SHORAN–A PRECISION BEACON-NAVIGATION SYSTEM

BY G. C. DANIELSON

A typical example of a precision beacon system is the Shoran system, produced (except for the computer, which is omitted from this discussion) by RCA Laboratories under the sponsorship of the Wright Field Radio and Radar Laboratory. Shoran is an *H*-navigational system which uses an AN/APN-3 interrogator-responsor in the aircraft, operating with two AN/CPN-2 beacons on the ground. The navigator in the aircraft determines his position accurately by measuring range only to the two fixed beacons at known locations on the ground. The system is designed for any application requiring precision range measurement, such as aerial mapping. A block diagram of the Shoran system is shown in Fig. 19·13.

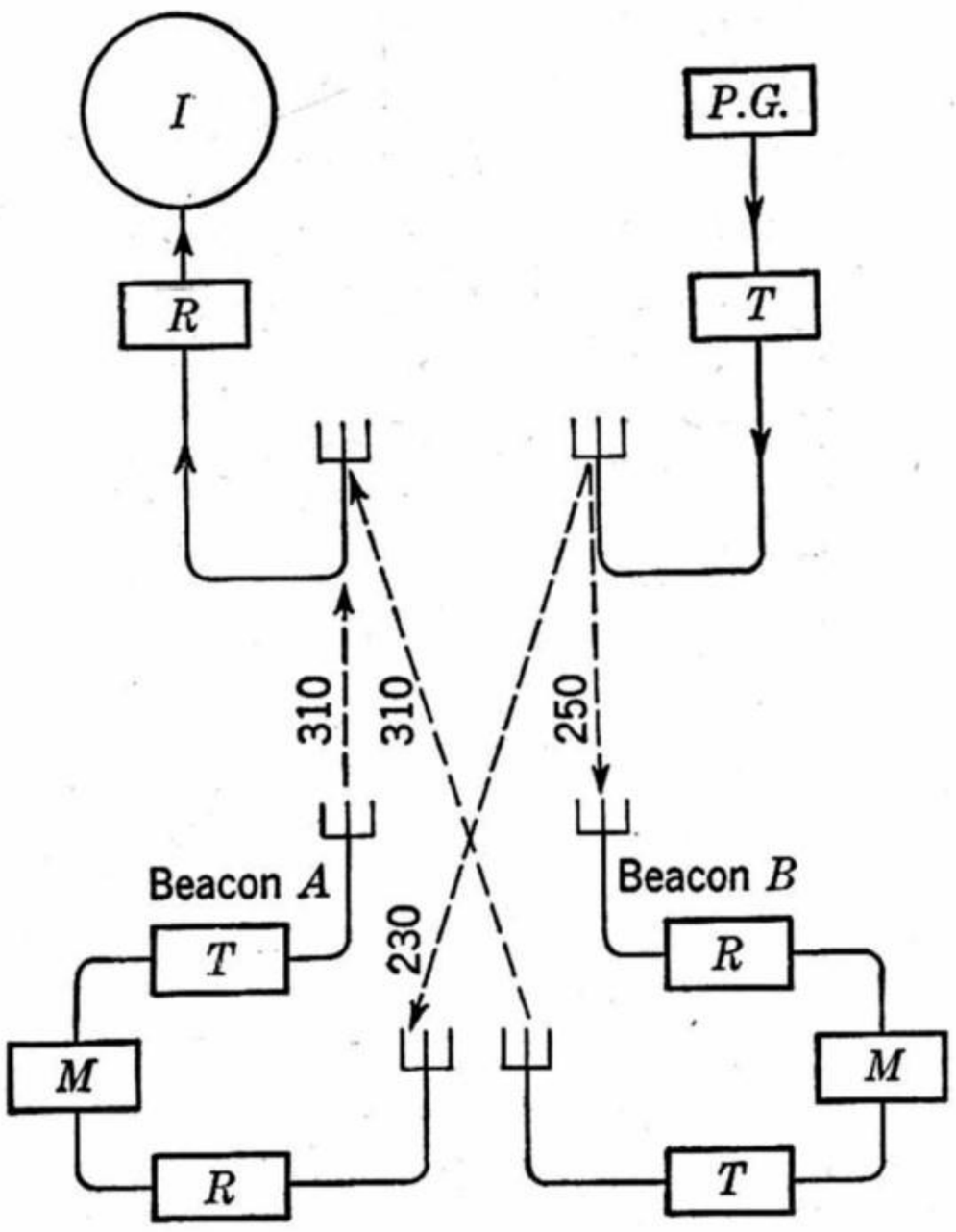

FIG. 19·13.—Block diagram of the Shoran navigational system. Figures refer to frequencies in Mc/sec. *R*—Receiver. *T*—Transmitter. *M*—Modulator. *I*—Indicator. *P.G.*—Pulse generator.

19·14. Interrogator-responsor (AN/APN-3).—The AN/APN-3 is designed solely for operation with ground beacons in an H-type system. It indicates accurately ranges to two beacons and is not required to indicate either radar echoes[1] or beacon azimuth. A photograph of the Shoran airborne equipment is shown in Figs. 19·14 and 19·15. Characteristics of the AN/APN-3 interrogator-responsor are listed below.

General

Wavelength: 1 m

Weight (installed): 205 lb, including cables but not bombing attachments; 280 lb with bombing attachments and inverter power supply

Number of operators: one

Power supply: 459 watts, 27.5 volts d-c; 665 volt-amp, 115 volts, 400 to 2400 cps

Packaging: four units; transmitter, timer-indicator, comparator, two antennas; bombing attachments include computer, comparator, and two PDI (pilot direction indicators)

[1] Ground echoes are sometimes used for altitude measurement.

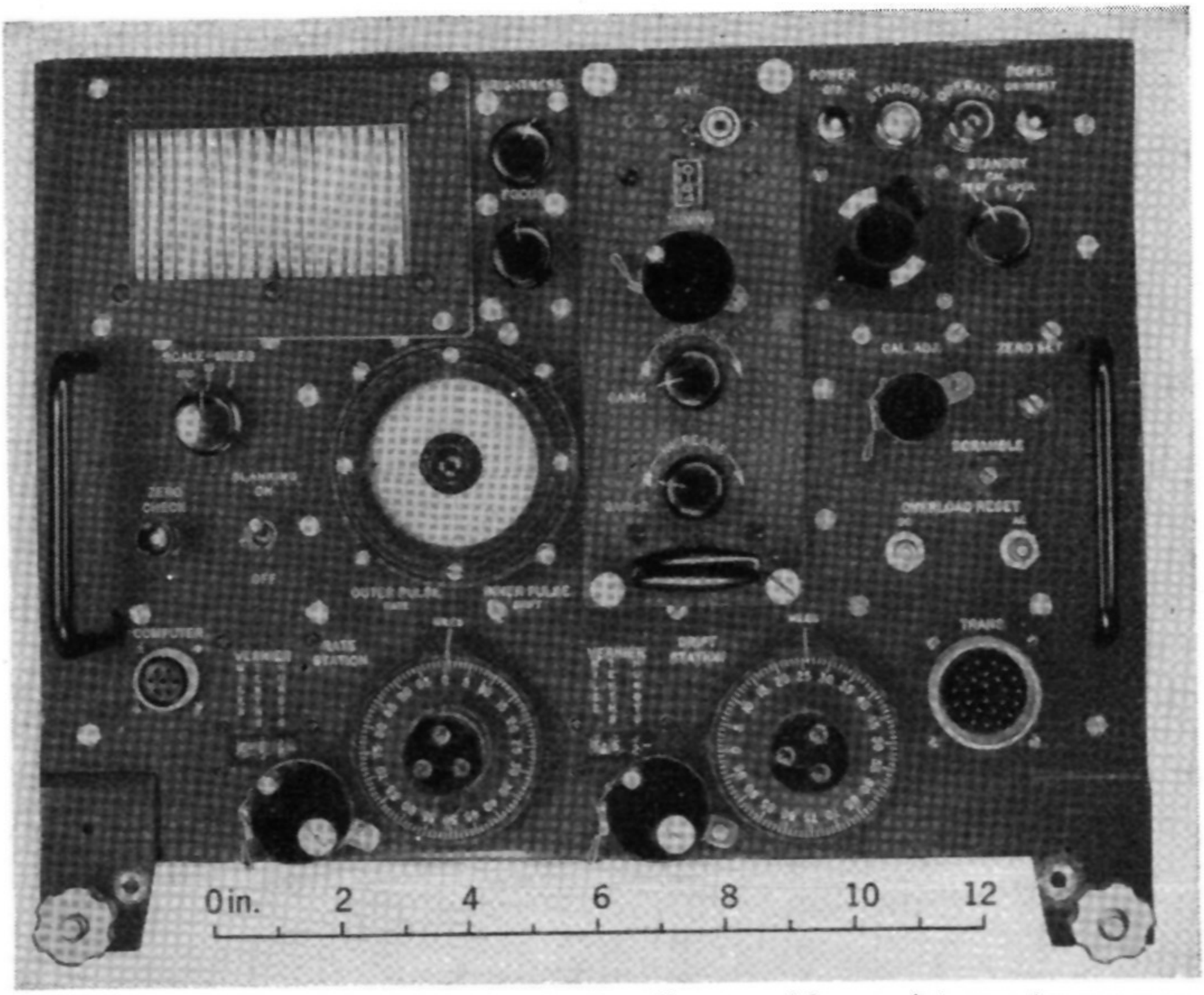

FIG. 19·14.—Timer-indicator unit of the Shoran airborne interrogator-responsor (AN/APN-3).

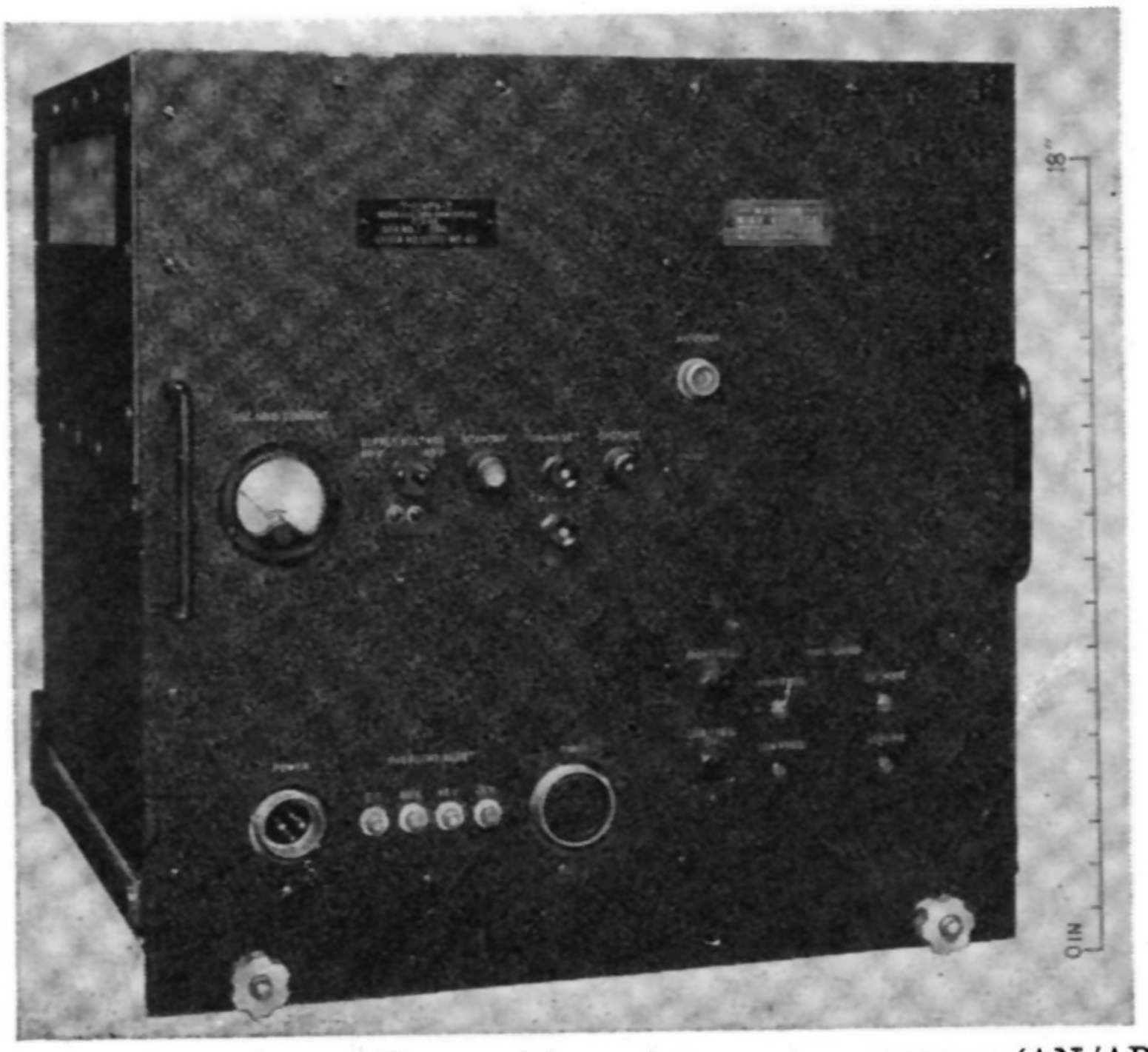

FIG. 19·15.—Transmitter of Shoran airborne interrogator-responsor (AN/APN-3).

Antenna Assembly

Type: vertical coaxial dipole; separate receiving and transmitting antennas; one antenna mounted on top, the other on bottom of aircraft
Azimuth coverage: 360°
Elevation coverage: ±45°
Polarization: vertical
Gain: 1·5

Transmitter

R-f source: triode, (2) 4C28
Radio frequency: two frequencies (one for each beacon) separated about 20 Mc/sec in the 220- to 260-Mc/sec band.
R-f stability: 0.2 per cent
R-f pulse power: 12 kw
Frequency switching rate: 10 cps ($\frac{1}{30}$ sec of interrogation for each beacon separated by $\frac{1}{60}$-sec intervals of silence)
Pulser type: hard-tube, (2) 3E29
Pulse rate: 931 pps derived from 93-kc master oscillator
Pulse duration: 0.5 μsec

Receiver

Type: superheterodyne
Frequency range: 220 to 330 Mc/sec
Stages: six i-f
I-f pass band: 4 Mc/sec
Sensitivity: 128 dbw

Indication

Type: (1) distance dials; (2) two PDI (pilot direction indicators); one PDI indicates displacement from track (full-scale deflection either 1000 or 400 ft) and the other PDI indicates rate of approach to track; (3) one 3-in. J-scope
Sweeps (J-scope): 1-mile time base (7 in./mile); 10-mile time base (0.7 in./mile); 100-mile time base (0.07 in./mile).
Range measurements: beacon range corresponds to phase shift in precision goniometers (100 mile, 10 mile, 1 mile) and is indicated on Veeder-root counter; accuracy of 1-mile goniometer is 1.5° or 22 ft; smallest dial on counter indicates 0.01 mile allowing estimates to 0.001 mile

19·15. Ground Beacons (AN/CPN-2).—Two AN/CPN-2 beacons are required for operation with the AN/APN-3 interrogator-responsor.

In the usual application, the aircraft flies a circular track around one of the beacons (called the "drift station") and determines its position on this circular track by the other beacon (called the "rate station"). The beacons are interrogated on different frequencies but respond on a common frequency. Photographs of the Shoran ground beacon are shown in Figs. 19·16, 19·17, and 19·18.

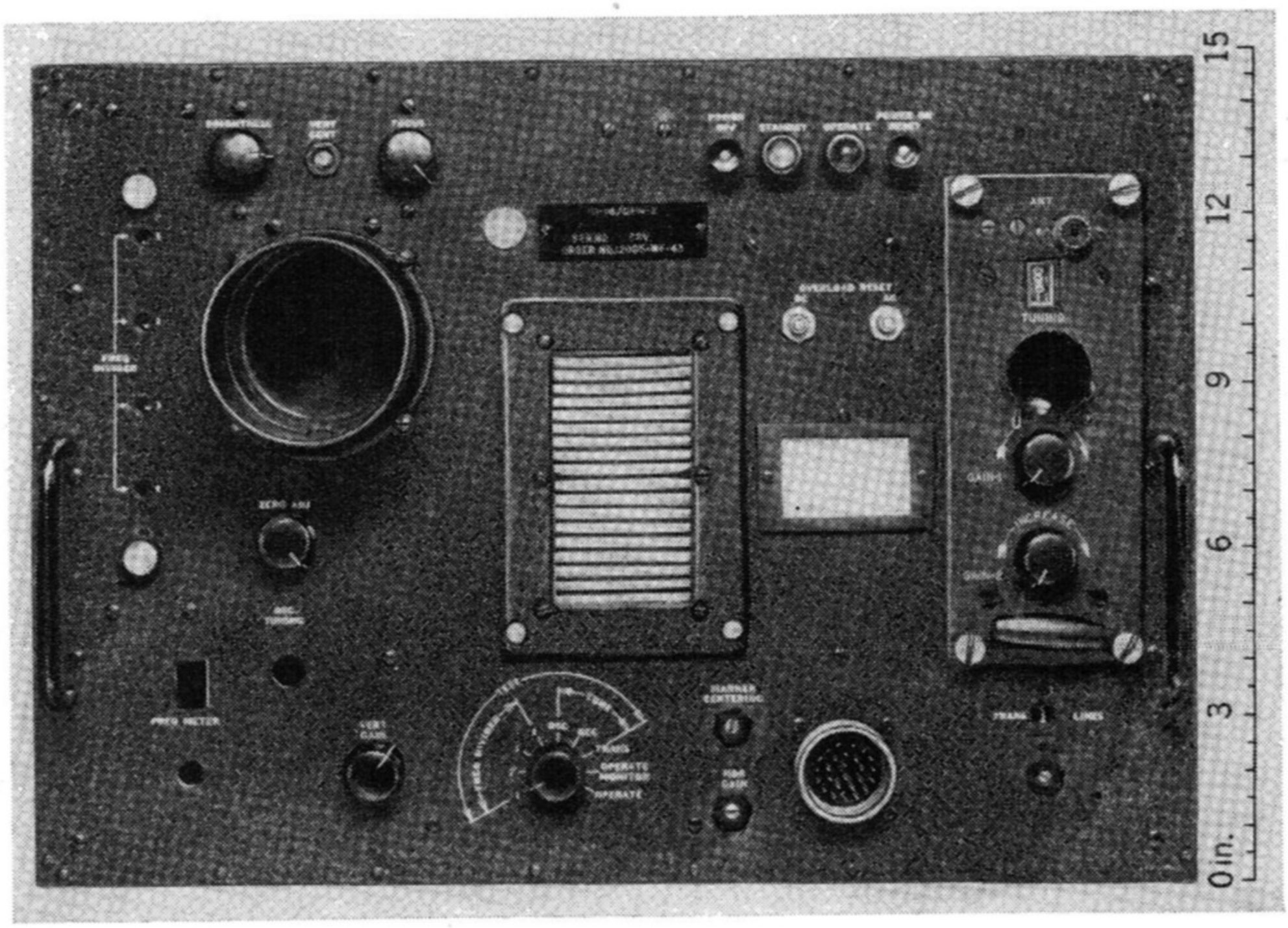

FIG. 19·16.—Shoran beacon (AN/CPN-2) receiver-monitor unit.

Characteristics of AN/CPN-2 are as follows.

General

Wavelength: one meter
Weight (installed): 1150 lb, including 310 lb for beacon, 460 lb for antenna and mast, and 380 lb for two power units and fuel cans
Number of operators: one
Power supply: 0.4 kw 24-volts d-c, 1.2 kw, 115 volts, 400 cps

Antenna assembly

Type: vertical coaxial dipole set in a corner reflector; separate receiving and transmitting antennas mounted on a 50-ft mast
Azimuth coverage: 90°
Elevation coverage: ±45°

Polarization: vertical
Gain: 6

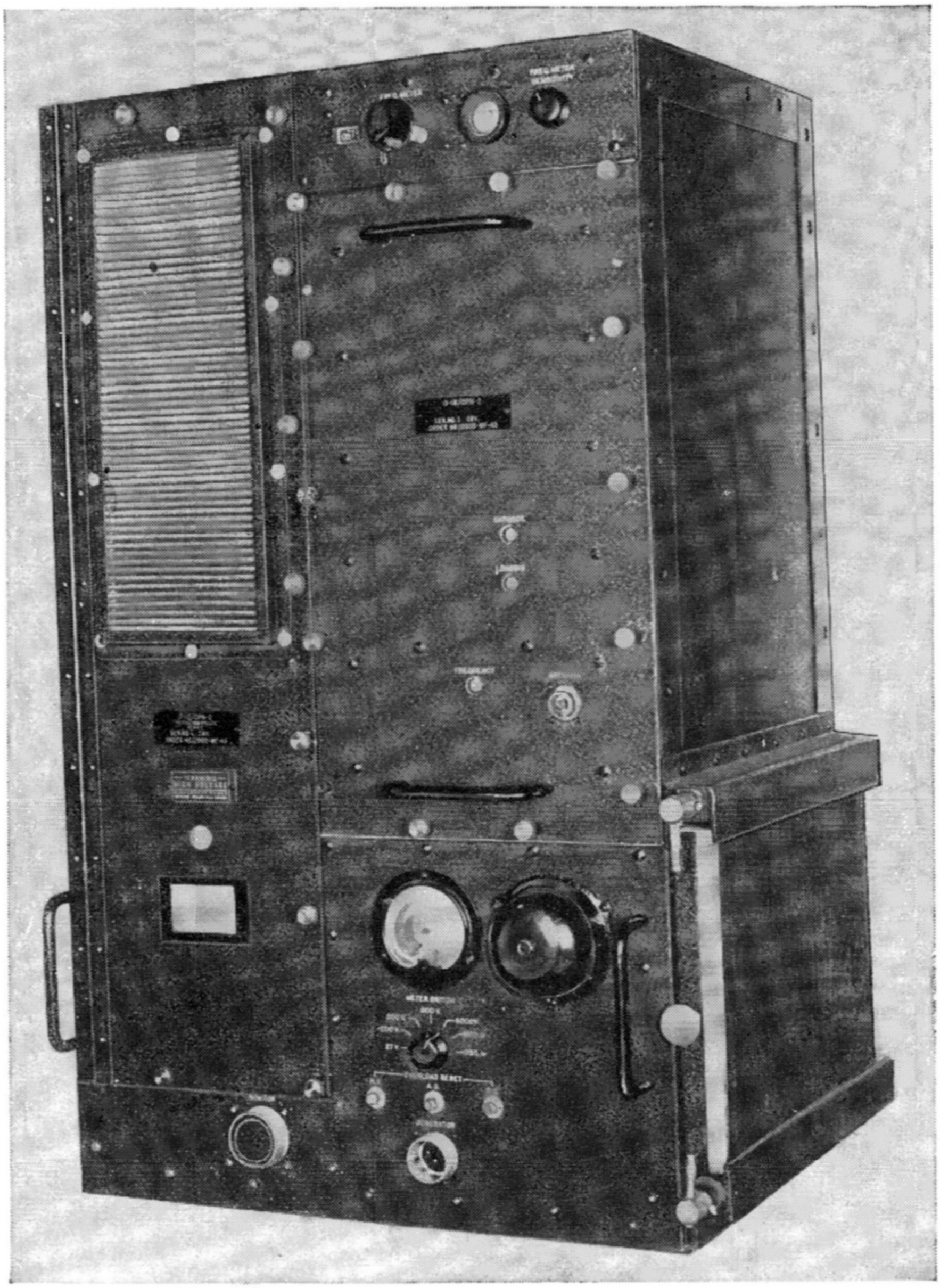

FIG. 19·17.—Shoran beacon transmitter unit.

Transmitter

R-f source: triodes, (2) 4C28
R-f response frequency: selected in 290 to 320-Mc/sec band by tunable transmitter
R-f frequency stability: 0.2 per cent

R-f pulse power: 30 kw
Maximum duty ratio: 0.4 per cent
Pulser type: hard-tube, (4) 3E29
Pulse duration: 0.55 μsec
Blanking gate duration: 5 μsec
Overinterrogation protection: high-voltage overload relay and warning bell

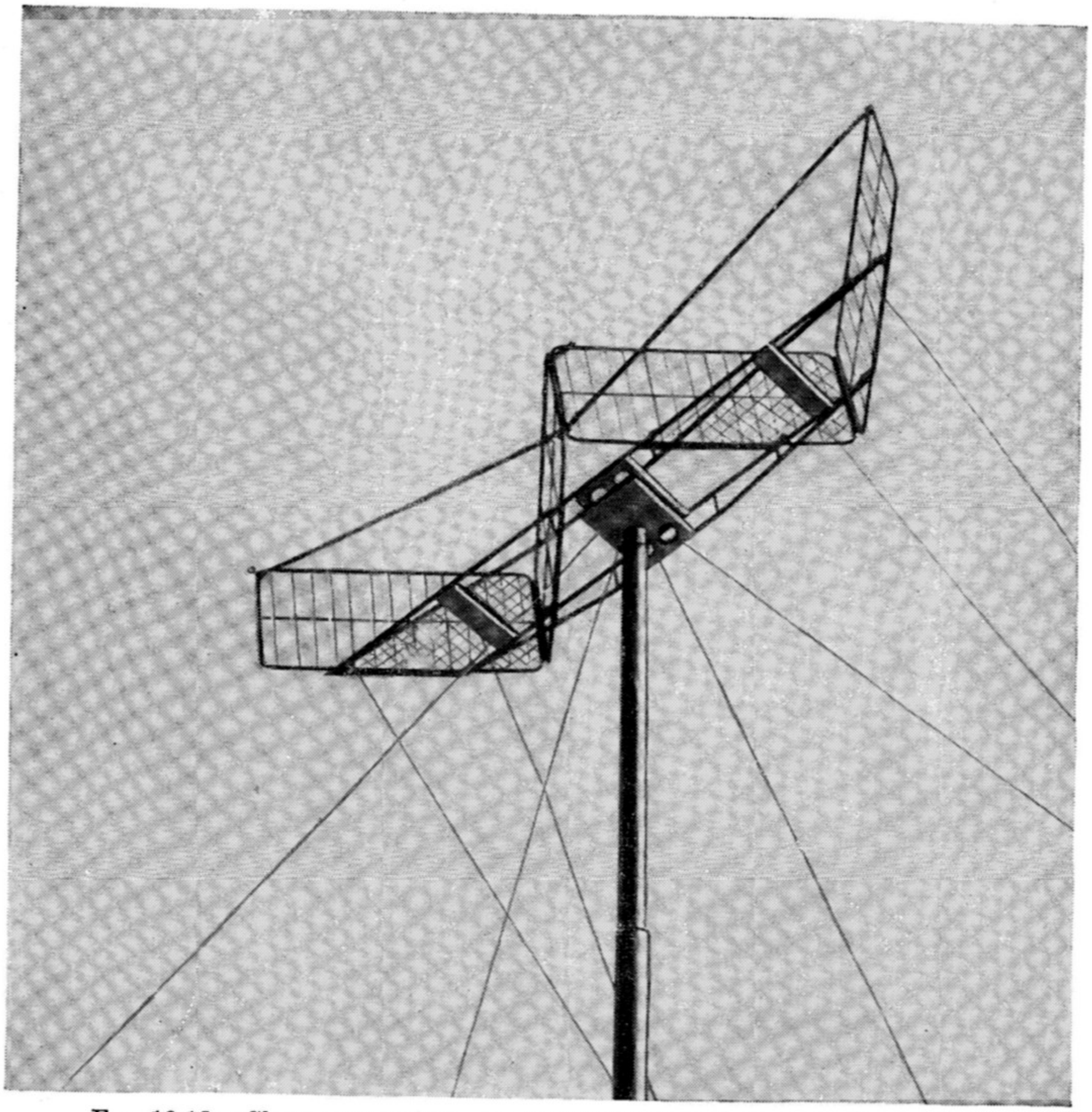

FIG. 19·18.—Shoran ground beacon (AN/CPN-2) antenna installation.

Receiver

Type: superheterodyne (identical with AN/APN-3 receiver)
Frequency range: 220 to 330 Mc/sec
Stages: six i-f
I-f passband: 4 Mc/sec
Sensitivity: 128 dbw

Coding

Interrogation: frequency discrimination by narrow-band receiver
Response: no range coding; provisions in aircraft to identify responses to its own interrogations and to distinguish drift from rate station (one appears as outward, the other as inward pip on circular trace in J-scope)

Special features

Power units: two PU-4/CPN-2 gasoline-power units are supplied with each beacon; each unit is 24-volt d-c, 115-volt 400-cps, 1.7-kw supply.
Frequency monitor: provisions for monitoring both interrogation and response frequencies
Beacon delay monitor: 3-in. A-scope with 1-mile sweep allows monitoring of delay to better than ± 0.1 μsec.
Calibration broadcast: pulses from a standard temperature-controlled crystal (93,109 $\pm$ 2 cycles) are broadcast by ground station at intervals of exactly 100 statute miles.
These pulses are used to check the time base in the airborne equipment.

19·16. System Performance. *Coverage.*—Range coverage is limited only by the horizon. Azimuth coverage is limited to a 90° sector from each beacon station when the corner reflectors on the beacon antenna are used; azimuth coverage is uniform in all directions when the corner reflectors are removed. Elevation coverage is uniform from 0 to 45°. Hence, when airborne and beacon antennas are properly mounted, the system gives essentially complete line-of-sight coverage.

Range.—Maximum reliable range is limited only by the horizon (about 280 miles at 40,000 ft). Theoretical maximum range calculations indicate adequate reserve power for strong signals (20 db above minimum discernible) and for interference nulls.

Accuracy.—The accuracy of the Shoran system depends as much upon external factors, such as variations in propagation velocity, as upon instrumental errors. By adjustment of the timing crystal with the aid of standard frequency transmissions the crystal error can be made negligible. With careful adjustment the errors in the equipment can be reduced to ± 25 ft. at any operational distance. This precision and the speed with which fixes may be taken make the system the best existing one for precise navigation for any purpose.

Traffic Capacity.—Twenty interrogator-responsors can operate with one pair of ground beacons simultaneously.

Coding.—Interrogation coding is by frequency channeling only and there is no response coding. Provisions are made in the interrogator-

responsor to distinguish the constant-range (drift, or "cat") station from the variable-range (rate, or "mouse") station.

Operational Reliability.—The equipment is designed for just one purpose: precision navigation as an *H*-system. The operation of the airborne equipment can be made almost entirely automatic; course information can be delivered to the automatic pilot and fixes can be taken automatically. Hence the period of training required to operate the equipment is very short and the possibility of personnel errors is reduced to a minimum.

Comments.—Shoran is the most accurate radar system for aircraft navigation to horizon ranges that has been developed to date (1945). It owes its great precision to the inherent advantage of requiring range measurements only (because these can be determined much more precisely than azimuth- or elevation-angle measurements) and to the excellence of its instrumentation, which utilizes this inherent advantage by employing devices such as expanded sweeps, tracking circuits, calibration checks, and automatic operation.

Shoran is not adapted to any applications other than those using *H*-navigation, since the equipment is not designed to indicate either radar echoes or beacon azimuth. Although its dipole airborne antenna has the advantage of low drag on the aircraft, it prevents getting the large traffic capacity associated with scanning radars even when range-coded beacons are used with the latter.

Extensive experimental work has shown that it is possible to incorporate the *H*-system of navigation into the airborne radar (AN/APS-10)-ground beacon (AN/CPN-6) system described earlier in this chapter. It is necessary to add an accurate ranging unit (a fundamental component of the Shoran interrogator-responsor), and provisions for a split-azimuth indication (one-half of the PPI for each beacon, described in Sec. 17). Sweep expansion, tracking circuits, and ground track determination (by the "pulse-doppler"[1] method) and a pilot's direction indicator greatly improve the accuracy. Such auxiliary equipment can give an *H*-system of precision ± 100 ft. without sacrificing the normal radar- and beacon-navigation features. The total weight of airborne equipment is comparable with that for Shoran. No modification of the AN/CPN-6 ground beacons is necessary.

Extensive experiments by RCA have also shown that the instrumental errors of Shoran can be reduced to a value not exceeding ± 10 ft.

[1] See *Radar Aids to Navigation*, Vol. 2, Chap. 3, Radiation Laboratory Series.