TELEVISION EQUIPMENT FOR GUIDED MISSILES

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Abstract.—Experiments with airborne television at Wright Field during 1941 showed some obvious defects such as inability to stand vigorous service conditions, limited number of carrier frequencies, and non-uniformity between units. From these limitations a 300-megacycle system was evolved that overcame the previous disadvantages. By judicious design compromises, size and weight were reduced to a minimum.

The camera or conversion unit was developed from the circuit of the 100-megacycle equipment by the addition of numerous refinements which resulted in acceptable operation. Considerable effort was necessary in order to reduce "cross-talk" and interlocking controls. The 300-megacycle transmitter utilizes a master oscillator and grounded-grid power amplifier. The amplifier plate circuit is modulated with synchronizing pulses and the grid with video and blanking. The receiver has a unique AVC system which was developed to eliminate the effects of airborne operation.

Actual tests in glide bombs showed up numerous faults and it became necessary to make a considerable number of changes in order to achieve good performance. Experimental operations over Europe are described. Numerous photographs were taken to illustrate the performance of the equipment.

I. INTRODUCTION

A new method of warfare; for offense, for defense, is upon us. We are fast realizing that the guided missile will be the means of waging the war of the future. The Army Air Forces early recognized these possibilities and established the foundation for a program of development for this arm. As a part of the endeavor, a television development project was initiated in order to exploit this field.

In searching for a smaller and lighter weight aircraft television transmitting system, new standards had to be established. Broadcast standards were used, where possible, but the following were finally adopted for military system.

1. Forty frames per second, 350 lines per frame, sequential scanning.
2. Video bandwidth of 4.5 megacycles per second.
3. Vertical polarization of radiated signal.
4. No d-c transmission.
5. Omission of equalizing pulses and of serration of vertical synchronizing pulse.
6. Synchronizing signal equal to approximately 35% of carrier.
7. Double-sideband transmission.
8. Wider than RMA standard vertical and horizontal blanking and synchronizing pulses.

The type 1846 iconoscope (similar to 1848) was utilized as the pickup tube since it was more fully developed for immediate application.

The military standards were chosen after consideration was given to the size, weight, power demand, circuit complexity, resolution, and linearity interrelationships. [*,1-10]

II. DEVELOPMENT OF 100-MEGACYCLE EQUIPMENT

In the design of the first small television system, known as SCR-549-T1, the previously stated characteristics were embodied. The total weight of the transmitting equipment, refer to Fig. 1, (power output 15 watts at 100 megacycles) installed in an airplane was approximately 60 pounds. This was less monitor unit and 14-volt 7-cell storage battery which weighed 20 and 37 pounds, respectively. The battery supplied 32 amperes at 13 volts.

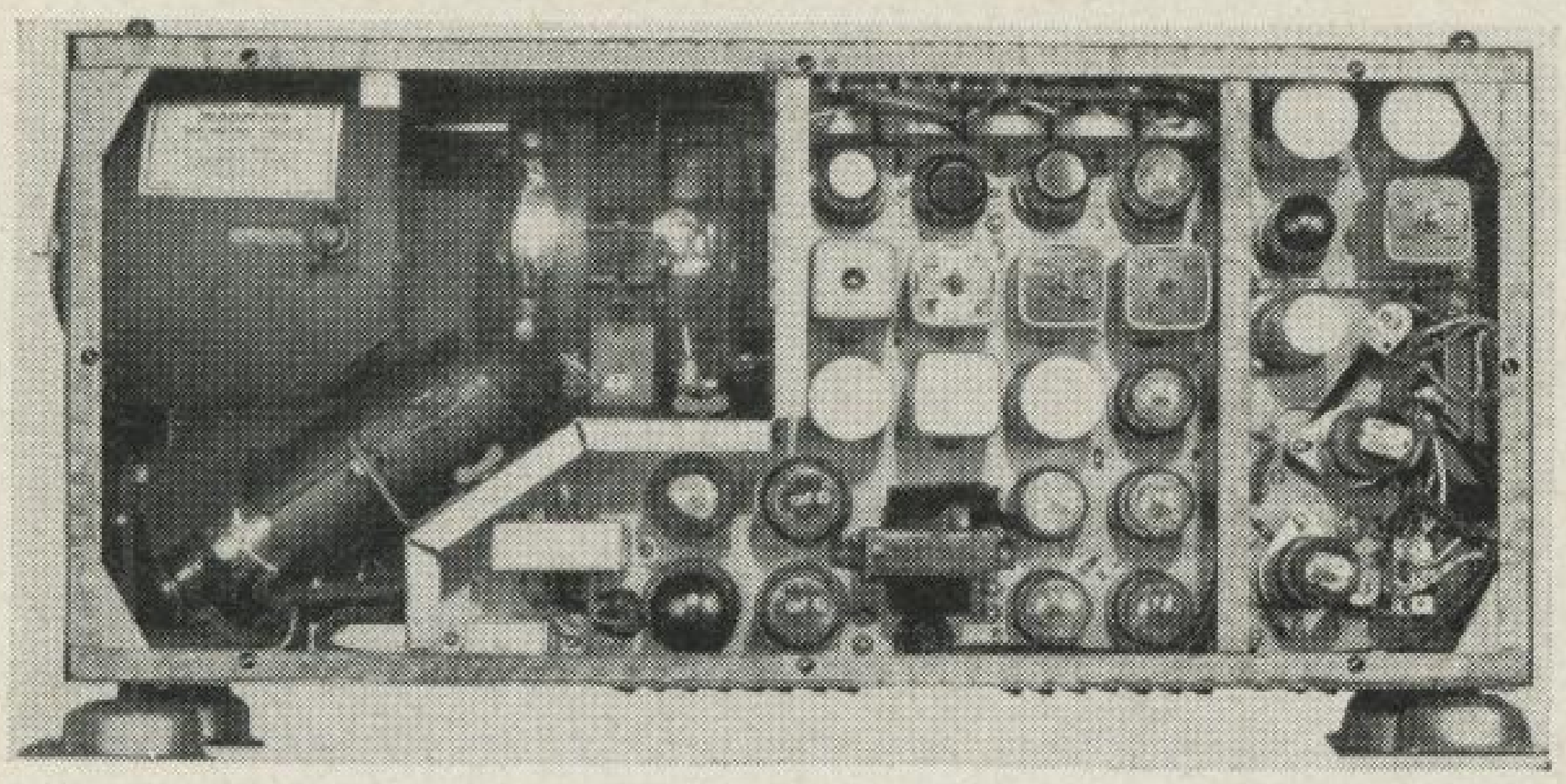

Fig. 1—Interior view of camera-transmitter of SCR-549-T2. All tubes except first video amplifier, high voltage rectifier and final amplifier are shown.

Simplifications which were applied to the design of the camera-transmitter unit could not be applied in general, to the receiver, SCR-550-T1, since the maximum possible sensitivity was needed in order to complement the relatively low transmitter power output. By judicious disposition of components it was possible to build a complete receiver, including the dynamotor power supply, into one case as illustrated in Fig. 2. For adjusting the performance of the camera-transmitter and for providing an additional picture at the receiving point a monitor unit, as shown in Fig. 2, was designed.

Although most of the receiver design is in accordance with accepted practice, the AVC system deserves special mention in that the AVC rectifier and amplifier operate on the video, rather than on the i-f voltage. Thus, compensation is made for the variation in light level and percentage modulation of the transmitter. Another important feature of the AVC system is its low time constant. In airplane to airplane transmissions the field strength at the receiver fluctuates widely from zero to a maximum at a

*See end of article for numbered references.

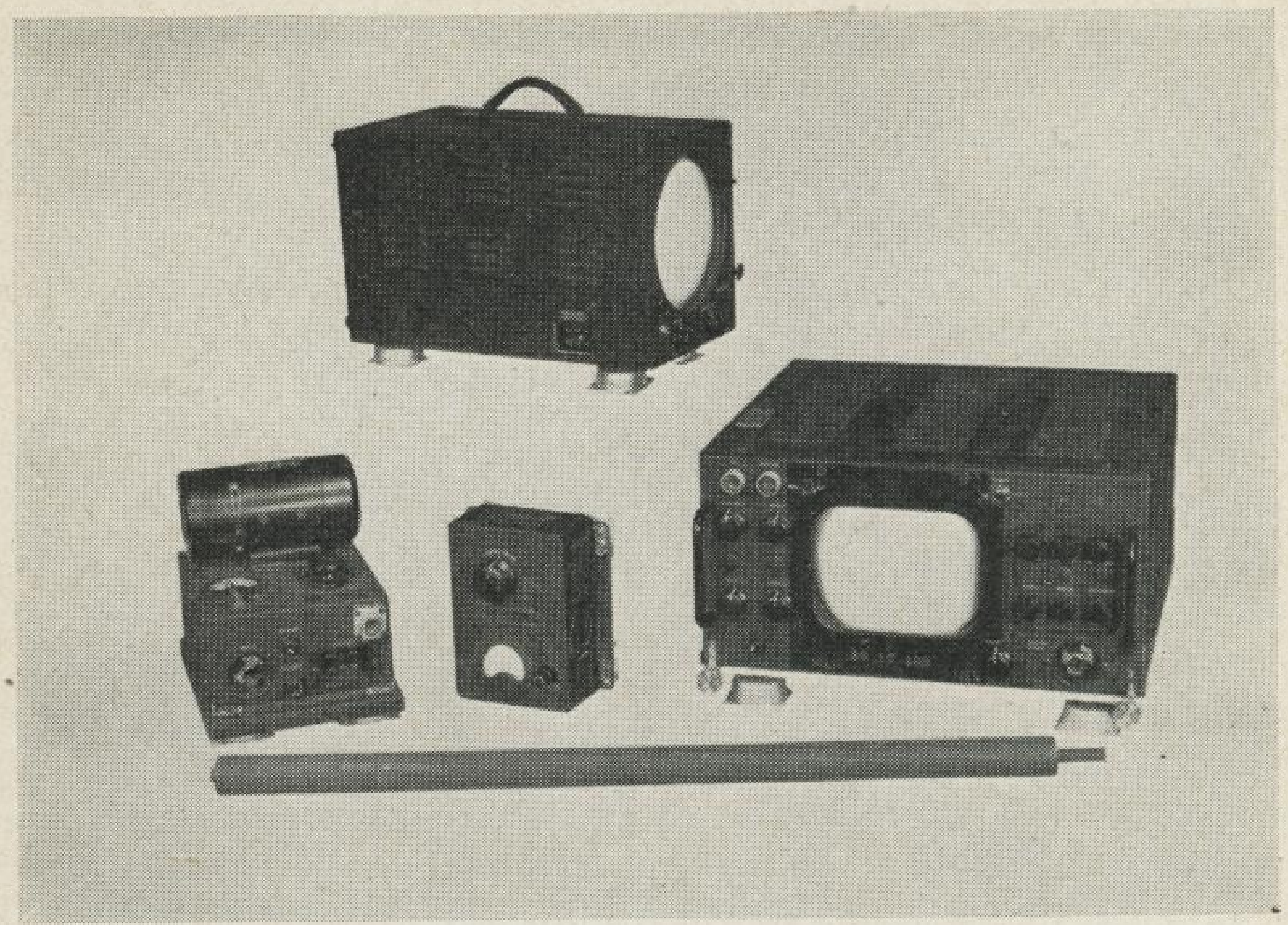

FIG. 2—Receiving equipment SCR-550-T2. Top row: Receiver monitor. Bottom row: Monitor power supply, receiver voltage control box, receiver, and 100 mc "bazzooka" just below.

rather rapid and unpredictable rate. The AVC must be capable of following these variations. The receiver weighed 40 pounds and required 9 amperes at 25 volts.

As a result of flight tests with the 100-megacycle equipment, it was demonstrated that light-weight television equipment was feasible for use in guided missiles. These sets, however, had a number of inherent limitations which made their use as a military equipment undesirable and it became necessary to formulate new specifications as to performance and operation.

The performance limitations which ruled out further use of the 100-megacycle equipment in guided missiles can be summarized as follows:

1. Change in input voltage requirements from 12.5 to 28 volts d-c.
2. Necessity for simultaneous operation of several television channels.
3. Desirability to separate the camera and transmitter into two units.
4. Necessity for the use of smaller antennas.
5. Necessity for the equipment to operate at low temperatures and high altitudes.

If success is to be achieved in the design of equipment for expendable missiles, the philosophy of low cost has to be disregarded entirely. While missiles have no recoverable material, they must be extremely reliable.

Since the cost of the television transmitting equipment (approximately $2000.) represents only a small portion of the cost of the entire missile, especially in the case of "war weary" aircraft, savings are not justified if they result in unsuccessful missions. Therefore it was emphasized that, although the equipment was expendable, design and production had to be according to standard Signal Corps requirements which represented, closely, actual conditions that would be encountered in military use of airborne radio equipment.

III. DEVELOPMENT OF 300-MEGACYCLE EQUIPMENT

The new 300-megacycle equipment, which was to incorporate all the aforementioned features and would avoid the limitations of the 100-megacycle equipment, became known as SCR-549-T3 and SCR-550-T3. In addition, a number of improvements were included which had been found to be of importance during field tests with the 100-megacycle equipment. For instance, experiments had shown that plate modulation of the synchronizing signals was superior to grid modulation as it prevented "clipping" of synchronization under conditions of high contrast which caused a shift in the operating point of the grid.

The operation of the 300-megacycle television sets is essentially similar to that of the 100-megacycle equipment, but differs as to details. In the case of the transmitting equipment (see Fig. 3) it can be seen that the camera-transmitter unit has been separated into two units and because of

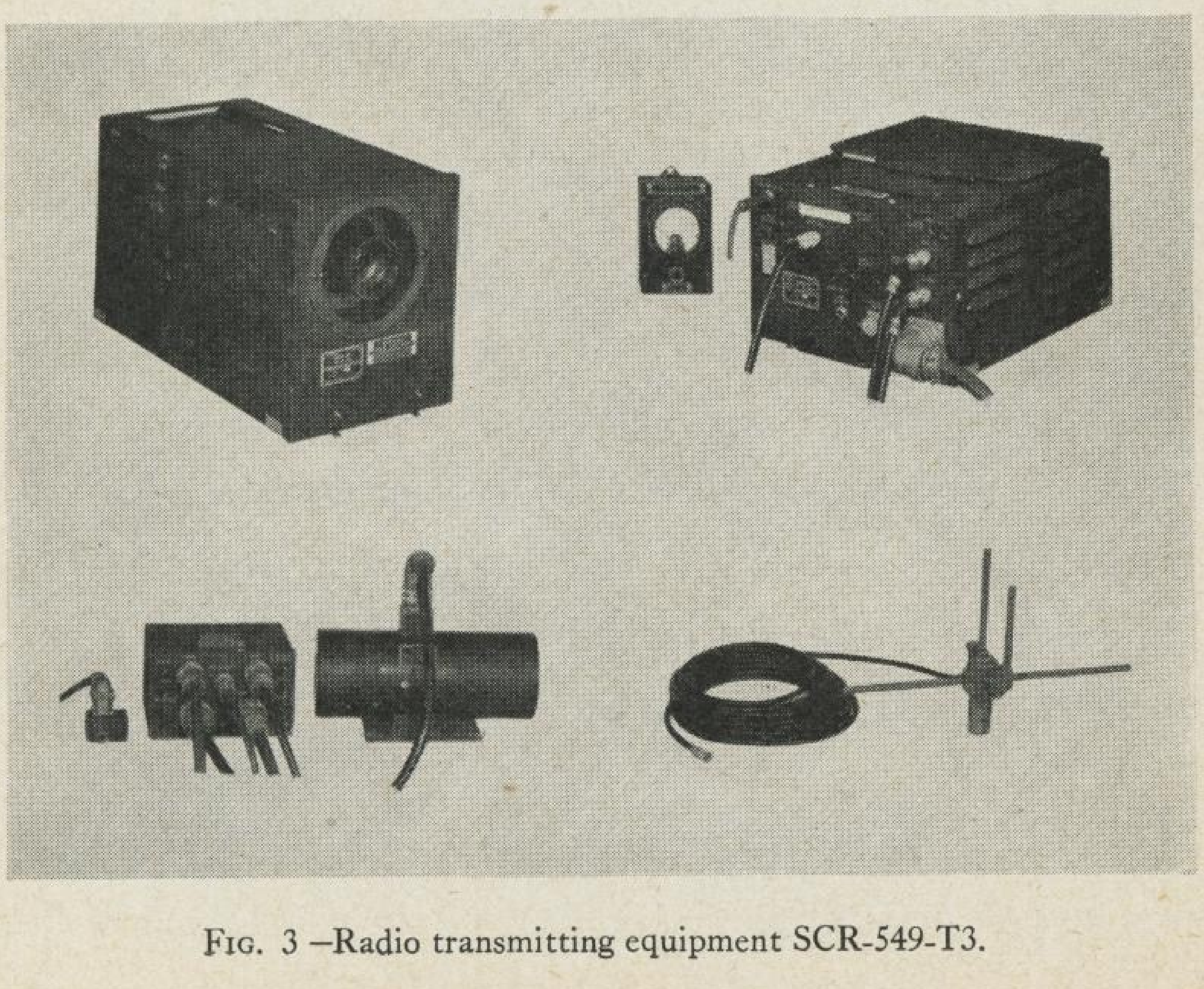

FIG. 3 –Radio transmitting equipment SCR-549-T3.

this its weight was increased to 90 pounds. Video and synchronization have been separated and modulate the grid and plate, respectively, of the power amplifier. In the camera, synchronizing amplifiers and mixers have been added to standardize these signals for operation of either the transmitter or the monitor. Because of the lower efficiency of 300-megacycle operation the input power was raised to 29 amperes at 26 volts.

Experience with the camera of early units indicated that more care would be required in the design of the video amplifier with regard to low-frequency microphonics. A leveler of "clamping" circuit was devised such that low frequencies, eliminated by the use of small coupling capacitors in the video amplifiers are in effect reinserted by the last video stage prior to the addition of the black level and blanking.

In the camera section of the 100-megacycle equipment, a particularly troublesome effect was the formation of a horizontal bright bar across the top edge of the received picture. The cause was finally determined as an undesired pulse which was produced by the vertical blanking pulse in cutting off the iconoscope beam. This was corrected by introducing a vertical pulse of opposite polarity for the purpose of neutralizing the unwanted effect. This compensating "flare blanking" pulse restored proper vertical blanking but produced a slightly wider interval than was desired.

The new transmitter was designed to cover a range of from 260-320 megacycles. This wide frequency range with one set of tuning elements necessitated the use of variable tuned lines (see Fig. 4).

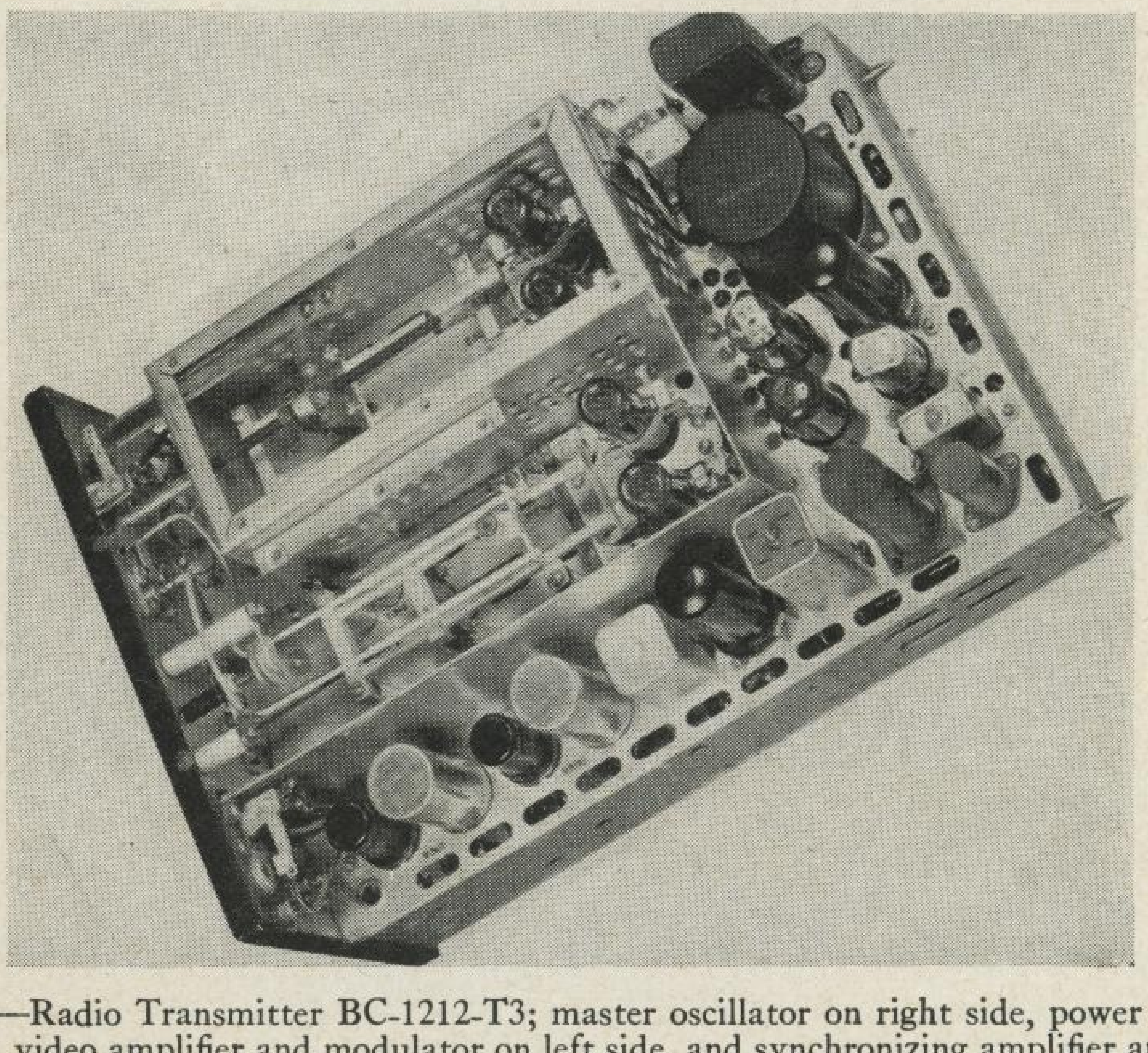

FIG. 4—Radio Transmitter BC-1212-T3; master oscillator on right side, power amplifier in center, video amplifier and modulator on left side, and synchronizing amplifier and modulator on the bottom.

The last versions of the 100-megacycle receivers operated so successfully that it was necessary to make but a few significant electrical changes in order to achieve the 300-megacycle design (see Fig. 5). The converter

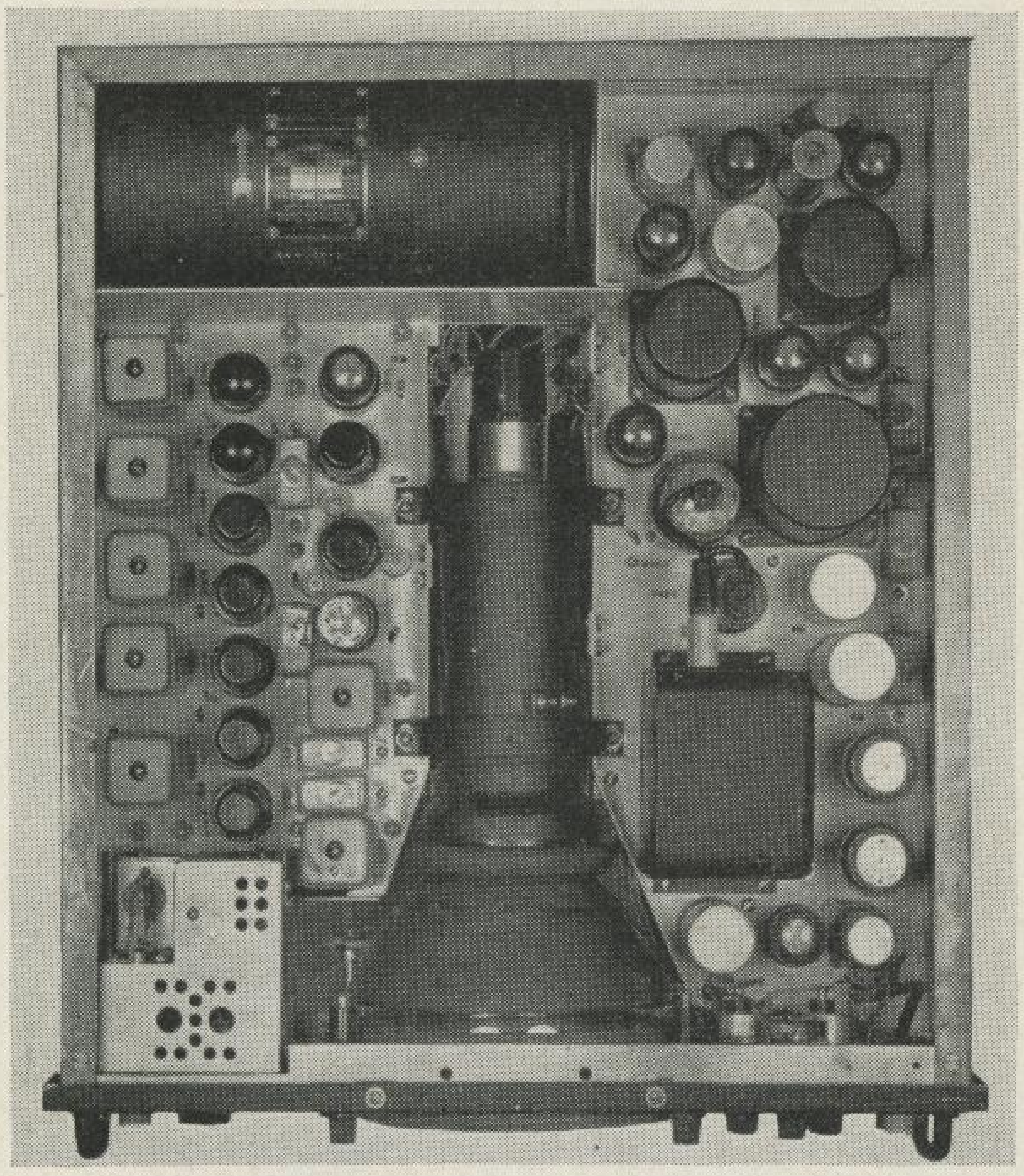

Fig. 5—Radio receiver BC-1213-T3; top view showing converter, i-f amplifier, and video amplifier on left side. Deflection and high voltage circuits are on the right side.

section, of course, was a completely new design. As in the transmitter it was found to be expedient to utilize tuned lines as the tuning elements of the r-f circuits in the receiver.

The monitor unit, as shown in Fig. 6, is of the direct-driven (slave sweep) type. It can be used either for observing the output of the camera or for providing an additional picture at the receiving location when it is driven from the output of the receiver.

After a number of flight tests had been performed with this equipment, it was found that a combination of FM and multipath transmission of the transmitted signal caused a great amount of interference in the receiver. Because no buffer stage was used between the master oscillator and the power amplifier, the latter would react on the oscillator and produce a frequency deviation of as much as 200 kc in early models.

The combination of multipath transmission and FM results in the simultaneous reception of two different frequencies in the receiver. This effect has been utilized to advantage in the FM radio altimeter, but is un-

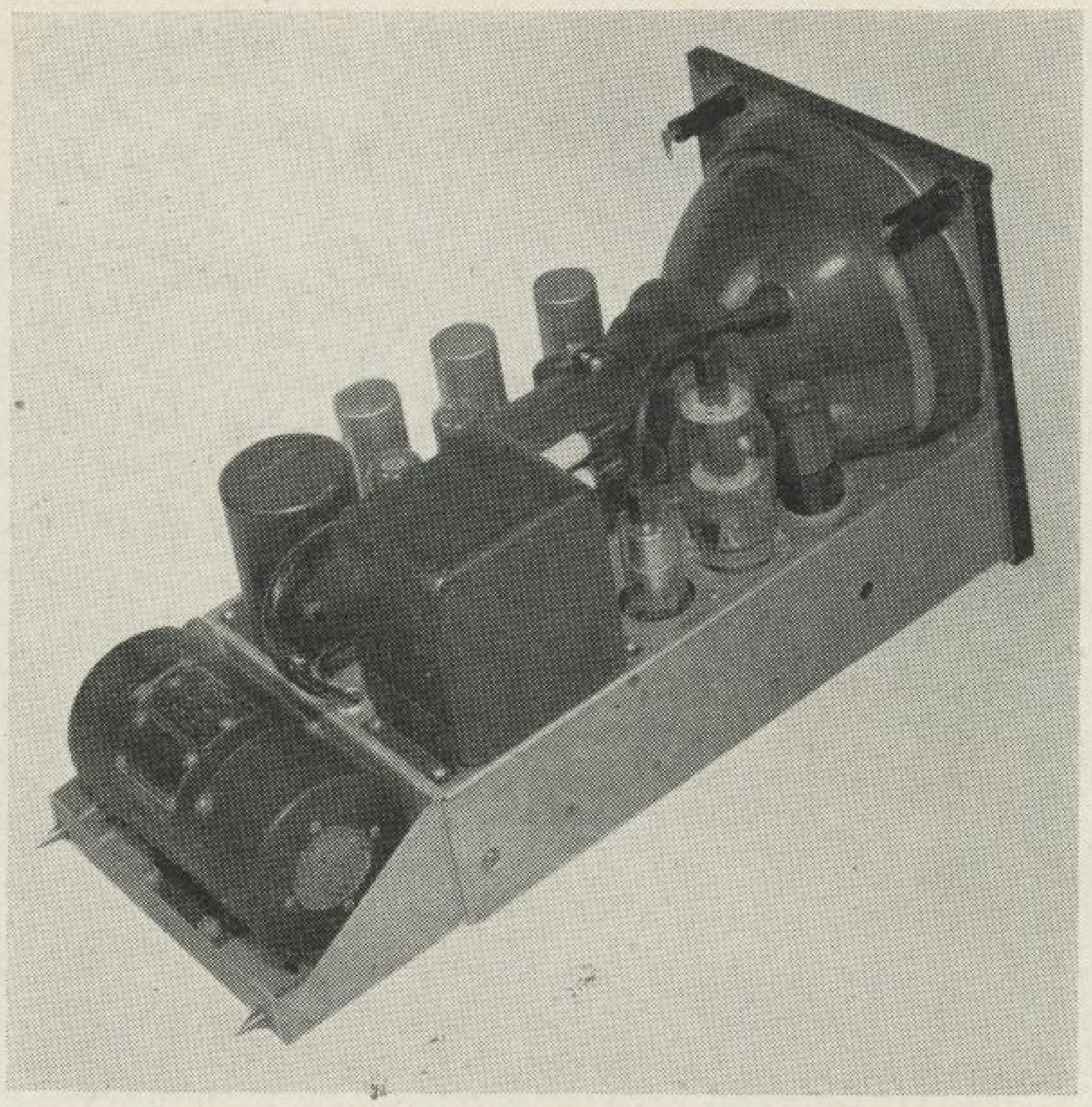

FIG. 6—Monitor unit BC-1214-T3.

desired in the transmission of television pictures. The resulting beat note due to the difference in the frequencies of the direct and reflected signals will be within the video band accepted by the receiver. A reduction in FM was made by changing the tuning procedure of the transmitter, and by reducing the load on the master oscillator. As a result, the power output was somewhat reduced, but this did not materially affect the tactical range of the equipment.

Difficulties were also experienced with the electrical noise caused by the ignition system of the airplane engines in the airplane which carried the receiver. The receiver is very sensitive and ignition interference will manifest itself as small white dots closely resembling a snowstorm in the picture. Improvements in the design of aircraft ignition system corrected this fault.

IV. PERFORMANCE TESTS

The 100-megacycle equipment was delivered early in 1942 and flight test work began immediately at Wright Field. The transmitting equipment was installed in a small PQ-8 target airplane while the receiving equipment was installed in a B-23 airplane (see Fig. 7). These flight tests demonstrated that airborne television was practical, but certain difficulties were found to exist which made redesign of the equipment necessary.

Upon close examination of Fig. 8, it will be apparent that the television camera must look through the propeller disc. The light reducing effect,

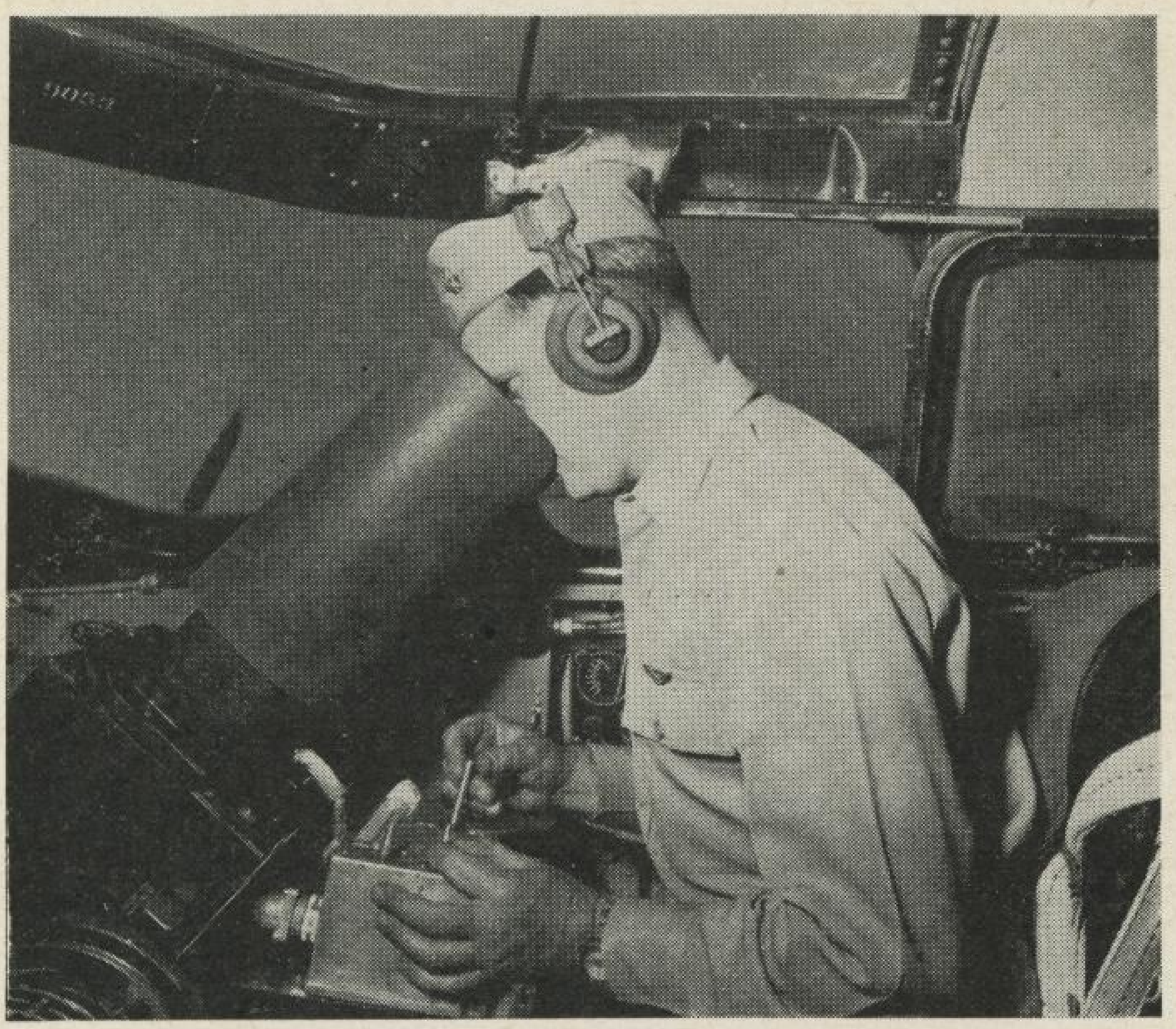

FIG. 7—Remote control pilot's installation in B-23 airplane.

caused by this fact, comes in the form of pulses, one pulse per blade. For typical small engines, the frequency generated is approximately 80 pulses per second or two bars per frame and can cause serious disturbances in the camera operation.

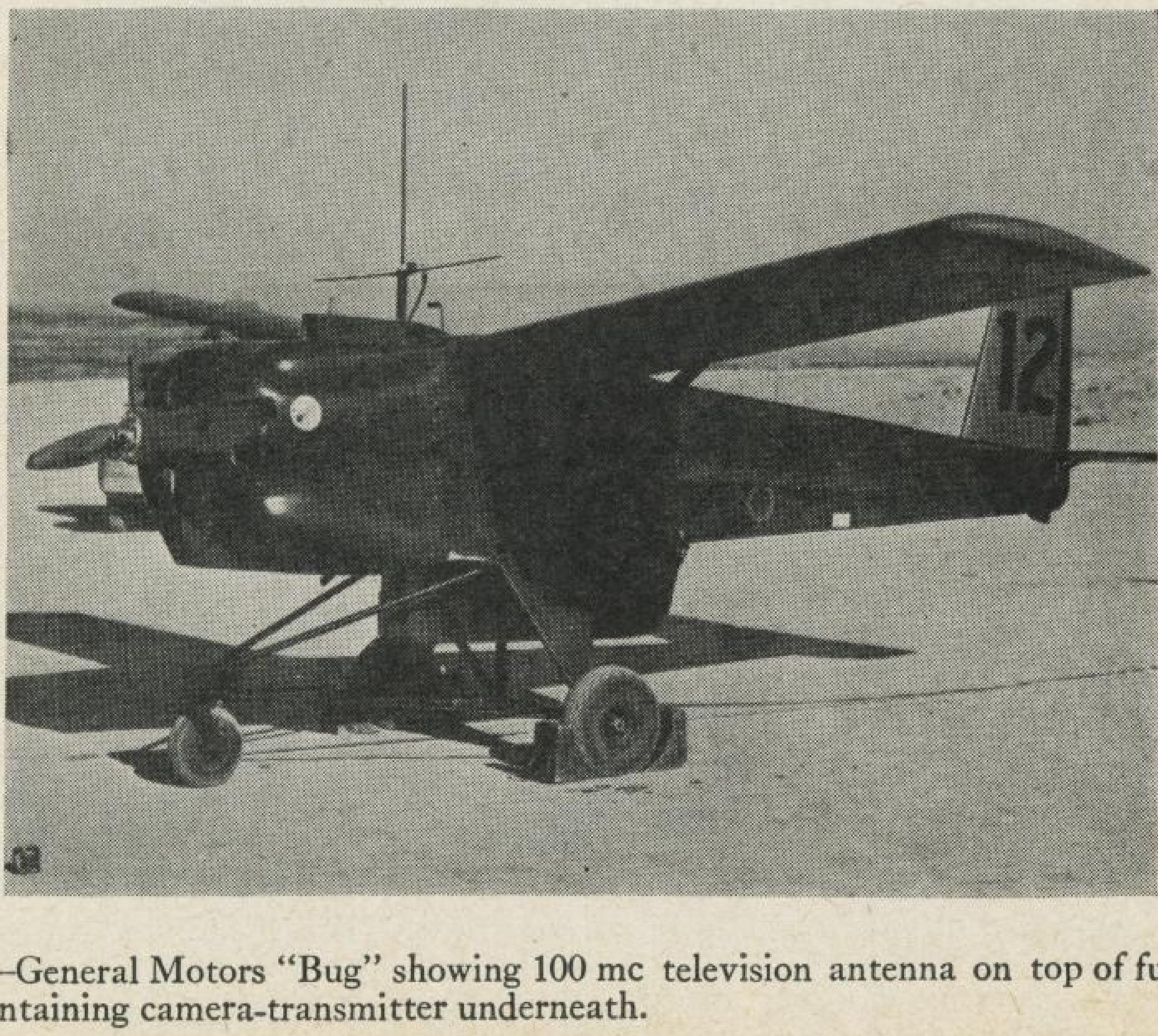

FIG. 8—General Motors "Bug" showing 100 mc television antenna on top of fuselage and nacelle containing camera-transmitter underneath.

Since there were no plans for the use of small single-engined aircraft as guided missiles, little effort was concentrated in finding an exact solution to this problem. A fair answer was found by reducing the low-frequency response of the camera video amplifier such that the attenuation of the low frequencies extended to about 8000 cycles per second.

During the month of May 1943, tests were made at Muroc Lake, California, using the General Motors "Bug" as a guided missile (see Fig. 8). In this particular installation the 100-megacycle television camera-transmitter unit was suspended beneath the fuselage of the "Bug", housed in a streamlined nacelle, while the antenna was mounted on top of the "Bug." The radio and flight-servo equipment were mounted inside the fuselage. After a number of tests had been made with this combination, the "Bug" was finally dived into a target by radio control using television as a means of guidance (see Fig. 9).

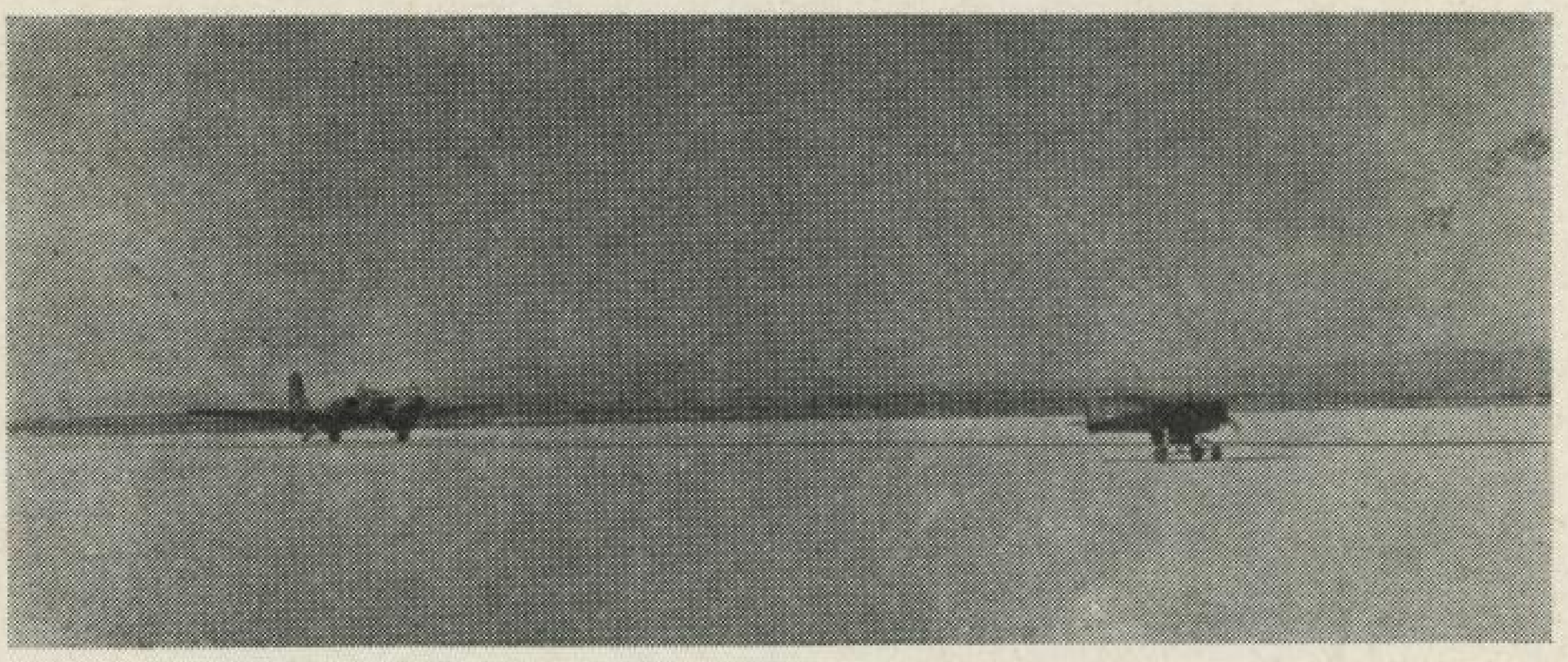

FIG. 9—General Motors "Bug" being taxied by radio control from B-23 airplane at Muroc Lake, California.

During August 1943, it became apparent that all of the units of the power driven bomb; that is, aircraft, power plant, flight-servo, radio control, and television equipment, had been sufficiently developed to warrant a demonstration before interested military officials. Therefore, an expedition was dispatched to Muroc Lake, California for the purpose of testing the military possibilities of these missiles. In this case, SCR-549-T2 transmitting equipments were installed in YPQ-12-A airplanes to be used as power driven bombs. The YPQ-12-A airplane (see Fig. 10) was of the single engine type but it was possible to mount the television camera so that its line of vision would be outside the propeller arc.

For the final or bomb run, a 500 pound bomb was placed in the safety-pilot's cockpit. During tests, the television picture was adequate so that complete control over the missile could be maintained at all times (see Fig. 11). For its final run, the missile was controlled directly behind a pilotless radio-controlled airplane and then exploded by means of signals over the radio control equipment.

During June 1943 a small number of GB-4 Glide Bombs became available and enabled the performance testing of the 300-megacycle equipment.

FIG. 10—YPQ-12A target airplane showing nacelle for camera-transmitter under right wing. In bomb position a 500 pound bomb is placed in pilot's cockpit.

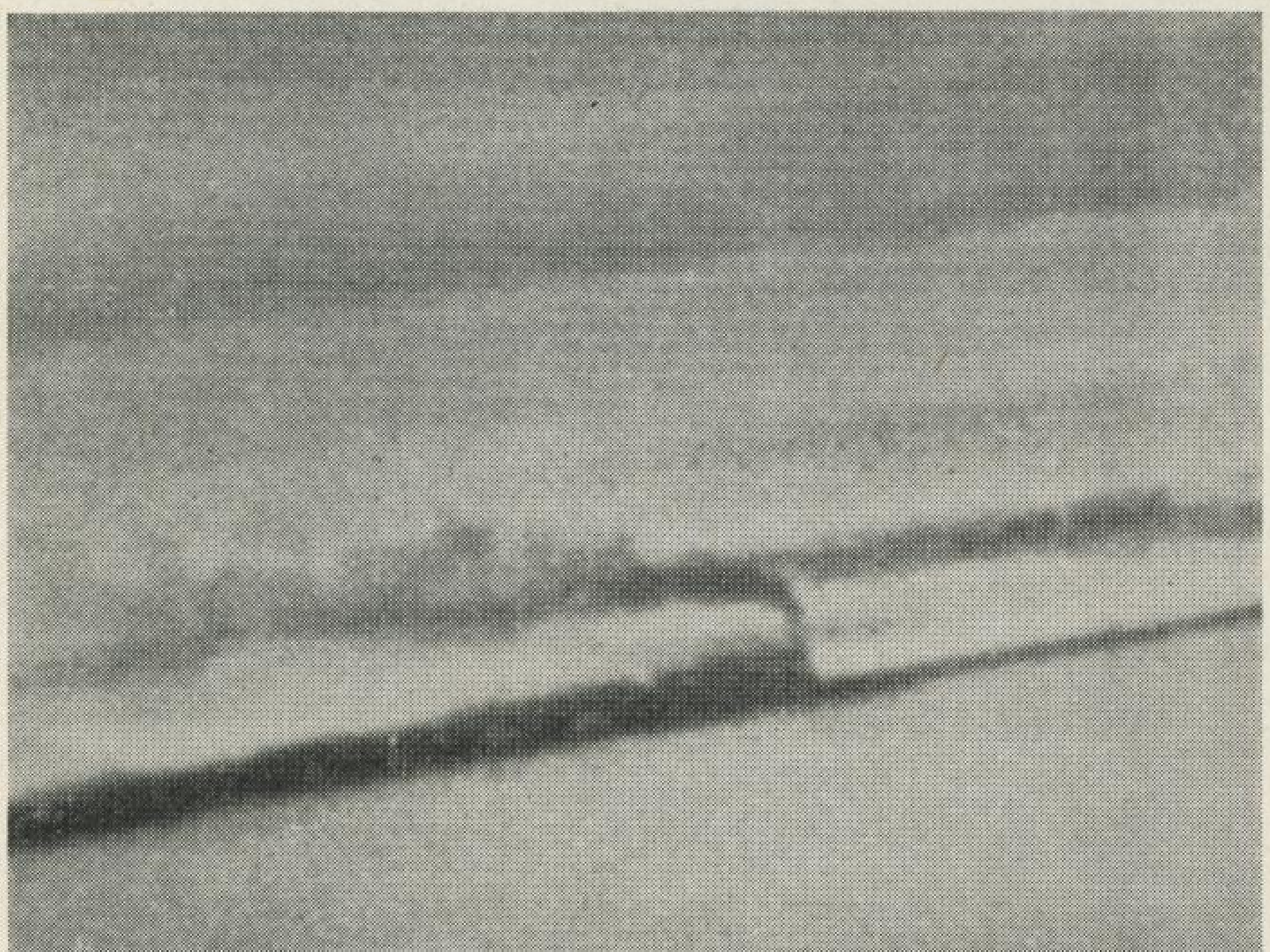

FIG. 11—Moving train as seen on television screen at Muroc Lake, California. Camera was located in YPQ-12A airplane making simulated attack.

The GB-4 Glide Bomb (see Fig. 12) consisted of a standard 2000 pound bomb to which an airframe had been fitted. The flight-servo equipment, radio control equipment, and television transmitting equipment were housed in the body of the airframe, while the camera was housed in a streamlined nacelle underneath the bomb.

After the first flight tests indicated that the installation and operation of the equipment was satisfactory, it was decided to drop a number of GB-4 Glide Bombs to determine the practicability of hitting a small target with this missile. Very unsatisfactory television pictures were received from the first 5 glide bombs dropped during August, 1943 at Eglin Field, Florida. After an analysis of the motion pictures taken of the television receiver screen, it was found that the following interference effects were present:

1. Fine horizontal lines in the picture, produced by acoustic pickup in the camera (3000-4000 cps). This high noise was generated apparently by wind rushing past the GB-4 Glide Bomb and a solution was found by placing the camera in a sound-proofed box.

2. Heavy horizontal bars in the picture, produced by acoustic pickup in the transmitter 120-200 cps, apparently generated by the plywood body of the airframe. A solution was found by soundproofing the inside of the airframe.

3. Heavy streaking through the picture caused by loose bonding. After all metal parts in the airframe had been bonded, no further trouble was experienced.

4. Change in picture shading caused by the influence of the earth's magnetic field on the iconoscope. The difficulty was overcome by installation of a magnetic shield around the entire iconoscope.

5. "Blooming" of the top half of the picture and loss of video information caused by iconoscope saturation. It was found that a yellow

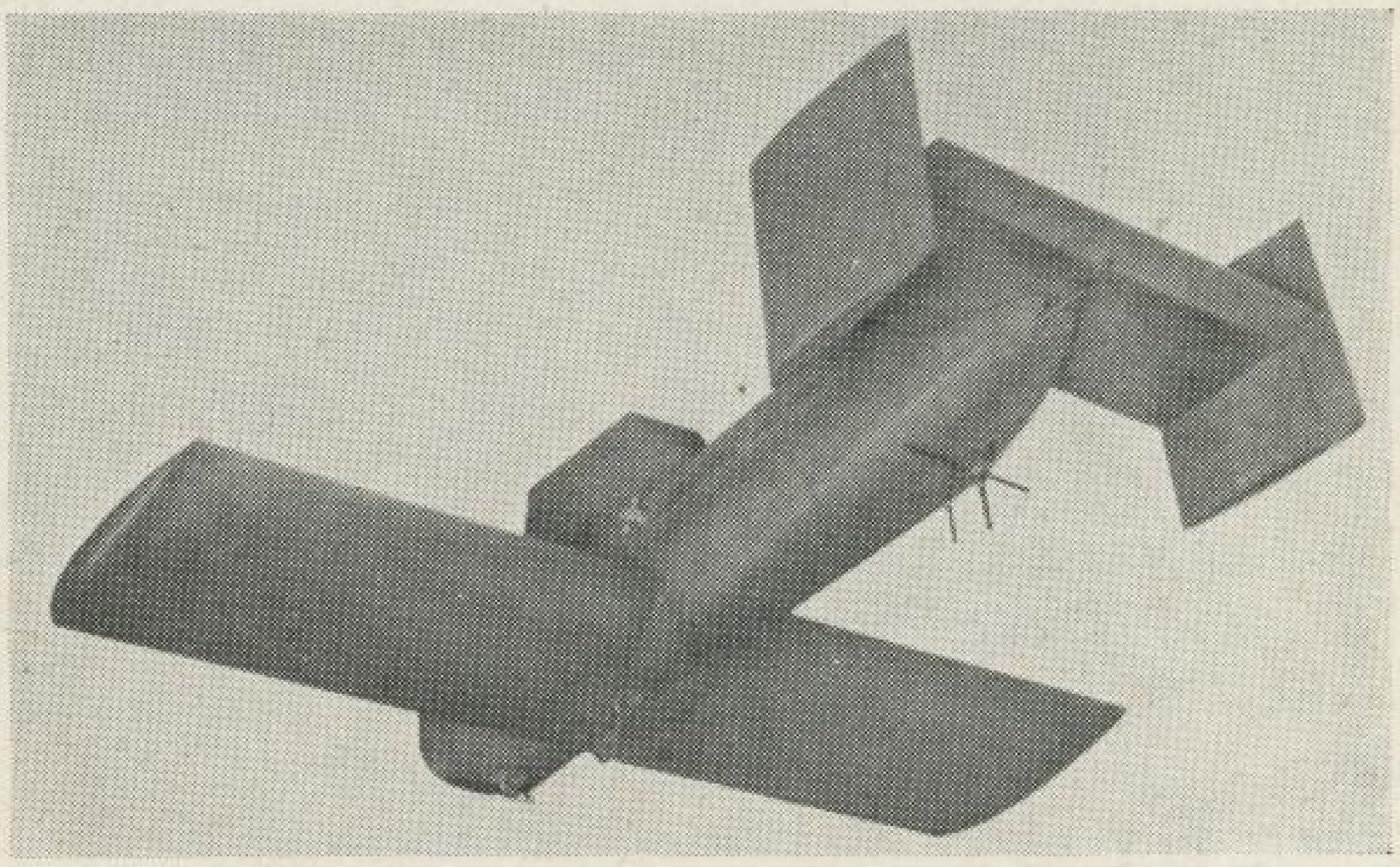

Fig. 12—Top view of GB-4 glide bomb. Television antenna is just ahead of horizontal stabilizer.

filter in front of the camera lens was the most effective solution, especially under conditions of high light levels and low contrast caused by haze. [11,12]

6. Loss of synchronization and streaking caused by r-f feedback in the cables going from the camera to the transmitter. Installation of a few bypass condensers solved the trouble.

7. Interference from the radio control system. The radio control system then in use, operated between 80-90 mc, the third harmonic of which would sometimes interfere with television reception. The difficulty was overcome by proper selection of r-f channels.

8. CW interference manifesting itself in a fine herringbone pattern obscured the picture similar to interference produced by diathermy machines. This disturbance was caused by other transmitting equipment in the control airplane. A solution was found by improved bonding of the receiver antenna cable.

During the investigation of microphonics it was found that certain iconoscopes had stronger microphonic tendencies than others and, therefore, standards were set up with the aid of an acoustic noise box in which iconoscopes were subjected to noise levels similar to those encountered in actual practice. Iconoscopes could be used if they passed this noise test. Troubles were also experienced, for the first time, with lens fogging and, consequently, optical heaters were installed in all cameras.

By this time, the tactics of guided missiles became more important and it was realized that in order to make full use of the equipment; the range, which was 12 to 20 miles at that time, would have to be increased. The combination of a directional antenna in the receiving airplane coupled to a gyros-tabilized antenna mount extended the range of the equipment to from 50 to 80 miles.

After all these difficulties had been eliminated, satisfactory television pictures were received from the GB-4 and the television equipment was considered ready for tactical operations (see Figs. 13 and 14).

A glide bomb operating group was ordered to England during June, 1944. Shortly afterwards, a "Castor" group was sent to the same location.

"Castor" was the code word for the use of "war-weary" heavy bombers as guided missiles. The aircraft were to be loaded with explosives and guided into targets by means of radio control and television. The television camera was located in the nose of the aircraft, while the transmitter, power supply and antenna were mounted in the tail. The equipment used was identical to that used in the glide bombs, except that power was derived from the airplane electrical system and a selsyn compass indicator was added to the camera. This compass projected a course reading directly on a small part of the iconoscope mosaic in the upper right hand corner.

Although difficulties were experienced in the beginning with reflections of a new variety due to the increased altitude of operation, this trouble

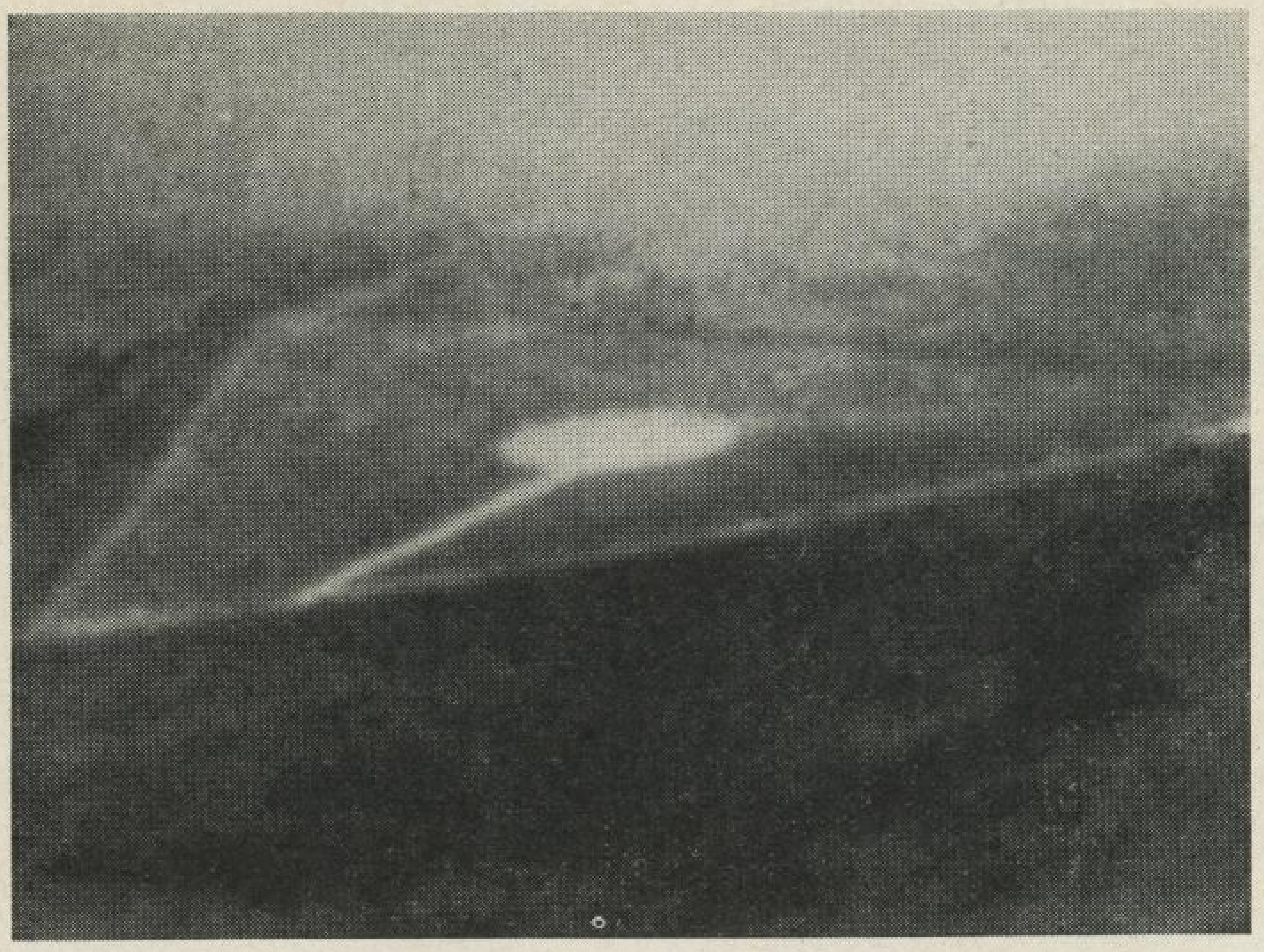

FIG. 13—Target area at Eglin Field, Florida, as seen on the television receiver screen Pyramidal target is in the center of the circular area.

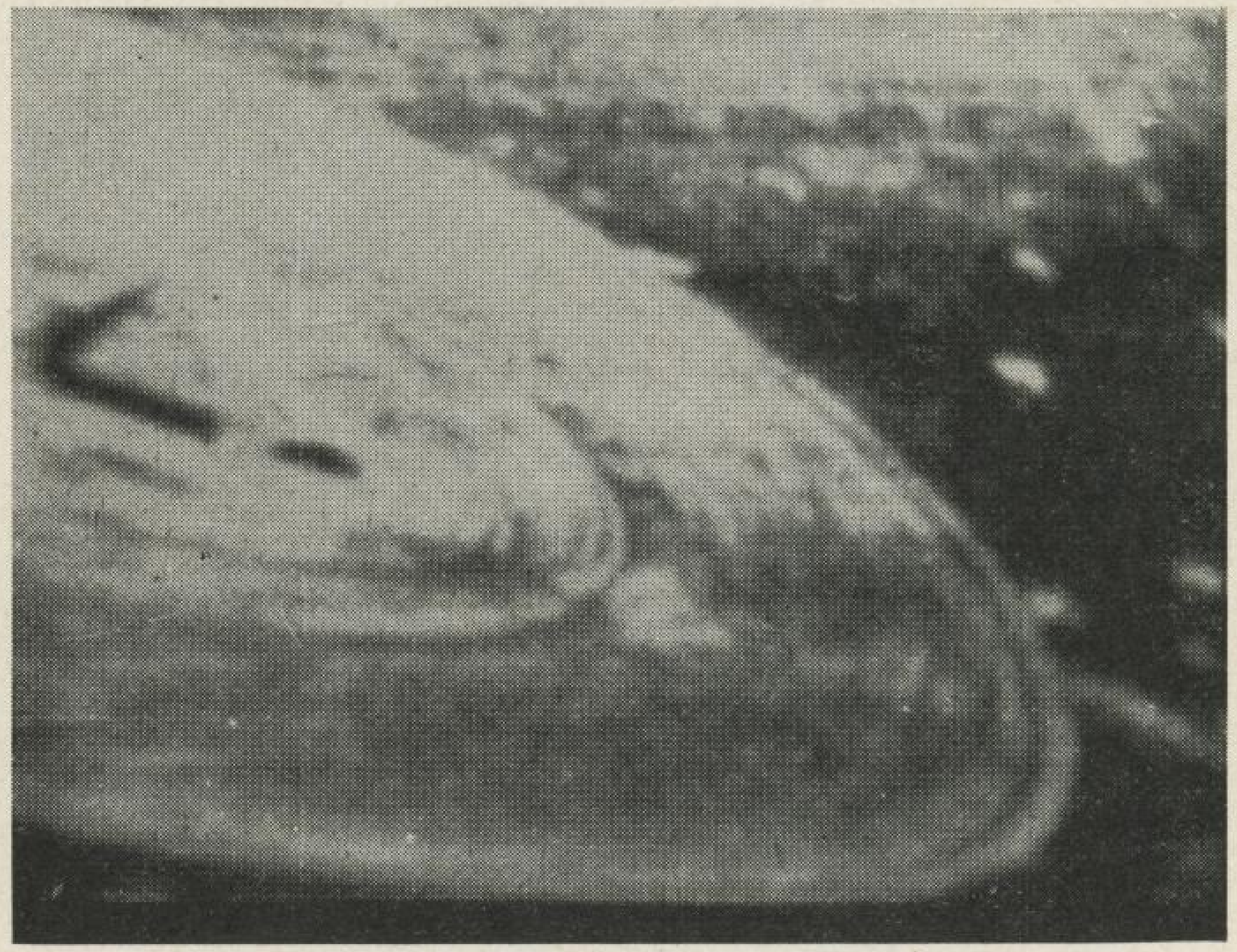

FIG. 14—Television picture received from GB-4 glide bomb turning into pyramidal target at Eglin Field, Florida.

was overcome and good pictures, free from all interference effects, were observed during the later raids employing GB-4 glide bombs and "war-weary" missiles (see Fig. 15).

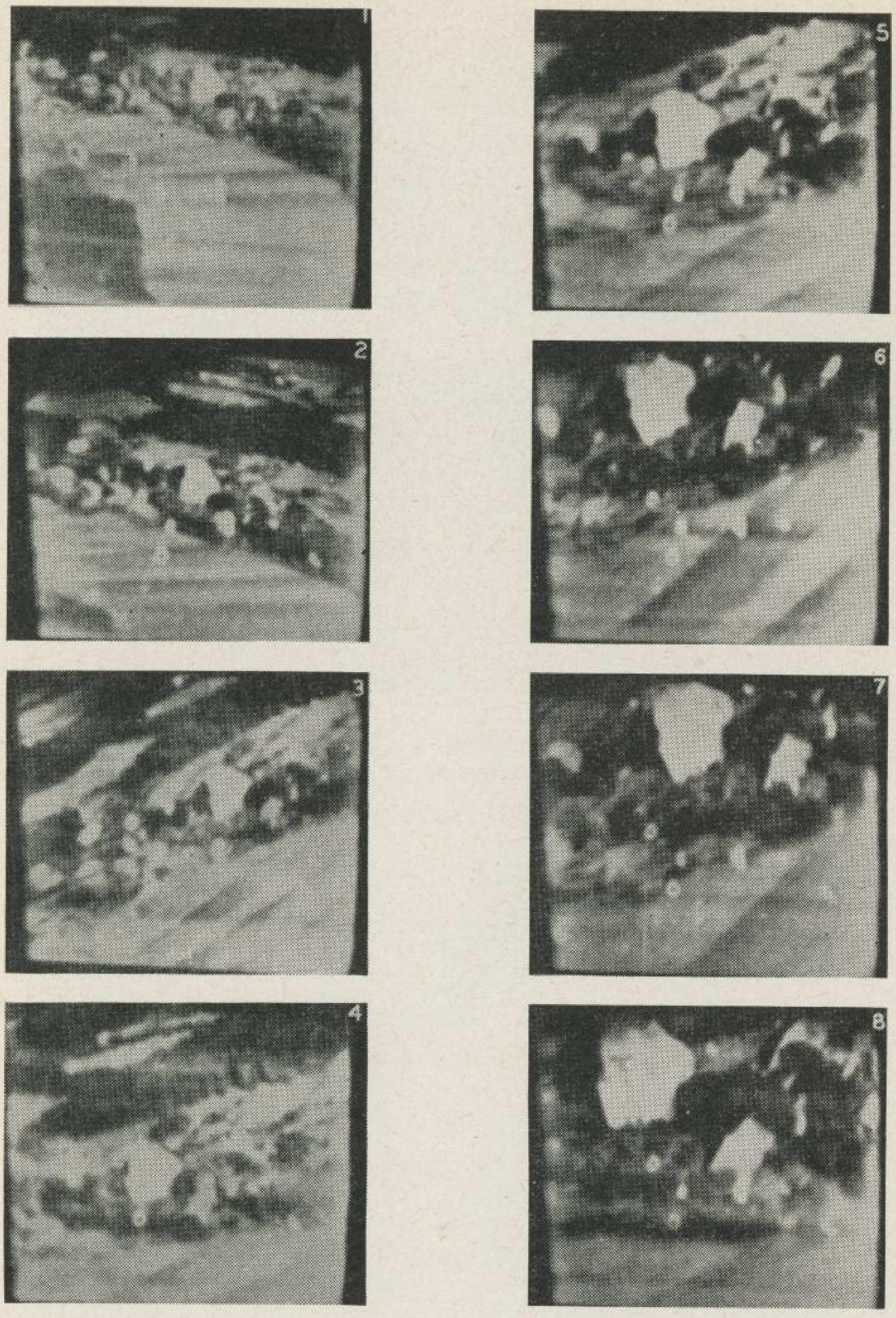

FIG. 15—A series of frames taken from motion picture film showing glide bomb approaching target in Germany.

V. CONCLUSIONS

In conclusion it may be said that airplane to airplane transmissions of television pictures are feasible. Many difficulties may still be encountered but, in general, successful transmission may be accomplished if the following precautions are observed:

1. Transmitting equipment must be protected from interference produced by acoustical noises encountered in aircraft.
2. A stable master oscillator has to be used in the transmitter, preferably followed by a buffer stage, in order to keep the frequency deviation due to frequency modulation less than the picture line frequency.

3. The ratio of direct to reflected signal strength in the receiving airplane must be kept as high as possible.
4. The contrast of the viewed scene must be high and possible targets should be chosen for their proximity to prominent landmarks so that they can be located easily. Compact light-weight television equipment can be used in guided missiles and clear pictures, free from all interference, can be obtained if the aforementioned points are heeded.[13]

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No small amount of assistance was provided by the National Defense Research Committee in the sponsorship of research endeavor which has resulted directly in the success of this development.

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