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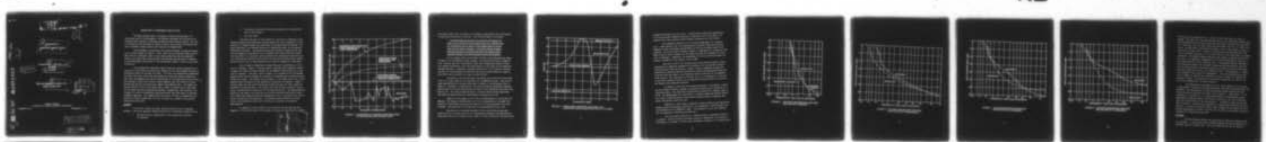

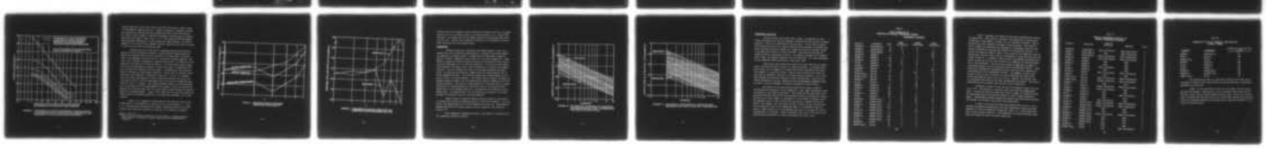

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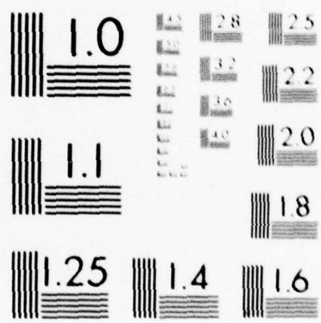
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6 INTRODUCTION TO

INTERFERENCE ANALYSIS STUDY

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~~Presented by~~ K. G. Heisler, Jr

~~at RADC~~

12 24 p

11 June 1962

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~~Contract Numbers~~ AF 30(602)-1934

~~and~~ AF 30(602)-2665

Jansky & Bailey
A Division of Atlantic Research Corporation

Alexandria, Va. Washington, D. C.

INTRODUCTION TO INTERFERENCE ANALYSIS STUDY

The RADC program, ~~which I am going to discuss this morning,~~ is a continuing study of electromagnetic interference phenomena with the aim of developing radio frequency interference prediction and analysis methods. The work to be described was performed by Jansky & Bailey under Contract AF-30(602)-1934 and is presently being extended under Contract AF-30(602)-2665.

The development of prediction and analysis methods is logically broken into two major fields of inquiry. First, what are the individual input factors which must be considered, what is their form and how may they be predicted? Second, once these input functions have been defined, how may they be combined to yield meaningful predictions of the interference likely to occur in any given stituation?

This presentation represents Jansky & Bailey's fourth presentation in the area of interference prediction and analysis at the various RADC Contractor's Conferences held over the past few years. The first two presentations emphasized the input functions, their form and methods for evaluating them by prediction. Last year, the emphasis was upon the methodology of the prediction process itself. This morning I would like to place primary emphasis upon the results of actual predictions and how the predictions compare with measured data. The sample predictions which I will use are chosen from a number of predictions we have made for the input functions representing antennas, transmitters, and receivers, and a number of over-all interference predictions which have been made for existing equipment complexes. The examples have been drawn, not only to demonstrate the quality of present predictions, but also to point out a number of the problem areas which still exist.

ANTENNAS

I will first discuss the input functions which we use to represent antennas. The three important antenna functions for interference prediction are:

1. The major-lobe or maximum gain of the antenna as a function of frequency

2. The pattern distribution function normalized to the major-lobe gain of the antenna.

3. The site effect.

The major-lobe gain of the antenna as a function of frequency is the maximum possible directional gain from an antenna for every frequency at which spurious or intended energy can conceivably be radiated from the antenna. The major-lobe gain of the antenna serves as a normalizing factor for the pattern distribution function. The pattern distribution function represents the cumulative probability distribution of all possible gain levels from the antenna. The site effect is a statistic which represents the difference between the pattern distribution function for an antenna in free space and the pattern distribution function for the same antenna placed within an operational environment.

Let us begin by examining the major-lobe gain of antennas as a function of frequency. Figure 1 contains several functions which represent various attempts to predict the main-lobe gain of the AN/FPS-8 radar antenna as a function of frequency. The upper curve on Figure 1 is a prediction of the maximum possible gain from the antenna as a function of frequency and is based on purely theoretical inputs. The lowest curve on Figure 1, the broken line curve, is the measured major-lobe gain for the antenna as a function of frequency. Figure 1 clearly shows that the purely theoretical prediction does not even closely approximate the measured data. The second curve from the top on Figure 1 represents a semitheoretical prediction for the desired function. The semitheoretical prediction was made in the same way as the above mentioned theoretical prediction except that measured major-lobe dimensions at the -3 db points were used in place of predicted lobe dimensions. The semitheoretical prediction is much closer to the measured values but still does not represent an acceptable approximation.

An empirical rule-of-thumb for the main-lobe antenna gain has been suggested. The rule-of-thumb is both simple to derive for each specific antenna

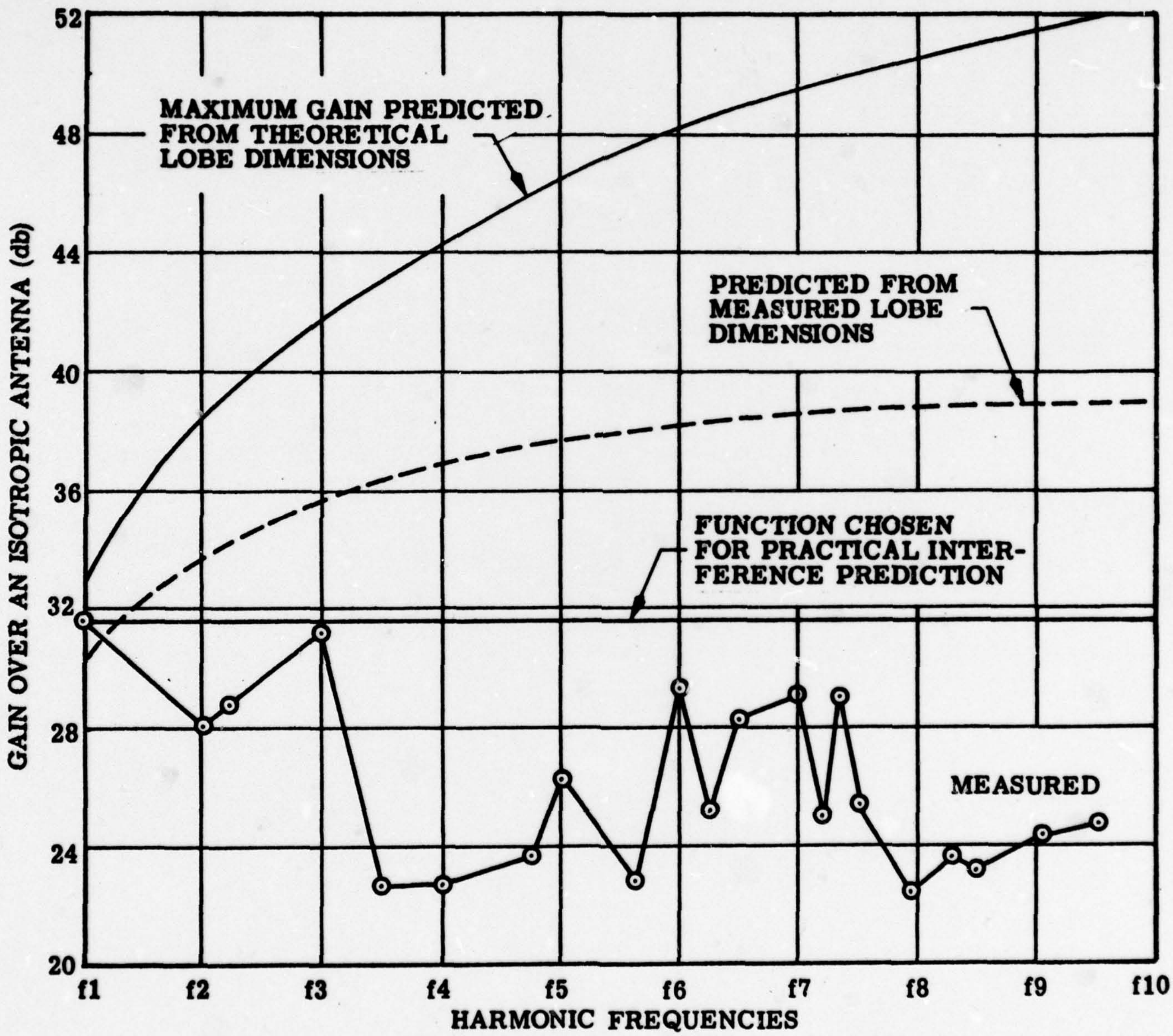

FIGURE 1. COMPARISON OF VARIOUS APPROXIMATIONS TO THE MAJOR LOBE ANTENNA GAIN.

and holds a great deal of promise as an adequate approximation for the purposes of practical interference prediction. The rule-of-thumb is as follows:

> <u>The major-lobe antenna gain as a function of frequency is taken to be a statistic whose median value is a constant over all frequencies and is equal to the maximum gain of the antenna at its design frequency. The actual values of major-lobe antenna gain are distributed about this median with a standard deviation somewhere between one and two decibels.</u>

Let us examine this rule-of-thumb in light of the measured data shown on Figure 1 for the AN/FPS-8 radar antenna. The measured data have a range of 9 db. We know that for a distribution which has a dispersion similar to that of a normal distribution, the total data range is on the order of six times the standard deviation. Assuming a standard deviation of 1.5 db, which is consistent with our rule-of-thumb, we find that the rule-of-thumb produces a range of data which exactly matches the range of observed data.

According to the rule-of-thumb, the median value would fall just below 32 db, at a value equal to the rated gain of the AN/FPS-8 antenna. The rule-of-thumb approximation to the major-lobe gain is shown by the horizontal line on Figure 1. As Figure 1 clearly shows, the rule-of-thumb has produced an approximation which is far more satisfactory than any of the predictions which have been made so far. The rule-of-thumb provides a statistic which closely duplicates the range of measured data but overestimates the median by 4.5 db.

Figure 2 is an example of the rule-of-thumb applied to the AT-316 horn antenna. The range of observed data is 11 db, corresponding to a standard deviation of 1.8 db which is within the range of 1 to 2 db as stated in the rule-of-thumb. The median for the AT-316 horn is underestimated by only 1 db.

Accuracy in the standard deviation for the major-lobe antenna gain function is not critical since for any interference prediction the main-lobe antenna gain function is combined with a number of other statistical functions whose

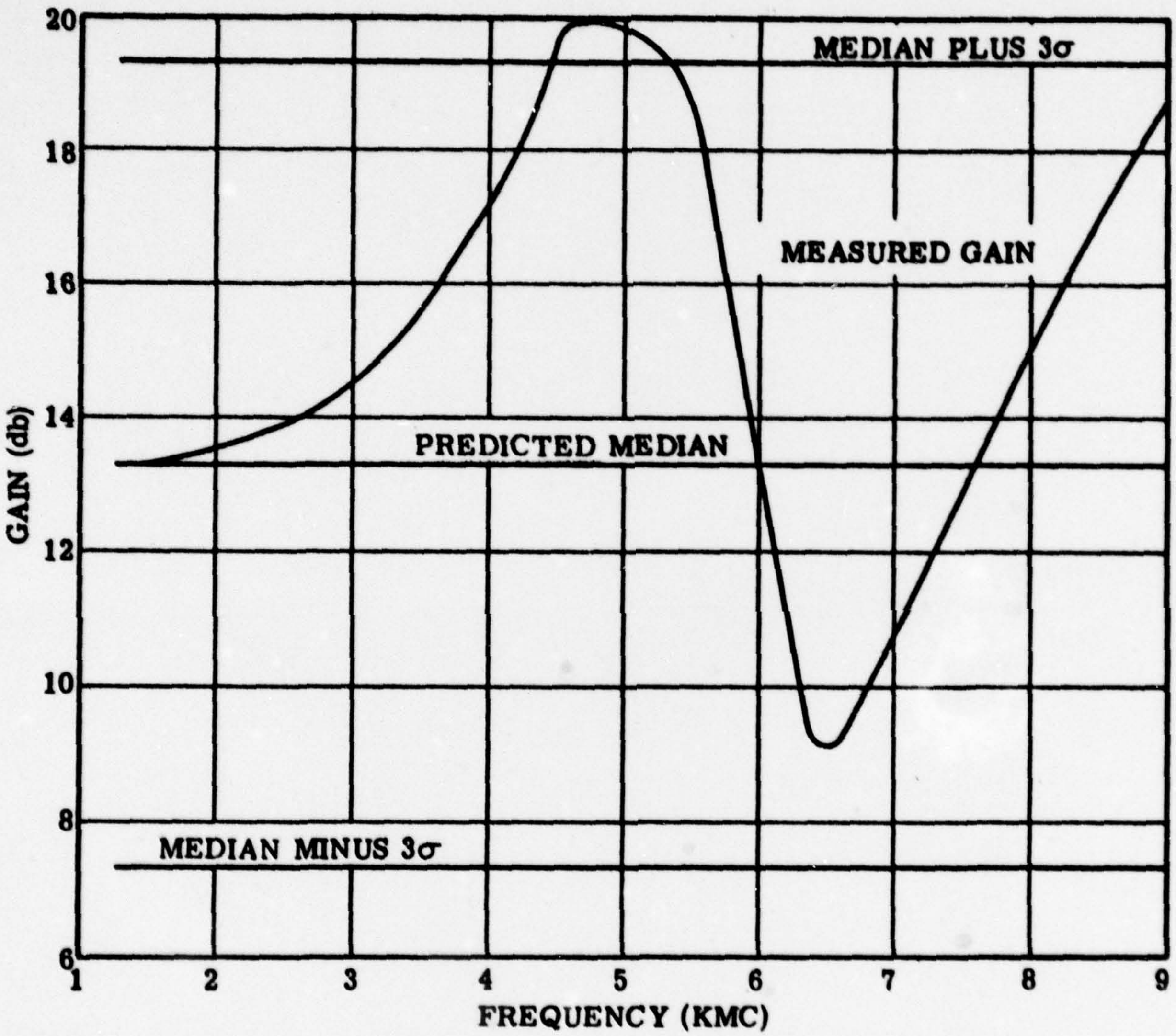

FIGURE 2. COMPARISON BETWEEN MEASURED AND PREDICTED MAJOR LOBE GAIN FOR AT-316 HORN.

standard deviations are 8 db or more. The practical statistical significance of a function whose standard deviation is less than 2 db is lost when it is combined with other functions whose standard deviations are 8 db or more.

The tremendous simplicity of the rule-of-thumb makes it a powerful tool. Unfortunately, only a few antenna major-lobe gain functions have been measured so that the possible universality of the rule-of-thumb cannot be determined. We are currently planning a number of experiments in conjunction with RADC to gain a better insight into the major-lobe gain for antennas as a function of frequency. Hopefully, the experiments will also provide the basis for greater confidence in the present rule-of-thumb.

Now let us turn to the antenna pattern distribution function, which represents the cumulative probability distribution for all possible levels of directional gain from the antenna. Figure 3 shows a comparison between the theoretically predicted pattern distribution function and measured pattern distribution functions taken at two different antenna locations for the AN/FPS-8 radar antenna. The comparison is favorable and it is interesting to note that at the lower radiation levsls, the two measured functions differ by as much as the measured and predicted functions.

It should be noted that the measured functions, of necessity, include the site effect statistic, whereas the predicted functions are calculated on a free-space basis. The theoretical predictions are made with a dynamic range of 60 db. The measurements are restricted to a dynamic range much smaller than 60 db so that in deriving pattern distribution functions based on measured data normal extrapolation has been used.

Figures 4, 5 and 6 show a comparison between predicted and theoretical antenna pattern distribution functions at the fundamental, second harmonic and third harmonic for the AN/FPS-35 radar. The agreement is more than adequate for the pruposes of interference prediction.

The site effect statistic is a function which is extremely difficult to predict. We are currently pursuing a series of experiments in conjunction with RADC in an attempt to obtain some rudimentary estimates of its significance.

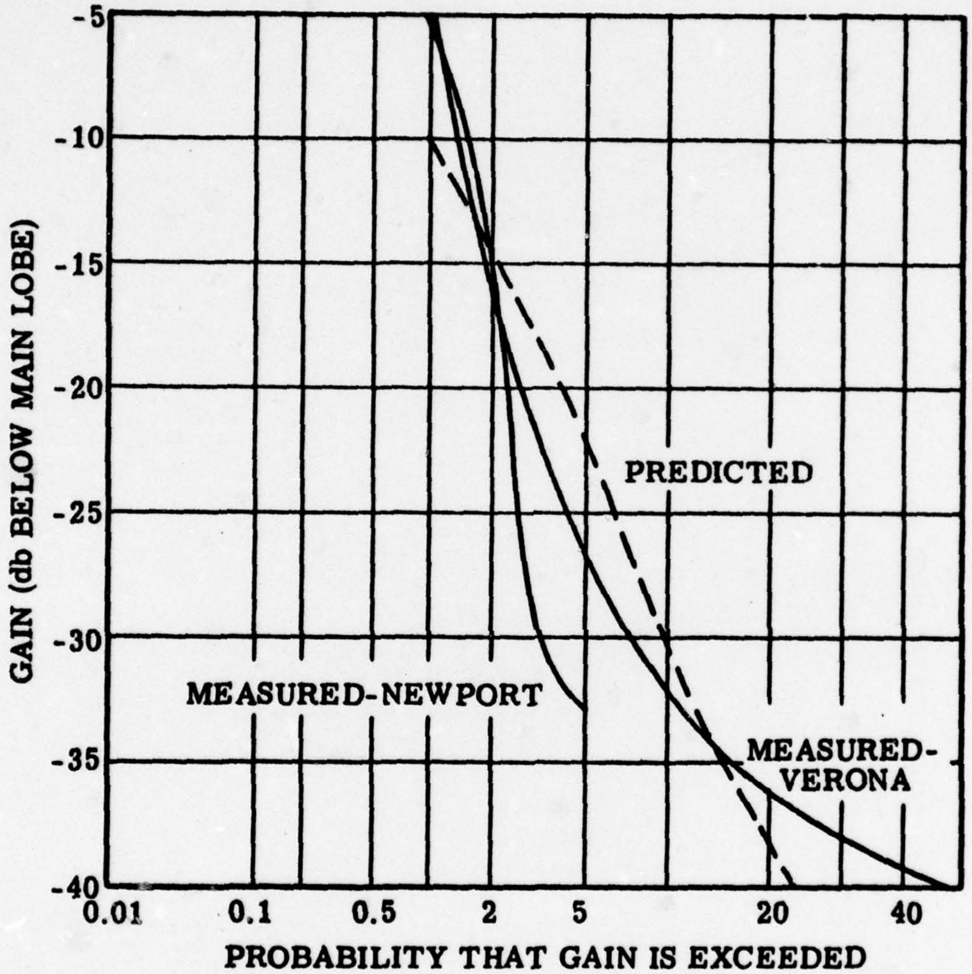

FIGURE 3. PATTERN DISTRIBUTION FUNCTION FOR AN/FPS-8 ANTENNA.

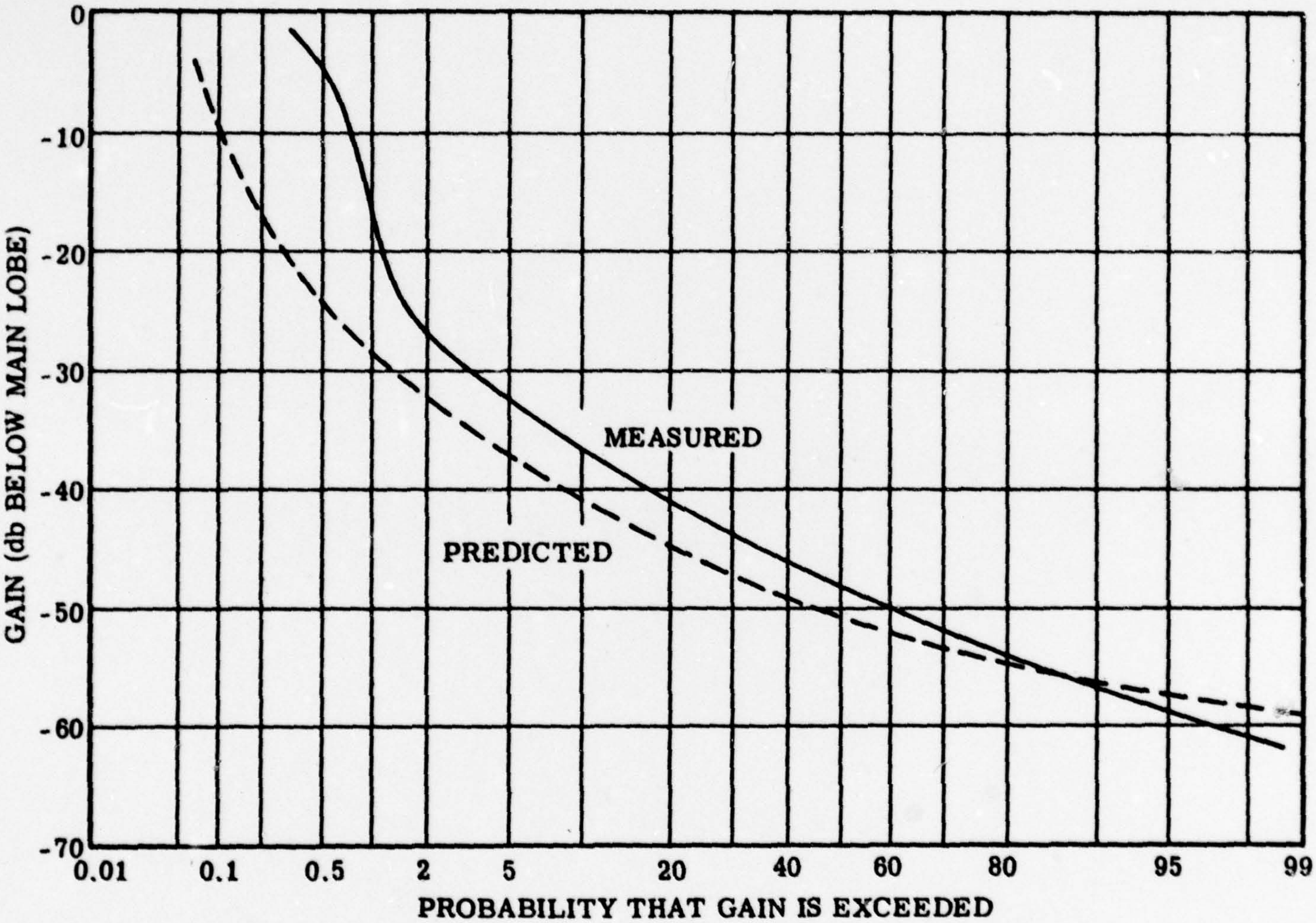

FIGURE 4. PATTERN DISTRIBUTION FUNCTION FOR AN/FPS-35, FUNDAMENTAL.

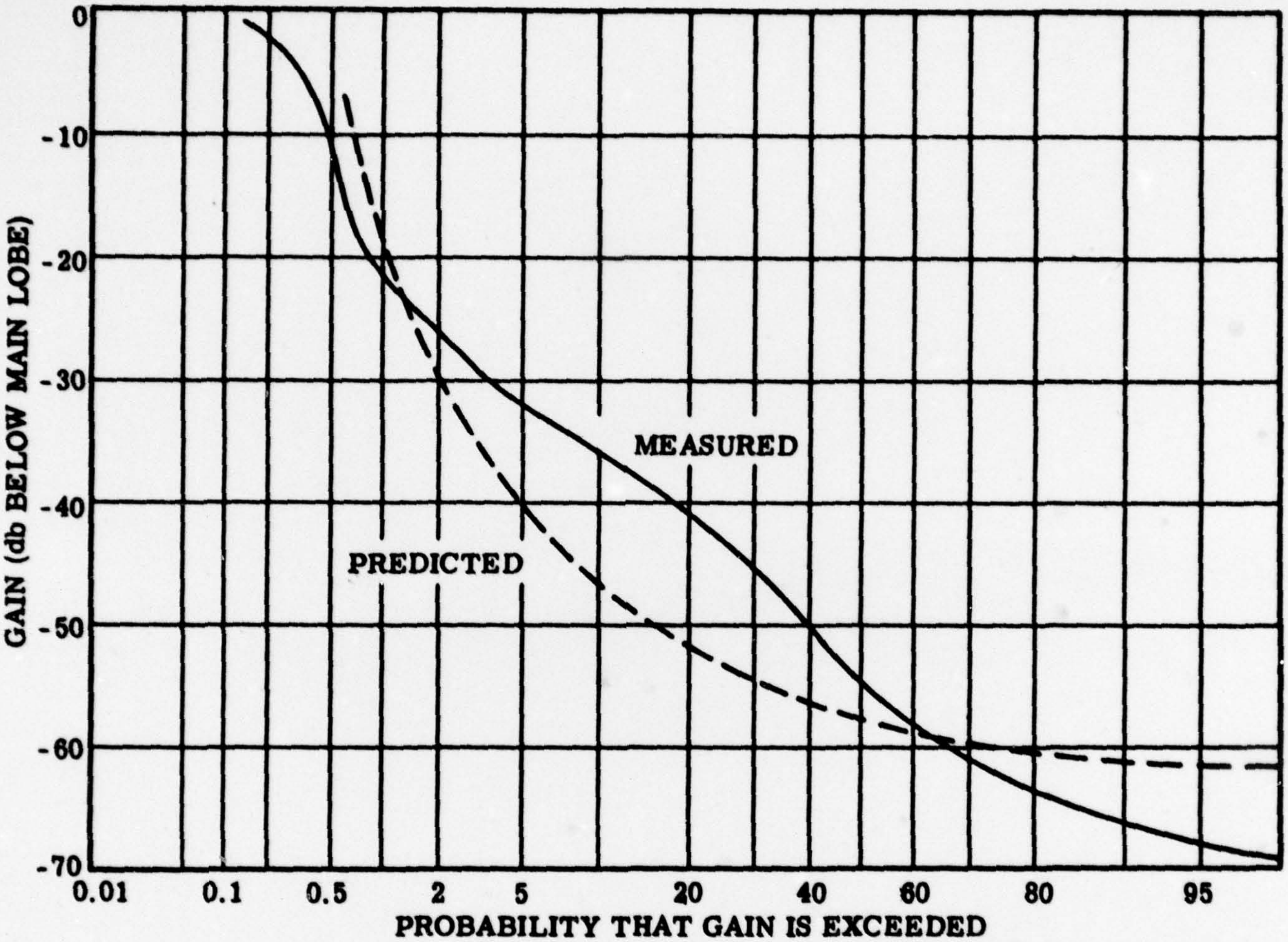

FIGURE 5. PATTERN DISTRIBUTION FUNCTION FOR AN/FPS-35, 2nd HARMONIC.

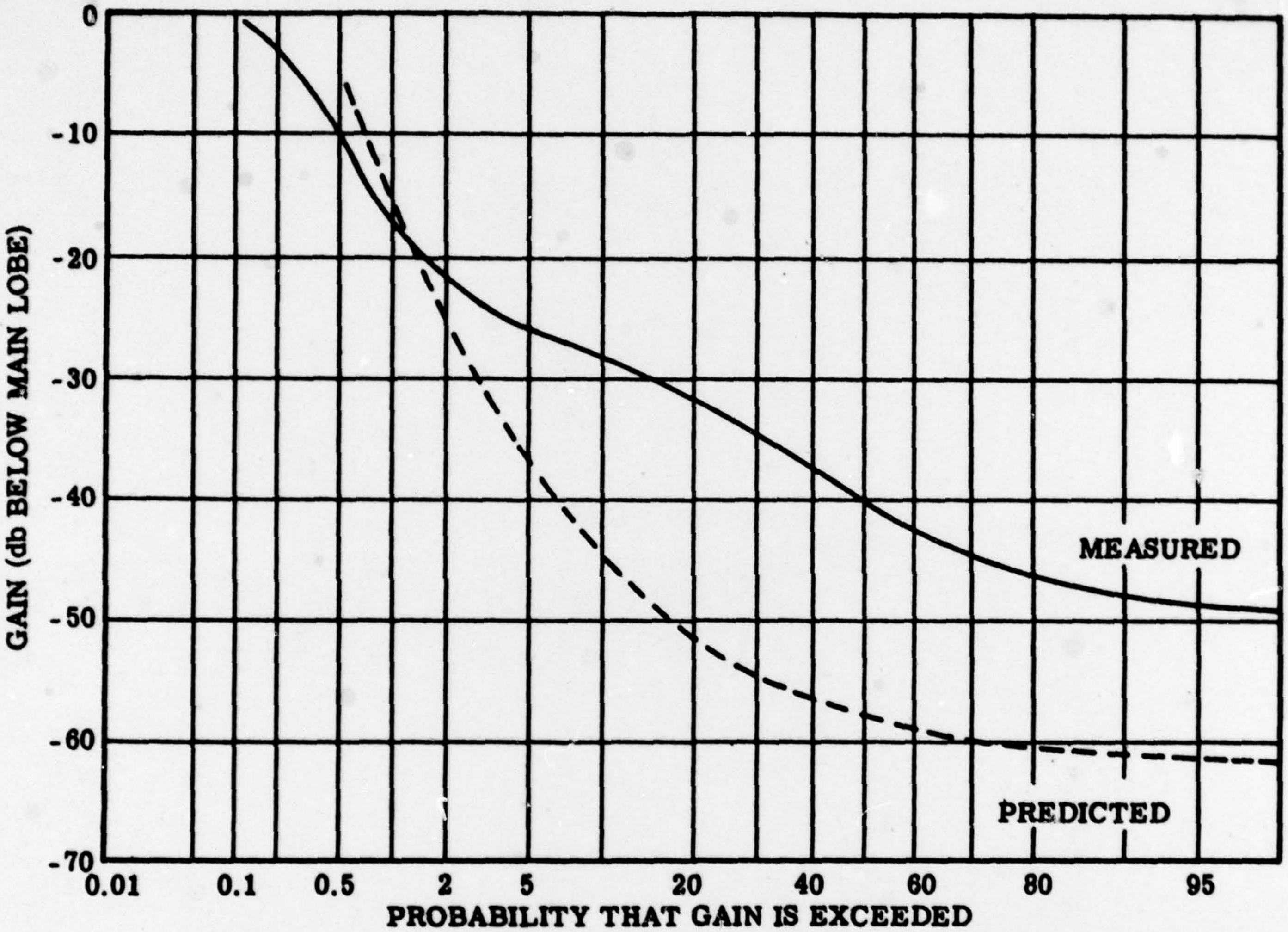

FIGURE 6. PATTERN DISTRIBUTION FUNCTION FOR AN/FPS-35, 3rd HARMONIC.

If the predicted antenna pattern distribution functions which are shown in Figures 3 through 6 are even approximately correct, the differences between them and the measured pattern distribution functions should represent the site statistic. Last year, with the hope of gaining some insight into the site effect statistic, we conducted an experiment which made use of a large number of plane reflectors in an open field. A number of antenna patterns were made under each of five different simulated site conditions and also under approximate free-space conditions. The measured antenna patterns were reduced to pattern distribution functions. No significant differences in the pattern distribution functions were noted above the -20 db radiation level. An extensive analysis was made of the differences between the free-space antenna pattern distribution functions and the antenna pattern distribution functions as observed under various simulated site conditions at the -20 db radiation level. The difference in cumulative probability was called the "enhancement". For each simulated site condition, a number of patterns were available and hence a number of different enhancement figures. The distribution of observed enhancement for each of the five site configurations is shown in Figure 7.

The differences in probability at the -20 db radiation level between a large number of predicted and measured pattern distribution functions has been tabulated. The distribution of these differences between measured and theoretical results is shown by the dotted line on Figure 7. From Figure 7, it is reasonable to conclude that, at least qualitatively, the differences between measured and predicted pattern distribution functions at the -20 db radiation level may be attributed to the site statistic. In addition, data such as that shown in Figure 7, provides the beginnings of a quantitative handle on the site function. It should be carefully noted, that although the site effect data are grossly approximate at present, they may well be within the practical accuracies required for interference prediction.

RECEIVERS

We have developed methods for predicting the spurious response levels for receivers. I will discuss the correlation between two sets of measured and predicted spurious response data. The two predictions are for the spurious

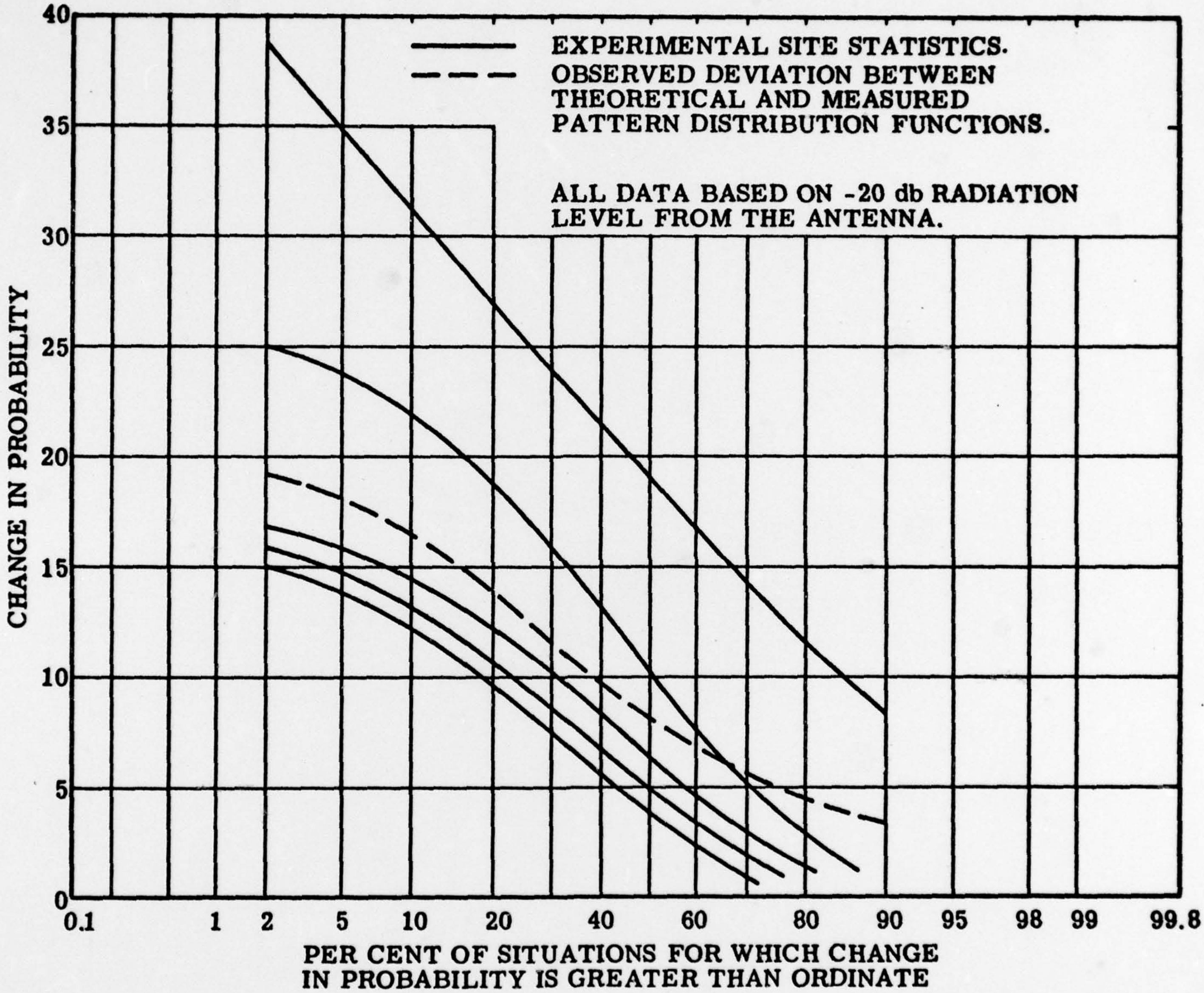

FIGURE 7. COMPARISON BETWEEN EXPERIMENTAL SITE STATISTICS AND OBSERVED DEVIATIONS BETWEEN THEORETICAL AND MEASURED PATTERN DISTRIBUTION FUNCTIONS.

response spectrum of the R-390 receiver and the R-278 receiver, which is part of the AN/GRC-27 communications set. Figure 8 represents a comparison between the predicted and observed spurious response spectrum of the R-278 receiver. The vertical bars on Figure 8 represent the range of nineteen distinct measurements which were made at each p for q = 1.[1] The nineteen different measurements represent differences in serial number and tuned frequency. The dotted segments of the vertical bars represent spurious response levels which are known to exist but were above the measuring range.

Extreme care must be exercised in comparing measured and predicted spectra since the prediction represents a single spurious response spectrum, whereas the measured results are the composite of a large number of results, which in the aggregate form the basis of a statistical response spectrum. The lower curve of Figure 8 represents a predicted lower bound. A prediction of the median was also made and is shown on Figure 8. We cannot expect perfect agreement since the measurements represent a statistical sample of significant size and the prediction represents only one sample. Considering the above factors, Figure 8 represents an encouraging validation. We see that the predicted lower bound does truly represent a reasonable lower bound. At the p = 2 response level, the lower bound appears to be well above the observed lower bound, but in actuality there is only one measurement that falls below the predicted lower bound for the p = 2 response. The predicted median follows the observed median well in the region for which measurements were possible, since the observed differences are no greater than those one would normally expect between two spectra taken for the same equipment. Figure 8 also shows that the predicted values rise rapidly above the measuring capability of the measuring equipment, just as was observed.

Figure 9 is a comparison between measured and predicted data for the R-390 receiver. The prediction is excellent up to and including p = 5. Above p = 5, the predicted and measured data diverge, indicating that for the R-390 receiver some significant phenomena is missing in the prediction technique.

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(1) The p and q are integers defined by the well known p, q equation which is used to predict the spurious response frequencies for superheterodyne receivers.

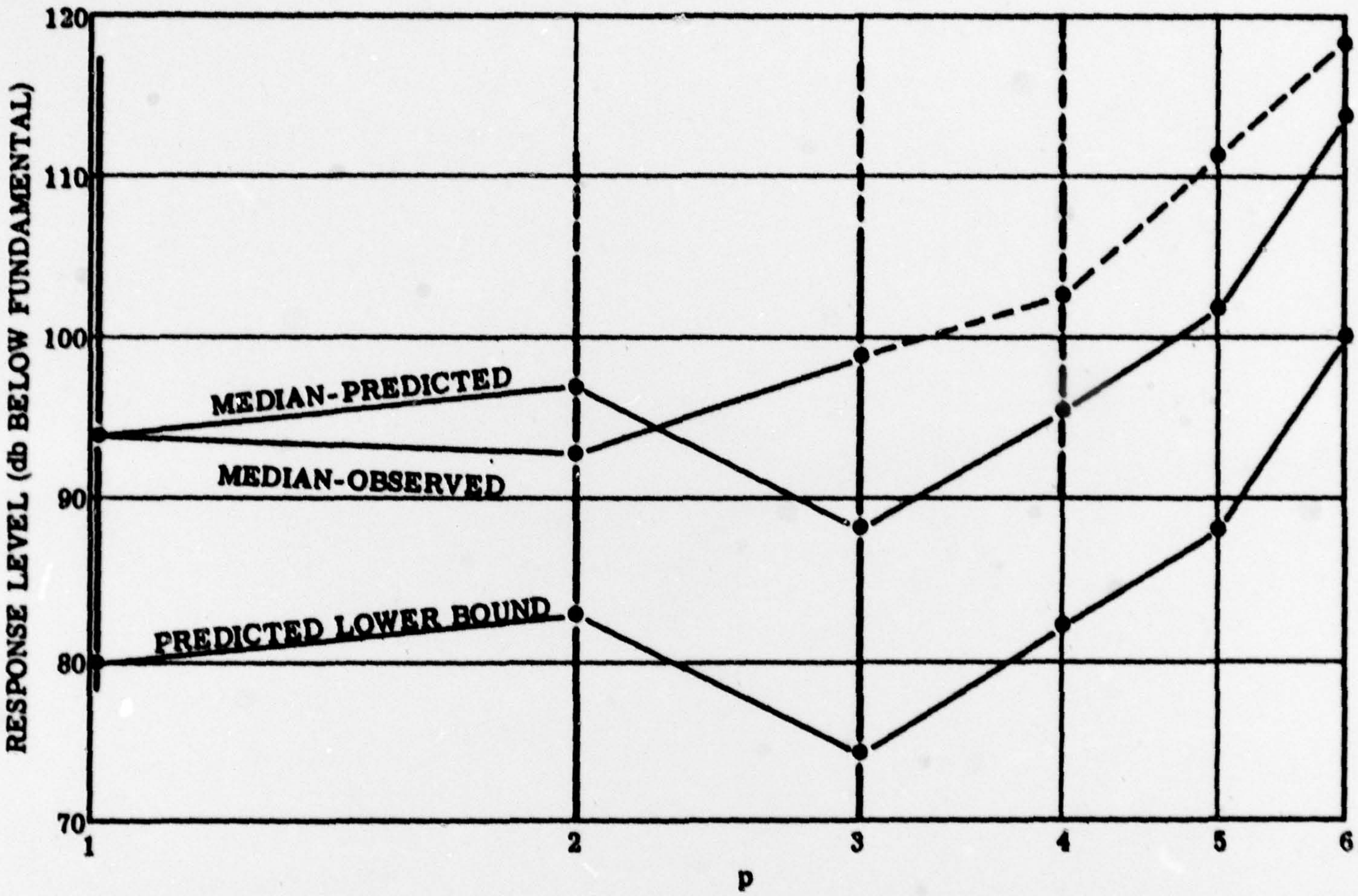

FIGURE 8. RECEIVER SPURIOUS RESPONSE PREDICTION FOR AN/GRC-27.

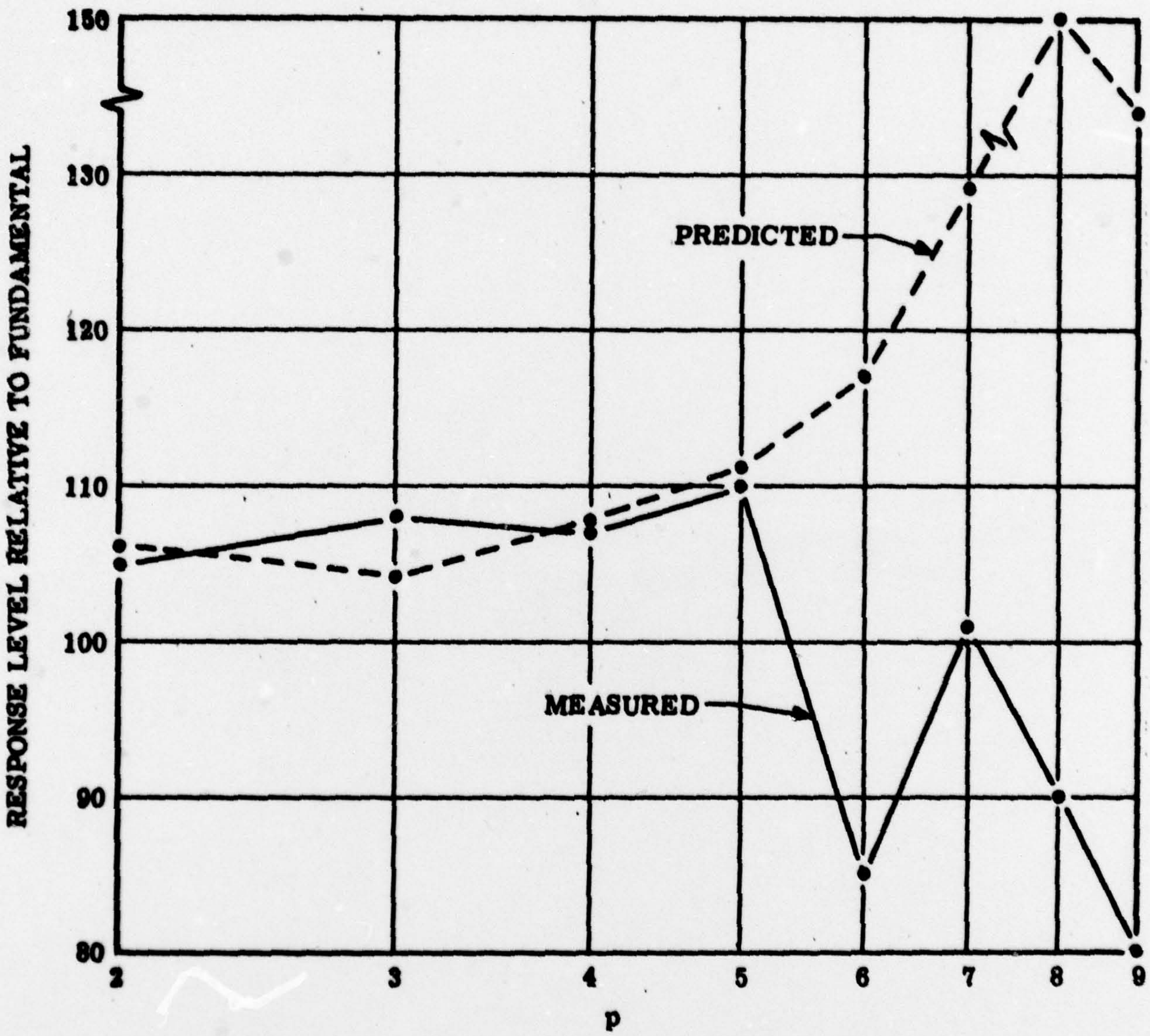

FIGURE 9. COMPARISON OF MEDIAN PREDICTED AND OBSERVED SPURIOUS RESPONSE FOR R-390.

We have found this divergence between measured and predicted data for the higher values of p to be a problem in many of the lower frequency (i.e., below 30 Mc) receivers. The predictions for the higher frequency receivers have been excellent thus far. We have just completed a prediction for the AN/TPS-1D receiver which correlates well with measured data.

TRANSMITTERS

Extensive study has revealed that the median harmonic output from transmitters can be adequately approximated by a straight line plotted against the logarithm of harmonic number. A method has been developed by Jansky & Bailey to predict transmitter output levels for tube type transmitters. Figure 10 shows a comparison between predicted statistics and statistics which were derived from measurements for the BC-610 transmitter. The width of each shaded area represents the range of data, which corresponds to six times the standard deviation. The line through the center of each range represents the median value. In Figure 10, the predicted standard deviation exactly matches the observed standard deviation. The predicted median value underestimates the output by 10 db at the second harmonic. The underestimation steadily decreases as harmonic number increases until the measured and predicted medians match at the twentieth harmonic. The over-all underestimation of the median value is almost wholly due to an underestimation of the output level at the second harmonic. A prediction of the standard deviation is as important as a prediction of the median value. As Figure 10 shows, the only difficulty at present is an underestimate of the median output at the second harmonic.

Figure 11 shows a comparison between predicted statistics and statistics which were derived from measured data for the BC-640 transmitter. For the BC-640, the underestimate of the second harmonic was only 8 db. The predicted standard deviation was slightly smaller than that measured, the difference being 0.7 db.

Both transmitter comparisons provide a high degree of confidence for the transmitter prediction methods.

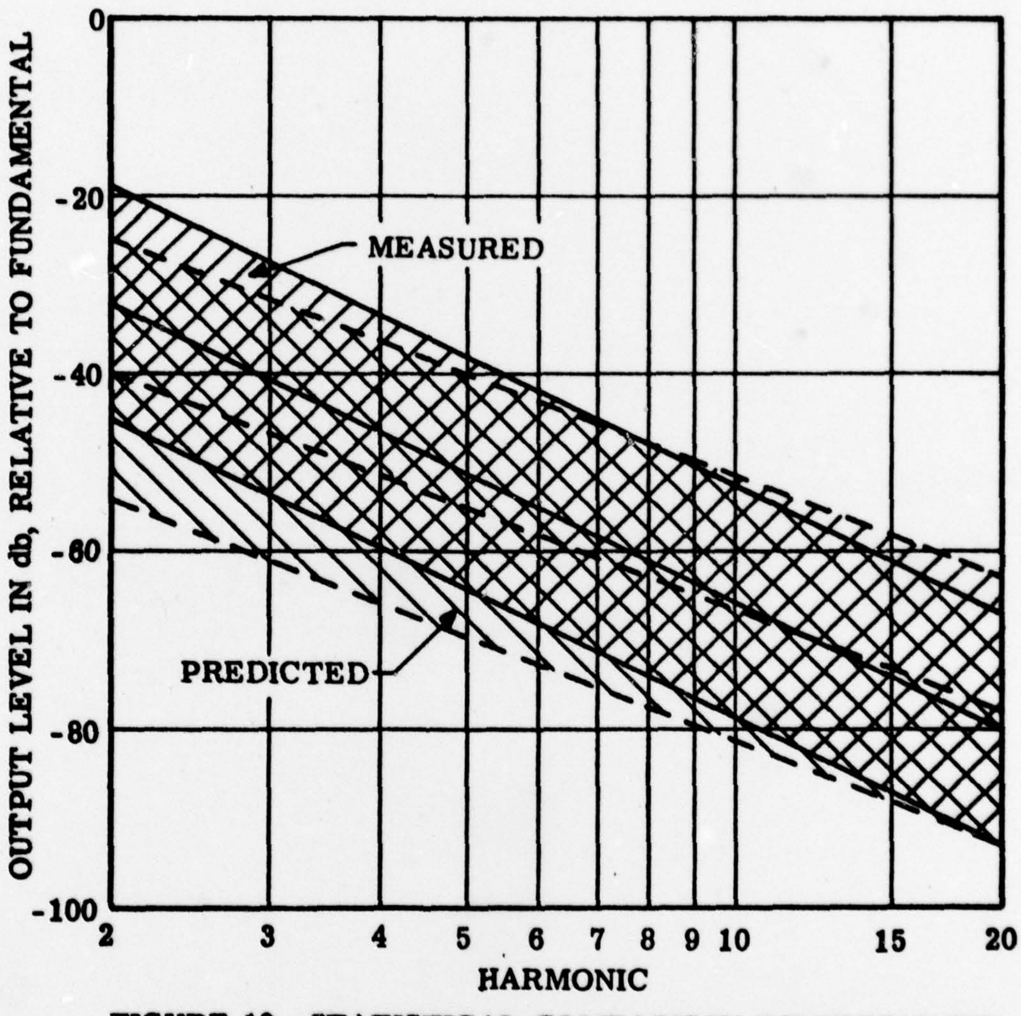

FIGURE 10. STATISTICAL COMPARISON OF PREDICTED AND MEASURED DATA FOR A TRANSMITTER WITH SINGLE ENDED OUTPUT.

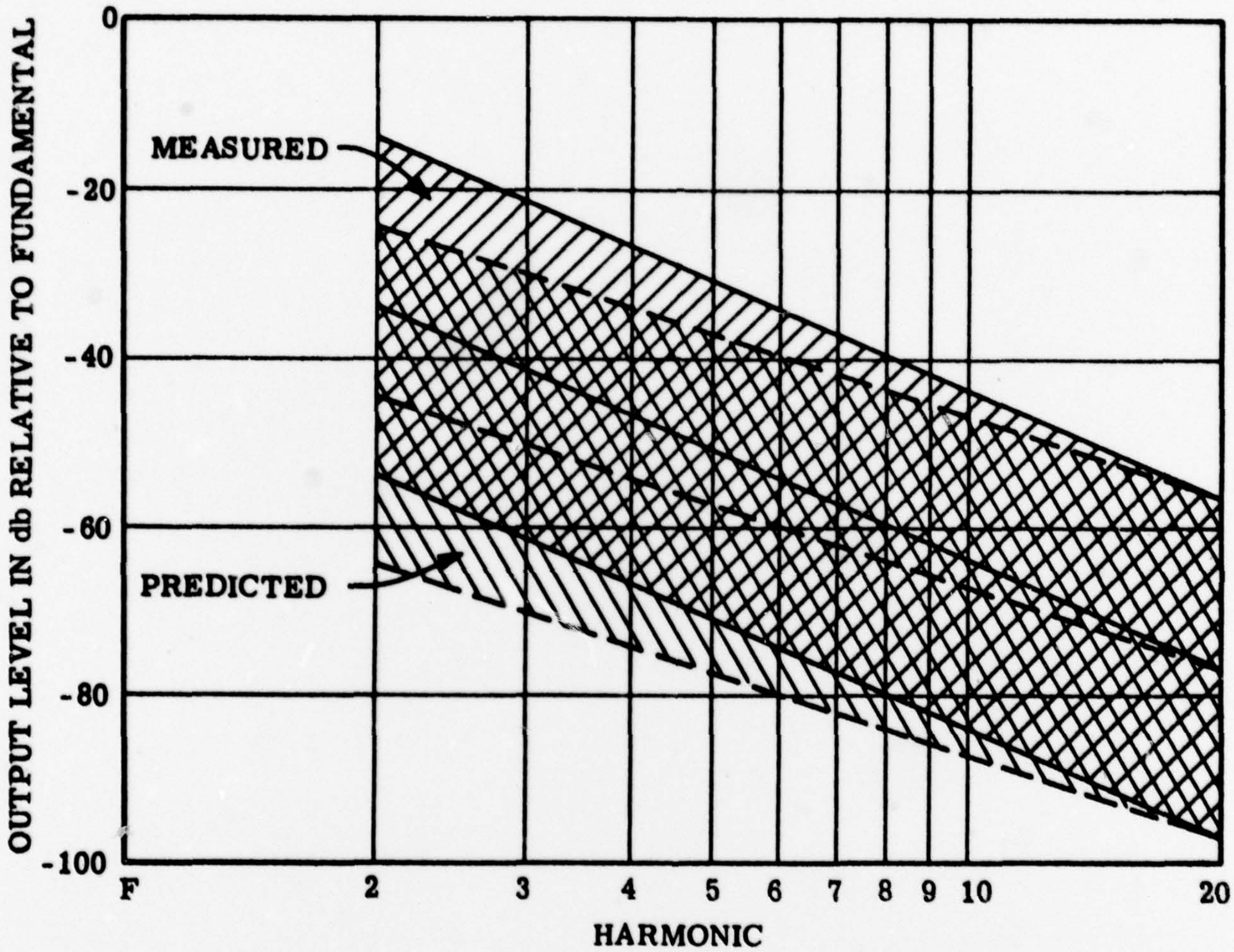

FIGURE 11. STATISTICAL COMPARISON OF PREDICTED AND MEASURED DATA FOR A PUSH-PULL TRANSMITTER.

INTERFERENCE PREDICTION

During the past year we have made a number of comprehensive interference predictions for existing equipment configurations with the aid of digital computers. Others are planned during the next year. I would like to present this morning the results of a sample prediction which was made to determine the likely interference pattern among nine transmitters and five receivers located at the RADC test facility in Verona, New York. The prediction was made for several different interference criteria. The complex consisted of two communication links, one jamming transmitter and six radar sets. The tuned frequencies of the equipments varied from 60 Mc to just under 3 kMc.

Since nature has dictated that each of the input functions is statistical, the prediction must be made on a statistical basis. To visualize what must be done, let us imagine for a moment that we have 100 Verona test facilities stamped out across the country. Each of these facilities will have the same types of equipment installed in the same relative locations. We all know that although the sites are identical in every outward detail, there will be random differences in siting, installation and the equipments themselves which can lead to entirely different interference phenomena at each location.

The results of the interference prediction are shown in Table I. Interference was considered in four categories: none, light interference, medium interference and heavy interference. The probability that each level of interference would be observed for each possible situation is tabulated in Table I. The entries in Table I might be considered to be the number of Veronas, out of the imaginary total of 100, in which each interference category would be observed. For example, the first entry in Table I treats the case of the potential interference caused by the AN/ALT-6B jammer to the AN/TPS-1D radar receiver. Table I shows that no interference will occur in 10 cases out of 100, a probability of 10 percent. Light interference will occur in 90 cases out of 100 and medium interference or heavy interference will never occur.

Table I

DIRECT PROBABILITY OF OBSERVING EACH POSSIBLE INTERFERENCE CATEGORY

			INTERFERENCE CATEGORIES		
Receiver	Transmitter	None	Light Interference	Medium Interference	Heavy Interference
AN/TPS-1D	AN/ALT-6B(f_1)	10	90	0	0
AN/FPS-6	AN/ALT-6B(f_1)	80	17	3	0
AN/FPS-6	AN/ALT-6B(f_2)	0	0	0	100
AN/TPS-1D	AN/FPS-8	0	0	0	100
AN/FPS-6	AN/FPS-8	100	0	0	0
AN/GRC-27	AN/FPS-8	98	1.2	.8	0
BC-639	AN/FPS-8	15	69	14	2
AN/FPS-6	AN/FPS-20	100	0	0	0
AN/TPS-1D	SCR-270	0	0	0	100
AN/FPS-6	SCR-270	56	27	16.7	.3
AN/FPS-15(f_1)	SCR-270	.4	3.6	55	41
AN/FPS-15(f_2)	SCR-270	26	33	37	4
AN/GRC-27	SCR-270	90	10	0	0
BC-639	SCR-270	4	17	66	13
AN/FPS-6	AN/TPS-1D	25	15	32	28
AN/GRC-27	AN/TPS-1D	100	0	0	0
BC-639	AN/TPS-1D	89	11	0	0
AN/GRC-27	AN/FPS-6	100	0	0	0
BC-639	AN/FPS-6	48	32	20	0
AN/TPS-1D	AN/FPS-15(f_1)	0	10	64	26
AN/FPS-6	AN/FPS-15(f_1)	14	24	59	3
AN/GRC-27	AN/FPS-15(f_1)	100	0	0	0
BC-639	AN/FPS-15(f_1)	100	0	0	0
AN/TPS-1D	AN/FPS-15(f_2)	0	0	48	52
AN/FPS-6	AN/FPS-15(f_2)	87	10	3	0
AN/GRC-27	AN/FPS-15(f_2)	100	0	0	0
BC-639	AN/FPS-15(f_2)	100	0	0	0
AN/TPS-1D	BC-640	95	5	0	0
AN/FPS-15(f_1)	BC-640	95	5	0	0

Table I represents the prediction that must be matched with a series of observations. The prediction represents the probability of interference, considering a large number of similar, but not identical situations. The observations can only represent one sample of each situation. The problem is then to compare the prediction and observation in some manner that will give the most information concerning the validity of the prediction process. To convert the prediction shown in Table I into terms that are compatible with the observations, the most likely level of interference is chosen for each case and listed in Table II. In addition, Table II gives the observed interference situation, along with an error score arrived at by comparing the converted prediction to the observation. The error score equals in magnitude the number of interference grades by which the prediction and the observation differ. A negative error represents an underprediction and a positive error represents an overprediction of the interference situation. For example, the first case listed on Table II has a prediction of light interference and light interference was observed; hence, the error is zero. However, for the next case, no interference was predicted but light interference was observed. This was an underprediction by one grade, hence an error score of minus one.

We observe in Table II that the sum of the absolute values of the errors is ten. The question is, does this error score have any significance? First, it should be noted that some error score is always to be expected since the observations were restricted by necessity to only a single statistical sample. Establishing a hundred similar but distinct test sites would alleviate the problem, but obviously this method lacks practicality.

In order to see just how likely the observed error score is, let us tabulate the predicted probabilities for those interference levels which were observed but were not predicted as being most likely; i.e., those cases which lead to error scores in Table II. The probability of actually observing cases which are classed as errors is given in Table III.

Table II

OVER-ALL INTERFERENCE PREDICTION AND
OBSERVED INTERFERENCE SITUATION

Receiver	Transmitter	Over-All Prediction	Observed	Error
AN/TPS-1D	AN/ALT-6B(f_1)	Light Interference	Light Interference	0
AN/FPS-6	AN/ALT-6B(f_1)	None	Light Interference	-1
AN/FPS-6	AN/ALT-6B(f_2)	Heavy Interference	Heavy Interference	0
AN/TPS-1D	AN/FPS-8	Heavy Interference	Heavy Interference	0
AN/FPS-6	AN/FPS-8	None	None	0
AN/GRC-27	AN/FPS-8	None	None	0
BC-639	AN/FPS-8	Light Interference	None	+1
AN/FPS-6	AN/FPS-20	None	None	0
AN/TPS-1D	SCR-270	Heavy Interference	Heavy Interference	0
AN/FPS-6	SCR-270	None	None	0
AN/FPS-15(f_1)	SCR-270	Medium Interference	Medium Interference	0
AN/FPS-15(f_2)	SCR-270	Medium Interference	Heavy Interference	-1
AN/GRC-27	SCR-270	None	None	0
BC-639	SCR-270	Medium Interference	Medium Interference	0
AN/FPS-6	AN/TPS-1D	Medium Interference	None	+2
AN/GRC-27	AN/TPS-1D	None	None	0
BC-639	AN/TPS-1D	None	Light Interference	-1
AN/GRC-27	AN/FPS-6	None	None	0
BC-639	AN/FPS-6	Light Interference	None	+1
AN/TPS-1D	AN/FPS-15(f_1)	Medium Interference	Medium Interference	0
AN/FPS-6	AN/FPS-15(f_1)	Medium Interference	Light Interference	+1
AN/GRC-27	AN/FPS-15(f_1)	None	None	0
BC-639	AN/FPS-15(f_1)	None	None	0
AN/TPS-1D	AN/FPS-15(f_2)	Heavy Interference	Medium Interference	+1
AN/FPS-6	AN/FPS-15(f_2)	None	None	0
AN/GRC-27	AN/FPS-15(f_2)	None	None	0
BC-639	AN/FPS-15(f_2)	None	None	0
AN/TPS-1D	BC-640	None	None	0
AN/FPS-15(f_1)	BC-640	None	Light Interference	-1

Table III

PROBABILITY OF ACTUALLY OBSERVING CASES WHICH ARE CLASSED AS ERRORS

Receiver	Transmitter	Probability that True Error Is Zero
AN/FPS-6	AN/ALT-6B(f_1)	17%
BC-639	AN/FPS-8	15%
AN/FPS-15(f_1)	SCR-270	4%
AN/FPS-6	AN/TPS-1D	25%
BC-639	AN/TPS-1D	11%
BC-639	AN/FPS-6	32%
AN/TPS-1D	AN/FPS-15(f_1)	10%
AN/FPS-1D	AN/FPS-15(f_2)	48%
AN/FPS-15(f_1)	BC-640	5%

The probabilities which are tabulated in Table III show that each of the events in Table II which were scored as errors actually have a significant probability of occurring.

Further, we see from Table II that out of 29 cases, the error score was zero for 20 cases. Additionally, 8 out of 9 nonzero error scores are one. The error scores are also roughly symmetrical about zero. Hence, it is fairly safe to conclude that the errors arise for the most part from the fact that only one set of validating observations was made and not from any invalidity in the prediction process itself.