THE EFFECTS OF NON-SYSTEMATIC INSTRUMENTATION ERRORS ON MEASUREMENT UNCERTAINTY

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ABSTRACT

The effects of non-systematic receiver instrumentation errors on precision antenna measurements are investigated. A simple uncertainty model relating dynamic range to random perturbation effects on amplitude measurements is proposed. Examples of measurement uncertainty versus both input level and measurement speed are presented using data taken on modern measurement receivers. Data are compared with the model to estimate measurement uncertainty at various pattern levels and acquisition speeds. Equivalent dynamic range specifications are deduced from the measured data.

Key Words
Antenna Measurements, Measurement Uncertainty

1. INTRODUCTION

Measurements on modern low sidelobe phased array antennas place increasing demands on antenna test methods and instruments. Sidelobe levels 50 dB or more below the beam peak are often encountered. Accurate and rapid characterization of these types of antennas is vital due to the interactive nature of adjusting them for optimum performance. An assessment of the uncertainties and inaccuracies attributable to the measurement receiver and their contribution to overall error budgets is essential for specifying the measurement systems for these applications.

When performing error analyses, the antenna metrologist establishes bounds of uncertainty for the instrumentation's operating conditions. These conditions include input level, operating frequency, and acquisition speed (number of samples). This study provides a simple model and measured data on modern measurement receivers for determining these bounds. Comparative data are used to associate amplitude measurement uncertainties across a wide dynamic range at many acquisition speeds.

2. CONCEPTS AND PERSPECTIVE

A fundamental concept in metrology is the uncoupled nature of measurement uncertainty and accuracy. A highly accurate instrument, that is one which produces data very close to the "true" value, is not required to perform low uncertainty measurements. An instrument with minimal uncertainty only needs to produce highly repeatable data for a known and stable excitation. Therefore, experimental techniques used to explore measurement uncertainty need not focus on absolute accuracy as the performance criterion. In antenna metrology, this approach is not usually limiting since most measurements are ratiometric. Figure 1 illustrates the differentiation between accuracy and uncertainty. An instruments's mean response to a given input may deviate from an ideal transfer function resulting in a basic inaccuracy. However, an instrument's uncertainty describes the extent particular measurements deviate from this mean. The advantage of measuring uncertainty is that it may be quantified independently from system accuracy. This allows more realistic error budgets for a given measurement type to be designed.

Error sources may be divided into two distinct categories, systematic and non-systematic. Systematic error sources can be readily identified and are repeatable. Non-linearity is a good example of a systematic error. The deviation of output versus input from a linear relationship may be due to numerous deterministic causes, such as individual device non-linearities, impedance mismatch, loading effects, temperature changes and many others. Regardless of their cause, systematic errors are deterministic in nature. They may be completely quantified if one has the desire and patience to do so. If quantification is complete, then error correction algorithms can be utilized to restore idealized performance.

Non-systematic, or random, errors on the other hand are totally non deterministic. That is, they possess the qualities of a random process. These random processes are often categorized in communications theory as random noise which adds as a uncorrelated phasor to the signal under consideration. Repeatability and stability, particularly as a function of input level and time, are the most important specifications affected by non-systematic errors for precision instrumentation. The physical manifestation of these types of errors can be attributed mainly to the presence of thermal noise power in the final detection bandwidth of microwave receivers and network analyzers, and quantization uncertainties in the A/D processing. Present instrumentation typically places quantization noise below the thermal noise level so it can usually be regarded as a second order effect. Therefore, characterization of the uncertainty effects of thermal noise appears as the primary component in determining measurement uncertainty versus input level and acquisition speed.

3. UNCERTAINTY MODEL

A simple amplitude uncertainty model is shown in phasor diagram form in Figure 2. The noise phasor, n(t), combines with the signal phasor, s(t), as a vector sum to produce a resultant phasor, r(t). The noise phasor, n(t), is presumed to have a Normal amplitude distribution and an uniform phase distribution (1). A simple expression may be derived for measurement uncertainty which relates the input level s(t) and the given system dynamic range (at S/N = 0 dB) which can be thought of as n(t). The expression below describes this relationship.

$$\text{Uncertainty} = 20 * \log[(s(t) + n(t))/s(t)]$$

The resulting measurement uncertainties versus input level for 80 and 90 dB dynamic ranges are plotted in Figure 3. In the plotted data, uncertainties due to n(t) will correspond to n(t) assuming its peak (3 sigma) value. Note that each graph actually consists of two lines, corresponding to worst case constructive and destructive phasor additions. In addition, note that uncertainty not only varies versus input level but also with acquisition speed. This is a direct consequence of using coherent digital averaging to improve dynamic range. Since averaging reduces an instrument's noise floor by suppressing uncorrelated signals which are in the IF passband with the signal to be measured, measurement speed must be reduced linearly by a factor at least equal to the number of samples averaged.

4. EXPERIMENTAL CONFIGURATION / METHODS

Measurements were performed to determine the degree of compliance with the error model. Two measurement receivers were utilized, the Hewlett-Packard 8510B, and the Scientific-Atlanta Model 1795. Results were compared with the error model to estimate actual dynamic range based on the uncertainties measured. The HP 8510B was used to provide a baseline of performance since it is readily accepted as an industry standard for accuracy and repeatability. The HP 8510B was configured with the HP 8511A Frequency Converter. The SA 1795 utilized the SA 14-11-20 Mixer. The method used to evaluate the measurement uncertainties of the HP 8510B and the SA 1795 is shown in Figure 4.

A synthesized Microwave signal source, the HP 8340, was set for constant CW power of 0 dBm at the test frequency of 3 GHz. A high directivity coupler provided a reference path for phase locking the Network Analyzer or Receiver. Fixed attenuators in both paths provided additional reference to signal path isolation. The fixed attenuator in the signal path was chosen to provide power levels corresponding to peak signal input (-10 dBm for the HP 8510B and -20 dBm for the SA 1795) for each instrument when 0 dB attenuation was chosen on the stepped attenuator. Each instrument was tested over an attenuation range of 110 dB from full scale input in 10 dB increments and for all selections of average samples (12 selections for both instruments from 1 to 2048). At each setting of attenuation and average sample selection, 100 distinct measurements were collected. From these data, the mean value, maximum and minimum values, and the standard deviation were calculated. The major potential systematic error source for these measurements would be due to short term (1 microsecond to 1 second) level drift from the HP 8340. The HP 8340 is specified for less than .01 dB amplitude stability at constant temperature. Actual level stability for these measurements was on the order of .001 dB.

5. DATA AND ANALYSIS

The data shown in Table 1 summarizes the results from the experiments described in Section 4. The standard deviations and peak deviations from the means are shown. Analyses of the data sets show that the amplitudes assume Normal distributions. This is the expected result for what appeared to be "white" noise in the IF passbands. The data also show the peak deviations from the mean values are approximately 3 times the standard deviation value (σ). This 3σ deviation will encompass more than 99% of all possible measurements which ensures that an adequate population sample has been gathered (2).

Figures 5 and 6 show the data for each instrument compared to the uncertainty model. The HP 8510B was configured for 1 average sample (1 KHz trigger rate) and the SA 1795 was configured for 4 average samples (1.25 KHz sample rate). Figure 7 shows data for the SA 1795 configured for 1 average sample (5 KHz sample rate). An exponential least squares fit algorithm was used to extract the best fit curve. Since measurement uncertainty decreases as the acquisition speed decreases, an analysis of this effect is important in specifying measurement system performance. Figure 8 shows the measured uncertainty at the 60 dB below full scale level for both instruments as a function of measurement speed.

Measured data indicate that random processes creating uncertainties have approximately Normal distributions in both instruments. The peak deviation uncertainties extracted from the measurements correspond approximately to a 3σ deviation from the mean value. Dynamic range specifications based on these deviations are lower than those based on the RMS deviations at S/N = 0 dB which are typically stated in manufacturer's product literature.

6. CONCLUSIONS

Precision measurements on low sidelobe phased array antennas require the lowest uncertainty measurement techniques and the highest data acquisition speeds possible. The data presented allow an analysis of the uncertainties due to receiver effects to be integrated into an error budget. In addition, these data show the effects of acquisition speed on the resulting measurement uncertainty. Antenna metrologists should factor the uncertainty versus level and acquisition speed effects into the design of test systems for these demanding applications.

7. ACKNOWLEDGEMENT

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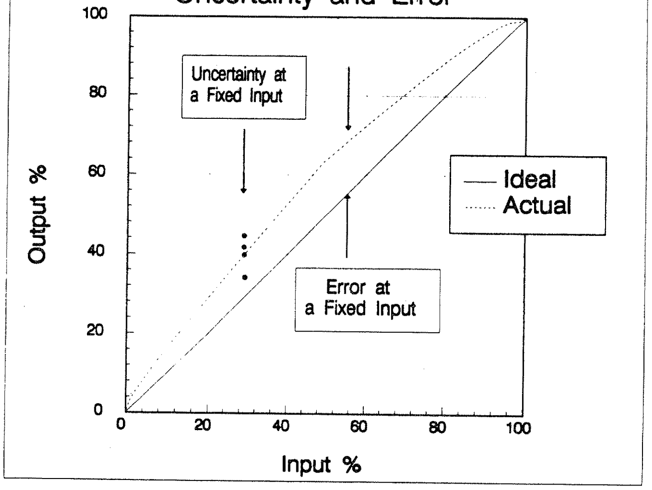

Figure 1 - Transfer Function
Uncertainty and Error

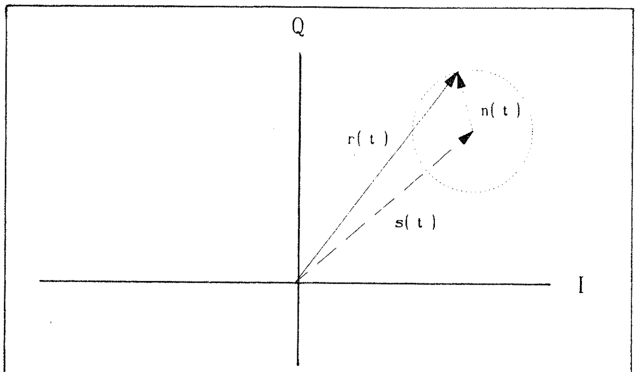

Figure 2
Phasor Diagram of
Uncertainty Model

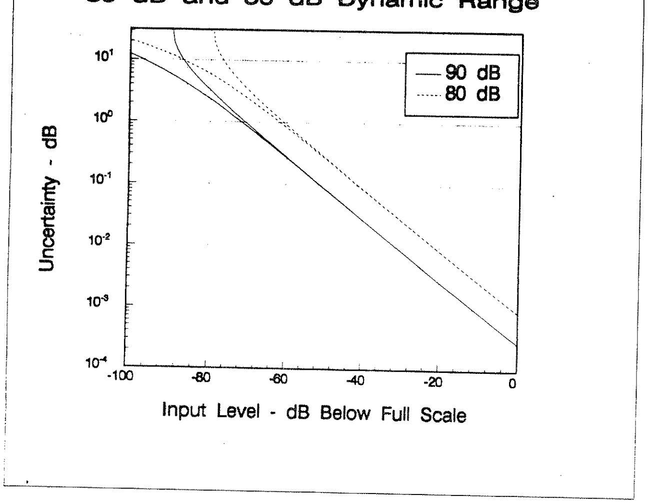

Figure 3 - Uncertainty vs. Input
80 dB and 90 dB Dynamic Range

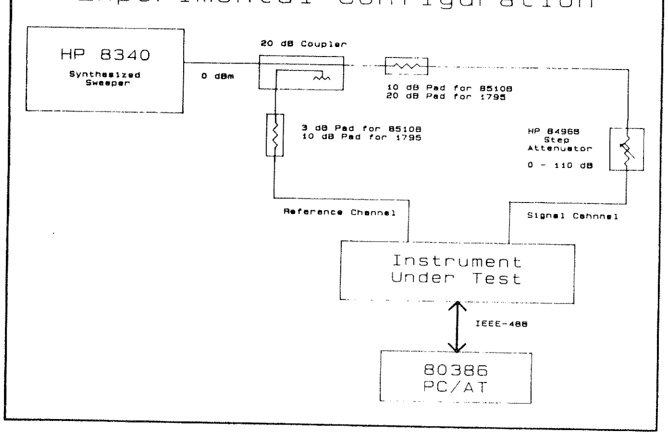

Figure 4
Experimental Configuration

INPUT LEVEL (dBC)		0 dB	0 dB	-10 dB	-10 dB	-20 dB	-20 dB	-30 dB	-30 dB	-40 dB	-40 dB	-50 dB	-50 dB	-60 dB	-60 dB	-70 dB	-70 dB	-80 dB	-80 dB	-90 dB	-90 dB	-100 dB	-100 dB	-110 dB	-110 dB
SAMPLES	PARAMETER	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B	SA 1795	HP 8510B
1	STD DEV	0.000544	0.002496	0.000648	0.006118	0.001522	0.006831	0.003979	0.010218	0.011212	0.027589	0.037765	0.087002	0.094504	0.297862	0.317836	0.861805	1.774232	2.739151	3.786664	4.661652	5.123287	5.441767	4.876700	5.198066
	PEAK DEV	0.001470	0.006155	0.001929	0.016490	0.003582	0.017638	0.012493	0.027101	0.032612	0.062145	0.087917	0.193060	0.212399	0.777380	0.760567	2.641745	4.931145	6.713225	10.249794	10.546775	11.727196	16.694790	10.967735	14.419865
2	STD DEV	0.000434	0.001491	0.000506	0.004157	0.001288	0.004770	0.002622	0.008005	0.007226	0.019417	0.025675	0.058527	0.081942	0.201713	0.237072	0.551929	1.075062	2.049720	2.754540	4.534195	5.753319	4.787981	5.508266	6.498527
	PEAK DEV	0.001011	0.003950	0.001286	0.010245	0.003490	0.012310	0.007809	0.019476	0.015526	0.047635	0.066601	0.150845	0.213589	0.480235	0.595482	1.477140	2.921005	5.142845	7.382530	9.920455	14.760376	11.633335	12.411880	17.929390
4	STD DEV	0.000329	0.001196	0.000528	0.002631	0.000866	0.003289	0.002173	0.005056	0.005687	0.014403	0.019335	0.014403	0.054674	0.142707	0.178369	0.440325	0.742671	1.462955	2.146846	4.379804	4.844396	6.358817	5.553978	5.214111
	PEAK DEV	0.000735	0.003215	0.001195	0.006890	0.002113	0.010473	0.005144	0.014561	0.012676	0.041435	0.050800	0.041435	0.134220	0.405550	0.400635	1.111690	1.481720	3.337735	5.905670	12.303730	13.662010	14.966900	13.477547	14.318300
8	STD DEV	0.000248	0.000836	0.000427	0.002000	0.000645	0.002324	0.001627	0.003305	0.004190	0.010032	0.012598	0.010032	0.040208	0.102685	0.122079	0.313152	0.616430	1.155343	1.262820	3.584535	6.090069	5.784900	6.408985	5.158099
	PEAK DEV	0.000643	0.002110	0.000827	0.005420	0.001379	0.006385	0.003490	0.007625	0.010380	0.025535	0.029305	0.025535	0.106289	0.217540	0.330994	0.777240	1.682724	3.337235	4.105354	11.407850	21.299744	17.384115	22.797520	12.458535
16	STD DEV	0.000279	0.000648	0.000349	0.001214	0.000550	0.001680	0.001405	0.002489	0.003033	0.008050	0.009416	0.021516	0.027137	0.068972	0.082850	0.227979	0.407396	0.718511	1.015410	2.165362	3.609304	5.437243	5.948951	4.783908
	PEAK DEV	0.000643	0.001655	0.000918	0.002895	0.001102	0.004318	0.004042	0.006201	0.007072	0.017870	0.025169	0.049930	0.064583	0.164535	0.238579	0.591125	1.261703	1.652840	2.352531	5.250375	11.389862	13.706595	18.944916	10.864460
32	STD DEV	0.000361	0.000926	0.000411	0.000969	0.000384	0.001015	0.001534	0.001689	0.002431	0.005105	0.006285	0.014950	0.018068	0.045685	0.067323	0.147288	0.277825	0.578704	0.635156	1.534898	3.037313	5.553428	4.425577	5.954310
	PEAK DEV	0.000827	0.002250	0.000919	0.002665	0.000917	0.002480	0.003675	0.004272	0.006245	0.012125	0.015617	0.033440	0.039227	0.121130	0.167198	0.338995	0.700119	1.540855	1.558067	3.708510	8.951797	18.717605	12.213715	14.374435
64	STD DEV	0.000313	0.000514	0.000293	0.000695	0.000330	0.000766	0.001905	0.001219	0.001731	0.003643	0.004064	0.010794	0.015569	0.032748	0.040049	0.122776	0.189431	0.374122	0.459883	1.052262	2.388176	4.053574	5.596367	5.737228
	PEAK DEV	0.000643	0.001150	0.000735	0.001605	0.000734	0.001791	0.003950	0.003490	0.005604	0.008500	0.010750	0.025635	0.042812	0.082450	0.097282	0.314875	0.495621	0.803290	1.493759	2.624385	7.153046	11.664710	19.576492	15.471570
128	STD DEV	0.000386	0.000329	0.000461	0.000553	0.000433	0.000611	0.001308	0.000978	0.001122	0.002287	0.003375	0.007550	0.010882	0.024822	0.030539	0.087234	0.131507	0.271915	0.345416	0.726348	1.458147	3.517984	6.171326	5.412972
	PEAK DEV	0.000735	0.000645	0.000827	0.001425	0.000919	0.001699	0.002756	0.002159	0.002575	0.005830	0.008728	0.017640	0.033623	0.061785	0.073677	0.180520	0.339905	0.744265	0.887344	2.250390	3.981796	10.587420	22.231377	14.725885
256	STD DEV	0.000323	0.000943	0.000394	0.000413	0.000374	0.000453	0.003172	0.000737	0.001467	0.001918	0.002660	0.005780	0.006675	0.016886	0.018257	0.051930	0.101813	0.160246	0.228494	0.585156	1.093220	1.718493	5.719184	5.090951
	PEAK DEV	0.000919	0.001560	0.000918	0.000965	0.000828	0.001148	0.009094	0.001792	0.003860	0.004780	0.006523	0.014560	0.019386	0.043455	0.049606	0.149150	0.248505	0.432930	0.704521	1.537815	2.723404	3.718210	17.666580	11.863225
512	STD DEV	0.000589	0.000540	0.000406	0.000385	0.000381	0.000432	0.002881	0.000532	0.004751	0.001421	0.002472	0.004035	0.004311	0.012160	0.015432	0.036655	0.066960	0.113865	0.150396	0.417227	0.713066	1.426874	6.589660	4.294974
	PEAK DEV	0.001654	0.001290	0.001010	0.000965	0.000826	0.001240	0.007532	0.001654	0.008450	0.003030	0.005054	0.010840	0.009739	0.031140	0.035179	0.092605	0.146713	0.264305	0.347351	1.041325	2.076103	3.447785	15.442657	13.113600
1024	STD DEV	0.000756	0.000419	0.000658	0.000610	0.000465	0.000342	0.012793	0.000513	0.002042	0.000967	0.002653	0.002755	0.003731	0.009841	0.010625	0.030707	0.046322	0.091350	0.106763	0.277931	0.543234	0.920382	4.312863	3.081081
	PEAK DEV	0.001654	0.000920	0.001561	0.001145	0.000917	0.001056	0.023703	0.001194	0.005329	0.002340	0.006523	0.006430	0.008911	0.022560	0.024620	0.074595	0.094620	0.271150	0.287086	0.800810	1.525360	2.466280	10.668236	9.079735
2048	STD DEV	0.000861	0.001402	0.000649	0.000601	0.001036	0.000317	0.008877	0.000334	0.004497	0.000687	0.003050	0.001985	0.003385	0.006231	0.007912	0.020788	0.033026	0.062646	0.078873	0.165985	0.330305	0.679042	4.360598	2.139951
	PEAK DEV	0.001837	0.002025	0.001562	0.001240	0.002022	0.000872	0.017454	0.000827	0.010838	0.001515	0.006432	0.005465	0.008820	0.014975	0.018738	0.053790	0.079002	0.160540	0.180893	0.369535	0.825432	1.524905	11.588478	5.737685

Table 1

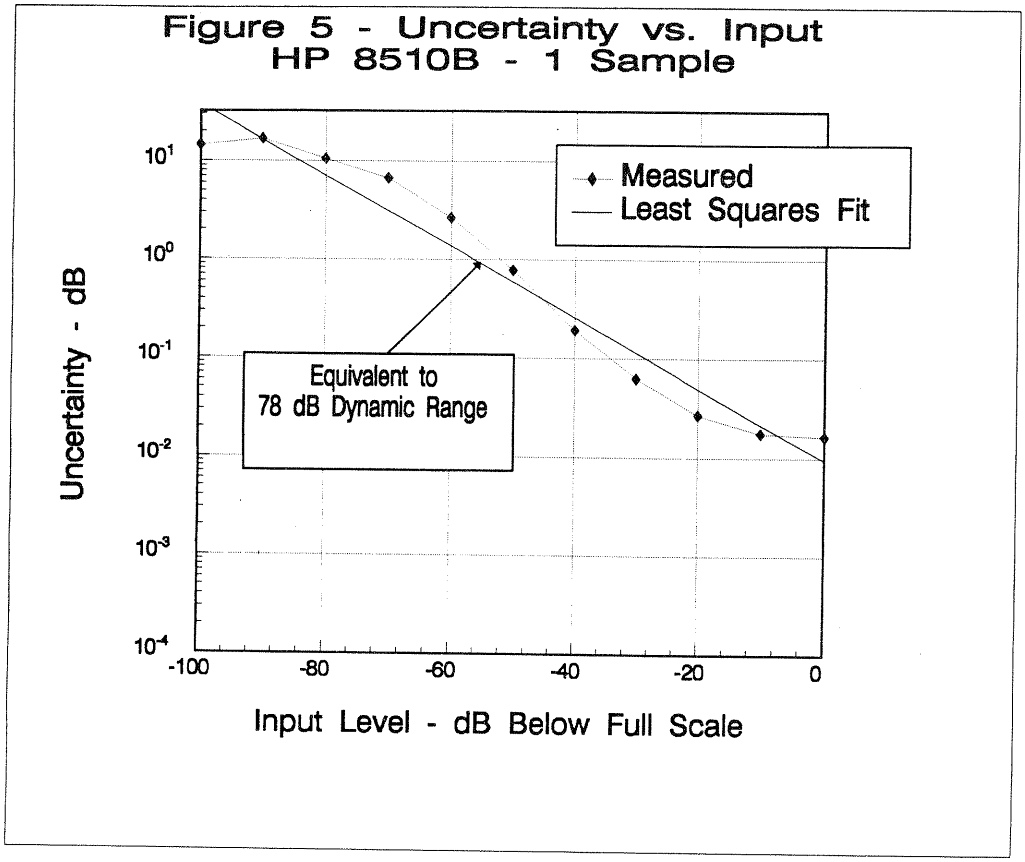

Figure 5 - Uncertainty vs. Input
HP 8510B - 1 Sample
Uncertainty - dB
Input Level - dB Below Full Scale
Measured
Least Squares Fit
Equivalent to
78 dB Dynamic Range

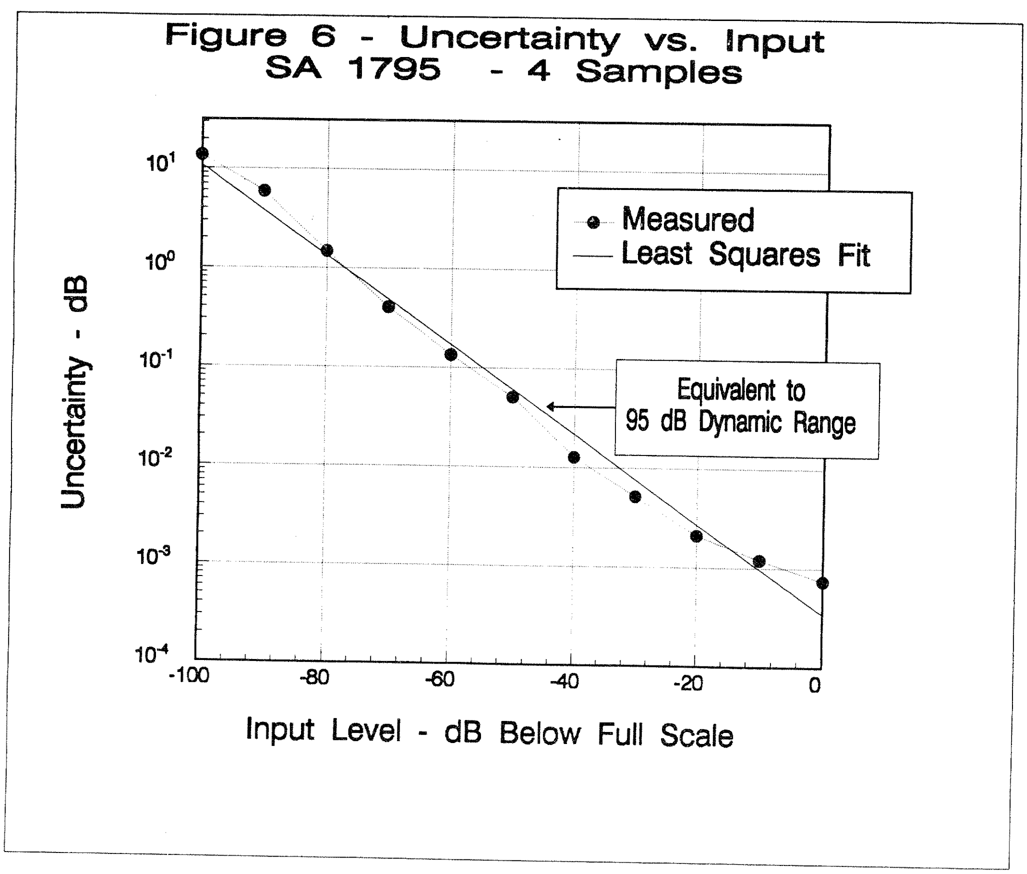

Figure 6 - Uncertainty vs. Input
SA 1795 - 4 Samples
Uncertainty - dB
Input Level - dB Below Full Scale
Measured
Least Squares Fit
Equivalent to
95 dB Dynamic Range

Figure 7 - Uncertainty vs. Input
SA 1795 - 1 Sample

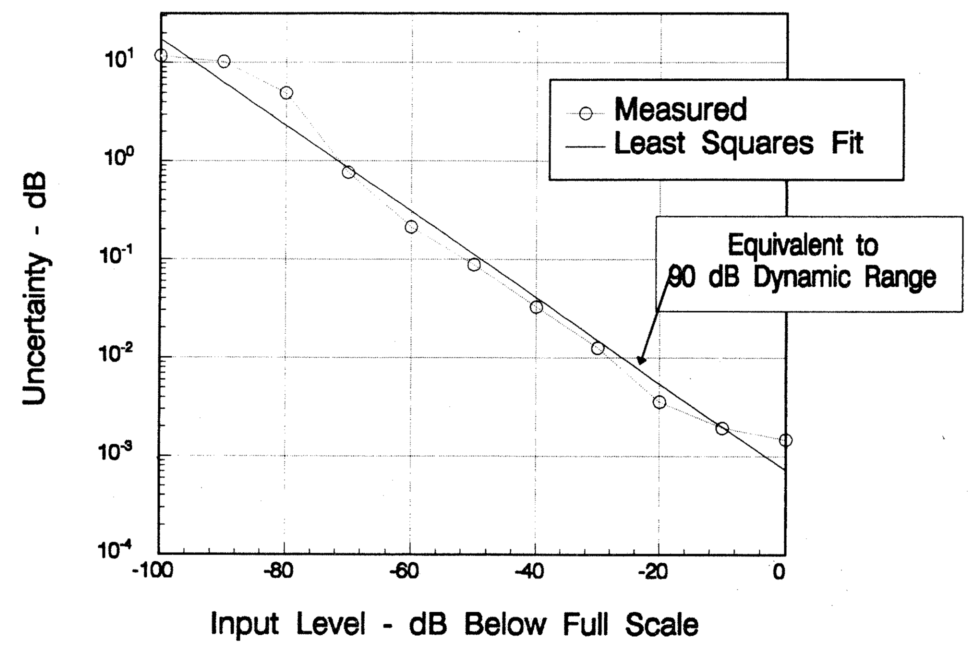

Figure 8 - Uncertainty vs. Speed
60 dB Below Full Scale