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PRECISION MEASUREMENT DEVICES

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REDUCED POWER BROADBAND DIGITAL SEISMOMETER SYSTEM MODEL EP300-DT

Date of Shipment March 15, 2004

OPERATION MANUAL

TABLE OF CONTENTS

Part 1. The EP300-DT Seismometer

1. Introduction.

The EP300-DT is a customized version of the Model EP300 seismometer designed in compliance with the specification of he ORION project.

Unlike traditional seismometers, electromechanical instruments are extremely rugged and do not need to be equipped with arresters or any other special devices for handling, packing, unpacking or transportation. The instruments also do not require mass centering and thus do not have mass position outputs and mass centering inputs. The leveling of a seismometer is intended only for the purpose of the proper orientation of the sensitivity axes. The instrument is fully functional with installation tilts of up to 10°. In order to account for the tilt and be able to rotate sensitivity axes into proper position in those field or ocean-bottom installations where leveling in not possible, model EP300-DT is equipped with a precision bi-axial tiltmeter. The EP300-DT outputs are directly connected to PMD Model 6503 Sensor Digitizer which is described farther below in this Manual. Seismometer, Tiltmeter and Digitizer are placed in the titanium pressure cylinder supplied by the Nautilus Gmbh of Bremen, Germany. Three seismic sensors are mounted directly on the base of the cylinder; the tiltmeter with its interface board and the junction blocks and then the digitizer are placed on the top of the seismometer in that order. A photo of the EP300-DT assembly with the cylinder tube removed in shown in the Section Part 3-1 below.

i. Orientation

An arrow and the letter "N" on the upper cover of the titanium cylinder points out to North. The tiltmeter is oriented the same way as the seismometer, with its 'X' axis aligned along the 'N' and 'Y' along the 'E' axes of the seismometer respectively.

ii. Connection.

This ORION project system is equipped with an 8-pin watertight connector whose wiring diagram is shown in the Part 3 of this Manual.

The differential outputs **+N**, **-N**; **+E**, **-E**; **+Z**, **-Z**, are connected to the differential inputs of the data recorder. Each of these outputs can have a maximum swing of ±10V, resulting in the differential swing of ±20V (40V peak-to-peak).

iii. Power

Nominal input voltage is 12 Vdc, with an acceptable range of 9 to 15 Vdc. Nominal current consumption for the EP300-DT seismometer is 14mA [1]. Peak consumption for several seconds immediately after power-on or during strong seismic events may reach up to 100mA; therefore it is necessary to use a power supply capable of producing such current. If an excessive and/or an improper polarity voltage is applied, the built-in resettable fuse will disconnect power. In this event it may be necessary to wait a few minutes until the fuse recovers.

2. Operation of the Instrument

The instrument has a very short settling time and begins operating normally within a few minutes after the power was turned on. However, like in any other seismometer, achieving the normal low noise level of operation may require many hours after the instrument has settled mechani- cally and the temperature gradients between and within all components come to or near zero. As any other electrochemical sensor, the EP300-DT seismometer requires no adjustment or any other maintenance over the whole life of the instrument.

3. Calibration

In the EP300-DT seismometer **CAL_EN (Calibration Enable)** inputs of all three seismometer channels are connected together with the common **CAL_IN** input. A corresponding calibration command sent to the digitizer results in a 3V step applied to the calibration coils of all three sensors. The calibration circuits are such that the output response signal should have the same initial amplitude at the input.

4. Transportation

The seismometer itself is extremely rugged and is difficult to damage during transport. Still, it is recommended to be pad the sensor with a dense foam so that it fits snugly in the packing box to prevent breaking the box in the event of a shock. If the sensor is shaken, a very slight rattling sound may be heard; it is normal and should not be a matter of concern.

[1] Important notice: since EP300 is a force-balanced instrument, the above current consumption numbers relate to very quiet conditions when seismic signal levels are low; when checked in a laboratory environment, where an inescapable cultural, weather-related, etc. noise is always present, the balancing feedback action will probably increase consumption by up to several milliamperes. In the quiet condition in a vault or especially on the ocean-bottom the above given number will be complied with.

5. Seismometer Transfer Function

Response of the Model EP300 seismometer is velocity-flat in the passband with the sensitivity 2000 V*sec/m; low-frequency cutoff: 2nd order filter; damping 0.707 critical; high-frequency cutoff: 3rd order Butterworth filter. Analytically, the seismometer transfer function can be described by the following expression:

$$W(jf) = \frac{K \cdot (j \cdot f)^2}{\prod_{n=1}^{5} (j \cdot f - p_n)}$$

Where f = frequency, Hz; j = imaginary unit; $K = 6.74 \cdot 10^7$ V/(m*sec^2).

Values of poles p_n are listed in the Table below:

n	Value
1	-0.012+0.012j
2	-0.012-0.012j 3
	-30.0
4	-16.8+30.0j
5	-16.8-30.0j

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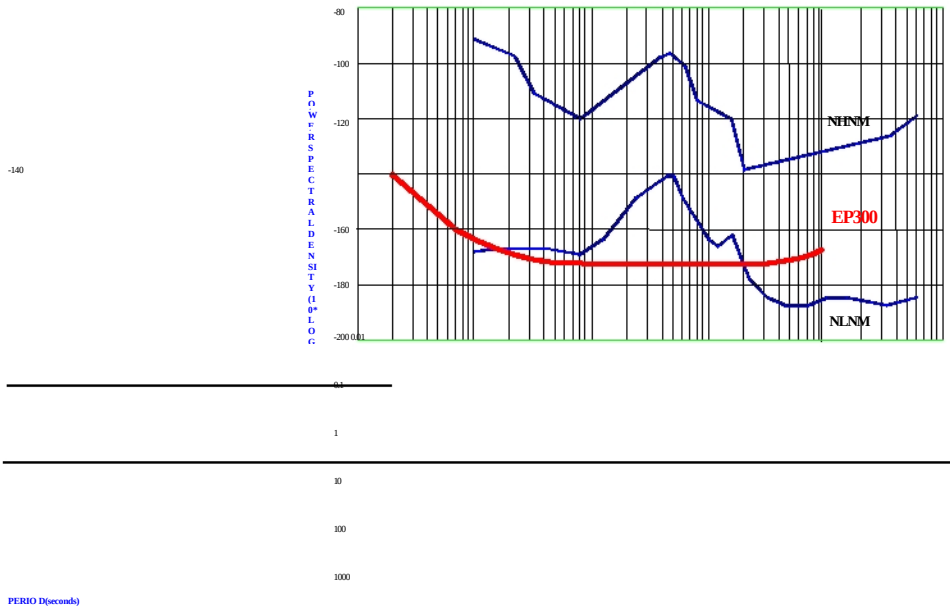
6. EP300-DT Seismometer Specifications[2]

Operating principle:	Electrochemical motion transducer with force-balancing feedback
Output analog signals	2 horizontal, 1 vertical; very broad passband, velocity flat response
Output analog signal swing	40 V p-p differential
Output digital signal	See "The Digitizer" section below
Dynamic Range	150 dB @ 1Hz
Bandwidth	0.0167 - 50 Hz
Self-noise	Below USGS NLNM in 0.05 - 5Hz range; -170dB @ 0.033Hz. (See noise curves below)
Generator constant	*Standard*: 2000 V/m/s; *Opt.*: 350 - 20,000 V/m/s
Calibration input	1kΩ; 1V in - 1V out
Mass Lock	*NONE REQUIRED*
Mass Centering	*NONE REQUIRED*
Maximum installation tilt [3]	10°
Mechanical resonances	>150 Hz
Environmental	Waterproof, submersible to 6000m
Temperature range	-12 to + 55° C
Case diameter	225 mm 538
Case height	mm
Weight (Al housing)	~37 kg
Power - Standard	9 - 15 Vdc; 12 Vdc nominal
Supply current	14mA

EP300 SEISMOMETER NOISE CURVES



[2] Specification of the Digitizer see farther down in this Manual

[3] All three sensors stay fully operational, however they sensitivity axes will rotate in accordance with the tilt.

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Part 2. The Digitizer

Rev. August 2003.

1. Introduction.

The **PMD 6503 Sensor Digitizer** is the essential minimum version of the **PMD 6500** family of data acquisition products, in that it eliminates both the hard disk and PC. When combined with a PMD, or other seismometer, it becomes ***a high-resolution digital seismometer***. The digital data stream can be connected via an RS-232 or RS-485 serial port and a digital radio or cable link to a central data collection computer. The large SRAM buffer ensures reliable data retrieval even in highly unreliable transmission conditions. The digitizer consumes extremely low power without sacrificing its high resolution, deep anti-aliasing filtering, and wide range of programmable parameters.

This versatile device can adapt to many applications and configurations:

- Mounted within the case of a PMD broadband seismometer.
- As a stand-alone attachment, it can convert the output of any analog sensor into a digital stream.
- It can be readily fit into a benthic sphere or other pressure vessel along with a PMD broadband seismometer for OBS applications.

2. Specifications.

DIGITIZER

Converter Type:	24-bit Δ-Σ; 320 kHz Base Rate
Dynamic Range:	>137 dB @ 100 sps (rms to FS)
Data Channels:	3 (4)[4]; opt. up to 16; Differential *or* Single-Ended
Sampling Rates:	0.1, 1, 10, 20, 40, 80, 100, 200, 500, 1000, 2000, 4000 sps
CMR @ 50, 60 Hz	120dB
Analog Anti-Aliasing Filter:	>100 dB @ primary sampling rate
Digital Filter (@ output Nyquist):	>140 dB @ 200 sps (FIR or opt. IIR)
Programmable Gains:	1,2,4,8,16,32,64
Differential Input Signal Range:	Programmable: ±2.5, ±20 V
Input Impedance	±2.5V - 1MΩ; ±20 V - 300kΩ
Overvoltage Prot.	±40 V
State-of-Health Channel:	Full 24-bit resolution
Static RAM Buffer:	Up to 16MB

[4] Fourth channel may be used as state-of-health channel or function as fully featured data channel

TIMING SYSTEM

Type:	PLL controlled, GPS-referenced
Max. Accuracy (Software Selectable):	<100µsec
Crystal Frequency Correction Resolution	0.016 ppm
GPS Duty Cycle (User Selectable):	Once every 18 hrs to achieve <1msec accuracy
1PPS	Level 5V
GPS connection:	RS-232; speed 4800; Rx and Tx signals.

CUSTOMIZED ORIONTIMING SYSTEM

Type:

PPS

Time reference connection:

Max. Accuracy (Software Selectable):

Crystal Frequency Resolution

Time reference Duty Cycle: 1

POWER

PLL controlled, GPS-referenced <100µsec

1 ppm; PMD factory calibrated:

Voltage:

0.016 ppm

0.5

-

1.5

hours

Level

3.3V

RS-232; speed 9600; Rx signal.

Overvoltage protection:

Power consumption

Size (PCB card stack)

Weight

USER INTERFACE

Remote PC:

Reset

COMMUNICATION

Continuous Data Retrieval:

ENVIRONMENTAL

Housing

Operating T° Range

Storage T° Range

6-16 Vdc ±600 V ≤5000 mW (3 channels, 100 sps)	onfigured via serial port	nds on application -30 to +50°C	o +60°C
C	Deepe	-40 t	L 120 x W 120 x H 50mm <0.5 kg

P

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3. Time keeping system.

The digitizer employs a unique time keeping system, with main clock fully synchronized with the clock used for Analog-to-Digital conversion. Therefore, exactly the pre-set number of samples is taken every second4 and thus the user never needs need to re-index data and there are never any gaps in the recordings.

With the GPS-receiver working periodically, as required, the system is capable to maintain time precision better than 100microseconds.

Without GPS if the system was pre-calibrated at the, factory the clock precision can be as high as 0.02 PPM.

The customized time keeping system that was implemented for the Orion Project corrects time just at the moments of synchronization. With 1PPM crystals installed a 1 sample gap (at 100 sps sampling rate) may appear once in 3 hours.

The messages id are to be sent for ~1 minute with periodicity from 0.5 to 1.5 hours. The system evaluates a few messages and uses the average value to reduce error. After successful synchronization the system remains in the "sleep" mode for 0.5 hours and then waits for 1 hour for the next session.

i. Electrical specifications.

Rx signal have RS-232 levels, communication speed 9600;
1 PPS has level 3.3V, square wave with a rising edge corresponding to the beginning of a second.

ii. Message format.

A time message that sent just after the rising edge of a PPS signal has the following format:

T**yyddmmHHMMSS\r\n**

where

T	- this letter "T" is a time message identifier;
yy	- two last digits of the year;
mm	- month;
dd	- day of month;
HH	- hour;
MM	- minutes; -
SS	seconds;
\r	- carriage return 0Dh;
\n	- new line symbol 0Ah.

4. Communication protocol.

This system is capable of transferring data over RS-485 port at up to 460.8 Kbps rate for a distance of up to 1km (the latter with a slight reduction of the baud rate), which is possible because this is a differential port and hence immune to noise. The current realization supports both full-duplex (4 wires) and half-duplex (2 wires) modes. The same port has an RS-232 interface.

The digitizer has an internal RAM buffer up to 16Mb. The use of a full size buffer could be necessary in case of communication problems.

The communication protocol has 3 layers:

Data - The system's internal format of data storage and transmission command is based on objects (C language STRUCTures). The type of structure is identified by a tag. All data are binary;

Block - Provides a transmitting block with a block length and a one's complement of a one's complement checksum;

SLIP - Transmission protocol over a serial port.

5. Data layer.

System internal format of data storage and transmission command is based on objects (C language STRUCTures). The type of structure is identified by a tag.

All data are binary. Data representation in DSP TMS320V5409 is a little tricky. A short integer has the same byte sequence as in IBM-PC. It means that LSByte comes first, MSByte - second. But a long integer number consists of two 2 byte-words, that are placed in reversed order in respect to the IBM-PC format. Thus, if in IBM-PC the byte sequence of bytes is [0123], in this DSP it would be [2301].

All tags contain headers; each header is similar to the header of a data block (see structure *BufCom* up to *aiBuf*). It is useful because some tags (log messages for instance) are saved with data blocks in the RAM buffer. Only some tags have structures associated with them. The others contain only a header.

Shown below is a self-explanatory declaration that can be used to interpret tags:

```
/* Info type definition TAGs. Define the type of transmitted
info.         */
#define TAG_EMPTY              0    /* Empty message was trans-
mitted. */
#define TAG_CHANNEL_INFO 1     /* ChannelInfo    transmitted. */
```

```
#define  TAG_CHANNEL_INFO_REQ    2     /* ChannelInfo     request.
*/
#define  TAG_TIME_INFO           3     /* Time keeping system infor-
mation.  */
#define  TAG_SYSTEM_RESET 4      /* System reset.
*/
#define  TAG_COMM_COMMAND 5      /* Communication command.
*/
#define  TAG_LOG                 6     /*  Block  contains  log  mes-
sages.        */

/* Calculates tag size.                                    */
/* Calculates a tag size.                                       */
#define TAG_SIZE(TAG) \
     ( ( (TAG) == TAG_CHANNEL_INFO )      ? sizeof( ChannelInfo )
     \
          : ( ( (TAG) == TAG_TIME_INFO ) ? sizeof( TimeInfo )
     \
               : ( ( (TAG) == TAG_COMM_COMMAND ) \
                         ? sizeof( CommCommand ) : 0 ) ) ) /*
Defines a TAG or a Block.                                    */
#define TAG_PROVIDED(P_BUF)     ( (P_BUF)->uNumber > BUFCOM_N )
/* Gives a TAG type.            */
#define TAG_TYPE(P_BUF)         ((P_BUF)->uChan)
/* Produces the repetition number of the TAG(array size).
*/
#define TAG_NUMBER(P_BUF)       ((P_BUF)->uNumber-BUFCOM_N-1)
/* Set a tag type and a number of the TAG(array size) in buffer
items.        */
#define TAG_SET(P_BUF,TAG,NUMBER)\
   (P_BUF)->uChan=(TAG); (P_BUF)->uNumber=(NUMBER)+BUFCOM_N+1
/* The script defines a tagged message size in 16 bit
words(short).        */
#define    TAG_MESSAGE_SIZE(SIZE)    /* SIZE is a size of sended
info.*/    \
     (((SIZE)+sizeof(     BufCom     )-sizeof(     short     )*BUFCOM_N-
1)/sizeof( short )+1)
/* The short integer in DSP TMS320V5409 has the same byte se-
quence as */
/* in IBM-PC. It means that LSB is the first, MSB is the second.
But */
/* long integer number consist of two words(2 byte), those are
swapped    */
/* in comparison with IBM-PC. That is if in IBM-PC sequence of
bytes      */
```

```
/* is [0123] then in DSP it is [2301]. The next script swaps
them back.      */
/* The script swaps the short halves of a long integer.
     */
#define SWAP_LONG(DEST)         \
     (((unsigned long)(*(unsigned short *)(&(DEST)))<<16)\
                          |(*((unsigned short *)(&(DEST))+1)))
/* The script swaps the short halves of a long integer in place.
     */
#define SWAP_LONG_IN_PLACE(DEST)     (DEST)=SWAP_LONG(DEST)
```

The tag descriptions below are presented in the same sequence in which they are supposed to be used:

i. Request of channel information - TAG_CHANNEL_INFO_REQ.

This tag requests that the digitizer send current channel configuration information. It is a simple command that does not have an associated structure. Can be expressed by the script:

```
TAG_SET(&suBuffer,TAG_CHANNEL_INFO_REQ,0);
```

Only 4[`TAG_MESSAGE_SIZE(0`] 16 bit words need to be sent. The script `TAG_MESSAGE_SIZE(0)` can be used to calculate a message size.
In response, the digitizer will send channel information. Format of this message is similar to the channel information command.

ii. Time information - TAG_TIME_INFO.

Sends to the digitizer initial time and other parameters not related to channel setting. Related structure:

```
/* The structure is used to save information about Time Sys-
tem.<TimeSys.h>*/
typedef struct { long lCallTime;           /* Preferable call
time.*/
         short     sTrsInitTime;         /* TRS init time.     */
         short     sEpochMsec;           /* Part of time (msec)
   */
         long      lEpochSec;            /* Current time (sec)
   */
         long      lEpochPrecision;      /*       Time       preci-
sion(mksec)*/
         long      lOscillator;          /*     Oscillator      fre-
quency.*/
         long      lFrequency;           /* Base frequency. */
         long      lCalibrInterval;      /*    Interval     between
imp.*/
```

```
        short     sCalibrDuration;     /* Duration of impulse.
   */
        short     sDummy3;         /* Compatibility with PC*/
                        } TimeInfo;
/* The script swaps the long intengers in a TimeInfo struc-
ture.      */
#define TIME_INFO_SWAP(P_TI)      \
   SWAP_LONG_IN_PLACE((P_TI)->lCallTime);
                                                  \S
   WAP_LONG_IN_PLACE((P_TI)->lEpochSec);          \
   SWAP_LONG_IN_PLACE((P_TI)->lEpochPrecision); \
   SWAP_LONG_IN_PLACE((P_TI)->lOscillator);            \
   SWAP_LONG_IN_PLACE((P_TI)->lFrequency);        \
   SWAP_LONG_IN_PLACE((P_TI)->lCalibrInterval)
```

where:

lCallTime	- preferable GPS call time (default 0);
sTrsInitTime	- Time Reference Source initiate time. In practice, this is the minimal time between TRS calls. In case of an uncontrollable TRS with 1 hour interval between sending a better choice is 1800sec;
lEpochSec	- initial time in seconds from January 1st, 1970;
sEpochMsec	- time fraction in milliseconds (default 0);
lEpochPrecision	- time keeping precision. Unrelated to the uncontrollable TRS and should be set to 1;
lOscillator	- oscillator frequency (64,000,000);
lFrequency	- base sampling rate of the ADC converters, default 4000Hz, but may be reduced in systems with more than 6 channels;
lCalibrInterval	- interval between calibration pulses in seconds (default 0);
sCalibrDuration	- duration of the calibration pulse in seconds (default 0).

The command can be formed by the following code:

```
       { TimeInfo suTimeInfo={ 0l, 1800, 0, 0l, 0l, 64000000l,
4000l, 0l, 0};

         suTimeInfo.lEpochSec=<current_time>;
         TIME_INFO_SWAP(&suTimeInfo);        /* Swap long.*/
         mem-
cpy(suBuffer.aiBuf,&suTimeInfo,sizeof(suTimeInfo));
         TAG_SET(&suBuffer,TAG_TIME_INFO,1);
       }
```

Ut is necessary to send only [TAG_MESSAGE_SIZE(sizeof(suTimeInfo))] 16 bit words.

iii. Channel information - TAG_CHANNEL_INFO.

Sends to the digitizer channel parameters. It is necessary to send this command if the digitizer was not configured before (it would return the **channel information** message with zero number of channels). Related structure and scripts:

```
/* Channel flag enumeration.
*/
typedef     enum     {    CHANNEL_FLAG_ON=1,     CHANNEL_FLAG_OFF=0,
CHANNEL_FLAG_TO_OFF= -1 }
                                                          ChannelFlag;
/* ChannelInfo structure definition. This in     configuration
info, use to      */
/* send by central computer.
*/
typedef struct { short       iNumHard; /* Channel number.
*/
         short           iFrequency;     /* Channel frequency.
*/
         short           iGain;          /* Channel gain.
*/
         ChannelFlag     enFlag;         /*                  Channel
flag(ON/OFF...). */
           long              lEpochStart;     /*     Seconds     from
70.01.01 0:0*/
           long              lEpochStop;      /*     Seconds     from
70.01.01 0:0*/
                             } ChannelInfo;

/* Channels definitions. */
/* Script to define channels info array. Must be put into the
file level.      */
#define CHANNEL_INFO_N        CHANNEL_N /*       Channels       num-
ber.Das6103.h*/
#define CHANNEL_INFO_DEFINITION()      \
   ChannelInfo     asuChannelInfo[CHANNEL_INFO_N];\
   int        iChannelInfoN=0
/* Script to set ChannelInfo for one channel.
*/
#define CHANNEL_INFO_SET(P_CHAN,NUMBER)      \
   (P_CHAN)->iNumHard=(NUMBER); (P_CHAN)->iFrequency=125;\
   (P_CHAN)->iGain=(1<<8)|1;                              (P_CHAN)-
>enFlag=CHANNEL_FLAG_OFF;\
```

```
   (P_CHAN)->lEpochStart=0; (P_CHAN)->lEpochStop=LONG_MAX
/* The script to set a number of input and a gain                    */
#define GAIN_SET(INPUT_N,GAIN) (((INPUN_N)<<8)|(GAIN))
```

where:


```
*/
iNum - hardware channel number (from 0 to 15);
HardiFrequency
iGain
```

- chann

el sampling rate. The latter must be selected from the sequence resulted from division of the base sampling rate (4000sps) by 2's and/or 5's. For instance 2000, 400, 125, 100□;

- number and gain of the input. The digitizer has two inputs for each channel with input spans:

Input span	Divider	Input Channel
2.5V	1	
	220.0V	
	1/8	
	1	

Available gains: 1,2,4 8,16,31,64. Use the following script to set the gain field:
suChannelInfo.iGain=GAIN_SET(2,16);

enFlag - channel flag. Can be On or Off. Use predefined enumeration to set the field:
suChannelInfo.enFlag=CHANNEL_FLAG_ON;

lEpochStart - channel start time in seconds from January 1st, 1970 (default 0);

lEpochStart - channel stop time in seconds from January 1st, 1970 (default LONG_MAX);

A command that starts 3 channels at 100sps, ±2.5V input and gain 16 can be formed by the following code:

```
   { /* Channels definitions. */
     #define CHANNEL_N            3    /* Number of channels in system.

   */
     ChannelInfo asuChannelInfo[CHANNEL_INFO_N];
     int iN;

     for( iN=0; iN < ChannelN; iN++ )
        { CHANNEL_INFO_SET(asuChannelInfo+iN,iN+1);
          asuChannelInfo[iN].iFrequency=100;
          asuChannelInfo[iN].iGain=GAIN_SET(2,16);
          asuChannelInfo[iN].enFlag=CHANNEL_FLAG_ON;
```

```
CHANNEL_INFO_SWAP(asuChannelInfo+iN); long integer. */
  }
memcpy(suBuffer.
```

lInfo

S

```
                                    ,sizeof(          ChannelInfo
                                                      )*
   CHANNEL_N)
   ;
   }
   TAG_SET(&suBuffer,TAG_CHANNEL_INFO,
CHANNEL_N);
```

It is necessary to send only [`TAG_MESSAGE_SIZE(sizeof(ChannelInfo)*CHANNEL_N)`] 16 bit words.

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iv. Communication command - TAG_COMM_COMMAND.

This command can be used to start or stop data transfer and switch digital output lines. The digitizer uses the same tag to send a 'no-more-data' message. Associated structure:

```
/* Communication command tag enumeration.          */
typedef enum { COMM_START=1, COMM_STOP=0, COMM_RESEND=2
             , COMM_OUT_SET=9, COMM_DATA_END=3 }       CommCom-
mandTag;
/* Communication command structure.                */
typedef struct     { short    iCommCommandTag;/*      Communication
Command Tag. */
                     short    iDataLevel;     /* Level in % when start
                   the host. */
                              } CommCommand;
```

where:

`iCommCommandTag` - communication command subtag. Use predefined enumeration to set it;

`iDataLevel` - data field (can be used differently depending on witch command is send).

In all cases it is necessary to send [`TAG_MESSAGE_SIZE(sizeof(CommCommand))`] 16 bit words.

a) Start communication - COMM_START.

This command can be set by the code:

```
                {       CommCommand         *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;

                  psuCommCommand->iCommCommandTag=COMM_STOP;
                  psuCommCommand->iDataLevel =100;
                  GLOBAL_TO_COMM_COMMAND(&Global,psuCommCommand);
                }
                TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

b) Stop communication - COMM_STOP.

[This option is not used in the ORION system]

Field `iDataLevel` defines percentage of internal buffer fill at which the digitizer turns on recorder at. The command can be generated by the following code:

```
                {       CommCommand         *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;
```

```
    psuCommCommand->iCommCommandTag=COMM_STOP;
    psuCommCommand->iDataLevel =95;
    GLOBAL_TO_COMM_COMMAND(&Global,psuCommCommand);
  }
  TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

c) Re-send last buffer - COMM_RESEND.

Requests to repeat sending of the last sent buffer in case of communication errors. This command can be formed by the following code:

```
  {     CommCommand     *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;

    psuCommCommand->iCommCommandTag=COMM_RESEND;
    psuCommCommand->iDataLevel =100;
  }
  TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

If there are no errors, just an empty block (zero word-length) is sent back to acknowledge the receipt.

d) Set the output digital lines - COMM_OUT_SET.

There are 3 output digital lines. The 3 least significant bits of the field `iDataLevel` can be used to change state of these lines. For instance, in order to turn on the inclinometer use the code:

```
    #define USER_TILT_ON      0x01 /* Turn On/Off(1/0) the tilt-
meter.     */
    #define USER_TILT_CHAN    0x02 /* Connect channel X/Y(0/2)
to dig. */
  {     CommCommand     *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;
    psuCommCommand->iCommCommandTag=COMM_OUT_SET;
    psuCommCommand->iDataLevel=USER_TILT_ON;
  }
  TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

e) No-more-data message - COMM_DATA_END.

The digitizer sends this message when the whole block stored in the internal buffer has been sent. The message can be identified by the following code:

```
if( TAG_PROVIDED(&suBuffer)
      && TAG_TYPE(&suBuffer) == TAG_COMM_COMMAND
        && suBuffer.aiBuf[0] == COMM_DATA_END )
```

v. Reset command - TAG_RESET.

The digitizer will restart data acquisition with previously set parameters. It can be implemented with the code:

```
TAG_SET(&suBuffer,TAG_SYSTEM_RESET,0);
```

It is necessary to send only [`TAG_MESSAGE_SIZE(0)`] 16 bit words.

vi. Log message - TAG_LOG.

This is a block which carries digitizer messages. The DSP is a 16 bit world-oriented processor and each symbol is saved in 2 bytes. One just needs to delete the most significant byte. In all other aspects the log message is a set of lines separated by the new line symbol ('\n'). The end of the log message is marked with the zero symbol ('\0').
Log messages can be printed using the code:

```
if( TAG_PROVIDED(&suBuffer)
          && TAG_TYPE(&suBuffer) == TAG_LOG )
 { register char *pcB=(char *)suBuffer.aiBuf, *pcE;

   UniToAsc(pcB,pcB,BUFCOM_N);       /*    Transform    TI
char. to char */
   printf("$s",pcB);
 }
```

vii. Data block.

This Block does not have a tag associated with it. In fact, any message without a tag is a data block. Associated structure and scripts:

```
#define BUFCOM_N 252 /* Number of words in a buffer.
*/
/* The real predefining name is _TMS320C5XX (__TMS320C5XX__ is
in docs.)     */
typedef struct {
#ifdef _TMS320C5XX      /* TI packs bits beginning at the most
significand.*/
         unsigned uChan     : 4;    /* Channel number.
*/
         unsigned uNumber :12;     /*   Number    of    samples    in
buffer.       */
#else              /* DOS packs bits beginning at the last sig-
nificand.*/
         unsigned uNumber :12;     /*   Number    of    samples    in
buffer.       */
```

```
        unsigned uChan     : 4;    /* Channel number.
*/
#endif /* __TMS320C5XX__ */
          short      iSecFract;    /* Number of fractions of
second.     */
          long             lEpochSec;    /* Seconds from 1 Janu-
ary 1970 00:00*/
        short       aiBuf[BUFCOM_N]; /* Buffer space.
*/
                        } BufCom;
#define SEC_FRACTION    10000l      /* Second fraction is a tenth
of millisec     */
/* Script to initiate a buffer.       */
#define BUFFER_INIT(P_BUFFER)     (P_BUFFER)-
>lEpochSec=(P_BUFFER)->uChan\
                       =(P_BUFFER)->uNumber=(P_BUFFER)-
>iSecFract=0
```

where:

- `uChan` - channel number;
- `uNumber` - number of samples in the buffer;
- `iSecFract` - number of fractions of a second;
- `lEpochSec` - time in seconds from `1 January 1970 00:00;`
- `aiBuf` - space used for packed data.

Recorded data are sent in compressed format. (The decompression c-function is provided.) Compression concept: Data are written as fist differences in 2 or 4 bytes words depending on the magnitude. Maximum compression factor is 2.

A data block can be processed using the following code:

```
if(                    !TAG_PROVIDED(&suBuffer)                    )
{                  #define                    BUF_N                  1024
  long       int       alBuf[BUF_N];       /*       Data       */

  /* Time of the first sample can be calculated by: */
  dEpoch=(double)SWAP_LONG(suBuffer.lEpochSec)
          +(double)suBuffer.iSecFract/SEC_FRACTION;
  /* Data can be unpacked by(look at the attached program):
*/

iN=ShlDeCode(suBuffer.aiBuf,min(suBuffer.uNumber,BUF_N),alB
uf);
}
```


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6. Transmission block layer.

Transmission block starts with its length in 16-bit words in the form of a short integer number that is followed by a data block (command or message) of up to 2 Kbytes long. Transmission blocks end with a one's complement checksum of a one's complement checksum in form of short integer. The checksum is not included in the block length. The checksum is calculated for whole block including the length. The C-function for calculation of the checksum is provided.

A transmission block can be treated just as:

```
  { short int aiTbuf[1024+2];

    .... /* Get a block. */
    if( aiTbuf[0] > 0 &&
              &&            aiTbuf[aiTbuf[0]]       ==       check-
sum(aiTbuf,2*(aiTbuf[0]+1)) )
     { .... /* Process the block. */ }
  }
```

7. SLIP layer.

The standard SLIP (Serial line IP) is used to frame a transmission block on a serial line. The C-function to encode and decode a transmission block in SLIP is provided. This is an example how it could be done:

```
    { short int             aiTbuf[1024+2];
      unsigned char         aucSlipBuffer[(1024+2)*2];
      int                   iN;
      .... /* Prepare a block. */
      if( ( iN=SlipEnCode(SlipBuffer,sizeof(aucSlipBuffer)
                                    ,aiTbuf,aiTbuf[0]+1) )
                                                    <= 0 )
            { printf("SLIP coding is invalid.\n");
        return -1;
       }
      .... /* Send the block. */
      .... /* Get a block. */
      iN=<number of received bytes>;
      if( ( iN=SlipDeCode(aiTbuf,sizeof(aiTbuf)
                                    ,SlipBuffer,iN,NULL) )
                                                     <= 0 )
       { printf("SLIP record is invalid. Data is ignored.
 Ret=%d\n",iN);
        return -1;
       }
     .... /* Process the block. */
    }
  A complete description of the SLIP protocol see in the
  Appendix V.
```

8. Appendix 2-A: SLIP protocol.

rfc1055

Press here to go to the top of the rfc 'tree'.

Network Working Group J. Romkey
Request for Comments: 1055 June l988

A NONSTANDARD FOR TRANSMISSION OF IP DATAGRAMS OVER SERIAL LINES: SLIP

INTRODUCTION

The TCP/IP protocol family runs over a variety of network media: IEEE 802.3 (ethernet) and 802.5 (token ring) LAN's, X.25 lines, satellite links, and serial lines. There are standard encapsulations for IP packets defined for many of these networks, but there is no standard for serial lines. SLIP, Serial Line IP, is a currently a de facto standard, commonly used for point-to-point serial connections running TCP/IP. It is not an Internet standard. Distribution of this memo is unlimited.

HISTORY

SLIP has its origins in the 3COM UNET TCP/IP implementation from the early 1980's. It is merely a packet framing protocol: SLIP defines a sequence of characters that frame IP packets on a serial line, and nothing more. It provides no addressing, packet type identification, error detection/correction or compression mechanisms. Because the protocol does so little, though, it is usually very easy to implement.

Around 1984, Rick Adams implemented SLIP for 4.2 Berkeley Unix and Sun Microsystems workstations and released it to the world. It quickly caught on as an easy reliable way to connect TCP/IP hosts and routers with serial lines.

SLIP is commonly used on dedicated serial links and sometimes for dialup purposes, and is usually used with line speeds between 1200bps and 19.2Kbps. It is useful for allowing mixes of hosts and routers to communicate with one another (host-host, host-router and router-router are all common SLIP network configurations).

AVAILABILITY

SLIP is available for most Berkeley UNIX-based systems. It is included in the standard 4.3BSD release from Berkeley. SLIP is available for Ultrix, Sun UNIX and most other Berkeley-derived UNIX systems. Some terminal concentrators and IBM PC implementations also support it.

SLIP for Berkeley UNIX is available via anonymous FTP from uunet.uu.net in pub/sl.shar.Z. Be sure to transfer the file in binary mode and then run it through the UNIX uncompress program. Take

the resulting file and use it as a shell script for the UNIX /bin/sh (for instance, /bin/sh sl.shar).

PROTOCOL

The SLIP protocol defines two special characters: END and ESC. END is octal 300 (decimal 192) and ESC is octal 333 (decimal 219) not to be confused with the ASCII ESCape character; for the purposes of this discussion, ESC will indicate the SLIP ESC character. To send a packet, a SLIP host simply starts sending the data in the packet. If a data byte is the same code as END character, a two byte sequence of ESC and octal 334 (decimal 220) is sent instead. If it the same as an ESC character, an two byte sequence of ESC and octal 335 (decimal 221) is sent instead. When the last byte in the packet has been sent, an END character is then transmitted.

Phil Karn suggests a simple change to the algorithm, which is to begin as well as end packets with an END character. This will flush any erroneous bytes which have been caused by line noise. In the normal case, the receiver will simply see two back-to-back END characters, which will generate a bad IP packet. If the SLIP implementation does not throw away the zero-length IP packet, the IP implementation certainly will. If there was line noise, the data received due to it will be discarded without affecting the following packet.

Because there is no 'standard' SLIP specification, there is no real defined maximum packet size for SLIP. It is probably best to accept the maximum packet size used by the Berkeley UNIX SLIP drivers: 1006 bytes including the IP and transport protocol headers (not including the framing characters). Therefore any new SLIP implementations should be prepared to accept 1006 byte datagrams and should not send more than 1006 bytes in a datagram.

DEFICIENCIES

There are several features that many users would like SLIP to provide which it doesn't. In all fairness, SLIP is just a very simple protocol designed quite a long time ago when these problems were not really important issues. The following are commonly perceived shortcomings in the existing SLIP protocol:

- addressing:

  both computers in a SLIP link need to know each other's IP addresses for routing purposes. Also, when using SLIP for hosts to dial-up a router, the addressing scheme may be quite dynamic and the router may need to inform the dialing host of

the host's IP address. SLIP currently provides no mechanism for hosts to communicate addressing information over a SLIP connection.

- type identification:

  SLIP has no type field. Thus, only one protocol can be run over a SLIP connection, so in a configuration of two DEC computers running both TCP/IP and DECnet, there is no hope of having TCP/IP and DECnet share one serial line between them while using SLIP. While SLIP is "Serial Line IP", if a serial line connects two multi-protocol computers, those computers should be able to use more than one protocol over the line.

- error detection/correction:

  noisy phone lines will corrupt packets in transit. Because the line speed is probably quite low (likely 2400 baud), retransmitting a packet is very expensive. Error detection is not absolutely necessary at the SLIP level because any IP application should detect damaged packets (IP header and UDP and TCP checksums should suffice), although some common applications like NFS usually ignore the checksum and depend on the network media to detect damaged packets. Because it takes so long to retransmit a packet which was corrupted by line noise, it would be efficient if SLIP could provide some sort of simple error correction mechanism of its own.

- compression:

  because dial-in lines are so slow (usually 2400bps), packet compression would cause large improvements in packet throughput. Usually, streams of packets in a single TCP connection have few changed fields in the IP and TCP headers, so a simple compression algorithms might just send the changed parts of the headers instead of the complete headers.

Some work is being done by various groups to design and implement a successor to SLIP which will address some or all of these problems.

SLIP DRIVERS

The following C language functions send and receive SLIP packets. They depend on two functions, send_char() and recv_char(), which send and receive a single character over the serial line.

```
/* SLIP  special character codes
 */
#define  END             0300    /* indicates end of packet */
#define  ESC             0333    /* indicates byte stuffing */
#define  ESC_END         0334    /* ESC ESC_END means END data byte */
#define  ESC_ESC         0335    /* ESC ESC_ESC means ESC data byte */

/* SEND_PACKET: sends a packet of length "len", starting at
 * location "p".
 */
void send_packet(p, len)
        char *p;
        int len; {

  /* send an initial END character to flush out any data that may
   * have accumulated in the receiver due to line noise
   */
     send_char(END);

  /* for each byte in the packet, send the appropriate character
   * sequence
   */
        while(len--) {
                switch(*p) {
                /* if it's the same code as an END character, we send a
                 * special two character code so as not to make the
                 * receiver think we sent an END
                 */
                case END:
                        send_char(ESC);
                        send_char(ESC_END);
                        break;

                /* if it's the same code as an ESC character,
                 * we send a special two character code so as not
                 * to make the receiver think we sent an ESC
                 */
                case ESC:
                        send_char(ESC);
                        send_char(ESC_ESC);
                        break;
```

```
                                                        /
/* otherwise, we just send the character                *
 */                                                     t
default:                                                e
        send_char(*p);                                  l
        }                                               l
                                                        t
p++;                                                    h
}                                                       e
                                                        r
                                                        e
                                                        c
                                                        e
                                                        i
                                                        v
                                                        e
                                                        r
                                                        t
                                                        h
                                                        a
                                                        t
                                                        w
                                                        e
                                                        '
                                                        r
                                                        e
                                                        d
                                                        o
                                                        n
                                                        e
                                                        s
                                                        e
                                                        n
                                                        d
                                                        i
                                                        n
                                                        g
                                                        t
                                                        h
                                                        e
                                                        p
                                                        a
                                                        c
                                                        k
                                                        e
                                                        t
                                                                *
                                                                /

                                                                s
                                                                e
                                                                n
                                                                d
                                                                _
                                                                c
                                                                h
                                                                a
                                                                r
```

```
    (EN             f more than len bytes                          n
    D);             are received, the                              ;
    }               packet will
                    *                                              {
/
*                   b                                              c
                    e                                              h
RECV_               t                                              a
PACKET:             r                                              r
                    u                                              c;
                    n                                              i
                    c                                              n
receives            a                                              t
                    t                                              r
a                   e                                              e
                    d                                              c
packet              .                                              e
                                                                   i
into                *      Returns the                             v
                    number of bytes                                e
the                 stored in the                                  d
                    buffer.                                        =
buffer              *                                              0
                    /                                              ;
located
                int                                                /
at                  recv_                                          *
                    packet(p,                                      sit
"p".                len)                                           in
                                                                   a
 *                          char *p;                               loop
                            int len                                reading
 I                                                                 bytes
                                                                   unt
```

```
il                cess
we                        *
put                       /
tog
eth                       c
er                        =
* a                       r
whol                      e
e                         c
pack                      v
et.                       _
*                         c
Make                      h
sure                      a
not                       r
to                        (
copy                      )
them                      ;
into
the                       /
pack                      *
et
if                        h
we *                      a
run                       n
out                       d
of                        l
room                      e
.                         b
*/                        y
                          t
w                         e
h                         s
i                         t
l                         u
e                         f
(                         f
1                         i
)                         n
                          g
{                         i
                          f
/                         n
*                         e
                          c
g                         e
e                         s
t                         s
                          a
a                         r
                          y
c                         *
h                         /
a
r                         s
a                         w
c                         i
t                         t
e                         c
r                         h(c)
                          {
t                         /*
o                         if
                          it's
p                         an
r                         END
o                         char
                          acte
                          r
                          then
                          we'r
                          e
                          done
                          with
                          * the
                          packe
                          t
                          */
                          c
                          a
                          s
                          e
                          E
                          N
                          D
                          :
                           /
                          *
                          a
                          m
                          i
                          n
                          o
                          r
                          o
                          p
                          t
                          i
                          m
                          i
                          z
                          a
                          t
                          i
                          o
                          n
                          :
                          i
                          f
                          t
                          h
                          e
                          r
                          e
                          i
                          s
                          n
                          o
                          * data in the
                          packet,
                          ignore it.
                          This is
```

```
        * meant to avoid
        bothering IP with all
        * the empty packets
        generated by the
        * duplicate END
        characters which are
        in
```

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```
                         * turn sent to try to detect line noise.
                         */
                        if(received)
                                return received;
                        else
                                break;

                /* if it's the same code as an ESC character, wait
                 * and get another character and then figure out *
                 what to store in the packet based on that.
                 */
                case ESC:
                        c = recv_char();

                        /* if "c" is not one of these two, then we
                         * have a protocol violation. The best bet
                         * seems to be to leave the byte alone and
                         * just stuff it into the packet
                         */
                        switch(c) {
                        case ESC_END:
                                c = END;
                                break;
                        case ESC_ESC:
                                c = ESC;
                                break;
                                }

                /* here we fall into the default handler and let
                 * it store the character for us
                 */
                default:
                        if(received < len)
                                p[received++] = c;
                        }
                }
        }
```

9. APPENDIX 2-B: Working with the tiltmeter.

1. Start the digitizer with all 4 channels turned On.
2. Turn the tiltmeter ON with axis X connected to the digitizer:

```
     #define USER_TILT_ON       0x01 /*Turn On(1) the tiltmeter.*/
     #define USER_TILT_CHAN     0x02 /* Connect channel X/Y(0/2)
to dig. */
     #define USER_TILT_OFF      0x00 /*Turn Off(0) the tiltme-
ter.*/
     { CommCommand *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;
       psuCommCommand->iCommCommandTag=COMM_OUT_SET;
       psuCommCommand->iDataLevel=USER_TILT_ON;
     }
     TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

Send [`TAG_MESSAGE_SIZE(sizeof(CommCommand))`] 16 bit words (6 words).

3. Accumulate sufficient data for the tiltmeter X-axis.
4. Switch tiltmeter output to the axis Y:

```
     { CommCommand *psuCommCommand=(CommCommand
*)suBuffer.aiBuf;
       psuCommCommand->iCommCommandTag=COMM_OUT_SET;
       psuCommCommand->iDataLevel=USER_TILT_ON|USER_TILT_CHAN;
     }
     TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

Send [`TAG_MESSAGE_SIZE(sizeof(CommCommand))`] 16 bit words (6 words).

5. Accumulate sufficient data for the tiltmeter Y-axis.
6. Turn the tiltmeter OFF:

```
     { CommCommand *psuCommCommand=(CommCommand
     *)suBuffer.aiBuf;
       psuCommCommand->iCommCommandTag=COMM_OUT_SET;
       psuCommCommand->iDataLevel=USER_TILT_OFF;
     }
     TAG_SET(&suBuffer,TAG_COMM_COMMAND,1);
```

Send [`TAG_MESSAGE_SIZE(sizeof(CommCommand))`] 16 bit words (6 words).

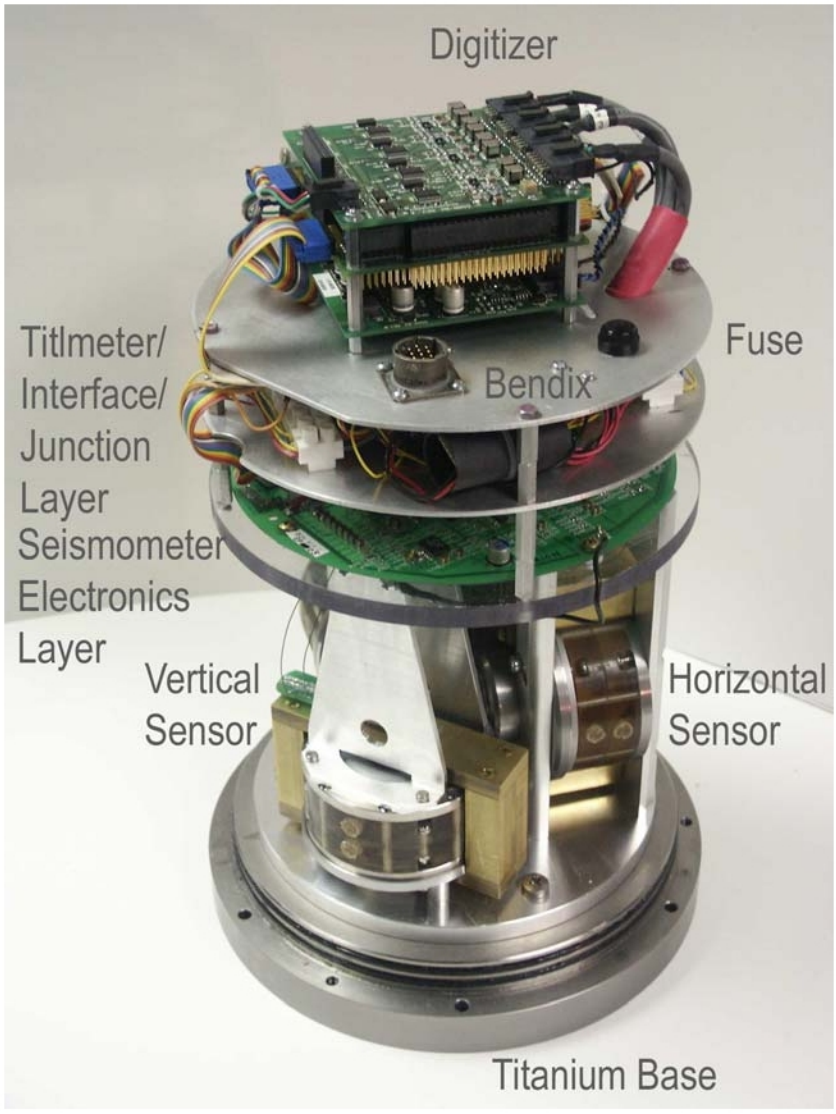
7. Turn off the 4th channel of the digitizer.
   To do it, send the same channel information, that was sent in the item 1, but with the Off flag of the 4th channel(`suChannelInfo.enFlag=CHANNEL_FLAG_OFF;`)

Part 3. The ORION System Interconnections

1 Instrument Assembly & Connectors Pinouts

In the ORION configuration EP300-DT assembly is mounted on the bottom lid of the cylindrical titanium pressure vessel[5]. This assembly consists of the three seismic sensors and three layers of electronics:

seismometer power and three amplification/correction/feedback electronics;
tiltmeter, tiltmeter interface, junction terminals and the intermediate Bendix connector;
6503 stack consisting, in turn, of three boards: power, analog (A-to-D converter and input filters and dividers), and digital (DSP, programmable logic, 16MB data RAM, 2MB program RAM, communication chipsets, PLL, etc.) board.



[5] For the pressure vessel outline and dimensions see the attached file "TiHousing.pdf"

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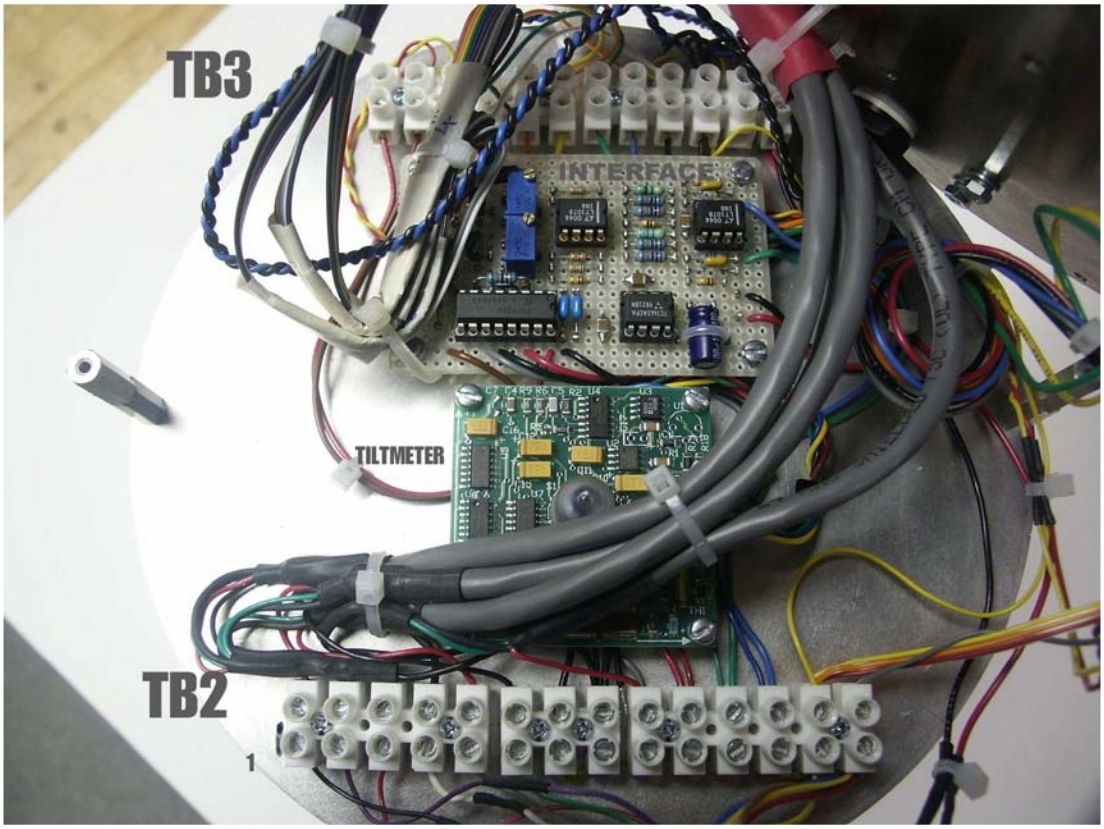
An 8-pin pressurized circular connector is screwed into the top lid of the titanium cylinder; a cable from this connector goes to the intermediate 10-pin Bendix connector mounted on the Junction layer. connector pinouts are show in the Table below:

Lid Connector Pin	Description	Bendix Connector Pin
1	+12V Supply	A
2	0V Supply	B
3	Tx - DATA	C
4	Rx - DATA	D
5	GND (Logic)	E
6	Tx - Timing	F
7	1 PPS	G
8	RESET IN	H

2. The Junction Board.

Photo of the Junction Board is shown below.



30

All major system components, i.e.

- Seismometer;
- Tiltmeter;
- Digitizer;
- Interface Board

are interconnected via two terminal blocks, TB2 and TB3.

- TB2 connects the Bendix circular connector to the Digitizer via 5 flat cables (actually, cable to the Digital Board connector J5 is reduced to a single wire). It also provides power from this connector and Tiltmeter control commands from the Digitizer to the In- terface Board.
- TB2 connects the Analog circular connector to Seismometer Calibration Enable and Calibration Input inputs and to Seismometer Signal Ground; to the buffered Seismometer differential outputs on the Interface Board. Analog connector also provide alternative power to the system.
- TB3 connects seismometer signal outputs directly and controlled and buffered tiltmeter outputs to the signal inputs of the digitizer.

Detailed Junction Board wiring diagram is shown in the attached file "JUNCTION.pdf".

i.

The Tiltmeter.

The EP300-DT system uses Applied Geomechanics Model 900 Tiltmeters ("Clinometers"). These sensors were selected so that their full scale tilt (±25°) includes the maximum specified operating tilt angle of the seismometers (±10°), and exhibit excellent resolution: 100mV per degree of tilt or 5592.4 counts/angular minute after digitizing. Tiltmeters data sheets can be found in the attached file "900-Series B-93-1012, Rev. C.pdf"

iii. Tiltmeter Interface Board.

This board is installed next to the tiltmeter. Its complete circuit diagram can be found in the attached file "TILT_CTL.pdf". The circuit contains voltage inverter providing negative power to all operational amplifiers employed. Each tiltmeter output is buffered by a follower- amplifier with a fine offset adjustment. After the system is fully assembled, it is placed on a leveled granite plate and both buffered tiltmeter outputs are set to zero using multiturn potenti- ometers. Analog switches U1 respond to the digitizer commands and turn tiltmeter power on-off and switch digitizer CH.4 input between tiltmeter axes outputs.

All micropower, low-noise amplifiers in the Interface board are Linear Technology LT1078 types.

P

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