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THE DEVELOPMENT OF FAN-TYPE ULTRA-HIGH-FREQUENCY RADIO MARKERS AS A TRAFFIC CONTROL AND LET-DOWN AID

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SUMMARY

The development of "Fan"-type ultra-high-frequency radio markers by the Bureau of Air Commerce for use along the airways as an aid to navigation and for utilization in traffic control started in the fall of 1936 with the installation of an experimental transmitter and antenna at the site of the Washington radio range station A second experimental installation was made at the site of the Bowie, Md, light beacon in October of the same year This beacon is located on the northeast leg of the Washington radio range and at a distance of 17 miles from the range station and the Washington airport, indicated on the airway chart as Site 57–B (See fig 1) Flight tests were conducted over these markers and the characteristics of the patterns were observed and recorded On the basis of the results obtained, a contract has been let for the purchase of a quantity of these markers for installation at various points throughout the country The marker equipments being purchased will have dual transmitters capable of automatically transferring to stand-by position in case of failure of the regular transmitter, and a special type of antenna and counterpoise designed to reduce the detuning effects of changing weather conditions such as rain, ice, and snow

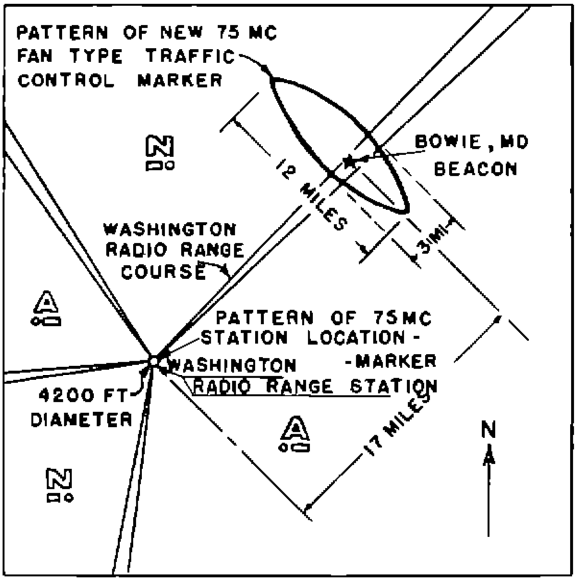

Figure 1—Relative patterns at 5,000 feet altitude of Z- and fan-type markers

INTRODUCTION

With the advent of scheduled airline operation, particularly with the adoption of the present traffic control system [1] by the Bureau of Air Commerce, there came the need for a positive means of accurately checking the position of aircraft when flying by instrument along the airways The first and the most obvious method of determining position adopted by the airlines was that of locating the intersections of radio range beams A particular example of this is encountered in flights between Pittsburgh and Washington, in which pilots calculate their expected time of arrival at Washington from the time at which they pass the point where the south leg of the Harrisburg radio range intersects their course The south leg of this range intersects the course in the vicinity of Sugar Loaf Mountain Similar intersections exist between other radio range courses throughout the country, and are plotted on the aeronautical charts, providing many "check points" or "fixes" for pilots flying by instrument

In some locations where adequate check points were not available through intersections of range courses, the Bureau has established facilities indirectly providing this service In some cases these facilities consist of lower power radio range stations [2] located along the course of the main range stations. These medium power range stations are used to fill in between the courses of the large terminal ranges which may become too weak or too wide because of distance, or where conditions exist which make accurate flying especially essential. However, their signals provide a means of checking position as well. In locations where the additional range signals are not required, low-powered long-wave transmitters have been installed to produce a nondirectional marker signal. These were termed "Class A Markers" [2] (now Class M), and are receivable on the same equipment used to receive the main radio range signals. Numerous experiments were conducted to determine optimum modulation frequency, power, and keying intervals for these markers, and their use as a warning of obstructions was thoroughly investigated.[3] All such markers operate on the same frequency as the range station on whose course they are located. Their signals are received by the pilot as an interference on the range signal without need for returning his range receiver. Provision is also made at these marker stations for radio telephonic transmission to aircraft on a common frequency of 278 kc., the latter replying on high frequency.

As air-line traffic increased, many disadvantages became evident in the use of long waves for marking purposes. Generally where range course intersections are used, the accuracy of the fix is not very great due to the progressive widening of courses with distance. Furthermore, constant retuning to the frequency of the intersecting range is necessary unless duplicate range receivers are available. Low-power, low-frequency marker stations provide only a general check on position since their distance of receivability is inherently difficult to control and maintain.[4] Night effect and differences in antenna efficiency and in readjustment of the ship receiver volume control as determined by the signal strength of the main range station, which the marker beacon supplements, all affect the distance over which the marker is heard. The use of ultra-high frequency to provide a suitable stable elliptical or fan-shaped pattern was considered, and the development conducted along this line is described in this report.

APPARATUS

The first use of ultra-high frequencies for marker service by the Bureau was in 1935 when several of the major air terminal range stations were equipped with transmitter and antenna capable of producing an inverted vertical cone of signal [5] to afford the pilot a positive warning of his arrival over the range station and

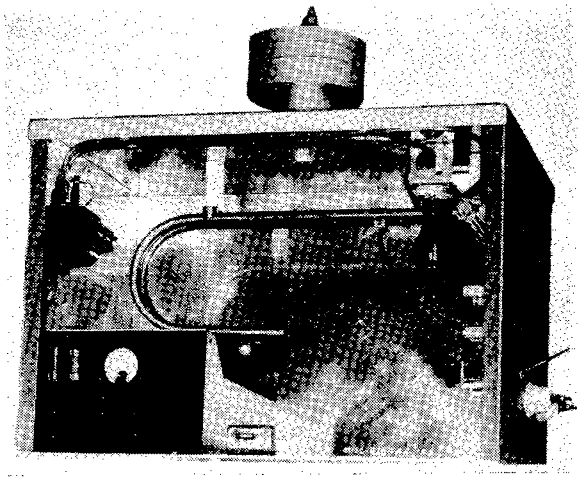

Figure 2.—Original Ultra-high-frequency marker transmitter.

to supplement the use of the cone of silence [6] which otherwise provides the only such indication. One of these transmitters was converted in the fall of 1936 for use in the development of a fan-type marker which would give an elliptical instead of circular pattern for use along the airways to provide aircraft with an accurate "fix" where required. The original transmitter, shown in figure 2, was modified to contain a pair of Eimac 150–T tubes connected as a simple push-pull 75-megacycle oscillator with long line frequency control. A schematic diagram is given in figure 3. The filaments were heated with 60-cycle power, and the plates were connected to a 890-cycle motor-generator through a step-up transformer as shown in the diagram.

The output of the transmitter was coupled through a two-conductor transmission line to an antenna array consisting of four half-wave doublets in line end to end and spaced a quarter-wave above ground. A temporary installation was made at the site of the Washington Airway Radio Range Station, Hunters Point, Va., and later moved to the site of the Bowie, Md., light beacon. The installation at Bowie is shown in figure 4. The motor-generator used to supply the 890-cycle plate power was located in a small 7′ by 7′ frame building placed inside the base of the beacon light tower. In February 1937, a new motor-generator was installed to produce 3000-cycle plate power. Three thousand cycles was selected to provide a marker tone distinctive in contrast to the 1020-cycle tone of the range and one that could be filtered easily from

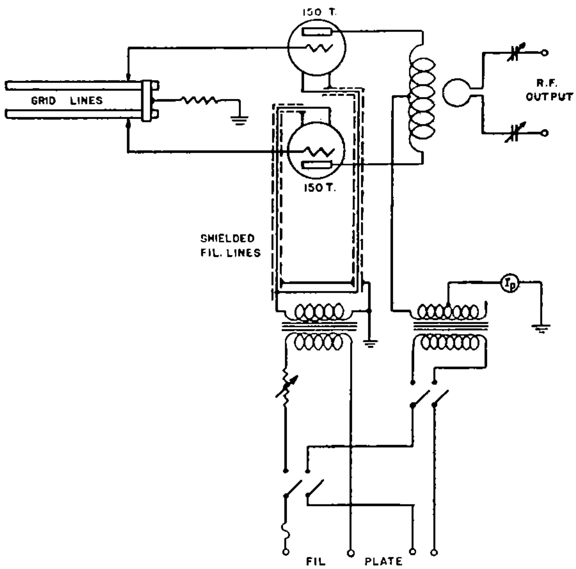

Figure 3.—THL 75-Mc. marker transmitter.

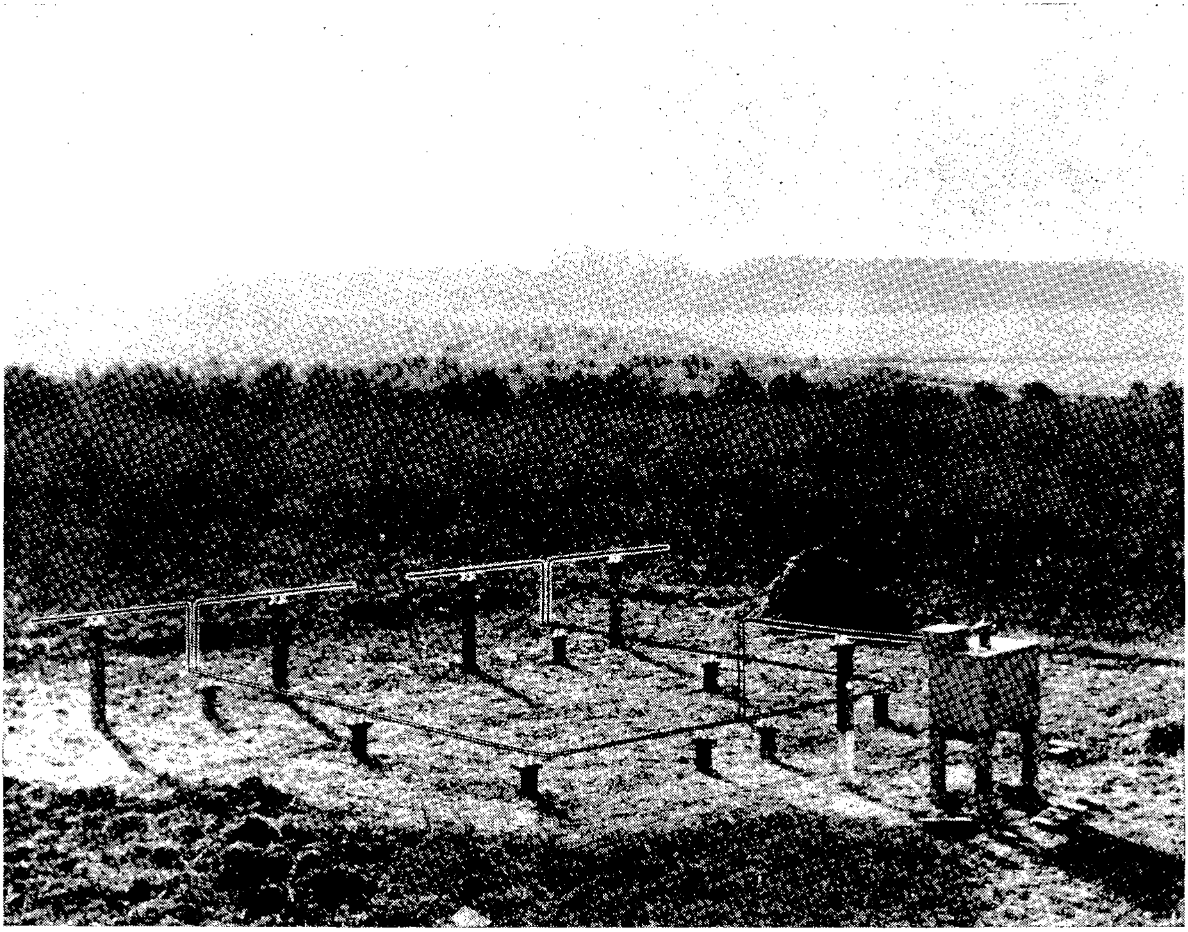
Figure 4.—Original fan marker installation at Bowie, Md.

unwanted ultra-high-frequency signals. An agreement was reached by the Radio Technical Committee for Aeronautics in May 1936, establishing 3000 cycles as the desired marker modulation frequency.[7] In April 1937, the Bureau completed and installed a crystal-controlled transmitter at the Bowie marker. The original antenna system was retained and the transmission line was extended to the new transmitter in the building in the beacon tower base. Continuous operation has been maintained since October 1936.

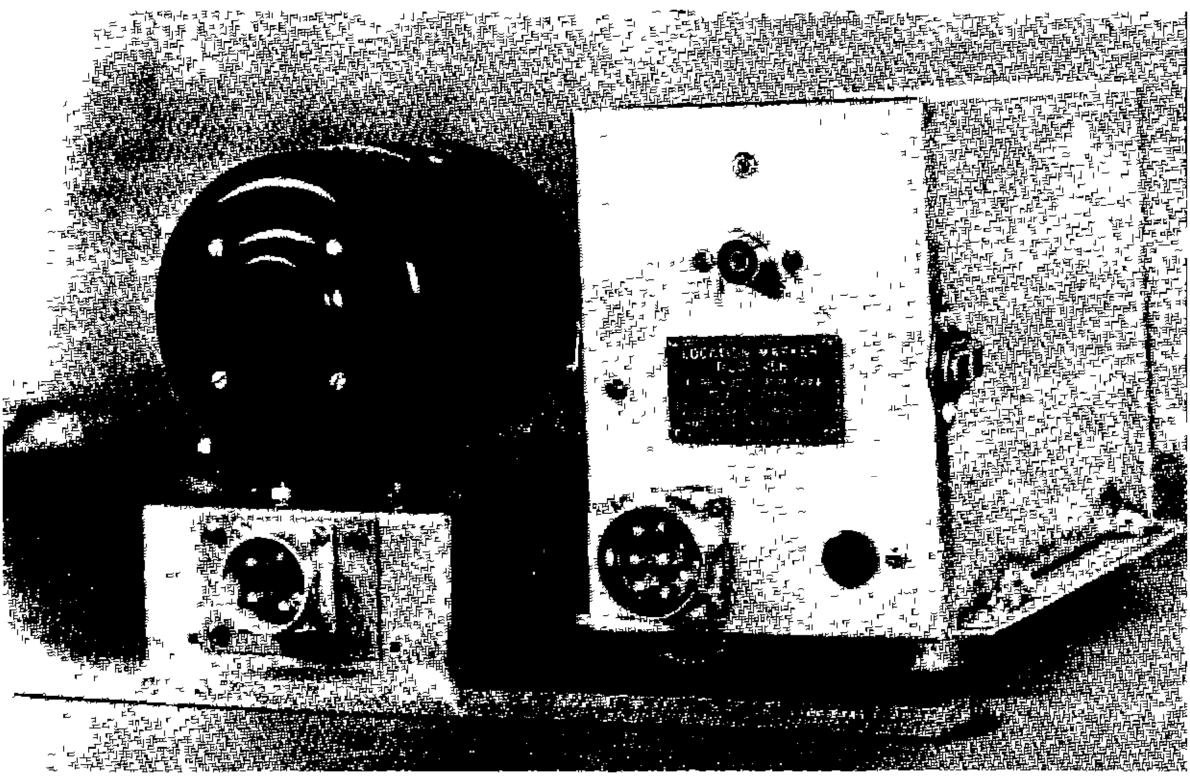

Figure 5.—Type RUD marker receiver.

The essentials of the receiver used in connection with the flight testing of the marker were described in Vol. 8, No. 8, February 1937 issue of the Air Commerce Bulletin.[8] A view of this receiver is shown in figure 5. It consists of a grid leak detector and audio amplifier with an output band pass filter, a diode rectifier and a sensitive d. c. relay. The receiving antenna, as shown in figure 6, consists of a single wire antenna supported longitudinally beneath the belly of the ship. A 6-volt to 200-volt dynamotor is used with the receiver.

Both aural and visual indications are provided for the pilot in the ship. A 12-volt white lamp is provided on the instrument panel to be controlled by the d. c. relay. The aural output of the receiver is connected through a switch to the plane's regular headphone jack circuit so that the marker signal alone can be heard or it can be superimposed on the range signal if desired.

In the recordings of figures 8, 10, and 11, the center portion is somewhat flattened because of receiver overloading. Actually the center lobe is much stronger than the side lobes and not equal to the side lobes as shown in the recordings.

Three different airplanes have been used in tests of fan markers; these were: (1) NS–62, a 4-place, fabric, high-wing Stinson monoplane; (2) NS–31, a 2-place, fabric, high-wing Fairchild monoplane; (3) NS–1, a twin-motor, low-wing, all-metal Lockheed Electra transport. Belly antennas were used on all three of these ships.

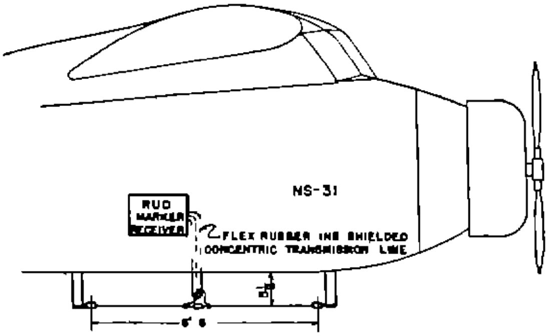

Figure 6.—Marker receiving antenna—NS-31

TESTS

The tests with the initial set-up at the site of the Washington Radio Range Station indicated that a suitable elliptical field pattern could be obtained with a transmitting antenna array consisting of four half-wave elements arranged in line end to end, spaced one-quarter wavelength above ground and excited in phase. A simpler antenna, consisting of only two half-wave elements, was tried and a comparison of patterns obtained is shown in figure 7. The desired pattern for fan markers is one having greatest length and minimum width, or thickness. The ratio of length to width for the four-element array is 11 to 3 compared with about 8 to 3 for the two-element array. The four-element array, according to both theory and observation, produces three lobes of radiation (fig. 8) whereas only one lobe is observed for the two-element array. However, it was observed that the three lobes are very closely spaced and in passing from one to another the period during which the marker indicator lamp is out is relatively small. Furthermore, the two outer lobes are present only in the zone directly above the transmitting antenna. The recording (fig. 8) made on a flight directly over the station shows the lobes very definitely whereas a similar and parallel flight (fig. 9) made 2.8 miles to the right of the station shows no lobes. It was believed that, regardless of its greater size and lobes, the use of the four-element array was justified. All subsequent

Figure 8.—Recording of flight over fan marker—Altitude 3,000 feet.

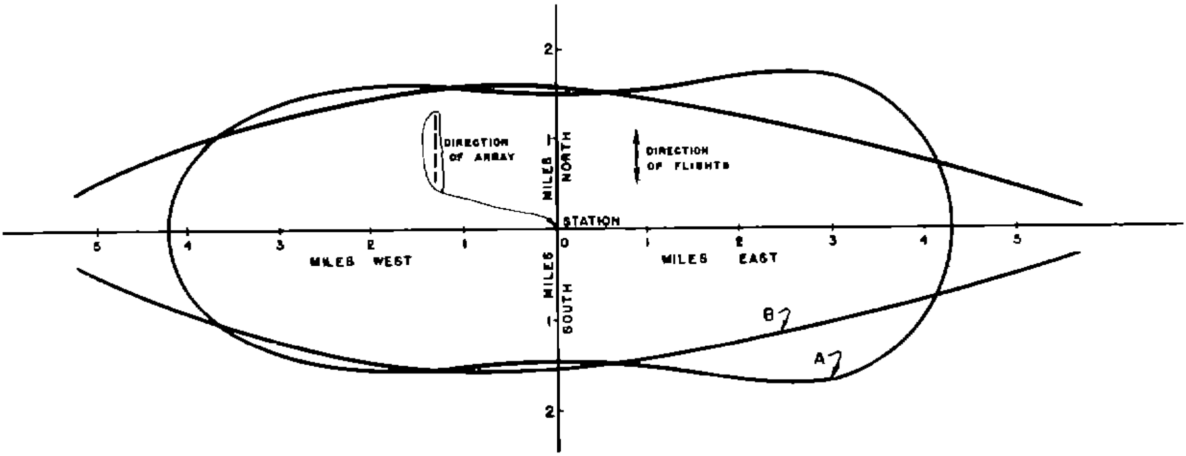

Figure 7.—Relative patterns for two types of transmitting antenna arrays.

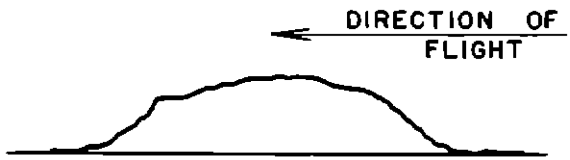

Figure 9.—Recording of flights over fan marker 2.8 miles east of station—Altitude 3,000 feet.

tests, therefore, were conducted with a four-element array

When the installation was made at Bowie Md a keying device arranged to send the letter M (two dashes — —) in continuous succession, was connected to the transmitter This was done primarily to make this fan marker easily distinguishable from the unkeyed Z marker at the Washington Range Station It was found to accomplish its purpose with remarkable contrast, and in addition it almost eliminated the noticeable effect of lobes at altitudes of less than about 3,000 feet (See fig 10) At higher altitudes, up to about 7,000 feet, the brief dead spots between lobes are not considered objectionable (See fig 11) Above about 7,000 feet the amplitude of the side lobes is below that which will operate the marker lamp so that only the steady signal of the main lobe is obtained Regarding these lobes in a useful sense, it has been possible in flights to determine relative lateral position and to check the accuracy of the radio range course because the "outs," or dead spots are found only over the station and not on either side Flights were made up to 13,000 feet, and satisfactory results were obtained

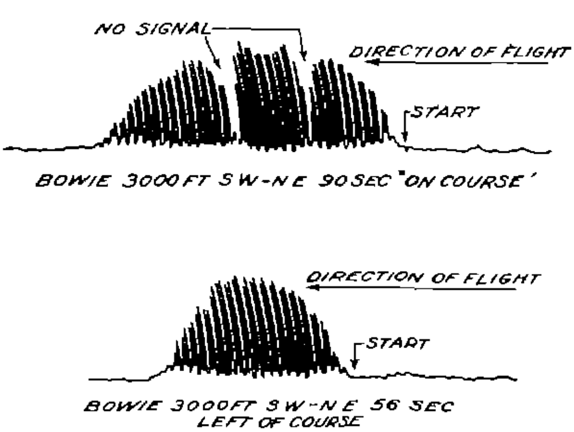

Figure 10—Recordings of flights over fan marker, keyed signals

With regard to the keying of these markers, it was considered possible to render additional aid to navigation and facilitate traffic control by keying each of the several markers associated with a given range station with a different grouping of dashes Since there are four courses to be marked for each radio range station, the four fan markers can be keyed accordingly in one two, three, and four dash groups Having a prescribed standard manner of arranging these fan markers, it would then be possible to know positively on which leg of the range the ship is flying

The airplane in which flight testing was started was observed to have greater receiving sensitivity from one side than from the other This effect was observed on flights at considerable distances to the right or left side of the marker transmitter and at the lower altitudes where the received wave approaches at a small angle to the wings This was a fabric covered four place Stinson (NS-62) The wings and landing gear were not believed to be causing difficulty, inasmuch as both sides are symmetrical The unshielded lead-in from the antenna was replaced by one with a metallic shield after which approximately symmetrical receiving characteristics were obtained Later a fine-mesh screen was installed on the belly of the ship and grounded to it, and although a slight unbalance remained, it was considered of no serious consequence It is believed that the position of the receiver and other parts in the ship contribute most to the dissymmetry

NS-31, a fabric-covered two-place Fairchild airplane was equipped with a marker receiver and used for a large number of flight checks Some dissymmetry was noted in the receiving sensitivity of this ship in addition, a pronounced flutter in the marker tone and light was observed This was found to be caused by vibration of control cables and other parts inside the ship adjacent to the belly antenna

Figure 11—Recording of flight over fan marker—Altitude 6,000 feet

NS–1, a low wing all-metal twin motor Lockheed Electra was also equipped for marker tests and various receiving antennas tried Two belly antennas were originally installed on this ship directly between the wheels and 24 inches from the belly of the ship The two were parallel and spaced 15 inches apart One was used for a low-frequency range beacon receiver, the other for the ultra-high-frequency marker receiver Flights were made using two different antenna lengths and with several spacings between antenna and the belly of the ship It appeared that a spacing of 24 inches from the belly was superior to anything less, both for fan and Z marker reception The length of 69 5 inches was found to give slightly better performance than a length of 73 inches A 78-inch antenna with an insulator at its middle and the shield and conductor of a low impedance concentric transmission line lead-in connected respectively to the forward and after sections (see fig 6) was found superior to a continuous half-wave antenna The presence of the parallel beacon antenna did not appear to cause difficulty with operation of the marker antenna

An extensive study of receivers was conducted during the marker development The detector and amplifier circuit as used in receiver, figure 5, was developed because of its light weight, simplicity, and compactness In the beginning, when the transmitters were not crystal-controlled, it was necessary to have a broadly tuned radio-frequency circuit Selectivity was obtained mostly through the use of a 3000-cycle audio output filter The circuits were arranged so as to give minimum change of sensitivity with variation of the 12-volt supply voltage A relay was finally chosen to operate the signal lamp on the instrument panel of the ship, after a number of other possible ways of providing visual indication were investigated

The use of a type-885 tube was tried in place of a relay This tube becomes very conductive when its grid voltage is made slightly positive A Neon-type indicator tube was used with the 885 tube While correct operation was obtained with this combination, it was found that lighting of the indicator was more affected by extraneous interference and the sensitivity was not constant for variations of ambient temperatures, and receiver plate voltages Also the filament current of the 885 tube is very high, causing the marker receiver to exert a considerable load on the airplane battery

The Neon indicator was once considered desirable because of its color and shape, but was abandoned for the following reasons (1) Its ability to light instantaneously makes it a poor discriminator of noise, (2) the standard lamps available require considerable space for mounting, (3) they require a high voltage for operation and when used with blind landing the lighting of the Neon light from the receiver plate voltage causes a transient in the glide-path circuit, (4) a rise in receiver plate voltage may cause the lamp to retain a partial glow if it is used with a type-885 tube The use of the Neon tube with a relay was discarded for reasons (1), (2), and (3) above

A "magic eye" type of tube was investigated, but the color (green) was not desirable and the illumination inadequate High plate voltage was required for this tube in addition to filament power

The advantages presented for the 12-volt type standard indicator lamp were

a It can be mounted between instruments on instrument panel

b There is momentary delay in its lighting that makes it less subject to lighting by extraneous influences

c It is standard and readily obtainable

d It requires no special voltages

It was for these reasons that the use of this type of lamp was adopted for all subsequent receivers made by the Bureau for experimental marker service

The Bureau developed and tested a crystal-controlled superheterodyne receiver suitable for marker reception This receiver was somewhat larger and heavier and many times more complicated electrically than the original type employing simple detector, but its development was necessitated by the fact that the assignment of radio-frequency channels within half a megacycle of the marker frequency was predicted

To obtain discrimination against these adjacent assignments, it is obviously necessary to resort to a more selective receiver. The entire system of receivers and transmitters must be completely standardized and stabilized with regard to frequency and to do this, the use of crystal control has been adopted. The crystal-controlled receiver was not flight checked, but sufficient data were secured in the laboratory to permit writing a specification from which a quantity of receivers will be purchased.

The use of 3000-cycle tone modulation of marker transmitters made it possible for both marker and range signals to be heard simultaneously in the headphones without appreciable cross interference or confusion.

RESULTS

Although several refinements remain to be tested, it is believed that sufficient knowledge has been obtained to predict satisfactory service operation of ultra-high-frequency fan-type markers. The knowledge gained can be summarized as follows:

1. A vertical fan-shaped wall of signal with an elliptical cross section, suitable for marking on radio range courses and for the proper control of airway traffic can be produced reliably by an array of four half-wave doublets in line, spaced ¼ wavelength above ground and excited in phase.

2. The shape of the pattern in cross section at 5,000 feet altitude is elliptical and has dimensions in the horizontal plane approximately 12 by 3 miles. Larger patterns of proportionate dimensions are obtainable through the use of more transmitter power or greater receiver sensitivity.

3. A transmitter power output between 100 and 150 watts will cover all ordinary fan marker requirements.

4. Marker signals can be properly received in aircraft through the use of a half-wave belly antenna and a receiver having a sensitivity of 1400 microvolts.*

5. The antenna system can be placed as close as 100 feet to an airway beacon light or similar metallic structure without causing serious distortion to the pattern. Less than 100 feet spacing is being investigated at a new installation at New Brunswick, N. J.

6. These markers have not yet been installed in mountainous terrain; however, knowledge at hand would indicate that no difficulty would be encountered if these markers were properly located, that is, located away from deep ravines and placed where the antenna is well within the line of sight to an airplane within the area to be served.

7. Proper spacing of these markers from the range station for air traffic control purposes will depend upon terrain and traffic operating conditions, and will vary from about 10 to 40 miles.

8. The keying of the signal in dashes to identify the particular leg of the range and to differentiate this marker from the Z marker is highly desirable.

9. The cost for each complete fan-type marker installation in quantities of 23 with an automatic stand-by transmitter and shelter is approximately $3,500.00.

CONCLUSIONS

It is concluded:

1. That if several, or all, of the Bureau patrol and radio aircraft are equipped with crystal-controlled superheterodyne receivers and routine flight checks started throughout the country, much information on the stability of these marker systems under adverse weather conditions can be determined.

2. That the use of a shelter over the transmitting antenna system should be investigated as an alternate to the screen counterpoise in places where there is little or no snow. The shelter would probably be a frame enclosure measuring 6 feet high, 4 feet wide and 30 feet long.

3. That routine flight checking of markers should be continued throughout the winter to obtain information on operation in all extremes of weather including snow through and after snow storms.

*Measured by direct connection to a Ferris Microvolter, type 18B, 30 percent modulation.

4. That means should be provided at each fan marker site to advise the pilot visually or aurally whether or not the regular marker transmitter has for any reason become inoperative. A visual or aural method would permit Bureau patrol pilots to observe this also, saving much time in ordering maintenance men to these remote marker sites when failures occur.

5. That provisions for monitoring the output signal should be investigated.

6. That tests should be continued to determine whether or not these marker systems can be placed less than 100 feet from light beacon towers, preferably on the same 100-foot plot of ground containing the light beacon.

7. That flight tests should be conducted at higher altitudes to determine the utility of these markers in substratosphere flying.

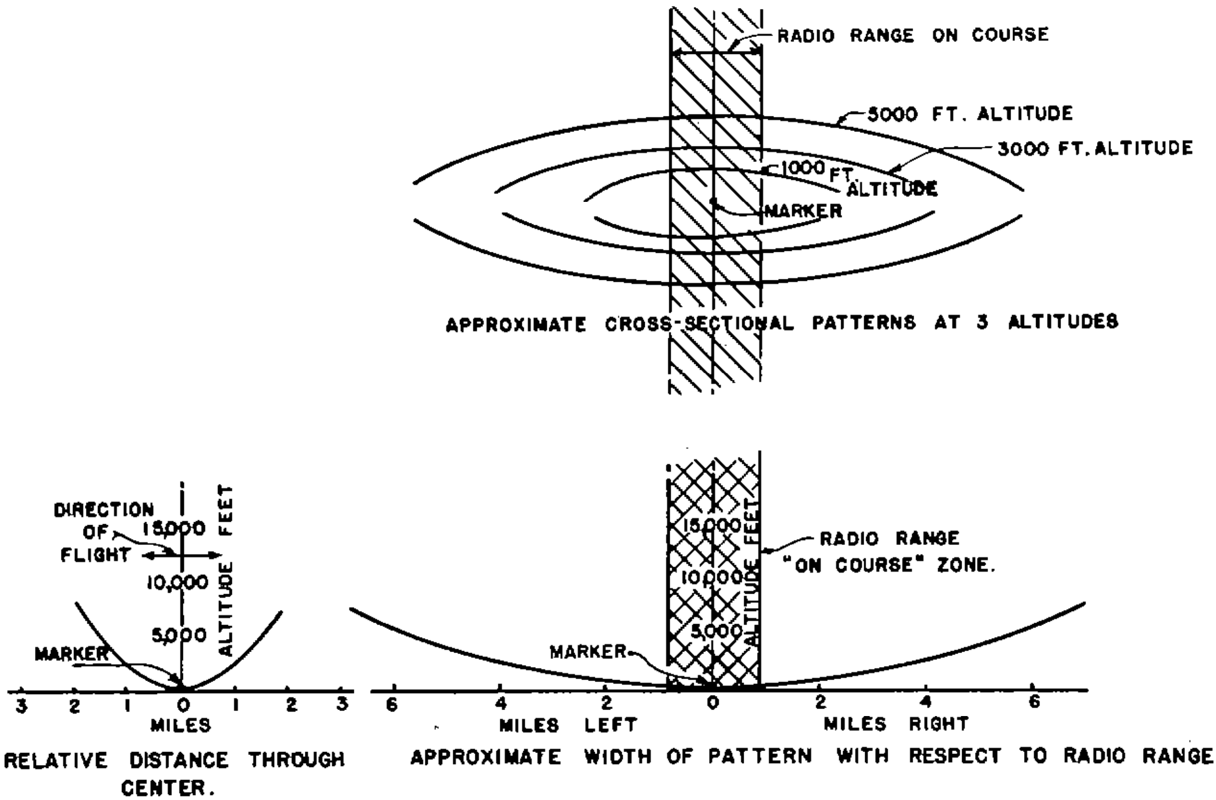

Figure 12.—Patterns of fan marker based on data taken at Bowie, Md.

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