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PREDICTION OF ANTENNA ARRAY PERFORMANCE FROM SUBARRAY MEASUREMENTS

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SUMMARY

Because of the practical difficulties involved in measuring the RF performance of large array antennas such as SEASAT, it is desirable to predict performance based on subarray and feed network measurements. Computer runs have been used at BBRC to determine the effect of mechanical distortions on array pattern performance. Subarray gain data, along with feed network insertion loss, and insertion phase data can be combined with the analysis of Ruze on random errors to predict gain of a full array. The performance predictions for the full SEASAT array will be compared with test data.

1.0 INTRODUCTION

There are significant practical advantages to be obtained if one is able to successfully predict RF performance of a large antenna array based on measurements of a single subarray. The subarray measurements can be performed on a much more compact range so that it may be possible to use an anechoic chamber. Environmental problems of an outdoor range and mechanical handling problems involved with interfacing a large array to a positioner are eliminated. Design modifications can be incorporated into a single subarray and the results quickly checked out.

1.1 SIMPLEST APPROACH

The full array performance characteristics to be predicted are the gain, beamwidths, and sidelobe levels. The most straightforward approach to predicting these parameters from subarray data is to assume the full array will be uniformly illuminated by a lossless feed network. In such a case the array gain is simply the subarray gain multiplied by the number of subarrays. The beamwidth in each dimension is the subarray beamwidth divided by the number of subarrays in the respective dimension. The sidelobe levels depend on the amplitude taper within each subarray. A best first guess at the first sidelobe levels in the arrayed direction(s) is -13.2 dB, corresponding to the sidelobes of a uniformly illuminated aperture.

Consider the SEASAT Synthetic Aperture Radar Antenna (SARA), sketched in Figure 1, as an example. It is an L-band (1275 MHz) 10.74m by 2.09m array made up of eight panels, each 1.34m by 2.09m. Each panel is a subarray consisting of 8 by 16 radiating elements. The intrapanel feed network is uniform in the E-Plane (8-element) direction and tapered in the H-Plane (16-element) direction to produce -18.2 dB sidelobes. The main feed network distributes power uniformly to each of the eight panels. The approach described above predicts, for the full array, a gain 9 dB above the single panel gain, an E-Plane beamwidth eight times smaller than the single panel E-Plane beamwidth, an H-Plane beamwidth identical to that of a single panel, E-Plane sidelobe levels of -13.2 dB, and H-Plane sidelobes identical to the single panel H-Plane sidelobes.

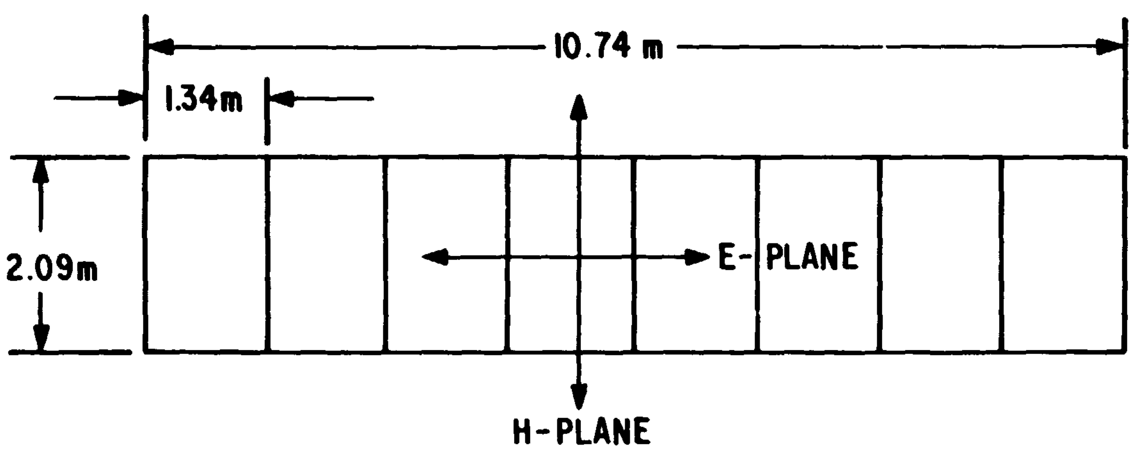

FIGURE 1
SEASAT SAR ARRAY

This simple approach to predicting array performance neglects several complications which should be taken into account in order to make an accurate performance prediction. These complications are:

- Mechanical distortion of support structure which combines subarrays
- Mechanical distortion of subarrays
- Power loss in main feed network
- Power tapers designed into main feed network
- Phase and amplitude errors in main feed network

Methods of dealing with these complications will be described in succeeding sections of this presentation.

2.0 MECHANICAL DISTORTION EFFECTS BY COMPUTER CALCULATION

2.1 DESCRIPTION OF PROGRAM

The effects on RF performance of mechanical distortions of an array can be calculated using a computer program developed at BBRC. The program calculates patterns for linear arrays which can be distorted into a second dimension. The relative gains of various distortion cases are calculated by simply comparing the magnitudes of the computed on-boresight fields for each case. When the program is used for a planar array, it calculates principal plane patterns for deflections out of the plane of the array. It accounts only for deflections within the principal plane being calculated.

2.2 FULL ARRAY DISTORTIONS

Subarrays must be combined on some kind of support structure to form a full planar array. In the case of the SEASAT SARA, the eight panels were supported side by side on a graphite epoxy Extendable Support Structure (ESS). There can be out-of-plane deflections of this structure due to manufacturing tolerances and to thermal effects. Figure 2 shows the results of computer calculations done for parabolic deflections in the long dimension of the ESS. The beamwidths and sidelobe levels are those for the principal E-Plane pattern. Based on these calculations, the ESS was designed to maintain a total deflection less than $\pm 1/4$ inch over its range of operating conditions. This type of analysis can obviously be done for any shape of deflection. Parabolic was chosen as the most likely possibility.

Deflections in the H-Plane (short dimension) of the array are due to deflections of the panels in that dimension. Figure 3 shows the results of computer calculations for parabolic deflections in the H-Plane of the panels. Note that the sidelobes begin at -18.2 dB because of the amplitude taper in the H-Plane.

2.3 SUBARRAY DISTORTIONS

As mentioned in the previous paragraph, deflections in the H-Plane of SEASAT panels are equivalent to deflections in the H-Plane of the entire array. Deflections in the E-Plane of the individual panels, however, produce effects different from deflections of the entire array. Figure 4 shows the results of computer calculations for parabolic deflections in the E-Plane of the panels. Since the E-Plane beamwidth and first sidelobes are determined by the array factor of eight panels, they are not changed to first order by an alteration of the individual panel pattern. The major effect which

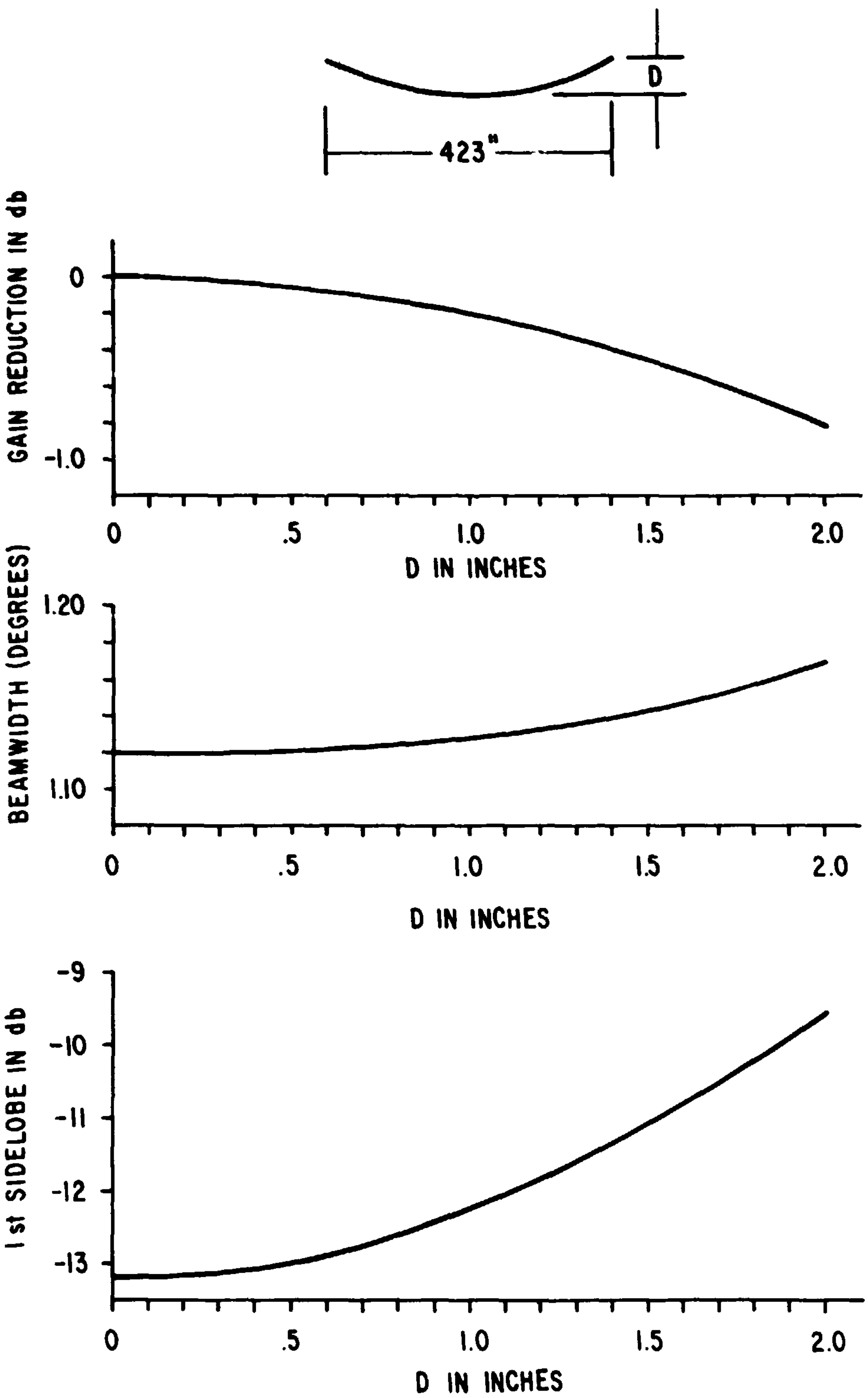

FIGURE 2

PERFORMANCE VS ARRAY E-PLANE DISTORTION

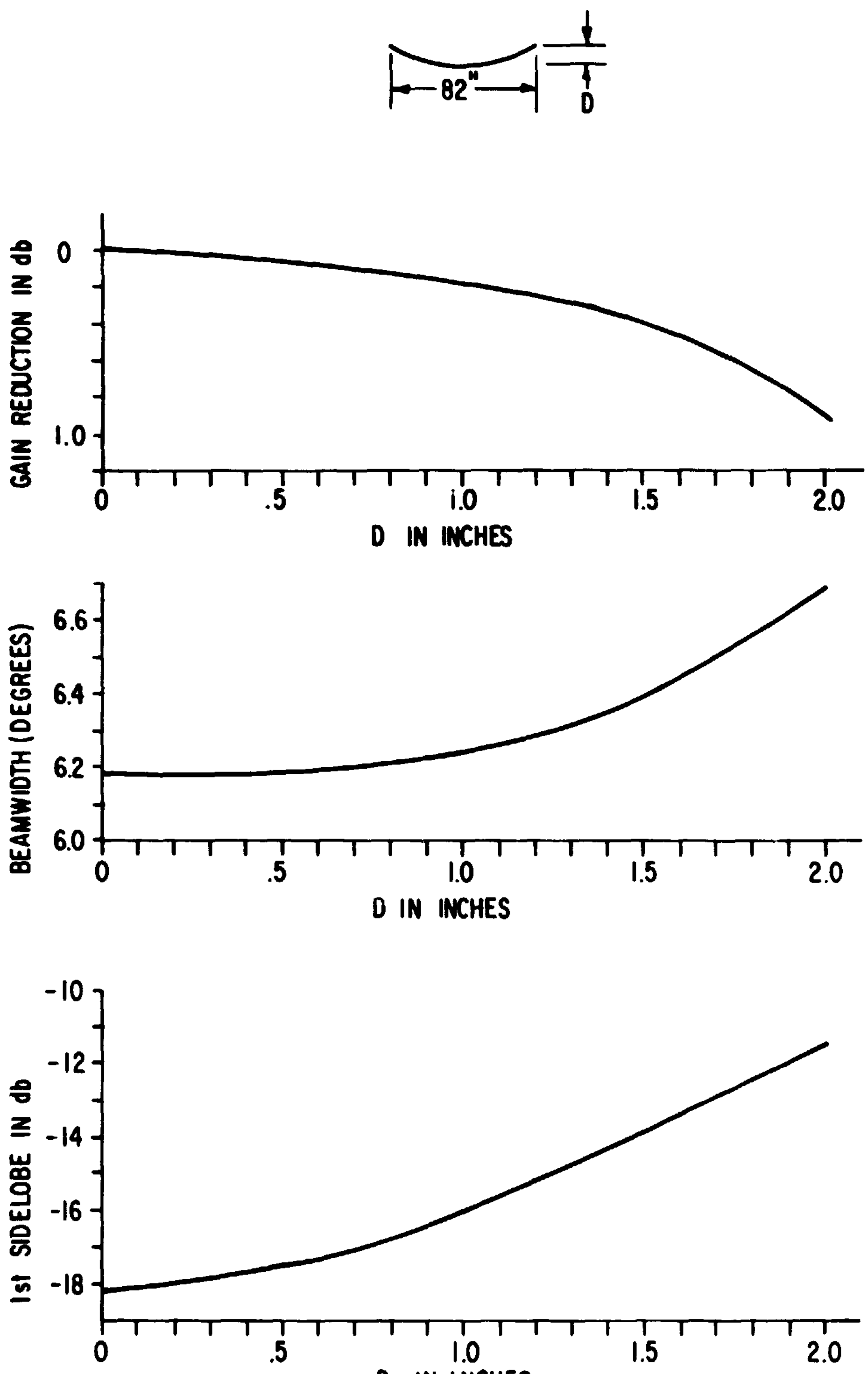

FIGURE 3

PERFORMANCE VS ARRAY H-PLANE DISTORTION

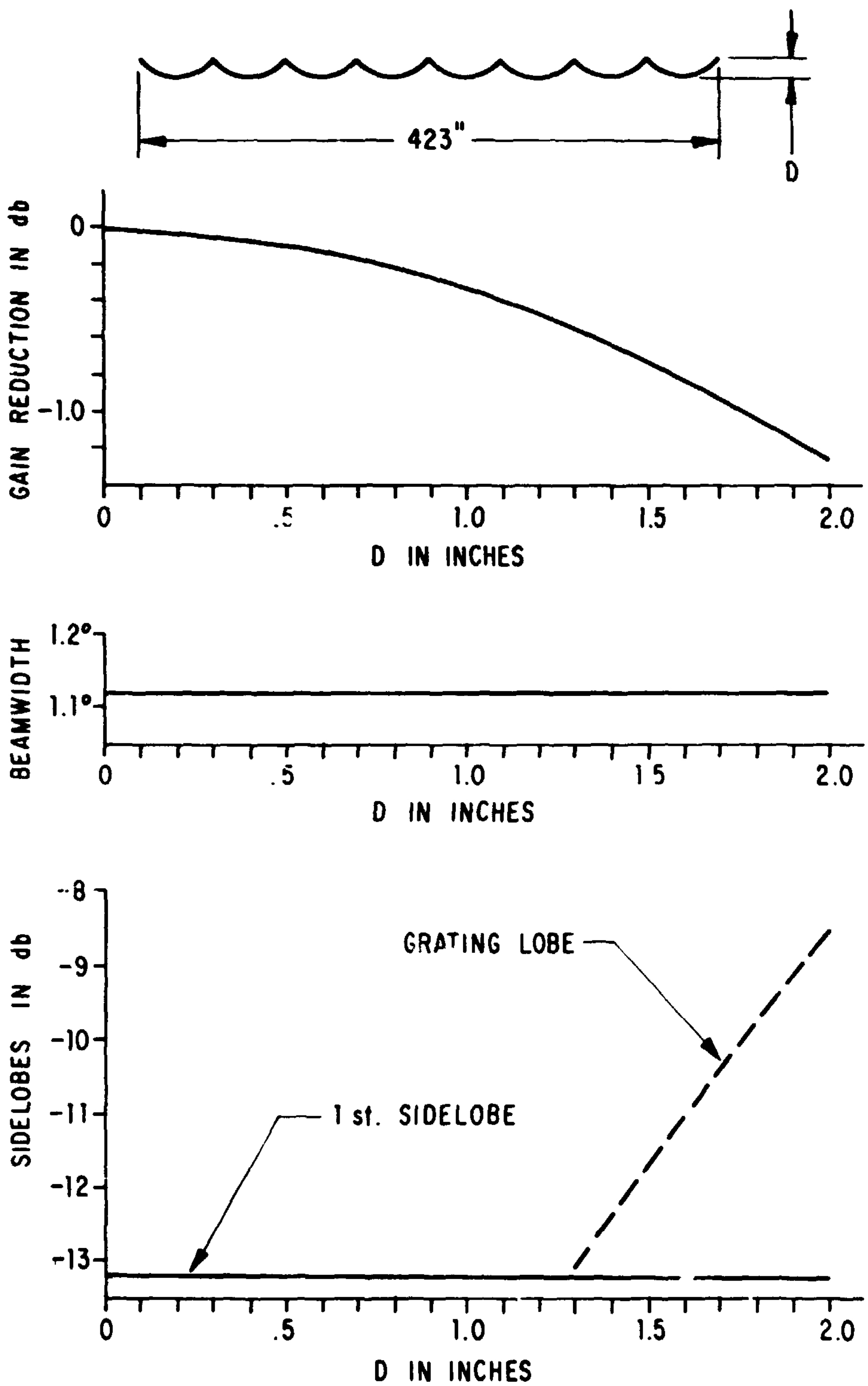

FIGURE 4

PERFORMANCE VS PANEL E-PLANE DISTORTION

occurs is the introduction of a grating lobe at about 10 degrees corresponding to radiating elements separated by one panel width ($10° = \sin^{-1} \frac{\lambda}{1.34m}$). These results were used to establish a design goal of $\pm 1/4$ inch deflection of the antenna panels over their range of operating conditions.

2.4 ALTERNATIVE CALCULATION OF GAIN REDUCTION

In Section 2.1 it was stated that relative gains of the various distortion cases can be calculated by comparing the magnitudes of the computer-calculated on-boresight fields for each case. This is true because the average radiated power remains constant as a function of distortion while the peak radiated power changes due to loss of phase coherence in the broadside direction.

This suggests a method of approximately calculating the gain loss due to mechanical distortions without using a computer. Ruze [1] has analyzed an aperture illuminated with a gaussian distribution of phases of mean square deviation $\overline{\delta^2}$ and found that the gain varies as $e^{-\overline{\delta^2}}$. One can apply this to a mechanically-distorted aperture by treating a distortion d as a phase error $\delta = \frac{2\pi d}{\lambda}$. Although the distribution of phase errors will in general not be gaussian, the mean square error $\overline{\delta^2}$ can be calculated and used to find the relative gain. This approximation to the gain becomes worse as the ratio of distortion to array length increases. As an example, consider a parabolic distortion with a peak-to-peak deflection of $f\lambda$ where f is some fraction. The mean deflection is $1/3\, f\lambda$, with a mean squared deviation of $4/45\, f^2\lambda^2$ corresponding to a mean squared phase error $\overline{\delta^2} = (2\pi)^2 \frac{4}{45} f^2$. Table 1 compares the results of this approximate calculation with the exact computer results for parabolic distortions in the E-Plane of the SEASAT array. The agreement is very good for small distortions.

TABLE 1

COMPARISON OF GAIN CALCULATIONS FOR SEASAT E-PLANE

Pk to Pk Parabolic Deflection f in Wavelengths	Computer-Calculated Gain Change	$10 \log e^{-\overline{\delta^2}}$
0	0 dB	0 dB
1/36	-.01	-.01
1/18	-.05	-.05
1/9	-.20	-.19
2/9	-.81	-.75

3.0 FEED NETWORK EFFECTS

3.1 LOSS

Insertion loss in the RF feed network supplying power to the subarrays is dealt with very simply. Such loss has no effect on the patterns; it decreases the array gain directly by the amount of loss in the feed.

3.2 AMPLITUDE TAPERS

It is often desirable to purposely design the feed network for an unequal power distribution to the subarrays. Usually the power is tapered from the center of the array outward in order to reduce sidelobes. Such tapers affect gain, beamwidths, and sidelobes. The effects on pattern performance can be found by using the previously-described computer program with the appropriate amplitude distribution on the array elements. The gain relative to a uniform power distribution can be found from the equation

$$\Delta G = 10 \log \frac{1}{n} \frac{\left(\sum_{i=1}^{n} A_i\right)^2}{\sum_{i=1}^{n} \left(A_i^2\right)} \qquad (1)$$

where n is the number of subarrays and A_i is the relative amplitude at the i th subarray (proportional to square of power at i th subarray).

3.3 PHASE AND AMPLITUDE ERRORS

Due to manufacturing tolerances and other variables, the power distribution produced by the feed network usually deviates somewhat from the desired distribution; and the phases at each subarray are not exactly equal. Such errors can be dealt with exactly if data have been taken on the relative powers and phases appearing at each output port of the feed network. One problem which should be noted is that the relative powers and phases at each output port may change when connected to the subarrays. The feed network measurements are usually done one output port at a time with matched loads connected to the other ports. Since the subarrays will not in general have the same input impedance as the matched loads, the measurements may not be completely valid. If, however, the subarray impedances are identical and reasonably well matched, the feed network measurements provide a good indication of the power distribution in the array.

The effect of the errors on pattern performance can be found using the computer program with the measured phases and amplitudes applied to the appropriate array elements. The gain relative to a uniform power distribution in amplitude and phase is found from an equation very similar to Equation 1,

$$\Delta G = 10 \log \frac{1}{n} \frac{\left(\sum_{i=1}^{n} \overline{A}_i \right)^2}{\sum_{i=1}^{n} A_i^2} \qquad (2)$$

where $\overline{A}_i$ is now a phasor accounting for both the amplitude and phase at the i th subarray.

4.0 SEASAT PREDICTIONS COMPARED WITH DATA

For the SEASAT SARA, pattern and gain measurements were taken on four of the eight panels which were combined as the flight unit. Power split and phase measurements were taken on the main feed network before it was combined with the panels. These data are used in this section to predict the flight unit RF performance which is then compared with acceptance test data taken at the LMSC Santa Cruz facility.

Figure 5 shows the power split versus frequency measured at the eight output ports of the main feed network. The numbers on each curve at 1275 MHz indicate P_{out}/P_{in} for each port at the center frequency. The insertion loss of the feed is found from the equation

$$\text{Loss} = 10 \log \frac{\sum_{i=i}^{8} P_{out_i}}{P_{in}} \qquad (3)$$

This gives an insertion loss of 0.58 dB at 1275 MHz. Figure 6 shows the relative phases measured at each output port of the feed network. Putting the phase and amplitude data into Equation 2, a loss of 0.04 dB is found due to the phase errors and unequal power split in the main feed.

The gains and beamwidths at 1275 MHz for the four flight panels which were measured are given in Table 2.

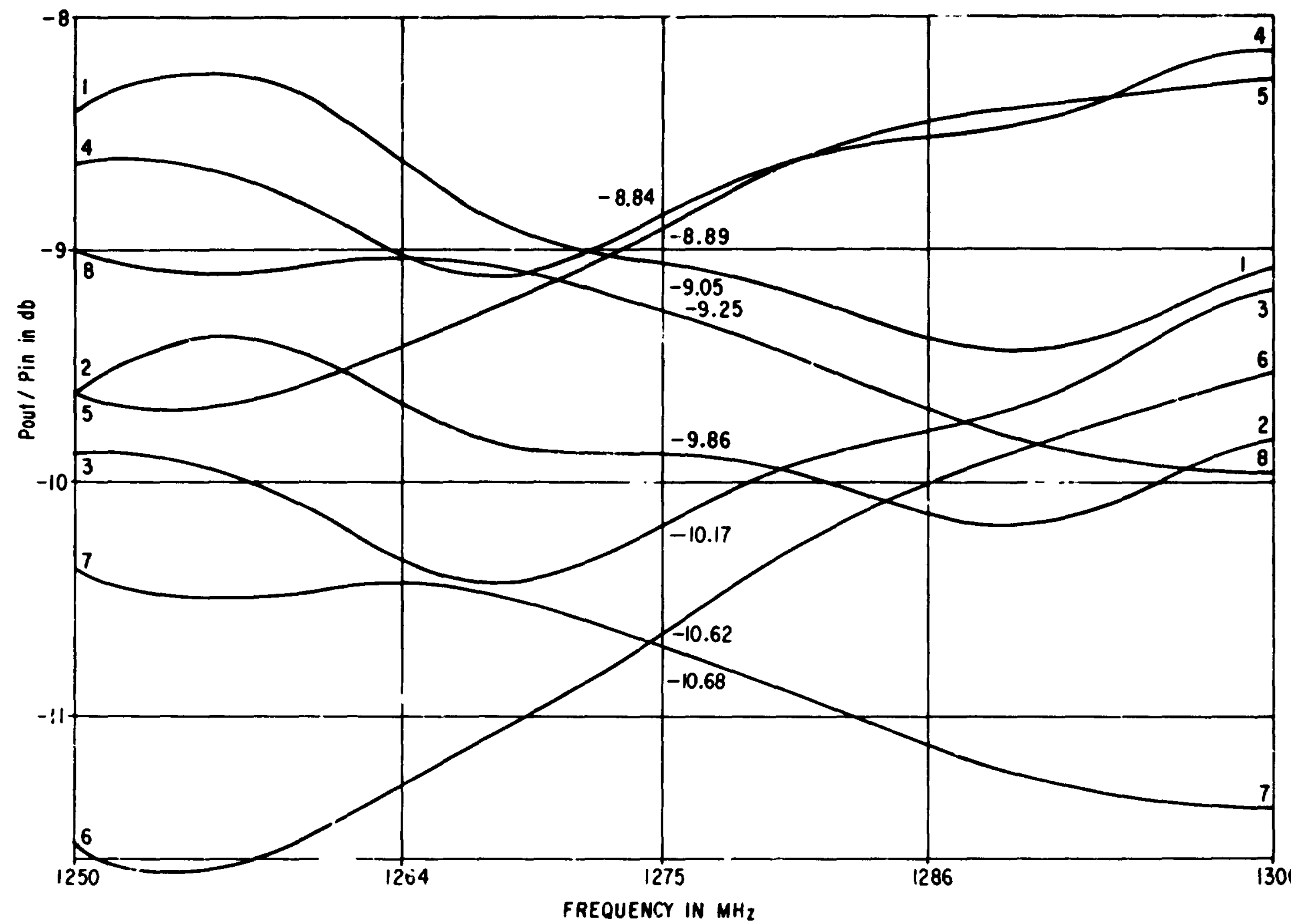

FIGURE 5

FEED NETWORK POWER SPLIT VS FREQUENCY

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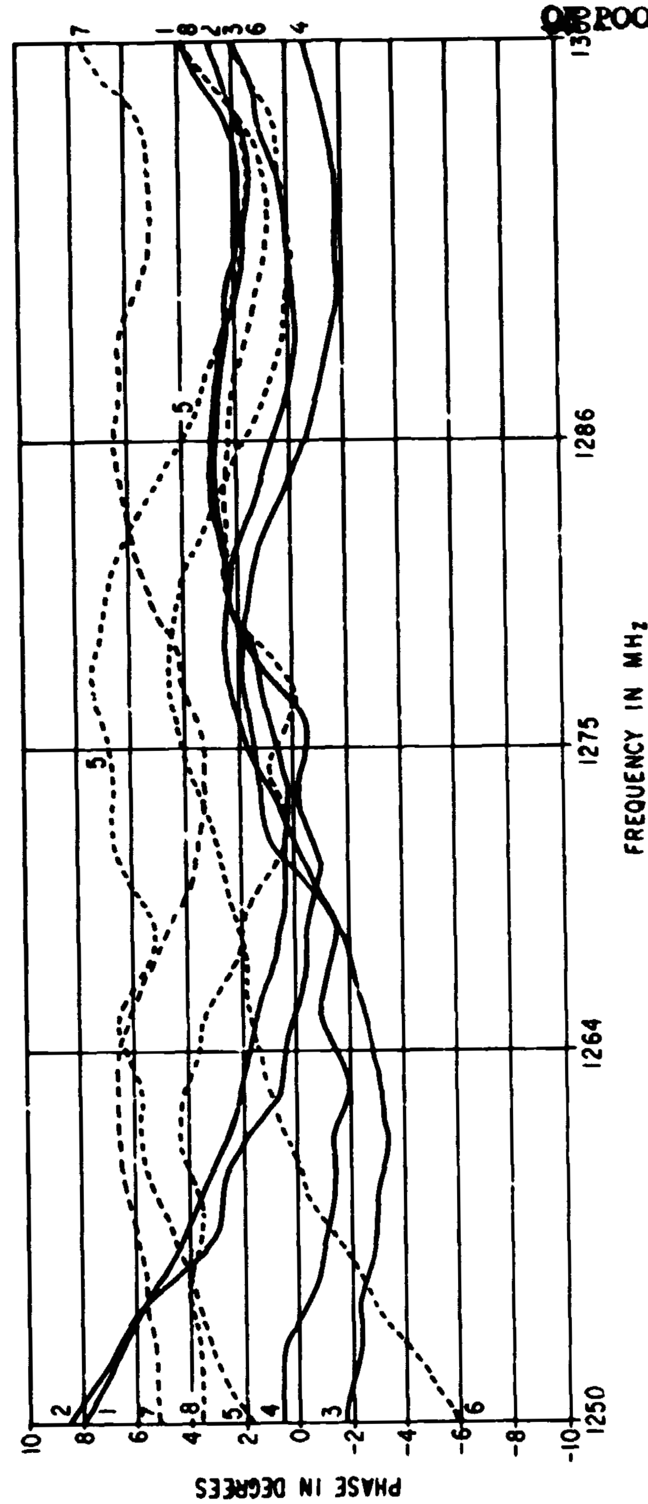

FIGURE 6

FEED NETWORK PHASE VS FREQUENCY

TABLE 2

SEASAT SINGLE PANEL DATA

Panel No.	Gain (dB)	E-Plane BW (°)	H-Plane BW (°)
F005	26.5	9.03	6.17
F007	26.5	9.00	6.20
F008	26.5	9.07	6.20
F009	26.4	9.02	6.25
Average	26.5	9.03	6.21

After the panels were attached to the ESS and hung on a gravity compensation fixture, they were surveyed to determine the flatness of the array. Six points on each panel were measured. The peak-to-peak deflection of the array was 0.5 inch. The shape of the deflection was not determined, but parabolic is a good assumption for the purposes of performance prediction.

4.1 GAIN

The foregoing data are used in Table 3 to predict the gain of the SEASAT array.

TABLE 3

SEASAT SARA PREDICTED GAIN

	(dB)
Single Panel Gain	26.5
Array Eight Panels	+ 9.03
Feed Network Loss	- .58
Feed Network Errors	- .04
Array Distortion	- .04
Predicted Array Gain	34.87
Measured Array Gain	34.9

The agreement between predicted and measured gain is remarkably good and certainly within measurement error! Mismatch losses have been neglected in the gain prediction since they affect both panel and array gain. (This assumes approximately equal VSWRs for the panels and the array plus feed network.)

4.2 BEAMWIDTHS

The array H-Plane beamwidth prediction is 6.21 degrees, the average of the beamwidths of the four measured panels. The beamwidth of the array was measured to be 6.25 degrees.

The array E-Plane beamwidth prediction is made using computer calculations. Eight elements were arrayed with a spacing equal to the panel spacing. They were fed with the phases and amplitudes found in the feed network measurements. The element pattern used in the calculations was the E-Plane pattern of a single panel. Figure 7 is a plot of the calculated pattern, while Figure 8 shows the measured E-Plane pattern. The beamwidth from the calculated pattern should be modified to account for the measured 0.5 inch mechanical distortion, but Figure 2 shows that the beamwidth is unaffected by that level of distortion. The predicted E-Plane 3 dB beamwidth is, therefore, the computer-calculated value of 1.13 degrees. This compares very well with the measured value of 1.12 degrees. It should be noted that the average measured panel beamwidth of 9.03 degrees divided by 8 is also 1.13 degrees.

4.3 SIDELOBES

The H-Plane first sidelobes measured for the array are asymmetric with levels of -19.4 and -17.2 dB on either side of the main beam. This behavior could be predicted closely from the single panel measurements which showed asymmetric sidelobes at approximately the same levels. In Section 1.1 it was stated that the H-Plane feed network was tapered to produce -18.2 dB first sidelobes. The measured deviation from this behavior is most likely due to phase and amplitude errors in the intrapanel feed network.

Figure 8 shows that the measured E-Plane sidelobes are also asymmetric with a maximum level of -12.9 dB. The computer-predicted pattern has asymmetric sidelobes, but the maximum sidelobe is at -13.8 dB. About 0.2 or 0.3 dB of this discrepancy can be accounted for by the 0.5 inch distortion of the array. The remaining discrepancy is probably due to an alteration of the feed network phases and amplitudes when the panels were connected.

5.0 CONCLUSION

Methods have been presented for predicting the gain, beamwidths, and sidelobes of an array based on subarray measurements. These methods were used to predict the performance of the SEASAT SAR eight-panel array from single panel measurements. The predicted and measured performance parameters are presented in Table 4.

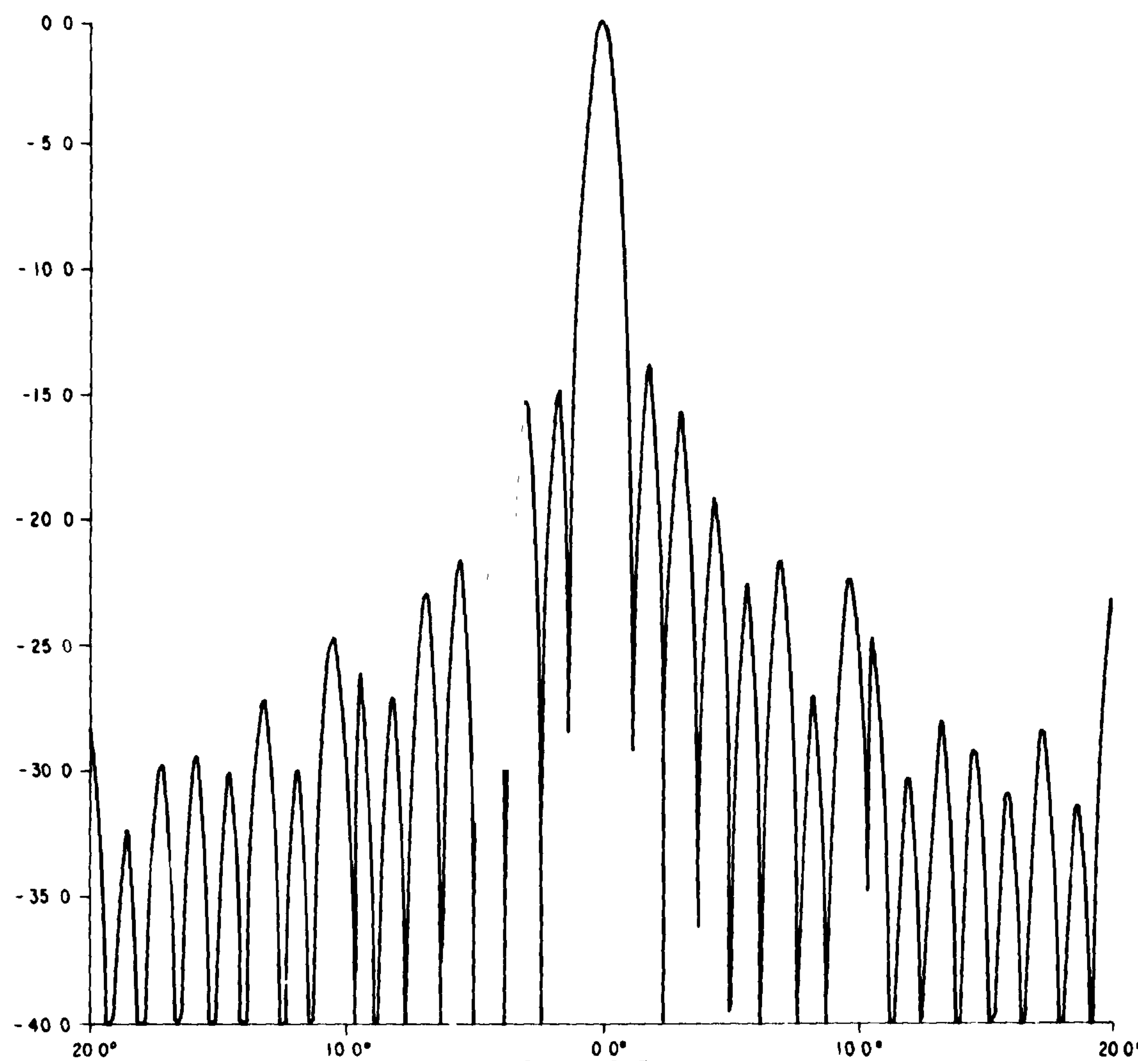

FIGURE 7

CALCULATED E-PLANE PATTERN

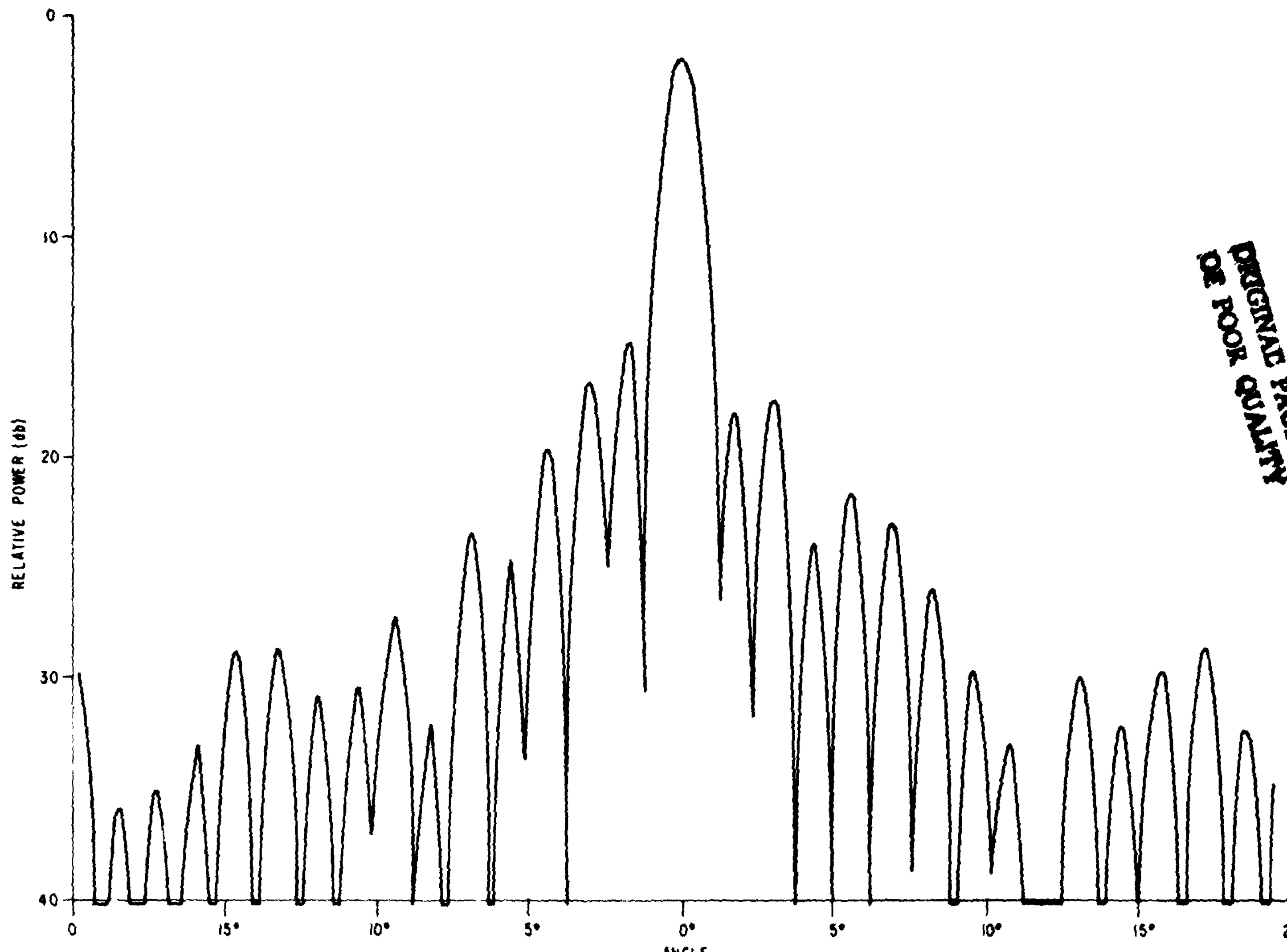

FIGURE 8

MEASURED E-PLANE PATTERN

TABLE 4

SEASAT PREDICTIONS VS ACTUAL PERFORMANCE

Parameter	Prediction	Measured
Gain	34.87 dB	34.9 dB
E-Plane Beamwidth	1.13°	1.12°
H-Plane Beamwidth	6.21°	6.25°
E-Plane Sidelobe	-13.8 dB	-12.9 dB
H-Plane Sidelobe	-17.2 dB	-17.2 dB

6.0 REFERENCES

[1] J. Ruze, "Antenna Tolerance Theory - A Review," Proc. IEEE, 54, 633–640, 1966.