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PREDICTION OF LOW SIDELOBE ANTENNA PERFORMANCE IN THE PRESENCE OF LARGE SCATTERERS USING RF FIELD PROBE TECHNIQUES

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Modern airborne radar systems that demand narrow beamwidths and low sidelobes require large antenna apertures. As the antennas become larger and sidelobe requirements tighter, the effects of scattering from the aircraft structure becomes more pronounced and the resulting antenna performance can become quite degraded. It would therefore be useful to know beforehand what affect the aircraft will have on the performance of the antenna. A brute force method of obtaining this information would be to build and mount a full scale antenna on the plane, but this would be quite expensive due to the high cost of fabricating the antenna. This paper presents a more practical measurement scheme using a full scale model of the plan and a field probe assembly.

The field probe track assembly is mounted on the aircraft in the same location as the proposed radar antenna. With a RF signal source in the far field, the field probe is moved over the whole area of the antenna aperture and data is taken at each point corresponding to a radiating element location. These complex data points are then processed along with the theoretical antenna aperture distribution to obtain a predicted actual antenna pattern in the presence of the aircraft.

2. Experimental Setup

The investigation described in this paper was conducted at the Westinghouse Ridge Road Antenna Range in Baltimore, Md. The range used was a 6000 ft, elevated X-Band range, with a large 3-axis positioner mounted on the roof of a 4-story building.

The hull of a government surplus airplane was obtained and mounted upside down on the 3-axis positioner. The upside down mounting provided better access to the proposed antenna mounting site which was under the forward part of the fuselage and off to one side. This configuration also helped eliminate unwanted reflections from the positioner itself (See figure 1).

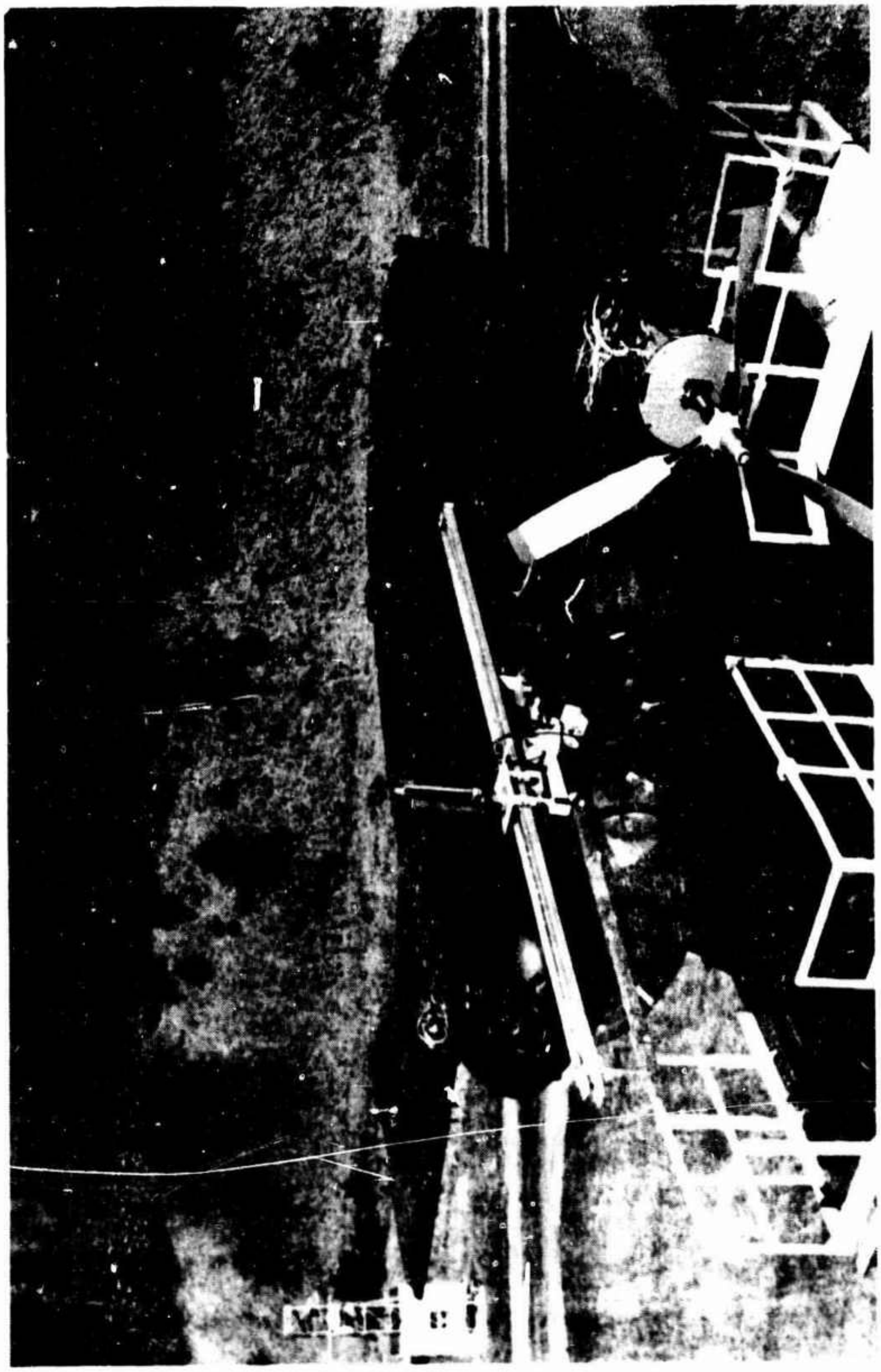

Figure 1. Mounting Configuration

The field probe assembly used was a Scientific Atlanta field probe with a 20-foot track and a servo controlled carriage that could be moved along the full length of the track. The assembly was mounted on the plane such that the field probe element would completely sweep through the proposed antenna aperture, which was approximately 15 ft long by 16 in. high. In order to reduce the number of data points that needed to be taken, a vertical slotted waveguide stick that completely covered the height of the aperture was used as the field probe element. This reduced the data taking and processing from a two dimensional case to a one dimensional case (See figure 2).

Extreme care was taken in the mounting of the field probe to insure that the track was as straight as possible and that the carriage and field probe element experienced little "wobble" as they moved down the track. Sturdy mounting structures and optical alignment techniques were employed. A piece of absorber was attached to the back of the stick to reduce backlobe reflections.

Figure 3 shows the block diagram for the experimental setup. The APC horn is a reference horn for the receiver that allows it to lock onto the correct frequency. Channel A is the measured data from the field probe and channel B is the reference signal for the measurement. The high speed RF switch continuously switches between these two channels at a high rate. The computer reads three values from the receiver. The first is the amplitude of A, the second is the amplitude of B, and the third is the difference in phase between A and B. The computer also reads the position of the field probe from the field probe controller.

The procedure for obtaining a set of data is as follows. First the field probe track must be aligned perpendicular to the range axis. This is accomplished by positioning the field probe at one end of the track and then slowly moving it while monitoring the phase on the pattern recorder. If the track is misaligned, the phase response will have a slope proportionate to the misalignment (See figure 4). The position of the track is adjusted using the lower azimuth table until the phase response is a straight line, at which point the track is boresighted.

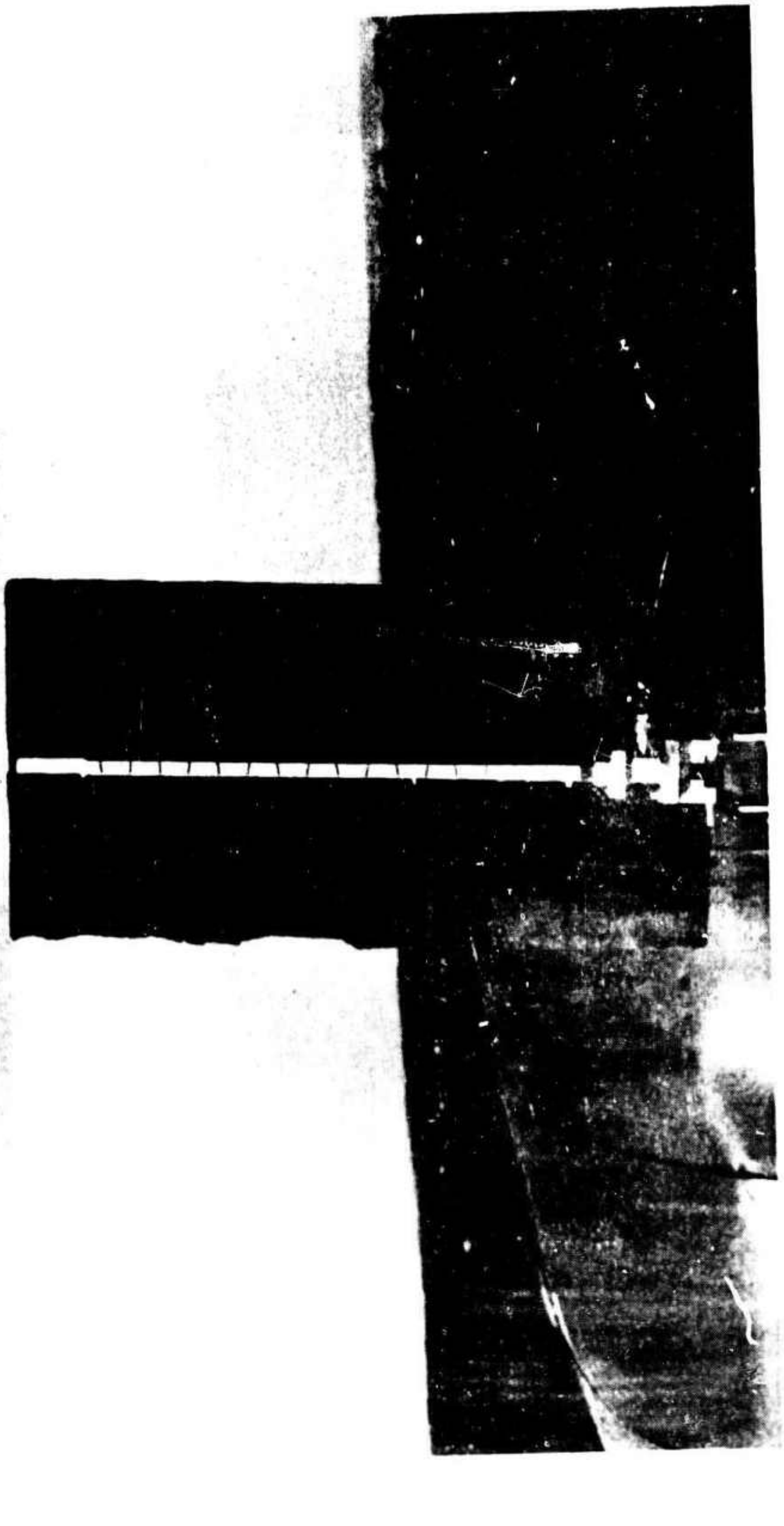

Figure 2. Field Probe Element

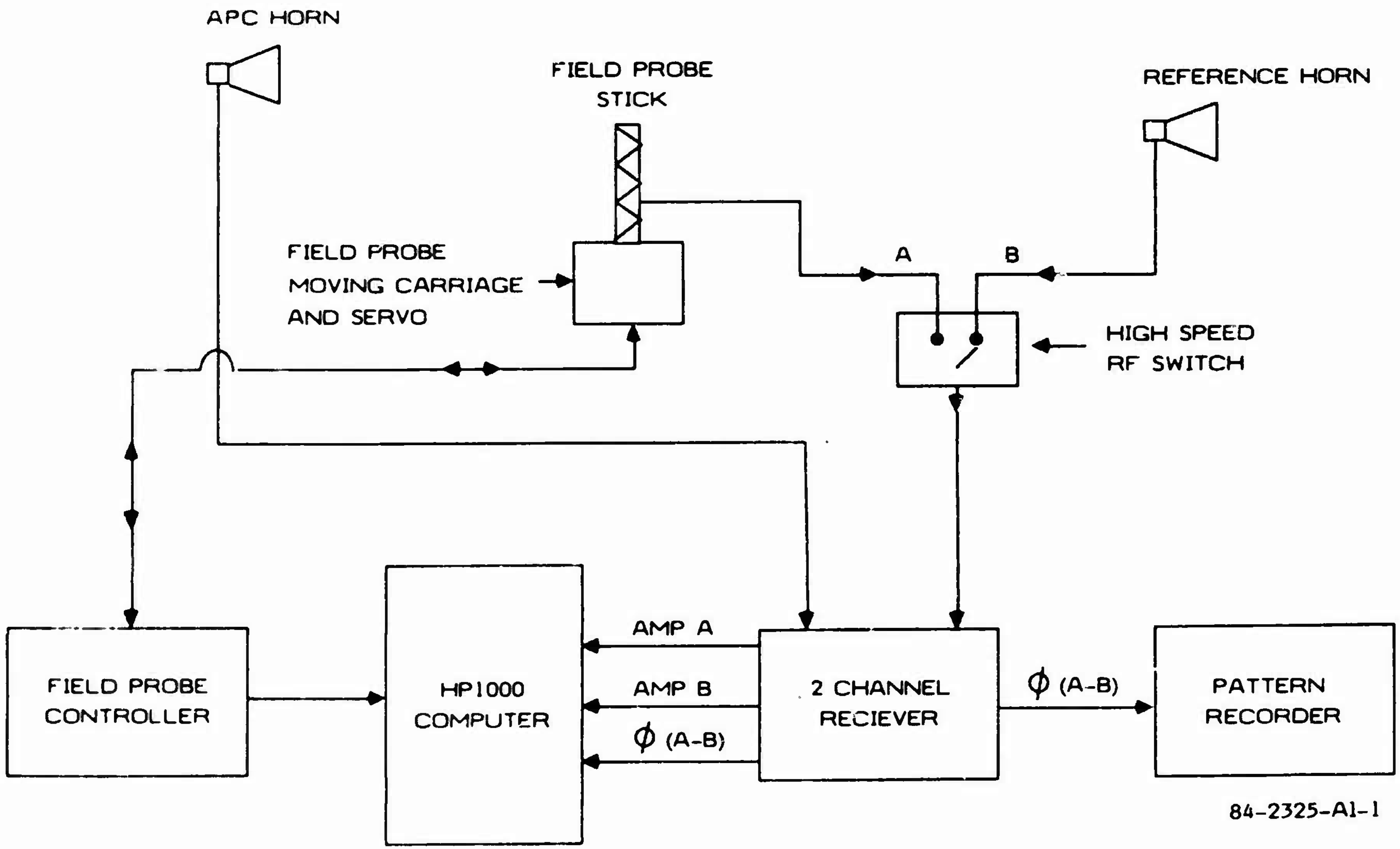

Figure 3. Experiment Block Diagram

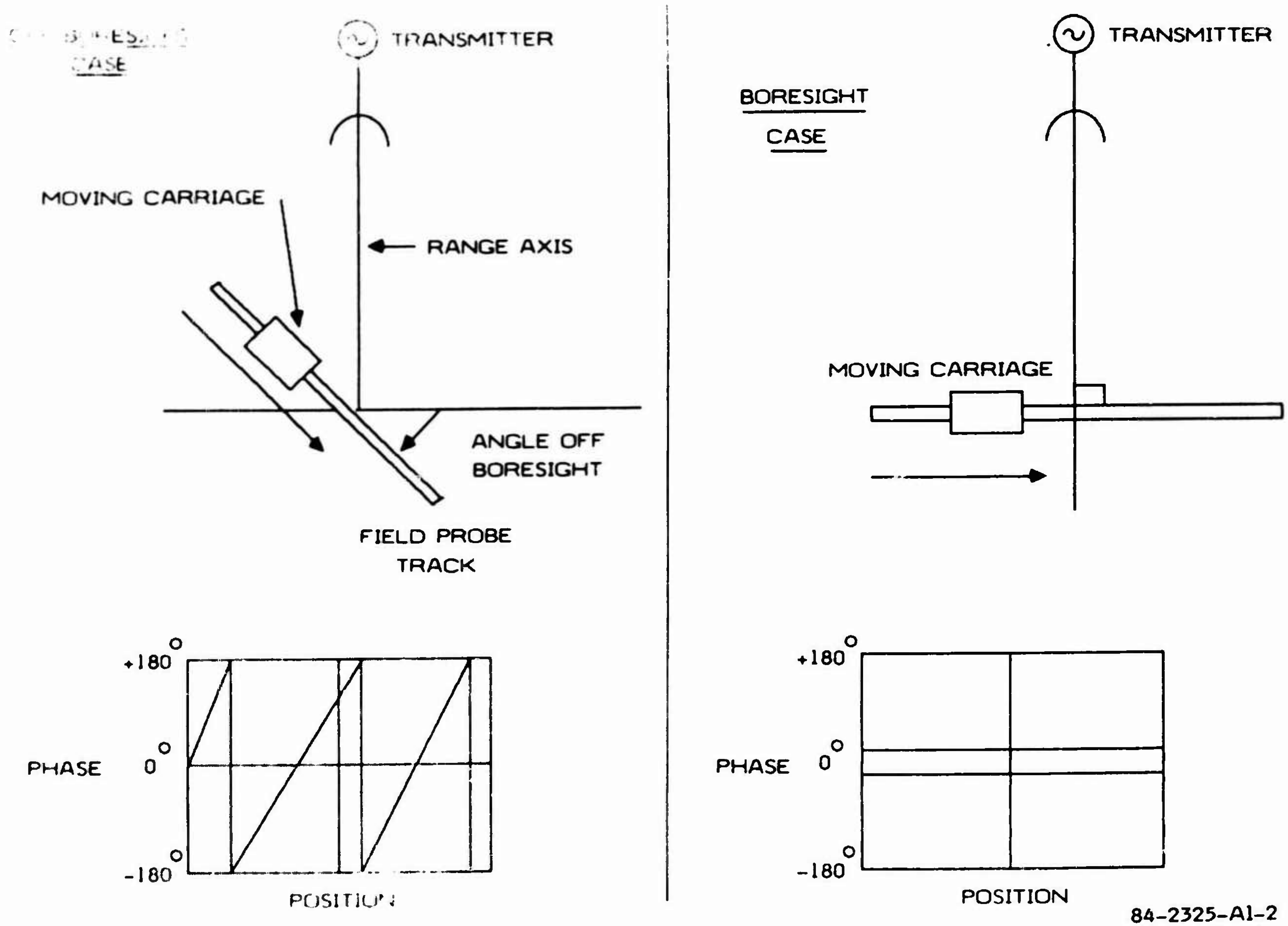

Figure 4. Boresighting

Once the field probe assembly is boresighted, the probe is once again positioned at one end of the track, and then slowly moved down toward the other end. The computer continuously monitors the position of the probe and once the probe reaches the position of the first radiating element of the antenna it takes ten reads of the three receiver values. The average of these ten reads is then stored along with the appropriate probe position. This process is repeated for each radiating position. During the run, the phase data is monitored on the pattern recorder. If a malfunction should occur in the setup during a run such as the receiver losing lock, this could be detected by a larger "glitch" in the phase and the run could immediately be stopped. Once a data run has been completed the data is stored on a disc.

After a sufficient amount of data is taken, it can then be processed. The processed data is to be presented in three ways. The first is a plot of the amplitude of the scattering data versus probe position. This information is obtained by taking the difference of the amplitude of channels A and B. The second is a plot of the phase versus probe position. The third way is in the format of a far field antenna pattern. The amplitude and phase of the scattering information is multiplied by a typical theoretical amplitude distribution and then processed using a Fast Fourier Transform (FFT). If desired, the aperture weights can be further modified by a random complex multiplier, prior to the FFT, to simulate aperture errors due to fabrication and aperture phase tuning. A typical example of a set of processed data is shown in figure 5.

During the early part of the experiment a high frequency ripple was noticed in the measured phase data. After a careful investigation, it was determined that the major cause of this ripple was due to field probe wobble. Most of this effect was removed by mechanical adjustments to the probe assembly. To further remedy this situation, a software filter was developed that used an averaging technique to smooth out this high frequency ripple. Figure 6 shows the same set of data filtered and unfiltered. The corresponding far field patterns are shown in figure 7.

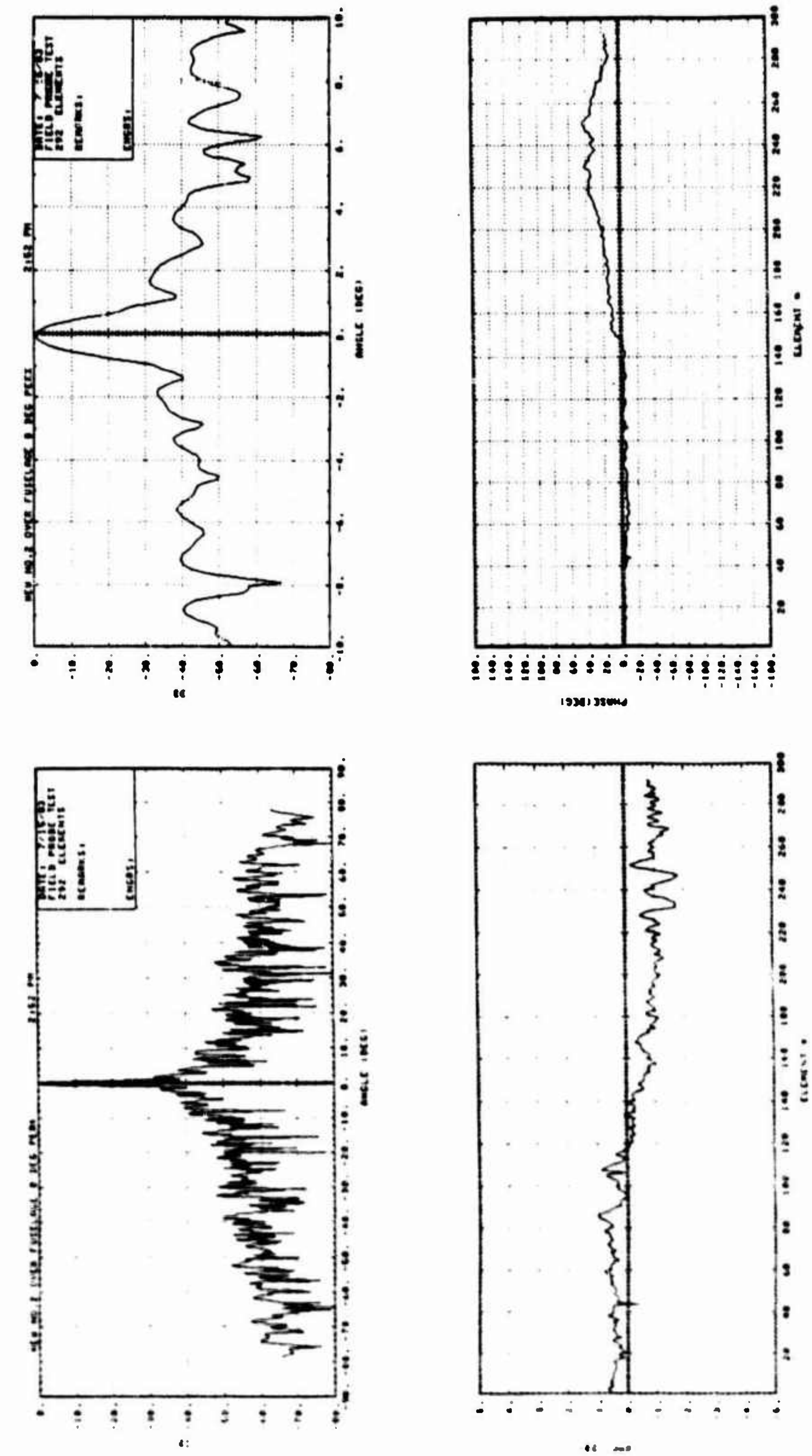

Figure 5. Example of Processed Data

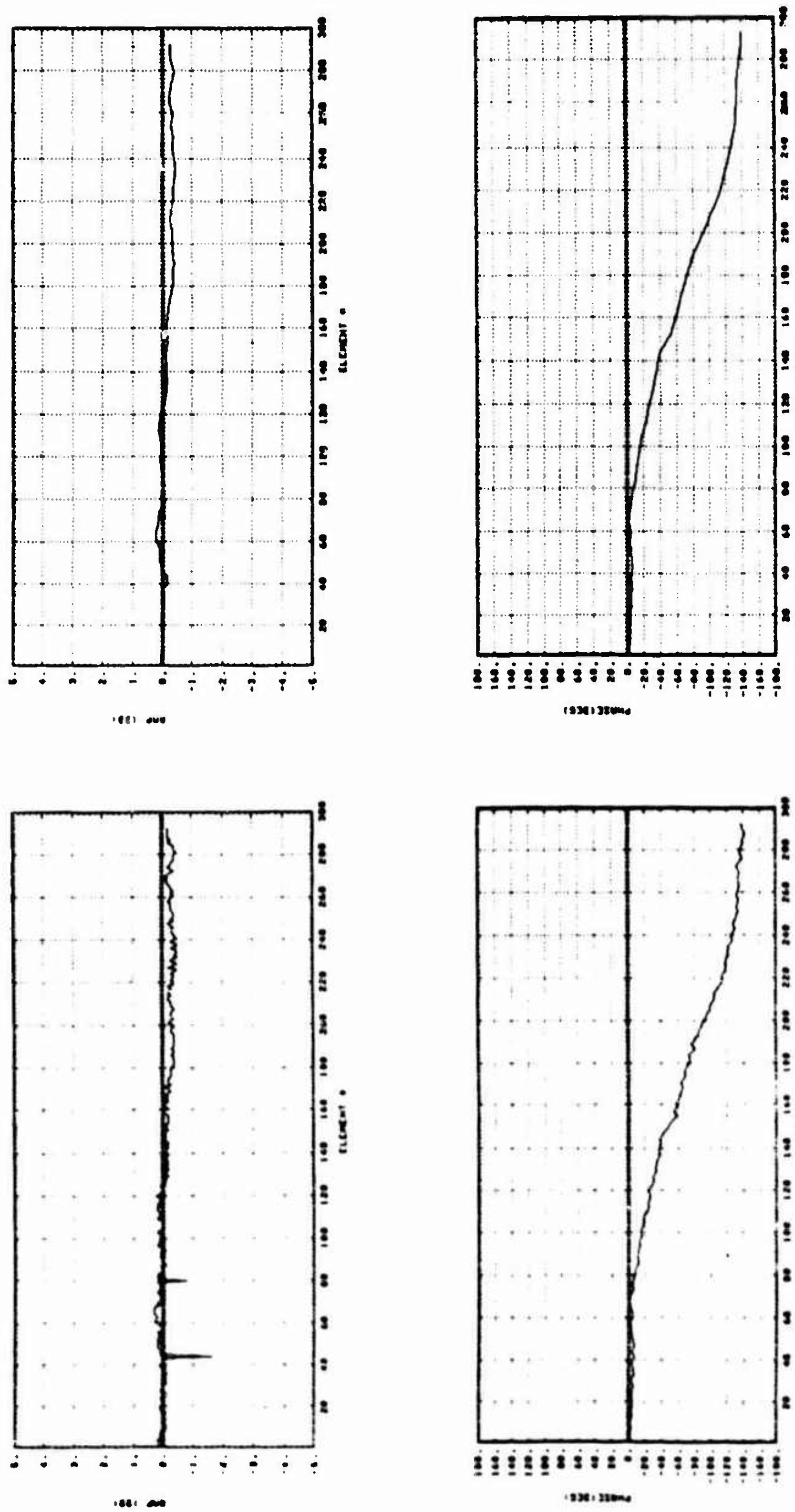

Figure 6. Effects of Filtering

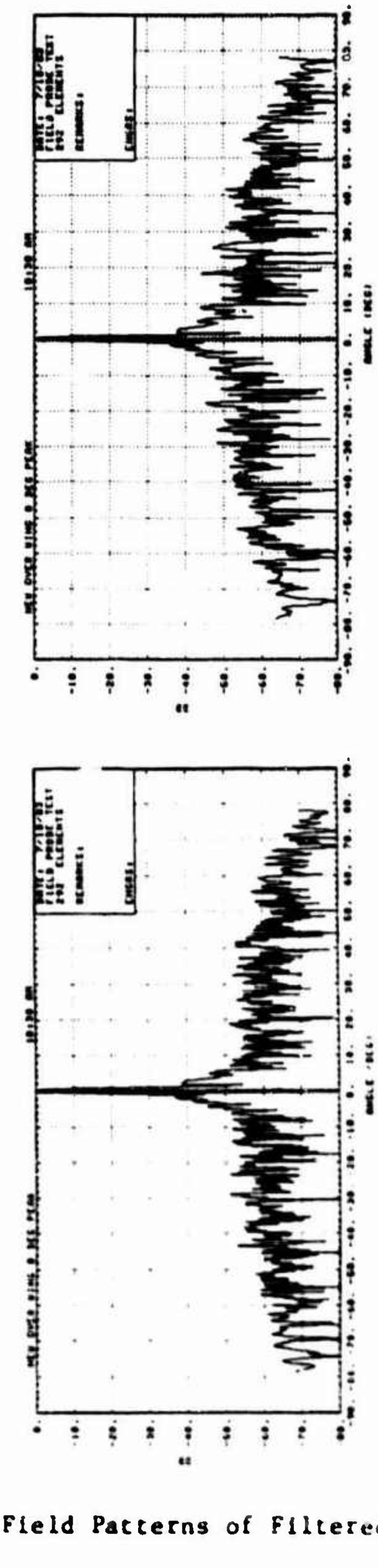

Figure 7. Far Field Patterns of Filtered and Unfiltered Data

3. Data

Data was taken for two basic aircraft/antenna geometeries. The first was for the case of the antenna looking out directly over the wing, and the second was for the case of looking across the fuselage. These two cases are shown schematically in figure 8 and will be referred to from now on as over the wing, and over the fuselage.

The effects of mechanical elevation scanning were simulated as shown in figure 9. First the airplane is tilted to some angle using the 3-axis positioner, and then the field probe element is mechanically boresighted using a level. Positive angles correspond to looking into the aircraft and negative angles correspond to looking away.

The effects of electronic azimuth scanning were also investigated. Figure 10 illustrates the geometry used to simulate this condition. The airplane was simply rotated to some angle relative to the range axis using the positioner. Due to the broad beamwidth in the azimuth plane of the field probe element, reboresighting of the element was only necessary for angles greater than 40 degrees. In order to make the phase plots more readable for these cases, the derivative of the phase was plotted instead of the actual phase, which would have consisted of a series of ramps. Positive angles correspond to the antenna scanning toward the front of the plane and negative angles correspond to scanning toward the tail.

Scattering off a fuel tank was also investigated by actually attaching a wing tank to the plane as shown in figure 11.

In order to obtain a reference set of data that is essentially free of aircraft effects, the probe was placed in the over the wing configuration and the plane tilted down -25°. This gave the field probe a clear line of sight view of the transmitter over the full length of travel. This data is shown in figure 12. For all of the data presented in this paper, a 60 dB Tschebyscheff distribution was used as the theoretical antenna distribution with added random errors of 0.15 dB RMS amplitude and 1° RMS phase. This ultra low

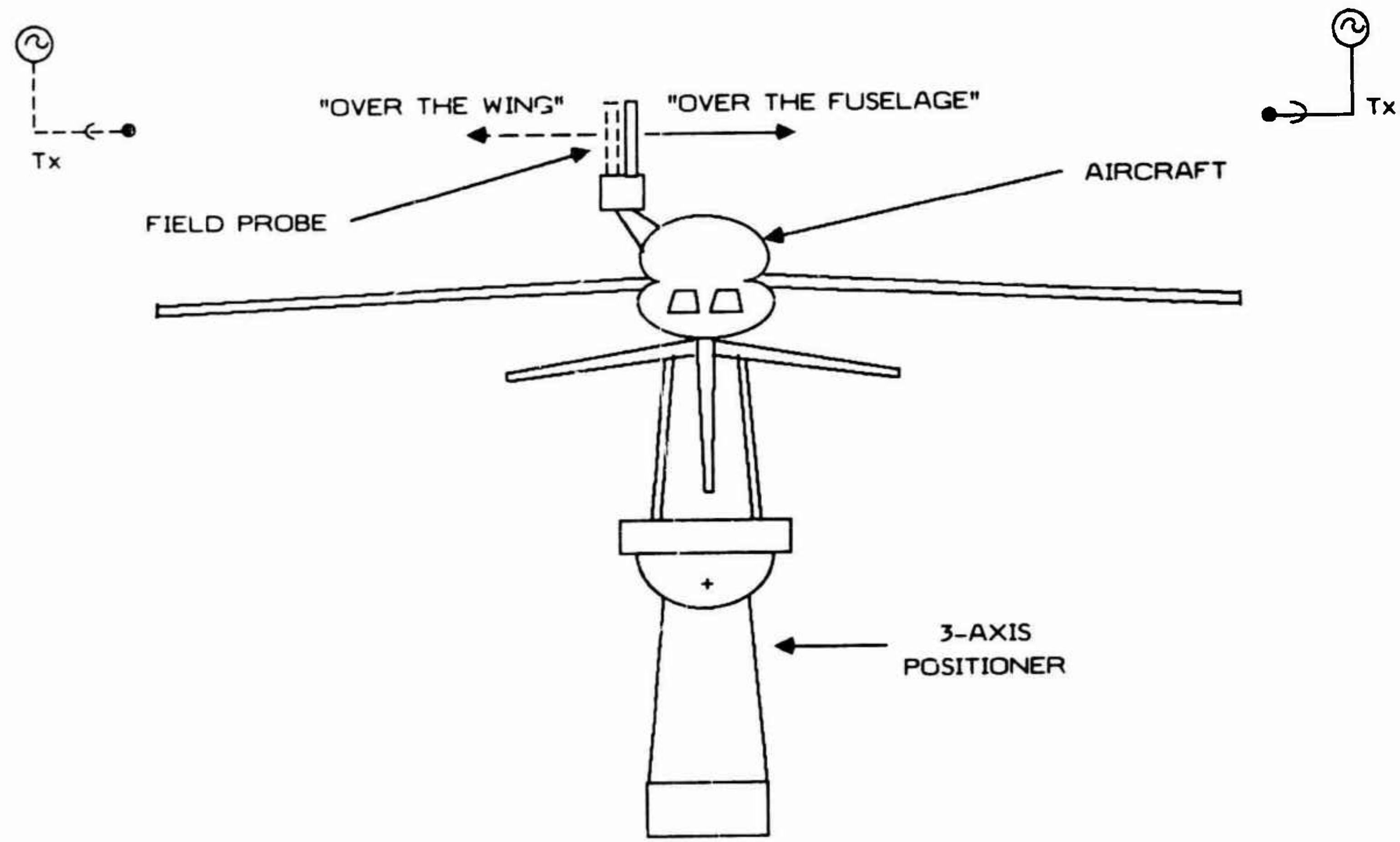

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Figure 8. Field Probe Test Setup

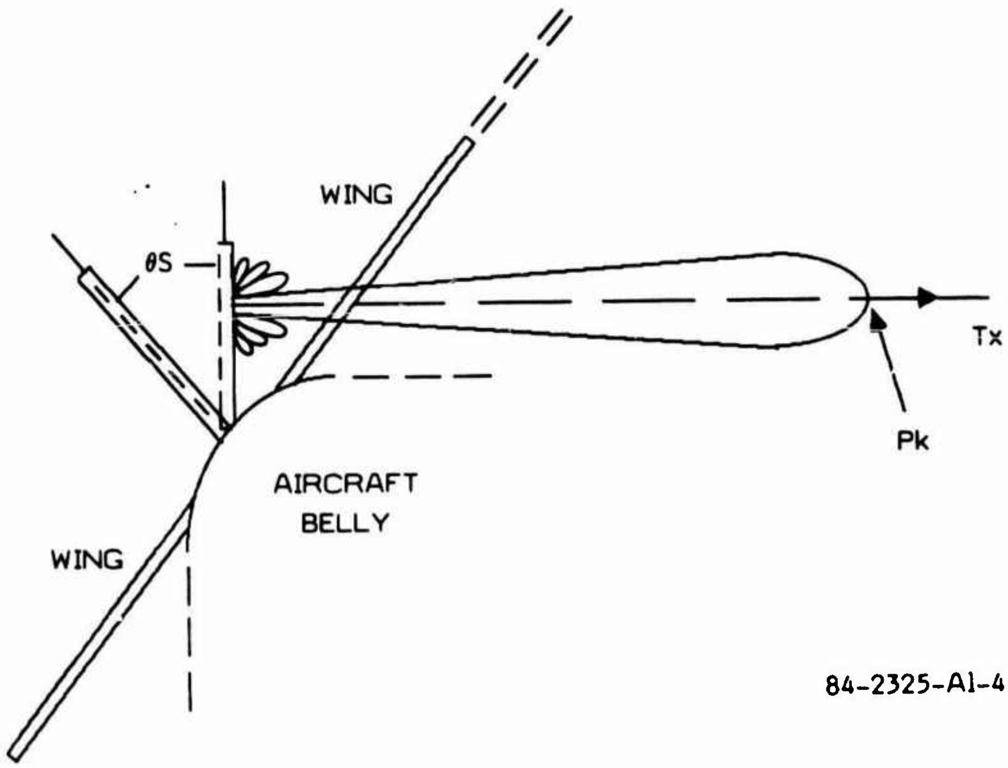

Figure 9. Elevation Scan.

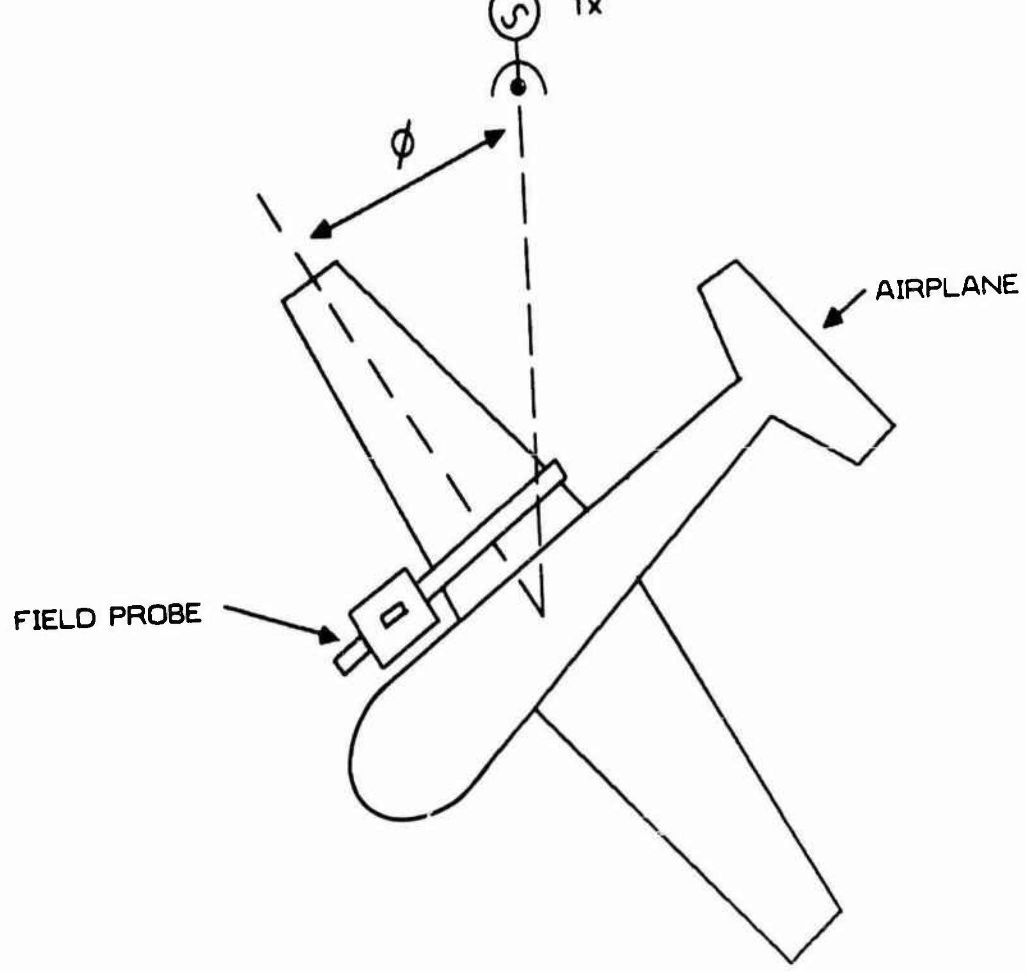

Figure 10. Azimuth Scan.

Figure 11. Wing Tank Position

sidelobe distribution was used so that scattering effects could be readily observed. Figure 12 indicates that all far out sidelobes are below 50 dB. The close in sidelobes are higher due to the phase fall off shown. This fall off was due to a twist in the probe track which could not be corrected during the experiment without significant additional expense.

Figures 13 and 14 present data for the two basic configurations of over the wing and over the fuselage. Both cases are for 0° elevation and 0° azimuth. The amplitude scattering is slightly greater for the fuselage case due to a slight blockage by the fuselage.

Figure 15 shows the results for a case of severe blockage. The probe is setup to look over the wing with the fuel tank in place. The azimuth scan angle is -40 degrees and the elevation angle is +15 degrees. The blockage effects of the wing and tank are very evident.

4. Conclusions

The conclusion that can be drawn from the data presented here is that the basic setup and instrumentation is quite clean and accurate. This is evidenced by the 50 dB peak far out sidelobes measured in the reference setup. The first few close in sidelobes are somewhat higher due to experimental errors caused by carriage "wobble" and twists in the track itself.

Improvements in the setup can be made to improve close in sidelobe performance. These improvements would include mechanical adjustments to the probe assembly, and carriage to remove wobble and twists. Consideration must be given however to the fact that good close in sidelobes are hard to obtain in the manufacturing of low sidelobe antennas and therefore the performance demonstrated in this paper may be sufficient.

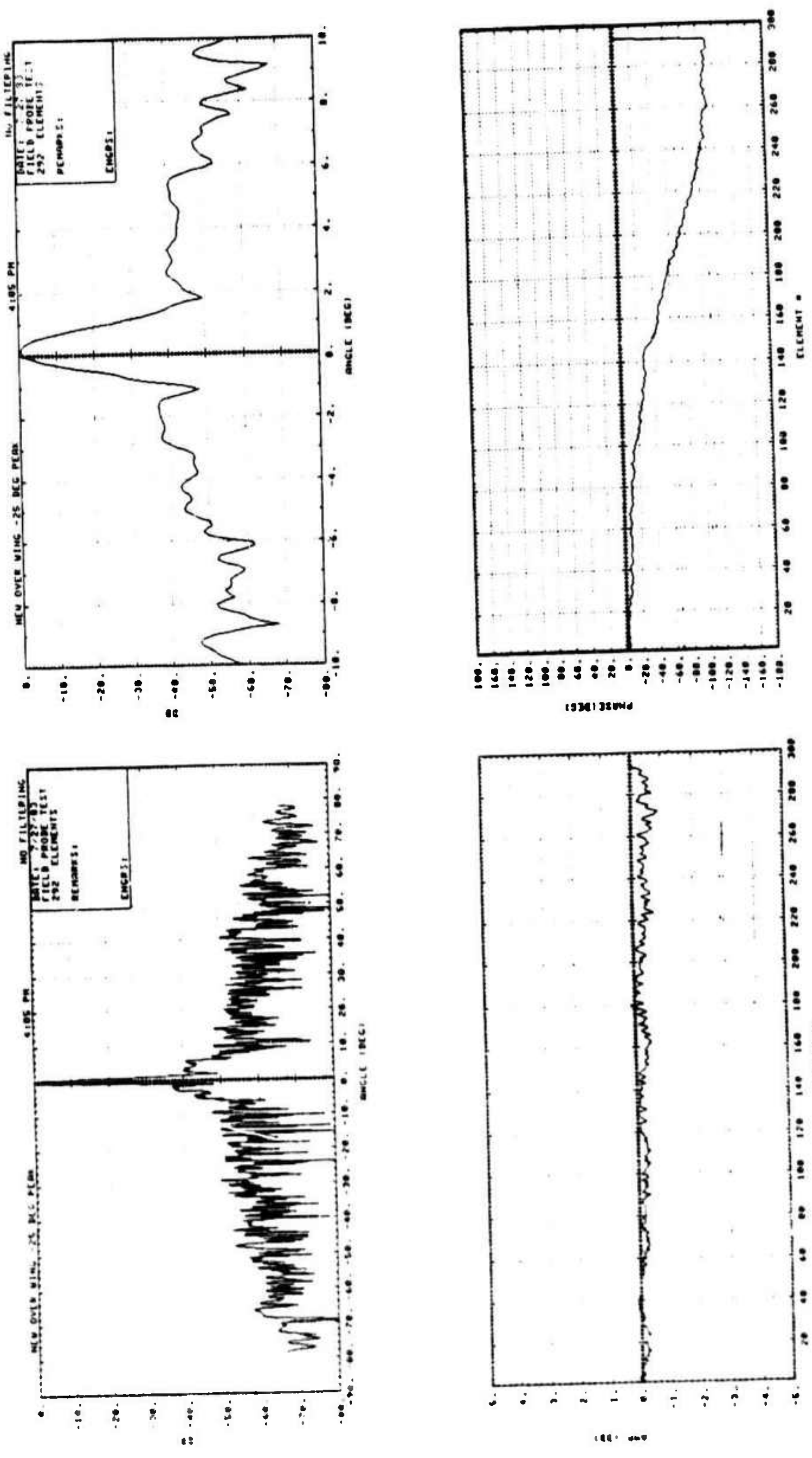

Figure 12. Field Probe Clear of Airplane

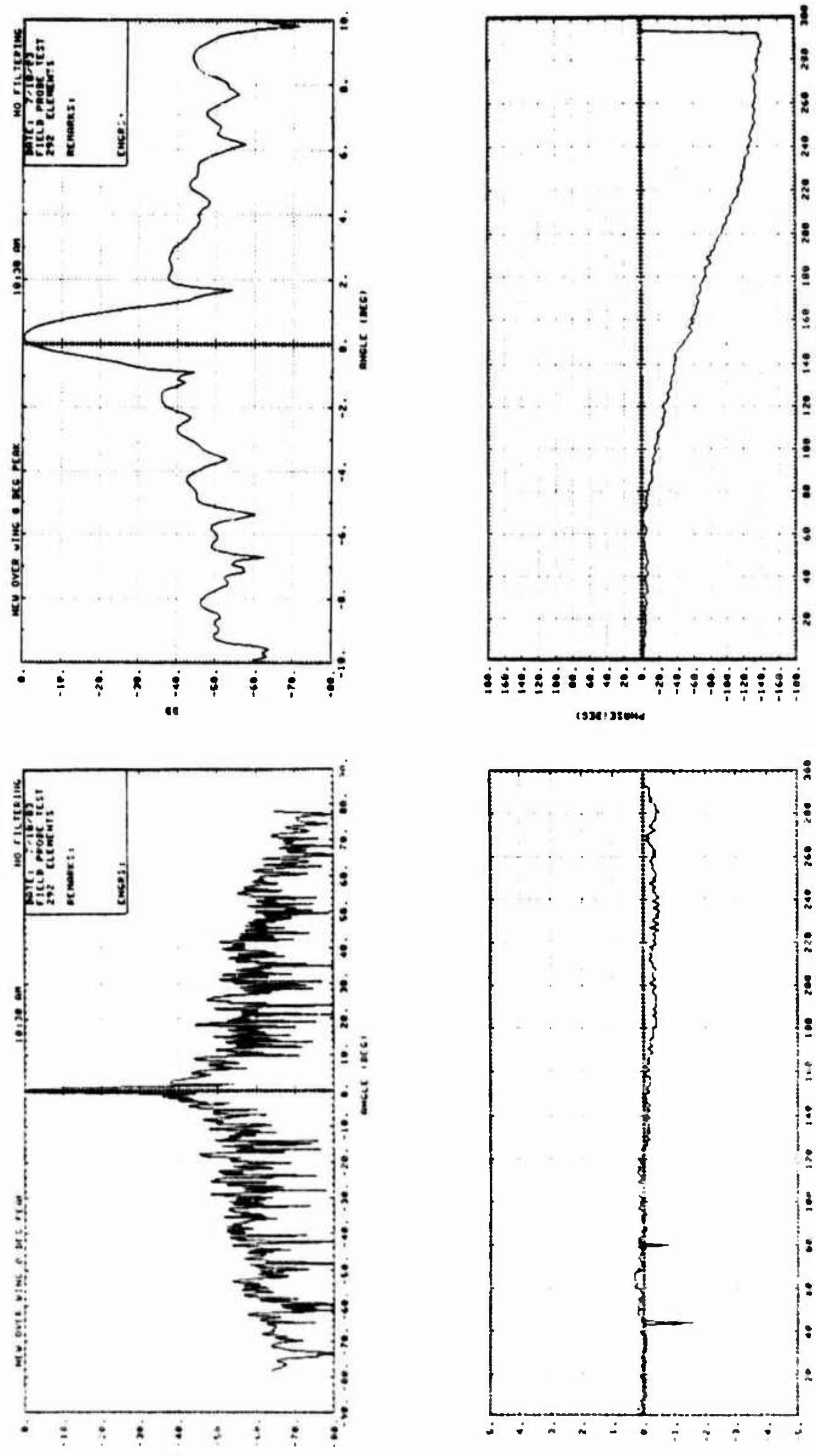

Figure 13. Over Wing

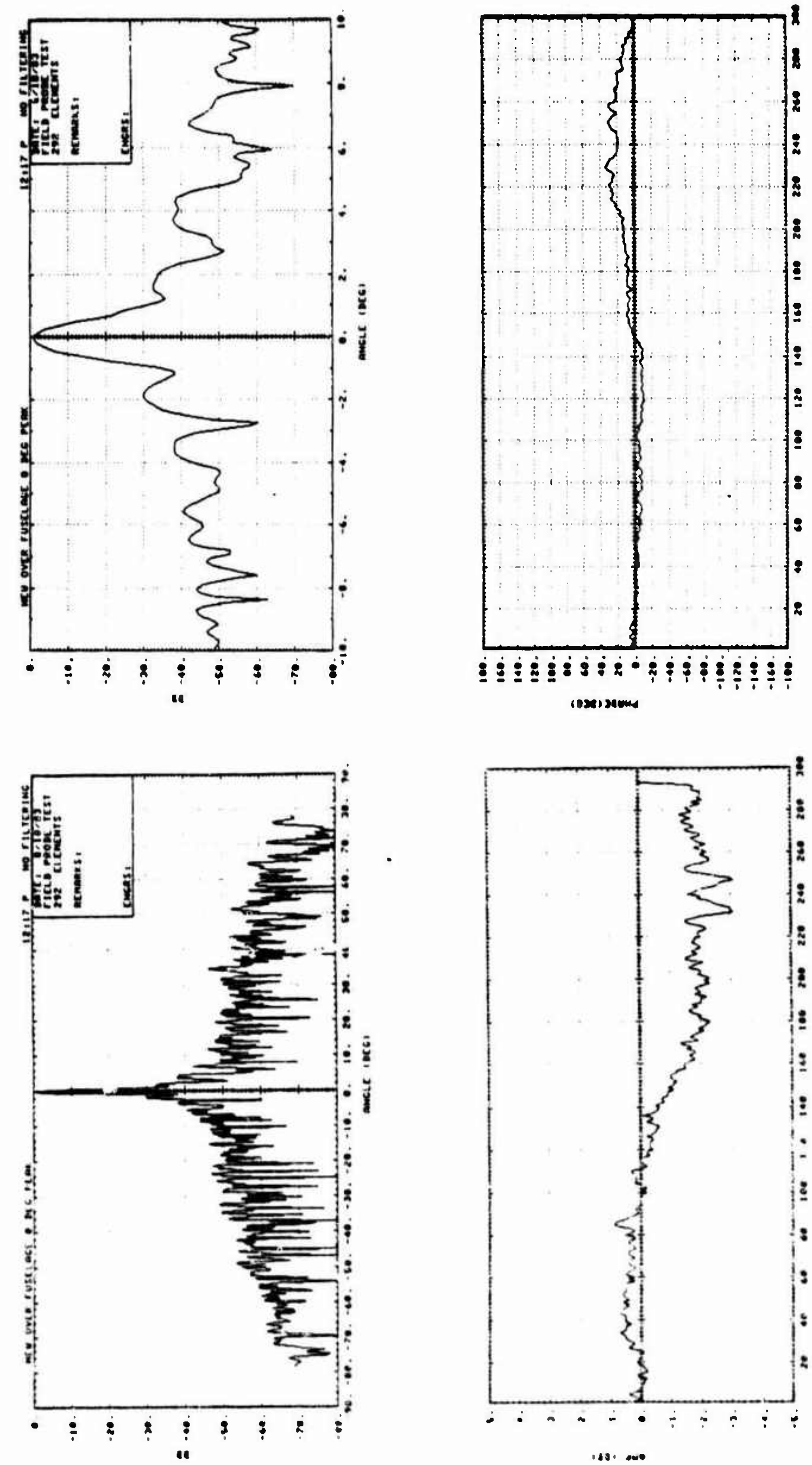

Figure 14. Over Fuselage

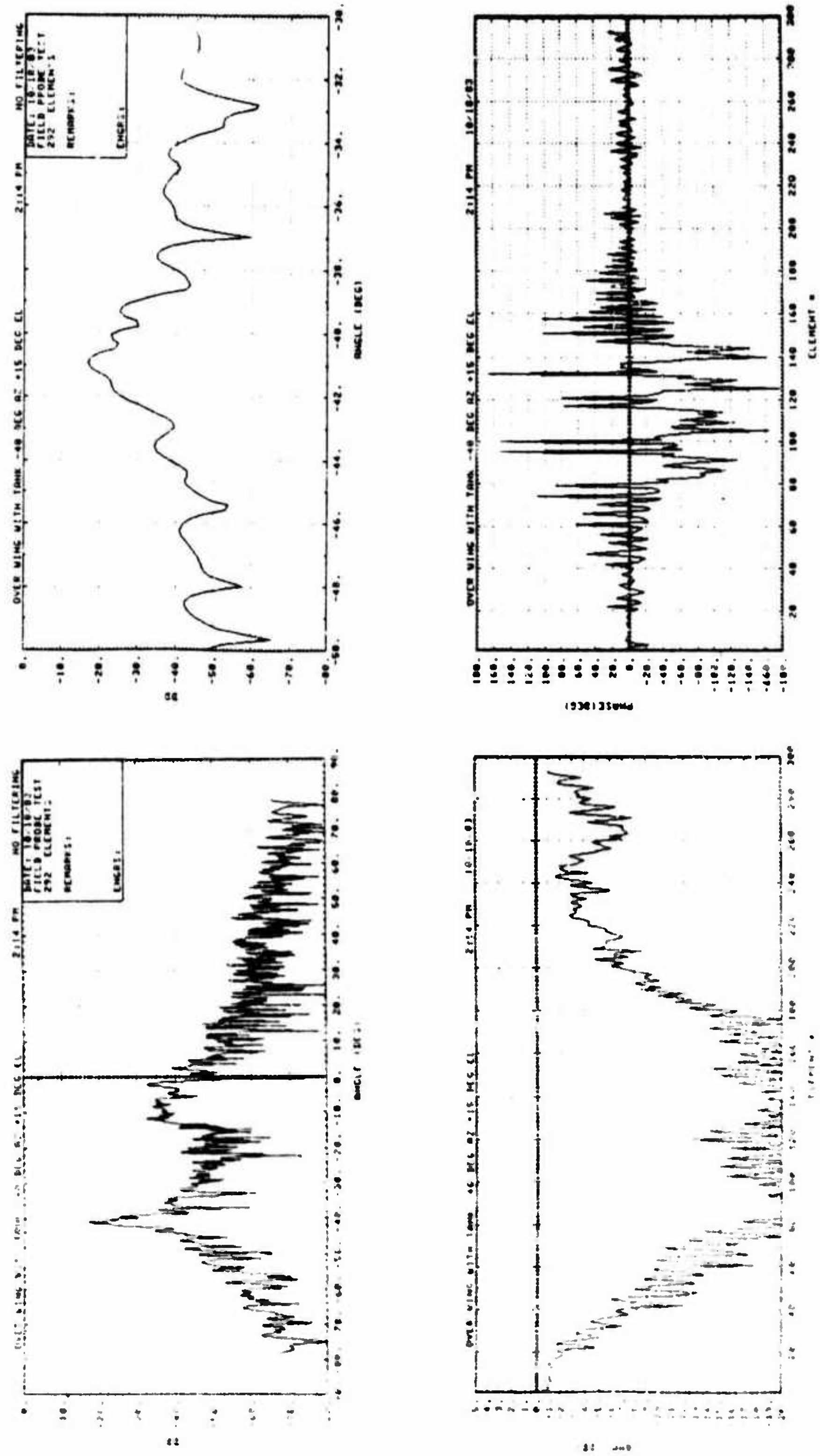

Figure 15. Over Wing With Wing Tank - 40°Az, +15° El