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THE METEOROLOGICALLY INSTRUMENTED WKY-TV TOWER FACILITY

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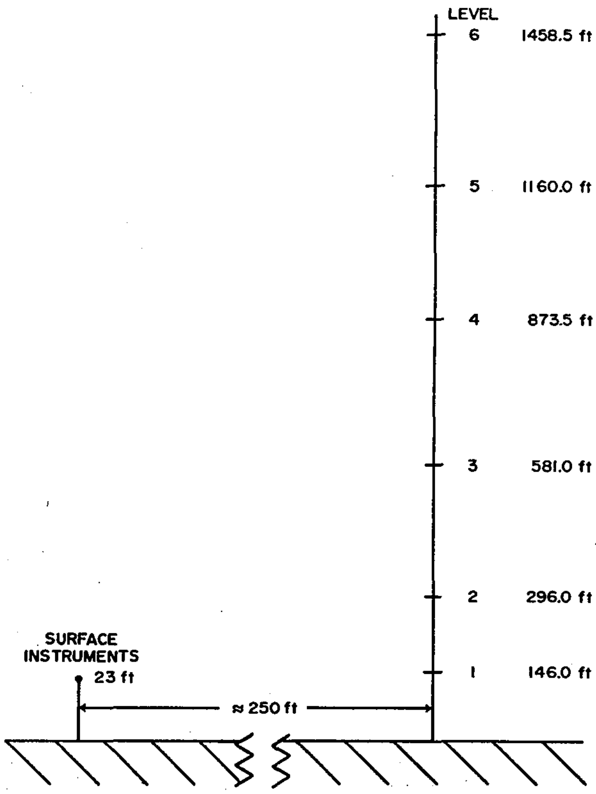

Figure 1. Tower positions and instrument locations for the main 1500 ft tower and the small 23 foot surface tower.

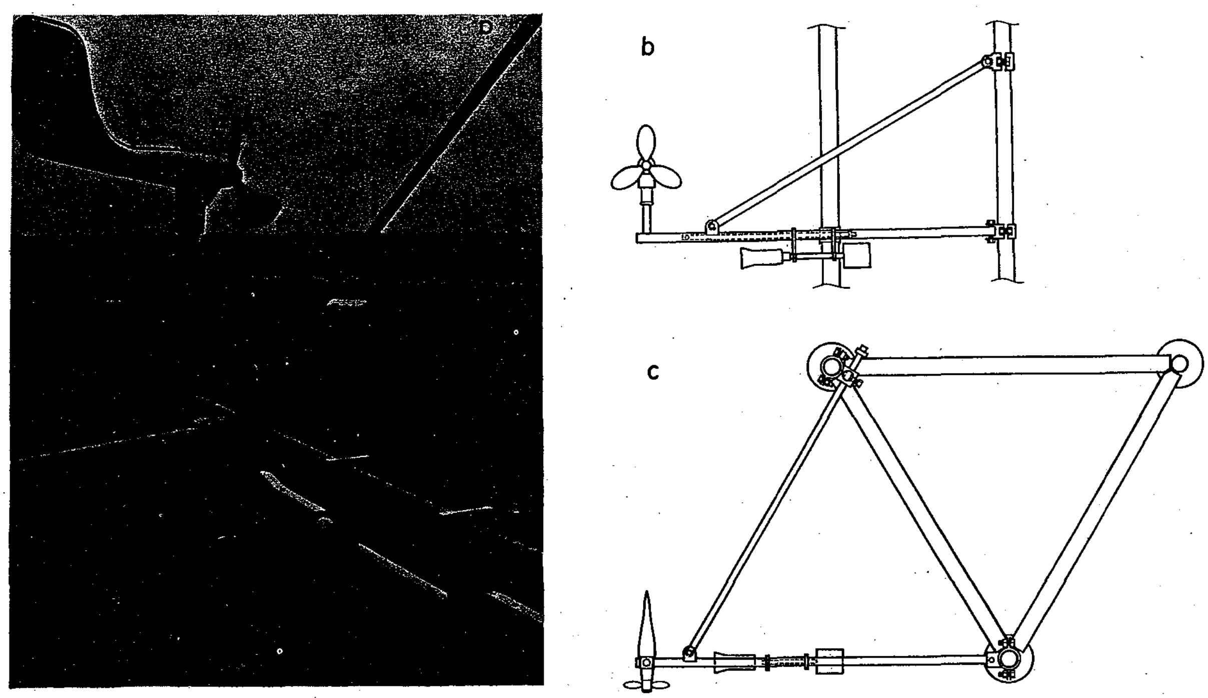

Figure 2: a- Tower boom assembly showing the aerovane and aspirated temperature shield; b and c- side and top views of boom assembly.

THE METEOROLOGICALLY INSTRUMENTED WKY-TV TOWER FACILITY

John K. Carter

Documentation of the meteorologically instrumented WKY-TV tower facility at Oklahoma City is presented. All meteorological instruments are described, and a summary of instrument response characteristics helpful to the data user is included. Data recording equipment and operational procedures are also specified.

1. INTRODUCTION

This report documents the instrumentation and data recording equipment installed and operated by NSSL personnel at the meteorologically instrumented WKY-TV tower facility. As an R & D facility the installation is continually being improved and updated; however, work at the facility and analysis of the data have now progressed sufficiently to warrant documentation. The location of the tower and characteristics of the surrounding terrain were presented in detail by Sanders and Weber (1970).

Instruments are mounted 23 feet high on a small surface tower and at 146.0, 296.0, 581.0, 873.5, 1166.0, and 1458.5 feet on the 1500-foot TV tower. Horizontal wind and temperature instruments are installed at all seven levels. Vertical wind component measurements are made at the 1458.5 foot level on the TV tower. Other instruments at the surface station measure relative humidity, pressure, rainfall, and total sky radiation. Instrument placement and tower positions are shown in figure 1.

2. INSTRUMENTATION

2.1 Horizontal Wind Measurement

Horizontal wind speed and direction are measured at all seven instrumented tower levels. The wind instrument, Bendix Model 120 aerovane unit, is mounted 10 feet from the tower on a boom attached to the tower, as shown in figures 2a and 2b. The boom member on which the aerovane is mounted is aligned to an azimuth

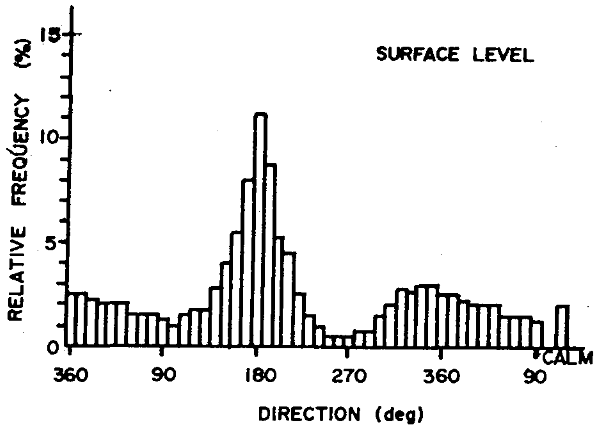

Figure 4. Distribution of wind directions at the WKY-TV surface site during 1966 (Crawford and Hudson, 1970).

Figure 6a illustrates the response characteristics of various anemometers to sinusoidal wind gusts as a function of gust wavelength. From the graph, the aerovane unit measures at least 90% of the peak amplitude of a sinusoidal gust if its wavelength is 200 feet (13 times its distance constant) or greater. Figure 6b shows the aerovane information of figure 6a transformed to coordinates of average speed and gust period. Since this anemometer is a first-order mechanical system, it never overestimates speed gusts but may underestimate gust amplitudes depending upon their periods.

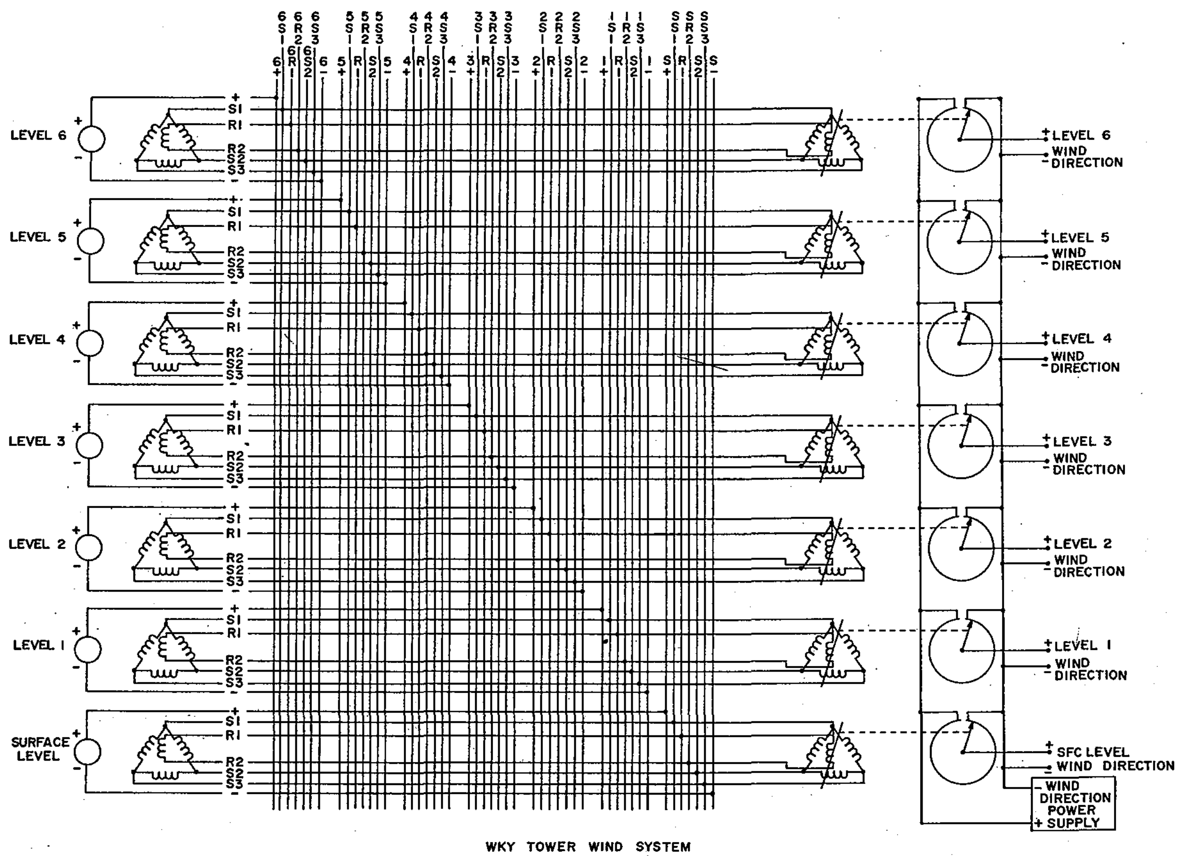

Figure 5. Wiring details of tower wind system.

angle of 240°. This placement represents a compromise between accuracy in measuring predominant winds and instrument accessibility.

Results of wind tunnel tests (Gill, Olson, and Suda, 1966) on model tower structures similar to the WKY-TV tower are in figure 3. This figure shows the ratio of wind speed measurements through 360° of wind direction made at point Q to a speed measurement made at a point in the wind field not effected by the tower structure. Tower effects on speed measurements become most serious between 350° to 070°. Figure 4 shows the annual frequency distribution of wind directions measured at the tower (Crawford and Hudson, 1970). Although the distribution shows a secondary maximum in the sector having the worst tower effect, the predominant wind direction during local severe storm measurement periods is southerly and therefore not greatly affected by tower structure.

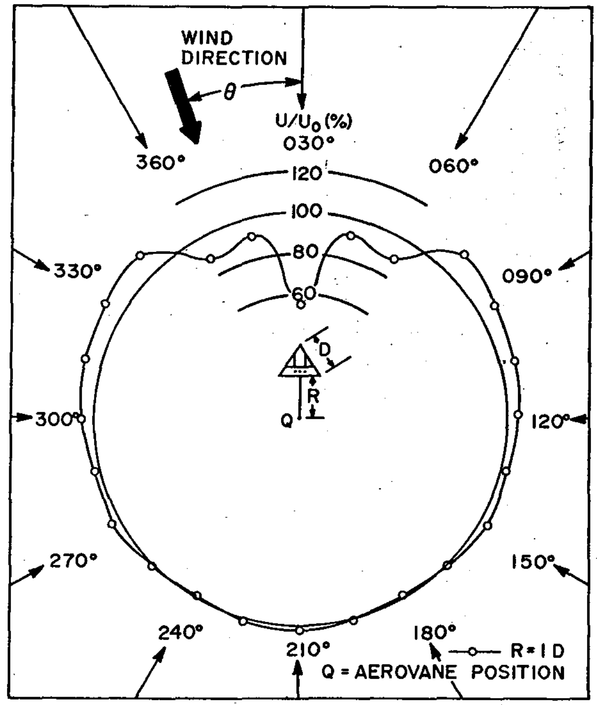

Figure 3. Tower effects on wind speed measurements as a function of wind direction (slightly modified from Gill, Olson, and Suda, 1966).

In the Aerovane Model 120 wind speed information is produced by a propeller-driven DC tachometer generator. Basic characteristics of the speed system are listed in table 1. Figure 5 shows the wiring details of the horizontal wind system.

Table 1. Basic Characteristics of Aerovane Wind Speed Sensor

Transducer: three-blade propeller-driven DC tachometer generator
Speed threshold (Mazzarella, 1954): 1.68 knots (ave.)
Maximum Speed: >100 knots
*Distance Constant (Schubauer and Adams, 1954): 15.3 feet
Output voltage constant: 0.1216 V $knot^{-1}$
Accuracy: ± 0.5 knot

*Distance constant defined as wind passage by the propeller required for the anemometer output to reach 63% of a step speed change.

The aerovane speed measurements are also affected by pitch and yaw of the incident wind vector relative to the propeller axis due to the effects of vane response. Both of these effects (Mazarella, 1954) are proportional to $\cos^2\theta$ (where θ is the angle of pitch or yaw) and are small for small angles. Errors of this nature are very difficult to correct in recorded data and are neglected here.

The aerovane direction vane acts as the prime mover attached to a synchro transmitter unit that converts the vane position information to a three-phase electrical signal for transmission to a remote point. The vane comprises a second-order mechanical system whose step response is defined in terms of the magnitude and angle of attack of an incident wind vector on a stationary vane, as in the following relation (Mazarella, 1954):

$$\theta = \theta_o \, \varepsilon^{-0.042ut} \cos\left[\frac{2\pi u}{40.3}(t) \right] ,$$

where θ = angular displacement of vane from wind vector at time t, θ_o = initial vane displacement, and u = wind speed in feet sec^{-1}.

The vane response is a damped cosine wave, where both the damping coefficient and the vane period are functions of wind speed. Figure 7a shows the time required for oscillations to be damped to 10% of their initial value as a function of the amplitude of the incident velocity vector for a constant initial displacement θ_o.

In nature the instrument never encounters the step function, and in fact, it is difficult to model the wind variation that it does encounter; however, a sinusoidal fluctuation of direction or speed provides a good wind model for estimating the dynamic gust response of the instrument. Figure 7b shows the response of the aerovane to sinusoidal gusts and indicates that the vane theoretically overestimates direction gusts as much as 180% near its natural wavelength. Because the postulated gust function never

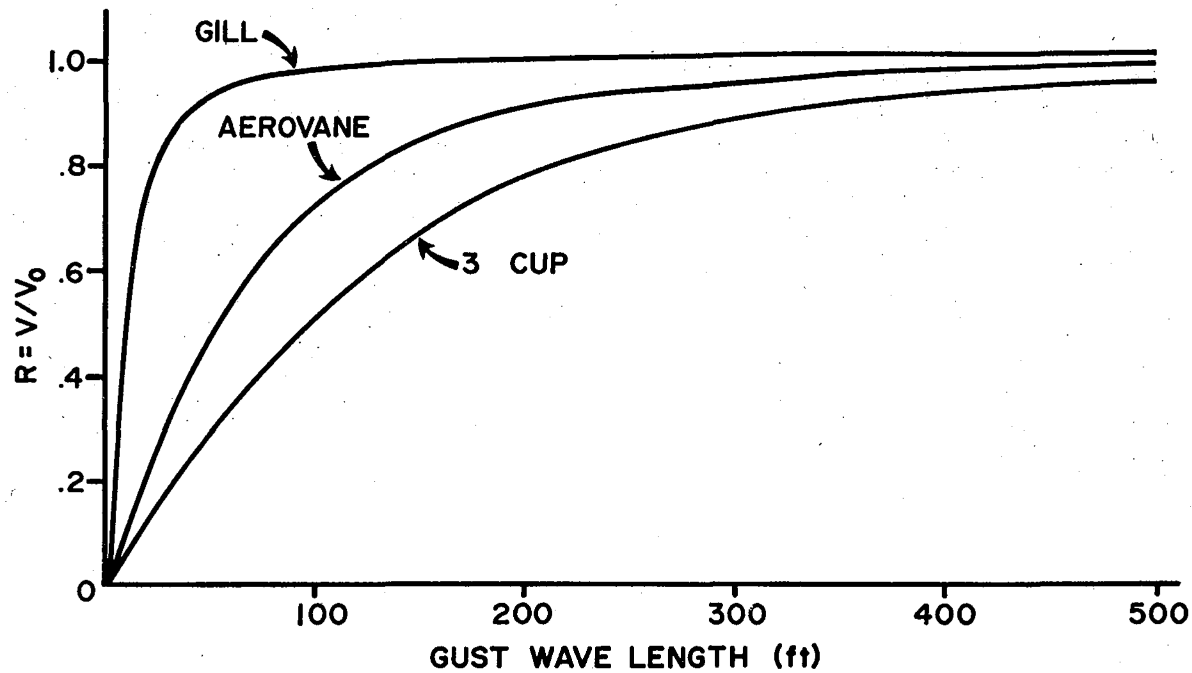

Figure 6a. Fractional anemometer responses to sinusoidal wind speed fluctuations as a function of gust wavelength (Gill, 1965).

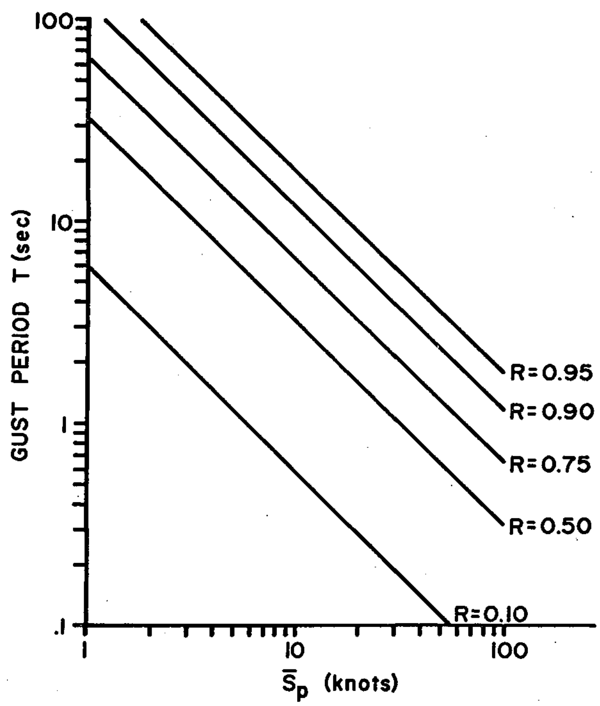

Figure 6b. Fractional response of the Bendix aerovane anemometer as a function of mean wind speed and gust period.

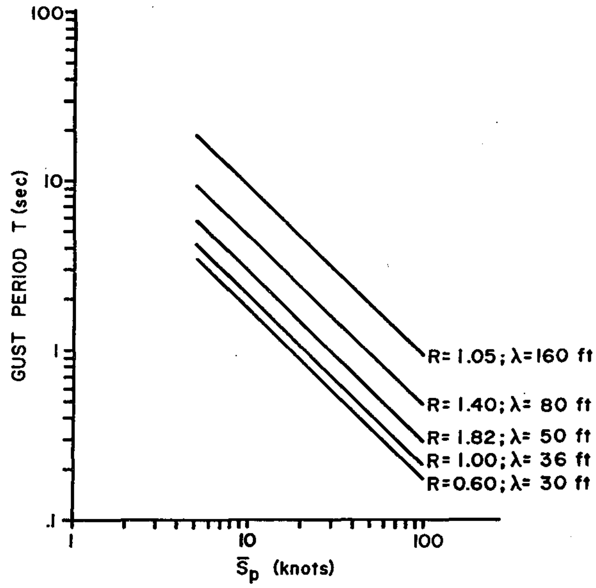

Figure 8. Fractional response R of the Bendix direction vane to sinusoidal direction gusts as a function of mean wind speed and gust period.

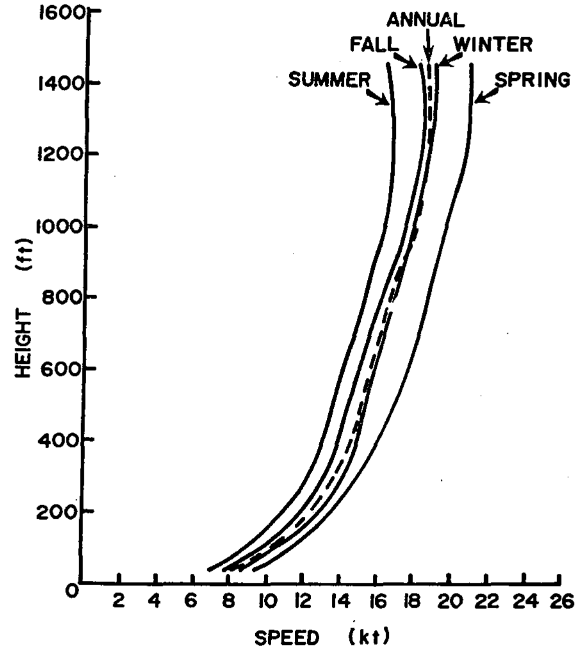

Figure 9. Annual and seasonal vertical profiles of the arithmetic mean wind speed measured at the WKY-TV tower during 1966 (Crawford and Hudson, 1970).

The delta system measures difference temperatures at all levels referenced to the ambient sixth level temperature. The delta system temperature range is ± 10° C from the sixth level reference temperature.

The temperature sensors are Yellow Springs Instrument Company linearized thermistor composites operated in a bridge voltage mode configuration. Figure 10 is a diagram of the basic ambient and delta temperature systems. The primary system thermistor units characteristics are listed in table 2.

Table 2. Thermistor Characteristics

Temperature Range (For specified accuracy)	-30° to +50° C
Linearity Deviation	± 0.05° C
Time Response (63% recovery)	≤ 25 sec
Output Voltage Constant	(10^{-2}) V C^{o-1}

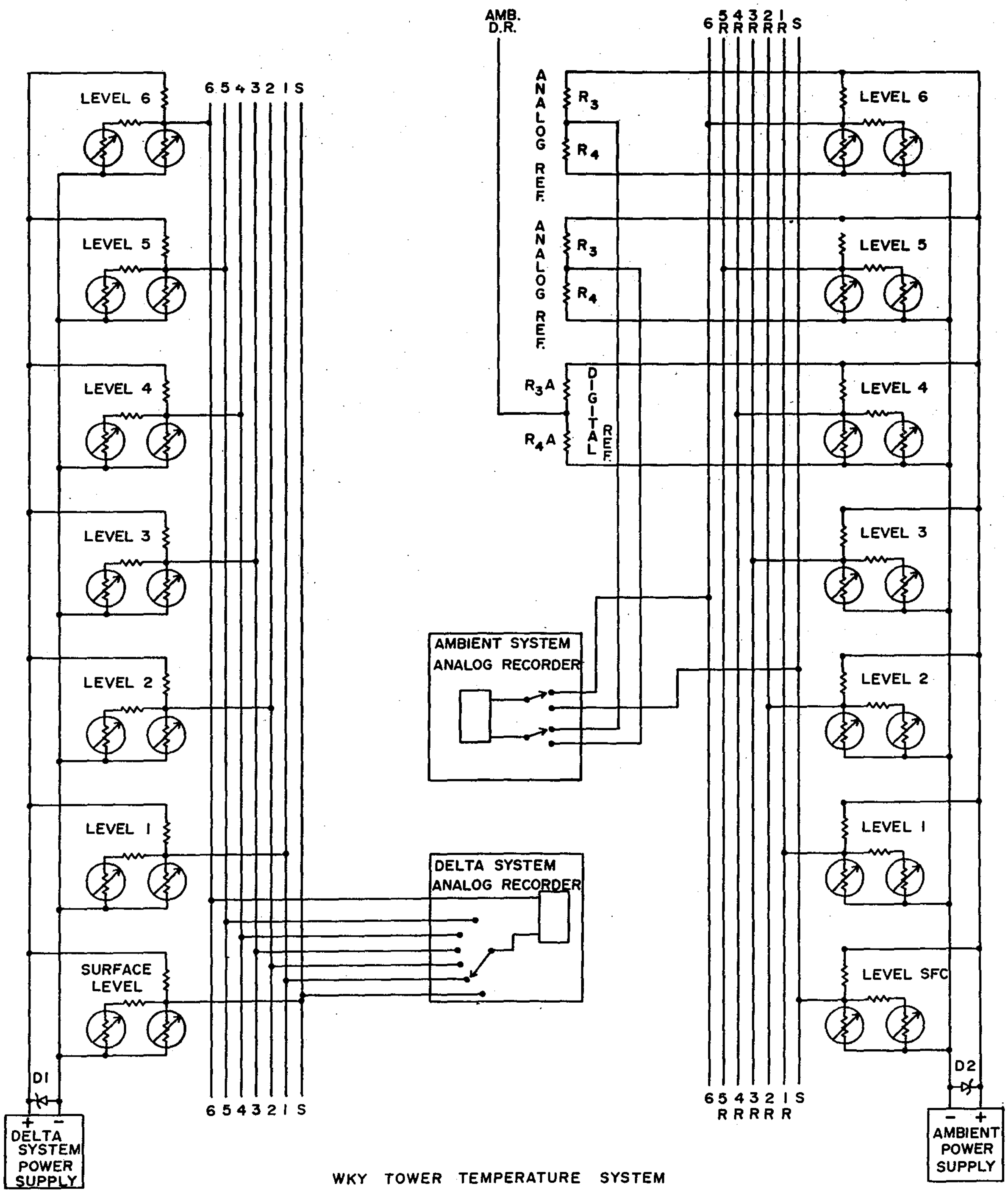

Figure 10. Wiring details of the tower temperature system.

The thermistor composites are housed in heat sink stainless steel probes, which are mounted in Climet model 016-1 motor aspirated radiation shields pictured in figure 2a. This shield provides aspiration for the temperature probe while reducing radiation heating effects to less than 0.11° C. Inflow air passes through a coarse fiber glass filter to trap dust and other unwanted particles. The aspirated shield is mounted on the instrument boom, as described in section 2.1 and figure 2.

The voltage that develops across the thermistor composites is cabled down the tower to the equipment room recording systems. Cable resistances are very small, introducing absolute temperature measurement errors of less than .001° C for worst-case temperature excursions. Cable resistances in the delta system are equalized by adding fixed resistors, so that whatever cable resistances are present are the same for all delta measurements.

The average measured time constant of the thermistor probes in free air is about 30 sec. Figure 11 shows the amplitude response of the thermistor probes compared with sinusoidally varying temperature as a function of the variation period.

The absolute accuracy of the thermistors was found to be within 0.2° C. by comparison tests with a secondary standard glass bulb thermometer. Figure 12 shows each delta thermistor departure from the reference thermistor at level number six. This figure shows delta temperature measurements always to be within ± 0.06° C.

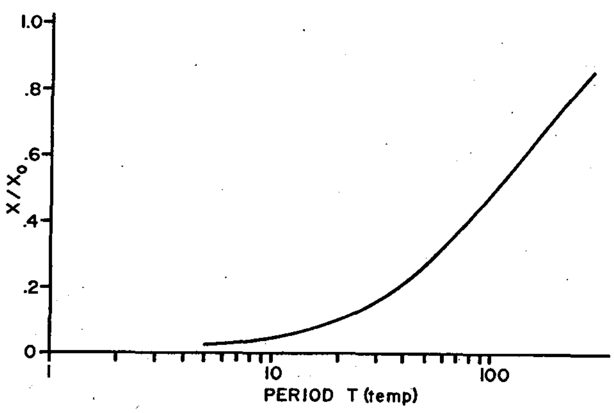

Figure 11. Dynamic response of the thermistor probes to sinusoidal temperature fluctuations.

2.3 Relative Humidity Measurement

The relative humidity (RH) measurement system includes the Phys-Chemical Research Corporation Model PCRC-11 humidity sensor, PT-500 platinum temperature compensation sensor, model PFS stainless steel probe, and type I-1A indicator unit.

The RH sensor is an electric circuit element whose impedance changes as the relative humidity changes. The metallic element is monolithic with a plastic wafer substrate material. The element impedance change is effected by water adsorption.

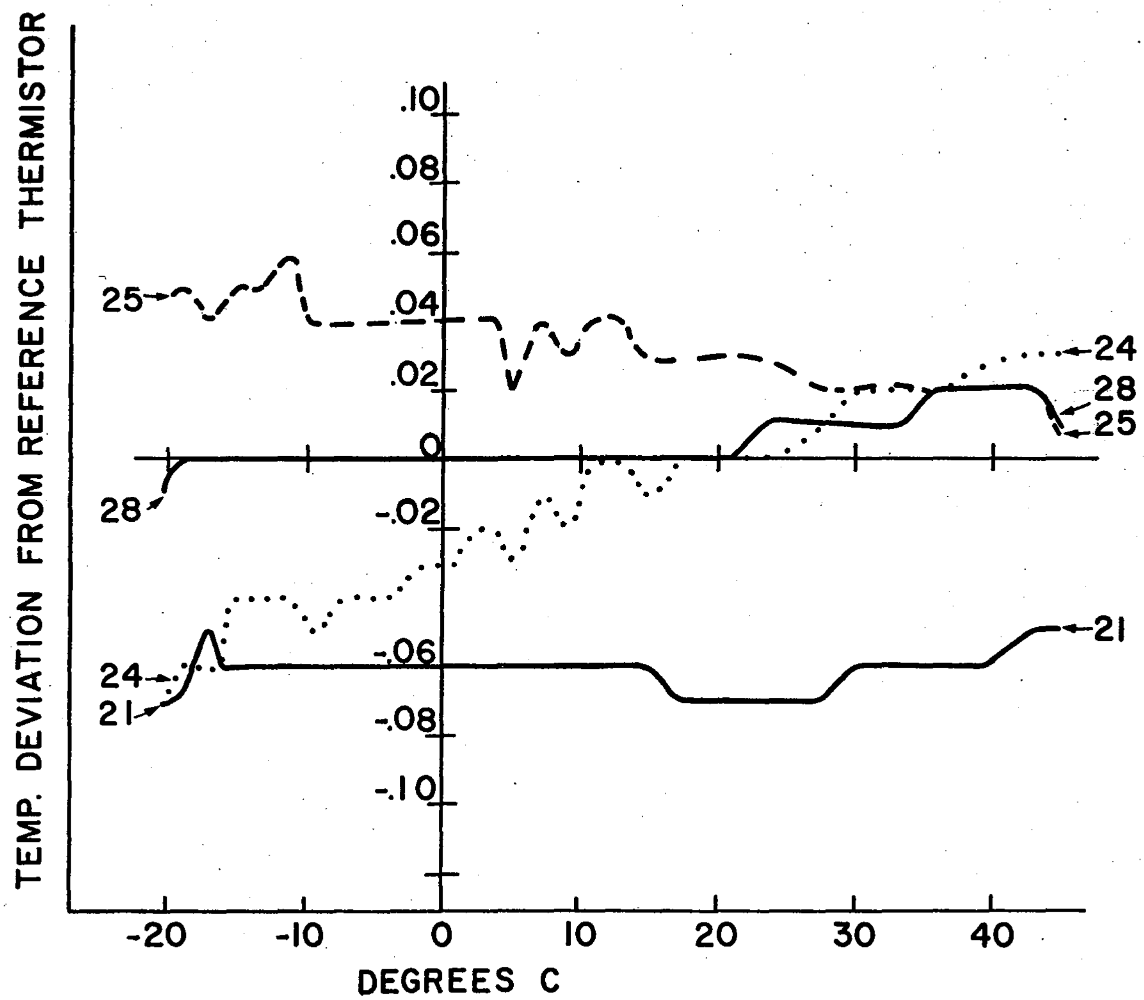

Figure 12. Delta system temperature calibrations.

Because adsorption is a surface adhesion phenomena rather than the diffusion process of absorption, the response time of this adsorbing type material is much faster than the commonly used adsorbing type lithium chloride element. The Phys-Chemical sensor has a time constant of about 30 sec in still air. The sensor as installed at the WKY-TV tower facility is exposed to the ambient air wind providing ventilation which reduces the time constant to about 5 sec for moderate speeds. The system ranges from 0 to 100% relative humidity, with overall accuracy of ± 3%, and is temperature compensated in the range from +5 to +60° C.

The sensor holds its calibration as long as it is not exposed to high concentrations of corrosive contaminants. The substrate material is particularly sensitive to sulfur gases, which decompose it. Measurements in the Oklahoma City area indicate that sulfur gas concentrations rarely if ever exceed 0.1 parts per million.[1] The sensor manufacturer estimates prolonged exposure to concentrations of a few percent would be necessary to cause noticeable substrate decay or sensor decalibration.

2.4 Rainfall Measurement

The rain gauge is a standard universal-recording rain gauge Belfort Model 5-780, 6-in single traverse instrument. The chart recording mechanism was removed and replaced by a gear train and low torque potentiometer. A dc voltage is applied to the potentiometer, and its output is a dc voltage proportional to the collected water. Accuracy is ± 0.5% of full scale with a sensitivity threshold of 0.01 in of precipitation. The rain gauge is located at the surface station adjacent to the tower.

2.5 Pressure Measurement

The pressure instrument used at the tower is the Belfort Model 6068. Changes in pressure are sensed by a bellows that transmits its motion through a system of levers and gears to a low torque potentiometer. A dc voltage is applied to the potentiometer, and its output is a dc voltage proportional to atmospheric pressure. The pressure range for this instrument is 930 to 1085 mb. Absolute accuracy is ± 0.5 mb with a sensitivity of ± 0.2 mb. Due to its restricted pressure range, the instrument is normally operated at the surface station adjacent to the tower.

2.6 Radiation Measurement

An Epply thermopile type 50 junction pyrheliometer is used at the surface near the tower to sense total sun and sky radiation on a horizontal surface. The sensor is the Epply Model No. 8 and is mounted about 15 feet above ground in an area not affected by shadows. The voltage output constant is certified at 7.41 mV per cal-cm^2-min with a linearity of ± 1.5% over the temperature compensated range of -20 to +40° C. The time constant of this instrument is 4 sec. Azimuth response from 10 to 90° is within 2% of the normalized cosine response.

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[1] Personal communication by Mr. Robert Blanche, Okla. St. Health Dept., Pollution Control Center, Okla. City, Okla.

2.7 Vertical Wind Component Measurement

A Gill propeller anemometer model 27100 is installed at level number six on the tower and oriented to measure the vertical component of wind velocity. Its range is 0 to 50 mph bidirectional with a threshold sensitivity of 0.5 mph or 0.25 m sec^{-1} and a distance constant of 3.1 feet. The transducer is a dc tachometer generator whose output constant is 2.35 (10^{-2}) V mph^{-1} with accuracy better than 0.25 mph. Figure 6 shows the dynamic response of the Gill anemometer to a sinusoidally varying gust speed as a function of gust period. The normalized response of the propeller to wind vectors at an angle θ from its axis follows (approximately) the cosine of the angle, as shown in figure 13.

3. DATA RECORDING

3.1 Analog Recording System

The analog recording system records all temperature and horizontal wind data on strip charts. Wind data are recorded on Bendix Model 141-8 wind recorders. A sample wind trace is shown in figure 14. These recorders provide a dual trace for wind speed and direction. A single mechanism drives the chart for both traces at the rate of either 6 in hr^{-1} or 6 in min^{-1}. Routine data are collected at 6 in hr^{-1}, but 6 in min^{-1} is used for special interest short term observations.

The speed trace is marked in 2-knot increments from 0 to 100 knots. This scale can be interpolated to ± 1 knot. Wind speed information to the recorder is an analog dc voltage driving a galvanometer movement that controls the speed pen arm.

The direction section of the chart has a 540° overlapping scale designed to reduce limit encounters near 0° or 360°. The direction scale is marked in 10° increments and can be interpolated to ± 1°.

Signal input for direction information is a three phase

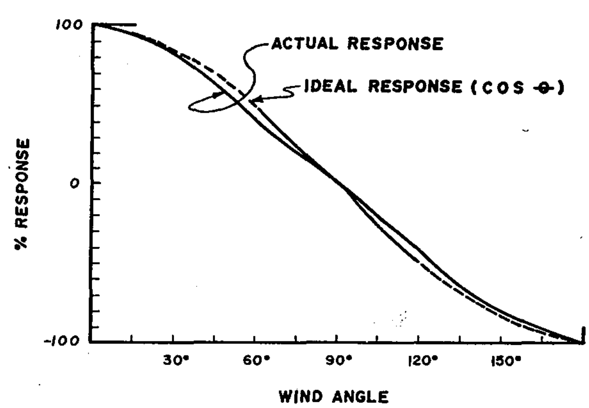

Figure 13. Normalized response of the vertical wind component sensor as compared with the ideal cosine response.

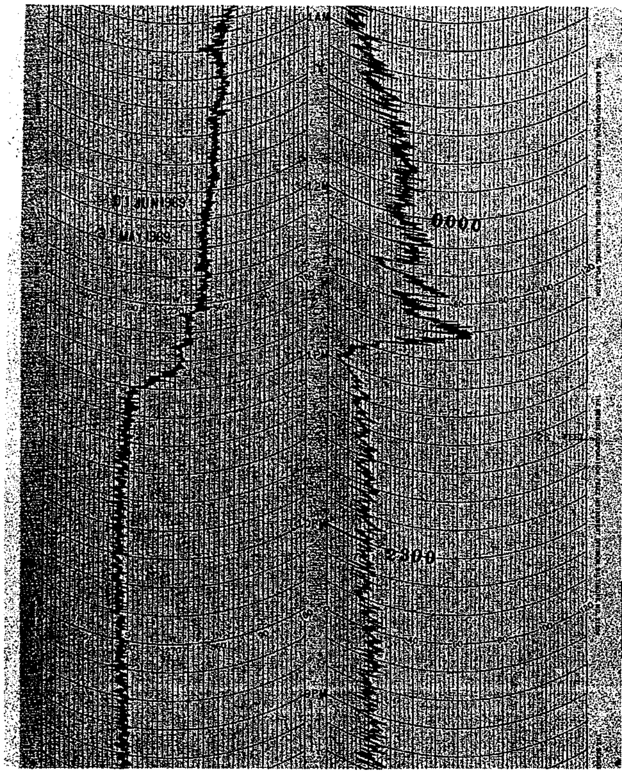

Figure 14. Sample horizontal wind record.

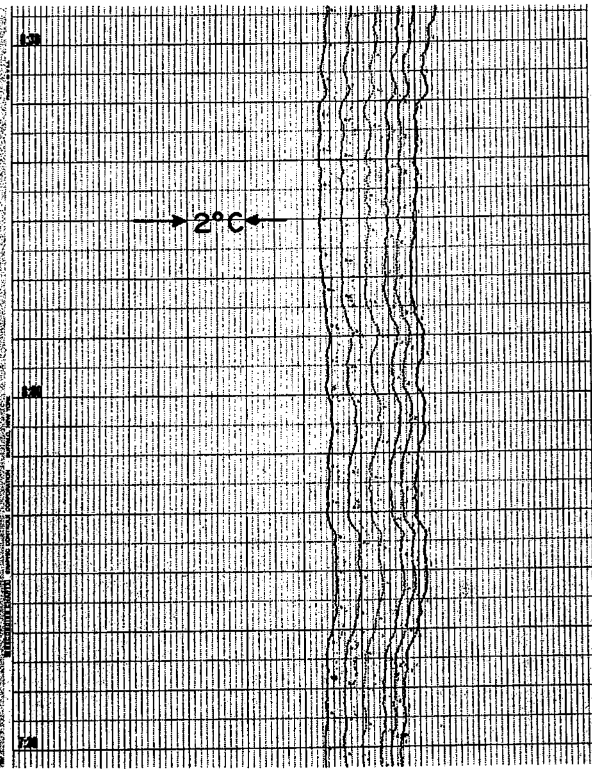

Figure 15. Sample delta temperature record.

60 Hz voltage that drives a synchro receiver that in turn controls the direction pen.

The wind recorders give a continuous trace and have a full scale pen travel time of less than 1 sec. The time response of these recorders is much faster than the time response of the instruments, thus allowing the sensor signals to be recorded with good fidelity.

The temperature recorders are Leeds and Northrup Speedomax Model W self-balancing potentiometer multipoint recorders. Sample temperature traces are shown in figure 15. The six levels of delta temperature information are recorded on a single multipoint recorder. Trace color coding is used so that ambiguities associated with crossovers and isothermals are minimized. The delta recorder discretely samples the six temperature signals sequentially at a rate of one sample per signal per 7.2 sec. The two ambient temperature signals are treated similarly and are recorded on a second multipoint recorder at a rate of one sample per signal per 6 sec.

Since the original continuous time function is represented by discrete samples, we should consider the Nyquist sampling criterion, and compare the sampling frequency with the effective data cutoff frequency as determined by the instrument response. For example, discrete samples are taken by the delta temperature recorder at the rate of one per 7.2 sec. The effective cutoff frequency (f_c), imposed by the inherent band limiting characteristic of the temperature sensors, is about 1/200 sec (for 0.7 amplitude response) or 0.005 Hz. The sampling frequency is 1/7.2 sec or 0.139 Hz. Thus the sampling frequency f_c exceeds the Nyquist frequency ($2f_c$) by a factor of 14. Similarly, the ambient temperature recorder sampling frequency is 17 times that of the required Nyquist frequency. We therefore expect that the input signal can be faithfully reproduced from the discrete samples.

3.2 Digital Recording System

Figure 16 shows a basic functional block diagram of the digital recording system. The system accepts up to 100 input data channels.

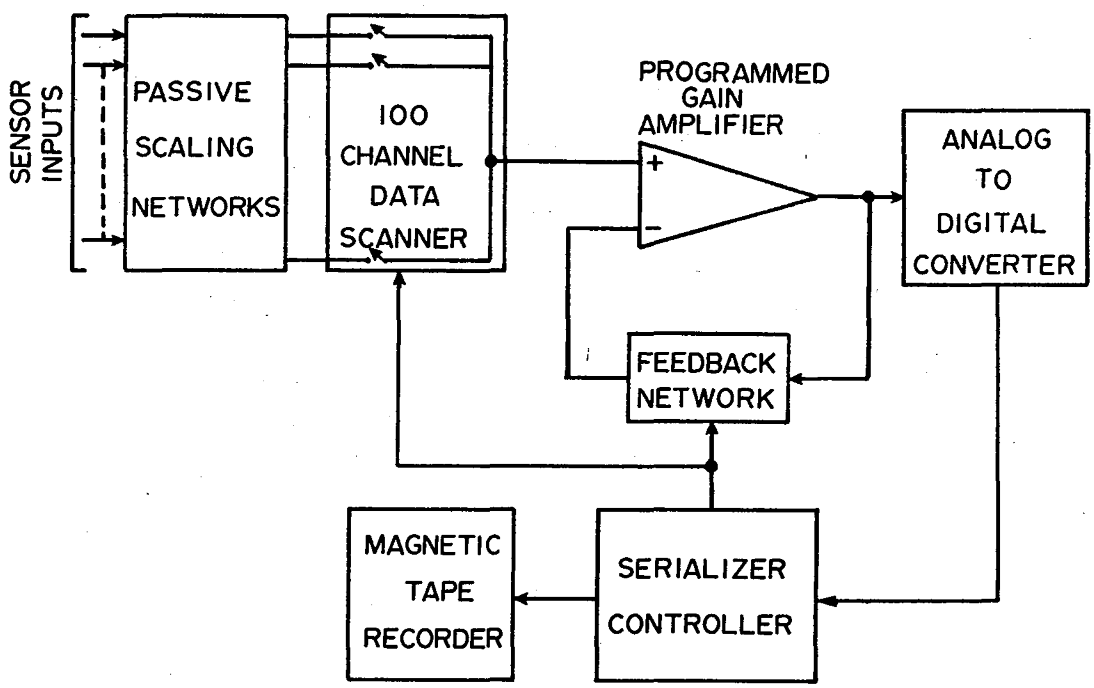

Figure 16. Digital recording system block diagram.

Each input channel is passively scaled, as required, and applied to the 100 channel scanner. The scanner sequentially scans through any preset number of data channels from 1 to 100 at a rate of 200 channels sec^{-1}. The selected output of the scanner is amplified by a programmed gain factor and digitized in a three bit BCD word at the A-D converter. Digital data from the A-D converter are then combined with time data in an IBM compatible format and written on magnetic tape. Normal sample rate of the system is one complete record of all parameters every 2 sec.

Table 3 lists the specifications of the overall digital recording system. Figure 17 shows a sample computer printout of the digital record.

Table 3. Specifications for Overall Digital Recording System

Channel capacity	100 channels
Max. data thruput rate	50 channels sec^{-1}
Overall system accuracy	$\pm$ 1 unit in L.S.D. of A-D converter output
Magnetic tape packing density	200 BPI
Data time resolution (absolute)	$\pm$ 0.5 sec
Max. data scan rate	100 channels sec^{-1}
Record length (variable)	16 to 316 characters
Programmed amplifier: Gains: 1, 3, 10, 30, 100 Input impedance $\geq$ 10 MΩ Full scale output 10V	

Following the Nyquist sampling criteria, the digital system can reproduce time varying signals from sensors whose band limited output cutoff frequency is as high as 0.25 Hz.

4. OPERATION, CALIBRATION, AND MAINTENANCE

The analog recording system as well as all the instrumentation can be operated continuously, except for demands of calibrations and maintenance and during very rare occasions when power is lost.

JUL DAY	TIME HHMMSS	SCAN NO	CHN NO	CAL VOLT	WIND SPEED SFC	1	2	3	4	5	6	VERTICAL WIND LVL 6	VERTICAL WIND LVL 4	WIND DIRECTION SFC	1	2	3	4	5	6	RAD	CAL VOLT	AMB TEMP DEG C SFC	AMB TEMP DEG C 6	DELTA T DEG C SFC	1	2	3	4	5	RH
246	060000	9511	0	501	130	153	220	306	299	382	443	050	06L	189	165	196	190	200	210	217	00K	360	243	231	121	123	097	047	000	02M	091
246	060100	9512	0	501	146	201	186	242	353	384	453	07M	000	194	190	195	196	202	208	218	00K	360	243	233	127	128	102	042	000	01N	091
246	060200	9513	0	500	077	147	199	222	344	404	443	07J	00E	195	203	193	185	201	208	217	00J	360	243	233	108	114	084	023	01R	03P	091
246	060300	9514	0	501	088	162	178	277	349	411	453	07N	011	206	189	189	200	195	208	218	00J	360	243	235	090	096	064	013	03J	05J	091
246	060400	9515	0	501	103	173	202	315	310	421	460	07P	04R	183	188	192	201	210	212	218	000	360	243	237	061	065	069	01M	06P	03R	091
246	060600	9517	0	501	119	155	213	272	297	389	470	08R	049	195	196	199	188	198	211	219	00J	360	243	238	068	064	042	00N	06M	04M	091
246	060700	9518	0	501	175	172	220	253	313	389	471	070	009	181	190	192	187	202	211	221	00J	360	245	238	071	063	037	010	06L	040	091
246	060800	9519	0	501	136	178	255	258	336	402	450	070	03K	179	193	187	185	203	212	220	00J	360	245	237	081	081	051	000	05K	03R	091
246	060900	9520	0	501	120	216	233	262	309	395	460	07J	004	178	187	198	180	200	211	218	00J	360	245	237	089	090	053	00E	05E	06N	091
246	061000	9521	0	501	135	244	226	266	325	419	454	07P	010	190	184	198	195	203	211	219	00K	360	245	237	089	090	053	00E	05E	06N	091
246	061000	9521	0	501	135	244	226	266	325	419	454	07P	010	190	184	198	195	203	211	219	00K	360	244	237	081	086	053	00N	05N	03P	091
246	061100	9522	0	501	087	204	263	232	336	407	467	06K	03L	194	190	190	190	203	210	218	00J	360	244	237	084	097	024	001	04R	020	091
246	061200	9523	0	501	157	211	233	262	331	407	450	08L	00M	190	191	189	194	202	210	218	00J	360	245	235	091	096	106	011	03M	02N	091
246	061300	9524	0	501	112	192	178	258	339	407	467	08E	005	186	196	193	187	204	212	219	00E	360	245	237	081	084	047	000	05M	02N	091
246	061400	9525	0	501	107	167	203	288	349	402	459	07N	016	190	197	198	197	203	212	219	00E	360	245	237	069	081	039	01M	04J	045	091
246	061500	9526	0	501	105	162	233	289	292	404	452	07M	08E	187	186	196	185	203	212	220	000	360	245	237	089	085	049	006	05L	04E	091
246	061600	9527	0	501	174	164	200	269	353	403	455	070	008	195	182	192	191	201	212	220	000	360	245	257	003	081	053	001	04N	030	091
246	061700	9528	0	501	116	189	198	282	336	428	466	05R	001	198	188	196	196	202	213	219	000	360	246	237	091	083	049	00P	06J	03R	091
246	061800	9529	0	501	144	141	191	268	321	391	451	080	000	211	187	195	200	205	208	218	000	360	246	237	095	084	064	006	04R	05K	090
246	061900	9530	0	501	159	198	200	228	324	403	463	08E	01P	183	190	200	187	203	209	218	001	360	247	237	101	088	003	00J	05M	040	091
246	062000	9531	0	501	134	165	188	260	344	395	454	08M	00N	175	183	191	195	203	209	218	000	360	247	236	112	098	070	016	03N	041	090
246	062100	9532	0	501	118	159	243	267	338	404	462	07R	00J	196	200	193	194	205	211	219	000	360	247	236	112	098	070	016	03N	04L	090
246	062200	9533	0	501	143	187	211	300	347	405	457	08J	001	185	191	198	193	209	209	217	001	360	247	236	111	103	066	008	06L	040	090
246	062300	9534	0	501	156	191	215	287	339	389	467	08M	09K	197	181	204	192	205	207	219	001	360	247	237	103	093	068	0UN	05R	05P	090
246	062400	9535	0	501	142	171	250	302	332	395	467	07N	006	189	190	197	195	206	210	219	001	360	247	239	069	076	044	00P	07E	060	090
246	062500	9536	0	500	152	162	187	274	348	407	465	05R	00J	206	188	184	188	205	213	220	001	360	247	239	080	065	033	02P	07L	04R	090
246	062600	9537	0	500	149	205	159	257	307	403	463	06K	00L	187	199	201	194	200	212	220	002	360	247	237	105	095	065	00K	04U	06M	090
246	062700	9538	0	500	157	217	217	229	319	390	458	07N	00J	190	197	209	197	199	212	219	002	360	247	237	108	095	060	00K	05R	05E	090
246	062800	9539	0	500	142	222	245	238	336	406	447	060	01E	188	193	190	192	202	212	218	002	360	247	235	132	118	083	022	030	02E	090
246	062900	9540	0	500	165	181	170	263	326	392	441	07J	00M	176	193	197	193	204	211	219	003	360	247	234	133	121	082	014	04L	04L	090
246	063000	9541	0	500	147	177	214	263	337	414	445	08P	004	189	203	199	189	203	208	218	003	360	247	235	140	121	082	025	02P	03P	090

Figure 17. Sample digital data record.

The digital recording system is normally operated in one of two primary modes. The first mode collects data continuously at a 2-sec sample rate for up to 6 hours or more during severe storm periods. Magnetic tape data capacity limits continuous collection at a 2-sec sample rate to 6 hr. Five minutes is required to change magnetic tapes.

The second primary mode collects the routine data during non-severe storm periods. This consists of continuous 2-sec samples of all data for 1 to 5 min at the beginning of each hour.

System flexibility allows quick departure from either primary mode to almost any operational program within system and personnel limits providing a wide choice of sample rates, sample volumes, and record lengths.

One electronic technician is on duty at the tower and performs the operation, installation, and calibration of all equipment and instrumentation at the facility. Calibration is done to maintain the specified accuracy of each instrument; this normally includes a complete system calibration immediately before and after the local severe storm season as well as daily, weekly, and monthly calibration checks.

5. ACKNOWLEDGMENTS

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