SDI-12;

A SERIAL DIGITAL INTERFACE STANDARD

FOR HYDROLOGIC AND ENVIRONMENTAL SENSORS

Version 1.0 October, 1988

<u>SCOPE</u>: This document includes background information and definition of a serial digital interface standard for use in monitoring and powering sensors. Contents include;

This standard is industry initiated and is not currently registered by any professional society, standards organization, or Government Agency.

Document copies, current document status or mailing list information may be obtained by contacting:

Campbell Scientific, Inc
P.O. Box 551
Logan, Utah 84321 Phone: (801) 753-2342

1. PURPOSE:

The purpose of this document is to define a standard method for interfacing microprocessor based sensors to data acquisition devices.

The SDI-12 standard is intended for applications having the following general requirements:

- Remote battery powered operation with minimal current drain.
- Low system cost.
- Up to 200 feet of cable between the most distant sensor and a data recorder.
- Single data recorder with multiple sensors on one cable.

2. TERMINOLOGY

SDI -- Serial Digital Interface.

SDI-12 -- An SDI conforming to specifications given in this document.

Data recorder -- A data acquisition system with primary functions that include timing, obtaining measurement results from sensors, data processing, data storage and data transfer to display devices or other data collection systems.

SDI Sensors -- Measurement devices that include one or more transducers and a serial digital interface. Functions include measuring and transferring results to a data recorder.

SDI-12 bus -- Cable connecting multiple SDI-12 compatible devices together.

3. BACKGROUND INFORMATION

3.1 Rationale for SDI-12

A simple serial digital interface is a logical choice for communicating with sensors that include digitizing and processing functions.

Integration of digitizing and processing functions in a sensor package can be justified by the following:

- Sensors can be completely interchangeable without the requirement to re-program the data recorder with calibration or correction information.
- Hybrid circuit and surface mount technologies are improving the practicality of including the necessary power supply regulator, microprocessor and digitizing circuitry in small sensor packages. Additional cost savings may be realized by using EEPROM for

calibration and correction information instead of internal trimming operations.

- Most inherently digital sensors already require a non-analog interface to a data recorder for adequate resolution or to transfer enough information. Microprocessors are easier to incorporate in these sensors and the use of a standard serial interface eliminates significant complexity in the data recorder design.

SDI-12 compatibility in sensors and recording or display devices can result in the following benefits:

- Standardized data recorders can be mass produced independent of future sensor development.

- Sensor manufacturers can interface directly to a variety of existing recording and read-out devices.

- Manufacturers of data recorders and transmitters can interface directly to a variety of SDI sensors.

- Logistics of installation, user training and servicing can be simplified.

Other supporting reasons for SDI-12 include:

- Existing SDI sensors can easily be adapted with minor changes.

- RS232 and other EIA or IEEE standards for serial data communications do not lend themselves to the low system current drain required for environmental and hydrological data recording.

- Protection and filtering circuitry can be sufficiently effective even in electrically noisy environments.

- In many systems, costs can be reduced by operating sensors from the same power system used by the data recorder.

3.2 Requirements:

1- The interface data line must not require more than a few microamperes from the sensor or the data recorder when in an idle state.

2- The interface must provide for continuous powering of sensors from the data recorder or other source connected to the interface cable to minimize power system complexity.

3- All devices on the interface must have a common circuit ground.

4- The interface terminations inside the data recorder and sensor must provide protection against electrostatic discharge and induced voltage transients.

5- The interface must be able to provide reliable data communications between a data recorder and sensors over inexpensive shielded cable with a length of at least 200 feet.

6- The interface must be able to provide multi-drop communication between a data recorder and at least 10 smart sensors.

7- There is no requirement for the interface to transfer data at rates higher than 1200 baud or for repetitive measurements to be made more frequently than once per second.

8- The interface must use a printable ASCII protocol to allow easy monitoring of data flow using a computer or printer with an RS232 interface. Connecting an RS232 receive line to the interface should require no more than a simple voltage level conversion device.

9- The interface design as implemented in either the sensor or data recorder must be simple, inexpensive to produce, and inherently reliable in field applications.

10- No hardware handshake lines are required.

11- Common sensor failure modes or powered down conditions must not disable the interface.

12- Any SDI-12 compatible data recorder must be capable of operating correctly with any SDI-12 compatible sensor(s) within the limits of a defined basic command set.

13- Programming of an SDI-12 compatible data recorder for operation with SDI-12 sensors should be simple with a very limited number of required parameters.

4. DESCRIPTION

SDI-12 is a Serial Digital Interface for monitoring and powering compatible SDI sensors operating at 1200 baud with a nominal 12 volts available for sensor power.

The following describes SDI-12 bus lines:

12v -- Nominal 12 volt sensor power source from data recorder or external power source.

Data -- Bi-directional, 3-State data transfer line.

Ground -- Power return and ground reference for data line.

5. PHYSICAL AND ELECTRICAL SPECIFICATIONS

In the following specifications, all values not indicating specific limits, have an allowable tolerance of $\pm$ 10% of the value.

Cable -- A cable with three conductors is required (12v, Data and Ground). The ground line will be connected to circuit ground at the point of connection to any circuit device. The ground conductor should be large enough to keep the voltage drop between the data recorder and the sensor less than 0.5 volts during the maximum sensor current drain.

Connector -- The connector type is not specified.

Serial Data Line

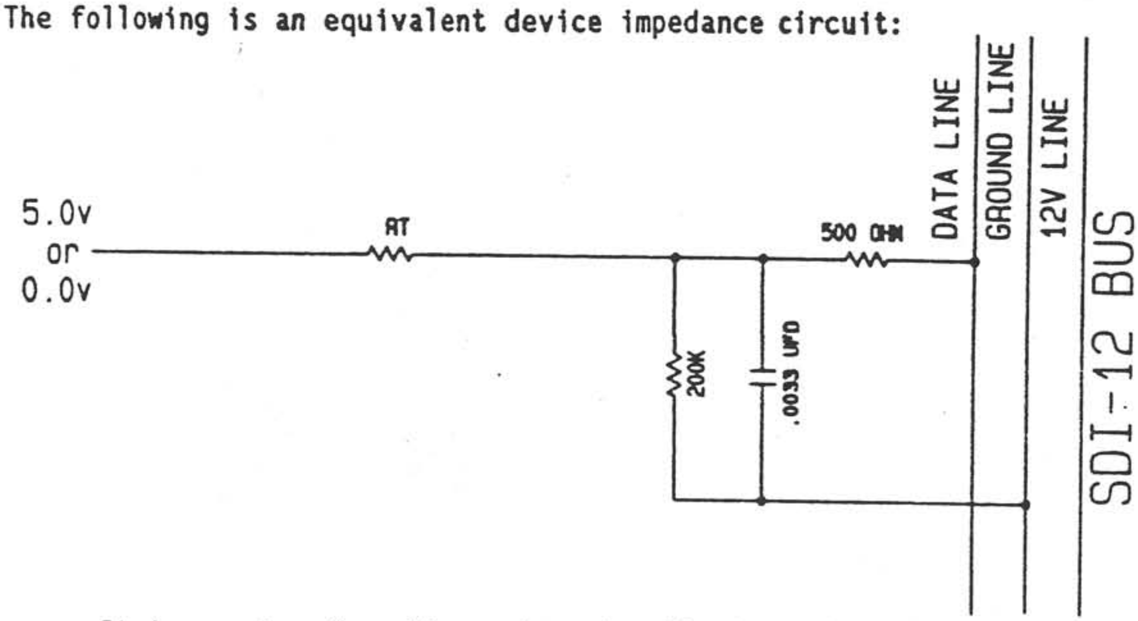
Voltage levels -- Serial data will be transmitted according to the following logic and voltage levels:

Condition	Binary State	Voltage Range
Marking	1	-0.5 to 1.0 volts
Spacing	0	3.5 to 5.5 volts
Transition	Undefined	1.0 to 3.5 volts

Voltage transitions -- During normal operation, the data line voltage slew rate will not be greater than 1.5 volts per microsecond.

Impedance -- When any device's transmitter is on, its DC source resistance will be more than 1000 ohms and less than 2000 ohms. When any device's transmitter is off (including during a low power standby mode), the DC resistance to ground will be 200k. If a sensor does not use the 12v line for power, its data line resistance to ground while powered down will be 200k.

The following is an equivalent device impedance circuit:



Rt is greater than 10 megohms when the transmitter is off and is between 500 and 1500 ohms when the transmitter is on.

Grounding -- The Ground line will be connected to circuit ground and Earth Ground at the data recorder. The sensor circuit ground will also be connected to the Ground line but not normally to its own earth ground. If it is necessary to connect the sensor circuitry to earth ground, a heavy (12 awg. or larger) ground wire should be connected between the sensor earth ground and the data recorder earth ground for lightning protection.

Transient Protection -- Not specified but highly recommended (See Appendix B.).

Sensor Power Supply

The 12v line will be set by the data recorder or external power source at a level between 9.6 volts and 16 volts with respect to ground as measured under a maximum sensor load of 0.5 amperes. The data recorder is not required to be the source of power to the 12v line.

Sensors connected to the 12v line will not have inductive loads. Voltage limiting for transient protection in the sensor is not specified but highly recommended (see Appendix B. for suggested circuits).

6. COMMUNICATION PROTOCOL

Overview

All communication will be in groups of successive bytes called blocks. During normal communication, the data recorder sends a command block with sensor address to an active sensor which immediately responds by transmitting a block back to the data recorder. The sensor response contains information about further processing it will do, or contains results from previous processing. If the sensor has more processing to do, it will complete the processing, then send a service request back to the data recorder indicating that it is ready for another command.

The normal operating sequence of initiating a measurement, waiting for it's completion, then collecting data will be completed on any sensor before starting with a subsequent sensor.

Inactive sensors are normally in a low power standby mode. Before initiating communications, the data recorder wakes all sensors by sending a break (continuous spacing for at least 12 milliseconds).

Tolerances

In the following specifications, all time values not indicating specific limits have an allowable tolerance of ± 0.4 milliseconds.

Block -- There will be no more than 1.66 milliseconds of marking between the end of a stop bit and the beginning of the start bit on the next byte in the same block. The beginning of a block is the first byte transmitted after the data line has been in the marking state for at least 8.33 milliseconds.

In all blocks transmitted by the data recorder, the first byte is the address of the sensor to receive the block and the last byte is 21H (ASCII "!").

In all blocks transmitted by a sensor, the first byte is the address of that sensor and the last two bytes are 8DH and 0AH (ASCII <CR> and <LF> with even parity) in that order.

Block Length -- A block of bytes or characters will be at least two bytes long and not more than 36 bytes long. This will allow the result of a basic command and its response to fit on a 40 character line.

Byte Frame Format -- All transmission will be asynchronous having 1 start bit, 7 data bits with the least significant bit first, 1 parity bit with even parity and 1 stop bit.

Baud Rate -- 1200

Code -- Every byte will be a printable ASCII character or a <CR> or <LF> control byte.

Break -- A break is transmitted by setting the data line to spacing for at least 12 milliseconds. A break is detected as continuous spacing on the data line for at least 6.5 milliseconds. This is a unique condition used to wake sensors from a low power standby mode.

Command-Response Characteristics -- The data recorder will transmit a command only after setting the data line to marking for 8.33 milliseconds.

After the last character of the command has been transmitted, the data recorder will turn off its transmitter within 7.5 milliseconds.

Sensor responses will be transmitted by setting the data line to marking for 8.33 milliseconds, then sending the response. The response must be initiated within 15 milliseconds of receiving the last byte of a valid command.

Sensor Service Requests -- After a measurement or other sensor processes, the sensor initiates a service request by sending its address byte followed by a <CR><LF>. This is normally used to indicate to the data recorder when a process is completed.

Low Power Standby Timing -- All sensors will wake up from a power down standby mode within 100 milliseconds after detecting a break on the data line. The data recorder will initiate sensor wake-up with a break of at least 12 milliseconds. The sensor will not recognize a break condition for a continuous spacing time of less than 6.5 milliseconds and will always recognize a break condition when the line is continuously spacing for more than 12 milliseconds.

Sensors will return to a low power standby mode after receiving an invalid address or after detecting a marking state on the data line for 100 milliseconds.

If a different sensor is being addressed or if the data line has been in the marking state for more than 87 milliseconds, the next data recorder command will be preceded with a break of at least 12 milliseconds.

Action on "No response" or "Invalid Response" -- If the first start bit of the response is not received by the data recorder within 16.67 milliseconds after the last stop bit of the command transmission, the command can be re-transmitted. If an invalid response is received from the sensor, a command can be re-transmitted.

If a correct response is not received after re- transmitting the command at least 2 more times, the entire sequence (including the break and the re-trys) should be repeated at least two more times. If there is still no response, the error will be identified (usually with out of range data) and the data recorder will proceed with the next operation.

If the data recorder is looking for a response and detects continuous spacing or a transmission block with a duration of more than 380 milliseconds the error will be identified and the data recorder will proceed with the next operation.

When Sensor Communications Are Disabled -- After the sensor receiver is disabled for a period of time (e.g. during a wake up sequence), as it becomes enabled again, it will not accept a block as valid until it has detected a continuous marking state on the data line for 8.33 milliseconds.

9-16-97 not in version 1.2 Bob Randall

7. BASIC COMMAND SET

Characters Used

All commands and data transferred by the interface will be in the form of printable ASCII characters, i.e. characters between "!"(21H), and "~"(7EH). The last character of a valid command block is an exclamation mark (!). The last two characters of a valid response are <CR> and <LF> in that order.

Device Addresses

The first character of a command block will be the sensor address. The first character of all responses will be the address of the responding sensor allowing the recorder to verify where the response is coming from.

Sensor addresses will be pre-programmed using physical jumpers, switches, or non-volatile memory in the sensor.
Standard address codes are as follows:

Character	Description
0	Default sensor address. Unless otherwise specified, all sensors will be initially programmed for this address for use in single sensor systems.
1 - 9	Addresses for additional sensors connected to the same SDI-12 bus.
Others	Any other printable ASCII character may be used as an address but not within the scope of this instruction set.

Command and Response Description

In the following description, commands and responses are enclosed in quotes with the sensor address represented by an "a". "ttt" represents a three digit integer specifying the maximum time in seconds for the sensor to have resulting data available in its buffer. This time includes the time required to send a service request back to the data recorder. The valid range of "ttt" is 000 to 999 seconds.

"n" is a single digit integer specifying the number of values that will be placed in the data buffer with a valid range of 0 to 9. Carriage return, and line feed will be represented by "<CR>" and "<LF>".

Command	Description and response
"aM!"	Initiate a Measurement. The response is "atttn<CR><LF>". The values generated by measurements in response to this command are retained in the sensor for subsequent collection using "D" commands. If "ttt" is not "000", a service request ("a<CR><LF>") is sent to the data recorder after the measurement is completed indicating that the sensor has data ready. Then "D" commands are used to collect the data. If the service request is not received properly before the specified processing time ("ttt") has elapsed, the data recorder wakes the sensor with a break and collects the data. If "ttt" is "000", then the specified number of data values will be available as soon as it can be retrieved with "D" commands and no service request will be sent from the sensor. Resulting data will be retained in the sensor until another "M" or "V" command is executed.

If an invalid response has been received, the re-try sequence may cause a break to be sent. The sensor should abort its measurement upon receiving a break and flag this condition so that subsequent "D" commands return no data. Then the sensor will be able to respond to a re-try of the "M" command.

Unless sensor operation is aborted with a break, no commands can be issued by a data recorder until after an anticipated service request has been received or until the maximum time "ttt" has elapsed.

"aV!" Initiate Verify sequence. The response is "atttn<CR><LF>". After the verify sequence is completed, a service request is sent to the data recorder (if "ttt" is not "000") and data will be collected using subsequent "D" commands.

The result of this command is exactly the same as an "aM!" command except that the data returned is from a verification sequence instead of a measurement. The data returned by this command may include ROM signatures or CRC's, RAM test results or results of other diagnostic processes.

"aD0!" through "aD9!" -- Send Data. The response is "a<values><CR><LF>" (see the next section for value format). Values returned by a "D" command will be sent in 33 characters or less. The data buffer in the sensor will not be altered by this command.

If the number of values returned by a "aD0! command is less than the number specified by the result of the previous "M" or "V" command, the rest of the data will be collected using "aD1!", "aD2!" ... and so on until all values specified have been collected.

If one or more values were specified and a valid response to "aD0!" is returned with no data, it means that the measurement was aborted and a new "M" command will have to be sent.

"aI!" Send Identification. The response is "allccccccccmmmmmmvvvxxx...xx<CR><LF>". "ll" is the SDI-12 level number indicating the SDI-12 version compatibility, e.g. version 1.0 would be represented as "10". "cccccccc" is an 8 character vendor identification to be specified by the vendor and usually in the form of a company name or its abbreviation. "mmmmmm" is 6 character field specifying the sensor model number and "rrr" is a 3 character field specifying the sensor version number. "xxx...xx" is an optional field of up to a maximum of 13 characters to be used for serial number or other specific sensor information that is not relevant to operation of the data recorder.

Level, Vendor, Model, and Version data will be provided as a unique response to allow a data recorder to automatically select sensor specific firmware if it has this capability.

"a!" Acknowledge active. This command returns a "a<CR><LF>" response and would usually only be used with the transparent mode (Extended Command Set) to make sure the sensor responds before sending a more lengthy command.

"aM1!" through "aM9!" -- Additional measurement commands for different types of measurements. The result of this command is exactly the same as the "M" or "V" command. This extension allows a data recorder to initiate different types of measurement, calibration, or control functions at different time intervals. If "n" is zero (0), no data will be available using subsequent "D" commands.

Data Format

Responses to the "D" command will be of the form "apd.d<CR><LF>" where "a" is the sensor address, and "pd.d" is the value ("p" is the polarity sign, "d" represents numeric digits before and/or after the decimal). A decimal may be used in any position in the value after the polarity sign. If a decimal is not used, it will be assumed to be after the last digit.

The polarity sign (+ or -) will always be the first character of a value. This means that in a response with multiple values, the polarity sign is the delimiter between values.

The data recorder will be able to receive values containing between 1 and 7 digits.

The following is an example of a data response block from a sensor (address 0) containing 5 values (29 characters of data):

0+3.29+23.5+65.3-25.45+75.5491<CR><LF>

Example of Interaction

The data recorder will only require knowing a sensor address and the type of measurement (M or M1 through M9) to read a sensor. The following is an example of a measurement sequence using the sensor at address 0, requiring a maximum of 3.4 seconds for the measurement:

1- When recording begins, a wake-up break and "0M!" is sent to a sensor. "0M!" may have to be repeated up to 3 times to allow time for wake up from a low power standby mode.

2- The sensor responds with "00042<CR><LF>" acknowledging that it is sensor "0" and indicating that after 004 seconds are allowed for the measurement, 2 values of data can be collected.

3- The data recorder waits for a service request or for 4 seconds to elapse. If a service request is received, "0D0!" is sent to collect the data. If a valid service request is not received before 4 seconds has elapsed, a break is sent to wake up the sensor, then the data is collected with a "0D0!" command. One or two re-trys may be required if the sensor doesn't wake up immediately.

4- A wake up break followed by "1M!" is issued to the next sensor (if a second sensor is on the line). Then the rest of the sequence is the same for retrieving data.

5- Within 100 milliseconds after the last data is collected, all sensors are in a power down standby mode.

8. EXTENDED COMMAND SET

A sensor is only required to be able to respond to the basic command set in order to work properly with any SDI- 12 compatible data recorder. However, sensors will usually require calibration, address changes, or other setup commands that could be executed from a separate computer or terminal connected to the data recorder. This requires that all data recorders are able to operate in a transparent mode with the following characteristics:

1- The data recorder buffers the command string as received from a computer, terminal, or modem until it receives "!".

2- The data recorder wakes up the sensor and sends the "a!" command until it responds, then it sends the buffered command to the sensor.

3- The data recorder stores the response from the sensor and re-transmits the response to the computer, terminal, or modem.

The definition of a standard extended command set may be developed in the future; however, commands other than the basic command set have no specified significance within the scope of this standard.

APPENDIX A

This document describes the SDI-12 Standard Version 1.0 dated Oct. 1988 and differs from the previous SDI-12 document, dated May, 1988, as follows:

Scope: Appendix A was changed from "List of supportive SDI-12 respondents" to "SDI-12 Documentation and Update Reference".

"Document copies may be obtained by contacting individuals listed in Appendix A" was changed to "Document copies" etc. "may be obtained by contacting Campbell Scientific" etc.

3.2 Requirements: 1- was changed from "must not require power" to "must not require more than a few microamperes".

2- was changed from "the data recorder" to "the data recorder or other source connected to the interface cable".

4. Description: On the description of the 12v line, "data recorder" was changed to "data recorder or external power source".

5. PHYSICAL AND ELECTRICAL SPECIFICATIONS:
<u>Sensor and Power Supply</u>: "data recorder" was changed to "data recorder or external power source".

The next two paragraphs about fusing the 12 volt line and current limitations were deleted.

6. COMMUNICATION PROTOCOL
<u>Overview</u>: After the first paragraph, the following was added: "The normal operating sequence of initiating a measurement, waiting for it's completion, then collecting data will be completed on any sensor before starting with a subsequent sensor."

In the next paragraph, "(continuous spacing for one byte frame of time)" was replaced with "(continuous spacing for at least 12 milliseconds)".

<u>Break</u>: definition changed to be in terms of what is transmitted and what is detected.

<u>Command-Response Characteristics</u>: In the third paragraph, "response must be transmitted" was changed to "response must be initiated".

7. BASIC COMMAND SET
<u>Command and Response Description</u>: References to "tt" and corresponding two digit integer were changed to "ttt" and corresponding three digit integer. Also, the valid range was changed from "01 to 99 seconds" to "000 to 999 seconds".

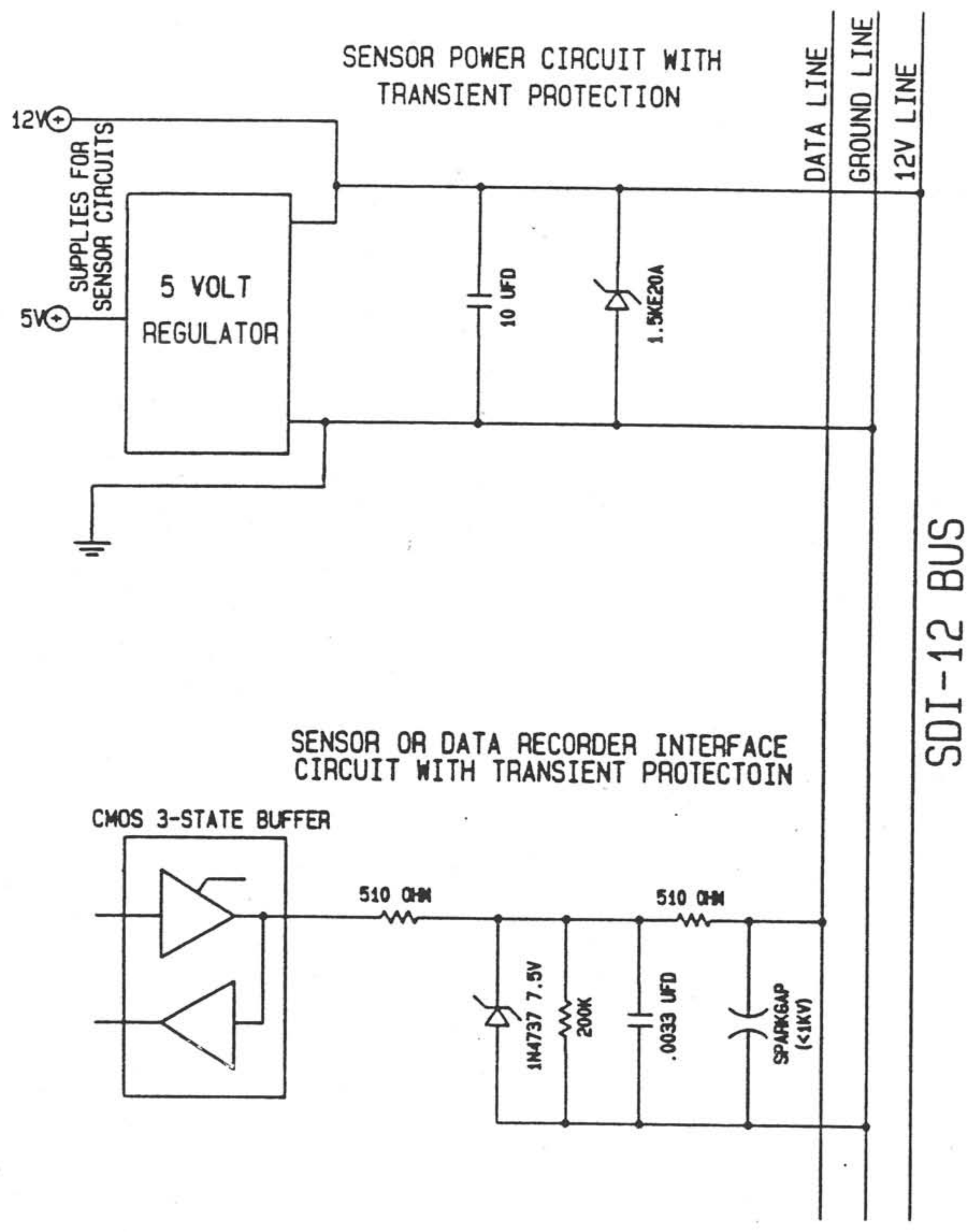
In the second paragraph, "nn" and the corresponding "two digit" were changed to "n" and a corresponding "single digit". The valid range was changed from "00 to 99" to "0 to 9".

In the "aI!" command, a two digit value "11" was inserted in the response to indicate the SDI-12 version level.

Example of Interaction: In step 2, "00402" was changed to "00042" to be consistent with above change to "tttn".

APPENDIX A: Was changed from a list of participants and interested parties to this list of changes.

APPENDIX B
SUGGESTED SDI-12 CIRCUITS



APPENDIX C

The flow charts shown represent possibilities for data recorder and sensor designs that comply with SDI-12 communication protocol. The data recorder flow chart only includes command-response interaction and does not represent functions between commands such as detecting a service request.

Symbol definitions and implications are as follows:

Rectangle -- Process. Flow will exit via a single path when the process is completed.

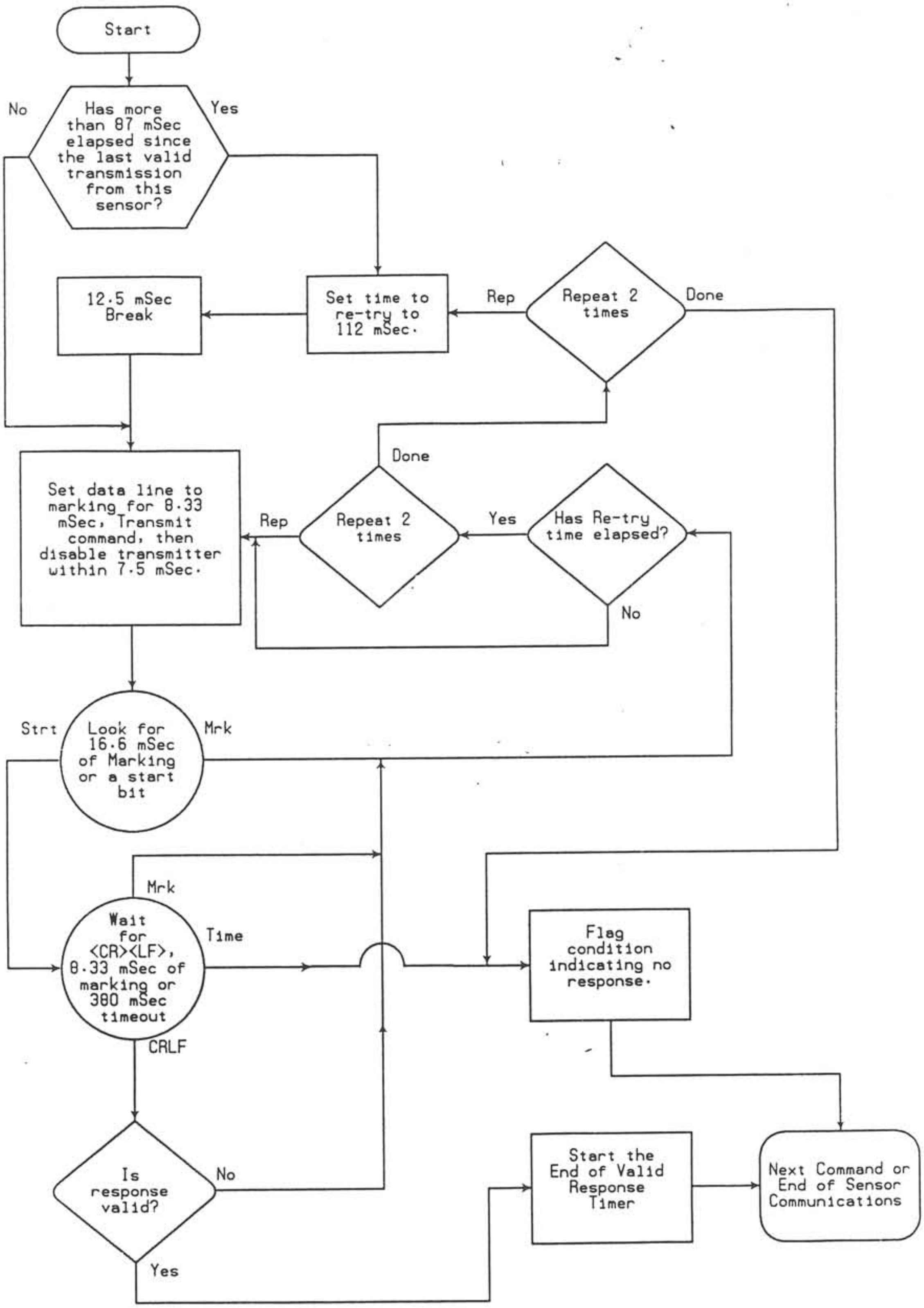
Rectangle with rounded corners -- Starting point or end of flow chart.

Circle -- State. System is waiting for an external condition or time-out. Flow will exit specified path when a corresponding condition is detected.

Diamond or Hexagon -- Decision based on result of process or immediately available condition.

Diamond with "Repeat n times" inside -- Entries to this decision are counted. When the entry count is less than or equal to "n", flow exits the "Rep" path. When the entry count is greater than "n", flow exits the "Done" path and the counter is reset to zero. The counter is also reset to zero at the starting point of the flow chart.

SDI-12 DATA RECORDER FLOW CHART



SDI-12 SENSOR FLOW CHART