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THE EFFECT OF A HIGH-FREQUENCY DISTURBANCE ON THE DIRECT-CURRENT CORONA FROM A SHARP POINT

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PREFACE

The purpose of this investigation, sponsored by the Radio Development Section of the Civil Aeronautics Administration and conducted by the Reed College Physics Laboratory, is to determine a method of discharging a plane so as to eliminate corona interference commonly known as rain or snow static.

The results of the investigation indicate the possibility of a practical method for discharging a plane by means of a low-power radio transmitter operating at medium-high or ultra-high frequencies.

The views expressed in this report are those of the writer and not necessarily of the Civil Aeronautics Administration

CONTENTS

ILLUSTRATIONS

THE EFFECT OF A HIGH-FREQUENCY DISTURBANCE ON THE DIRECT-CURRENT CORONA FROM A SHARP POINT

SUMMARY

This report is divided into three parts 1 A study of the nature of the radio interference caused by a point in d-c corona It is shown that the wave form of the radiation emanating from such a point is similar to that obtained from a relaxation oscillator 2 A comparison of the conductivity of the d-c corona from a sharp point with and without the superposition of a radio-frequency corona on the same point It is shown that the formation of a radio-frequency corona increases the conductivity from 4 to 20 times that of the d-c corona alone 3 A study of the suppression by means of a high-frequency field of the radio-frequency disturbances originating from a point in intermittent d-c corona using a frequency of 5 8 megacycles It is demonstrated that the nature of the discharge originating on the point is so modified as to eliminate entirely the radio interference

INTRODUCTION

With the advent of the high-speed passenger plane it was found that when the pilot was flying "blind" through certain types of cloud formations, radio-frequency disturbances occurred which would entirely obliterate the radio beam the only reliable navigation aid under these conditions Various hypotheses were offered as to the origin of this disturbance, one of which postulated that charged drops of rain or snowflakes striking the aerial produced this interference by shock excitation of the tuned circuits in the radio Accordingly, a shielded loop was used to replace the receiving aerial on the ship and it was found that this device materially increased the "signal-to-noise ratio," but surprisingly enough, for a different reason Experiments in the spring and early summer of 1937 by a group of investigators on the United Air Lines Flying Laboratory, demonstrated that this type of interference played a comparatively small role It was found that the major radio-frequency disturbance was due to a corona from points on the plane caused by its acquisition of a large electrostatic charge during the rapid passage through charged cloud formations

This writer put forth a hypothesis that the reason for the efficacy of the shield on the loop was that the static disturbance originated nearby and was concerned with the so-called induction field as opposed to the radiation field of an open aerial at a distance of more than a quarter of a wave length

In early August of 1937 experimental proof was obtained for the above hypothesis by the writer and his assistant Mr Howard Vollum In these experiments a shielded loop was used in connection with an automobile radio so well shielded that no appreciable signal was received without some sort of antenna The shield on the loop could be grounded at will It was found that a loop unbalanced with respect to the ground behaved in all respects, except as to any current losses introduced by the shield, the same as an unshielded loop The improvement in the signal-to-noise ratio with respect to the static came only when the shield of the loop was grounded

Further experiments were carried on with a signal generator, the output of which was connected to an open radiator The radio was tuned to a distant station and the modulated output of the signal generator tuned to the same frequency as the station. This signal then operated as a disturbing element in the radio reception. When the shield was grounded, however, the station would come in clearly with practically no interference from the signal generator. In other words, the shield on the loop behaves in the same manner toward a continuous wave from an open radiator placed nearby as for the discontinuous static pulses originating at the high-voltage corona. The above experiment was repeated using another loop as a radiator instead of an open aerial. In this case, grounding the shield had no effect whatsoever. This experiment demonstrated that the effect of the shield on the loop was to cut out a type of radiation which existed from an open radiator and was not present when a closed radiator was used.

An investigation of the ordinary equations for an oscillating doublet indicated the presence of a very large electrostatic field in the vicinity of an open radiator which would diminish as the cube of the distance between it and the receiver. This would show that its intensity would rapidly approach zero at a distance of only a few wave lengths away. The electromagnetic radiation, however, would diminish inversely as the square of the distance and would as a consequence be relatively far stronger at some distance from the radiator.

After the source of the "static" was determined, the obvious solution of the problem was to find some method of discharging the airplane without interference. A long trailing wire terminating in a sharp point was found to be good for this purpose. At the suggestion of Professor George, this point was isolated from the plane by means of a resistor, the purpose of which was to damp out any electric oscillations resulting from an intermittent discharge occurring on the end of the wire. (This device has been further perfected and is in use by the air-transport companies at the present time. Although it is fairly satisfactory, the general problem is of such major importance to the air-transport industry that the Radio Development Section of the Civil Aeronautics Administration has sponsored further investigations. This report deals with one such investigation carried on in the Reed College Physics Laboratory.

EQUIPMENT

The first and most necessary apparatus to be assembled was a rectifier and suitable filters to produce a readily controlled "hum-free" d-c voltage of such a magnitude as would be necessary to reproduce the type of radio-frequency disturbance originating on a charged airplane. Figure 1 gives the circuit details of this equipment. Transformer (T1) is a General Radio variac which gives a smooth control of the high voltage. An isolation transformer (T2) is inserted in the circuit in order that either the positive or the negative side of the high-voltage equipment can be grounded. This transformer is insulated for over 100,000

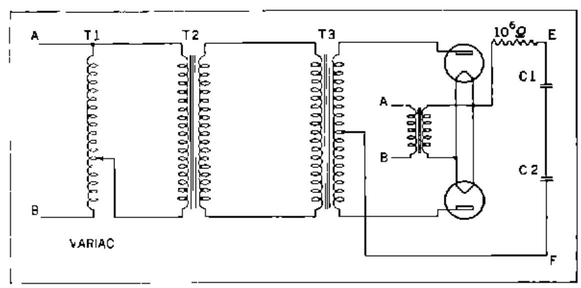

Figure 1.—Schematic diagram of rectifier and filter

volts. The high-voltage power transformer (T3) delivers a maximum of 100,000 volts on each side of the center tap. Rectification is accomplished by the use of two General Electric Kenotrons type KR–3. These are used in the conventional low-voltage full-wave rectifier circuit. This circuit has a disadvantage of limiting the high-voltage output to half the peak inverse potential of the tubes, in this case 70,000 volts. However, its convenience outweighs the above disadvantage, especially since the high-voltage transformer available had a grounded center tap. The circuit also uses fewer condensers for the same amount of filtering and it was found that 70,000 volts is greater than the amount needed to produce the desired effect. The filter system consists of a 1-megohm liquid resistance and a ¼-microfarad condenser formed by two General Electric Pyranol

½-microfarad condensers (*C–1* and *C–2*) in series, each one protected by spark gaps to prevent overloading. The entire apparatus is adequately fitted with corona shields consisting of hollow copper spheres 3 inches in diameter. There is no measurable corona in the system up to and including 70,000 volts. The ability to ground either the positive or negative side of the high voltage was found to be absolutely essential in subsequent investigations.

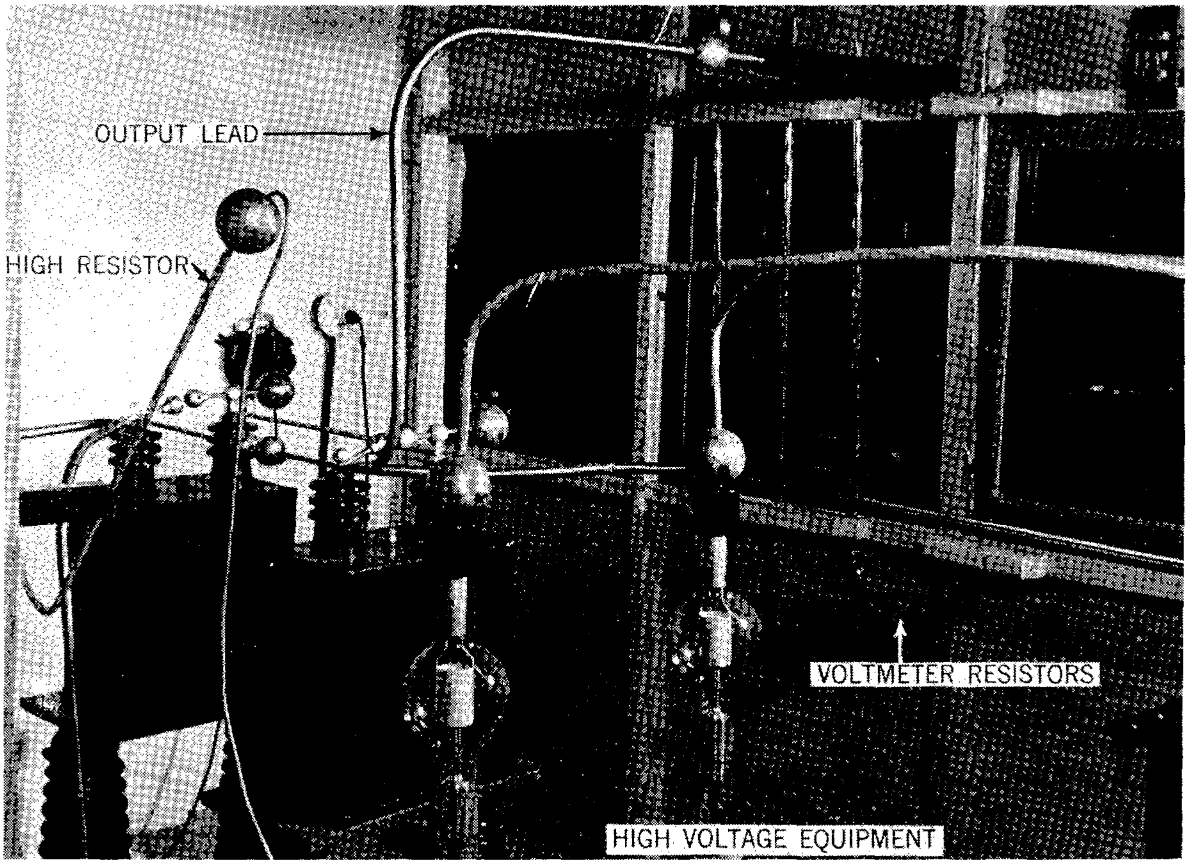

Figure 2.—High-voltage rectifier equipment.

A picture of this high-voltage apparatus is shown in figure 2, in which it will be noticed that the "hot" side of the output is fed through the wall of the room in a standard insulating tube such as is used in ordinary X-ray installations. Figure 3 is a picture of the other terminus of the high-voltage lead. *A* is a telescopic brass tube which allows plate *B* to be raised or lowered by means of a string. Electrode *B* is a standard aluminum corona shield about ten inches in diameter.

It will be noted in these experiments that the point *C* is always grounded. In earlier experiments electrodes *B* and *C* were interchanged, but we do not find any appreciable difference in the high-frequency interference with either connection. As will be shown in later photographs and diagrams, there are certain inherent advantages in grounding the point, since this may be part of a high-frequency coil, and it would be dangerous to have this coil connected to the radio-frequency transmitter and to the high voltage simultaneously.

Figures 4 and 5 are pictures of the radio-frequency transmitter and its associated feeder system. Figure 6 shows the other terminus of this feeder system and the associated tuning equipment. A radio-frequency ammeter is

270805 - 41——2

placed in this circuit. The primary of the high-frequency transformer, as can be seen from figure 6, consists of two turns of copper tubing one-half inch in diameter. A large number of secondaries have been tried, one of the most successful of which was a coil wound on a bottle about 5 inches in diameter, the turns being fastened in place by cellulose acetate cement. A very interesting phenomenon takes place in such a coil when a spark occurs in the high-voltage system. The very intense magnetic field between the wires of the coil, due to the high instantaneous current, will usually tear them from their positions and cause the coil to collapse. These coils are tuned by their own distributed capacity. During the process of manufacture, the natural frequency of the coil is determined by an accurately calibrated grid-dip oscillator. This method, devised by Mr. Bell-

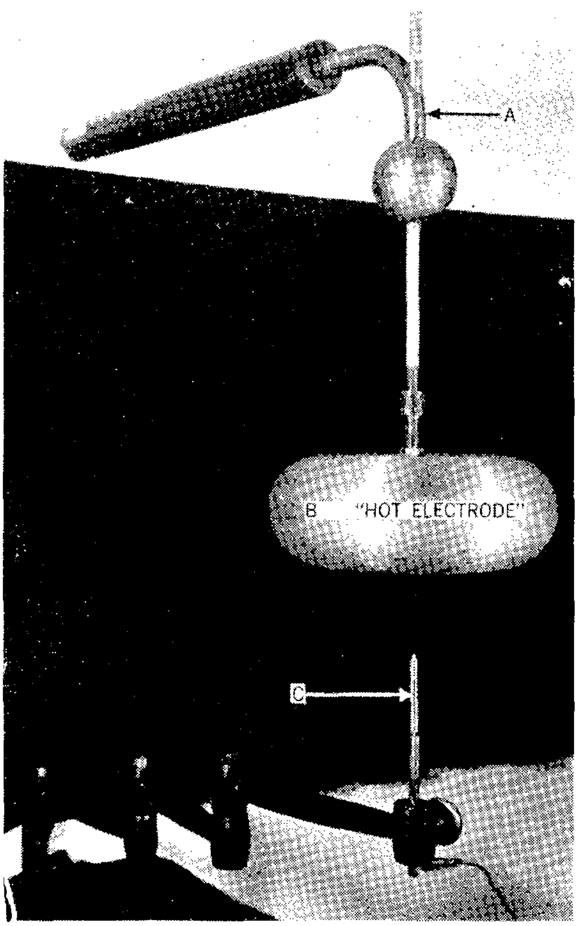

Figure 3.—High-voltage electrodes.

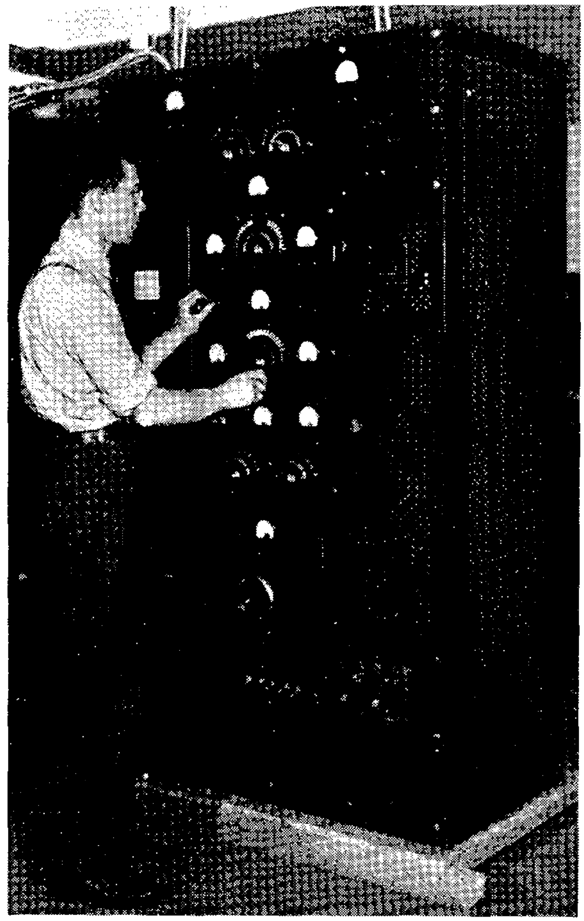

Figure 4.—Transmitter used to produce medium high-frequency field.

ville of the Forest Service Laboratory, has proved to be very rapid and convenient. The last coil used is shown in a picture, and consists of 45 turns on a grooved isolantite form four inches in diameter. This coil is shown in more detail in figure 7. Note the provision made at the top of the coil for the insertion of electrodes of any desired shape. It has been found that points made of wire of less than one-eighth of an inch in diameter burn very quickly, because of the local heating. Successful experiments have been carried on using either brass or copper rods 1/4 inch in diameter and ground to a point of the desired shape. There is enough mass and good thermal conductivity to take the heat from the point with sufficient rapidity so that even with a very hot radio-frequency arc, there is very little damage to even a fairly sharp point. The

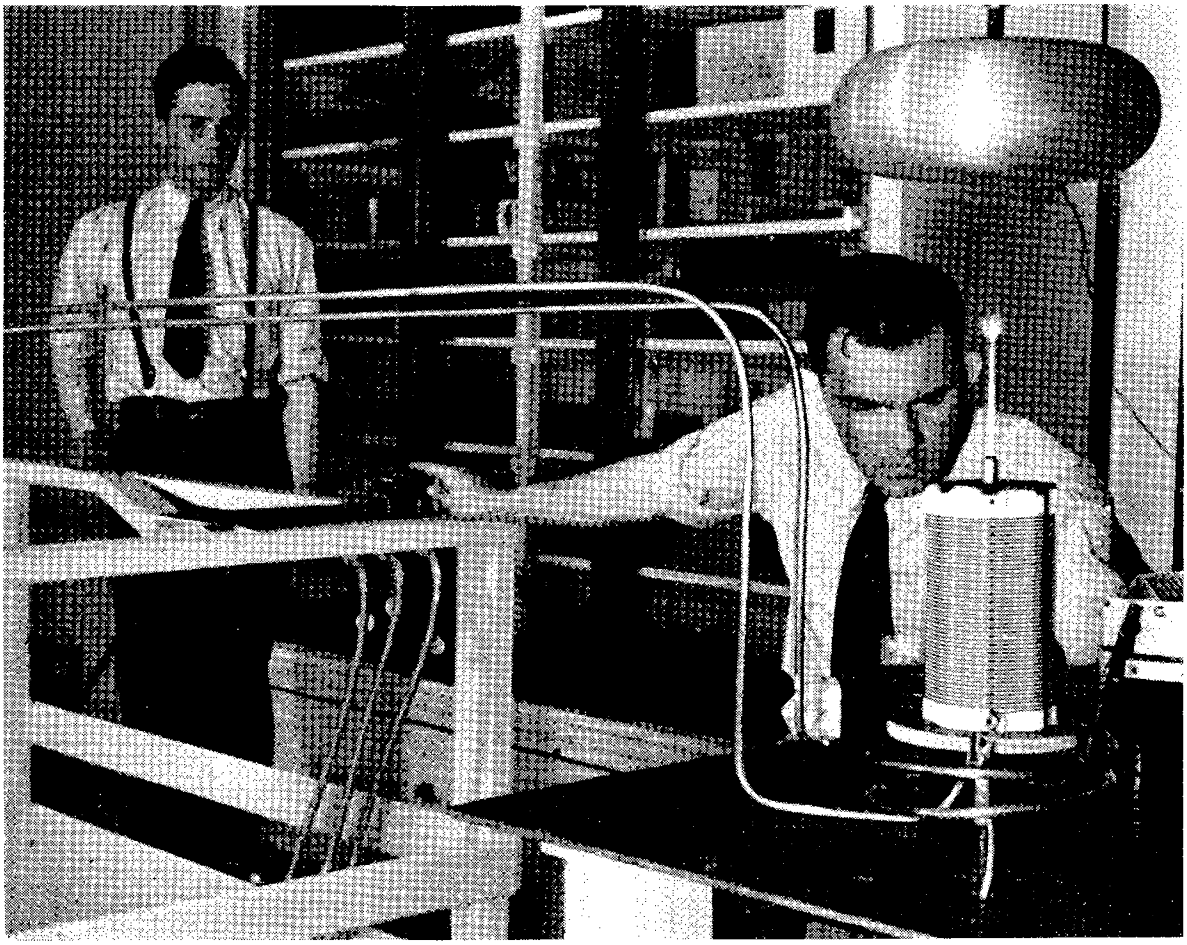

Figure 5.—Transmitter feeder system.

above statements might imply conclusions which could be erroneously interpreted. There is, of course, a limit as to how sharp a point one can use for discharging a ship. When a long tapering point is used, burning of the point takes place without any radio-frequency arc.

The circuit used in connection with the studies of the electrical conductivity of the radio-frequency arc is shown in figure 8. A portion of the laboratory set-up is shown in figure 9. It was necessary to ground the dead end of the coil through a shielded wire cable about 20 feet long, in order to remove sufficiently the d-c amplifier from the very intense high-frequency field. At the coil a good deal of the high frequency was bypassed through condenser *C*–1, which consisted of twelve 0.004 microfarad condensers connected in parallel, and of the type formerly used in spark transmitters. The total capacity was 0.048 microfarads. However, even with this large amount of direct bypass, a sufficient high-frequency signal will get to the grids of the first stage of the amplifier to cause rectification of this circuit. This proved to be one of the most difficult experimental problems to solve. A very high-Q wave trap *EF* inserted as shown in the diagram took care of the situation. It was found that the tuning of this wave trap depended to some extent upon the amount of current in the main feeder lines. Consequently it was necessary to make frequent checks in order to ascertain whether or not conditions had changed. A microammeter was placed directly in the ground circuit, and a constant check was made between the readings of this d-c instrument and the recording mil-

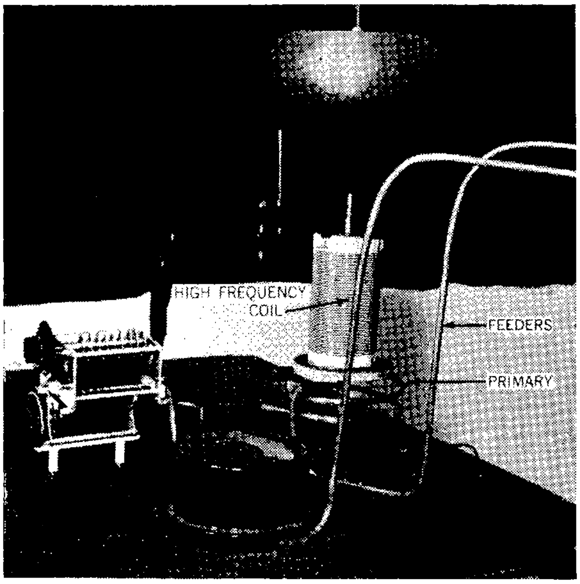

Figure 6.—Terminus of feeder system showing the high-frequency transformer and coupling arrangement.

liammeter. The measuring equipment is shown in figure 10. We can safely say that the data given in the curves of figures 11A–11F, inclusive, are accurate and exact, and are not in any manner due to superfluous signals which might have entered the amplifier.

A number of various receivers have been used in this investigation, the most satisfactory of which is shown in figure 12. This is a field strength measuring apparatus purchased from station KOIN. Incorporated in the equipment is a Philco battery type superheterodyne re-

Figure 7.—Secondary coil of the high-frequency transformer.

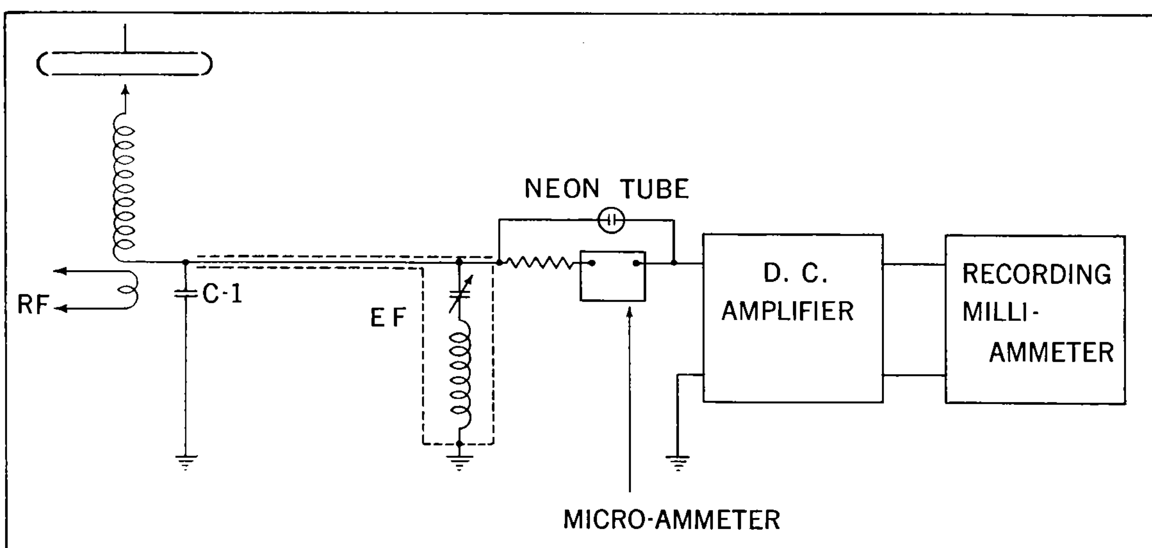

Figure 8.—Schematic diagram of circuit used for studying the electrical conductivity of the radio-frequency arc.

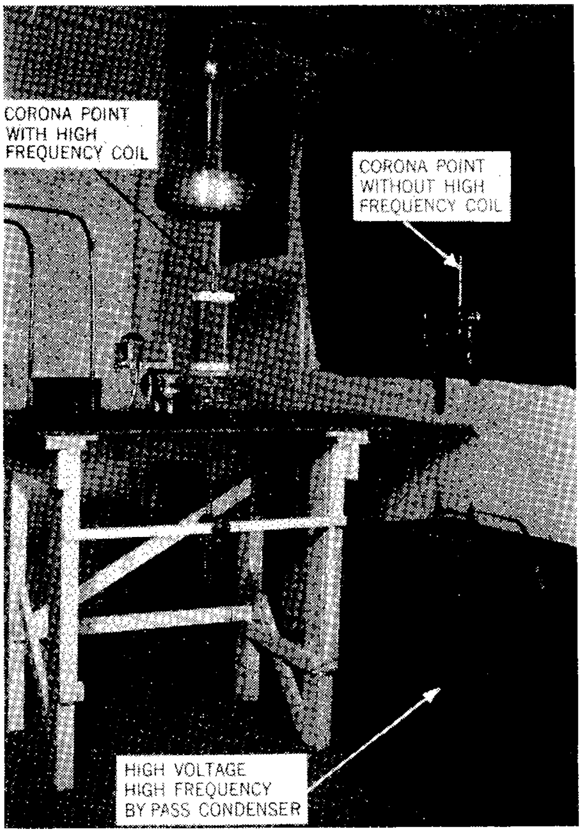

Figure 9.—Equipment used for studying the electrical conductivity of the radio-frequency arc.

ceiver. For the purpose of receiving the interference from the crying corona, an unshielded loop has been far more satisfactory than an aerial. In order to increase the disturbing signal from the crying corona, the loop was inductively coupled to the ground circuit of the coil as shown in figure 13.

An analysis of the d-c corona consisted of two parts: 1. A series of experiments to determine if other physical and electrical phenomena similar in nature accompany the interference originating in the corona discharge. 2. A determination of the lowest audio frequency appearing in the output of the radio and associated with the "crying" static. An arrangement was made so that the wave analyzer could be very quickly connected to points *AB*, *EF*, or *GH* as shown in figure 14. Data from the first arrangement gave the characteristics of the audio-frequency current flowing in the ground circuit; from points *E* and *F* the output of the radio receiver, and from *G* and *H* the actual sound as received by a crystal microphone. In this manner it could be ascertained whether or not the disturbance was connected with the point alone or with the associated circuit elements. Attempts were made to use a photo-electric cell and associated amplifier to check further on this point. This method was later abandoned.

In order to have a record of the frequency range of the crying corona from a given point and with different field strengths, it was found necessary to arrange the wave analyzer for the insertion of the recording milliammeter. This was accomplished by connecting the d-c amplifier with an adapter to the last tube of the analyzer, so that the presence of this connection in no manner interfered with the normal operation of the instrument. In preliminary measurements, the dial of the analyzer was operated manually, in an attempt to keep it in synchronism with the motion of the recorder. Later experiments were conducted with the dial of the analyzer connected directly by means of a flexible shaft to the driving gear of the recording milliammeter. Figure 15 shows a picture of the analyzer, recording milliammeter, and the flexible connection. Since the graduations on the dial of the analyzer are not a linear function of the frequency, it was necessary to devise some means of calibrating the record. Figure 16 shows how this was done. The key labeled *K* is a single-pole double-throw switch which normally connects the milliammeter to the amplifier.

Figure 10.—Apparatus used to measure the conductivity of the radio-frequency arc.

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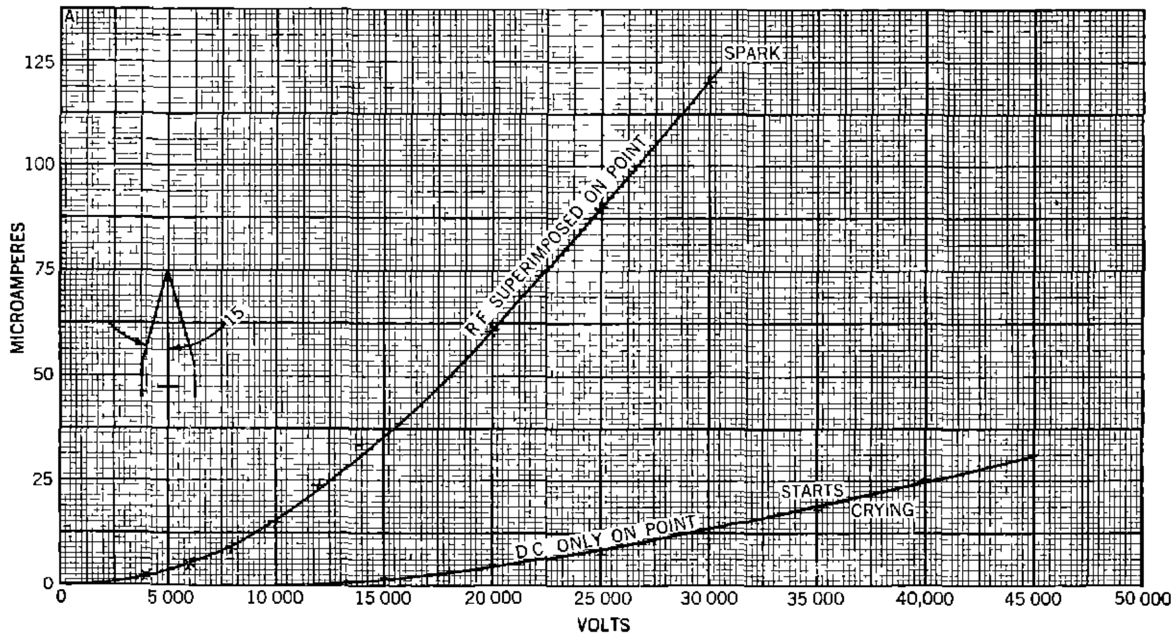

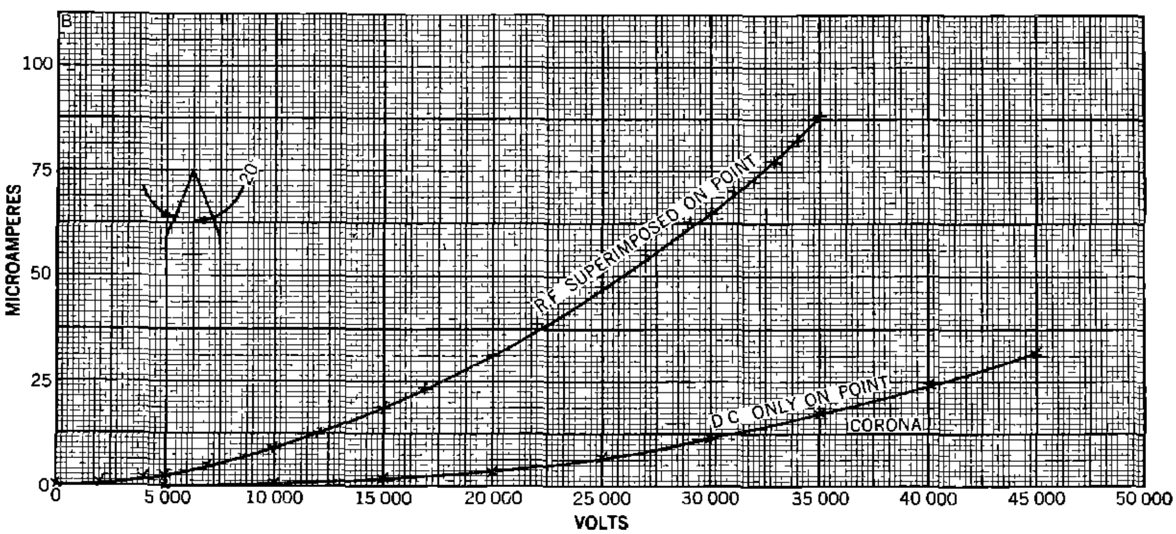

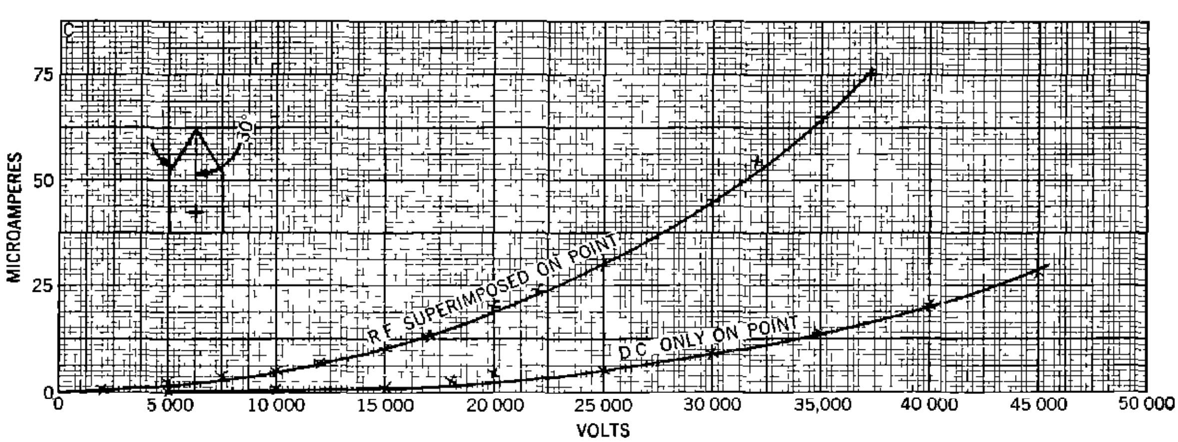

Figure 11.—Ionization current of d-c corona

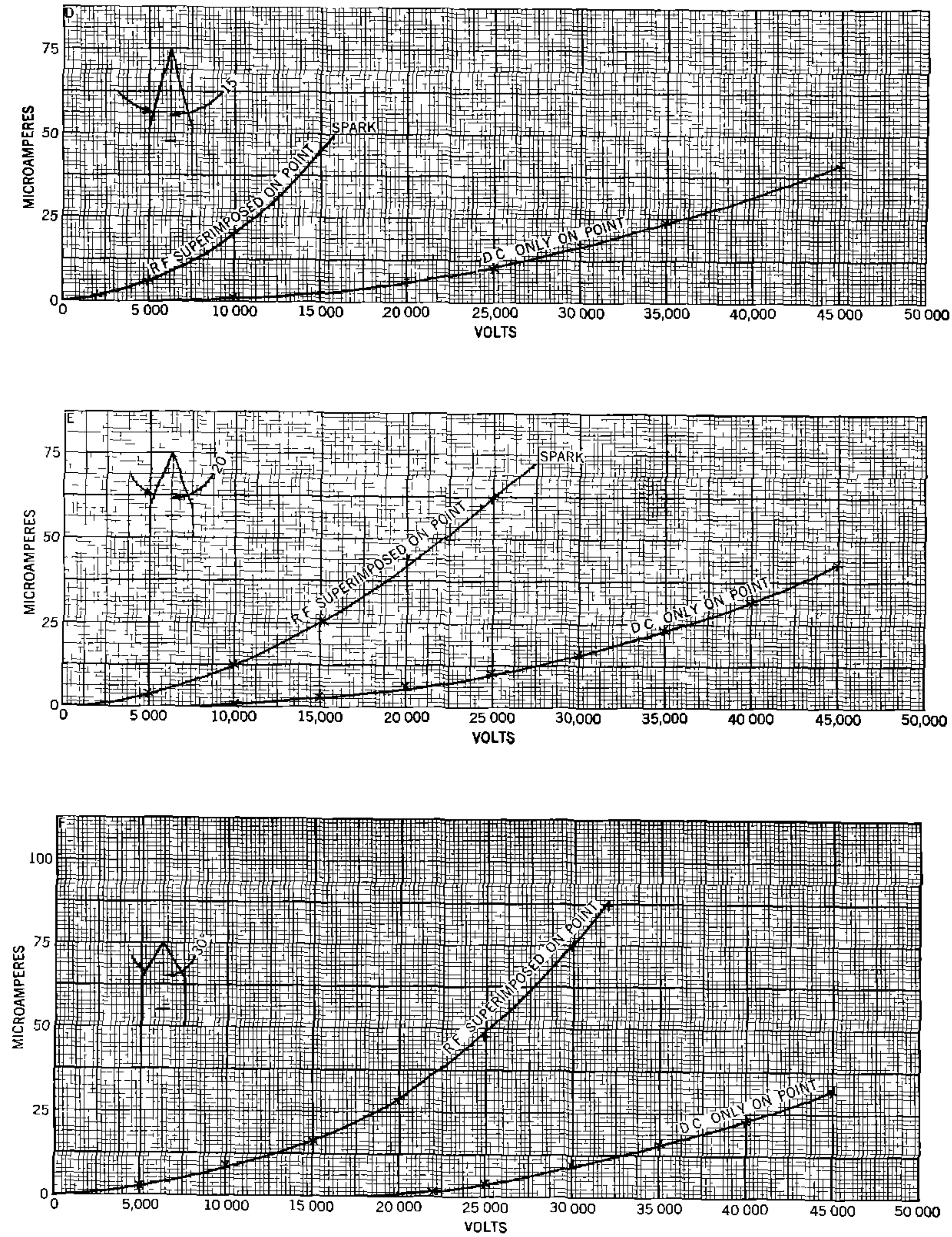

Figure 11 —Ionization current of d c corona—Continued

As the frequency dial on the analyzer rotates, the key is depressed at those times when a graduation passes the index. The battery is arranged to deflect the recording milliammeter in a direction opposite to that normally encountered. These marks, therefore, give an accurate calibration of the record.

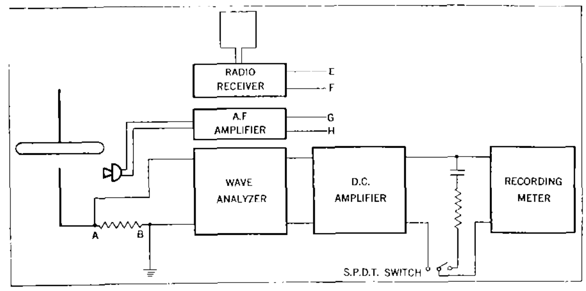

Figure 14.—Circuit arrangement used to study characteristics of the corona discharge.

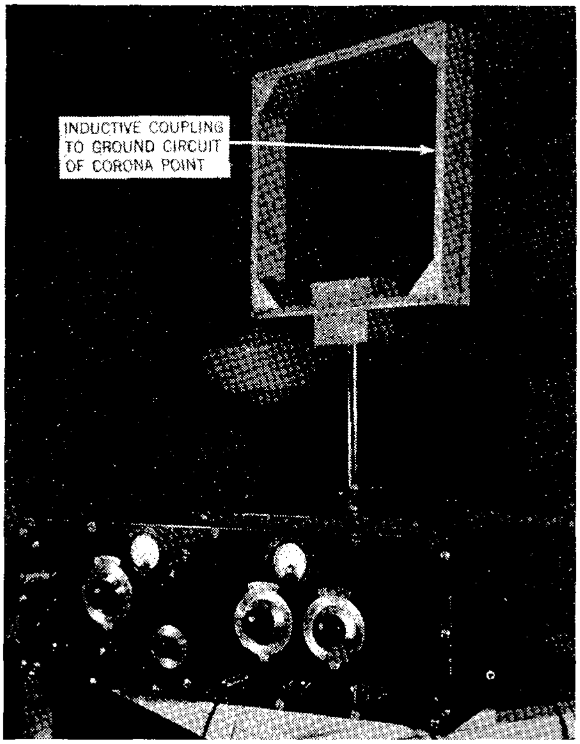

Figure 12.—Receiving apparatus used in conductivity and interference tests.

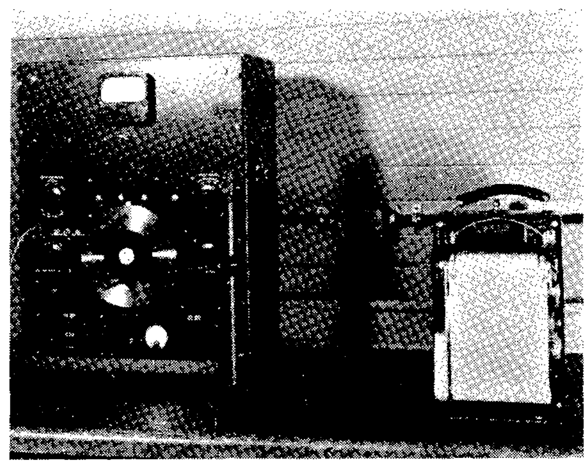

Figure 15.—Wave analyzer and recording milliammeter.

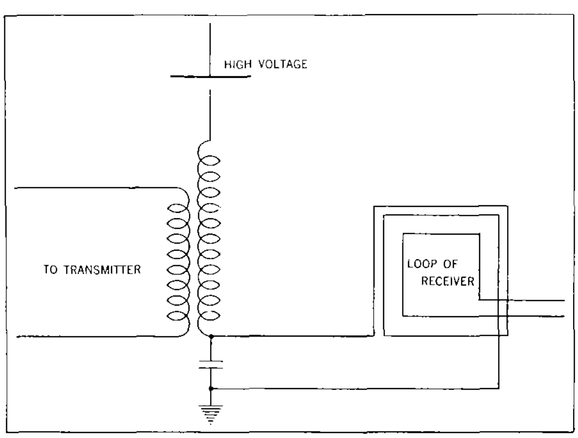

Figure 13.—Circuit used to couple the receiver to the corona apparatus.

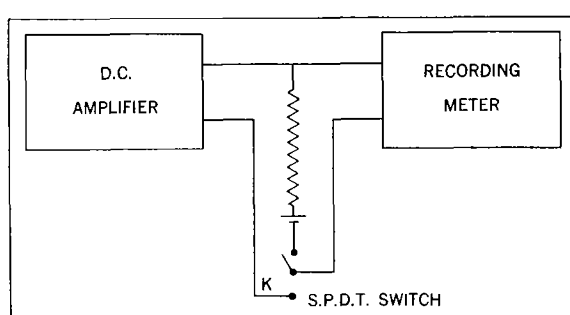

Figure 16.—Circuit for calibrating wave analyzer record.

TESTS AND RESULTS

The first test was to determine the type of interference originating in a crying corona when the point was positive Accordingly, the output of the radio was connected directly to a cathode-ray oscilloscope, and it was found that the wave shape was very similar to that obtained with the ordinary gas discharge relaxation oscillator Figure 17A shows the type of wave observed on the screen It was apparent that these oscillations take place at an audio rate and the proposition has been advanced by this writer, in agreement with several others, that the action in a radio is a shocking of the tuned circuits into oscillation by the very steep wave front characteristic of this particular interference

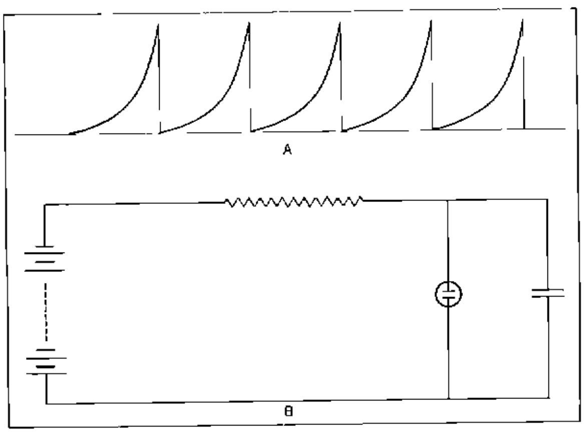

Figure 17.—(A) Wave shape of positive point corona interference (B) Schematic diagram of relaxation oscillator

To check this conclusion, an ordinary neon tube oscillator, the circuit of which is given in figure 17B, was constructed, the output of which through a 0 0001 microfarad condenser was connected to the antenna of a radio receiver The action of this type of interference on the radio was identical, as far as could be ascertained, with the interference due to the crying corona It, therefore, seems fairly conclusive that with this particular type of interference, there are no radio frequencies of the order of magnitude of 300 kilocycles, such as are used for the radio range beams It was found that when the radio was adjusted to maximum sensitivity, it was not even necessary to couple the output of the oscillator direct to the antenna circuit the electromagnetic field being of sufficient intensity to actuate the tuned circuits of the radio This experiment shows that such interference as that caused by the crying corona can originate with an ordinary relaxation oscillator performing at a comparatively low audio frequency, the fundamental of which can be less than 3000 cycles

In the case of a negative point corona, however, the pattern on the screen of the cathode-ray oscilloscope is entirely different There are no definite wave shapes within the audio-frequency range, and later tests of the wave analyzer indicate no audio frequencies below 17000 cycles The disturbance is of a higher frequency Experiments by others have shown that the frequency of the negative point corona may run as high as 200000 cycles This has been the cause of a rather interesting phenomenon observed recently in the laboratory There would be very little interference in the radio except at certain definite electrostatic field strengths A very slight change in the voltage on the plate would cause the interference to die out An observation by Mr W E Jackson, Chief of the Radio Development Section, Civil Aeronautics Authority, to the effect that it sounded like a heterodyne, led to the explanation The discharge from the negative point takes place at a radio frequency, and the frequency of the discharge is a function of the strength of the electrostatic field at the point With a given spacing, it is of course proportional to the voltage difference between the two electrodes Certain intense radio-frequency fields due to local broadcasting stations, etc , are present in the room When the voltage is just right so that the radio-frequency disturbance from the negative point is of such a value that it can heterodyne with one of these high-frequency fields so that the sum or difference frequency is that to which the radio is tuned, a large disturbance is noted It was found that when the voltage on the point was changed, it was often possible to get the interference by retuning the radio It is also possible that the radio-frequency interference from the point may reach into the broadcast band In this case, there is a possibility that it would be received in the ordinary manner by "beating" with the local oscillator in the receiver. Further investigation of this hypothesis is contemplated.

With this explanation in mind, it is natural to seek for the reason for the large amount of interference when the plane is negative. My explanation is that a large number of points probably are breaking into a corona. The frequency of the interference will depend upon the character and position of the point. The electrostatic field will not be constant as in the laboratory, but will undoubtedly vary over very wide limits. The total interference reaching the receiving antenna on the ship will cover a large band of radio frequencies. There will, therefore, be a practical certainty that these radio-frequency disturbances heterodyning with each other and their harmonics together with incoming signals will completely cover the frequency band to which the radio is tuned. The action on the radio itself in this case will be entirely different from the action when the plane is positive.

In the early experiments with a corona discharge, the writer used a method for visual observation which was extremely satisfactory and which he can recommend to other investigators. An 18-inch concave mirror, such as is used in the older type searchlights, was placed behind the point and at the proper distance. The observer could then stand at a safe distance and observe the greatly magnified image of the point. It was therefore possible to note the streamers, etc., which are ordinarily very difficult

Figure 18.—Mirror used to focus corona arc.

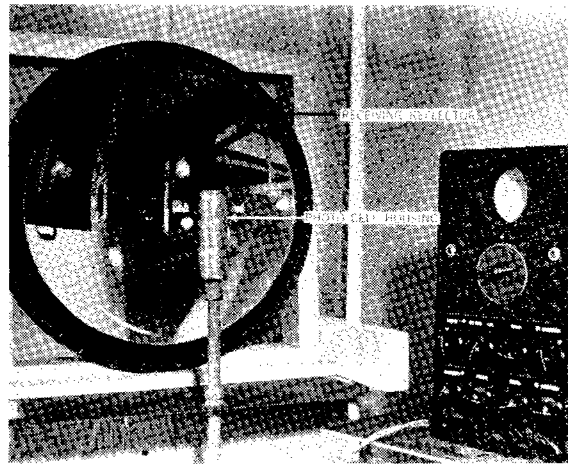

Figure 19.—Photo cell and shield placed at focus of mirror.

to see unless the observer is very close to the phenomenon. It is not feasible to make visual observations in the immediate vicinity of the point, because of the proximity to the high-voltage electrode. The large condensers in the high-voltage system make it a very dangerous piece of apparatus near which to work.

One of the earliest observations of the writer in working with the d-c corona was that the sounds from the radio seemed to be of the same frequency as the sound which could be heard directly from the corona itself. This led him to attempt an investigation and correlation of phenomena occurring simultaneously with the intermittent discharge from the positive point known as the "crying" corona. Four different types of phenomena may be present: 1, As the corona burst occurs, it would be natural to suppose that an emission of light would accompany it; 2, There is a sudden evolution of heat and a corresponding expansion of the gas in the neighborhood giving rise to the sound; 3, The motion of this charge should give rise to an electromagnetic field; and 4, The charge must come from the ground. If, now, the point is connected to the ground through a resistor, there should appear across this resistor a difference of potential corresponding to the passage of the charge. It was the hope of the writer that he could pick up these various phenomena and by means of electronic switches, show them simultaneously on a large oscilloscope. The first investigation was an attempt to focus the light from the corona onto a photo-cell. Two search-light mirrors were used, and the photo-cell and amplifier not only well shielded but balanced with respect to the ground, so that with respect to the photo-cell the amplifier acted in a differential manner. The mirror used to focus the arc is shown in figure 18, and the mirror used to focus the photo-cell is shown in figure 19. To the writer's great surprise, no recurrent character of the emitted light was noticed, even though the cell and amplifier were many times more sensitive than necessary. This was checked by putting a very feeble intermittent light in place of the point. Although these experiments ended in failure, the writer is not yet convinced that a sudden emission of light does not accompany the burst of the corona, but feels that some other phenomenon occurring has masked the effect which he sought to measure. These experiments will be repeated later with different apparatus. A great deal of trouble was encountered, since the photo-electric cell is inherently a high-impedance device, and consequently is very difficult to shield from the very intense electrostatic field which is present with the d-c corona. It may be possible that in some manner a partial blocking of the amplifier took place, although the writer felt that he had thoroughly investigated this possibility.

The other experiments in this connection were more successful. Two 24-inch mirrors were used to pick up the sound from the corona and

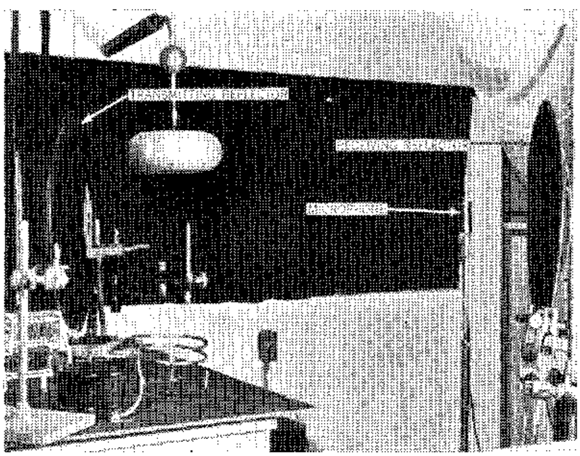

Figure 20.—Reflectors used to focus sound from the corona on the microphone.

focus it on the microphone as shown in figure 20. Although the sound from the corona is perfectly audible, and it would seem that a microphone placed nearby would be sufficient for the experiment, it was found that when the amplifier had the proper gain, all of the sounds in the building were also received by the system. However, by means of the arrangement of mirrors, it was possible to increase the signal-to-noise ratio of the combination so as to eliminate all noises except those occurring in the immediate vicinity. The output of the microphone was fed into an amplifier, the output of which was fed through a selector switch to the input of a General Radio wave analyzer. The output of the radio also was connected to the amplifier through the proper terminal of the selector switch, as was also the voltage occurring across the resistor of the point. It was found that in case of the positive point corona, the frequencies of the noise received by the microphone and of the static received by the radio and of the signal occurring across the resistor were identical for any given electrostatic field strength. Because of the rapid attenuation of high frequencies in the audio system of the radio, very few harmonics of the fundamental frequency were received. As far as could be ascertained, the analysis of the sound from the microphone was identical with the analysis of the voltage occurring across the resistor in the ground circuit. These could not be compared exactly, because of the fact that the microphone and its associated amplifier did not have the same characteristics as the amplifier which would receive the signal across the resistor. Time did not permit accurate calibration of these instruments, which would be unjustified because of the fact that the d-c voltage impressed upon the point could not be held to the required constancy to make exact experimental comparison possible. However, there seems to be little doubt that these three phenomena have essentially the same frequency characteristics, and for this reason the writer is loath to accept the negative result he obtained with the photoelectric cell.

Later the recording milliammeter was arranged to drive the wave analyzer, which had been connected electrically to the recording milliammeter through the proper amplifier as shown in figure 15 When the point was negative, it was found there was no definite audio frequency which characterized the interference This type of interference has been described by pilots as "hash" It is now well known however, that under certain conditions one can get very definite relaxation oscillations when the point is negative But in our experiments, we have failed to obtain any definite frequency within the range of the wave analyzer, namely, 0–16500 cycles There was, however, a definite high-pitched note as heard by the ear, although the wave analyzer would not show it at all The writer puts forth the hypothesis that this note as heard by the ear is due to the beating of two high-frequency oscillations above 10000 cycles The nonlinear characteristic of the ear would allow the beat frequency to be heard

Loeb (p 517), *Fundamental Processes of Electrical Discharge in Gases*, states that these periodic discharges have been observed at frequencies as low as 5000 cycles per second We can only say that with the various points we have investigated, no frequencies this low have been observed The analysis of this general noise level of the negative point corona indicates that most of the energy is in the higher audio frequencies, very little occurring below 2000 cycles It is to be noted that what is referred to as noise is just the random disturbance characteristic of this type of static

Interference from the positive point corona is always characterized by a definite audio-frequency note and its overtones A complete record of this interference was made at voltages varying between 25000 and 50000 as measured between the point and plate

All of the energy of the crying corona existed in high audio frequencies and at no time have we observed a frequency below 700 cycles This would indicate that if the carrier wave from the beam station were keyed with an A or an N and if the intermediate frequency amplifier of the pilot's receiver were only 400 cycles wide, he could by means of his beat-frequency oscillator receive the signal even though the ship were heavily charged with many points in d-c corona However, for certain very practical reasons, to enable the simultaneous broadcasting of weather reports and the radio beam, a beat-frequency oscillator cannot be used in this connection, since it would beat continuously with the wave from the central tower The carrier wave from the central tower is continuous and differs in frequency by 1020 cycles from the beam which is keyed A possible arrangement of the radio receiver suggested by my research assistant, Mr George Guthrie is as follows

It will be assumed that there are two intermediate frequency amplifiers in the pilot's radio The sharply tuned one would be used only in case of an emergency, such as when the static would drown out the beam The other intermediate frequency amplifier would be used as at present To illustrate we will assume that the pilot's radio is tuned to the Portland range The central tower has a frequency of 332 kilocycles, and the keyed carrier is on a frequency of 333 02 Let us assume that we have an intermediate frequency amplifier sharply tuned to 464 kilocycles and the regular amplifier to 465 kilocycles, but which has a crystal of the type used in the R M E 69 This crystal can be inserted by the same switch as used to divert the signal through the narrow band amplifier during conditions of extreme static The signal from the central tower is stronger in all cases than the keyed carrier from the pairs of towers The pilot will tune his radio so that the local oscillator will be 797 kilocycles

It, therefore, is seen from figure 21 that the automatic frequency control will tie into the continuous carrier, and will hold the radio in tune This would answer the argument that would immediately be presented that this tuning would be too precise for a pilot to make in an emergency If no other method for the elimination of the static were available, these experiments would indicate a possible and practical method for the reception of the desired navigation signal For instance, the pilot still would be able to take bearings in static if his intermediate-frequency amplifier had a filter which would cut off at about 200 cycles Experiments in the laboratory verified this result With the 400-cycle crystal of the R M E receiver inserted in the intermediate-frequency amplifier, it was found possible to receive a comparatively small signal from a signal generator even though under normal operations the interference from the d-c corona was many times too intense for reception. The immediate practical difficulty is the construction of such a filter which cannot be shocked into oscillation by the sharp bursts of static. Some trouble was noted even with the single crystal used in these experiments. These experiments are included in order that this report may be a complete record of all experiments performed rather than a proposal for a practical method of eliminating the static disturbance. Undoubtedly the most satisfactory method for accomplishing the latter would be to keep the charge off the plane.

A large number of curves were plotted to determine the efficacy of a radio-frequency arc for discharging the plane. The curves of figures 11A–11F, inclusive, all show that the arc is much better than a sharp point. It was felt that from the practical standpoint, the efficacy of a sharp point should be the basis upon which comparison is to be made, since a sharp point is in use at the present time in connection with the trailing wire. Points of various shapes were used, and it is seen that not only does the current which will pass from a point to a plane increase as a point is made sharper, but there is a corresponding increase in the current which will pass through the radio-frequency arc originating on the point. In this connection figures A and B of this series should be compared. There is a limit as to sharpness of a point which can be used, since it is found that even the corona discharge with the high-frequency arc will generate sufficient heat to burn and thus change the character of a long tapering point. For this reason the writer has not considered to be practical the suggestion advanced by another worker in this field to the effect that points of certain shapes can be used to discharge the plane without interference. Unfortunately, these shapes are such as to give a long tapering point which is very easily burned and the character of which will therefore change.

An examination of these curves will show that the radio-frequency arc has a "figure of merit" with respect to the point ranging from 4 to 10. We will define this "figure of merit" as the ratio of the current which will pass through the radio-frequency arc to that passing from a sharp point with the same voltage difference. The ratio is especially high at low field strengths, and it indicates a possibility of using the arc to keep the charge on the plane to a very low value.

The main part of this investigation has dealt with the elimination of the interference present when the point is in either positive or negative d-c corona. The interference is due to an intermittent action. That is the charge which passes from the point into the surrounding region is not continuous such as is the case of a current flowing in a battery circuit. Some changes in the amount of charge flowing give rise to electromagnetic fields which are picked up by the radio receiver either in the frequency band to which it is tuned, as is probably the case of the negative point corona, or by shock excitation of the tuned circuits by very sudden pulses, as is in the case of the positive point corona. The method which will be described below for the elimination of the interference applies to both the positive and negative point corona. However, the interference from the positive point corona is more difficult to eliminate and is much more severe although more seldom in practice. In both cases, the ionization of the gas in the neighborhood of the point of sufficient amount to pass the required current must be due to the very

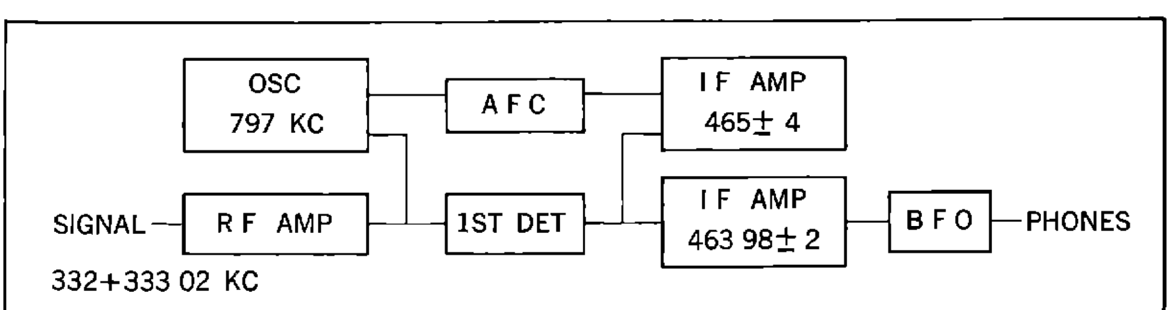

Figure 21.—Block diagram of narrow band receiver.

intense electrostatic field existing there This is evidenced by the fact that no current flows without that field For the exact mechanism of such discharges the reader is referred to a recent book by L B Loeb, *Fundamental Processes of Electrical Discharge in Gases* in which there is an excellent discussion of the fundamental mechanisms of the corona discharge Without looking too closely at the mechanism, one might postulate that if a continuous amount of ionization could be produced by some external source and not by the electrostatic field, a continuous flow of ions could take place without the disruptive action characteristic of the intermittent positive point corona

The above is a post-rationalization of the series of experiments described below Actually the writer thought of this method while listening to a paper by Mr Alford and Mr Pickles of the Mackay Radio Co presented at a Pacific coast convention of the I R E in 1938 Mr Alford described experiments with the high-frequency corona and then stated that as the frequency was gradually raised to above 3 megacycles, it was impossible to obtain a corona that in place of this corona an arc would suddenly appear The words "it was impossible to obtain a corona" immediately roused the interest of the writer He put forth the hypothesis that perhaps a d-c corona could be "squelched" by the superposition of a radio-frequency field of the proper amount and frequency When the subject was broached to Mr Alford, he tentatively agreed that such a phenomenon might be possible and invited the writer and Dr Knowlton to go to Palo Alto to witness the experiments This we did in the fall of 1938, when Mr Alford and Mr Pickles attempted to set up apparatus for obtaining the "crying" positive point corona The object of the experiments was then to superimpose upon these points in d-c corona a high-frequency field The experiments were inconclusive, because of the fact that it was impossible to make any point "cry" We now know that the reason for this was that the very intense high-frequency field from the transmitting aerials located in the immediate vicinity so modified the d-c corona as to eliminate the intermittent action In Portland, a transmitter was hurriedly assembled in the laboratory on 3 5 megacycles There seemed to be some reduction in interference but the results were not too conclusive at that time Special care had to be taken to keep the radio from being blocked by the high-frequency field This high-voltage system was not completely corona-free at that

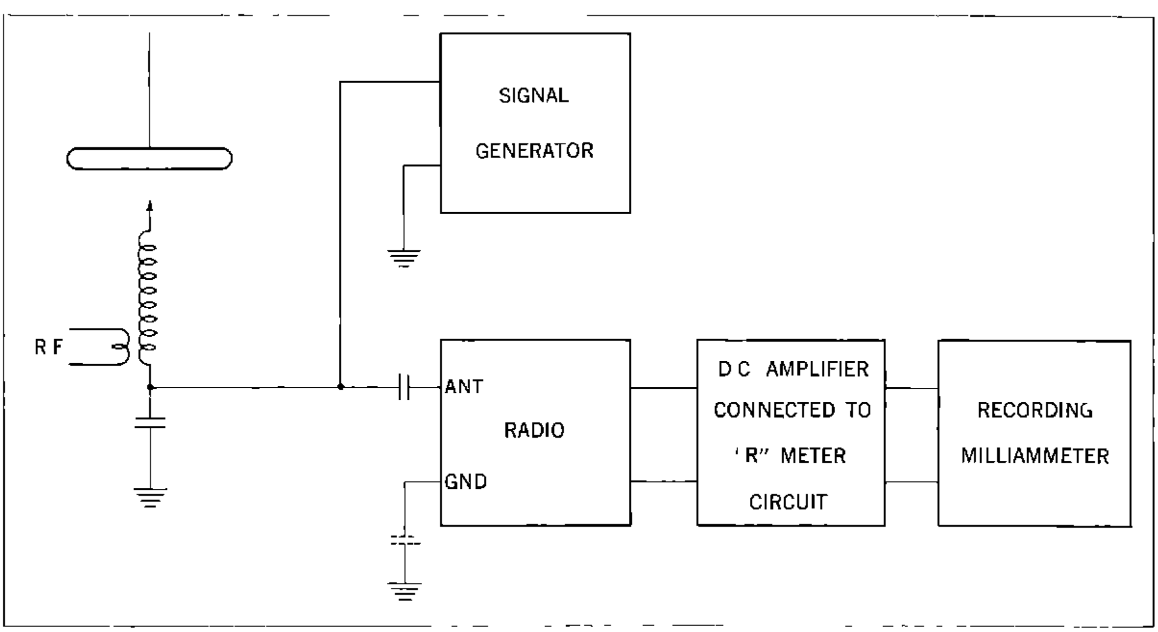

Figure 22 —Circuit used to determine the effect of a radio frequency arc on d c corona interference

time, and other difficulties prevented an immediate and clear-cut proof of the above hypothesis. However, in December 1939, all conditions leading to extraneous results had been eliminated, and it was definitely shown that the presence of a very small high-frequency arc at the point would eliminate all radio interference caused by the d-c field being applied.

These experiments show that when a visible arc from a radio-frequency source originates at the point and thus produces the ionization, direct current can flow through or from the point into the surrounding medium without any interference. A phonograph record to demonstrate this effect was made and sent to the Civil Aeronautics Authority, it being the most satisfactory and spectacular method to show the effect. However, phonograph records cannot be published, and the following method was devised to show graphically the effect on the radio interference of a radio-frequency arc. The diagram for this set-up is shown in figure 22. As can be seen, the recording milliammeter through its associated amplifier is put in the same circuit as the 'R-meter' of a RME–69 communication receiver. This receiver is directly coupled into the ground circuit of the point as shown. When a high d-c voltage is impressed between the plate and the point, interference originating at the point will become very intense. This interference which occurs at an audio rate is too fast for the milliammeter to follow, and therefore shows merely as an increase in signal. Coupled directly into the radio receiver is a signal generator which is being "keyed" slowly. Figure 23 shows the normal reading of the R-meter without a signal, with the keyed signal impressed, with the d-c voltage applied, and with the d-c voltage plus the radio-frequency arc. It is to be emphasized that in the last three cases a keyed signal is being impressed upon the radio whether or not interference is present. An ex-

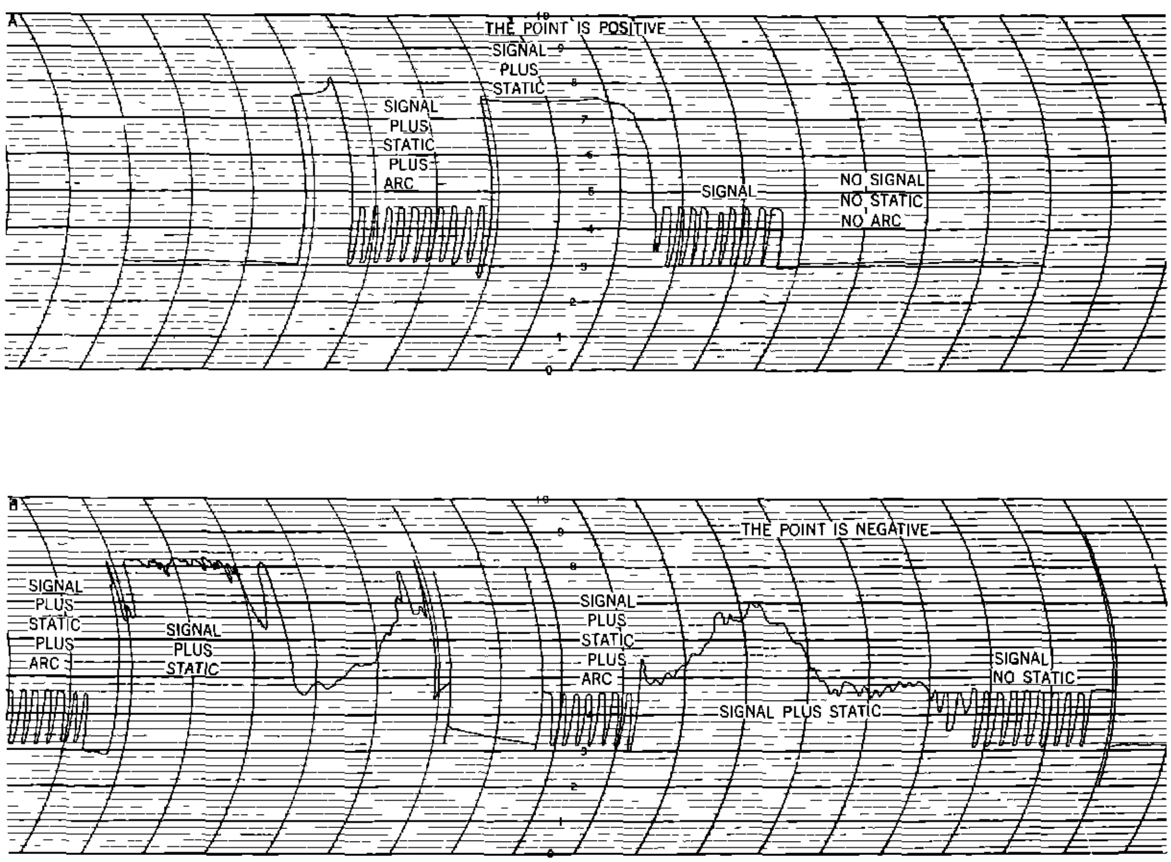

Figure 23.—Recordings of interference elimination tests of d-c corona by a radio-frequency arc

amination of these curves will show the following points:

1. When the static interference is present, no signal is received by the radio from the signal generator, since the line is approximately smooth and does not show the keying of the signal.

2. The interference from the point due to the d-c field impressed upon it is eliminated entirely by means of the radio-frequency arc.

3. The signal comes in exactly the same as if the d-c field were not present. IT IS TO BE EMPHASIZED IN THIS CONNECTION THAT THE LACK OF INTERFERENCE IN THE RADIO IS *NOT* DUE TO ANY PARALYSIS OF THE RADIO CAUSED BY THE RADIO-FREQUENCY FIELD. This is shown by the fact that with the radio-frequency arc and the d-c field both applied to the point, the radio is receiving the carrier in exactly the same way as it did without either radio-frequency or d-c field existing at the point.

Most of these experiments were carried on at a frequency of 5.8 megacycles at a radio-frequency power of approximately 100 watts. Recently Mr. Bellville of the Forest Service Radio Laboratory has constructed a small coil for use with a 32-megacycle transmitter. Mr.

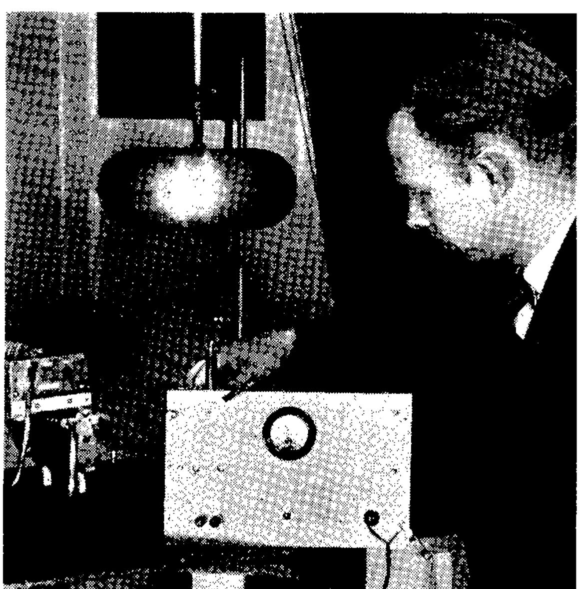

Figure 24.—Forest Service 32 mc. transmitter.

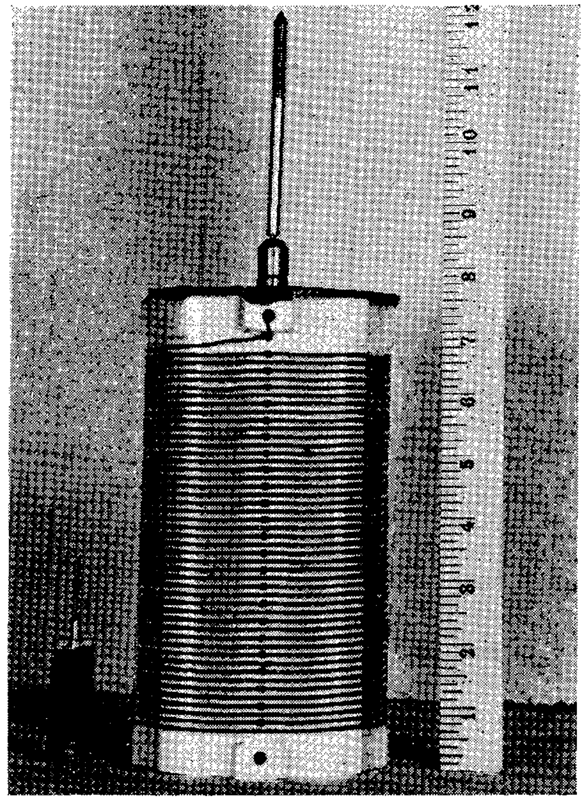

Figure 25.—Comparison of 5.8 mc. and 32 mc. coils.

Bellville is shown pointing to this coil in figure 24. A comparison of the two coils is shown in figure 25. The ultra-high-frequency coil, when used in conjunction with one of the semi-portable Forest Service 32-megacycle transmitters, produced a radio-frequency arc which behaved in all respects the same as the coil operating at a lower frequency. In this case, however, a power of less than 20 watts was necessary to eliminate the interference from the point in d-c corona. The small size of the coil and the associated transmitter added to its practicability in connection with its application as a discharge device on an airplane.

CONCLUSIONS

The results of all the above experiments can be summarized as follows:

1. The interference from the negative point corona is in general of the nature of a radio-frequency wave modulated by variations of the field strength, etc.

2 In the case of the positive point corona, the interference is at an audio-frequency rate with a very steep wave front which shocks the tuned circuits of the radio into oscillation The fundamental frequency of this disturbance is usually above 1500 cycles, and the lowest frequency detected was 700

3 The intermittent character of the corona which gives rise to the radio-frequency disturbance can be eliminated, if, from some external source, sufficient ionization can be produced in the neighborhood of the point to pass the required current

4 It has been conclusively demonstrated that a comparatively small high-frequency field existing at the point and imposed upon the d-c field can produce the required amount of ionization to eliminate entirely this interference This applies to both the positive and negative point corona

5 The radio-frequency arc existing at a point is several times as efficient as a sharp point alone for discharging the plane

6 The small size of coil found necessary at 32 megacycles indicates the practical application of this phenomenon to discharging the plane

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