Vulnerability of the Doppler Detection System to countermeasures: report no. 2 - airborne jamming

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO AND ELECTRICAL ENGINEERING DIVISION

VULNERABILITY OF THE DOPPLER DETECTION SYSTEM TO COUNTERMEASURES

REPORT NO. 2 – AIRBORNE JAMMING

J. K. PULFER

OTTAWA
JANUARY 1958

ABSTRACT

The vulnerability of the Doppler Detection System to jamming by an airborne superregenerative repeater was studied. A theoretical investigation of some of the problems encountered in airborne repeater jamming was made, and results are presented. Measurements of ground echo levels, and field strengths along particular jamming tracks are included.

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VULNERABILITY OF THE DOPPLER DETECTION SYSTEM TO COUNTERMEASURES

Report No. 2 - Airborne Jamming

- J.K. Pulfer -

INTRODUCTION

The Doppler Detection System is a bistatic doppler system. A block diagram of a link of the system is shown in Fig. 1. The distance AB is approxi-

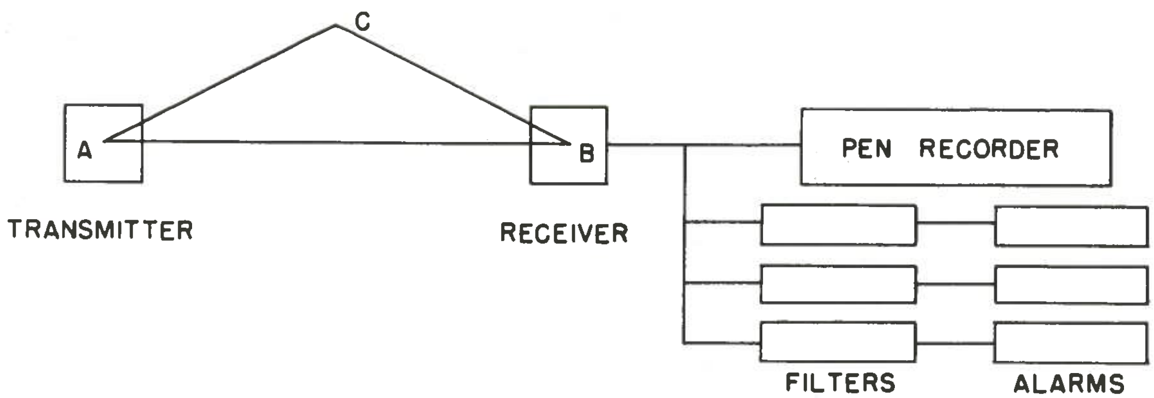

FIG. 1 BLOCK DIAGRAM OF A LINK OF THE DOPPLER DETECTION SYSTEM

mately 60 miles. The transmitter emits a stable c-w signal at a frequency between 470 and 500 mc/s. The direct signal from the transmitter is detected at the receiver which is a conventional double-conversion superheterodyne. When a reflected signal is received from a target at C this signal travels the distance AC plus CB, and since this changes its phase relative to the direct signal its presence at the receiver changes the d-c output of the second detector. When C is a moving target the phase delay, and hence the d-c level, is changing at a rate proportional to the velocity of C. The constant proportionality, however, depends on the position and heading of C relative to A and B. The changing d-c output is effectively a low frequency a-c signal which is recorded by a pen recorder and is also passed through narrow-band audio filters to an alarm. Before discussing the vulnerability of the Doppler Detection System to airborne jamming, it is important to know the precise function of the system, since otherwise it is impossible to say when it has been successfully jammed. To provide a basis on which to study its vulnerability, its function has been stated as follows:

a) The Doppler Detection System will, with very high probability, be alarmed by the crossing of one or more aircraft anywhere in the line, and will give information as to time and approximate place of crossing.

b) The occurrence of an alarm on the Doppler Detection System will, with very high probability, indicate the presence of one or more aircraft at the time and approximate place indicated. An alarm is taken to mean the tripping of the alarm of the Doppler Detection System and the production of the "signature" or doppler waveform on the recording apparatus. This implies that the production of a "signature" is an essential part of an alarm in the operational sense. It is believed that this is the present plan for use of the Doppler Detection System.

Jamming the Doppler Detection System, therefore, means either producing an alarm when no aircraft is crossing, or disguising the fact that an aircraft is crossing, or obscuring or confusing the information about time and place of crossing.

The following types of jamming have been considered:

a) Deceptive Jamming

Deceptive jamming is production of alarms which are difficult to distinguish from true alarms, when in fact no aircraft is crossing the Doppler Detection System, by providing the appropriate input to the Doppler Detection System receiver from a jammer. It is also the production of signatures during the crossing of an aircraft which may be confused with false alarms.

b) Confusion Jamming

Confusion jamming is production of returns on the Doppler Detection System which need not look like alarms, but which would cause confusion, delay in recognizing true signals, and perhaps extra work or an extra load on facilities.

c) Denial Jamming

Denial jamming would provide the receiver with meaningless signals of sufficient strength to prevent extraction of information about aircraft crossing from at least one link of the Doppler Detection System. A refinement of this kind of jamming would be a signal with the right characteristics to saturate the receivers without writing anything on the pen recorder. This would open up the possibility of denying information from the system without disclosing that it was being jammed.

SUPERREGENERATIVE JAMMING

Studies made at this Division [1] indicate that the periodically quenched oscillator or superregenerative repeater is a very effective jammer for static c-w doppler systems. The output spectrum of a periodically quenched oscillator which is "locked" to the Doppler Detection System signal has a component on the frequency of the locking signal, and the phase of this component can be varied by changing the oscillator tank-circuit frequency [2]. A signal of a few microvolts can control the output spectrum of an oscillator with an output 100 db or more higher in level. Furthermore, the output frequency is independent of the stability of the oscillator, permitting simple, fairly low Q construction.

The relation between the phase of the re-transmitted signal and the frequency of the oscillator tank circuit is given by

$$d\theta = \frac{\pi}{2F} \, df_c,$$

where $d\theta$ is the change in phase of the re-transmitted signal caused by a change in oscillator tank-circuit frequency df_c. F is the frequency at which the oscillator is quenched [2].

A simple superregenerative repeater was constructed and operated from a fixed location on the ground at the center of the Rougemont-Huntingdon 60-mile test line. The jammer, which had a power output of about 5 watts, was found capable of producing satisfactory denial jamming of the link. Measurements made on a simulated link set up in the laboratory indicated that confusion and deceptive countermeasures would also be possible from a ground-based jammer.

Because it was found that the Doppler Detection System is vulnerable to a properly placed ground jammer, an investigation into the problems of airborne jamming of the system has been made. Difficulties encountered can be classified into three main groups which will be discussed in detail. These are:

a) Ground Echoes

A superregenerative repeater, since it contains both transmitting and receiving sections, is subject to interference from its own echoes. This interference might seriously limit the usefulness of the jammer in airborne situations.

b) Field Strengths and Antenna Patterns

Since the aircraft containing the jammer must fly on many different tracks and headings with respect to the link being jammed, antenna patterns of the jammer, transmitter, and receiver play an important part in the effectiveness of countermeasures.

c) Phase Contours

An aircraft containing a jammer will probably be travelling at least 135 mph (100 wavelengths per second at 485 mc/s), and, as a result, except for unusual tracks, there will be some unavoidable phase modulation on the repeater output. This may have a considerable effect on the utility of the jammer depending on whether denial, confusion, or deceptive countermeasures are being used.

Investigation of the vulnerability of the Doppler Detection System to an airborne superregenerative repeater was made in three steps. These were:

a) A theoretical investigation of the problems outlined above, designed to supply approximate data upon which design of the jamming equipment could be based.

b) A short flight trial and extended mobile ground trials to verify the ground echo calculations.

c) A series of short flights during which field strength measurements of the Doppler Detection System transmitter were made on particular jamming tracks and at various altitudes.

GROUND ECHOES

The superregenerative repeater used is shown in Plate I. It operated on a frequency of 485 mc/s with an external quenching system. The quench repetition rate was approximately 115 kc/s, resulting in a quench period of 8.6 μsec. The length of the "on" pulse was approximately 2 μsec. Waveforms of jammer output power as a function of time, as seen on an oscilloscope, are shown in Plate II. Plate II(a) illustrates the power output waveform when the oscillator is operating coherently, i.e., when the phase in successive radio-frequency pulses is coherent owing to improper adjustment of bias resulting in only partial decay of the oscillations between pulses. The output power waveform when the oscillator is operating coherently owing to the presence of an external "locking" signal in the cavity is shown in Plate II(b).

By making use of the measurement of average output power on a wattmeter and the photograph of Plate II(b), the graph of output power versus time has been plotted in Fig. 2. The details of the operating cycle are as follows:

a) At a time t_0 the cathode of the oscillator tube is driven negative, and oscillations build up at a rate determined by cavity Q, and loop gain.

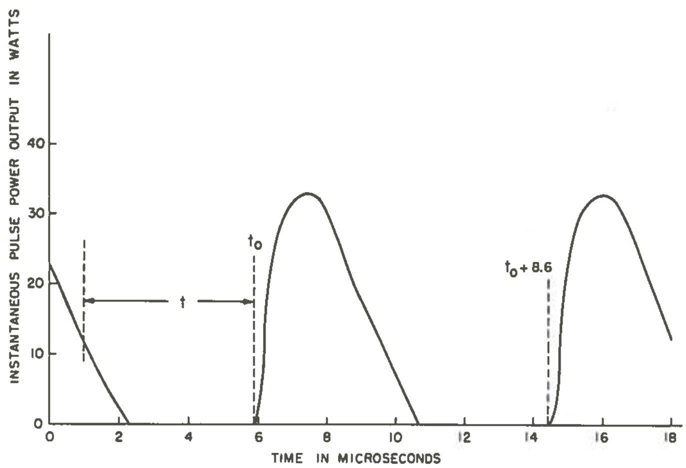

FIG. 2. GRAPH OF OUTPUT POWER vs. TIME FOR A SUPERREGENERATIVE JAMMER

b) At a time $t_o + 2$ μsec, the cathode of the oscillator is driven positive, cutting off the oscillator tube, and allowing the oscillations in the cavity to decay exponentially. (Because of the very rapid decay, the power output appears to go to zero in Fig. 2.)

c) At a time $t_o + 8.5$ μsec, oscillations have decayed to below noise level. At any time previous to $t_o + 8.6$ μsec all signals which are intercepted by the antenna induce a field in the cavity.

d) At $t_o + 8.6$ μsec another cycle is initiated, and oscillations building up will be phase-locked to the received signal, provided that it is greater than noise.

It is important to notice that the receiver is in effect "gated", and that only those signals which arrive at the receiver immediately preceding the initiation of oscillations are effective. In other words, since the oscillations in the cavity must decay more than 100 db in 6 μsec, only signals fed into the cavity at the last moment will be of any importance. (Of course, if the signal intercepted by the antenna is building up at a rate greater than 15 db/μsec this is not true.)

Following the above reasoning, an initial calculation of ground echo levels can be made. It will be assumed as a first approximation that the earth is a perfectly reflecting plane surface. The situation is illustrated in Fig. 3. The distance from the jammer to the reflecting surface is d feet, as shown. The time necessary for the jammer output power to travel the distance d (in feet) to the reflector and arrive back at time t_o is t microseconds, as shown in Fig. 2.

When t is expressed in microseconds, t and d are related by $t = 2.04 \times 10^{-3} d$.

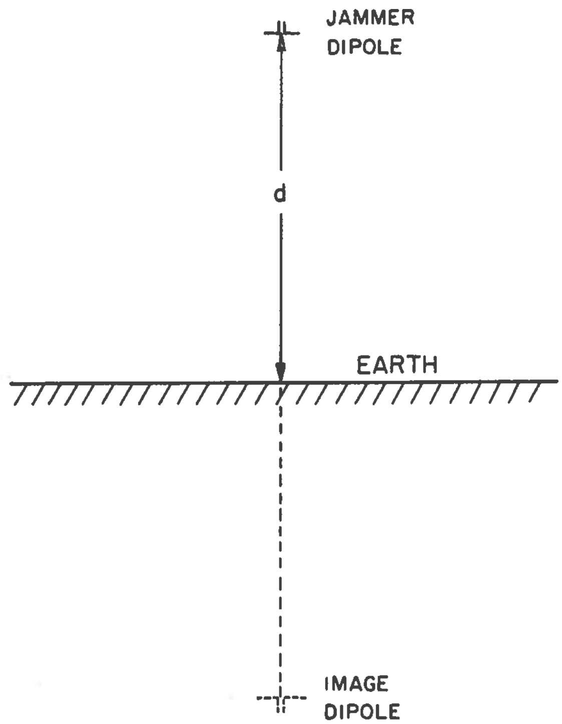

FIG. 3. DIAGRAM OF AIRBORNE JAMMER
ABOVE A PERFECTLY REFLECTING GROUND PLANE

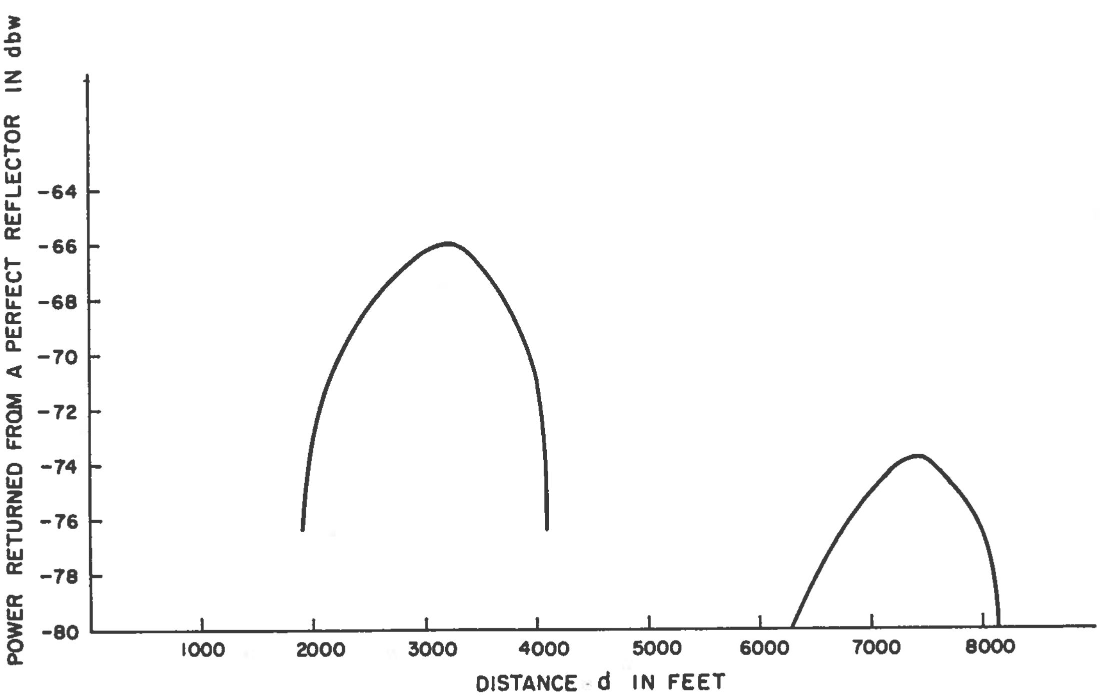

FIG. 4. GRAPH OF POWER RETURNED TO A SUPERREGENERATIVE JAMMER FROM A PERFECT PLANE REFLECTOR vs. DISTANCE TO THE REFLECTOR

Using the instantaneous power output of the jammer from Fig. 2, the amount of power reflected from a distance d and arriving at the jammer at t_o can be calculated. The power received would be approximately the same as that coming from an antenna at a distance 2d, which was radiating an amount of power equal to the instantaneous jammer output at a time $t_o - t$. A more accurate calculation of this power would be obtained by considering all the power received by the cavity previous to t_o, and summing by a superposition integral. However, the increased accuracy was not justifiable.

Using the approximate method, the information illustrated in Fig. 4 was calculated. It should be noted that only the power returning from preferred distances is accepted by the receiver. In fact, if the ground were a plane reflector there would be some altitudes at which no appreciable ground echoes would be accepted. Unfortunately, however, actual ground reflection is diffuse, and as long as the slope distance from the aircraft to the earth is correct, there will be some power returned to the receiver at the correct time. This is illustrated more clearly in Fig. 5. At slant distances between 2400 and 3800 feet from the jammer antenna, there will be an annular plane area on the surface of the earth which will contribute to the overall ground echo. Similarly, at slant distances between 6700 and 8000 feet there will be another surface reflecting less power for the same area. For purposes of calculation, it will be assumed that the power comes from the average distance for each echoing region. As a model to calculate reflections, therefore, we will use a set of concentric concave spherical surfaces composed of isotropic reflectors, with the jammer located at the center of curvature. Secondary reflections will be ignored in this model. Power returning from each surface will be proportional to the fractional area illuminated, and also it will be a function of the distance of the surface from the jamming antenna. Calculating the areas illustrated in Fig. 5 for various altitudes, curves of reflected power versus altitude are plotted in Fig. 6. Only the first four reflections are used. The reflector power is given relative to the power returned by a plane reflector at 3250 feet. Curve (a) is proportional to the power which would be returned to an isotropic antenna. Curve (b) is similar, except that all echoes from an area subtending a solid angle of 120° below the antenna are neglected. This was done to simulate the effect of mounting the jammer antenna on the top of the fuselage of the aircraft to minimize ground echoes.

To obtain a measurement of the relative amount of power absorbed and reflected by the ground, a series of field trials were made with the jammer antenna mounted on a moving truck containing the jamming equipment. The truck was driven over various types of terrain, and the level of power returning to an antenna on the roof of the truck was measured. The results of these tests are given in Table I.

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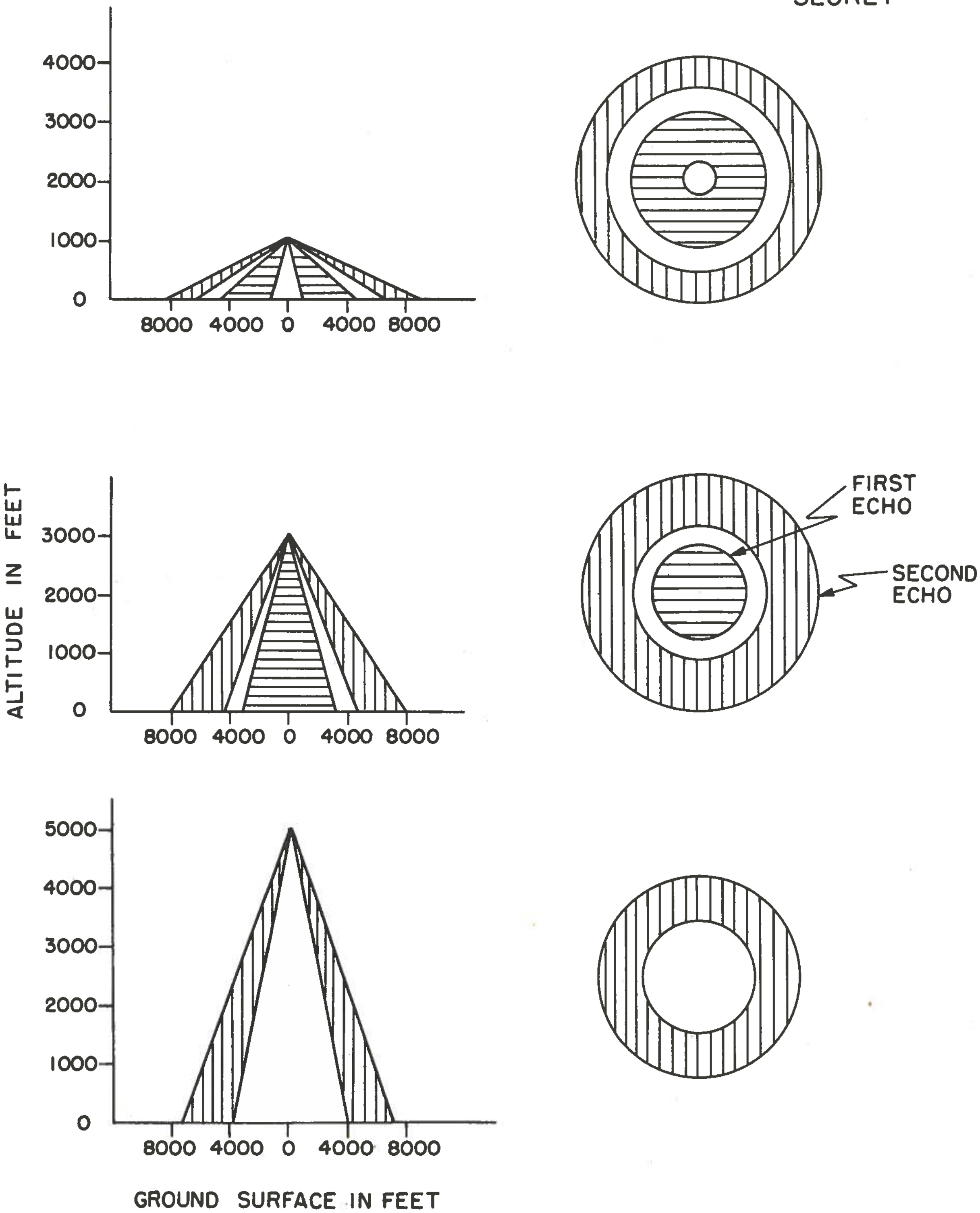

FIG. 5. ILLUSTRATION OF GROUND ECHO COVERAGE FOR AIRCRAFT AT VARIOUS ALTITUDES

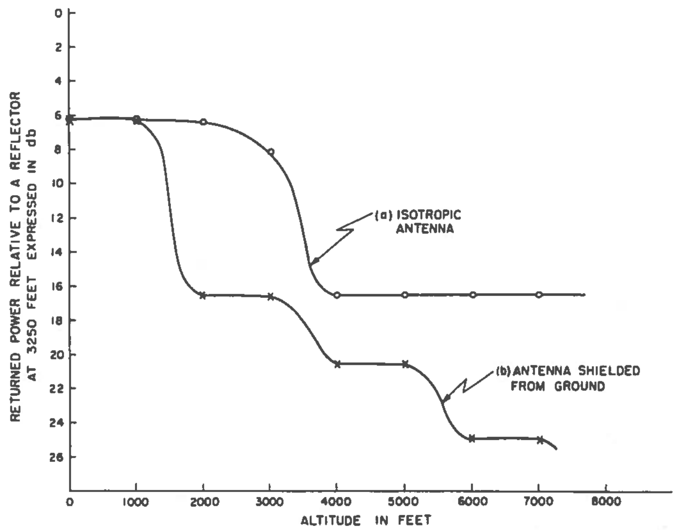

FIG. 6. GRAPH OF RELATIVE ECHO POWER RETURNED TO AN AIRBORNE JAMMER vs. ALTITUDE

TABLE I

MEASURED ATTENUATION OF REFLECTED SIGNALS

Description of Terrain	Round Trip Attenuation (db)
Perfect plane reflector at a distance of 3250 feet	82
Flat farming country with few trees; or long, straight, wide city streets	91 - 97
Suburban areas with average streets and some open country	97 - 105
Densely populated urban areas with narrow winding streets	105 - 110
Fairly heavy wooded farm areas with no power lines or other large metallic objects	110 - 117
Unpopulated swampy country with dense woods and curved roads	118 - 121

It can be seen that under unfavourable conditions the power returned is within 10 db of that returned from a perfect plane reflector. It was also determined that vertically-polarized echoes were approximately 3 db stronger than horizontal ones.

With the jammer used in the field trials, the antenna was coupled to the oscillator by means of a movable probe, adjustment of which could vary the output power by as much as 14 db. At the same time, of course, the sensitivity of the jammer to locking signals changed by 14 db. The extremes of coupling gave the following figures.

Maximum peak output power + 15 dbw	Sensitivity -114 dbw — a difference of 129 db
Minimum peak output power + 1.0 dbw	Sensitivity -100 dbw — a difference of 101 db

Assuming various ground absorption losses and combining the information in Fig. 4 and curve (b) of Fig. 6, the graphs of Figs. 7 and 8 were plotted. They give an approximate indication of the ground effects which might be encountered in an airborne jammer. Fig. 7 gives the reflected power for minimum jammer power output while Fig. 8 represents the case of maximum output power. From the results of Figs. 7 and 8 one would expect that the ground echoes from altitudes less than 1000 feet would be objectionable even at minimum output power. However, above 5000 to 6000 feet, the ground echoes should be from 10 to 20 db lower down, in which case higher output powers and sensitivities might be used.

Measurements made from the DC-3 aircraft indicated that in most cases ground echoes were negligible above 5000 feet, and that even at altitudes as low as 2000 to 3000 feet there were times when they were not objectionable.

At altitudes below 1000 feet, however, ground echoes were always present, even with maximum attenuation in the antenna circuit, and proper jammer operation was not possible. This would indicate that a large percentage of the power was reflected at low grazing angles, while at higher angles more was absorbed.

Because of the large changes in reflection coefficient encountered with different types of ground, no experimental curve of ground echo level vs. altitude is presented. It has been found, however, that the theoretical curves agree with the average experimental results, and provide a reliable basis for future jammer design calculations.

It can also be stated, that from the viewpoint of obtaining minimum ground echoes, and therefore maximum jammer sensitivity and transmitter power,

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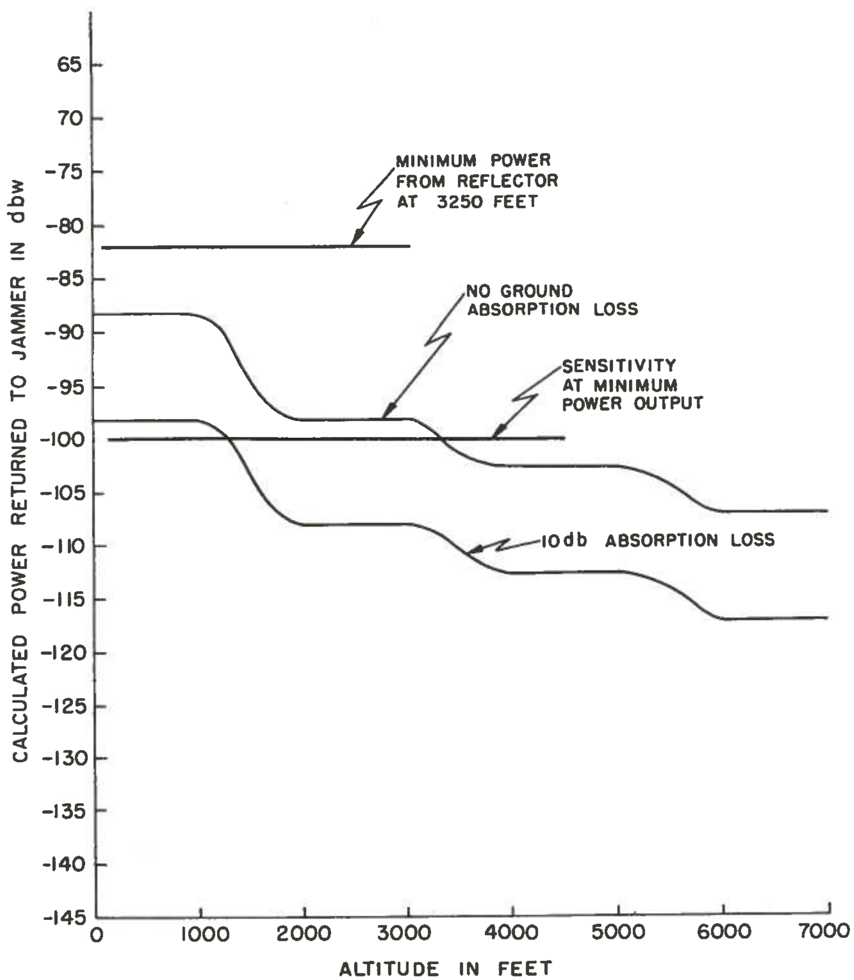

FIG. 7. CALCULATED POWER RETURNED TO JAMMER vs. ALTITUDE FOR GROUND ECHOES FROM AN AIRBORNE REPEATER JAMMER WITH MINIMUM POWER OUTPUT

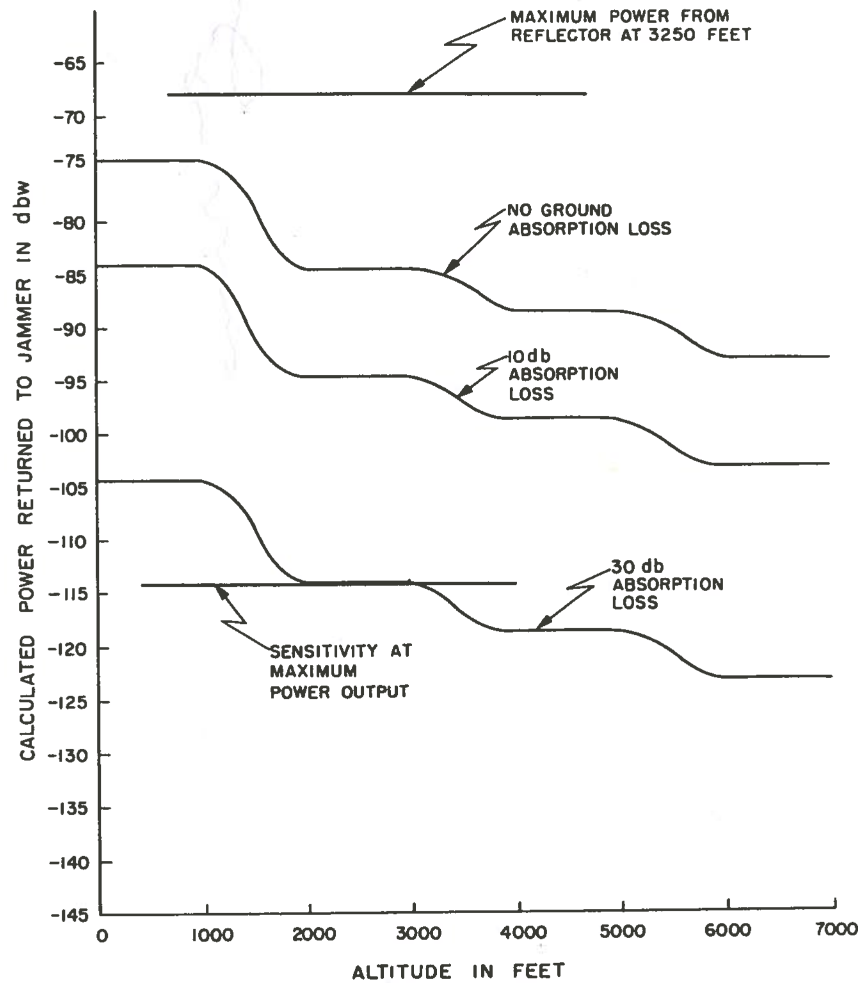

FIG. 8. CALCULATED POWER RETURNED TO JAMMER vs. ALTITUDE FOR GROUND ECHOES FROM AN AIRBORNE REPEATER JAMMER WITH MAXIMUM POWER OUTPUT

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ANTENNA-PATTERN RANGE

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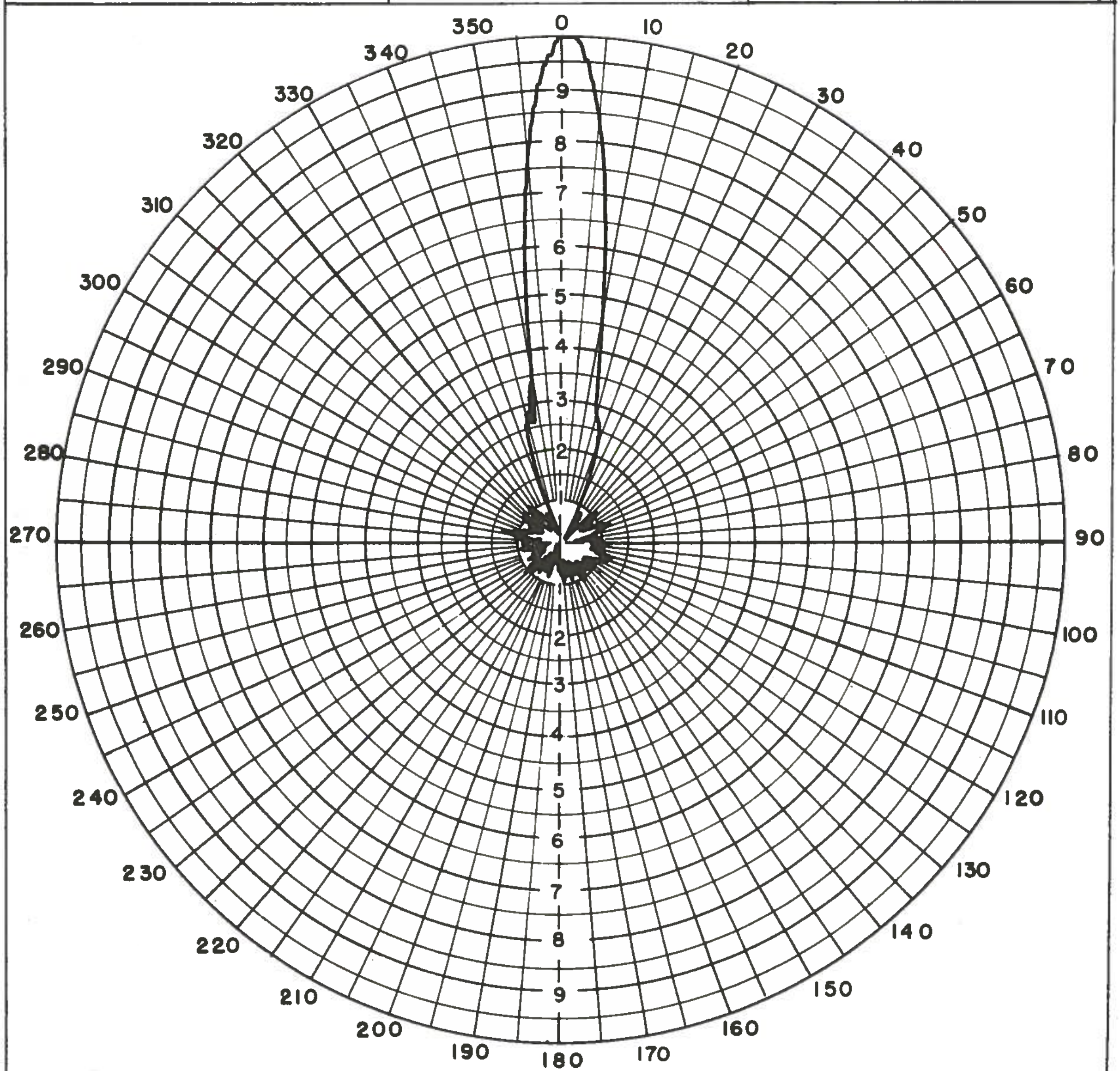
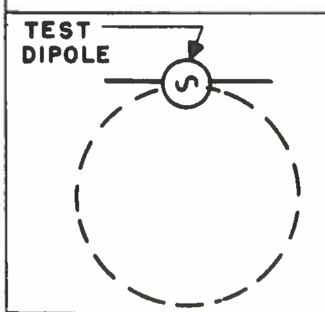
MODEL:	SCALE:	MODEL FREQ: Mc/s
PLANE: ELEVATED	POLARIZATION: HOR.	ACTUAL FREQ: 480 Mc/s





ANTENNA: AN/FPS-503

FIG. 9. TYPICAL CONICAL RADIATION PATTERN FOR THE DOPPLER DETECTION SYSTEM ANTENNA

operation at altitudes above 5000 feet was highly desirable with the antenna system used.

If it is desired to increase jammer power, ground echoes may be reduced by

a) increasing aircraft operating altitude approximately 1500 feet per 3-db increase in power,

b) increasing the solid angle within which the jammer is shielded from ground echoes.

DOPPLER DETECTION LINK FIELD STRENGTHS

The problem of field strengths involved in jammer operation is so complex that it will be analyzed in two parts:

a) The Doppler Detection System antenna patterns, and the resulting field distribution in space produced by the Doppler transmitter.

b) The antenna patterns of the airborne jammer, and the effects of these patterns on

i) the locking signal received by the jammer,

ii) the signal re-radiated by the jammer in the direction of the doppler receiver.

A typical radiation pattern for a Doppler Detection System transmitting (or receiving) antenna is given in Fig. 9, [4]. This is a conical pattern, taken at an angle of 15° above the horizontal. The pattern taken in the horizontal plane

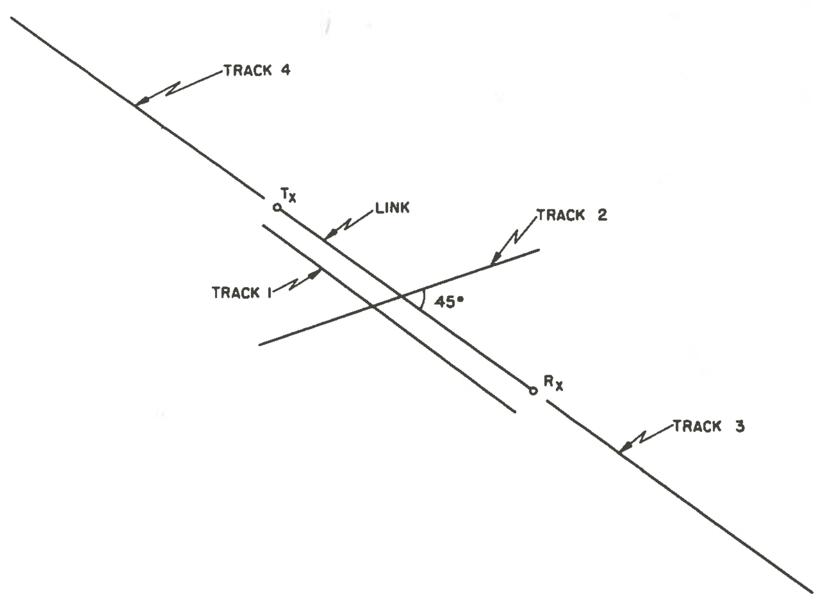


FIG. 10. TRACKS ALONG WHICH JAMMING OF THE DOPPLER DETECTION SYSTEM HAS BEEN INVESTIGATED

is similar, with the exception that the maximum of the pattern is approximately 6 db below the maximum of the conical pattern. The half-power beamwidth of the antenna is approximately 12°.

While the field strength at all points in space around the DDS transmitter is of interest, there are several tracks along which it is particularly important. These are shown in Fig. 10. The tracks are:

1) along a line parallel to the link, and separated from it by 5 miles;
2) along a line crossing the link at the center, and at an angle of approximately 45°;
3) along a line extending from the receiver end of the link directly away from the transmitter;
4) along a line extending from the transmitter end of the link directly away from the receiver.

Using the radiation patterns of the DDS antenna, nominal DDS transmitter power of 50 watts, and the antenna gain of 17 db, the power that would be received by a half-wave dipole along the above tracks has been calculated. In Figs. 11(a) and (b), power received by a dipole on an aircraft at 5000 feet for tracks 1 and 2 is presented. In Figs. 12(a) and (b), values of received power for an aircraft at 10,000 feet on tracks 3 and 4, respectively, are given. The higher altitude is used on tracks 3 and 4 to increase the line-of-sight distance on these tracks.

To simplify the above calculation, the effect of the earth has been omitted, since line-of-sight transmission is possible in all cases. Bullington's nomograph for free space field intensity and received power between half-wave dipoles has been used [5]. Depending on the magnitude and phase of the signal reflected from the ground, however, received power at a given point might be completely cancelled, or as high as 6 db above the value given. It should also be pointed out that the figures given represent the power received by a properly polarized half-wave dipole with optimum orientation.

Some experimental measurements were made to provide a check on the above calculation, and to determine the effect of ground reflections, aircraft reflections, and aircraft antenna. A C-119 aircraft with an AN/AT-49 discone antenna mounted at an angle of 45° to the horizontal was used for the measurements. Fig. 13 shows how the antenna was mounted. Fig. 14 is a measured horizontal radiation pattern for the antenna on a 4' × 6', 45° ground plane. In the aircraft the output of the antenna was fed to a Stoddard-type calibrated radio-frequency voltmeter. The received power was calculated and plotted from the voltmeter readings. The results of the

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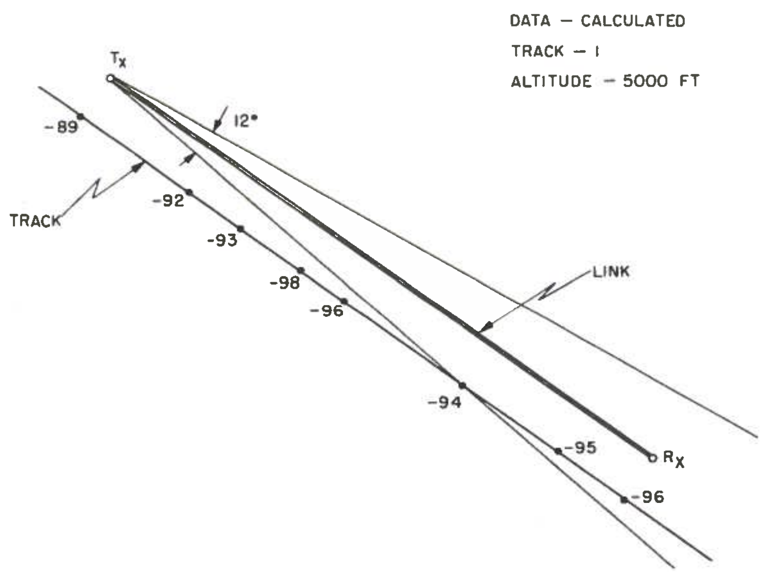

FIG. 11(a). CALCULATED FIELD STRENGTHS ON TRACK 1 AT AN ALTITUDE OF 5000 FEET

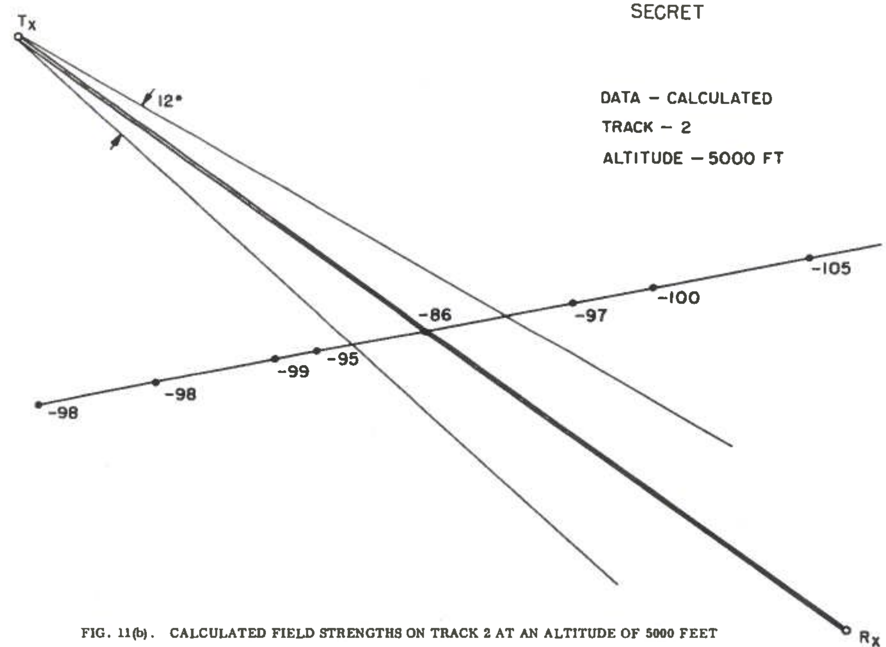

FIG. 11(b). CALCULATED FIELD STRENGTHS ON TRACK 2 AT AN ALTITUDE OF 5000 FEET

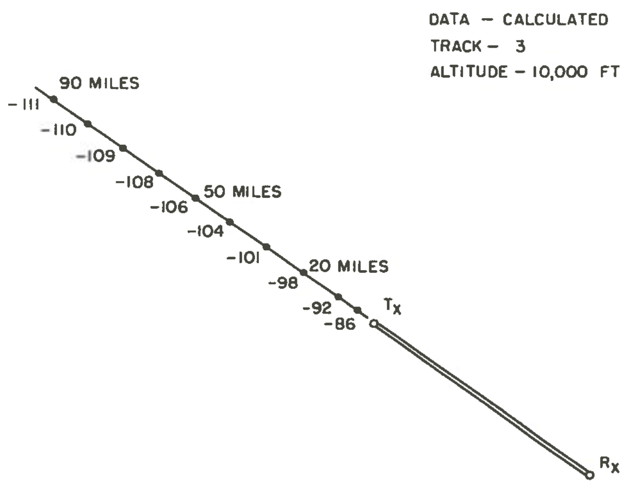

FIG. 12(a). CALCULATED FIELD STRENGTHS ON TRACK 3 AT AN ALTITUDE OF 10,000 FEET

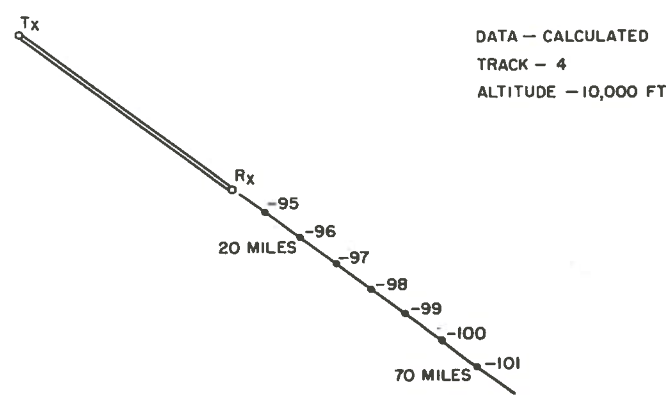

FIG. 12(b). CALCULATED FIELD STRENGTHS ON TRACK 4 AT AN ALTITUDE OF 10,000 FEET

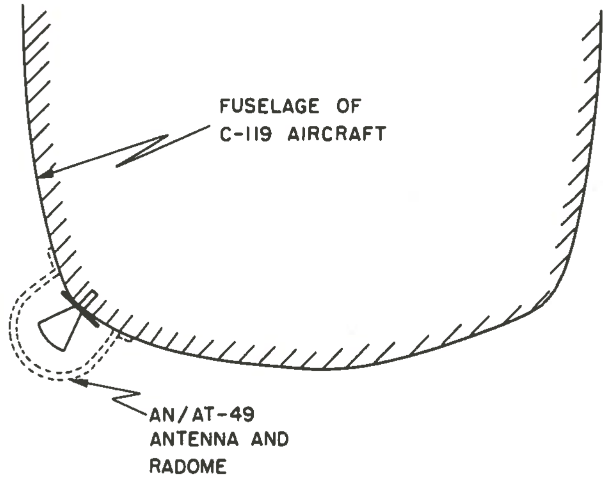

FIG. 13. DIAGRAM SHOWING THE MOUNTING POSITION OF THE AN/AT-49 ANTENNA ON THE FUSELAGE OF THE C-119 AIRCRAFT

measurements made on a typical track at 5000 feet are given in Fig. 15. Measured values are consistently lower than calculated values near the transmitter although the track flown was somewhat less than 5 miles from the line. This can be explained by the null in the receiving antenna pattern at right angles to the heading of the aircraft. The low measured values near the center of the line are also probably due to a null in the pattern of the jammer antenna caused by reflections from the wings and other parts of the aircraft structure. A further reason is that the AN/AT-49 antenna is considerably lower in efficiency than a dipole.

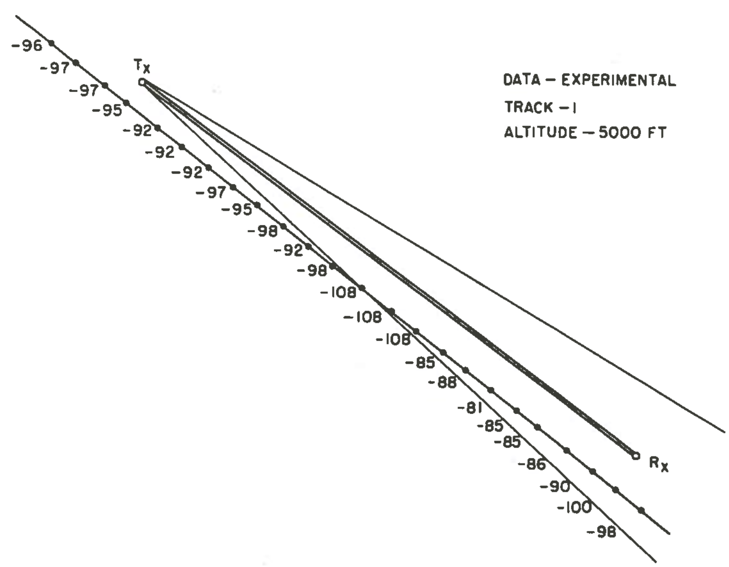

FIG. 15. EXPERIMENTAL FIELD STRENGTHS ON TRACK 1 AT AN ALTITUDE OF 5000 FEET

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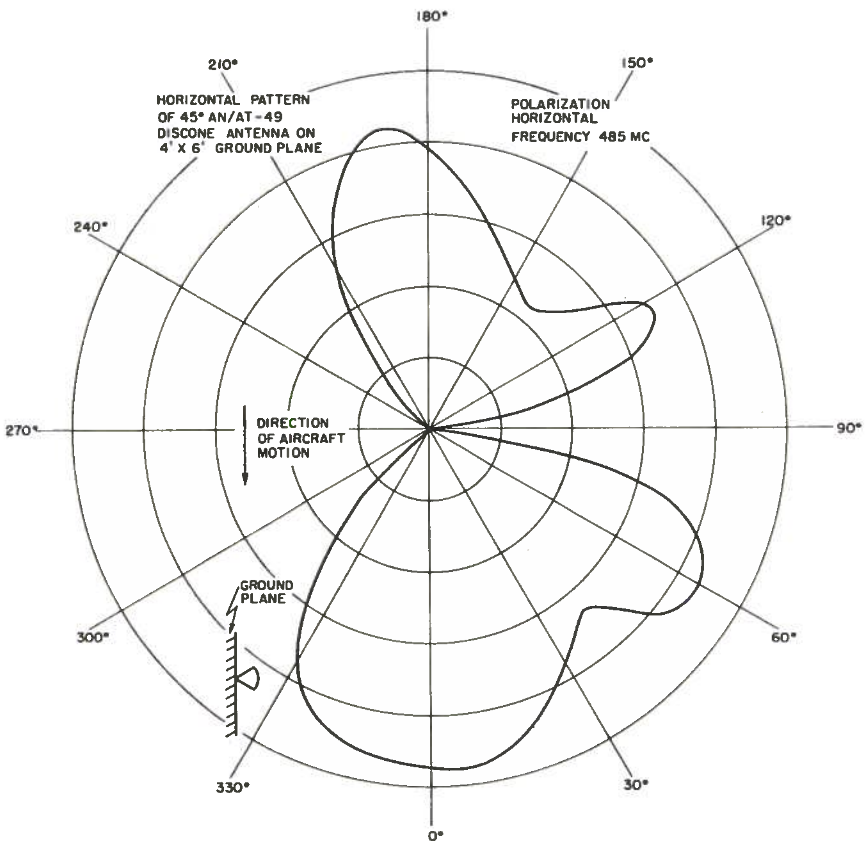

FIG. 14. HORIZONTAL RADIATION PATTERN OF THE AN/AT-49 ANTENNA MOUNTED ON A 4' × 6' GROUND PLANE AT 45° TO THE HORIZONTAL

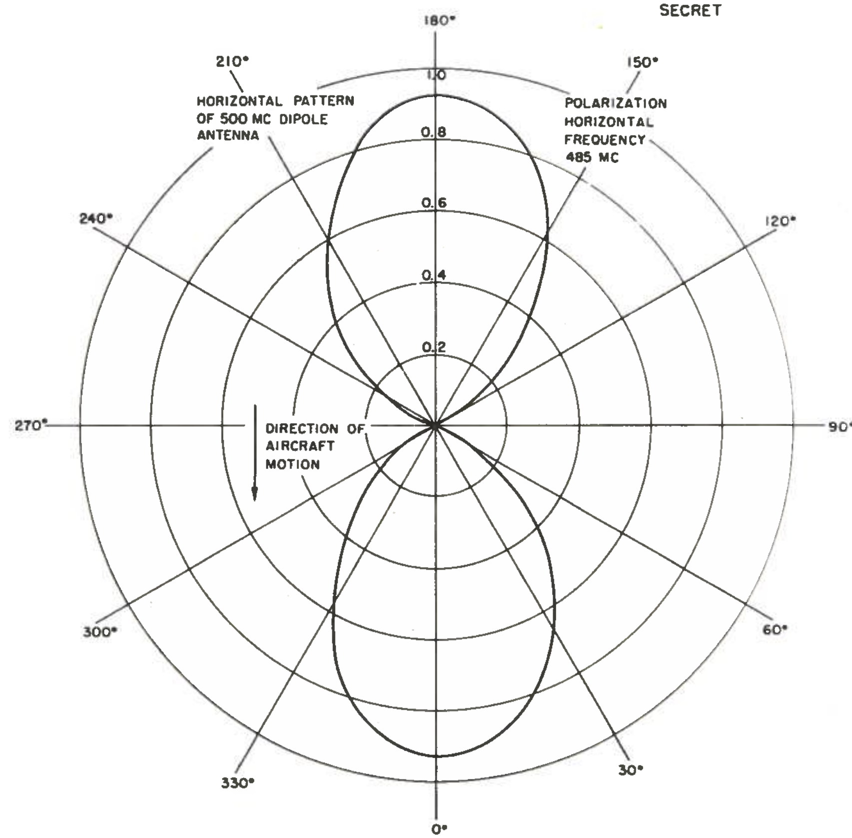

FIG. 17. HORIZONTAL RADIATION PATTERN OF THE 500 MC/S DIPOLE ANTENNA

JAMMER FIELD STRENGTHS

Considerable thought was given to the choice of the optimum antenna for the jammer on the aircraft. Some of the factors which are desirable, are listed below, in order of importance.

a) The antenna should be horizontally polarized since DDS antennas are horizontally polarized. (It is fortuitous that vertical polarization seems to be somewhat more susceptible to ground echoes.)

b) A pattern which will have as little radiation as possible directed vertically downward within a solid angle of 120° below the antenna is desirable, so that reflections from the ground will be minimized.

c) The horizontal radiation pattern should be uniform, so that aircraft heading will not affect jammer operation.

d) The radiation pattern should have a null at the zenith, since power radiated at any angle above the horizontal will be almost entirely wasted.

e) Preferably the antenna should be structurally simple and rigid so that it can be mounted on high speed aircraft without affecting the aerodynamic characteristics of the aircraft or the electrical characteristics of the antenna.

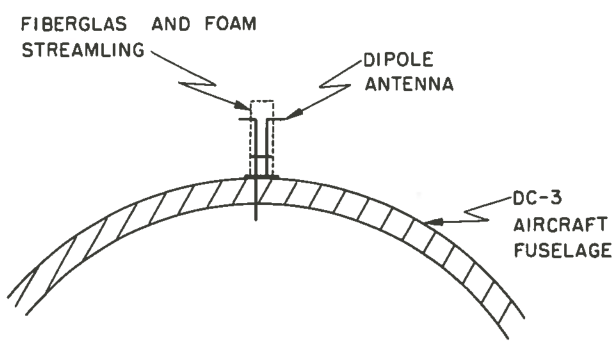

FIG. 16. DIAGRAM SHOWING THE MOUNTING POSITION OF THE DIPOLE ANTENNA ON THE DC-3 AIRCRAFT

The antenna which was finally chosen meets all but two of these requirements. It is illustrated in Fig. 16, and consists of a horizontal dipole, mounted on the upper side of the fuselage, and one-half wavelength from the surface of the aircraft. It has the following disadvantages:

a) The horizontal dipole does not have a uniform horizontal radiation pattern, but since the nulls are at 90° to the aircraft heading, they do not seriously handicap a jammer flying on any of the four tracks described above.

b) The antenna is far from ideal in a mechanical sense. It is not structurally strong enough for high-speed aircraft unless some form of radome is used, and its size (1 foot high) is prohibitive for small aircraft.

A horizontal radiation pattern for the case of the antenna mounted on a ground plane has been taken (Fig. 17) and this has been used to calculate the effects of the pattern on a signal received at the aircraft. The results (Fig. 18(a)) are given in decibels relative to the performance of a correctly oriented dipole antenna. The gain of this antenna over that of a dipole in free space was not considered in the calculations. The results show at what points the jammer may be most strongly locked on the system signal.

The jammer antenna pattern is used again in determining the jamming power received at the DDS receiver. For 1 watt radiated by the jammer antenna, the signal strength arriving at the DDS receiver, taking into account both antenna patterns, is given in Fig. 18(b).

The field strength problem in airborne jamming with a repeater is now clearly evident. Except in the colinear tracks, a jammer dipole antenna can never be correctly oriented with respect to both the link transmitter and receiver. As the signal radiated by the jammer is stronger than necessary in most cases, the jammer antenna should favour the DDS transmitter, if possible, in order to obtain a good locking signal.

Some of the conclusions which may be reached from the above calculations of field strengths are:

1) Field strength along both colinear tracks at the ends of a link should be sufficient for jamming from distances of 80 miles with high altitude aircraft. Under favourable conditions of antenna height and local topography, this distance may be almost doubled for the receiver end track.

2) Jamming should be possible from a parallel track 5 miles from the link, except at points immediately opposite the DDS transmitter and receiver, and at points where the DDS patterns have deep nulls.

3) It should be possible to jam a link of the fence while crossing it at an angle of 45° near the center of the link. Complete denial of information should be possible while the jammer is within 5 miles of the line. This would be for approximately 5 minutes in the case of a slow (150 mph) aircraft.

PHASE MODULATION CAUSED BY JAMMER MOVEMENT

An investigation of the phase modulation of different jamming tracks is

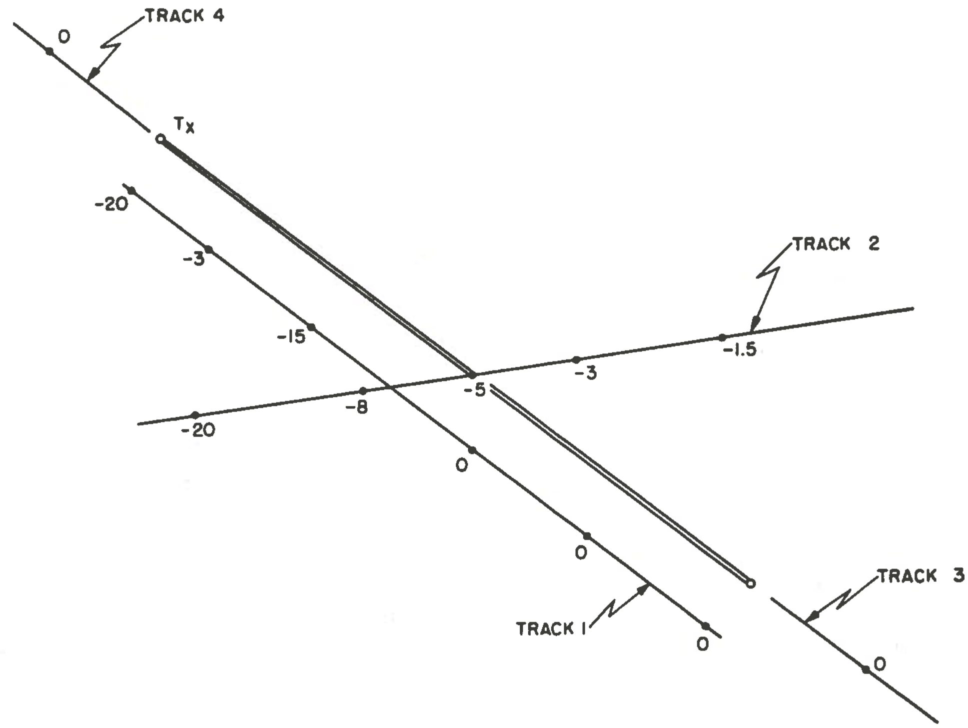

FIG. 18(a). CALCULATED RECEIVING LOSS FOR AN AIRBORNE JAMMER ON TRACKS 1, 2, 3, AND 4 DUE TO RADIATION PATTERNS OF THE JAMMER DIPOLE

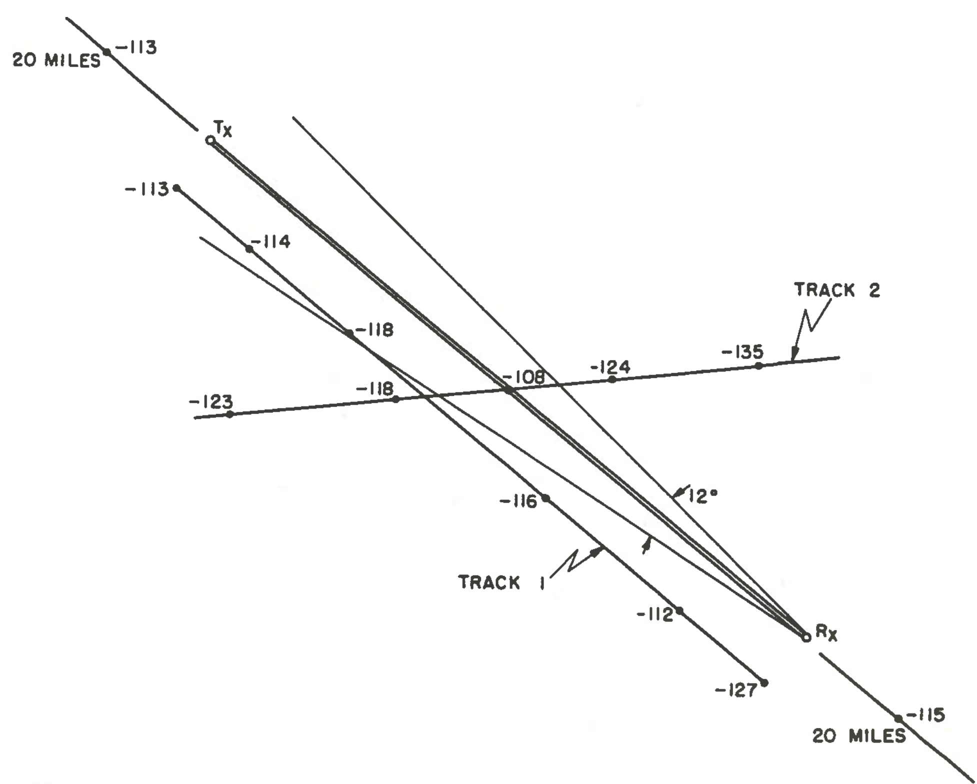

FIG. 18(b). CALCULATED SIGNAL RECEIVED AT THE DOPPLER DETECTION SYSTEM RECEIVER FROM A JAMMER RADIATING 1 WATT WITHIN THE RECEIVER BANDWIDTH ON TRACKS 1, 2, 3, AND 4 important in a study of the possibilities of deceptive countermeasures using an airborne phase-modulated repeater jammer.

Consider Fig. 19. This is a vector diagram showing the voltages arriving at the DDS receiver for a particular aircraft location. V1 is the direct signal from the DDS transmitter and is nominally 10 microvolts or -117 dbw. V2 is the signal reflected from the aircraft, and is used by the Doppler Detection System to trigger the alarms and write the signature. The amplitude of this signal may be from -180 to -110 dbw, although typical reflections are of the order of -120 to -140 dbw at the center of the crossing. θ_1 is the difference in phase between the direct and reflected signals, and is usually varying at rates between zero and 3000 radians per second, depending on the track. The third voltage V3 is due to the signal radiated by the repeater jammer. The amplitude of this signal may vary over large ranges, but is usually of the order of -115 dbw. Angle θ_2 is the phase angle between V2 and V3, and can be controlled by varying the frequency of the jammer oscillator tank circuit. Angle θ_1 cannot be controlled from the aircraft, and the total angle $\theta_1 + \theta_2$ between the direct signal V1 and the jamming signal V3 is not directly under control of the jammer operator.

For some tracks, θ_1 will vary quite rapidly, making any deception jamming performed by varying θ_2 ineffective. The rate of change of θ_1 in cycles per second for various aircraft locations and headings is given in Fig. 20.

Fig. 20(a) shows typical frequencies involved in aircraft crossing the line at 500 mph. Because of the high frequencies involved, and the rapid rate of change of frequency with position of the aircraft near the crossing, any low frequency modulation applied to the jammer would be wasted unless the jammer signal were at least 20 db stronger than the reflected signal. A jammer with an output power of 10 watts should produce a signal of -100 dbw at the DDS receiver for the center of the crossing, which would completely mask the aircraft reflection providing that full 360° phase modulation was applied. The production of artificial doppler echoes from an aircraft on a crossing track with a 10-watt transmitter would be quite difficult to achieve, because of the very low frequencies involved at the center of the signature.

In a similar way, deceptive jamming from colinear tracks, as shown in Fig. 20(b), would be impractical because of the very high reflection frequencies involved, even for a slow aircraft.

On a parallel track displaced 5 miles from the link, however, there is a distance of almost 40 miles in which the reflection frequency is very low (below 10 cps for a DC-3 aircraft) and during which deceptive signals of almost any form could be used (Fig. 20(c)).

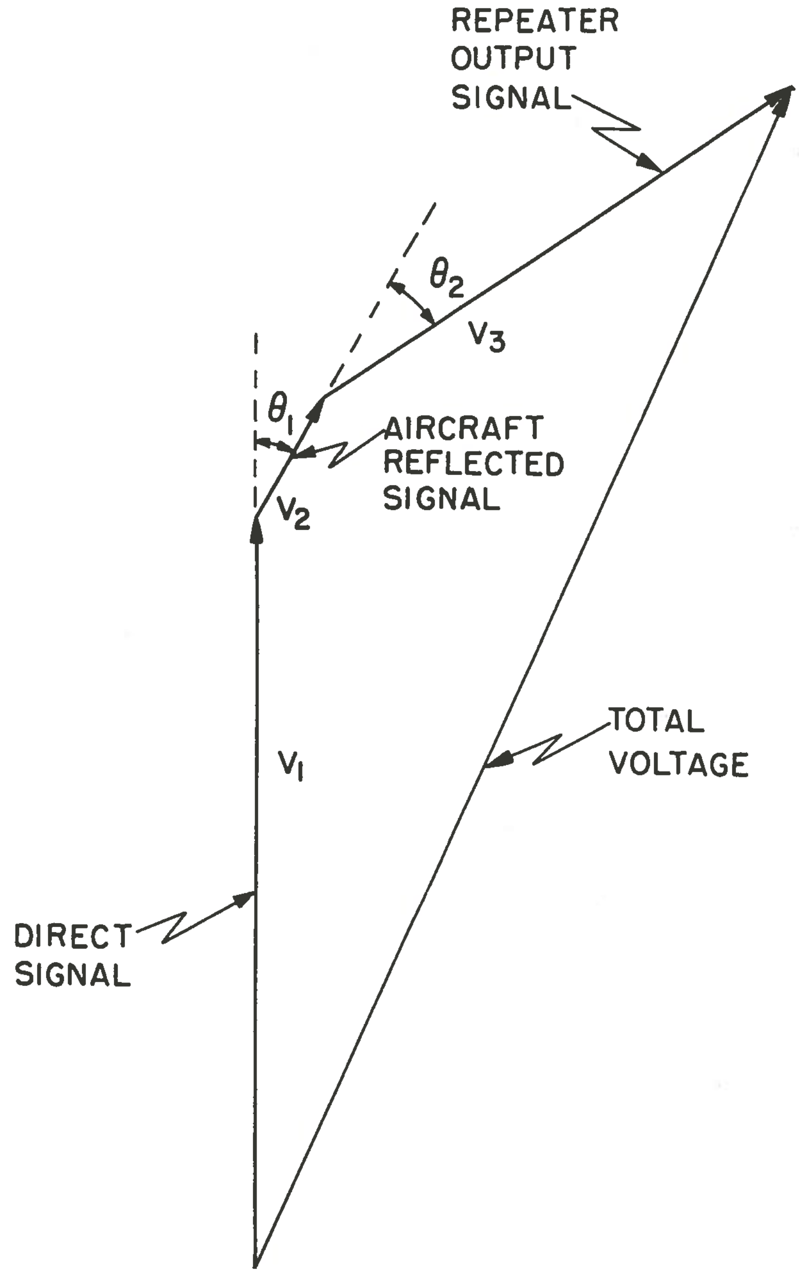

FIG. 19. DIAGRAM ILLUSTRATING VECTORIALLY THE SIGNALS ARRIVING AT THE DOPPLER DETECTION SYSTEM RECEIVER UNDER JAMMING CONDITIONS

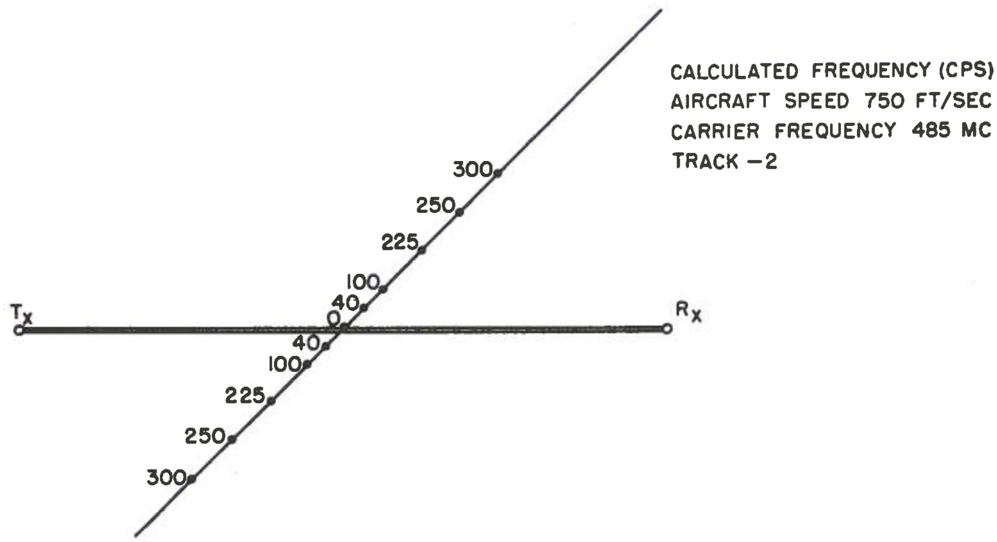

FIG. 20(a). CALCULATED DOPPLER FREQUENCIES PRODUCED BY A 750 FT/SEC AIRCRAFT ON TRACK 2

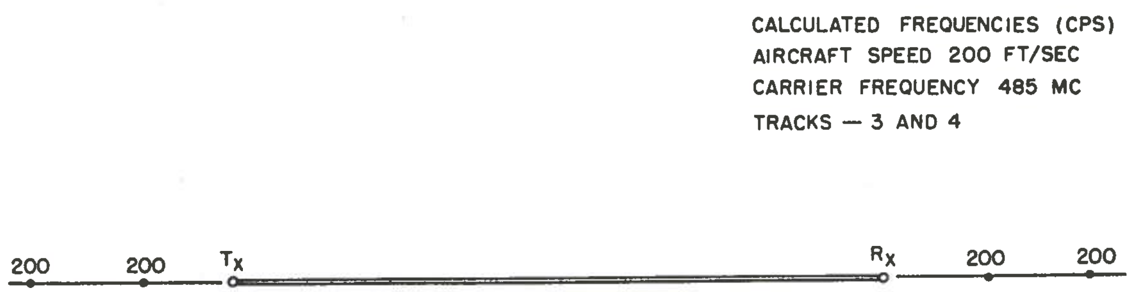

FIG. 20(b). CALCULATED DOPPLER FREQUENCIES PRODUCED BY A 200 FT/SEC AIRCRAFT ON TRACKS 3 OR 4

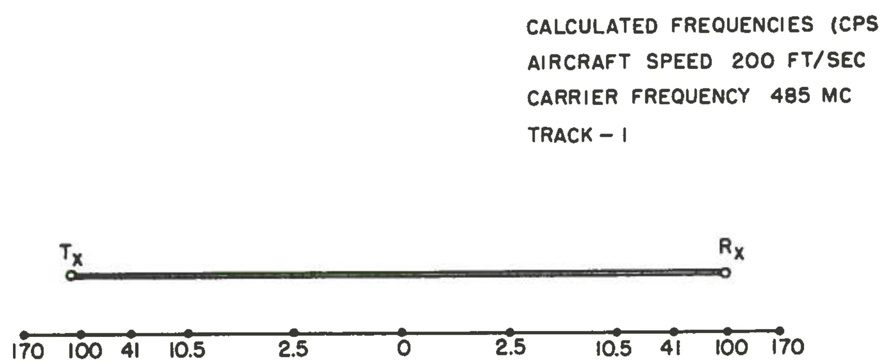

FIG. 20(c). CALCULATED DOPPLER FREQUENCIES PRODUCED BY A 200 FT/SEC AIRCRAFT ON TRACK 1

One possible way of avoiding the above limitations would be the use of a combination of amplitude and phase modulation. The resultant jammer output could be high-frequency phase modulation changing in amplitude at a low rate, which can resemble some types of false alarms, and therefore be classed as deceptive jamming.

CONCLUSIONS

From the calculated and experimental data presented in this report, the following conclusions can be stated.

1. Because of the large reflecting area of ground below an aircraft, difficulty is experienced with a superregenerative-repeater type of jammer owing to a tendency to lock on its own echoes from the earth.

2. A jammer with 30 watts peak power output, and a sensitivity of -114 dbw can operate free from ground echoes at altitudes greater than 5000 feet above the earth, providing the jammer antenna is mounted on the upper part of the aircraft fuselage so as to be shielded from all reflections returning from an area of the earth's surface subtending an angle of approximately 120° below the aircraft.

3. The presence of the earth can cause the power received from the DDS transmitter by the jammer to vary in an almost random fashion with aircraft location. The magnitude of the variation depends on the height of the DDS transmitting antenna, the terrain over which propagation occurs, and the height above ground of the aircraft carrying the jammer.

4. The power radiated by a DDS transmitter results in a field strength distribution in space which should be more than sufficient to provide locking signals for an airborne jammer with a sensitivity of -114 dbw or better. The aircraft containing the jammer is considered to be flying on one of the following:

   a) a 45° track crossing at the center of the line;

   b) a parallel track 5 miles from the line;

   c) colinear tracks off the end of the line, within 80 to 110 miles of the center of the line.

5. Experimental evidence obtained from flight trials indicates that variations in signal strength received by the jammer from the DDS transmitting antenna are not large enough to prevent satisfactory locking on the above tracks.

6. Ten watts peak power radiated by the jamming transmitter should be adequate to provide a denial jamming signal from any of the four jamming tracks.

7. Deceptive jamming will likely be severely limited on crossing and co-linear tracks owing to the unavoidably high doppler frequencies created by the movement of the jammer.

8. A combination of amplitude and phase modulation might prove quite useful for paths with high doppler frequencies.

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PLATE I AIRBORNE SUPERREGENERATIVE JAMMING EQUIPMENT
USED IN STUDYING THE VULNERABILITY
OF THE DOPPLER DETECTION SYSTEM

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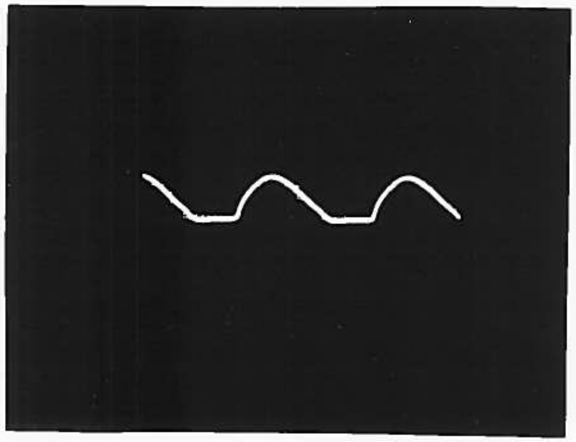
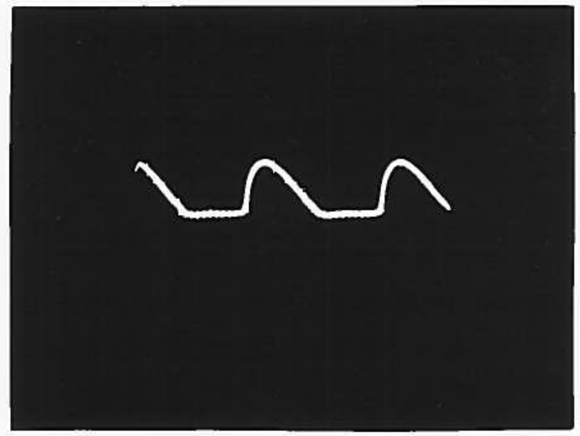


(a) OSCILLATOR LOCKED INTERNALLY



(b) OSCILLATOR LOCKED EXTERNALLY

PLATE II OSCILLOSCOPE PHOTOGRAPHS OF OUTPUT WAVEFORM OF SUPERREGENERATIVE REPEATER

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