Diffraction and Shielding Effects of Radar Screens

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SUMMARY

This report describes the results of tests to determine the effectiveness of shielding screens for surveillance radars in reducing the strength of ground-clutter signals in critical areas. The attenuation of ground-clutter signals can increase effectively the subclutter visibility performance of the moving-target indicator surveillance radars. Although the scope of the experimental tests was very limited, it was found that properly designed screens can provide a worthwhile reduction in ground-clutter signal strength in areas where the subclutter visibility performance of the radar is inadequate. It was found also that any improvement thus obtained may be negated by the performance of the radar and by certain inherent characteristics of the radar system. The experimental screen tested provided a 12- to 15-db attenuation of ground-clutter signals with essentially negligible reduction in the low-angle coverage of the surveillance radar.

INTRODUCTION

One of the many operational requirements for airport-traffic-control surveillance radars is that of monitoring the final approach of aircraft to the runway. In many cases it is possible to effect a plan-position-indicator (PPI) approach by monitoring the aircraft distance and azimuth position with respect to the runway and by continuously advising the pilot accordingly.

If the assumptions are made that the radar is capable of providing the required data with adequate accuracy for a PPI approach and that qualified personnel are operating the equipment, the success of the operation is determined largely by the visibility of the aircraft target on the radar display. The target visibility is determined by a number of factors, the technical aspects and a complete analysis of which are not covered in this report. It is sufficient to state that certain characteristics of the radar impose definite limitations on its ability to detect and display aircraft-target signals to the exclusion of undesired target signals in the adjacent areas. The ability of the controller to distinguish positively the desired target from the undesired target also is limited by the amount of undesired clutter displayed in the critical sector through which the aircraft is or will be operating.

Ground-target signals affect the visibility of the desired aircraft target principally in two ways. First, slight motion of the ground targets and/or residual instabilities in the radar equipment will allow a certain amount of ground clutter to be displayed on the PPI. Second, the visibility of moving targets such as aircraft is limited by the strength of the ground-clutter signals at the same azimuth and distance. The amplitude relationship of these signals is referred to as the subclutter visibility ratio (SCVR), and it is a measure of the strength of the aircraft-target signal in relation to the ground-target signal for a given ratio of moving target to ground clutter or background signal at the output of the moving-target-indicator (MTI) circuits. It is apparent, therefore, that the most favorable conditions are obtained when the ground-clutter signal amplitude is at a minimum.

It is common practice to tilt the radar-antenna beam upward to minimize the energy directed toward ground objects. The low-angle coverage required of the radar limits the degree of permissible uptilt. Consideration was given to another means of further reducing the radio-frequency (rf) energy directed toward ground objects in which a screen is used to obtain shielding and diffraction effects. An experimental screen was erected at the Newark, New Jersey, airport's ASR-2 radar by personnel of Region 1, Civil Aeronautics Administration, for preliminary evaluation of the technique. The results obtained established that the screen did reduce the ground clutter and that further exploration to investigate the potentialities of the technique was warranted.

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A theoretical analysis of the technique was made and an experimental screen was erected near the ASR-2 radar at the Indianapolis airport. The results of tests and measurements of the diffraction patterns produced and the attenuation of ground-clutter signals are described in this report.

THEORY

It was anticipated that if a screen of reflective or absorbent material (at microwave frequencies) were erected near a radar antenna and to the height of its center, a diffraction effect might be obtained similar to the optical diffraction of light over a straight edge. Obviously no strict adherence to optical equations could be expected owing to the difference in wavelength, the limited attenuation of the screen, the nature of the source, and other considerations. A definite similarity is exhibited, however, in the one-way diffraction patterns obtained during the tests. Patterns were obtained for the transmission path only. It can be shown mathematically that the diffraction pattern for the return path should be similar, with greater signal attenuation for all targets beyond twice the distance of the screen from the antenna. According to the tests conducted, it is indicated that the return-path attenuation is by far the greater part of the total attenuation. This effect can be visualized by considering a similar situation in optics. A straight-edged opaque object placed between an ordinary light bulb and a reflective screen, but much nearer to the light, produces a very indistinct, fuzzy-edged shadow. This might be compared to the effect on the transmitted radar signal. If the relative distances are reversed, however, a sharply defined and darker shadow is produced. This is analogous to the effect on the radar-echo path.

Two possible adverse effects of the screen might be expected. First, the effect of the screen on low-angle coverage cannot be predicted with any degree of certainty, and it is somewhat difficult to specify on the basis of flight tests. A fair index may be obtained by comparing the average video level under given transmitted power and receiver conditions in the screened and adjacent sectors. This should show the average reduction in signal strength in the screened sectors, provided there is no video-limiting in the radar receiver. Because under normal operating conditions such limiting does exist, a plot of the relative signal levels is not a valid quantitative indication. Limiting affects the average signal values by compression of the stronger signals. Thus, the actual average of all signals may be higher than is indicated. For signals below the limiting level, however, the indication is reasonably valid. Second, ambiguous ghost targets of aircraft with a bearing 180° from that of the screen or directly overhead conceivably might be produced by reflections from the screen, the latter being possible when the top of the screen is tilted 45° away from the radar antenna. Such ghost targets, if obtained, would be displayed at the bearing of the screen.

Fig. 1 Screen

TESTS AND MEASUREMENTS

The attenuation of various mesh sizes of hardware cloth ranging from 1/8 inch to 1 inch was measured at 2900 megacycles (Mc). Average attenuation ranged from 30 decibels (db) for 1/8-inch mesh to 5 db for 1-inch mesh. A 1/2- by 1/2-inch mesh, which had a 10-db attenuation, was selected for the screen after consideration of its weight, strength, and wind resistance. A 40- by 90-foot screen was erected in two sections, with a connecting strip in the middle to cover a 20° sector centered on a bearing of 255° with respect to the radar antenna at a distance of 250 feet as illustrated in Fig. 1. The top of the screen, approximately 32 feet above ground, was on a horizontal through the center of the antenna reflector. The initial antenna tilt was 0°.

In order to establish the diffraction pattern and the general effect of the screen, field-strength measurements were made at three positions behind the screen, from 2° below to 2° above the horizontal in increments of 0.25°. For these measurements, a continuous-wave (cw) signal at 2900 Mc from a Hewlett-Packard 616 signal generator was coupled into the waveguide to the radar antenna. An AN/APR-4 receiver, with a horn antenna mounted on a 60-foot vertical track, was calibrated and used to measure the signal strength at identical positions with and without the screen. See Figs. 2 and 3. Readings were obtained at 100, 200, and 400 feet from the screen directly behind its center. Curves of the average values of field strength are plotted in Figs. 4, 5, and 6. The curves indicate average values; therefore, they do not include minor deviations which were attributed to ground reflections. More severe reflections are indicated on Fig. 6 for negative angles without the screen. The oscillatory portions of the lower curves indicate the diffraction effect of the screen. If a smooth curve is drawn through these oscillations and through the minor variations of the upper curves, the effective attenuation provided by the screen can be measured as the difference between the curves and can be plotted against distance as shown in Figs. 7 and 8. From these curves it is evident that beyond a few hundred feet from the screen the attenuation of the transmitted signal becomes negligible along and for a small angle below the horizontal.

To compute the two-way diffraction effect or attenuation of ground-clutter signals, a vernier rf gain control was installed on the radar receiver and was calibrated with the signal generator and a synchroscope (A-scope). This permitted measurement of the signal level in decibels of individual targets with and without the screen when the receiver's normal video was displayed on the A-scope. Three groups of photographs were taken of A-scope presentations with gain-control dial settings of 200, 350, and 700. The 350 value approximated a normal operational gain setting. Each group consisted of 6 photographs, 2 without the screen and 4 with the screen. Other variations included tilting the screen 45° in each direction and tilting the antenna upwards 3.5°. All photographs were taken at a bearing of 255°. Typical photographs with and without the screen and with and without an antenna tilt at a gain setting of 350 are shown in Figs. 9, 10, 11, and 12. The main portion of the sweep is 100 microseconds or approximately 8 miles in range from the left to the right vertical graticule lines. Because

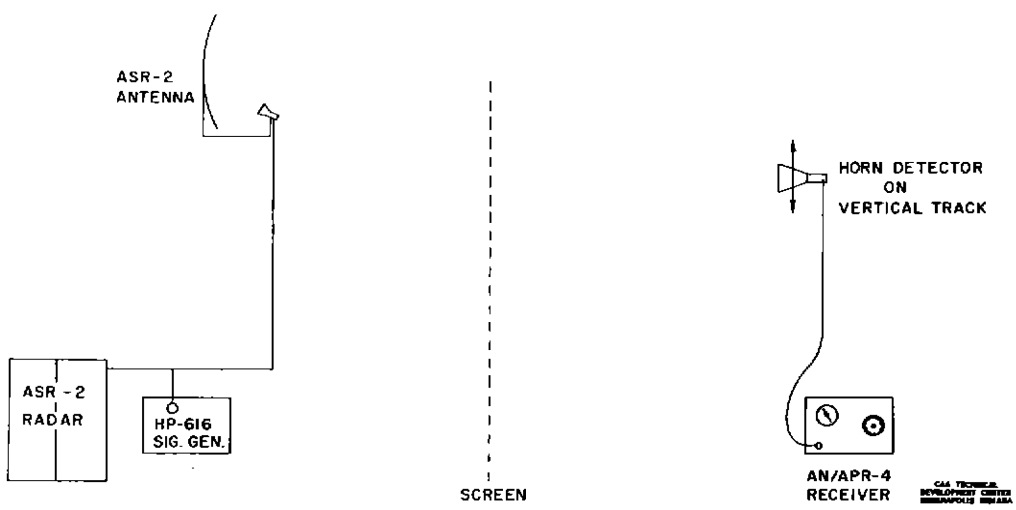

Fig. 2 Block Diagram of Test Setup

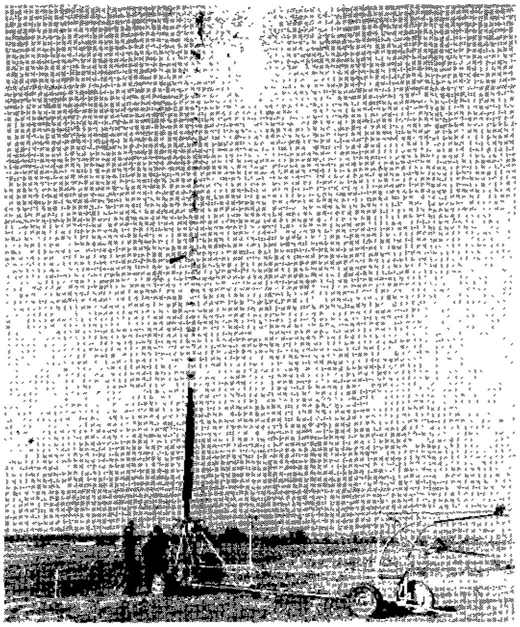

Fig. 3 Vertical Track Detector

no measurable difference was indicated reliably when the screen was tilted as compared to when a vertical screen was used, no photographs are included showing the effects of the tilted screen.

Concurrently, photographs were taken of the PPI display to show the effect on ground-target visibility. Photographs were taken on the 6-, 10-, and 20-mile ranges for the 3 gain-control settings and for other conditions as outlined previously. Thus, the relative effects could be correlated with the A-scope photographs, and the attenuation of certain targets could be checked fairly closely.

Typical photographs are shown as Figs. 13, 14, and 15. Figure 13 shows the normal video for the 6-mile range with a gain setting of 350 without a screen and the antenna tilt set at 0°. In Fig. 14 the effect of the screen is quite noticeable in the 245° to 265° sector. The

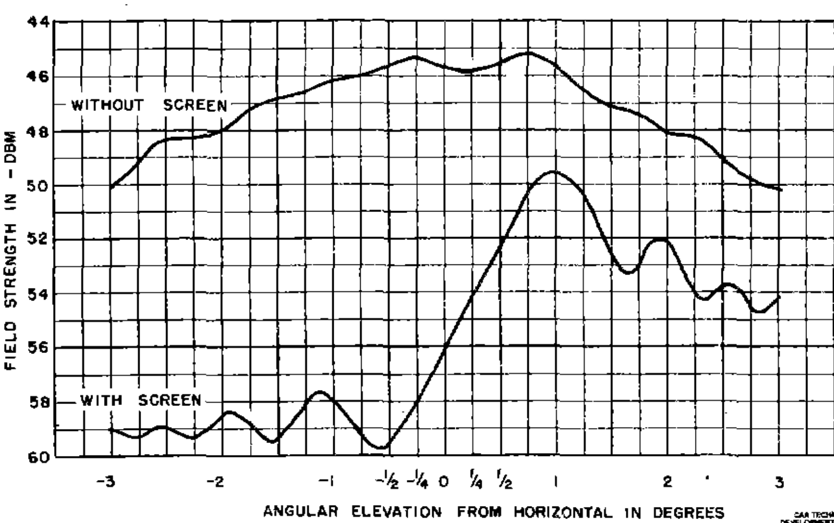

Fig. 4 Field Strength Behind Screen

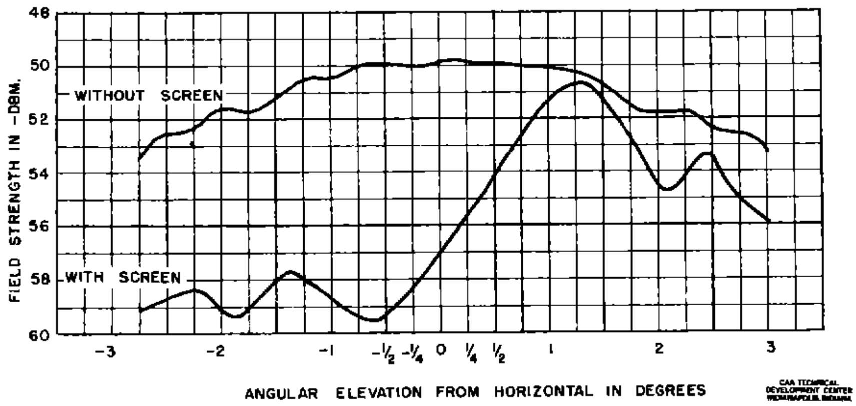

Fig. 5 Field Strength Behind Screen

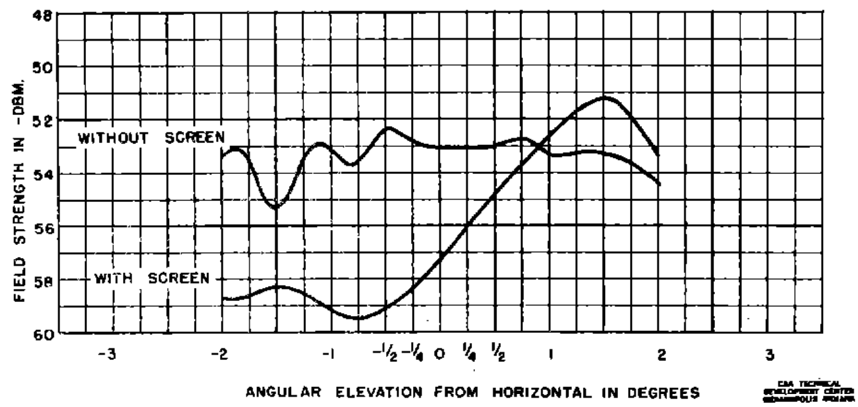

Fig. 6 Field Strength Behind Screen

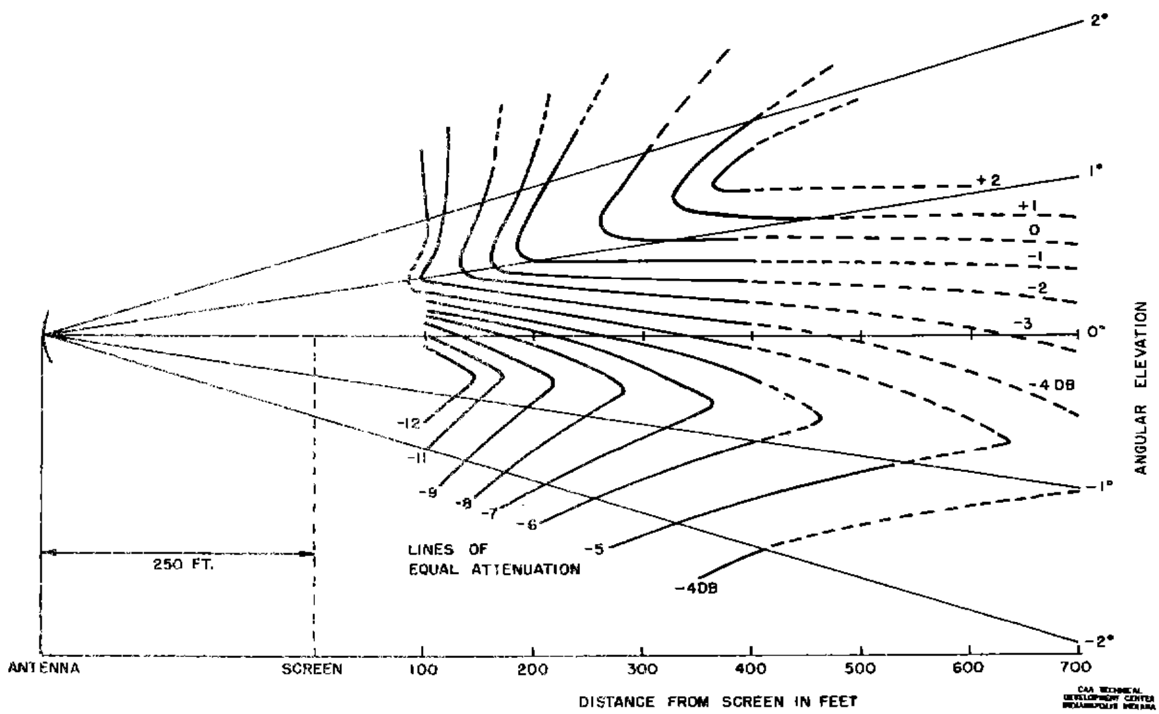

Fig. 7 Attenuation of CW Signal by Screen

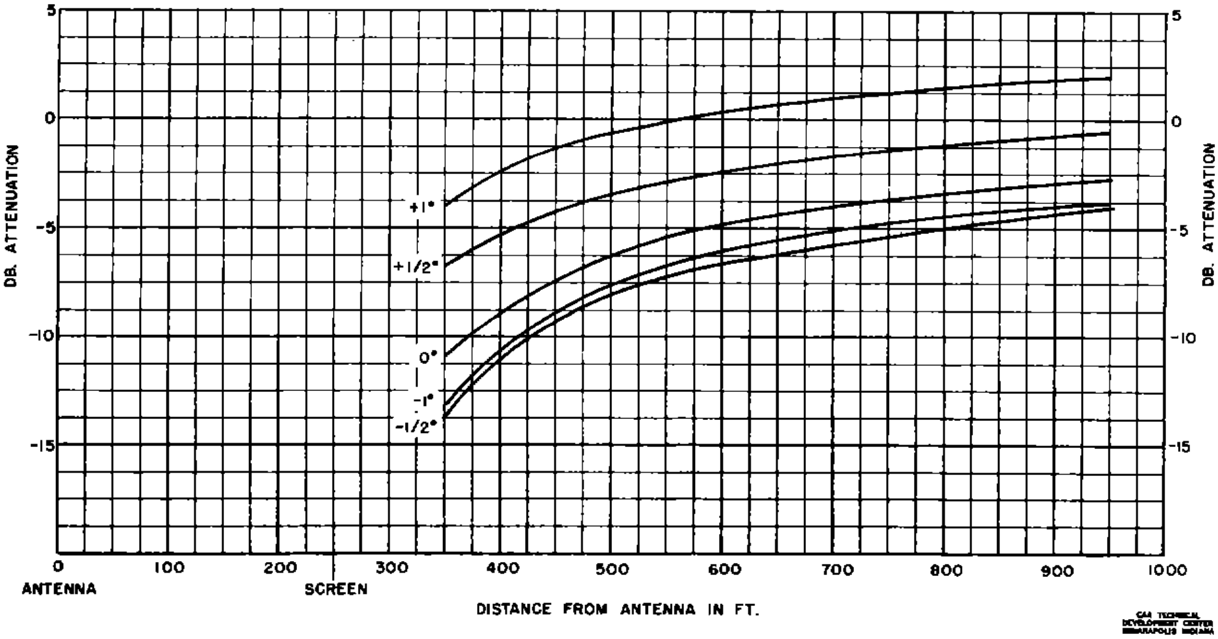

Fig. 8 Attenuation of CW Signal by Screen

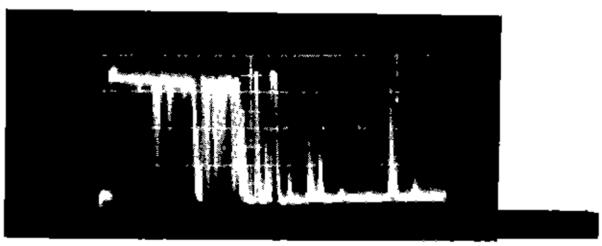

Fig. 9 A-Scope Photograph of Normal Video, No Screen, No Antenna Tilt

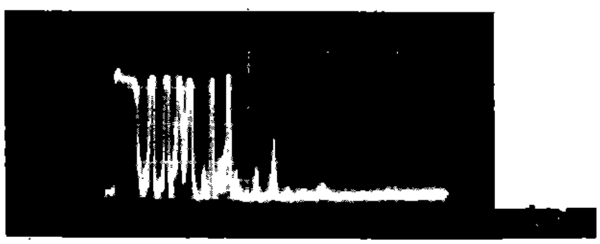

Fig. 10 A-Scope Photograph of Normal Video, Screen Up, No Antenna Tilt

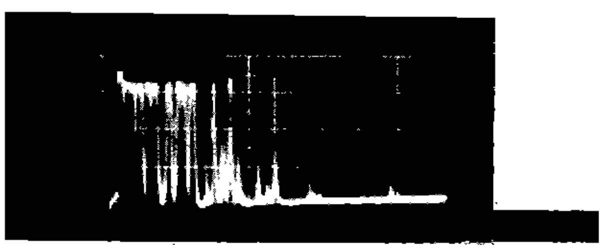

Fig. 11 A-Scope Photograph of Normal Video, No Screen, 3 1/2° Antenna Tilt

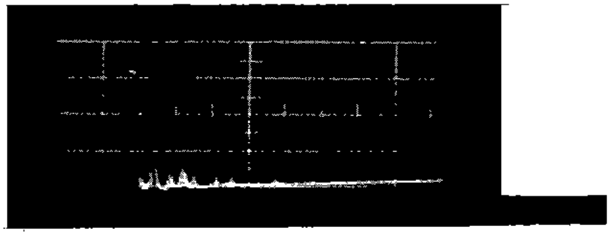

Fig. 12 A-Scope Photograph of Normal Video, Screen Up, 3 1/2° Antenna Tilt

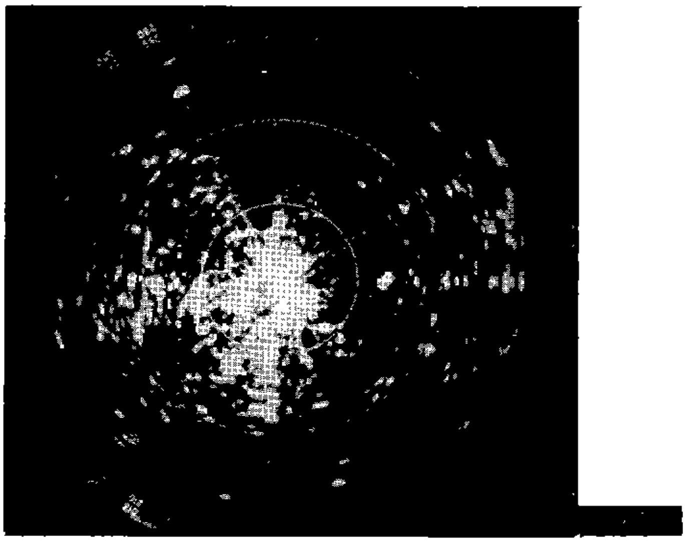

Fig. 13 PPI Photograph on Six-Mile Range, No Screen, No Antenna Tilt

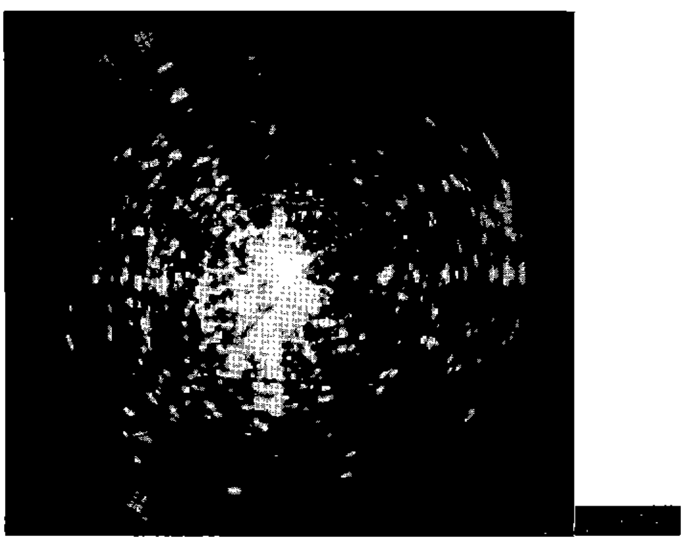

Fig. 14 PPI Photograph on Six-Mile Range, Screen Up, No Antenna Tilt

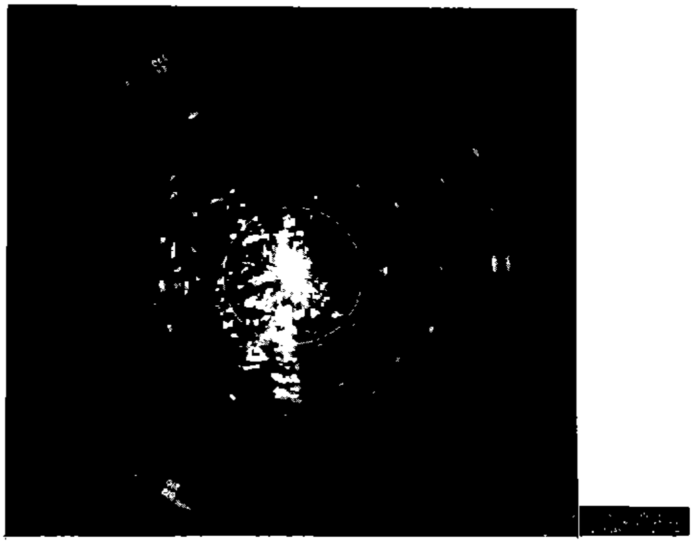

Fig. 15 PPI Photograph on Six-Mile Range, Screen Up, 3 1/2° Antenna Tilt

combined effect of the screen and an antenna tilt of 3.5° is illustrated in Fig. 15. In this case the combined attenuation is sufficient to cause an opening through moderately heavy ground clutter.

Measurements of clutter signals on the A-scope with the antenna tilt set to 0° indicate an attenuation of ground-clutter signals owing to the screen of approximately 15 db out to 5 or 6 miles and approximately 12 db at 10 to 12 miles. Setting the antenna tilt to 3.5° contributes approximately 10 to 12 db additional attenuation of clutter signals out to 5 miles and 8 to 10 db out to 12 miles. The combined effect of the screen and the tilted antenna was approximately equal to the sum of their separate effects, or 20 to 25 db attenuation. Although there was some evidence that tilting the top of the screen toward the antenna was slightly more effective, the difference was considered to be within the tolerance of the measurements. A greater accuracy could not be obtained because of the rapid fluctuation of the clutter signals.

Radial and orbital flight checks were made in the screened and adjacent sectors with a DC-3 aircraft to determine if the screen is noticeably detrimental to low-angle coverage. Six orbital flights were made; one with the screen vertical, one with it tilted 45° toward the radar antenna, one with it tilted 45° away from the radar antenna, and three without the screen. All flights were made at 2000 feet above the ground at a distance of 28 miles. Relative signal strengths of 0 to 4 were assigned to PPI targets and were recorded for each scan. These values were averaged over 5° sectors. They are plotted in Figs. 16 and 17. The small inset drawings on these figures indicate the position of the screen with respect to the antenna. Figure 16 shows that the average signal strength in the majority of the 5° sectors in the screened area was below that of the adjacent sectors on the same flight. It is not valid to compare the actual signal levels of one flight with those of another because of variable propagation effects and slight variations in the radar performance from day to day. Without the screen, the average signal strength in the same sectors was equal to or above that of the adjacent sectors in the majority of the cases. See Fig. 17. There were some exceptions to these general indications, both with and without the screen. It will be noted that the average signal strength for the screened sector in Fig. 16 is the lowest of the three curves when the screen was up. This is attributed to the fact that the screen was about two feet higher in this test than when the screen was tilted. Good coverage with no blind spots was obtained in additional flight checks at 1000 feet above ground at 9 miles, conducted in accordance with MANOP I-B-7-1,[1] Paragraph 5.322, and on a simulated approach through the screened sector from 1200 feet above ground at 15 miles to 300 feet above ground at 1 mile. The flight tests established that there was a noticeable adverse effect on low-angle coverage behind the screen, but it was not severe enough to be significantly detrimental to the radar display. Again it was not established that there was any appreciable advantage or disadvantage to tilting the screen either way.

Radial and figure-eight flights were made in an area opposite the direction of the screen from the antenna for all angular positions of the screen to check for ghost targets, but none were observed definitely.

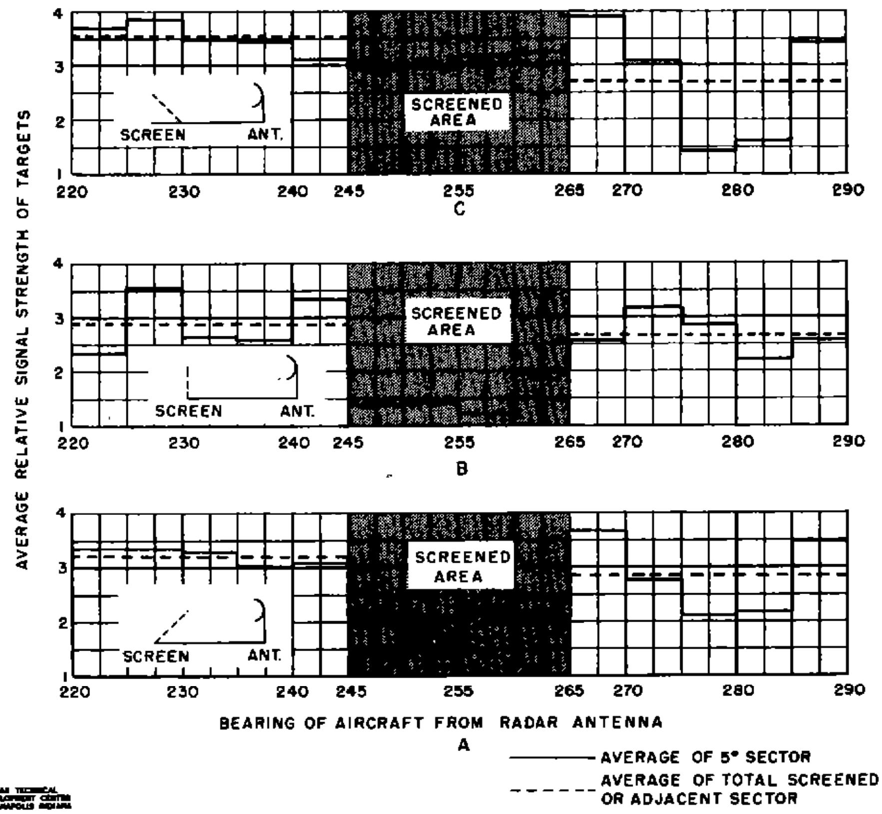

Fig. 16 Flight Check of ASR-2 Radar With Shielding Screen

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[1]Federal Airways Manual of Operation I-B-7-1, "Flight Inspection of Airport Surveillance Radar (ASR) Facilities," Paragraph 5.322, Test Procedure, "(a) With the antenna tilt the same as for the previous tests, and after performing all other tests, the aircraft shall fly by visual contact, in a 360° circle having a 9-mile radius and centered at the equipment. Three such circles should be flown; at constant altitudes of 1,000, 2,000, and 3,000 feet above airport elevation. The 2,000-foot and 3,000-foot circles need not be flown if no 'blind spots' occur at 1,000 feet. The technician shall record the signal strength (0, 1, 2, 3, and 4, in this case) for every scan around the circumference on standard Form ACA-496.32. This test shall be performed with Normal Video only."

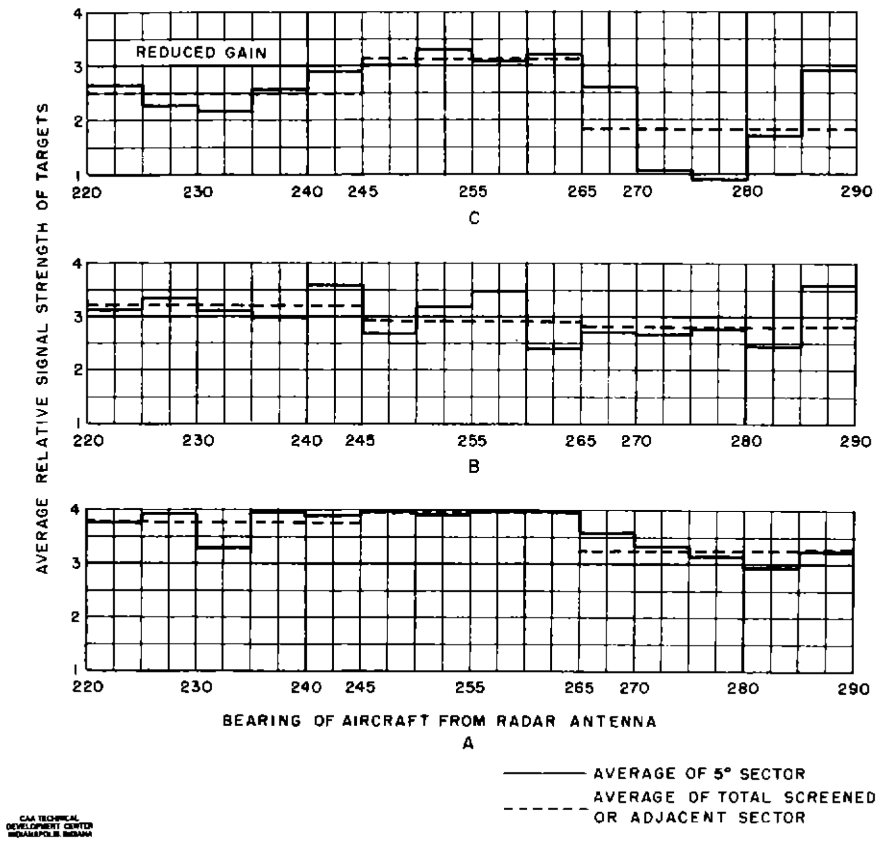

Fig. 17 Flight Check of ASR-2 Radar Without Shielding Screen

CONCLUSIONS

It is concluded that a wire-mesh screen such as is described in this report can be effective in the reduction of ground-clutter signal amplitude without seriously reducing the low-angle coverage of the radar. The effect on the subclutter-visibility (SCV) performance of the radar could not be determined conclusively because it was not possible to leave the screen erected for a sufficiently long period during which the radar was necessarily decommissioned.

Because the curves of Fig. 7 indicate that the field strength of the transmitted signal along the horizon beyond approximately 1500 feet is essentially the same with or without the screen, it is apparent that the ground-clutter signal-strength attenuation is due to the combined shielding and diffraction effects of the screen on the return (echo) path. There is reason to expect, therefore, that the curves of Fig. 7, for an antenna to screen distance of 250 feet, would be approximately correct for the return-path signal where the aircraft or ground-target signals are considered to be the source and the radar the detector. This assumption does not account fully for the higher attenuation indicated by the A-scope measurements, however.

Analysis of the data presented in Figs. 4, 5, and 6 indicates that the screen has little effect on the field strength for targets at elevation angles above approximately 1.4°. On the basis of the A-scope measurements, a conservative estimate of an average ground-clutter signal attenuation would be approximately 10 db. Thus, the ratio of the aircraft to ground-target signal levels may be considered to have been increased by approximately 10 db.

It is important to recognize that under certain conditions there may not be a significant improvement in the visibility of aircraft targets on the PPI display. Even though the screen attenuates the level of ground-clutter signals, a large amount of uncancelled residue still will be displayed on the PPI because of phase fluctuations if the antenna-scan rate is excessively high. The situation is not improved in the case where the amplitude of the ground-clutter signal is such that it does not reach a limiting level in the radar MTI receiver because amplitude and/or phase fluctuations are probable, which can result in limited cancellation and SCV ratios. It is evident, therefore, that sufficient attenuation of ground-clutter signals must be afforded by the screen to reduce the amplitude to something less than the threshold of visibility level. If this is not the case there will be no material improvement in the visibility of targets. For signals above the visibility level, cancellation ratio limitations will be imposed by residual instabilities in the radar, target motion, scanning phase, and amplitude fluctuations.

On the basis of the limited attenuation provided by the screen and considering the high scanning losses for the ASR-2 and ASR-3 radars, it is believed that the slight improvement in performance which might be obtained through use of a screen would not justify the cost of the screen installation.