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DESIGN OF A DIGITAL TELEMETRY DATA COLLECTION SYSTEM

J. N. Carlson, Jr.

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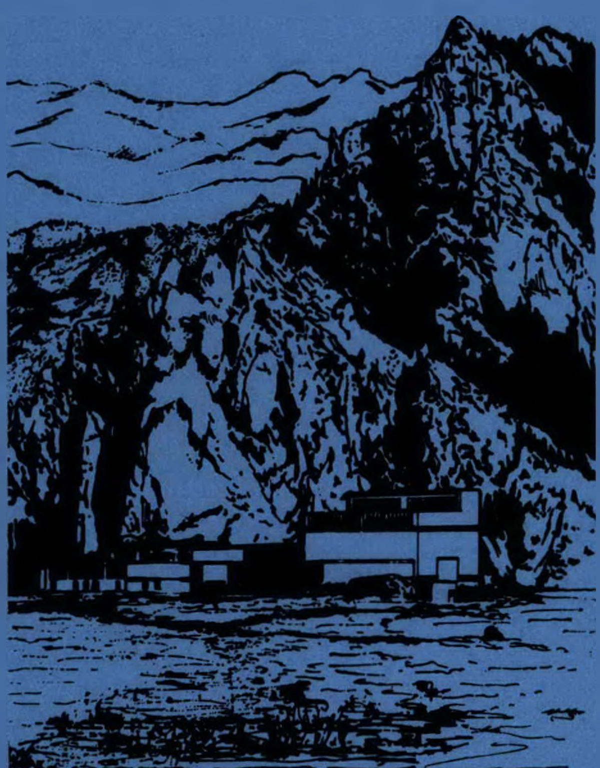

Prepared by

Rockwell International Corporation
Energy Systems Group
Rocky Flats Plant
Wind Energy Research Center
Golden, Colorado 80402

As a part of the

UNITED STATES DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGY DIVISION
FEDERAL WIND ENERGY PROGRAM

Contract No. DE-AC04-76DP03533

Rocky Flats
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ABSTRACT

Collecting load data from rotating wind system components is often an integral part of research and development performed at the Department of Energy's Wind Energy Research Center (WERC) at Rocky Flats, Colorado. In order to avoid problems commonly encountered with conventional methods of data collection (i.e., signal noise caused by sliprings and the high cost of multi-channel telemetry systems), a unique digital telemetry system was designed using off-the-shelf components. This flexible system not only has reduced size and cost, when compared to a previously used telemetry system, but has also proved to be very accurate in actual application. The purpose of this report is to discuss the design and operation of this system, as well as the rationale for its use.

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NOMENCLATURE

AD - Analog Devices

ADC - National Semiconductor model number

A/D - analog to digital

ALE - address latch enable

AMPSEL DPSW - amplifier selector dip-switch

D/A - digital to analog

EOC - end of conversion

GRN - ground

IC - integrated circuit

I/O - input/output

K - thousand

μsec - micro-second

NOAA - National Oceanic and Atmospheric Administration

NRZ - non-return to zero

RAM - random access memory

RCA - Radio Corporation of America

RF - Rocky Flats

S/H - sample and hold

STD - industry standard, 56 pin, 8 bit microprocessor buss

SWECS - Small Wind Energy Conversion System

XTAL - crystal

WERC - Wind Energy Research Center

1.0 INTRODUCTION

Transferring load data with minimal distortion from the rotating to the stationary parts of a wind system can be a major problem. Three methods of accomplishing this have been used at the WERC before a digital telemetry system was developed. Use of these systems has resulted in varying degrees of success, but their shortcomings were major reasons for development of the digital telemetry system.

Probably the simplest method for collecting load data is to have a wire connecting the transducers to the readout. The slack in the wire is taken up as the system rotates, making it necessary to periodically unwrap the wire. Obviously, this method is practical only in the slowest of rotating systems, such as across the yaw axis of a machine that doesn't rotate in the axis more than once or twice a day.

Another solution is the use of sliprings and brushes. This method has been used successfully in many machines on both fast and slow rotating parts of the system. There are, however, major problems with their use. One is the physical space required between the two components for mounting, and since each machine is of a different design, the installation has to be custom adapted. Other problems are corrosion and intermittent contact, causing noise in the signal. Sliprings also require more contacts as the number of channels increases, thus increasing their physical size.

The third method is use of a telemetry (radio transmitter/receiver link) system. A commercial system used at Rocky Flats (RF) consists of a five-channel receiver with a separate transmitter and frequency for each channel, with the transmitter frequencies scattered across the commercial FM band. However, since the Denver area has this band almost completely filled, interference from stations created problems. A second problem with the system was drift of the signal strength. The analog design made it susceptible to drifting since the output varied with the quality of the radio reception. Another problem was that separate transmitters were required for each channel, thereby increasing maintenance. In addition, the system cost was quite high (approximately $25,000 for five channels).

The telemetry system developed as an alternative to these methods and described herein is a multiplexed system. One amplifier is needed for each channel, but after multiplexing, only one transmitter, analog to digital converter (A/D), and microprocessor are required. This feature reduces the size, expense and complexity. The other significant aspect of the RF-developed telemetry system is that the signal is digitized immediately after amplification to minimize noise and drift.

2.0 OBJECTIVES OF THE RF DIGITAL TELEMETRY SYSTEM DESIGN

The purpose of developing a digital telemetry system was to avoid the common deficiencies in available data transmission systems, while maintaining a high degree of accuracy. The following statements list design parameters considered important:

- The frequency of the transmitter(s) should be in a seldom used band to reduce interference from broadcast or other communication transmissions in the area.

- The analog signal from the sensors should be digitized as soon as possible prior to transmission to minimize noise and drift.

- There should be available as many channels as will be needed in the majority of installations. Typically, eight channels are adequate.

- Digitizing the signal implies that a data sampling is taken at a number of sequential times. A minimum of two readings per waveform cycle is required to reconstruct the waveform. The sample rate should be high enough to ensure faithful reproduction of the frequency of interest. In many applications the highest frequency of interest is 3 to 5 Hz. Therefore, a minimum sample frequency of 10 samples per second is indicated. Often cyclic signals containing higher frequency components will require even higher data sampling rates.

- The system should be flexible enough to process signals from a wide variety of sensors, such as strain gages, potentiometers, etc.

- Every effort should be used to minimize power consumption to allow for battery operation.

- The smallest physical size that can be achieved, while retaining the desired performance, is important.

- Range should be a minimum of 50 feet to allow location of the antenna on the ground.

- The package and components must be rugged enough to withstand high centrifugal forces and other common physical shocks. Included in this should be an allowable temperature range consistent with expected conditions.

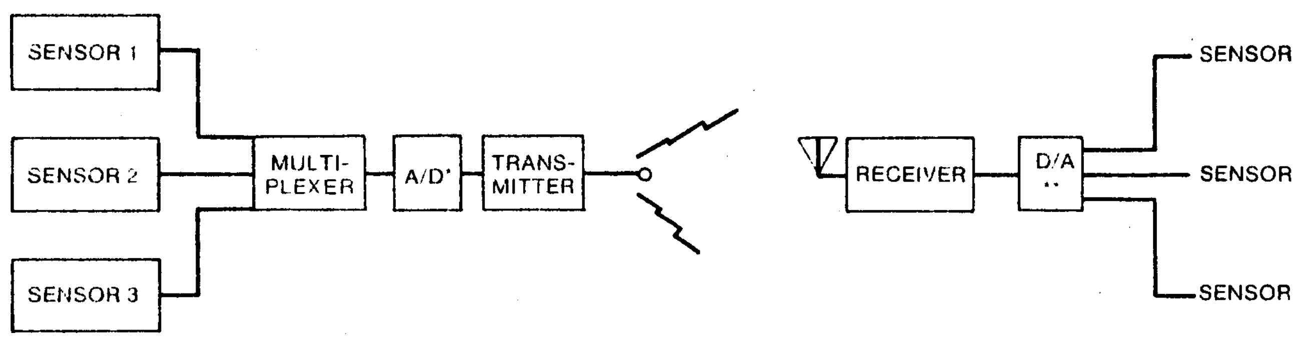
- Of course, keeping costs down was a major concern.

3.0 DESCRIPTION OF BASIC DIGITAL SYSTEM CONCEPT

After considering use of multiple transmitters and receivers (one for each data channel), it was suggested by Lloyd Thomas, of the National Oceanic & Atmospheric Administration (NOAA), that a single radio link would be sufficient if the data were multiplexed. Multiplexing in this context basically means using the equivalent of a selection switch to periodically read the signal present from each of a series of channels. This has the effect of sequentially placing the information from all channels on one line, thus allowing the use of one analog to digital converter and microcomputer for the system. Without multiplexing, a set of these components would be required for each channel. This obviously reduces the complexity and allows for a smaller, more compact unit.

A schematic of this basic telemetry system design concept is shown in Figure 1. Three channels are shown but up to 16 may be used. Operationally, the sensors output a voltage proportional to the parameter that they are designed to read. These signals are applied to the input terminal of the multiplexer, which samples each channel in a sequential pattern. The signal from the sampled channel is applied to the analog to digital converter which, as the name implies, converts the analog voltage to a digital number. The advantage of converting to digital is that noise and drift are not factors in system accuracy after conversion.

The transmitter sends the reading to the receiver which transfers it to the digital to analog converter. This unit changes the signal back to the original analog signal. The output can then be recorded or displayed on standard analog test equipment.



* Analog to Digital Converter
**Digital to Analog Converter

Figure 1
Basic Telemetry Design

4.0 DESIGN OF THE RF DIGITAL TELEMETRY SYSTEM MODEL

Figure 2 is a schematic of the digital telemetry system designed by Rocky Flats. The first block is the sensor which is usually a strain gage. These devices have an output in the micro to milli-volt region so an amplifier is required to bring the signal up to the five volt range required by the analog to digital converter. The amplifier system, designed by S. L. West, Rocky Flats, has two amplifiers in series. The first has an adjustable gain of 1 to 1000, while the second has a fixed gain of 10. The fixed gain amplifier will not be needed in the majority of RF applications and can be bypassed by the setting of switches. If the sensor has a high enough output (e.g. Potentiometer), the output can be fed directly into the multiplexer.

The signal from the amplifier(s) is applied to the multiplexer. Under the control of the microprocessor the multiplexer selects each channel periodically and passes the signal on to the sample and hold amplifier (S/H Amp). The multiplexer sampling rate is limited by the transmitter, but the A/D itself has a conversion time of 100 μsec which translates to 10,000 conversions/sec. The S/H Amp holds a constant analog value while the analog to digital conversion is being made. The analog to digital converter (A/D) changes the voltage level to a proportional number which is sent to the transmit microprocessor (micro) in parallel form.

The two microprocessors (Motorola 68701) are the central components of the telemetry system. The 68701 was selected because one chip includes 2K bytes of EPROM, 128 bytes of RAM, 29 Parallel I/O lines and a full duplex serial communications interface. In many systems, each of these features would be a separate chip. The system can be basically characterized as one micro talking to another over a radio link. The transmit micro receives the parallel data from the A/D, converts the data to a serial data stream, adds a start and stop pulse, then sends the data to the transmitter.

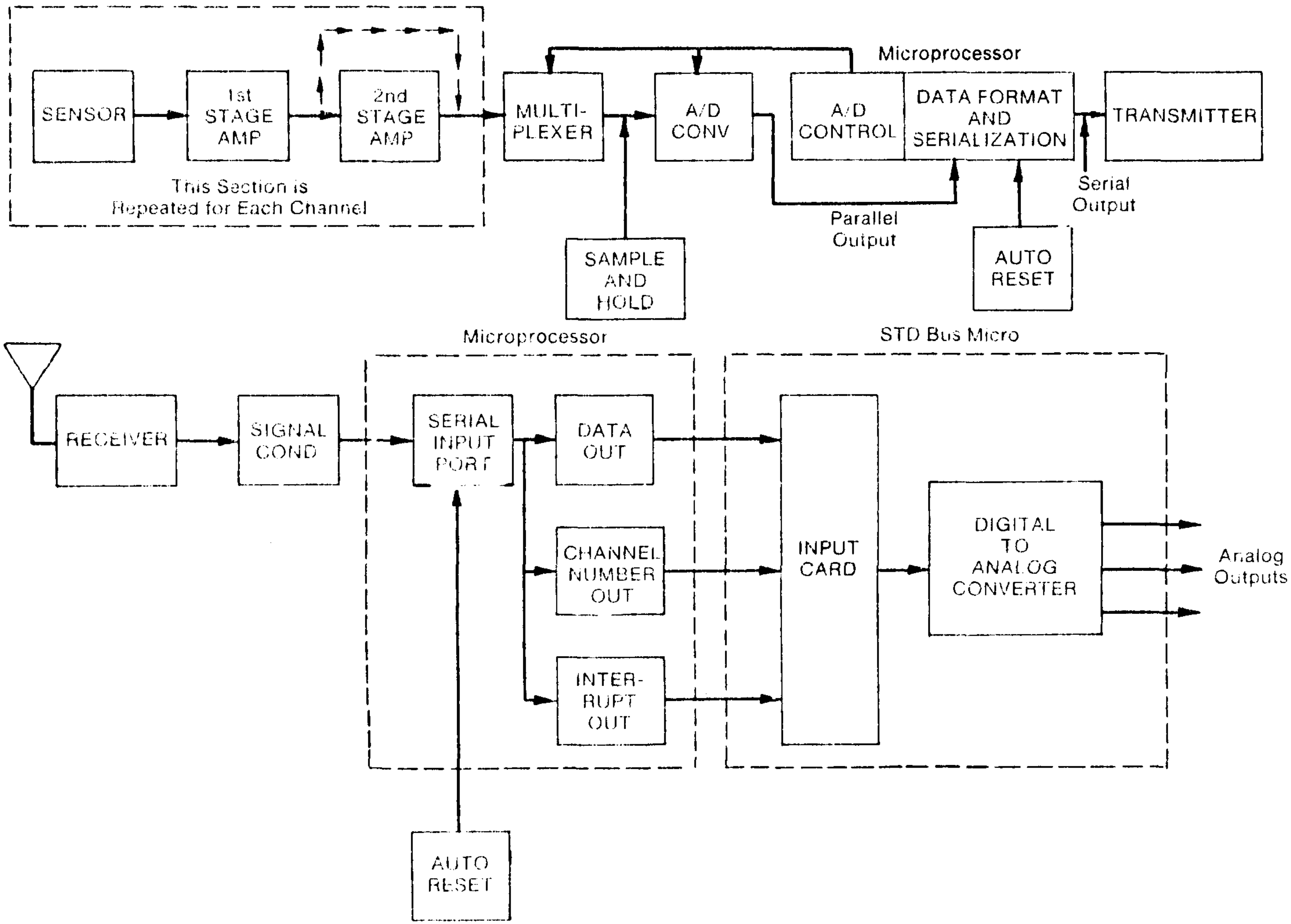


Figure 2
Digital Telemetry System Schematic

The transmitter/receiver link is provided by a HME model 44C wireless microphone. This unit was selected primarily due to availability and low cost. However, after researching many other sources, equipment that would perform better in the desired application was not found. The model 44C has a 100 Hz low frequency roll-off which causes problems if using a non-return to zero (NRZ) format and the values being read are very high or low. For this reason, a biphase format was used to keep the frequency above the low end limit. The NRZ format produces a level corresponding to a bit value during each bit time which is sampled by the receiver at the middle of each bit interval. If the number being transferred is high or low, there will be minimum bit values changes, thereby lowering the frequency being transferred below the low frequency cut-out of the receiver. However, the biphase format requires a transition (in either direction) at every bit time. An additional transition at the half-bit time is required whenever the bit value is "1". These transitions keep the frequency above the low frequency cut-out of the transmitter regardless of the number being transferred. Another advantage of biphase over NRZ is that biphase can, theoretically, tolerate a 25% difference in transmitter and receiver clock frequency, while NRZ can tolerate less than 4%.

The transmitter high frequency limit determines our maximum baud rate which directly affects the sample rate, thus limiting our resolution. This relationship can be expressed by the formula:

$$\text{Sample Rate (samples/sec)} = \frac{\text{Baud Rate (bits/sec)}}{\text{10 bits/byte X (No. of Channels + 2)}}$$

The term 10 bits/byte results from the micro adding a start and stop bit to the eight bits of data. The " + 2" is caused by the existence of an "identification byte" and a "number of channels to be sent byte" that takes as much time to transmit as the data bytes. The sample rate for a given signal can be increased by decreasing the number of channels or increasing the baud rate.

The receiver picks up the FM signal and passes it on to a signal conditioner that squares up the pulses. The pulse train is then sent to the receive micro. This micro converts the data to parallel form and outputs the digital data number, channel number and interrupt to a digital to analog converter. The analog values obtained can then be used on various analog recording and display devices. Both the transmit and receive micros have an automatic reset circuit that starts the micro at power up and resets it if the micro gets "hung up". A discussion on how the micro is programmed and set up may be helpful in understanding the system. Wiring diagrams for the receiver, transmitter and strain gage amplifier are contained in the Appendices.

5.0 MICROPROCESSOR PROGRAMMING

The micro's first action is to send an identification byte. This locks in the receiver micro. The next byte sent contains the number of channels of information to be sent. This number is stored and as each channel of data is sent, the program compares the number of channels sent with the number to be sent. When they are equal, the sequence starts over with an identification byte.

After the "number of channels byte" is sent, the micro has the multiplexer select the first channel to be sampled. The A/D gets a command to convert this value and passes the data to the transmit micro. The micro adds start and stop bits and sends the data to the transmitter. The transmitter then passes the data on to the receiver. The receiver detects the pulse train and applies it to the signal conditioner and, from there, into the serial input port of the receive micro. The receive micro numbers the data channels sequentially and outputs the data on one set of parallel lines and the channel number on another set of lines. An interrupt then lets the STD digital/analog (D/A) take the information and output it in analog form.

The transmit micro then selects the next channel of analog data and similarly send the digitized data until all channels have been serviced. Finally, the transmit micro sends an identification pulse as the process starts over. Program listings are for both transmitter and receiver are presented in Appendices A and B, repectively.

6.0 TESTING OF THE DIGITAL TELEMETRY SYSTEM

In order to assess the accuracy of data collected by the digital telemetry system, it was installed on an operational wind system at the WERC. This wind system was also instrumented with sliprings, thereby allowing a comparison of collected data. Both blades of the two-bladed system were instrumented with strain gages, with the telemetry system transferring data from one blade and the sliprings from the other. The strain gages were placed at the same location on each blade. Consequently, the signals should have been close to the same waveform but 180° out of phase if the telemetry system was operating correctly.

The comparative traces shown in Figure 3 indicate this was the case and that the data correlated very well. Data were collected during normal machine operation as well as during application of the brake. Time is depicted as moving toward the top of the page in these reproduced traces. While results from one comparative test do not totally validate the system's ability to collect high quality test data, they do confirm the design concept and give promise for other future applications. Additional testing is now underway at the WERC to further verify the system's integrity.

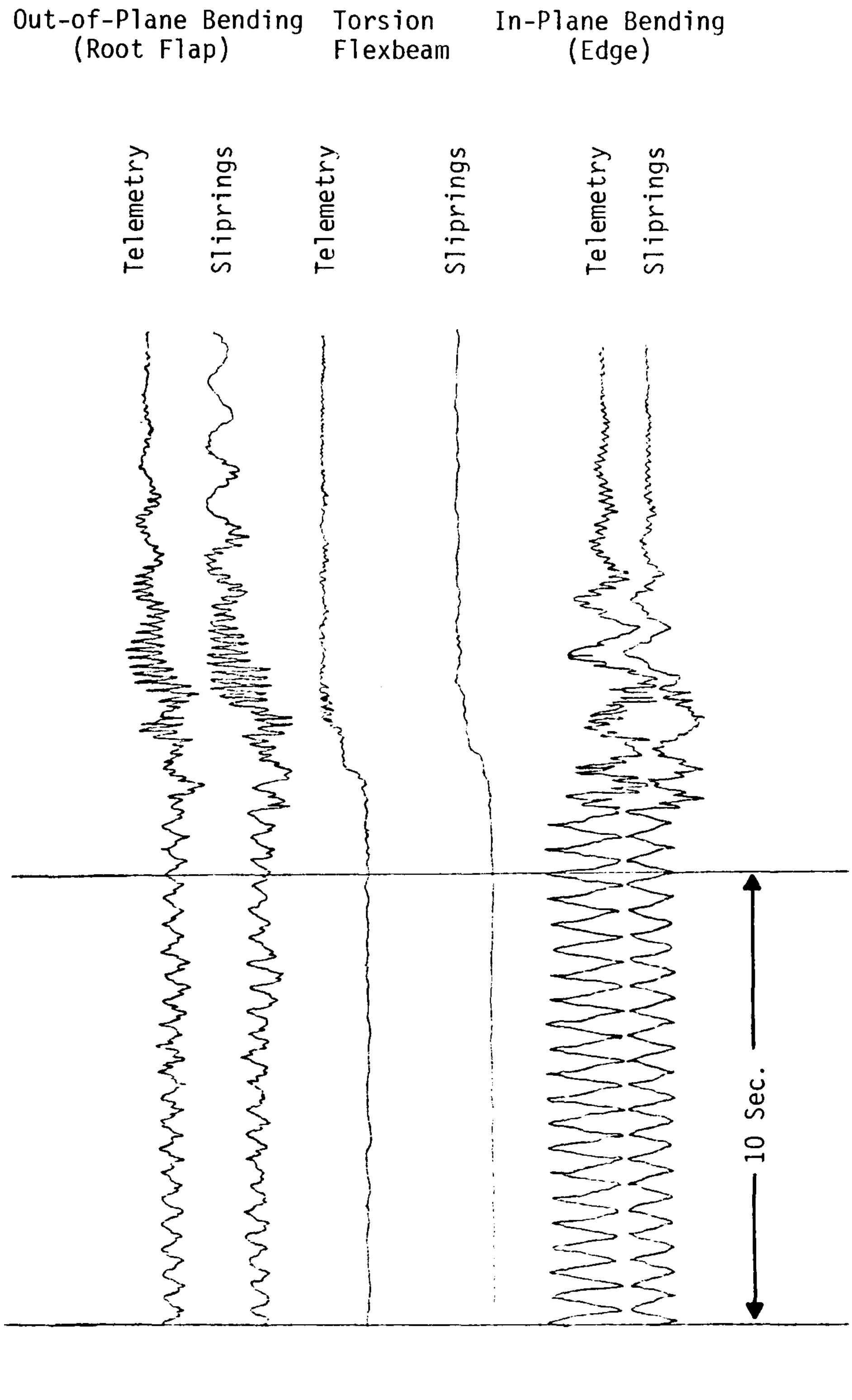


Figure 3
Comparison of Load Data
(Digital Telemetry System vs. Sliprings)

7.0 CONCLUSIONS/RECOMMENDATIONS

As was noted previously, there were deficiencies in the available telemetry systems that needed to be addressed in this design. The biggest problem, from an accuracy standpoint, was drift and interference from other radio sources. Drift was minimized by digitizing the signal early in the data transmission process. Also, the transmitter/receiver link being used had a frequency in a rarely used band which eliminated interference from other FM sources.

Although all major objectives of this project were met, this is not to say, however, that the system is perfected. The power consumed is excessive for battery operation and various ways of reducing it are being considered, including the use of "cheap" sliprings to bring power from the mainframe to the rotor and allow long-term data collection. Also, since the resolution of the received signal is directly proportional to the baud rate, there will always be incentive to improve on our current 4800 baud. One suggestion is to investigate the feasibility of using a microwave link to allow a practically unlimited band width. Such a link would allow data transmission to be as fast as the analog to digital converter would operate.

APPENDIX A

Transmitter Machine Language Program for Motorola 68701 Chip

Step No.	Command			Description
00	C6	01		LOAD ACC B WITH 01
02	D7	10		STORE ACC B IN 10 (RMCR)
04	C6	02		LOAD ACC B WITH 02 (T.E.)
06	D7	11		STORE ACC B IN #11 (TRCR)
08	D6	11		LOAD ACC B FROM #11 (TRCR)
0A	C5	20		BIT B WITH #20
0C	27	FA		BEQ FA
0E	86	88		LOAD ACC A WITH 88 (ID CHAR.)
10	97	13		OUTPUT TO TRANSMITTER
12	B6	FF	DF	LOAD A FROM FFDF (NO. OF CHAN.)
15	97	96		STORE ACC A IN #96
17	C6	02		LOAD ACC B WITH 02 (T.E.)
19	D7	11		STORE ACC B IN #11 (TRCR)
IB	D6	11		LOAD ACC B FROM #11 (TRCR)
ID	C5	20		BIT B WITH #20
IF	27	FA		BEQ FA
21	97	13		OUTPUT TO TRANSMITTER
23	86	00		LOAD ACC A WITH 00
25	97	95		STORE ACC A IN #95
27	86	F7		LOAD ACC A WITH F7
29	97	00		STORE ACC A IN PORT 1 DDR
2B	86	00		LOAD ACC A WITH 00
2D	97	02		STORE ACC A IN PORT 1
2F	A6	00		LOAD ACC A FROM IX ADDRESS
31	8B	40		ADD TO ACC A #40 (HOLD PULSE)
33	97	02		STORE ACC A IN PORT 1
35	8B	30		ADD TO ACC A #30 (ALE AND START PULSES)
37	97	02		STORE ACC A IN PORT 1
39	86	40		LOAD ACC A WITH #40
3B	97	02		STORE ACC A IN PORT 1
3D	96	02		LOAD ACC A FROM PORT 1
3F	85	08		BIT A WITH 08
41	27	FA		BEQ FA
43	86	80		LOAD ACC A WITH #80
45	97	02		STORE ACC A IN PORT I
47	86	00		LOAD ACC A WITH 00
49	97	05		STORE ACC A IN PORT 4 DDR
4B	16			TRANSFER ACC A TO ACC B
4C	C6	02		LOAD ACC B WITH 02 (TRANSMIT ENABLE)
4E	D7	11		STORE ACC B IN 11
50	D6	11		LOAD ACC B FROM 11
52	C5	20		BIT B WITH 20
54	27	FA		BEQ, FA
56	96	07		LOAD ACC A FROM PORT 4
58	97	13		STORE ACC A IN 13 (TDR)
5A	96	95		LOAD ACC A FROM ADDRESS 95
5C	4C			INCREMENT ACC A
5D	97	95		STORE ACC A IN ADDRESS 95
5F	08			INCREMENT IX
60	91	96		COMPARE ACC A TO ADDRESS 96

APPENDIX A (continued)

Transmitter Machine Language Program for Motorola 68701 Chip

Step No.	Command			Description
62	25	C3		BLO C3
64	CE	FF	E0	SET IX TO FFE0
67	7E	F8	00	JUMP TO F800
7DF				NUMBER OF CHANNELS TO BE SENT
7E0				FIRST CHANNEL NUMBER
7E1				SECOND CHANNEL NUMBER
				:
				:
7EF				16TH CHANNEL NUMBER
7FE				F8
7FF				00

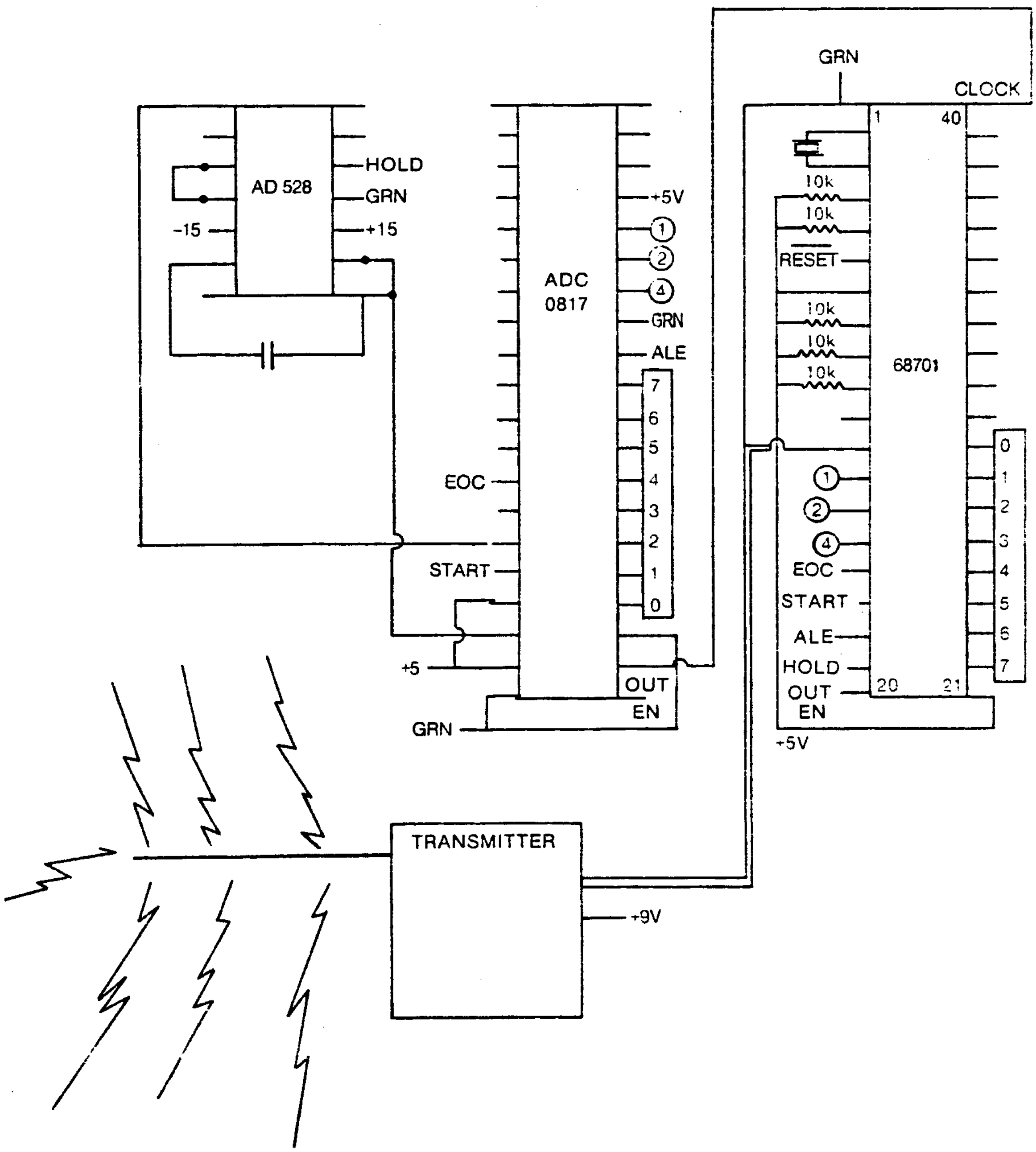


Figure 4
Transmitter Wiring Diagram

APPENDIX B

Receiver Machine Language Program

Step No.	Command			Description
00	86	01		INTERNAL CLOCK, BIPHASE, 4800 BAUD W/2.5 MHZ CRYSTAL
02	97	10		STORE ACC A IN RMCR
04	9E	FF		LOAD STACK POINTER
06	86	FF		LOAD ACC A FF
08	97	00		STORE ACC A (PORT 1 DDR)
0A	7F	00	83	CLEAR 0083
0D	86	3F		LOAD ACC A 3 F
0F	97	05		STORE ACC A (PORT 4 DDR)
11	86	08		LOAD ACC A IMM (RECIEVE ENABLE)
13	97	11		STORE ACC A (TRCSR)
15	96	11		LOAD ACC A FROM 11
17	85	80		BIT A #80 (RECIEVE DATA REGISTER FULL)
19	27	FA		BEQ FA
1B	96	12		LOAD ACC A FROM 12 (RECEIVE DATA REGISTER)
1D	81	88		COMPARE ACC A TO 88 (I.D. WORD)
1F	26	DF		BNE DF
21	86	08		LOAD ACC A WITH 08 (RECEIVE ENABLE)
23	97	11		STORE ACC A IN 11
25	96	11		LOAD ACC A FROM 11
27	85	80		BIT A #80 (RECEIVE DATA REGISTER FULL)
29	27	FA		BEQ FA
2B	96	12		LOAD ACC A FROM 12
2D	81	10		COMPARE ACC A WITH #10 (LESS THAN 16?)
2F	22	CF		BHI CF
31	97	82		STORE ACC A (STORE NO. OF CHANNELS IN #82)
33	86	08		LOAD ACC A WITH 08
35	97	11		STORE ACC A IN 11 (RECEIVE ENABLE)
37	96	11		LOAD ACC A FROM 11
39	85	80		BIT A WITH #80 (RECEIVE DATA REGISTER FULL)
3B	27	FA		BEQ FA
3D	96	12		LOAD ACC A FROM 12
3F	97	02		STORE ACC A IN PORT 1
41	96	83		LOAD ACC A FROM #83 (NO. OF TIMES THROUGH)
43	8B	10		ADD TO ACC A #10 (ADD INTERRUPT)
45	97	07		STORE ACC A (OUTPUT THE CHANNEL NO. AND INTERRUPT)
47	01	01		NO OPS
49	80	10		SUB ACC A IMM (REMOVE INTERRUPT)
4B	97	07		STORE ACC A IN PORT 4
4D	96	83		LOAD ACC A FROM #83
4F	4C			INC ACC A
50	97	83		STORE ACC A IN #83
52	91	82		COMPARE ACC A TO #82
54	25	DD		BCS DD (BRANCH IF #83 IS LESS THAN #82)
56	7E	F8	00	JUMP TO F800 (GO TO START)
7FE	F8			
7FF	00			

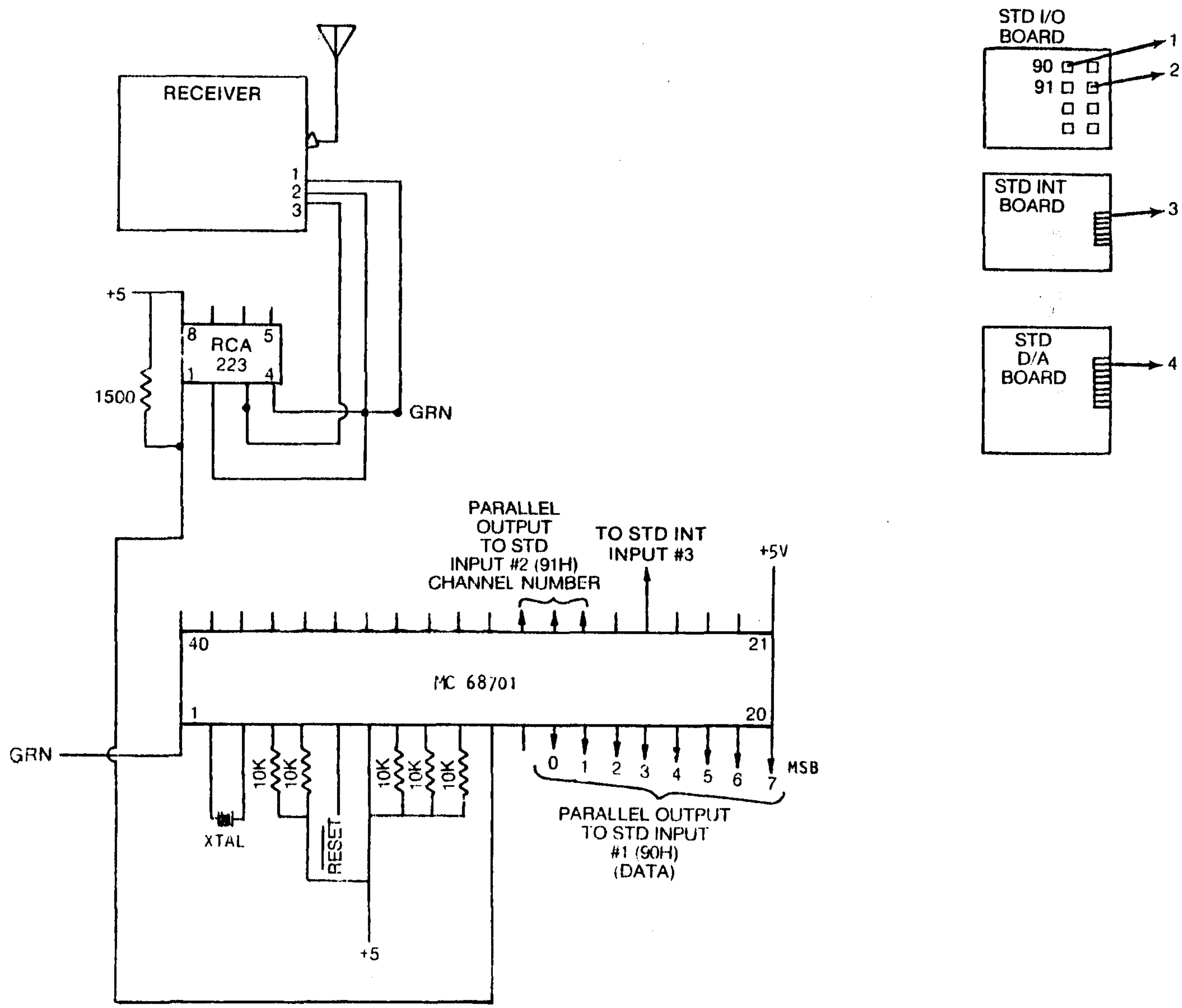


Figure 5
Receiver Wiring Diagram

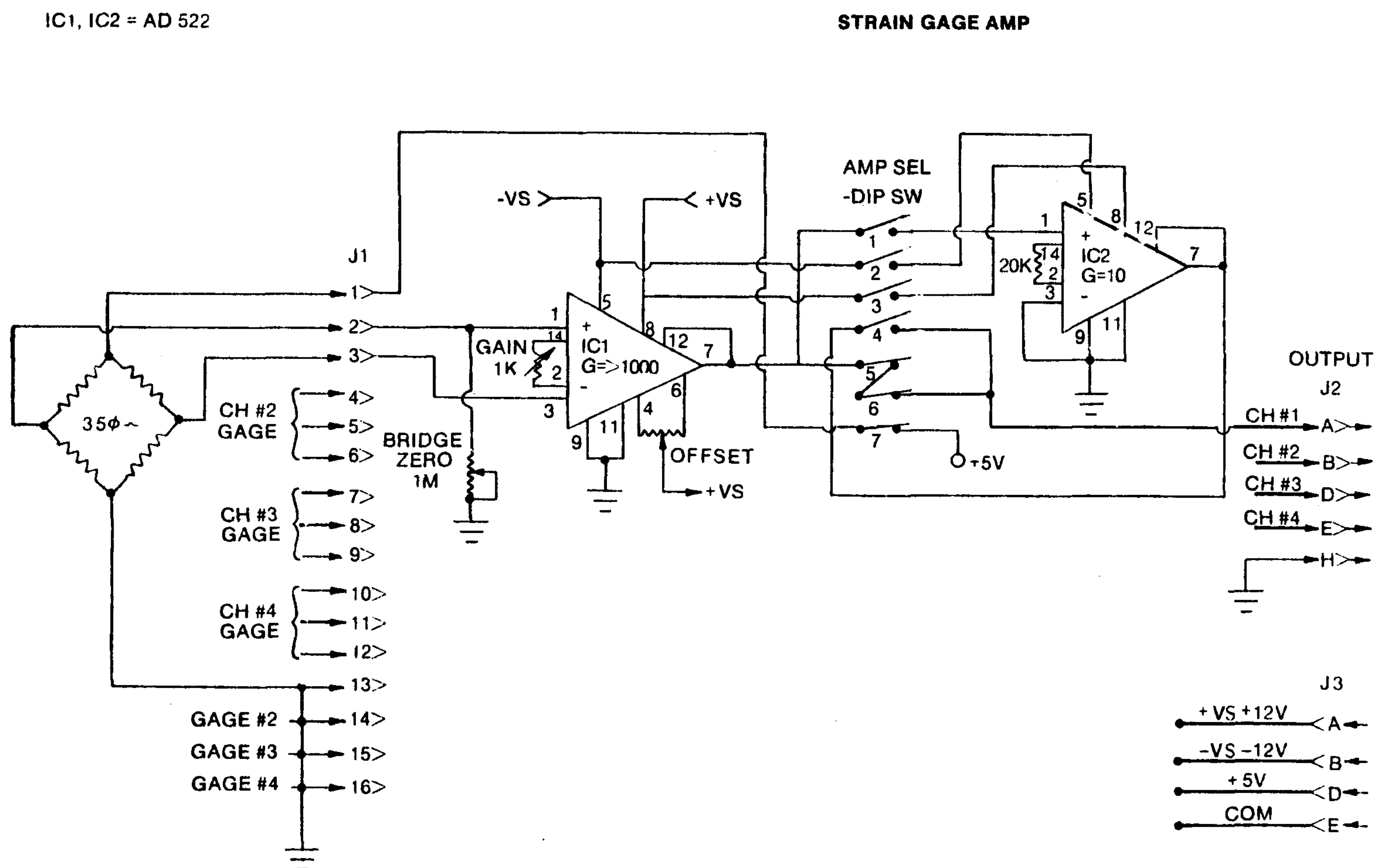


Figure 6
Strain Gage Wiring Diagram