IAN 38

METHOD FOR LOCK-IN AMPLIFIER NOISE MEASUREMENT USING DIGITAL INTEGRATION

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INTRODUCTION

Noise measurement with a Lock–In Amplifier has just been greatly improved by using an integrating A to D converter on the lock–in output. Signal–to–noise–density ratios from 90 dB to below –20 dB can be measured. Noise and signal information can be acquired independently or simultaneously.

This Application Note explains how to use the Model 385EO Integrator/Coupler firmware and GPIB compatible host computer to measure signals, noise and signal–to–noise ratios. An RS–232 compatible host computer can be used with a Model 386EO Integrator/Coupler.

The procedure presented here will work well for most noise measurements. If discrete frequency interferences are present, drift is large, or special problems arise see ITHACO IAN 36 "Digital Techniques For Random Noise Measurement Using Lock–In Amplifiers". IAN 36 presents theory, applications hints, and experimental results in detail.

HOW THE LOCK–IN MEASURES NOISE

The Lock–In Amplifier (LIA) measures signals obscured by noise and interferences. It does so by acting as a narrow band filter centered on the frequency of the signal of interest. The bandwidth of this filtering is controlled by the lock–in time constant and the integrator sampling time. Noise close to the signal in frequency can be measured at the lock–in output because it is within the passband of the time constant filter. Measurement of this noise is useful for two reasons:

First, the user can determine the level of confidence in the reproducibility of a signal measurement by calculating its standard deviation due to noise. This information allows one to figure how long a measurement would take with a specified standard deviation by allowing a long enough lock–in amplifier signal output averaging time (lock–in amplifier time constant combined with Coupler integration time).

Second, the noise value can be used to determine the operating limits of a detector or system. This information could be used to measure photo–detector spectral noise at any number of discrete frequencies.

NOISE MEASUREMENT SETUP

All examples in this application note use the configuration shown below:

Any ITHACO Lock–In Amplifier will work. The following control settings are used:

LIA Time Constant Rolloff	12 dB/octave
LIA Phasing	Set for maximum signal output when using a single phase lock–in ***if signal is also being measured.***
LIA Output	From rear panel A and B, X and Y or Acos ϕ and Asin ϕ connectors, 10VDC full scale output
385 Integrator/ Coupler Line Frequency	60 Hz

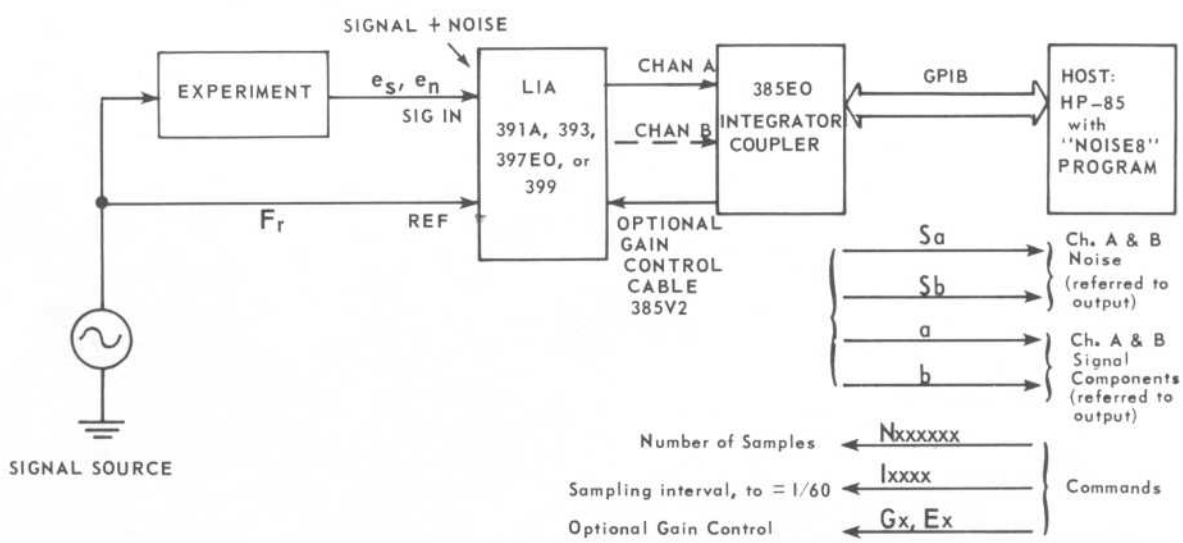

Figure 1 TYPICAL NOISE MEASUREMENT SETUP

The host computer must have a GPIB or RS–232 interface. We programmed a Hewlett–Packard Model 85 with GPIB interface to control the Model 385EO Integrator. The control program, called NOISE8, prompts the operator to enter lock–in settings, integration times, and number of samples. More on this later. It receives signal amplitude (a and b) and standard deviation (S_a & S_b) from the integrator and calculates noise density (e_n) and signal amplitude (e_s) as follows:

(A) $$e_n = \frac{1}{G}\sqrt{\frac{(S_a^2 + S_b^2)}{(2\ \mathrm{SENBW})}}$$ noise density in volts $\sqrt{\mathrm{Hz}}$

(B) $$e_s = \frac{1}{G}\sqrt{a^2 + b^2}$$ vector sum, signal input in volts rms

The a and b symbols refer to the in-phase and quadrature outputs of a dual phase lock–in amplifier. SENBW is the calculated system equivalent noise bandwidth and G is the lock–in gain. If NOISE8 is used for single channel measurements; S_b and the 2 in the denominator are not present in equation A, and b is not present in equation B.

The program will ask the user to enter the 385 sampling time parameter I ($1 \leq I \leq 1000$) and the number of samples, N, to be taken for the computation of 385 output data ($30 \leq N \leq 999{,}999$). You should set these parameters as low as possible to get the fastest measurement.

PROGRAM FOR MEASURING SIGNAL AND/OR NOISE

Assuming signal input is present, set the lock–in amplifier sensitivity and time constant to get a reasonable deflection on the front panel meter (5% to 100% full scale). Noise will be readily measured if you can see any needle fluctuation. There is no need to adjust the phase of a dual phase lock–in amplifier. Single phase lock–in amplifiers must be phase adjusted to maximize signal output for combined signal and noise measurements.

NUMBER OF SAMPLES, N

The larger the number of samples, the more accurate the calculated noise will be. Given your required reproducibility and confidence level, determine N from Figure 2. For example, if we want to be 95% sure of an answer within ±5%, we would read N = 800 samples, single channel, or 400 samples, dual channel.

LIA TIME CONSTANT, T

For the shortest measurement times, set as short as possible given the level of discrete frequency interference mixed with the signal. In low level work T often must be set between 12.5 and 125 msec to attenuate 60 Hz hum pickup. See Section 3.5.2 in IAN 36 for more details.

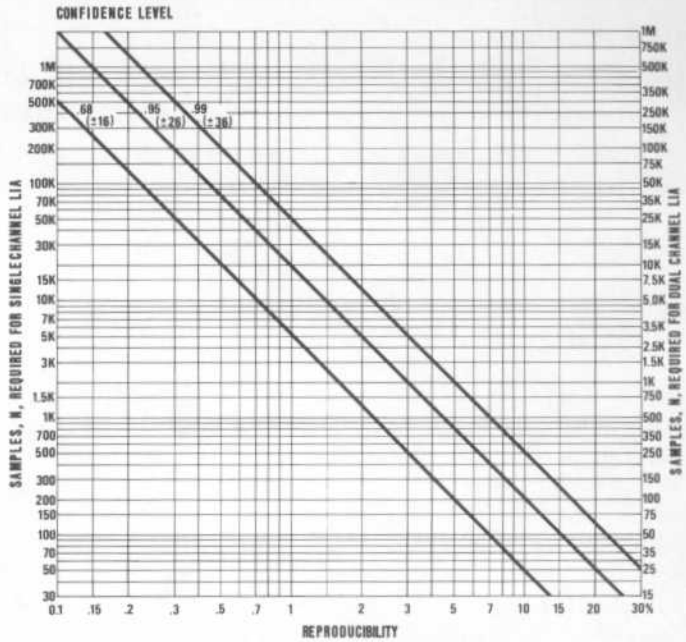

Figure 2 NUMBER OF SAMPLES, N, AS A FUNCTION OF NOISE MEASUREMENT REPRODUCIBILITY, AND CONFIDENCE LEVEL

SAMPLING INTERVAL, I PARAMETER

The reproducibility predicted by Figure 2 will be correct if the sampling interval, I, is sufficiently large compared to the lock–in time constant setting, T. A large I value insures that the bandwidth of the integrator is much smaller than the lock–in bandwidth. Given your time constant, use Figure 3 to select a sampling interval that yields an intersection point on or above the line. Keep I as small as possible to minimize measurement time.

If T = 40 msec to filter discrete frequency interferences, then Figure 3 gives I = 12 or larger to prevent oversampling. Measurement time T, from Figure 5, is 80 seconds, for 400 samples. The measurement will have ±5% error at the 2σ confidence level.

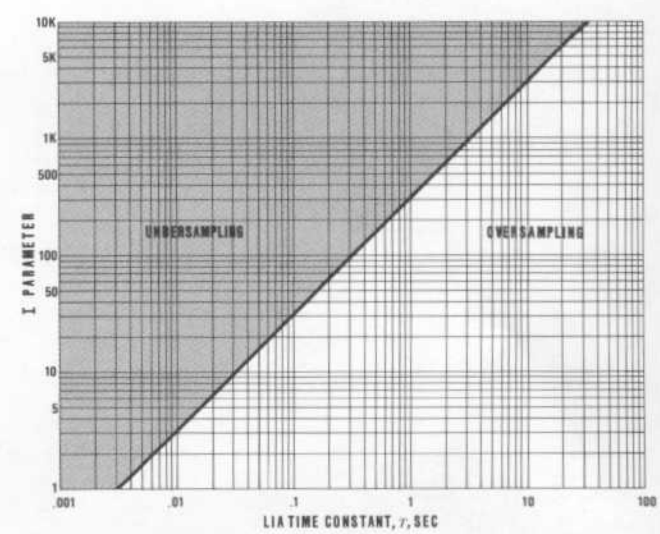

Figure 3 IDEAL I PARAMETER FOR NOISE MEASUREMENT WITHOUT OVERSAMPLING

Unfortunately, selection of I in this simple fashion does not always yield a noise measurement in the minimum amount of time. Unless the lock–in amplifier time constant, T, is set to the very fastest setting (1.25 or 2.5 msec), measurements up to 50% faster can be made by deliberately oversampling (setting I shorter and increasing N).

Oversampling occurs when the integrator bandwidth is close to or larger than the lock–in bandwidth. Use NOISE8 routines to calculate I and N when oversampling.

Invoking the NOISE8 program routine called SENBW assists in the juggling of I and N by displaying a number called the sampling ratio. If the sampling ratio is less than unity, you are undersampling and the reproducibility of the noise measurement from Figure 2 is correct. When greater than unity, the sampling ratio is the degree of statistical oversampling (what you must multiply N by to get the reproducibility expected from Figure 2). One enters trial values of I to come up with a sampling ratio between 3 (33% faster) and 10 (45% faster). This done, one invokes the routine NSAMP which calculates the reproducibility and measurement time from N, I, and T.

Suppose we wish to increase measurement speed in our example. If we set I = 2, the sampling ratio is 3.55. Selecting N = 1400 yields reproducibility of ±2.48%, at the 1σ confidence level which meets our original requirement for ±5% at the 2σ confidence level. The measurement time is 47 seconds; for a 42% speed improvement. Oversampling is covered in greater detail in IAN 36, Section 3.8.

COMBATTING QUANTIZATION EFFECTS BY INCREASING SAMPLING PERIOD, I

The A to D resolution of the 385EO or 386EO is proportional to the sampling time. When the lock–in full scale sensitivity to noise ratio is greater than 60 dB the sample–to–sample quantization error can obscure the noise, causing an abnormally high reading. Given your highest expected sensitivity to noise density ratio, use Figure 4 to select I as a function of quantization error. Figure 4 is accurate for the shaded section of Figure 2 (undersampling). Refer to IAN 36 Section 4.7 to avoid quantization problems when the Integrator/Coupler oversamples the lock–in output.

To get the expected accuracy, only certain values of I will work. Choose the next highest value in the following sequence if I is greater than 10 and does not equal one of the sequence values: 12, 13, 15, 17, 20, 25. Values over 25 have no effect in decreasing quantization effects.

NOISE, SIGNAL OR BOTH

As indicated by equations (A) and (B), NOISE8 returns a signal and a noise measurement. If no signal is present, the system will still measure the noise at the reference frequency. Use the lock–in internal reference or an external frequency source in this case.

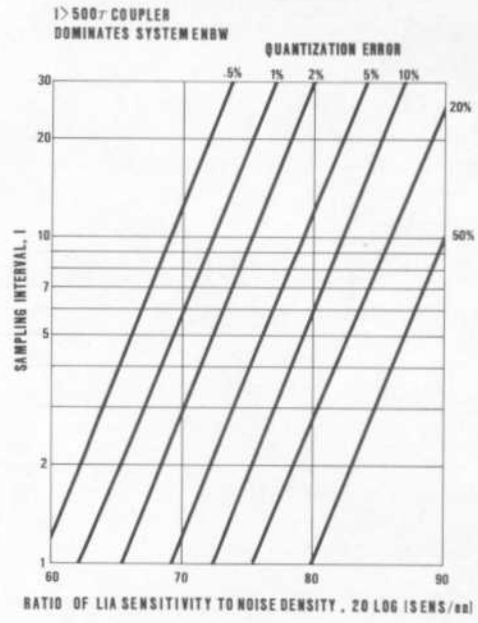

Figure 4 *I PARAMETER AS A FUNCTION OF LIA FULL SCALE SENSITIVITY TO LIA INPUT NOISE DENSITY RATIO AND QUANTIZATION ERROR*

CURRENT NOISE MEASUREMENT

When using a current preamplifier on the lock–in input, divide the noise and signal measurements by the transimpedance of the preamplifier; R_f = voltage out/current in. The 397EO has a built–in current preamp with R_f = 100K (I × 1 range) or 1K (I × 100 range). When using NOISE8 enter the equivalent voltage sensitivity of the LIA when the program asks for lock–in sensitivity, then divide the signal and noise voltage results by R_f to get the current measurements. See IAN 36, Section 4.11, for more details.

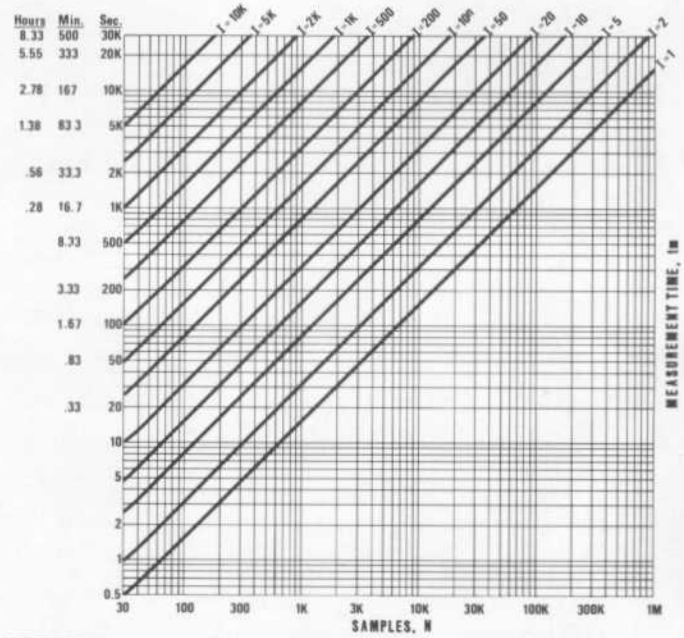

Figure 5 *MEASUREMENT TIME AS A FUNCTION OF NUMBER OF SAMPLES AND 385 I PARAMETER WHEN SAMPLING RATIO IS ONE*

AN EXAMPLE, USING A DUAL CHANNEL LIA

Suppose e_s/e_n is about 10, and we want to measure noise to ±5% at the 1σ confidence level. Also assume that discrete frequency interferences are present and the lock–in amplifier time constant must be set to $T = 12.5$ msec.

The following parameters should be entered as the noise measurement commands from the host to the 385EO Integrator/Coupler:

(From Figure 2) N = 100 (for dual channel LIA)

(From Figure 3) I = 4

The measurement time will be:

(From Figure 5) $t_m = 7$ sec.

NOISE8 will calculate the averaged signal equivalent noise bandwidth, AENBW, (a complex function of N, I and T) from which the signal reproducibility can be calculated. For I = 4 and T = .0125, AENBW turns out to be .075 Hz and our signal reproducibility (σx) will be:

$$\sigma x = \frac{\sqrt{AENBW}}{e_s/e_n} = \frac{\sqrt{.075}}{10} = .0274$$

The signal measurement, es, will be within ±2.74% of the true value 68% of the time, or within ±8.22% of the true value 99.7% of the time, under the conditions given above.

COMMENTS

A. Do not connect the vector sum output of a dual phase lock–in amplifier to the 385. The 385 must operate directly on the lock–in amplifier phase sensitive detector output(s).

B. Try to operate the ITHACO Model 393 or 399 Lock–In Amplifiers in the Lo–Q mode. Use Hi–Q if overload due to high signal–to–noise ratio occurs or if Lo–Q does not give a sufficient lock–in amplifier output at maximum sensitivity. Hi–Q can be used to suppress discrete frequency interferences.

C. For the ITHACO Model 397EO Lock–In Amplifier, Gain Control Option 06 must be installed if remote control of the ac input sensitivity is desired. Quadrature Output Option 10 is mandatory to bypass the normal vector sum output (See A above).

D. Gain control commands Ex, Gx are for Model 399 or 397EO Lock–In Amplifiers only. Omit cable 385V2 (Figure 1) if you do not change lock–in gain with the host computer.

E. Channel B input to 385EO may be omitted for single channel operation (391A Lock–In Amplifier or only one output taken from 397EO or 399 Lock–In Amplifiers).

F. When operating with a long lock–in amplifier time constant T, allow sufficient time for the lock–in amplifier output to settle after changing any lock–in setting. The signal input coupling time constant, which may be set to 10 seconds (lock–in amplifier internal switch set to HI) with Brown or Red cardsets could also cause long settling time.

G. If you don't use an HP–85 Computer, translate the NOISE8 program from HP basic to the language used in your computer. NOISE8 is listed in Appendix A.

APPENDIX A

PROGRAM "NOISE8" FOR HP–85 HOST COMPUTER

The listing is provided to assist those who wish to convert the program to other computer languages, use selected subroutines in applications programs, or to review the computations being performed. Remark lines 4155–4620 define all variables.

The data acquisition and computation routines are highlighted. The remainder of the program deals with prompting and display formatting. Routines are also included to prevent the hangup of the GPIB bus or interruption of execution by depressing the wrong key. Operation is menu driven from the HP–85 function keys.

```
NOISE MEASUREMENT SETUP
AND INITIATION

K1-SETUP: ENTER ALL CONDITIONS
K2 SENBW: CHANGE I & T ONLY
K3 NSAMP: CHANGE N ONLY
K4 START: TAKE MEASUREMENT
K5 LIAFS: CHANGE LIA SENS ONLY
K6 Z-OFF: CANCEL ZERO CORRECTION
K7 Z-VAL: VIEW ZERO CORRECTION
--------------------------------
LIA FS   Z-OFF    Z-VAL
SETUP    SENBW    NSAMP    START
```

Upon completion of a measurement, a second menu will appear for display and printing of results.

```
END ACQUISITION LOOP
SEC ELAPSED TIME= 7.956

K1-COND  : DISPLAY SETUP
K2-DATA  : DISPLAY DATA
K3-CPRNT : PRINT SETUP
K4-DPRNT : PRINT DATA
K5-Z-ON  : INVOKE ZERO CORRECTION
K6-Z-OFF : CANCEL ZERO CORRECTION
K7-Z-VAL : VIEW ZERO CORRECTIONS
           IN EFFECT
K8-AGAIN : EXIT FOR NEXT RUN

--------------------------------
Z-ON     Z-OFF    Z-VAL    AGAIN
COND     DATA     CPRNT    DPRNT
```

The "Z–ON" selection performs baseline correction using LIA output data collected in the current run. It assumes quiescent input conditions (e.g. LIA input shorted if we desire to null the LIA offsets, etc.). This feature will not be needed unless you are dealing with very low SNR (e_s/e_n <1) or the zero suppression of coherent signals.

Pressing the "DATA" key will display the measurements. The example below shows the results of placing a 500K resistor (generating a thermal noise, e_n, of $90.9nV/\sqrt{Hz}$) in series with a signal about $1\mu V$ in amplitude.

```
CH.A, B, & VECT.SUM SIGNAL(+-σx̄)
es(a)= 668.573 nVRMS    (± 3.45%)
es(b)=-785.460 nVRMS    (± 3.01%)
es   =   1.031 μVRMS    (± 2.26%)
CH.A,B,V.S. NOISE/ROOT Hz (+-σn)
en(a)=  89.377 nVRMS    (± 3.28%)
en(b)=  91.526 nVRMS    (± 3.28%)
en   =  90.458 nVRMS    (± 2.33%)
CH.A,B,V.S. SIGNAL/NOISE RATIO
es/en(a)=              7.4804
es/en(b)=              8.5818
es/en   =             11.4028
---------------------------------

            DATA
```

Program lines 190–540 initialize operation, ending in a loop (lines 540–570) to await function key commands for setup. After data has been acquired, a similar loop 2240–2250 is entered. These loops are active whenever a function key menu K1–K8 appears on the CRT screen.

As part of the initialization, the timeout routine 3920–4130 is called in order to provide continued operation in the event of difficulties on the GPIB (the HP–85 is quite suceptable to bus hangups).

Lines 3510–3740 compute system ENBW. Two passes are made, with the first iteration computing the AENBW of the ***average signal.*** The second iteration computes the SENBW for the noise. Lines 1250–1300 compute *noise* reproducibility, σn, given N.

Lines 1650–1750 initiate a noise acquisition by the 385EO (1660) and collect the raw data, a, Sa, b, Sb (1750). From this, lines 1860–2070 compute referred–to–input signal, noise, SNR and signal reproducibility for channel A, channel B and the vector sum.

Lines 3230–3240 send baseline correction commands to the 385EO.

```
10 ! "NOISE8"
20 !
30 ! NOISE8 REV.41 04/29/85 JLS
40 !
50 ! SIGNAL & NOISE MEASUREMENT
60 ! PROGRAM FOR ITHACO MODEL
70 ! 385EO-3 INTEGRATOR/COUPLER
80 ! ALSO FOR 385-A-EO 385EO-1
90 ! OR 385EO-2 WITH VN510 OR
100 ! LATER EPROM FIRMWARE
110 !
120 ! CHANGE LINE 380 FOR 50Hz
130 ! CHANGE 330 FOR 391A LIA
140 !
150 ! HIT 'CONT' KEY TO BEGIN
160 CLEAR @ LIST @ BEEP @ PAUSE
170 CLEAR
180 !
190 DIM A$[90]
200 DIM B$[90]
210 S$=CHR$(43+128)
220 IMAGE 2D.4D,3X,5D.4D
230 IMAGE 5D,X,4D.3D
240 IMAGE XX,2D.3D,"  VRMS",3X,"
    (",A,2D.DD,"%)"
250 IMAGE 4D.3D,AA,"VRMS",3X,"(",A,2D.DD,"%)"
260 IMAGE X,10D.4D
270 !
280 S=1 @ GOSUB 4080
290 ! INIT GPIB TIMEOUT
300 !
310 ! DEFAULT CONDITIONS
320 A=701 !          GPIB ADDR. #1
330 T1=.00125 !       391A: .00047
340 !   T/C OF FIXED L.P. FILTER
350 T=.00125 !  LIA T.C. 1.25 MS
360 F=.000003162 ! LIA '3uV'SENS
370 N=450 !            # OF SAMPLES
380 L=60 !         L=50 FOR 50 Hz
385 !          385 LINE FREQUENCY
390 !
400 CLEAR A
410 OUTPUT A "A1B1D3I1MAOCR0TBZ0"
420 ! 385 COMMANDS
430 GOSUB 4000 ! GPIB TIMEOUT
440 !
450 DISP "NOISE MEASUREMENT SETUP","AND
    INITIATION"
455 ! MENU#1 ******************

460 DISP @ DISP "K1-SETUP: ENTER ALL
    CONDITIONS"
470 DISP "K2-SENBW: CHANGE I & T
    ONLY"
480 DISP "K3-NSAMP: CHANGE N ONLY"
490 DISP "K4-START: TAKE MEASUREMENT"
500 DISP "K5 LIAFS: CHANGE LIA SENS ONLY"
502 DISP "K6 Z-OFF: CANCEL ZERO CORRECTION"
504 DISP "K7 Z-VAL: VIEW ZERO CORRECTION"
510 !
530 ON KEY# 1,"SETUP" GOSUB 810
540 ENABLE KBD 1+32+64+128
550 ! INPUT, PAUSE, RESET, K1-8
560 KEY LABEL
570 GOTO 540
572 ON KEY# 1,"SETUP" GOSUB 810
574 ON KEY# 6,"Z-OFF" GOSUB 3330
576 ON KEY# 7,"Z-VAL" GOSUB 3390
580 ON KEY# 2,"SENBW" GOSUB 3440
590 ON KEY# 3,"NSAMP" GOSUB 1490
600 ON KEY# 4,"START" GOTO 1570
605 ON KEY# 5,"LIA FS" GOSUB 1114
608 OFF KEY# 8
610 RETURN
620 !
630 ! 385 PARAMETERS *********

640 CLEAR
650 DISP "PRESENT 385 PARAMETERS:"
660 OUTPUT A ;"?"
670 ENTER A ; A$@ DISP A$
680 DISP @ DISP "DO NOT ENTER M,N, Z
    PARAMETERS!" @ DISP
690 DISP "DURING NOISE ROUTINE,D3 OC TB"
700 DISP "EFFECTIVE (AUTOMATIC, MOMENTARY)"
    @ DISP
710 DISP "A,B,R CHANGES MAY CAUSE ERROR"
    @ DISP
720 DISP "ENTER 385 CHANGES (END LINE=NONE)"
730 INPUT A$
740 IF A$="" THEN GOTO 780
```

```
750 OUTPUT A ;A$&"?"
760 ENTER A ; A$
770 CLEAR @ DISP A$
780 GOSUB 4000 ! GPIB TIMEOUT
790 DISP @ DISP @ RETURN
800 !
810 ! SETUP *****************

820 GOSUB 580
830 GOSUB 840 @ GOTO 1030
840 CLEAR @ DISP "ENTER MEASUREMENT
    CONDITIONS" @ DISP
850 GOSUB 650 ! 385 PARAM
860 DISP "HIT 'ENDLINE' TO RETAIN PREVIOUS"
870 DISP "MEASUREMENT CONDITION"
880 DISP "(IN PARENTHESES)" @ DISP
890 ! ************************
900 DISP "LIA TIME CONST, 'T' (";T;")";
910 X=T @ GOSUB 1510 @ T=X
920 !
930 ! ************************
940 DISP "385 SAMP.RATE 'I' PARAM(";I;")";

950 X=I @ GOSUB 1510 @ I=X
960 X=INT(X)
970 IF I<1 THEN I=1
980 IF I>9999 THEN I=9999
990 OUTPUT A ;"I"&VAL$(I)
1000 GOSUB 4000
1010 RETURN
1020 !
1025 ! ************************
1030 GOSUB 3490 ! ENBW
1040 DISP
1045 GOSUB 1060 @ GOTO 1130
1050 !
1060 ! ************************
1070 DISP "LIA FULL SCALE VOLTS"
1080 DISP "(";F;")"
1090 X=F @ GOSUB 1510 @ F=X
1100 DISP "F.S. MV =";F*1000
1110 DISP @ DISP
1112 RETURN
1114 CLEAR @ GOTO 1060
1120 !
1130 ! ************************

1140 DISP "NUMBER OF SAMPLES 'N'(";N;")";
1150 DISP "1 TO 999999"
1160 X=N @ GOSUB 1510
1170 IF A$="" THEN GOTO 1265
1180 N=X
1190 N=INT(N)
1200 IF N<1 THEN N=1
1210 IF N>999999 THEN N=999999
1220 CLEAR @ DISP "DISREGARD UNDERFLOW
     WARNINGS" @ WAIT 1000
1230 T0=N*I/L @ GOSUB 3580
1240 ! RECALCULATE SIGNAL NBW
1250 B4=B3
1260 T0=I/L @ GOSUB 3580
1265 GOSUB 1270 @ GOTO 1320
1270 D1=SQR(1/2/N)-1/4/N
1280 D2=SQR(1/4/N)-1/8/N
1290 D3=SQR(R2/2/N)-R2/4/N
1300 D4=SQR(R2/4/N)-R2/8/N
1305 RETURN
1310 !
1320 CLEAR
1330 DISP "NOISE REPRODUCIBILITY(STD.DEV.)"
     @ DISP
1340 DISP TAB(10);"NOMINAL";"ACTUAL"
1350 DISP TAB(10);"          (OSR CORRECTED)"
1360 DISP "σn(A,B)=";
1370 DISP USING 220 ; D1;D3
1380 DISP "σn(A+B)=";
1390 DISP USING 220 ; D2;D4
1400 DISP "S.RATIO=";R1
1410 !
1420 DISP @ DISP "MEASUREMENT TIME (NxI/60)"
1430 T4=N*I/60
1440 DISP "Tm=";T4;"SEC"
1450 DISP @ DISP "NUMBER OF SAMPLES"
1460 DISP "N =";N
1470 DISP @ DISP
1480 RETURN
1490 CLEAR @ GOTO 1130
1500 !
1510 ! INPUT ROUTINE **********

1520 ON ERROR GOSUB 1550
1530 INPUT A$
1540 IF A$#"" THEN X=VAL(A$)
1550 OFF ERROR @ RETURN
1560 RETURN
1570 ! NOISE ACQUSITION *******

1580 ON KEY# 8,"STOP" GOTO 1820
1590 OFF KEY# 1 @ OFF KEY# 2 @ OFF KEY# 3
     @ OFF KEY# 5 @ OF F KEY# 6 @ OFF KEY# 7
1600 CLEAR @ KEY LABEL
1610 DISP "NOISE MEASUREMENT BEING TAKEN"
1620 DISP "APPROX 1 SEC POLLING"
1630 DISP "USE K8 TO ABORT"
1640 DISP "Tm=";T4;"SEC"
1650 CLEAR A
1660 OUTPUT A ;"N"&VAL$(N)
1670 T5=TIME @ X=0
1680 WAIT 914 @ X=X+1
1690 P=SPOLL(A)
1700 A$=DTB$(P)
1710 IF A$[13,13]="1" THEN GOTO 1730 ELSE
     DISP X @ GOTO 1680
1720 !
1730 ! DATA VALID
1740 T5=TIME-T5
1750 ENTER A ; X1,S1,X2,S2
1760 ! CH.A,B: MEAN, STD.DEV
1770 CLEAR @ DISP "END ACQUISITION LOOP"
1780 DISP "SEC ELAPSED TIME=";T5@ DISP
1781 DISP "K1-COND : DISPLAY SETUP"
1782 DISP "K2-DATA : DISPLAY DATA"
1783 DISP "K3-CPRNT: PRINT SETUP"
1784 DISP "K4-DPRNT: PRINT DATA"
1785 DISP "K5-Z-ON : INVOKE ZERO CORRECTION"
1786 DISP "K6-Z-OFF: CANCEL ZERO CORRECTION"
1787 DISP "K7-Z-VAL: VIEW ZERO CORRECTIONS","
     IN EFFECT"
1788 DISP "K8-AGAIN: EXIT FOR NEXT RUN"
1790 DISP @ DISP
1800 BEEP 99,99
1810 GOTO 1850
1820 !
1830 P=8 @ GOTO 1700
1840 !
1850 ! DATA COMPUTATION *******
1860 G=10/F ! LIA GAIN
1870 X3=SQR(X1^2+X2^2)
1880 X4=X1/G
1890 X5=X2/G
1900 X6=X3/G
1910 S3=SQR((S1^2+S2^2)/2)
1920 X=B3^(-(1/2))/G
1930 ! RTI NORMALIZATION
1940 S4=S1*X
1950 S5=S2*X
1960 S6=S3*X
1970 ON ERROR GOSUB 2110
1980 Y=X4/S4
1990 R4=Y ! CH A SNR es/en
2000 Y=X5/S5
2010 R5=Y ! CH B SNR es/en
2020 Y=X6/S6
2030 R6=Y ! COMPOSITE SNR
2050 Y=ABS(SQR(B4)/R4) ! σx̄(a)
2052 D8=Y
2060 Y=ABS(SQR(B4)/R5) ! σx̄(b)
2062 D9=Y
2070 Y=SQR(B4)/R6 ! COMP σx̄
2072 D0=Y
2075 OFF ERROR
2080 !
2090 GOSUB 2140 @ GOTO 2240
2100 !
2110 Y=999999999 @ RETURN
2120 !
2140 ! MENU#2 *****************

2150 ON KEY# 1,"COND" GOSUB 2310
2160 ON KEY# 2,"DATA" GOSUB 2480
2170 ON KEY# 3,"CPRNT" GOSUB 2590
2180 ON KEY# 4,"DPRNT" GOSUB 2640
2190 ON KEY# 5,"Z-ON" GOSUB 3210
2200 ON KEY# 6,"Z-OFF" GOSUB 3330
2210 ON KEY# 7,"Z-VAL" GOSUB 3390
```

```
2220 ON KEY# 8,"AGAIN" GOTO 2270
2230 RETURN
2240 ENABLE KBD 1+32+64+128
2250 KEY LABEL @ GOTO 2240
2260 !
2270 OFF KEY# 5 @ OFF KEY# 8
2280 GOSUB 580
2290 CLEAR @ GOTO 450
2300 !
2310 ! SETUP DISPLAY **********
2320 CLEAR @ DISP "MEASUREMENT CONDITIONS"
     @ DISP @ WAIT 1000
2330 DISP "LIA TIME CONS=";T
2340 DISP "LIA NOM ENBW =";B1
2350 DISP "LIA F.S. MV  =";F*1000
2360 DISP "385 I,To(SEC)=";
2370 DISP USING 230 ; I;T0
2380 DISP "385 EQUIV NBW=";B2
2390 DISP "SYSTEM EQ.NBW=";B3
2400 DISP "SAMPLE RATIO =";R1
2410 DISP "SAMPLES, N   =";N
2420 DISP "T(meas) NI/60=";T4
2430 DISP "AVE.SIG ENBW =";B4
2440 DISP "385 PARAMETER CODES:"
2450 DISP B$ @ DISP @ DISP
2460 RETURN
2470 !
2480 ! NOISE DATA DISPLAY *****

2490 CLEAR @ DISP "MEASUREMENT RESULTS"
2500 GOSUB 2710 ! RAW DATA
2510 ON KEY# 2,"DATA" GOSUB 2810
2520 OFF KEY# 1 @ OFF KEY# 3 @ OFF KEY# 4 @
     OFF KEY# 5 @ OFF KEY# 6 @ OFF KEY# 7 @
     OFF KEY# 8
2530 KEY LABEL @ GOTO 2530
2540 ! 5200=COMPUTED RESULTS
2550 GOSUB 2140
2560 CLEAR @ KEY LABEL
2570 RETURN
2580 !
2590 ! SETUP PRINTOUT *********

2600 CRT IS 2 @ GOSUB 2310
2610 CRT IS 1 @ RETURN
2620 !
2640 ! NOISE DATA PRINTOUT ****

2650 CLEAR @ DISP@ DISP "MEASUREMENT RESULTS"
2660 CRT IS 2
2670 GOSUB 2710 ! RAW DATA
2680 GOSUB 2830
2690 CRT IS 1 @ RETURN
2700 !
2710 ! NOISE DATA FROM 385 ****

2720 DISP @ DISP "RAW DATA OUTPUT FROM 385"
     @ DISP
2730 DISP "CH.A OUTPUT,VDC (a/)=";X1
2740 DISP "CH.A FLUCT,VRMS (Sa)=";S1 @ DISP
2750 DISP "CH.B OUTPUT,VDC (b/)=";X2
2760 DISP "CH.B FLUCT,VRMS (Sb) =";S2 @ DISP
2770 DISP "BASELINE CORRECTIONSIN EFFECT,",
     "CH.A,B =  ";
2772 OUTPUT A ;"Z3" @ ENTER A ; A$@ DISP A$
2780 DISP @ DISP
2790 RETURN
2800 !
2810 ! DISPLAY RESULTS ********

2820 ON KEY# 2,"DATA" GOTO 2540
2830 CLEAR
2840 DISP "COMPUTED RESULTS/REPRODUCIBILITY"
2850 WAIT 1000
2860 DISP @ DISP "CH.A, B, & VECT.SUM SIGNAL
     (+-σx̄)"
2870 DISP "es(a)=";@ X=X4
2880 Y=D8*100 @ GOSUB 3100
2890 DISP "es(b)=";@ X=X5
2900 Y=D9*100 @ GOSUB 3100
2910 DISP "es    =";@ X=X6
2920 Y=D0*100 @ GOSUB 3100
2930 DISP "CH.A,B,V.S. NOISE/ROOT Hz (+-σn)"
2940 DISP "en(a)=";@ X=S4
2950 Y=D3*100 @ GOSUB 3100
2960 DISP "en(b)=";@ X=S5
2970 Y=D3*100 @ GOSUB 3100
2980 DISP "en    =";@ X=S6
2990 Y=D4*100 @ GOSUB 3100
3000 DISP "CH.A,B,V.S. SIGNAL/NOISE RATIO"
3010 DISP "es/en(a)=";@ X=R4
3020 GOSUB 3170
3030 DISP "es/en(b)=";@ X=R5
3040 GOSUB 3170
3050 DISP "es/en   =";@ X=R6
3060 GOSUB 3170
3070 DISP @ DISP
3080 RETURN
3090 !
3100 ! OUT VOLTS DISPLAY ******

3110 Y=ABS(Y) @ Z=ABS(X)
3115 IF Y>99.99 THEN Y=99.99
3120 IF Z>=1 THEN DISP USING 240; X,S$,Y @
     RETURN
3130 IF Z>=.001 THEN DISP USING 250 ; X*1000,
     " m",S$,Y @ RETURN
3140 IF Z>=.000001 THEN DISP USING 250 ;
     X*1000000," µ",S$,Y @ RETURN
3150 DISP USING 250 ; X*1000000000," n",S$,Y
     @ RETURN
3160 !
3170 Z=ABS(X)
3180 DISP USING 260 ; Z
3190 RETURN
3200 !

3210 ! BASELINE CORRECTION ****

3220 CLEAR
3230 OUTPUT A ;"Z4,"&VAL$(X1)&","&VAL$(X2)&",
     " ! SEND OFFSETS
3240 OUTPUT A ;"Z3" @ ENTER A ;A$ ! READ THEM
     BACK
3250 DISP "BASELINE CORRECTION INVOKED."
3260 DISP "SYST SIG INPUT ASSUMED QUIESCENT"
3270 DISP "WHEN PRESENT DATA TAKEN."
3280 DISP @ DISP "CHAN.A & B OFFSETS a/ & b/,
     ",,,"("&A$&"),",,,
3290 DISP ;"HAVE BEEN TRANSFERRED TO THE 385",
     "TO BE SUBTRACTED FROM SUBSEQUENT"
3300 DISP "CHAN.A & B DATA BEFORE COMPUTA-",
     "TION OF RESULTS IN 385 OR HOST."
3310 RETURN
3320 !
3330 ! ************************

3340 CLEAR
3350 DISP "BASELINE CORRECTION CANCELLED",
     "FOR SUBSEQUENT DATA AQUISITIONS"
3360 OUTPUT A ;"Z0" @ RETURN
3370 !
3380 ! ************************

3390 CLEAR @ DISP "PRESENT BASELINE
     CORRECTIONS" @ DISP
3400 OUTPUT A ;"Z3" @ ENTER A ; A$
3410 DISP "CH.A & B VOLTS=",A$
3420 DISP @ DISP "(REFERRED TO LIA OUTPUT)"
3430 RETURN
3435 !
3440 ! SYST EQIV NOISE BW *****

3450 CLEAR
3460 DISP "SYSTEM EQUIV.";
3470 DISP " NOISE BANDWIDTH" @ DISP
3480 GOSUB 860 ! GET I,T
3490 CLEAR @ DISP "DISREGARD UNDERFLOW
     WARNINGS" @ WAIT 1000
3500 ENABLE KBD 0 ! KILL KBD
3510 T2=1.01*T
3520 T3=.99*T ! SPREAD POLES
3530 T0=N*I/L ! FOR SIG NBW
3540 GOSUB 3580 @ B4=B3
3550 T0=I/L @ GOSUB 3580
3560 GOSUB 1270 @ GOTO 3750
3570 !
3580 ! SYST ENBW CALC *********

3590 X1=-(T1^2^3/(T0^2*(T1^2-T2^2)*
     (T1^2-T3^2)))
3600 X2=-(T2^2^3/(T0^2*(T2^2-T1^2)*
     (T2^2-T3^2)))
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3610 X3=-(T3^2^3/(T0^2*(T3^2-T1^ 2)*
(T3^2-T2^2)))
3620 X1=(1-EXP(-(T0/T1)))*X1
3630 X2=(1-EXP(-(T0/T2)))*X2
3640 X3=(1-EXP(-(T0/T3)))*X3
3650 X1=X1/(2*T1)
3660 X2=X2/(2*T2)
3670 X3=X3/(2*T3)
3680 X0=1/(2*T0) ! = L/2I
3690 B1=1/8/T ! NOM LIA ENBW
3700 B2=L/2/I ! NOM 385 ENBW
3710 B3=X1+X2+X3+X0 !  SENBW
3720 R1=B2/B3/SQR(2)
3730 IF R1>1 THEN R2=R1 ELSE R2= 1
3740 RETURN
3750 CLEAR
3760 T4=N*I/L
3765 H=I*SQR(B3)
3770 DISP "EQ. NOISE BW ROUTINE RESULTS"
     @ DISP @ WAIT 1000
3780 DISP "LIA T          =";T
3790 DISP "LENBW 1/8/T    =";B1
3800 DISP "385 I          =";I
3810 DISP "CENBW L/(2I) =";B2
3820 DISP "SENBW (SYST) =";B3
3830 DISP "SAMPLE RATIO =";R1
3840 DISP "I*SQR(SENBW) =";H
3850 DISP "SAMPLES, N     =";N
3860 DISP "AENBW          =";B4
3870 DISP "(ENBW FOR AVE OF N SIG SAMPLES)"
3880 ENABLE KBD 1+32+64+128
3890 ON KEY# 3,"NSAMP" GOSUB 1490
3900 RETURN
3910 !
3920 ! HANGUP RECOVERY ********

3930 BEEP @ CLEAR
3940 DISP "GPIB TIMEOUT"
3950 ABORTIO 7
3960 CLEAR A
3970 DISP "RESUMED EXECUTION"
3980 GOSUB 572 @ GOTO 530
3990 !
4000 ! TIMEOUT SETUP **********

4010 OUTPUT A ;"?"
4020 ENTER A ; A$@ B$=A$
4030 IF A$[11,11]="E" THEN A$=A$ [18,21]
     ELSE A$=A$[12,15]
4040 I=VAL(A$)
4050 T0=I/L
4060 IF T0>20 THEN GOTO 4110
4070 S=T0+1
4080 SET TIMEOUT 7;(S*1500)
4090 ON TIMEOUT 7 GOTO 3920
4100 RETURN
4110 SET TIMEOUT 7;0
4120 OFF TIMEOUT 7
4130 RETURN
4140 !
4150 END
4155 ! VARIABLES *************
4160 ! A = GPIB ADDR. (701)
4170 ! A$= UTILITY STRING
4180 ! B1= LIA ENBW
4190 ! B2= 385 ENBW
4200 ! B3= LIA+385 ENBW
4210 ! B4= LIA+385(N*To) ENBW
4220 ! FOR SIGNAL σx̄ COMPUTATION
4230 ! B$= 385 PARAMETER STRING
4240 ! * NOISE REPRODUCIBILITY
4250 ! D1= CH.A OR B σn(a,b)
4260 ! D2= COMBINED CHAN σn
4265 ! (IDEAL)
4270 ! D3= CH.A OR B σn(a,b)
4280 ! D4= COMBINED CHAN σn
4285 ! CORRECTED FOR OSR (R2)
4290 ! * SIGNAL REPRODUCIBILITY
4300 ! D8= CH.A  σx̄(a)
4310 ! D9= CH.B  σx̄(b)
4320 ! D0= ChA+B σx̄
4330 ! F = LIA FULL SCALE SENS
4340 ! G = LIA GAIN (FSO/FSI)
4345 ! H = QUANT NOISE FACTOR
4347 !     EQ.29 IN IAN 36
4350 ! I = 385 SAMP RATE PARAM
4360 ! L = POWER LINE FREQUENCY
4370 ! N = NUMBER OF SAMPLES
4380 ! R1= SAMPLING RATIO
4390 ! R2= OVERSAMPLING (OSR)
4400 ! R4= CHAN.A SNR
4410 ! R5= CHAN.B SNR
4420 ! R6= COMPOSITE SNR (es/en)
4430 ! S = GPIB TIMEOUT SEC
4440 ! S1= ChA REF-TO-O/P NOISE
4450 ! S2= ChB REF-TO-O/P NOISE
4460 ! S3= COMBINED R-T-O NOISE
4470 ! S4= ChA REF-TO-I/P NOISE
4480 ! S5= ChB REF-TO-I/P NOISE
4490 ! S6= en, COMB R-T-I NOISE
4500 ! S$= +- SIGN CHAR
4510 ! T = LIA TIME CONSTANT
4520 ! T0= 385 SAMP INTERVAL To
4530 ! T1= LIA FIXED FILT T.C.
4540 ! T4= MEAS TIME (NI/60)
4550 ! T5= ACTUAL MEAS LOOP TIME
4560 ! X,Y,Z = UTILITY VARIABLES
4570 ! X1= ChA REF-TO-O/P SIGNAL
4580 ! X2= ChB REF-TO-O/P SIGNAL
4590 ! X3= VECTOR SUM RTO SIGNAL
4600 ! X4= ChA REF-TO-I/P SIGNAL
4610 ! X5= ChB REF-TO-I/P SIGNAL
4620 ! X6= VECT SUM RTI SIG es
9999 END
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