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Westinghouse Astronuclear Laboratory

WANL WIDE BAND DATA CONVERTER

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WANL WIDE BAND DATA CONVERTER

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WANL WIDE BAND DATA CONVERTER

1.0 INTRODUCTION

The WANL Wide Band Data Converter is used in the reduction and analysis of data taken in NRX testing at NRDS. The device is a high-speed multiple-input analog-to-digital converter and tape formatting unit, capable of handling wide band (to 1000 cycles) data at sufficient rates to prevent aliasing, and with a reasonable degree of conversion accuracy.

Because it occupies a significant place in the handling of NRX data, tests were conducted on the Wide Band Data Converter to determine the overall accuracy of the device in converting test data. Known inputs were introduced into the discriminator section directly from tapes and the corresponding outputs measured at the converter section output. Figure 1 is a block diagram of the WANL Wide Band Data Converter. Separate tests were made to determine drift (long and short term), linearity, and crosstalk. No attempt was made to analyze aliasing errors; the sampling rate may be made sufficiently high to eliminate such errors.

Data were analyzed using statistical techniques, and assistance was provided by Mr. William H. Horton in this preparation and analysis; his help is hereby gratefully acknowledged.

2.0 TEST OBJECTIVES

The evaluation tests were designed to accomplish the following objectives.

- 2.1 Determine the individual average errors for drift; linearity, and crosstalk from which the overall system error is calculated.

- 2.2 Determine the overall system error which is defined as follows:

$$E_s = \sqrt{\bar{E}_D^2 + \bar{E}_L^2 + \bar{E}_C^2}$$

where: E_s = overall system error for the five channels as a percent of full scale deviation.

$\bar{E}_D^2$ = mean square value obtained by combining the long and short term full scale drift and zero shift values.

$\bar{E}_L^2$ = mean square value reflecting deviations from a straight line fit relating the measured outputs and the known inputs for the linearity measurements.

$\bar{E}_C^2$ = mean square value calculated from crosstalk measurements.

3.0 SUMMARY

- 3.1 The average errors for drift, linearity, and crosstalk are as follows:

Drift $E_D = 0.396\%$

Linearity $E_L = 0.184\%$

Crosstalk $E_C = 0.144\%$

- 3.2 The average system error (E_s) for all five channels tested is 0.45%.

- 3.3 The values given above in 3.1 and 3.2 are RMS values. As such, these values are standard deviations, i.e., approximately 68% of randomly observed outputs would agree within the percentage given.

If a greater percentage of agreement of random observations is to be considered, then the above values must be multiplied by a factor to reflect the percentage desired. For example, the factor for 95% agreement is approximately 2, and for 99% is approximately 2.6.

4.0 TEST DESCRIPTION

4.1 NRX Data Room System Description

The system block diagram is given in Figure 2. Data on magnetic tape are used as inputs to the system. In the "Direct" mode of operation (normal for NRX data), these data are in the form of composite FM signals and are routed to a discriminator bank. Here, each composite signal is separated into its FM components, demodulated to its analog signals and passed along to either a quick look recorder, the Westinghouse Wide Band Data Converter, or both. Facilities exist which allow low-pass (anti-aliasing) filtering of the converter system input signal. The output of the converter (a series of digital signals) is fed to an IBM-729 VI tape recorder, where it is put on 1/2 inch magnetic tape. This tape can be played back directly into an IBM-7094 (or similar computer) for analysis. If the system input is a single FM signal rather than a composite FM signal, it may be routed past the discriminator banks. The system is also capable of on-line real-time operation.

4.1.1 Discriminators

The discriminators are grouped in banks of five, and operate on an input signal of 10 millivolts to 10 volts. This bank utilizes Data Controls System GFD-5 discriminators with 100KC tape speed compensation, separating and discriminating the composite FM signal into its component signals which are reproductions of the data signals. Data signal bandwidths corresponds to the following Inter-Range Instrumentation Groups (IRIG) channels:

TABLE I
IRIG BANDWIDTHS

<u>Channels</u>	<u>Frequency</u>	<u>Bandwidth</u>
14	22 KC $\pm$ 7.5%	330 cps
15	30 KC $\pm$ 7.5%	450 cps
16	40 KC $\pm$ 7.5%	600 cps
17	52.5 KC $\pm$ 7.5%	790 cps
18	70 KC $\pm$ 7.5%	1050 cps

4.1.2 Digitizing and Formatting

The rate of sampling or multiplexing is 3050 samples per second (to be increased to 3200 in the near future) per data channel. The input can be so arranged as to sample one channel as fast as 15250 samples per second (16000 in the future). Other sampling rates between these two limits are available. An increase in sampling rate is accompanied by a decrease in the number of channels which can be sampled simultaneously. The converter unit can accept a maximum of five data channels and one timing signal as input.

The final section of the converter unit is the tape formatting section. This section prepares the digital output from the converter into gapped tapes, using an 11-bit-plus-sign digital output acceptable by the IBM-7094 and other computers. Figure 3 illustrates the tape format used.

A more detailed description of the WANL Wide Band Data Converter facility is given in Appendix B.

4.2 Test Setup and Procedure

4.2.1 Drift Test

In order to check the system drift an exact calibration was performed to establish values for comparison. A Vidar 820B Oscillator was used, and its output amplitude was adjusted to .3V RMS. This signal was applied to the input jack of the discriminator bank using a center frequency corresponding to one of the five IRIG channels (see Table I). The output of the discriminator was monitored with a Fluke differential voltmeter and the discriminator zero control potentiometer was adjusted until the output voltage of the channel being tested was 0 ± 10 mv. This same procedure was used for each IRIG channel from 14 to 18. The procedure was then repeated for each of the upper and lower bandedge frequencies for each IRIG channel, and the gain potentiometer was used to adjust the output voltage to full scale. (Normal full scale digitizer output is set at 9 volts to allow some tolerance for signals in excess of full scale, which occasionally occur in data received from NRDS.) The system was then allowed to digitize for one hour. Using the same voltmeter, deviations from the original settings for each upper and lower bandedge frequency and center frequency were recorded as short term drift and short term zero shift. Long term drift was obtained in a similar manner except that the system was allowed to digitize for 15 hours after initial calibration.

4.2.2 Linearity Test

Signals from a specially-prepared tape were applied to the input jack of the discriminators. This tape contained frequencies which correspond to the entire signal band covered by each IRIG channel

in sequence from channels 14 through 18. As the frequency band of each channel was covered in increments of frequency, the corresponding digital output values of the converter system were recorded.

4.2.3 Crosstalk Test

To measure the effects of crosstalk, a special test tape was made and applied as the input to the discriminators. The tape was made so that the input signal to channel 14 (for example) was modulating from its lower to upper bandedge ($22\text{KC} \pm 7.5\%$) while simultaneously the other four channels were held at their specific center frequencies. The cross-coupling effect on each of the adjacent four channels caused by the modulating AC on channel 14 was recorded (in octal units) at the output of the converter system. The next section of the test tape was applied to channel 15, modulating the input signal $30\text{KC} \pm 7.5\%$, and the cross-coupling effects recorded on channels 14, 16, 17, and 18. The test was repeated in a similar manner for each of the remaining channels.

5.0 DATA ANALYSIS AND PRESENTATION

5.1 Drift

Table II (Appendix A) lists the measured data and the calculations for the five channels for (A), the short term, and (B), the long term drift. Each of the five values of measured data was squared; and the mean square value of the combined full scale and zero error for the short and long term drift obtained in column 5. It should be noted that the $\bar{s}^2$ drift values shown in columns 1, 2, and 4 are negligible in comparison with the long term full scale value in column 3. The full scale long term drift values were measured after the

discriminators were energized for a period of 15 hours after an exact calibration. During normal wide band data reduction, the discriminators are recalibrated at the beginning of each 8 hour shift. Thus, the drift figures obtained are probably higher than would be obtained in actual operation.

5.2 Linearity

Table III (Appendix A) is the tabulated linearity test data. The octal read-out was converted to voltage in column 3 (each octal bit corresponds to .005V). Table IV (Appendix A) shows the calculations for the statistical method used to determine the linearity. Since the increment of the applied frequencies was not equal for each IRIG channel, the analysis of the linearity was based on the evaluation of the relationship of two variables, frequency input versus voltage output. The mean square value for the five channels was obtained and is denoted by the symbol E_L^2 .

5.3 Crosstalk

Table IV (Appendix A) lists the four crosstalk values in millivolts for each IRIG channel tested. The table also illustrates the analysis of variance technique and calculations used to obtain the mean square value indicated by E_C^2 .

5.4 System Error

The overall system error was calculated as shown in section 2.2. The individual percentage values shown in section 3.1 for drift, linearity, and crosstalk were obtained by taking the square root of the separate $\bar{s}^2$ values and dividing each by the 9 volt full scale value.

6.0 CONCLUSIONS

The WANL Wide Band Data Converter exhibits an inaccuracy of 0.45% (one sigma level) on data digitized from analog tape. Included in this figure are the individual contributions for drift, linearity, and crosstalk for the entire system from analog tape to digital output.

CONVERSION SYSTEM
FIGURE 1

SYSTEM BLOCK DIAGRAM

FIGURE 2

TIME CODE FORMAT

FIGURE 3

ONE PER BLOCK												50 SUCH DATA GROUPS PER BLOCK															
3/4" tape gap	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	d	d	d	d	d	d	d	d	d	d	P _h	M ₃₂	S ₁	D ₁	S ₂	D ₂	S ₃	D ₃	S ₄	D ₄	S ₅	D ₅	P _h	M ₃₂	S ₁		
	d	d	d	d	d	d	d	d	d	d	P _h	M ₁₆	D ₁	D ₁	D ₂	D ₂	D ₃	D ₃	D ₄	D ₄	D ₅	D ₅	P _h	M ₁₆	D ₁		
(one per block)	T ₈	T ₈	T ₈	T ₈	T ₈	T ₈	C ₈₀₀	C ₈₀	C ₈	d	d	P _h	M ₈	D ₁	D ₁	D ₂	D ₂	D ₃	D ₃	D ₄	D ₄	D ₅	D ₅	P _h	M ₈	D ₁	
	T ₄	T ₄	T ₄	T ₄	T ₄	T ₄	C ₄₀₀	C ₄₀	C ₄	d	d	P _h	M ₄	D ₁	D ₁	D ₂	D ₂	D ₃	D ₃	D ₄	D ₄	D ₅	D ₅	P _h	M ₄	D ₁	
	T ₂	T ₂	T ₂	T ₂	T ₂	T ₂	C ₂₀₀	C ₂₀	C ₂	d	d	P _h	M ₂	D ₁	D ₁	D ₂	D ₂	D ₃	D ₃	D ₄	D ₄	D ₅	D ₅	P _h	M ₂	D ₁	
	T ₁	T ₁	T ₁	T ₁	T ₁	T ₁	C ₁₀₀	C ₁₀	C ₁	d	d	P _h	M ₁	D ₁	D ₁	D ₂	D ₂	D ₃	D ₃	D ₄	D ₄	D ₅	D ₅	P _h	M ₁	D ₁	

Tens of Thousands of Seconds
 Thousands of Seconds
 Hundreds of Seconds
 Tens of Seconds
 Seconds
 Tenths of Seconds
 100's digit, channel no.
 10's digit, channel no.
 1's digit, channel no.

Total block length = 612 characters
 d = dummy bit

Scan number
 Data point 1
 Data point 2
 Data point 3
 Data point 4
 Data point 5
 Horizontal parity
 Scan number

P = vertical parity bit

P_h = horizontal parity bit

W-2 DIGITAL TAPE FORMAT

FIGURE 4

APPENDIX A

SAMPLE CALCULATIONS

TABLE I

This table is shown in section 4.1.1.

TABLE II

This table is discussed in section 5.1.

TABLE III

This table is discussed under Table IV.

TABLE IV

The following will explain the computations of Table IV. The dependent variable is voltage. Steps 1 through 4 (of Table IV) are associated with the voltage values in the various column 3's of Table III (one column for each channel). Step 1, Table IV, ΣY , is the algebraic sum of the voltage values of each column 3, Table III. Step 2, Table IV, ΣY^2 , is the algebraic sum of the squares of each voltage value in each column 3, Table III. Step 3, $(\Sigma Y)^2/11$, the correction factor, is obtained by squaring ΣY and dividing by 11, the number of paired values, in columns 1 and 3, Table III. Step 4, Table IV, $\Sigma (Y - \bar{Y})^2$, is obtained by subtracting the values of step 3 from those of step 2.

The independent variable is frequency. The calculations for steps 5 through 8 of Table IV are made as indicated above for steps 1 through 4, using the frequency values from column 1 of Table III.

Step 9, Table IV, ΣXY , is the algebraic sum of the products of frequency and voltage from Table III. For example, from Table III, the channel 14 frequency value of

22000 cps (column 1) is multiplied by the voltage value of +.015 volts (column 3). This product is algebraically added to the next product, 22300 cps x -1.630 volts. The algebraic sum for channel 14 is shown in step 9 of Table IV.

The balance of this discussion deals with Table IV. Step 10, $(\Sigma X)(\Sigma Y)/11$, is obtained by multiplying ΣX (241,800) and ΣY (1.220) and dividing this product by 11.

Step 11, $\Sigma(X-\bar{X})(Y-\bar{Y})$ is obtained by subtracting step 10 from step 9. Note the minus sign, i.e., $\Sigma XY - [(\Sigma X)(\Sigma Y)/11]$.

Step 12 is the value obtained in step 4. Step 13 is obtained by squaring the value in step 11, and dividing by the value from step 8 ($[\Sigma(X-\bar{X})(Y-\bar{Y})]^2 / \Sigma(X-\bar{X})^2$). This is known as the sum of the squares (explained) associated with the linear fit.

Step 14 is obtained by subtracting step 13 from step 12 $[\Sigma(Y-\bar{Y})^2 - \text{S.S. (explained)}]$. This is known as the sum of the squares (unexplained).

Step 15 is obtained by dividing step 14 by $n-2$, or 9 (since there are two parameters estimated). This is known as the variance.

Step 16 is the sum of the variances and step 17 is the mean variance value. Similar calculations were performed for channels 15 through 18. (See Table IV.) Comparison of the five channel values from step 15 shows that channel linearity varied from 0.14% (for channel 16) to 0.22% (for channel 14). (These percentages were obtained by taking the square root of the $\bar{s}^2$ value and dividing by the full scale value of 9 volts.) This, of course, correlates with the mean value of 0.184% given in section 3.1.

TABLE V

The following description will explain the computations of Table V. The list of twenty measurements is given in millivolts. The blank in each column indicates the stimulated channel; the resultant level of crosstalk measured in the adjacent four channels appears in the same row. This test was described in section 4.2.3.

Step 1, ΣX_{ij} , is the algebraic sum of the 20 measurements.

Step 2, $\Sigma (X_{ij})^2$, is the algebraic sum of the squares of each measurement.

Step 3, $(\Sigma X_{ij})^2/n$, is obtained by squaring the value of step 1 and dividing by $n = 20$, where n is the number of measurements.

$$\frac{\Sigma (X_{ij})^2}{n} = \frac{-705^2}{20} = \frac{497,025}{20} = 24851.25$$

Step 4, $\Sigma (X_{ij} - \bar{X}_{ij})^2$, is the subtraction of step 3 from step 2.

The analysis of variance has two sources of variation; namely, that due to the controlled factor, between channels, and that due to extraneous effects, within channels. For 20 measurements there are 19 "degrees of freedom". The four degrees of freedom (column B) for between channels are associated with the four independent comparisons between the five channels. The remaining 15 degrees of freedom are related to the variation within channels.

Column C, "Sums of Squares", is the measure of variation attributed to each source of variation. Step 5, column C, the value, 5914.37, is obtained as follows. The sums shown (X_i) for each channel are squared. These squares (X_i^2) are added to give a value of 123,062.5 (ΣX_i^2). This value is divided by four, the number of observations per

channel (N), giving $\Sigma(X_i)^2/N$ (30,765.62). The value $\Sigma(X_i)^2/N - (\Sigma X_{ij})^2$ is then found by subtracting the value (of step 3) 24,851.25, from 30,765.62 giving 5914.37.

Step 6, column C, the value 2509.28 is obtained by subtracting 5914.37 (step 5) from the step 4 value of 8423.75. This number represents $\Sigma(X_{ij} - \bar{X}_{ij})^2 - [\Sigma(X_i)^2/N - (\Sigma X_{ij})^2/n]$.

Column D, "Mean Squares", are average values and are obtained by dividing the values of column C by the values of column B.

The number 167.292 is the average crosstalk variance in millivolts.

REFERENCES

WANL-SP-008, "Notes for a Seminar on Analyzing and Interpreting Industrial Experiments," by Mr. William H. Horton, dated March 1965.

TABLE II
CALCULATIONS AND DATA FOR LONG AND SHORT TERM DRIFT

	(A) Short Term				(B) Long Term			
	(1) Full Scale		(2) Zero Shift		(3) Full Scale		(4) Zero Shift	
	Measured Deviations From Full Scale	s^2 Variances	Measured Deviations From Full Scale	s^2 Variances	Measured Deviations From Full Scale	s^2 Variances	Measured Deviations From Full Scale	s^2 Variances
14	0	0	.001	1×10^{-6}	.03		-.081	
15	.001	1×10^{-6}	0	0	-.028		.054	
16	0	0	-.002	4×10^{-6}	0		.060	
17	.003	9×10^{-6}	0	0	.123		.013	
18	0	0	.002	4×10^{-6}	.087		-.014	
$\Sigma s^2 =$		10×10^{-6}		9×10^{-6}		.024382		.013442
$\bar{s}^2 = \Sigma s^2 / N =$		2×10^{-6}		1.8×10^{-6}		4876×10^{-6}		2.69×10^{-6}

(5)
 $\Sigma \bar{s}^2$

Short Term Full Scale	2×10^{-6}
Long Term Full Scale	4876×10^{-6}
Short Term Zero Shift	1.8×10^{-6}
Long Term Zero Shift	2.7×10^{-6}
$\Sigma \bar{s}^2$	4882.5×10^{-6}

$$\Sigma \bar{s}^2 / n = \bar{s}^2 = 1220.62 \times 10^{-6} = \underline{\underline{0.00122}} = E_D^2$$

N = Number of readings taken.
n = Number of means.

TABLE III
SYSTEM LINEARITY TEST DATA

14			15			16			17			18		
Discriminator Frequency Input cps	Octal Readout *	Digital Conversion volts	Discriminator Frequency Input cps	Octal Readout *	Digital Conversion volts	Discriminator Frequency Input cps	Octal Readout *	Digital Conversion volts	Discriminator Frequency Input cps	Octal Readout *	Digital Conversion volts	Discriminator Frequency Input cps	Octal Readout *	Digital Conversion volts
20350	+3410	9.0	+27750	3412	9.01	37000	+3410	9.0	48560	+3410	9.0	64750	+3410	9.0
20700	2606	7.07	28200	2642	7.21	37600	2637	7.195	49300	+2667	7.315	65800	+2636	7.19
21000	2102	5.45	28700	2013	5.175	38200	2067	5.395	50100	+2107	5.485	66850	2070	5.4
21300	1371	3.805	29100	1307	3.555	38800	1317	3.595	50900	+1327	3.675	67900	1323	3.655
21700	0512	1.650	29600	0467	1.555	39400	0543	1.775	51700	+0546	1.79	68900	+0572	1.89
22000	+0003	+ .015	30000	-0006	- .03	40000	0000	0	52500	-0007	- .035	70000	+0004	+ .02
22300	-0506	-1.630	30400	-0520	-1.68	40600	-0553	- 1.815	53200	-0512	-1.65	71000	-0523	-1.695
22600	-1216	-3.27	30900	-1334	-3.66	41200	-1320	-3.64	54000	-1273	-3.495	72100	-1312	-3.560
22900	-1726	-4.91	31300	-2035	-5.265	41800	-2074	-5.42	54800	-2050	-5.32	73100	-2042	-5.29
23300	-2577	-7.035	31800	-2657	-7.275	42400	-2642	-7.21	55600	-2633	-7.175	74200	-2632	-7.17
23650	-3371	-8.925	32250	-3424	-9.06	43000	-3410	-9.0	56440	-3430	-9.08	75250	-3400	-8.96

*Each octal bit corresponds to 0.005 volts.

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TABLE IV
LINEARITY TEST
CALCULATIONS FOR THE LINEAR RELATIONSHIP
BETWEEN THE VARIABLES FREQUENCY AND VOLTAGE

		Channels 14	15	16	17	18
Volts	Steps					
	1 ΣY	1.220	-0.465	-0.125	.510	.480
	2 ΣY^2	344.492900	353.949225	356.853025	358.472350	354.008850
	3 $(\Sigma Y)^2/11$	<u>.135309</u>	<u>.019657</u>	<u>.001420</u>	<u>.023645</u>	<u>.020945</u>
	4 $\Sigma (Y - \bar{Y})^2$	344.357591	353.929568	356.851605	358.448705	353.987905
Freq.	5 ΣX	241800	330000	440000	577100	769850
	6 ΣX^2	5326865000	9921925000	17639600000	30344637200	53999967500
	7 $(\Sigma X)^2/11$	<u>5315203636</u>	<u>9900000000</u>	<u>17600000000</u>	<u>30276764540</u>	<u>53879002040</u>
	8 $\Sigma (X - \bar{X})^2$	11661364	21925000	39600000	67872660	120965460
	9 ΣXY	-36551.2500	-102040.0000	-123875.0000	-129220.2000	-173336.5000
	10 $(\Sigma X)(\Sigma Y)/11$	<u>26817.8182</u>	<u>-13950.0000</u>	<u>-5000.0000</u>	<u>26756.4545</u>	<u>33593.4545</u>
	11 $\Sigma (X - \bar{X})(Y - \bar{Y})$	-63369.0682	-88090.0000	-118875.0000	-155976.6545	-206929.9545
	12 Total S.S.*	344.357591	353.929568	356.851605	358.448705	353.987905
	13 Linear S.S.*	<u>344.354126</u>	<u>353.926937</u>	<u>356.850142</u>	<u>358.446490</u>	<u>353.985394</u>
	14 Residual S.S.*	.003465	.002631	.001463	.002215	.002511
	15 s^2	.000385	.000292	.000162	.000246	.000279
	16 $\Sigma s^2 =$	.001364				
	17 $\bar{s}^2 =$	<u>.000273</u>	$= E_L^2$			

*S.S. = Sums of Squares

TABLE V
ANALYSIS OF CROSSTALK VARIANCES

	Measured Data in Millivolts				
	14	15	16	17	18
Crosstalk Value Obtained with Full Scale on Channel 14	---	+15	-20	-40	-60
Crosstalk Value Obtained with Full Scale on Channel 15	-22.5	---	-30	-40	-60
Crosstalk Value Obtained with Full Scale on Channel 16	-40	-10	---	-40	-57.5
Crosstalk Value Obtained with Full Scale on Channel 17	-45	-30	-10	---	-60
Crosstalk Value Obtained with Full Scale on Channel 18	<u>-57.5</u>	<u>-30</u>	<u>-10</u>	<u>-57.5</u>	<u>---</u>

Calculations

Step 1	ΣX_{ij}	= -705	-165.0	-55	-70	-177.5	-237.5
Step 2	$\Sigma (X_{ij})^2$	= 33275.00					
Step 3	$(\Sigma X_{ij})^2/n$	= <u>24851.25</u>					
Step 4	$\Sigma (X_{ij} - \bar{X}_{ij})^2$	8423.75					

	(A) Source of Variance	(B) Degrees of Freedom	(C) Sums of Squares	(D) Mean Squares (Variances)
Step 5 $\Sigma (X_j)^2/N - (\Sigma X_{ij})^2/n$	Between	4	5914.37	1478.597
Step 6 $\Sigma (X_{ij} - \bar{X}_{ij})^2 - [\Sigma (X_j)^2/N - (\Sigma X_{ij})^2/n]$	Within	15	2509.38	167.292
Step 7 $s^2 = 0.000167 \text{ volts} = E_C^2$				

APPENDIX B

WIDE BAND DATA CONVERSION SYSTEM

I. INTRODUCTION

The following is a description of the Westinghouse Astronuclear Laboratory Wide Band Data Conversion System. Also included is an explanation of how the components of this system are integrated to give successful operation and to produce valid, reliable data. (See Figure 2.)

Data on magnetic tape are used as inputs to the system. In the "Direct" mode of operation, these data are in the form of composite FM signals and are routed to a discriminator bank. Here, each composite signal is separated into its FM components, demodulated to its analog signals and passed along to either a quick look recorder, the analog to digital converter, or both. Facilities exist which allow low-pass (anti-aliasing) filtering of the A to D converter input signal. The output of the A to D converter (a series of digital signals) is fed to an IBM-729 VI tape recorder, where it is put on 1/2 inch magnetic tape. This tape can be played back directly into an IBM-7094 (or similar computer) for analysis. If the system input is a single FM signal rather than a composite FM signal, it may be routed past the discriminator banks. The system is also capable of on-line real-time operation.

II. INPUT

A Consolidated Electrodynamics Corporation VR-2800 data tape unit is available and may be used to supply input data to the system. This unit is capable of operating with standard one inch tapes on 10-1/2 or 14 inch reels at the following speeds: 1-7/8 ips, 3-3/4 ips, 7-1/2 ips, 15 ips, 30 ips, and 60 ips. A maximum of 14 tracks of information can be recorded on each tape. Each track, however, can contain many channels of data in FM multiplexed form.

A. Discriminators

During normal operation, a single track of composite FM signal is played back into one of two discriminator banks. Playback amplifiers boost the tape output signals to a usable level. These signals are then applied to a variable attenuator unit which provides a means of reducing the signals to the level most suitable for optimum discriminator operation.

The discriminators operate on an input signal of 10 millivolts to 10 volts. This bank utilizes Data Controls System GFD-5 discriminators with tape speed compensation and separates the composite FM signal into its component FM signals, each with its own center frequency. These center frequencies correspond to the following Inter-Range Instrumentation Group (IRIG) channels:

<u>Channel</u>	<u>Frequency</u>
14	22 KC $\pm$ 7.5%
15	30 KC $\pm$ 7.5%
16	40 KC $\pm$ 7.5%
17	52.5 KC $\pm$ 7.5%
18	70 KC $\pm$ 7.5%

The discriminator bank uses the following IRIG channels for reducing timing signals (ROVER format, or similar) which may be on the input data tape:

<u>Channel</u>	<u>Frequency</u>
C	40 KC $\pm$ 15%
E	70 KC $\pm$ 15%
16	40 KC $\pm$ 7.5%
18	70 KC $\pm$ 7.5% (Modulated at 1 KC)

B. Tape Speed Compensation

Three separate 100KC tape compensation units are available for use on both the timing and data channels if needed. The tape compensation units will remove any error which might arise from tape speed variation. For these compensators to function, a 100 KC signal must be superimposed on each track of data and timing during the recording. A maximum error in tape speed of 3% (far in excess of the normal error) can be corrected by these units. The signals from the discriminators pass to the quick look facility and to the converter complex in parallel. These units may be employed simultaneously or separately.

III. OSCILLOGRAPHIC OUTPUT

The quick look facility consists of three parts, the first of which is the oscillograph control chassis. This unit can be used to short out or attenuate signals from the discriminator bank. The second part of the quick look facility is the galvanometer driver-amplifier section. This section causes the galvanometers to appear as high input impedance devices to the preceding circuitry while supplying the current necessary to drive the galvanometers. The last part of the quick look facility is a Consolidated Electrodynamics Corporation 5-133 data oscillograph. This is a light beam, galvanometer-driven oscillograph with channel capability for 35 channels of data. Twelve inch light sensitive paper is used as the record in this oscillograph. The following paper speeds are available: 1, 4, 8, and 16 in/sec with multipliers of .1, 1, and 10. Any record made on this oscillograph may be processed for a permanent record. This capability is available at WANL.

Because of the size of the paper and the limiting number of galvanometer drivers available, the present capability of the quick look facility is 12 channels of recorded information.

IV. ANALOG TO DIGITAL CONVERTER COMPLEX

A. Filter Section

The converter complex is separated into two sections. The first of these is the anti-aliasing filter control unit. This unit contains low-pass filters which attenuate to a maximum of 120 db, any frequencies above the cutoff value of the filter. The filters are tunable with cutoff frequencies from 1 cps to 1000 cps. There are six filters in the system, one for each discriminator output (including timing). Any combination of cutoff frequencies can be employed, and any or all of the filters can be by-passed if necessary or desirable. In addition, a gain of 1 or 10 can be applied to any and all of the signals passing through this system.

B. Analog to Digital Converter Section

The final section of the converter complex (and the central point of the Data Room operations) is the A to D converter unit. This unit samples the analog data from each discriminator channel at high speed and produces a digital pulse train containing the same information.

1. Sampling Rate

The converter can accept as input a maximum of 5 data channels and one timing signal. The rate of sampling or multiplexing is 3050 samples per second (to be increased to 3200 in the near future) per data channel. The input can be so arranged as to sample one channel as fast as 15250 or (5×3050) samples per second (16000 in the future). Other sampling rates between these two limits are available. An increase in sampling rate is accompanied by a decrease in the number of channels which can be sampled simultaneously.

2. Input Voltage Levels

Any data input signal applied to the converter must have a minimum voltage peak level of 1/2 volt. No peak voltage greater than a 10 volt maximum is acceptable. Timing signals supplied to the converter must have at least a minus 3 volts level to represent a pulse and a zero volt level to represent the absence of a pulse.

3. Automatic Timing

The converter can operate properly with either of two types of timing, automatic time or manual time. If the timing is automatic, the converter merely reads the unmodulated timing signal (which must be in ROVER or similar format, see Figure 3) until a preset start time is reached. At this time the converter begins to digitize the incoming analog data signal and does not stop until a preset stop time is reached. The digitized output tape records a running time corresponding exactly to the unmodulated time used as an input to the converter.

4. Manual Timing

Although automatic timing requires the presence of an unmodulated time signal, manual timing can be used whether the unmodulated time signal is present or not. As the name implies, manual timing requires an operator to start and stop the digitizing when he desires. A notation on the output tape describing the manual time (as present on the front panel) is made.

5. Output and Format Information

For every sample of analog data input signal an output of 12 binary pulses (11 bits plus sign) is applied to the IBM-729 VI tape unit. The

corresponding conversion accuracy is $\pm .05\%$. The resulting tapes will contain data which will have associated with it the proper sequence of time, channel identification (3 digits entered manually) and a scan number. The format of this tape, as shown in Figure 4, consists of 50 data groups per block (one group is equal to one complete multiplexer scan). Sixty-one blocks of digital data are generated each second on digital tape. This satisfies the IBM tape unit input requirements when writing on tape at a density of 556 bits per inch and a speed of 112.5 inches per second.