it could be carried under the wing of a fighter in a nacelle which could also partially house the target for takeoff - Probably most practical of all would be a ~~system~~ target and small reel which could be attached to a conventional ~~car~~ bomb or tank rack ~~and~~ of a fighter Once airborne the target could be released and after completion of mission both target and cable be detached from aircraft. This is an entirely feasible system even from an economic standpoint since cable and target should cost less than $50. At present a marquisette target ~~costs~~ and reflector costs almost $300. Seven of the smaller targets discarded after every mission would provide much longer time in the air than a single banner. ~~and at~~ These targets would ~~also~~ provide performance performance which banners never can.

If cost of maintenance of a present bomber type tow plane ~~were~~ are compared to ~~a~~ those of fighter using small targets, target price becomes insignificant. Fighter type tow craft would provide ~~squa~~ individual squadron with presently lacking tow facilities. There are many squadrons which if tow facilities were provided could carry ~~out~~ on firing programs rather than ~~endlessly~~ ~~show~~ 'shadow boxing' ~~[illegible]~~ which is ~~the extent~~ what ~~is~~ the present training amounts to.

~~[illegible]~~ The radar optic scoring system described is a presently available ~~at~~ for immediate application to ~~[illegible]~~ scoring of 'E' systems equipped interceptors. New, and presently unique methods are involved but ~~it~~ but this is necessary if we are to close the ten year lag that presently exists in tow target facilities. ~~Even though this system is at presently~~ ~~the importance of a satisfacto~~