Proceedings

of the

Radio Club of America

March - 1929

Volume 6, No. 3

RADIO CLUB OF AMERICA
55 West 42nd Street :: New York City

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PROCEEDINGS
of the
RADIO CLUB OF AMERICA

VOL. 6 MARCH, 1929 NO. 3

HIGH-FREQUENCY RADIO EXPERIMENTS IN AIRCRAFT

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A Paper Delivered Before the Club on December 12, 1928

BEFORE entering into the purpose of this paper, it may be well to review, briefly, some of the aircraft radio activities and experimental work that have been done. We must bear in mind the fact that even to-day, radio and its direct application to aircraft for commercial purposes is yet in swaddling clothes. No one can set forth any definitely fixed rules and regulations concerning aircraft radio and its method of installation and operation without having certain specific objectives in view. There are too many variables, most of them unknown or about which little is known. It is these variables which must be overcome before fixed standards can be set down for the proper design, construction, installation and operation of aircraft radio equipment.

Mr. M. P. Hanson, in a recent number of the *Proceedings* of the Institute of Radio Engineers, pointed out a number of problems, some of which had to do with special installations where radio was deemed very desirable, though not necessary unless safety in case of mishap was to be considered. A trend of development is included in Mr. Hanson's article.

Mr. Ross Gunn, in an article appearing in the *Journal* of the Franklin Insitute, June, 1928, points out further trends, particularly with respect to navigation of aircraft and the use of radio beacons for directive flying.

In the October, 1928, number of the Bureau of Standards *Journal of Research* an article by Mr. H. Pratt and Mr. H. Diamond discloses the design of some special light-weight receiving sets of high sensitivity for reception in aircraft. Design details for three receivers of slightly different types, with numerous characteristic and performance curves are discussed along with a brief discussion of the results of practical flight tests. Such important considerations as frequency range, tuning means, volume control, vacuum tubes, amplifier characteristics, size, weight and performance specifications are given.

In the November, 1928, number of the above publication, Mr. F. W. Dunmore describes the use of the tuned reed indicator and its use in directive beacon flying. This beacon gives the pilot a visual indication as to whether or not he is flying his beacon course.

All of the above articles are indicative of the modern trend in aircraft radio and yet all of it is still in the experimental stages. No one can doubt the interest in aircraft radio, if he will but survey the strides that have been made during the past two years. Much knowledge has been acquired but there is much to be gained in the months before us when more important use will be made of commercial aircraft in passenger carrying when safety will become a major item in successful flights. To our knowledge, most of the experimental work has been done on frequencies less than 3000 kilocycles.

PURPOSE OF THIS PAPER

THE purpose of this paper is to describe, in some measure, our specific experimental work and the problems which confronted us particularly in high frequency radio. Our first attempt was a reception test in which we used a very compact regenerative receiver which was completely shielded in an aluminum case. It weighed eight pounds, including batteries. A supporting frame, large enough to permit packing in balsam wool (a shock absorbing material, was suspended in the cockpit of a Waco biplane, powered with a Curtiss OX-5, 90 horsepower motor. The antenna consisted of a 12–foot piece of insulated stranded wire. This was suspended from an insulator fastened to one of the wing struts. The operator wore a helmet in which we managed to jam a pair of bulky Baldwin head phones. The head arrangement was quite uncomfortable, to say the least.

By prearrangement we sent continuous-wave telegraph signals during the test flight of ten minutes, but we insisted that the pilot fly not more than a mile away from the transmitter. The transmitter, operating on a frequency of 3800 kilocycles had an input of approximately 500 watts. We had visions of all sorts of interference from swinging guy wires, frictional exhaust noises, ignition interference and wind.

Either the transmitter was powerful enough to jam a signal through it all or as much didn't exist as we had pictured. We had no knowledge of what might be expected. Mr. Zurian (of the Burgess Battery Company), the operator, reported signals throughout the entire test. We learned that more consideration had to be given the mechanical construction as well as the electrical construction of the receiver. Everything had to be rigid. No flexible wiring could be used, where such would effect the operation or adjustment of the receiver.

Accordingly, the receiver design was discussed and a new receiver was assembled. This one included the proposed refinements.

At the same time, design and construction of the smallest practical transmitter was started. This transmitter was to use receiving type tubes, since we proposed to make tests over short distances and because we wanted to use an independent plate supply of dry-cell batteries. I say independent because we did not want to rely on a wind-driven generator and because such a generator, even with a one-foot propeller uses up about 60 pounds of pay load in flight. In addition, we wanted some ground tests when the plane was not in flight.

In looking over the available dry batteries, sufficiently capable of supplying plate power, we learned that weight would be a problem if we attempted to use standard "B" battery blocks. The cockpit of a three-place airplane is not overburdened with space. This necessitated the development of a special battery of minimum weight. This brought out the "PL" battery, recommended for high potential uses at low current drains. It was pressed into this airplane radio service during development. A block of 108 volts weighs less than six pounds, whereas the same voltage in the standard "B" battery blocks would weigh 10 pounds. For filament supply, we used standard dry "A" batteries.

The transmitter was given much consideration because it involved the problem of maintenance of a steady signal on a swinging trailing antenna, which we proposed to use in our tests. It was decided to use a circuit employing a fixed oscillator and a balanced power amplifier; tuning the antenna to resonance by reeling out the antenna until maximum current was obtained. The antenna was inductively coupled to the amplifier and based on previous dummy antenna tests we knew what might be expected or at least we worked toward that goal. Antenna resonance was indicated by a small flash light in series with the antenna and which could be shunted out after tuning to resonance, since this resistance in the antenna circuit, might be of some consideration.

When the transmitter was completed for telegraphy, it occurred to us that we might try voice, using a one-turn loop around the oscillator for absorption loop modulation. Several ground and auto tests were made and we guessed that we might receive voice from the airplane up to three or five miles in actual test flight. The transmitter was tuned to a frequency of 3700 kilocycles.

THE FIRST TEST FLIGHT RESULT

ON THE first test flight, two-way communication was maintained with the airplane, telegraphy 45 miles and voice 18 miles. The plane was forced to return because of frozen oil lines, shortage of fuel and head winds. The second flight took place at night when a demonstration was given for the benefit of one of the technical clubs of Madison. This test lasted for a half hour during which time two-way voice communication was maintained throughout the test. The plane flew within a few miles of the ground receiver while Mr. Zurian described the sights and talked with several people at the meeting. Three days later we received a report from a radio amateur in Dayton, Ohio who said he overheard the whole conversation from the airplane. This distance is about 280 miles air line. Numerous short tests were made, the details of which may be omitted here. We planned one test to take place during a two-hour flight over Madison between 3:00 and 5:00 P. M. when an effort would be made to communicate with radio amateurs in every direction in order to determine a distance for transmission and reception. The transmitter and receiver were installed in a three place airplane, an Air King powered with a Curtiss OX-5, motor. This same plane was used in the two previous tests mentioned.

Two-way telegraph communication was established at a distance of 500 miles and signals from the airplane were reported up to 725 miles. A standard regenerative receiver was set up at the hangar and used to observe signals and signal reports as compared with those in the airplane. In practically every instance Mr. Zurian, apparently was receiving better in the plane than we on the ground. Lieutenant Roberts, operating at Wright Field, Dayton, Ohio, used his voice transmitter and although we could hear him faintly, Mr. Zurian, the plane operator, had no difficulty in receiving his voice in spite of the additional noise in the plane.

This transmitter used two CX-301A tubes, one as oscillator with a plate supply of 180 volts at 12 milliamperes and the other as amplifier with a plate supply of 360 volts at 30 milliamperes. It weighed $4\frac{1}{2}$ pounds, less batteries. Another transmitter, made up the same way but for operation on 7500 kilocycles was used in later tests. Voice signals were not as good and fading was more noticeable. Installed in a Travel-Air biplane powered with a Wright J5c, 200-horsepower motor, a test was made while the plane flew from Madison to the Great Lakes Naval Training Station, a distance of 100 miles. It was planned to land there and make a ground test. Except for fading or skip-distance effect, communication was maintained practically all the time the plane was in flight. Because the pilot was unable to locate the landing field at Great Lakes, it was necessary to fly back to Milwaukee and put up for the night. The return flight to Madison was made next day during which time communication was maintained. For this short-distance communication, indications are that a frequency of 3500 kilocycles is better than one of 7000 kilocycles although there is marked effect on both frequencies at different altitudes. However, if severe fading is noticed, let us say at 50 miles at an altitude of 800 feet and 7000 kilocycles, an increase in altitude to 1500 or 2000 feet may bring the signal back to normal intensity. Whether or not this is a function of frequency, distance or altitude remains a problem.

While we were summing up the results of these tests, we were asked to make five such transmitters and receivers for Commander Byrd's Antarctic Expedition. This was done, fixing the transmitters on a frequency of 6600 kilocycles. This work prevented additional tests as we had to devote practically all our time to this construction. In the midst of it all came an urgent request for radio equipment for the Greater Rockford, a Stinson cabin monoplane equipped with a Wright 200-horsepower motor and which was to attempt a flight from Rockford, Illinois, to Stockholm, Sweden with Bert Hassell pilot and Parker Cramer navigator and radio operator. We learned from past experience that this dual duty of radio operator and something else usually develops into something else and no radio operation. This is one of the problems of specialized aircraft radio and in which the human element must be considered.

We made a hasty survey of this plane and installed our small receiver, but built up a special transmitter using two 7.5-watt tubes, one as oscillator and the other as amplifier in the same circuit arrangement but not to include voice. A special suspension frame had to be made and this had to be supported in the cabin of the airplane. Space was at a premium, what with two large gas tanks and such paraphernalia as Arctic explorers carry. It was necessary that the apparatus be assembled, installed and tested within three days.

Although a license had been issued for certain transmitter frequencies, this was not available and we had to select a frequency that we thought would meet the requirements of communication over 500 miles and we therefore chose a frequency of 9250 kilocycles, fixing the oscillator on that frequency. Time would not permit a ground test. Shortly before midnight of the day of arrival of the plane, the installation was completed and all plans made to make a test flight starting at 4:30 the following morning. The fight would be to Memphis, Tennessee 600 miles and return, barring weather conditions.

The plane took off at 4:35 A. M. Mr. Mix (Burgess Battery Company) and Mr. Zurian squeezed themselves into the small remaining space and within thirty seconds after the plane took off established contact with the ground stations. A landing was made at Rockford where fuel was taken and the plane was off again at 6:15 A. M. While on the ground at Rockford, Mr. Mix reported reception of NPN, the Naval Station at Guam in addition to several others. Shortly after leaving Rockford the signals from the plane were received and during the regular intervals of observation, the signal remained a constant *r-6* and even when the plane was about to land at Memphis there might have been a slight increase in signal strength. The plane landed at 12:51 P. M., refueled and took off again at 1:57 P. M. Signals were picked up while the transmitter was being tuned to resonance at 2:07 P. M. and held until the plane returned to Rockford at 7:10 P. M. Every scheduled transmission was heard although there was a very decided change in signal strength when the plane was within the skip distance zone.

Four blocks of the "PL" type battery were used, each being a block of 108 volts. These were for plate supply with a drain of 140 milliamperes. Antenna current 0.6 ampere. Twenty one "A" dry-cells were used for filament supply, there being seven units of three cells in series parallel.

RECEPTION IN A CABIN SHIP

MR. MIX reported reception of the ground station with utmost difficulty. He said the motor noise was terrific and even more intense than that in open planes. However, it was demonstrated that any well constructed transmitter which works well on the ground will work equally well in the air providing it will remain on frequency with a swinging antenna. The inside of a cabin plane, unless it is well designed and treated acoustically, is much like the inside of a bass drum. Every outside noise or vibration is transmitted inside with marked amplification. In the remaining time before the start of the actual flight to Greenland it was necessary that we spend some time in trying to teach Parker Cramer all there was to know about this particular set and its operation. His knowledge of radio was not very great and after taking him through the motions of operation several times and with necessary orderly sketches as guides, he was able to put the sets into operation. Because of his lack of operating ability, Cramer decided to use letters of the alphabet to indicate towns over which they were passing and these he would transmit every hour on the hour but would attempt no reception.

The plane took off August 16th, the first stop to be at Cochrane, Ontario, a distance of about 600 miles from Rockford. The first signal picked up was the letter "E" indicating the plane was over Pardee, Ontario and about 150 miles from Cochrane. Signals were *r-7*. The plane landed at Cochrane shortly after noon and remained there until August 18th when it took off about noon headed for Mount Evans, Greenland. The following is quoted from Mr. Mix's report:

WHAT DONALD MIX HEARD

AT 1:57 P. M. KHAH was heard at my receiving point. Cramer at this time gave the plane's location as over Rupert House, a point not given on the code list, but found to be located between points I and J. This indicated that the speed of the plane was being reduced below the figure orginally estimated when the code list was made.

Signals on this schedule were only slightly weaker than on the previous one. Mr. Hoffman did not hear the plane on this schedule as he was engaged in a readjustment of his receiver. The plane's distance from Cochrane at this time was 192 miles and the average speed since leaving Cochrane was estimated at 69.5 miles per hour, No signal from the plane was heard on the 3 P. M. schedule although Messrs. Hoffman and Zurian were also listening this period. Before the next schedule, a telephone call was received from Rockford stating that although the signals from the plane had been heard on previous schedules, nothing was heard at Rockford at 3 P. M. Conclusions based in this report and the fact that signals were heard again later were that Cramer, engrossed in other duties, did not transmit at this time.

At 4:09 P. M. KHAH was heard at all three receiving points. Cramer gave the position as Eye Lake, a point between points J and K on the code list. Signals were *r-4* to *r-5*. The distance flown from Cochrane at this time was 331 miles and the average speed 67 miles per hour. This transmission was concluded at 4:17 P. M.

"At 5:00 P. M. KHAH was heard at all three receiving points sending the letter "L," the letter denoting the plane's position as over Fort George River. The signals at this time were continuing at a strength of *r-4* to *r-5*. The transmission was concluded at 5:07 P. M. The total distance from Cochrane at this time was 398 miles and the average speed 68.5 miles per hour.

At 6:04 P. M. KHAH was again heard by Mr. Hoffman and myself. The letter "M" which he transmitted located him over Apishkigamish Lake. This transmission lasted until 6:10 P. M. and was the last time the signals were positively identified by anyone reporting to date. The distance at this time from Cochrane was 526 miles and the average speed estimated at 76.5 miles per hour. The signals were still holding up well at a strength *r-4* to *r-5*. At this time, the plane was located approximately 1200 miles from Madison and daylight was prevailing over the entire distance.

Between 3:00 and 3:10 A. M. extremely weak signals were heard at all three receiving points which were believed to be those of KHAH and locating the plane at this time over Davis Straits, 75 miles east of Cape Chidley, the northernmost point of Labrador. None of the operators wished to state the identification as positive. Yet circumstances were presented which left very little doubt as to the origin of the signals."

The fliers returned to Rockford and later visited us at Madison when we were able to check our observations. Cramer said that all our reports were correct in every detail. He said they abandoned the plane immediately after landing at Greenland as they thought they had only to walk for a day to reach the Hobbs base. They realized that had they remained until dark and then attempted operation they would have been heard and could have relieved their families and friends of the suspense and anxiety which lasted two weeks. A press report indicated that the Navy Department felt the advisability of criticizing installation of high frequency radio apparatus in place of the usual 500-kilocycle apparatus which could be used for communication with ships at sea and shore stations. Apparently it was done in good faith but a study of possible ship and shore stations in that vicinity would soon enlighten one on the absence of such stations. In addition, the length of trailing wire antenna for this frequency was beyond consideration especially if it became necessary to operate from the ground this long low sort of antenna would be very inefficient, whereas the shorter antenna which was used could easily be raised to the full limit of the quarter wavelength fundamental. The criticism appeared, however, when it seemed certain the fliers were given up for lost but it must be said that we had not given up hope and based on an analysis of our reception reports we felt certain the plane had reached Greenland. In this we were borne out.

COMMERCIAL AIRCRAFT RADIO

FOLLOWING this came an opportunity to make a study of some practical use of aircraft radio for commercial purposes. The problem of voice communication for a distance of about 25 miles from plane to ground was given us. For this transmitter three 7.5-watt tubes are used; one as fixed oscillator, one as amplifier and the other as modulator. Every precaution was taken to make the transmitter foolproof, yet embodying simplicity in operation because we realized untrained pilots would have to operate the transmitter and receiver and it should be done with the same ease as that surrounding a line telephone.

For this short distance communication, a frequency of 3500 kilocycles was selected. Upon completion, the transmitter was ground tested. To enable us to make a determination of range in miles, we set up a receiver in an automobile and arranged transmission tests. The distances at which tests were made were 14, 25, and 36 miles. Mileage is taken from the speedometer and therefore would be somewhat less in air line miles. All tests were satisfactory and voice reception was clear and of good strength in spite of short and inefficient receiving antennas hastily set up at the various points.

A flight test of the transmitter was made November 23rd. No receiver was taken in the plane. For this test, a Travel-Air biplane, with a Curtiss OX-5 motor was used. The plane took off at 2:55 P. M., flew directly south of Madison for a distance of 50 miles and returned at 4:20 P. M. At the ground receiving station, two receivers were used. One a super-heterodyne, using two impedances coupled intermediate stages at radio frequencies and two audio stages, and the other a full-wave detector, radio frequency and two audio stages. At 25 miles, there was sufficient volume to operate a loud speaker through heavy induction interference from the power lines, indicating very clearly that a 25 mile range was entirely feasible with this power. This, of course, was a short test, but plans for continued tests in a large cabin type plane have been arranged.

COMMENTS AND SUMMARY

IN CONNECTION with aircraft radio, regardless of frequency, the amount of extraneous noise is quite an item. There is engine vibration, ignition, exhaust noise, wind rush, valve noise, propeller noise, strut and fuselage noise. We have equipped a Ryan monoplane with a muffler designed on an entirely new principle, which has reduced practically all engine exhaust noise. But with this reduced, other noises seem emphasized and even the valves on the Wright motor can be heard at low r.p.m. The solution, no doubt, will come in the better acoustical treatment and construction of cabins whereby the noise, inside a cabin plane properly treated, can be brought to a level below that in the pullman car and where conversation is possible without shouting.

Unquestionably, all future airplanes will be bonded. The matter of ignition, probably will end with shielded leads and become standard equipment. There is some doubt among pilots as to the wisdom of this because their contention is that shielding the ignition leads introduces a hazard. Others contend this is merely a question of psychology and requires only education to remove this feeling of hazard. Pilots do not like to wear helmets and head phones although many of them have no objection to it if it will enhance their safety. It is generally true that pilots fly more by instinct and feeling rather than by reliance on their instruments.

Some pilots are adverse to flying a closed cabin plane because they lose that sense of feeling. They are reluctant to fly by instruments in closed planes simply because they have been flying without instruments in open planes where the horizon is the beacon. However, there is no horizon in a fog and it is only a question of time before all commercial pilots will use their instruments instead of their instincts. It is here that radio is destined to play a very important part in airplane flight with safety. It will become as desirable to the safety of airplanes and passengers as it has to ships and passengers at sea.

Based on the results of our experimental work it is our opinion that commercial radio for aircraft will use high frequencies and low power for a number of reasons. The first being, the impracticability of a long trailing wire for a transmitter on the lower frequencies, the inability to set up this antenna in case of forced landing, because such apparatus can be more compact in construction. Further, the present trend is toward landing fields separated about forty or fifty miles where high power is unnecessary. Further, because there is bound to be less interference on the higher frequencies and especially where the communication is from the plane to the ground. It has already been pointed out by several others that the present directive radio beacons can be used for voice transmission from the ground to the plane and where weight and power may be unlimited. It might be pointed out here that battery power is suitable for airplane transmitters and receivers, especially since the cost in 1928 has been reduced seventy-five per cent. over that of 1922.

THE RADIO CLUB OF AMERICA

NEW YORK

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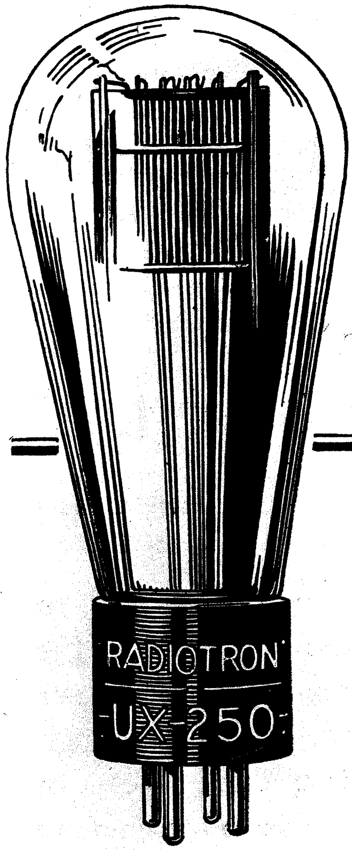
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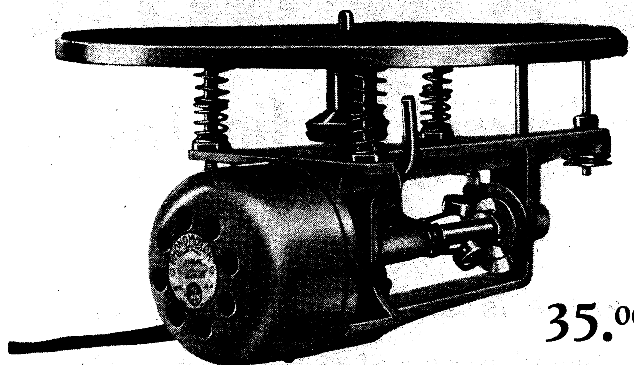

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