INTERFACE **C**ONTROL **D**OCUMENT

for

LAUNCH PAD LIGHTNING WARNING SYSTEM

ELECTRIC FIELD MILL TO
BASE STATION COMPUTER
COMMUNICATIONS

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0 Errata

For Self-Test Mode (sect. 4.2.4), the Self-Test data record is not transmitted, and for Reset mode (sect.4.2.5), the Reset data record is not transmitted.

During the execution of Self-Test and Reset procedures, the command synchronization state is set to "FREE", so that when the first command after Reset or Self-Test is received, the mill aborts the Reset or Self-Test data record. After the first command is received, the mill waits one second, then transmits a data record corresponding to the command.

1 Referenced Documents

Statement of Work, Electric Field Mill Network for Launch Pad Lightning Warning System, RFP 8-H-9-ES-21493, NASA/MSFC

"Advanced Ground-Based Field Mills", Preliminary design Review, February 7, 1991

"Interface Control Document", Preliminary dated June 26, 1991.

"Interface Control Document", dated February 16, 1991.

"Interface Control Document", dated July 8, 1992.

2 Modifications to Previous Versions of This Document

1. Version -310791: Section 3, Third paragraph re-written, and 4 more paragraphs were added. Mill reports potential gradient, NOT electric field.

2. Version -310791: Section 4.1, General format section was added.

3. Version -310791: Section 4.2, Command definitions were changed.

4. Version -160292: Section 3, Communications Overview modified.

5. Version -160292: Section 4.1 and 4.2 added/modified to specify new command sequences.

6. Version -160292: Section 4.2.3 modified to describe computer-controlled timing of calibration sequences. Also, measurement of mill offset requires that the field calibration fixture to be mounted to the mill.

7. Version -160292: Section 4.2.4 modified; mill status and error log memory locations are no longer preserved by Self-Test. Mill no longer idles until command received.

8. Version -160292: Section 4.2.5 modified; mill no longer idles until command received.

9. Version -160292: Section 6.2.2 modified; Station address values out of defined range reserved for future test modes.

10. Version -160292: Section 6.2.6.1, Electric Field Mill Data record now specifies potential gradient data as Motorola format 16 bit integers (more significant byte first) rather than VAX format 16 bit integers (less significant byte first)

11. Version -160292: Sections 7.1, 7.2, 7.3 on communication error sources and solutions added.

12. Version -080792: Section 6.2.4.5, extended status reports 68HC11 configuration register

13. Version -120493: Errata section added and status not implemented documented

3 Electric Field Mill / Base Station Communications Overview

The atmospheric potential gradient sensing and data collection portion of the Launch Pad Lightning Warning System consists of a centrally located Base Station Computer and up to 64 remotely located Electric Field Mill sensors.

Data communication between the Base Station Computer and the field mills consists of commands sent from the Base Station to the mills and data records sent from the mills to the Base Station. These communications occur over dedicated, unloaded, two twisted-pair, wire lines and utilize a full duplex, asynchronous serial protocol at 2400 baud, 8 data bits, no parity, 1 stop bit. A UDS model D19.2 modem will terminate each end of the data channel and provide an RS-232C compatible interface to the mill or Base Station end of the channel.

The Base Station commands allow the mode of operation of the field mills to be altered and allow timing of field mill data acquision processes to be synchronized across the field mill network. In order to distinguish the various required mill operating modes, a unique command string is sent to command each mode. The time of arrival of these command strings is used by the mill to synchronize internal data acquisition timing. Command strings are broadcast to the mills once per second, referenced to an IRIG-B standard.

The data records sent from the field mills to the Base Station contain potential gradient data and mill operating status information.

4 Electric Field Mill Commands

4.1 Command Format:

The commands that the Base Station may issue to the field mills have the following format:

1. Sync character ->Constant (=$A5) used to identify start of command sequence.
2. Message Length character ->Indicates message length (nominally = 3)
3. Command Function character ->Actual command to Field Mill Station.
4. Checksum character ->Byte addition of this character with preceding message characters results in zero.

The length character allows the expansion of the command set to include messages longer than 4 characters. This would, for example, expedite the downloading of code from the base station to modify field mill firmware.

4.2 Valid Command Definitions: The electric field mills respond to the following commands from the Base Station:

Command Function	**Command Sequence**	**Operation**
Normal	$A5,$03,$C3,$95	Set Normal Mode
Split	$A5,$03,$E7,$71	Set Split data acquisition Mode
Cal Mode 0	$A5,$03,$EC,$6C	Set Calibration Mode 0 (0 v/m)
Cal Mode 1	$A5,$03,$EE,$6A	Set Calibration Mode 1 (+E1 ref)
Cal Mode 2	$A5,$03,$33,$25	Set Calibration Mode 2 (-E1 ref)
Cal Mode 3	$A5,$03,$37,$21	Set Calibration Mode 3 (+E2 ref)
Cal Mode 4	$A5,$03,$3C,$1C	Set Calibration Mode 4 (-E2 ref)
Self-Test	$A5,$03,$3E,$1A	Set Self-Test Mode
Reset Mode	$A5,$03,$73,$E5	Set Reset Mode
Demod: lock	$A5,$03,$77,$E1	Demodulator reference locked
Demod: free	$A5,$03,$7C,$DC	Demodulator reference free
Motor On	$A5,$03,$7E,$DA	Turn motor on
Motor Off	$A5,$03,$CC,$8C	Turn motor off
Reserved	$A5,$03,$CE,$8A	TBD
Reserved	$A5,$03,$C7,$91	TBD
Reserved	$A5,$03,$E3,$75	TBD

The function of each of the operating modes and the command sequence required is described in the following sections.

4.2.1 Normal Mode

Normal Mode is the default data acquisition mode and implies that the Electric Field Data portion of the data record contains 50 samples (equally spaced over one second) of the local atmospheric potential gradient as measured by the mill.

When a power-on or manual reset occurs, the mill automatically executes the Reset Mode procedures (see sect. 4.5) followed by the Self-Test Mode procedures (see sect. 4.4), and then defaults to Normal Mode. If no commands from the Base Station are received within a 1.0 second timeout interval after Self-Test has completed, the mill will default to Normal Mode data acquisition with potential gradient sampling and data record transmission based on mill internal timing (This allows functional verification of a mill in the absence of commands).

If Normal Mode Commands are received at any time after the Self-Test mode procedures have completed, the mill will stay in Normal Mode and synchronize the timing of potential gradient sampling and data record transmission with the reception of commands (see sect. 5). Since the mill formats and builds data records on a once per second basis, the Base Station should send Normal Mode Commands at regular one second intervals. The data record sent in response to a Normal Mode Command will contain information acquired during the one second time interval prior to receiving the command.

The Normal Mode Command can also be used to switch the mill from either Split Mode or Calibration Mode to Normal Mode. In this case the first data record sent after the command was issued will reflect the prior mode, and the second data record sent (and all subsequent records until a mode change) will reflect Normal Mode status and potential gradient data (see sect. 6.1, Data Record Structure).

Normal Mode Commands also remove any calibration fields that may have been previously commanded.

4.2.2 Split Mode

Split Mode is a data acquisition mode in which the Potential gradient Data portion of the data record contains 25 samples of the local potential gradient as measured by the mill and 25 samples of the analog signal present at the external analog input connector, both equally spaced over one second and interleaved, with the local mill signal occurring in the data record first.

The Split Mode Command is used to switch the mill from Normal

Mode or Calibration Mode to Split Mode. To keep the mill in Split Mode and to synchronize the timing of the sampling of the potential gradient/external analog input and the transmission of the data record with the reception of commands, the Base Station should send Split Mode Commands at regular one second intervals. Transmission of Split Mode data records will commence on the reception of the second Split Mode Command.

Split Mode does not specifically remove any calibration fields that may have been applied. This can be used to facilitate testing of the mill.

4.2.3 Calibration Mode

Calibration mode is a test data acquisition mode with a data record similar to a Normal Mode data record (50 samples of potential gradient data) except that a calibrated electric field (0, E1, or E2) is imposed on the mill's electric field modulator while the mill is acquiring potential gradient samples. This imposed field may take one of five values,

1. 0 volts/meter (Cal Mode 0)
2. +E1 volts/meter (Cal Mode 1, reported as a negative value)
3. -E1 volts/meter (Cal Mode 2, reported as a positive value)
4. +E2 volts/meter (Cal Mode 3, reported as a negative value)
5. -E2 volts/meter (Cal Mode 4, reported as a positive value)

according to the particular Calibration Mode Command received.

The Calibration Mode Command is used to switch the mill from Normal Mode or Split Mode to Calibration Mode. To keep the mill in Calibration Mode and to synchronize the timing of the sampling of the test electric field and the transmission of the data record with the reception of commands, the Base Station should send Calibration Mode Commands at regular one second intervals. Transmission of Calibration Mode data records will commence on the reception of the second Calibration Mode Command.

Under fair field conditions (approximately 100 volts/meter) a sequence of calibration mode commands will allow an operator at the Base Station Computer to acquire sufficient information to perform an end-to-end calibration of the gain of a mill's potential gradient sensitivity without visiting the site. In this case, local potential gradient drift during the calibration sequence will limit the accuracy of the calibration. Improved accuracy in calibration is obtained when the field calibration fixture is attached to cover a mill's field modulator to remove the influence of the local potential gradient during the calibration sequence. This configuration also allows the offset of a mill to be determined.

The Base Station will have explicit control over the calibration sequence timing in one second intervals: each reference field will be imposed on the modulator by one of the Calibration Mode Commands and persist for as long as the Base Station continues to send that command. It is anticipated that the Base Station will automate the sequencing of Calibration commands with a programmable dwell time for the application of calibration fields; this would remove the operator from the timing of the calibration sequence.

<u>Data acquired in Calibration mode should not be used to evaluate potential gradient conditions at the site</u>: bit 4 of Status Byte 1 will be set to indicate invalid field data (see Data Record Element specification below).

4.2.4 Self-Test Mode

Self-Test Mode is a non-data acquisition mode in which the mill performs diagnostic routines and reports extended status results in place of potential gradient data.

Unlike other modes, the duration of this mode is determined not by the Base Station but by how long it takes the mill to complete internal testing procedures. The Self-Test Mode Command should be sent once by the Base Station to change the mill's state to Self-Test and start the test sequence.

On receipt of the Self-Test Mode Command, if a data record is pending, it will be flushed and not transmitted. While the mill is executing the Self-Test procedures, it will not respond to Base Station commands and will not transmit any data.

When the self-testing is completed, the mill will wait 1.0 seconds for a command from the Base Station. If a command is received within this timeout interval, the mill will assume the commanded operating mode and commence both an potential gradient data acquisition sequence and the transmission of the Self-Test data record synchronous with the arrival of the command.

If a command is not received within this 1.0 second timeout interval, the mill will default to Normal Mode and initiate a data acquisition sequence and the transmission of the Self-Test data record.

4.2.5 Reset Mode

Reset Mode is a non-data acquisition mode entered as a result of a hardware reset of the mill's circuitry. The hardware reset can occur at power-on, by depression of the manual reset switch, or in response to a Base Station command. Entry of this mode by Base Station command is made available to allow an attempt at remotely correcting the operation of a faulty mill (as indicated by reported status information). The usefulness of Reset mode is limited by the requirement that the mill must be capable of detecting and responding to the Reset command.

In Reset Mode the mill performs hardware initializations and clears all memory (including status and error log locations). The mill then automatically transitions to Self-Test Mode. The data record report issued at the end of Self-Test will indicate Reset Mode in the Mode/Command Byte (sect. 6.2.3), but will otherwise be identical to a Self-Test data record. Aside from this difference in the data record, Reset functions will appear to the Base Station as identical to Self-Test.

The command sequence for Reset Mode is similar to Self-Test: the Reset Mode Command should be sent once by the Base Station to change the mill's state to Reset and start the initialization and test sequence.

4.2.6 Demodulator Lock and Demodulator Free

Demodulator Lock and Demodulator Free commands commands allow the selection of the reference signal used by the mill to demodulate the modulated potential gradient to be derived from either a signal that is phase-locked to the modulator's rotor (Lock) or a signal that is not phase-locked (Free). The operating mode active at the time these commands are received is not changed.

4.2.7 Motor On and Motor Off

Motor On and Motor Off commands allow the Base Station to remotely start or stop the motor driving a mill's electric field modulator. This facility is useful for testing. The operating mode active at the time these commands are received is not changed.

5 Synchronization of Potential Gradient Sampling

Synchronization of the potential gradient sampling at each mill site, and of the start of transmission of a data record from each site, are achieved by the broadcast of a system-wide clock signal from the Base Station.

Under normal operating conditions, the Base Station will send a command string to each mill once per second to request transmission of a data record. The sending of these commands will be precisely referenced by the Base Station to an IRIG-B modulated time code signal. On receipt of a command, each mill will adjust its internal timing to align its potential gradient sampling and data record transmission processes. In this manner the uniformity of potential gradient sampling across the field mill network will be limited only by the uncertainty (or timing jitter) associated with the propagation delays of 1) the Base Station command dispatch processes, 2) the communication channel, and 3) field mill timing alignment processing.

In the event that broadcast of regular commands from the Base Station are interrupted, each mill will continue to sample the potential gradient and transmit data records based on an internal timing reference. In this case, the timing of these processes will begin to drift away from synchronization. If commands from the Base Station are never received after power-on or reset, a mill will default to the Normal data acquisition mode and rely solely on its internal timing reference.

6 Electric Field Mill Data Record

The structure of the electric field mill data record and the elements comprising that structure are specified in this section.

6.1 Data Record Structure

The data record transmitted by the Electric Field Mill will consist of 114 bytes of mill operational status, potential gradient and raingauge data, and an error checking parameter. The data record is summarized below with the "Byte No." indicating the number or position in the data record and the "Type" specifying the format of the information:

I = Two's complement 16 bit integer, Motorola byte order
UI = Unsigned 16 bit integer
BI = 16 bit binary pattern
C = Two's complement 8 bit integer
UC= Unsigned 8 bit integer
BC = 8 bit binary bit pattern
X = Not defined

Byte no.	Type	Function
1-2	BI	Synchronization Pattern
3	UC	Station Address
4	BC	Mode/Command Byte
5-11	-	Status Bytes 1-7
12	UC	Rain Gauge Tip Count
13-112	I/-	Potential Gradient Data or Extended Status Report
113-114	BI	CRC-16 Value

Depending on the operating mode of the mill, the data record transmitted will be of one of four types distinguished by the contents of the 100 byte Potential Gradient Data or Extended Status Report:

Record Type	Contents
1. Normal	50 16-bit samples of potential gradient
2. Split	25 16-bit samples of potential gradient plus 25 16-bit samples of external signal
3. Calibration	50 16-bit samples of potential gradient (positive, negative, & zero imposed calibration fields)
4. Diagnostic	Extended status reporting (Self-Test and Reset Modes)

The type of data record can be determined by the "Mode byte" in the status portion of the data record, as defined below. Only Normal and Split type data records should be used to evaluate potential gradient conditions at a mill site.

6.2 Data Record Elements

The data elements that comprise the data record transmitted by the electric field mill are specified below.

6.2.1 Synchronization Pattern (Bytes 1-2)

This fixed pattern (=$D60D) allows the start of the data record to be identified solely on the basis of position in a data stream. The first character sent to the Base Station will be $D6.

6.2.2 Station Address (Byte 3)

Station Address is used to identify the physical location of the electric field mill. It can assume values that range from 1 to 64 ($01-$40). Values out of this range are reserved for future test modes.

6.2.3 Mode/Command Byte (Byte 4)

The less significant nibble of this byte identifies the current mode of operation of the mill. The more significant nibble of the byte functions as a command echo and indicates the last command received from the base station.

6.2.3.1 Mode Nibble

The specifications for the Mode portion of the Mode/Command Byte are:

[xxxx 0001] Normal Mode
[xxxx 0010] Split Mode
[xxxx 0011] Calibration Mode
[xxxx 0100] Self-Test mode
[xxxx 0101] Reset mode
[xxxx 0111] CRC Transmission Error
[xxxx 1000 - xxxx 1110] Undefined
[xxxx 1111] Sensor Inoperative

where '[xxxx xxxx]' implies an 8 bit binary bit pattern ('x' implies "don't care" for that bit position).

CRC Transmission Error and Sensor Inoperative are not true mill operating modes, but are provided to allow the Base Station a means of flagging an error condition.

CRC Transmission Error is a flagging state that is set by the base station computer when corruption of a data record by the communication medium is detected at the base station computer via a CRC mismatch. The base station computer overwrites whatever mode pattern was received in the data record. The Station Address should also be re-written in the data record by the base station computer to guarantee correlation of transmission errors with the correct mill site by users of the electric field mill data records.

Sensor Inoperative is a flagging state that is set by the base station computer when a mill site is determined to be non-responsive (non-existent, disconnected, or faulty). It is assumed that the base station computer will set up a dummy data record with at least a valid Station Address and Mode/Command byte for distribution to users of the electric field mill data records.

6.2.3.2 Command Acknowledgement Nibble

The specifications for the Command Acknowledgement portion of the Mode/Command Byte are:

[0000 xxxx] Normal Mode
[0001 xxxx] Split Mode
[0010 xxxx] Calibration Mode, 0 v/m ref
[0011 xxxx] Calibration Mode, +E1 ref
[0100 xxxx] Calibration Mode, -E1 ref
[0101 xxxx] Calibration Mode, +E2 ref
[0110 xxxx] Calibration Mode, -E2 ref
[0111 xxxx] Self-Test Mode
[1000 xxxx] Reset Mode
[1001 xxxx] Demodulator ref: lock to rotor
[1010 xxxx] Demodulator ref: free of rotor
[1011 xxxx] Motor On
[1100 xxxx] Motor Off
[1101 xxxx - 1111 xxxx] Not defined

6.2.4 Status Bytes (Bytes 5-11)

6.2.4.1 First Status Byte (Byte 5)

Bit 0-1 [xxxx xx00] Imposed field = 0 v/m
[xxxx xx01] Imposed field = + E1 v/m
[xxxx xx10] Imposed field = - E1 v/m

Indicates the commanded state of the imposed calibration electric field (default is zero volts/meter).

Bit 2 [xxxx x0xx] External 110 VAC good
[xxxx x1xx] External 110 VAC fail

Indicates if the supply of external 110 VAC has failed.

Bit 3 [xxxx 0xxx] 110 VAC line protector good
[xxxx 1xxx] 110 VAC line protector fail

Indicates if the 110 VAC transient protector has failed.

Bit 4 [xxx0 xxxx] Potential gradient data valid
[xxx1 xxxx] Potential gradient data not valid

True indicates that:

a) the Potential gradient data portion of the data record is being used for status reporting in Self-test mode;
b) the analog-to-digital converter system is not responding;
c) the mill is in one of the Calibration Modes, or the motor has been commanded off, or the demodulator has been commanded "Free".

Bit 5 [xx0x xxxx] Ref 1 used for calibration field
[xx1x xxxx] Ref 2 used for calibration field

Indicates if the first or second set of calibration reference fields are being utilized in Calibration mode.

Bit 6 [x0xx xxxx] Motor subsystem OK
[x1xx xxxx] Motor subsystem fault

Indicates if the motor system driving the rotor is experiencing a fault.

Bit 7 [0xxx xxxx] NO SYNC
[1xxx xxxx] SYNC

Indicates whether or not the mill's potential gradient sampling and data record transmission timing are synchronized to received Base Station commands.

6.2.4.2 Second Status Byte (Byte 6)

Bit specifications:

Bit 0-5 [xx00 0000 - xx11 1111] Motor velocity

Indicates the current motor velocity (1 RPS/bit)

Bit 6 [x0xx xxxx] Demodulator reference locked
[x1xx xxxx] Demodulator reference free

Indicates if the reference signal used to demodulate the modulated potential gradient signal is locked to the rotor (default) or to an independent, internally generated signal.

Bit 7 [0xxx xxxx] Motor on
[1xxx xxxx] Motor off

Indicates if the motor system has been commanded off (default is on).

6.2.4.3 Third Status Byte (Byte 7)

All 8 bits are used to indicate the current backup battery voltage (0.078 volts/bit).

6.2.4.4 Fourth Status Byte (Byte 8)

The 4 less significant bits act as sub-multiplex identification codes for Status Byte 5 and the 4 more significant bits act as sub-multiplex codes for Status Bytes 6-7.

6.2.4.5 Fifth Status Byte (Byte 9)

This byte can provide up to 16 different indicators depending on the value of the 4 least significant bits of Status Byte 4. The indicators defined are:

Status Byte 4 Code	Type	Status Byte 5 Function
[xxxx 0000]	UC	Sensor Head ID (identifies mill head)
[xxxx 0001]	UC	Firmware Version
[xxxx 0010]	UC	Motor Current Monitor (16 mA/bit)
[xxxx 0011]	BC	SCI error log (0 -> no err) Bit 7 = undef Bit 6 = false TC irq Bit 5 = undef Bit 4 = false IDLE irq Bit 3 = OR err Bit 2 = NF err Bit 1 = FE Bit 0 = UNKNOWN SCI irq
[xxxx 0100]	BC	Bad character rcv'd count Bits 0-6 = Bad async char cnt (not implemented) Bit 7 = Bad checksum flag on cmd
[xxxx 0101]	BC	Overflow flags Bit 0 = RCV_Q overflow Bit 1 = ADC_Q overflow Bit 2 = CMD_Q size greater than 1 Bit 3 = Early command Bit 4 = Illegal command Bit 5 = Data record overwrite Bit 6 = ADC timeout flag Bit 7 = cmd pending flag set w/o cmd in queue
[xxxx 0110]	BC	MCU Fault flags (not implemented) Bit 0 = Clock Fail irq occurred Bit 1 = COP Watchdog timeout irq occurred Bit 2 = Illegal Op Code Trap irq occurred Bit 3 = XIRQ occurred Bits 4-7 = undef

Status Byte 4 Code	Type	Status Byte 5 Function
[xxxx 0111]		UCBUF_SKIPPED count = # "START_XMT_SEQ" skips (not implemented)

Status Byte 4 Code	Type	Status Byte 5 Function
[xxxx 1000]		UCBAD_FILL_CNT: cnts each occurence of illegal "BUF_FILL_P"
[xxxx 1001]		UCCONFIG_REG: reports value of 68HC11 configuration register programmed into internal EEPROM. (Should be = 09h to enable 'HC11 Computer Operating Properly Watchdog function).
[xxxx 1010-xxxx 1111]	X	Spare

6.2.4.6 Sixth and Seventh Status Bytes (Bytes 10-11)

These bytes can provide up to 16 different indicators depending on the value of the 4 most significant bits of Status Byte 4. The indicators defined are:

Status Byte 4 Code	Type	Status Bytes 6 & 7 Function
[0000 xxxx]	I	Rotor (Cal) Voltage (6.04 mV/bit)
[0001 xxxx]	UI	Motor Fault Pulse Count
[0010 xxxx]	UI	Idle Loop Count
[0011 xxxx]	UI	LOCK_2_FREE count = # occurrences of LOCK to FREE sync mode
[0100 xxxx]	UI	FREE_2_LOCK count = # occurrences of FREE to LOCK sync mode
[0101 xxxx]	UI	REC_OVRW_CNT count = # occurrences of data rec overwrite
[0110 xxxx]	UI	Max interval between arrival of Base Stn cmds
[0111 xxxx]	UI	Min interval between arrival of Base Stn cmds
[1000 xxxx- 1111 xxxx]	X	Spare

6.2.5 Raingauge (Byte 12)

The Raingauge tip count indicates the number of tips detected during the last second.

6.2.6 Potential Gradient Data or Extended Status Report (Bytes 13-112)

Depending on the mode of operation, the 100 bytes associated with this section of the data record will contain digitized potential gradient samples, digitized external signal samples, or an extended status report (see section 5.1).

6.2.6.1 Potential gradient Data

The three types of data records that contain potential gradient data are Normal, Split, and Calibration. See section 5.1 for a description of each. The 50 potential gradient samples are in the form of two's complement 16 bit integers in Motorola byte order, with one LSB corresponding to 4 volts/meter.

6.2.6.2 Extended Status

The following bytes are defined as the extended status indicators for the Reset and Sensor Self-Test modes, with

a) a zero value ($00) indicating that the test was not executed;
b) a value = 1 ($01) indicating that the test was successful
c) a value = -1 ($FF) indicating that the test failed

Byte 13: Microprocessor EPROM checksum test
Byte 14: MC68HC11 internal RAM test
Byte 15: Microprocessor external SRAM test
Byte 16: Microprocessor internal Serial Communications Interface test
Byte 17: R65C22 Versatile Interface Adapter test
Byte 18: Microprocessor internal intervalometer test
Bytes 19-112: Undefined

(Note: Extended status is not implemented for firmware ver 5 = MSFCEFM5)

6.2.7 CRC-16 Value (Bytes 113-114)

This parameter is a 16-bit cyclic redundancy check value computed over all bytes (1-112) of the data record by the mill microprocessor using the CRC-16 generator polynomial.

7 Potential Communication Error Sources and Solutions

Since the data communication link may consist of very long (to 25 miles) wire pairs which may be routed through multiplexers, the following deviations from ideal conditions can be expected to occur:

1. A propagation delay will exist for each link that will exhibit a fixed delay and a variable delay (jitter) due to mutiplexer proceesing delays;

2. Noise and interference due to lightning activity or anthropomorphic noise sources can couple into the communications channel.

The design of the communications protocol between the mills and the base station should allow correct operation of the network while these conditions exist.

7.1 Fixed Propagation Delay Errors

A fixed propagation delay to and from a mill will simply offset the time at which data samples are taken. This will not be a problem if the difference between the shortest delay and the longest delay is less than 20 ms; a difference greater than this would violate the potential gradient sampling timing error specification. The maximum fixed delay has been measured by KSC to be less than 15 ms. The Base Station may be able to measure the delay for each link as an operational feature. Fixed delays of any amount will have no affect on mill operation other than to delay the time at which an potential gradient sampling sequence is initiated.

Fixed delays will be visible to the Base Station. The Base Station design is required to maintain correct operation with fixed propagation delays of 20 milliseconds or less (40 milliseconds round-trip). Since the current system configuration involves the transmission of 114 byte data records at 2400 baud, the Base Station should be able to tolerate delays on the order of hundreds of milliseconds.

7.2 Variable Propagation Delay (Jitter) Errors

Propagation delay jitter can result in lengthening or shortening the time between arrival of successive commands from the Base Station to the field mills. This will obviously translate into potential gradient sampling jitter. In addition, it is necessary to ensure that commands arriving too early do not cause erroneous mill operation.

To address this contingency, the mill operating firmware will be designed to maintain correct operation under conditions where the propagation delay jitter is up to 20 milliseconds.

Propagation delay jitter will also alter the times at which data records are received by the Base Station. The Base Station design should maintain correct operation with total round-trip propagation delays of up to 80 milliseconds.

7.3 Data Corruption Due to Noise and Interference

Noise on the communication lines should not be allowed to cause a mill to erroneously change operating modes or alter its data acquisition sequence timing. If noise corrupts a data record being transmitted from a mill to the Base Station, this corruption must be detected so that the record can be marked as erroneous to prevent its use in evaluating potential gradient conditions.

In order to achieve these objectives, the following features will be implemented in the data communications protocol:

1. In the presence of noise, the UDS 19.2 modem will present properly composed but erroneous asynchronous serial characters. Therefore, overrun and framing error checks at the mills and at the Base Station are pointless.

2. Data communication from the Base Station Computer to the electric field mills will be based on four character command packets. The first character will be constant equal to A5 hex to increase the reliability of identifying the start of the command sequence. The fourth character of a command packet will be a checksum byte which allows the characters of a correctly received command packet to add to zero. While allowing only one fixed length message packet size during nominal operations tends to provide some noise immunity, the primary protection mechanism is the checksum. Some additional protection is gained by defining actual commands (the third character of the command packet) such that 2 bits separate each command from all others.

3. A mill will accept valid command packets at any time, but will discard all invalid packets.

4. If one command packet, or a few successive command packets, become corrupted by noise and rejected by the mill (such as might occur with noise occurring during a nearby lightning discharge), the mill should continue to acquire and transmit data. Provided the switch is accomplished with a delay that allows the continued reception of data records by the base

station, and provided the transmitted data records are not corrupted, this will prevent the loss of data.

5. The 114 byte data record transmitted by the field mill to the Base Station will begin with a fixed 16 bit synchronization pattern and end with a 16 bit CRC pattern. The synchronization pattern increases the reliability of detecting the start of a data record (which has time dependence known within the uncertainty of propagation delay errors). The CRC pattern provides a high degree of protection against acceptance of corrupted data.