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FINAL TECHNICAL SUMMARY

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L. B. Loughran (ed.)

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VII.10 P-wave coda -- scattering research

The purpose of this study is an on-going effort to determine the nature of the teleseismic P coda seen on short period seismograms, and specifically to separate it into a contribution from scattering near the source, if the source is in the crust, and scattering near the receiver. To accomplish this, digital data from NORSAR and NORESS were used in the frequency range 1-7 Hz and covering a time span of 20-200 sec after first P. The variation of the coda power spectrum of various types of events with time was examined and found to fit a simple exponential decay for all events, although the amplitude of the coda relative to first P was quite different for different types of events, being large for crustal earthquakes and lower for deep-focus earthquakes and explosions. Data from NORESS were examined using frequency-wavenumber methods, particularly by determining the power as a function of wavenumber at a fixed frequency; this is equivalent to finding the power as a function of apparent velocity. Deep-focus events had a coda dominated by low apparent velocities (3.5-4.5 km/sec), explosions a coda with equal power in high (10 km/sec) and low apparent velocities, crustal earthquakes a coda dominated by high apparent velocities. These results indicate that the teleseismic P coda in the time and frequency range considered indeed consists of energy scattered near the source if the source is in the crust (the high apparent velocity component), and energy scattered near the receiver (low apparent velocity component), and energy scattered near the receiver (low apparent velocity component). The low velocities indicate that teleseismic P to Lg (trapped shear wave) is the dominant mode of scattering near the receiver; the differences between crustal earthquakes and explosions suggest Lg to teleseismic P near the source. Multiple scattering is probably occurring in the coda. These results indicate that coda magnitudes will depend on conditions in broad (~ 500 km) regions around the source and receiver, perhaps explaining their stability. It may be possible to separate the coda from the source and receiver regions, leading to even greater stability. The difference between crustal earthquakes and explosions may be useful as a discriminant. These results are detailed in a recent report by Dainty (1985).

An interesting aspect of coda analysis is to what extent scatters can be separated into deterministic and random contributions. A first experiment here was to identify clear crustal scatters (Pg vel. ≤ 7 kms^{-1}, $7.0 < Pn \leq 10.0$ kms^{-1}) by 3-comp. coda analysis, and then using differential travel times (re P-onset time) to actually locate these scatters. Preliminary results are displayed in Figs. VII.10.1 and VII.10.2 and the following comments apply. Pg-scattering sources are mainly concentrated to the north and east of NORESS, and the apparent clustering roughly coincides with major tectonic boundaries. Surprisingly, for events to the south hardly any crustal scatters were found (mainly non-shield areas). Roughly the same results are found for Pn-scatters, but the source locations here are more dispersed. The scatter locations in this case would be relatively less constrained, as the scattering mechanism may well be a "bumpy" Moho or asymmetric reflections from the surface (Pn-mode of propagation would be preferential beyond say 250 km).

A. Dainty (MIT)
E.S. Husebye

References

Dainty, A. (1985): Coda observed at NORSAR and NORESS, Tech. Rep. School of Geophys. Science, Georgia Institute of Technology, Atlanta, GA, USA.

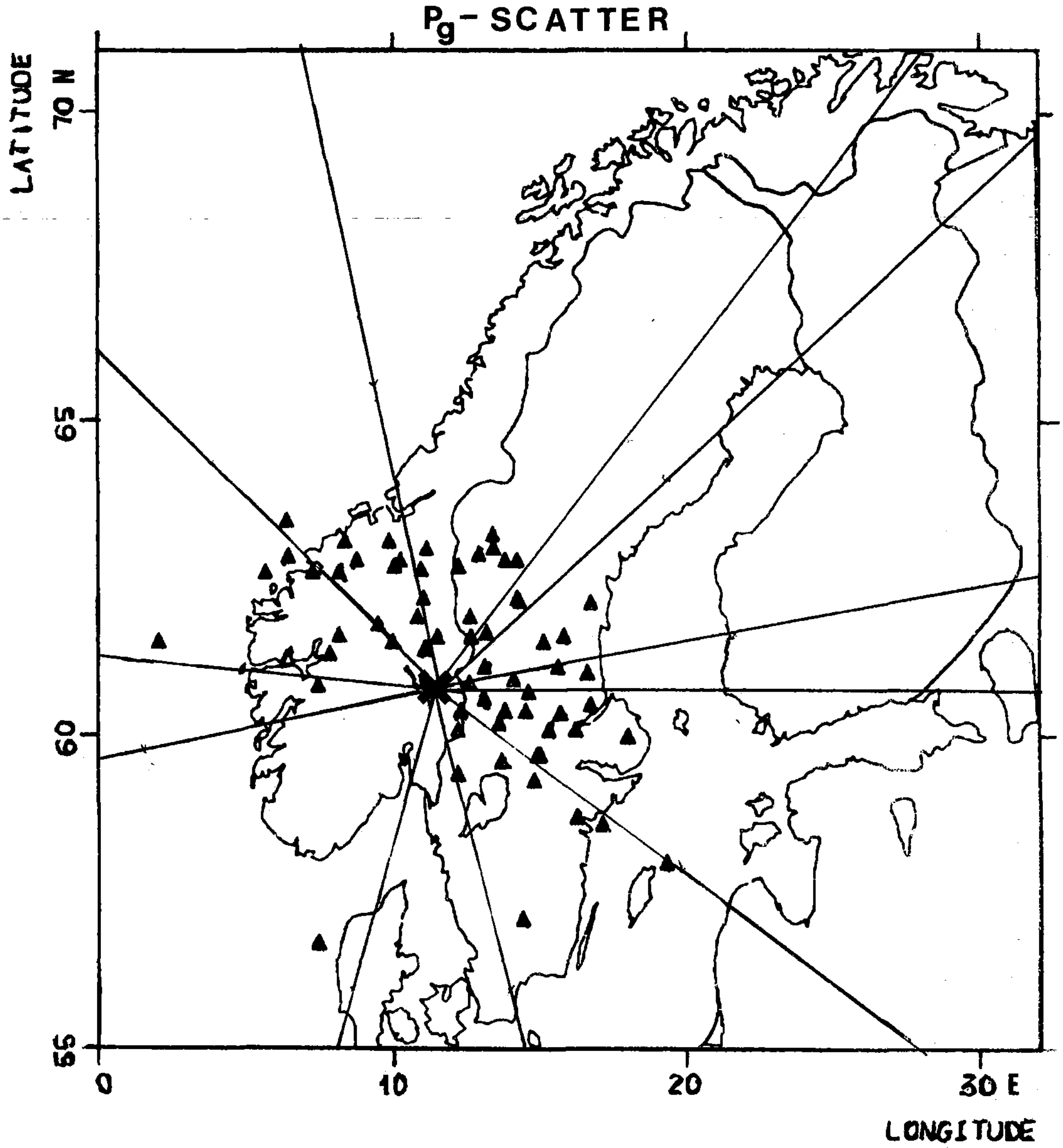

Fig. VII.10.1 Locations of secondary "sources" for coda phases of Pg wave type being subject to scattering at the receiver side. The thin lines represent azimuth of the events used in analysis. Note that the scattering efficiency appears to be relatively weak to the south and west.

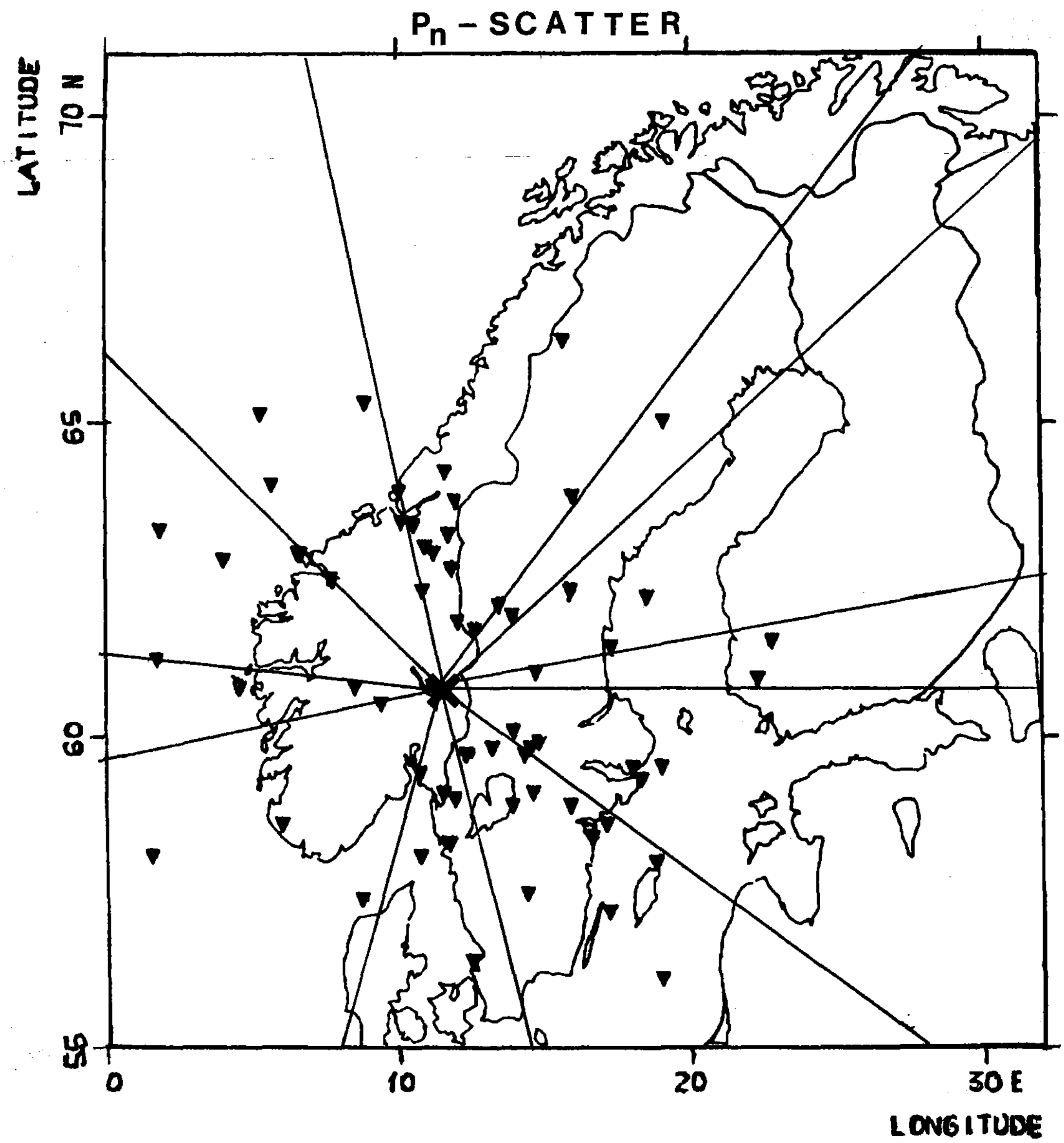

Fig. VII.10.2 Caption as for Fig. VII.10.1 except that now the wave type is Pn. Scattering sources are a bit dispersed and reflect poorer resolutin in "secondary" source locations for Pn than Pg.

APPENDIX A

NORESS DATA TAPE FORMAT

The following tape format has been agreed between SANDIA, LIVERMORE and NORSAR. On request, NORSAR will provide NORESS data tapes with the following options:

- 1 sec. blocking (3540 bytes per record)
- 2 sec. blocking (7080 bytes per record)
- 10 sec. blocking (35400 bytes per record) (standard)
- 800/1600 or 6250 bpi, 9 track tapes (6250 bpi is standard
- Array Geometry Record in EBCDIC (standard) or ASCII

A NORESS tape consists of 3 sections:

1. FILE HEADER (TAPE HEADER) 80 bytes
   1 * EOF
2. ARRAY GEOMETRY (AG) RECORD 3600 bytes
   IRG (INTER RECORD GAP)
3. DATA (35 FRAMES * 100 BYTES + RECORD HEADER 40 BYTES)
   TOTALLY 3540 BYTES IN EACH 1 SEC. BLOCK.
   IRG between each sec.

   Last 1 sec. block is followed by EOF.

Note that the data record lengths will be different if 2 or 10 seconds blocking has been requested.

In some cases, it might be practical to include several data intervals on one magnetic tape. These intervals will then each comprise three sections (File header, AG record, Data), separated by EOF, unless otherwise specified in documentation accompanying the tape.

1. FILE HEADER:

Bytes 1-14: Fixed format as follows:

Bytes 1-2 :	2 byte binary....Type	00 - AG record in EBCDIC 01 - AG record in ASCII
Bytes 3-4 :	2 byte binary....Month	This time corresponds to the first data on the file
Bytes 5-6 :	2 byte binary....Day	
Bytes 7-8 :	2 byte binary....Year	
Bytes 9-10:	2 byte binary....Hour	
Bytes 11-12:	2 byte binary....Min.	
Bytes 13-14:	2 byte binary....Sec.	

Bytes 15-80: Variable format. Tapes generated at NORSAR will contain:

byte 15,16,17,18,19,20	EBCDIC	tape number
byte 21,22	EBCDIC	Creation month
byte 23,24	EBCDIC	Creation day
byte 25-28	EBCDIC	Creation year
byte 29-32	EBCDIC	Array Geometry version no.
byte 38-80	EBCDIC	comments.

2. ARRAY GEOMETRY: (EBCDIC or ASCII)

2.1 General layout

byte 1 - 80	Text (free field) specifying date and time for last change in array geometry. See Table A-1, first line.
byte 81 - 160	Text (Table A-1, second line)
byte 161 - 240	Text (Table A-1, third line) Note: Latitude of center (degrees) in bytes 172-179; Longitude of center (degrees) in bytes 189-196
byte 241 - 320	Blanks
byte 321 - 400	Text
byte 401 - 480	Blanks
byte 481 - 560	specification of first data channel (see 2.2)
. . .	
byte 3521 - 3600	specification of 39th data channel

2.2 Contents of specification field

Each specification field mentioned above is 80 bytes in length, and describes one data channel. The format is currently as follows:

byte 2-3 :	channel identification (e.g., 21)
byte 7-8 :	site name (e.g., FO)
byte 13-15:	component (e.g., SPZ)
byte 16-23:	position relative to center of array (NS), in meters
byte 24-31:	position relative to center of array (ES), in meters
byte 32-40:	elevation (meters above sea level)
byte 41-60:	instrument type (e.g., GS-13)
byte 61-80:	comments

The ARRAY GEOMETRY RECORD is distributed on all tapes in either ASCII or EBCDIC. The record gives the array configuration corresponding to the actual data on tape. An example is given in Table A-1.

3. DATA:

Each one second data block is 3540 bytes in length and consists of:

RECORD HEADER	40	bytes
1 status frame	100	bytes
34 data frames	34*100	bytes

RECORD HEADER:

byte 1 - 2	EBCDIC:	data identification EBCDIC 'NO', (CFDO) Hexadecimal X'CFDO'
byte 3 - 4	Binary:	sampling delay (LP) in tenths of ms (currently 1008, i.e., 100.8 ms)
byte 5 - 6	Binary:	sampling delay (IP) in tenths of ms (currently 508, i.e., 50.8 ms)
byte 7 - 8	Binary:	sampling delay (LP) in tenths of ms (currently 60, i.e., 6.0 ms)
byte 9 - 10	Binary:	correction in milliseconds (fixed) for UTC. Current value is 1000, i.e., 1000 ms should be subtracted from all data times
byte 11 - 40	Binary:	spare

DATA:

35 frames (1 status frame, 34 data frames) as described in HUB documentation. (Table A-2)

STATUS FRAME: word 50 of this frame contains the total number of frames in this record (1-35).

Note that many conventions used for NORESS status information and data follow those established for the RSTN network. Reference is made to Breding (1983) for additional detail.

Reference:

Breding, D. (1983): Data users' guide for the Regional Seismic Test Network (RSTN), Sandia report SAND82-2935.

Table A-1

Example of an Array Geometry Record.
Each line corresponds to 80 bytes.

AG - ARRAY GEOMETRY RECORD 09/27/85 13:30 GMT
NO - NORESS DATA 40.0HZ , 10.0HZ AND 1.0HZ
FO - LAT(D) 60.7353 LON(D) 11.5414

CID	SITE	COMP	NS(M)	EW(M)	ELEV(M)	INSTRUMENT	COMMENTS
21	F0	SPZ	0	0	247	S-3	
61	F0	SPN	0	0	247	S-3	
A1	F0	SPE	0	0	247	S-3	
22	A0	SPZ	3	4	302	GS-13	TEMP. POSITION
62	A0	SPN	3	4	302	GS-13	TEMP. POSITION
A2	A0	SPE	3	4	302	GS-13	TEMP. POSITION
0D	A1	SPZ	146	49	291	GS-13	
0E	A2	SPZ	- 103	108	311	GS-13	
17	B1	SPZ	321	70	299	GS-13	
18	B2	SPZ	30	334	315	GS-13	
0A	B3	SPZ	- 298	143	314	GS-13	
0B	B4	SPZ	- 217	- 228	299	GS-13	
0C	B5	SPZ	163	- 272	289	GS-13	
13	C1	SPZ	687	109	299	GS-13	
0F	C2	SPZ	341	603	339	GS-13	TEMP.CID
14	C3	SPZ	- 238	647	352	GS-13	
23	C4	SPZ	- 657	208	311	GS-13	
63	C4	SPN	- 657	208	311	GS-13	
A3	C4	SPE	- 657	208	311	GS-13	
15	C5	SPZ	- 569	- 396	299	GS-13	
16	C6	SPZ	- 48	- 687	303	GS-13	
24	C7	SPZ	548	- 447	275	GS-13	
64	C7	SPN	548	- 447	275	GS-13	
A4	C7	SPE	548	- 447	275	GS-13	
04	D1	SPZ	1480	192	305	GS-13	
05	D2	SPZ	1015	1098	372	GS-13	
06	D3	SPZ	76	1493	453	GS-13	
07	D4	SPZ	- 901	1189	379	GS-13	
08	D5	SPZ	-1451	335	348	GS-13	
09	D6	SPZ	-1326	- 681	352	GS-13	
10	D7	SPZ	- 566	-1368	337	GS-13	
11	D8	SPZ	414	-1336	301	GS-13	
12	D9	SPZ	1257	- 802	278	GS-13	
C1	E0	IPZ	- 2	3	247	KS-36000-04	
C1	E0	IPN	- 2	3	247	KS-36000-04	
C1	E0	IPE	- 2	3	247	KS-36000-04	
C1	E0	LPZ	- 2	3	247	KS-36000-04	
C1	E0	LPN	- 2	3	247	KS-36000-04	
C1	E0	LPE	- 2	3	247	KS-36000-04	

Table A-2

HUB/Element Data Link Interface

HUB is equipped with 26 synchronous 2400 bit/sec ports for element frame acquisition. Each element uses the HUB transmitter (element receiver) clock as its data frame transmitter clock. At initialization each element will enable output starting when the last byte of a command frame is received from HUB. This method of data frame synchronization, which applies to all elements, defines a single sampling interval throughout the array, so time correlation of individual element data is simple. RSAS elements generate 50 word Short Period (SP) or Broad Band (BB) frames. Three axis elements generate 3 SP frames/sec, one for each axis. Formats and data definitions for the 2 frame types are given in the article below.

<u>SP Frame Format</u>

15 | 14 | 13 | 12 | 11 | 10 | 09 | 08 | 07 | 06 | 05 | 04 | 03 | 02 | 01 | 00

FRAME SYNC WORD 1 (F325 HEX)		
FRAME SYNC WORD 2 (0CDA HEX)		
2^{0} TIME WORD 1 2^{15}		
2^{16} TIME WORD 1 2^{23}	2^{07} CHANNEL STATUS (CS) 2^{0}	
40 WORDS OF SHORT PERIOD DATA		
CHANNEL SOH		
2^{15} COMMAND 2^{0}		
COMMAND 2^{19} … 2^{16}	AID 2^{03} … 2^{0}	TIME WORD 2 2^{27} 2^{26} 2^{25} 2^{24} 2^{19} 2^{18} 2^{17} 2^{16}
2^{15} TIME WORD 2 2^{00}		
CID	FA HEX	
6 BITS UNDEFINED (*)	10 BIT AUTHENTICATION NUMBER	

* The upper 6 bits of any authentication word must be set to 0 before authentication comparison is performed.

SP frame channel status format

Each Z, E or N SP frame contains one Channel Status (CS) byte containing digital status for the axis as defined in the table below.

Bit	Function
0	unused
1	CAL flag
2	Clip flag
3	mass motor busy
4	period motor busy
5	mass position motor busy
6	motor direction
7	unused

SP, BB frame channel, frame ID (CID) format

Each SP or BB frame CID byte contains a 6-bit channel and a 2-bit frame type identification field as shown below. The CID byte is a constant programmed by a strap port in each element. For SP and BB elements only 1 CID byte is required. A TSP element generates 3 CID bytes and the strap value will be assigned to the Z axis SP frame. The element processor will add 40 hex or 80 hex to the Z axis CHANNEL ID for the N and E axis SP frame CID byte, respectively.

SP, BB frame time word formats

A 28-bit frame count incremented once per second and used for authentication variable selection by the element processor is the source of TIME WORD 1 and 2 for all SP and BB frames. The integrity of the 24 most significant bits of frame count is supported by three 8-bit ports which have battery backup for power. TIME WORD 1 contains bits 2**0 through 2**23 of frame count in reverse order. TIME WORD 2 contains frame count bits 2**27 through 2**24 and bits 2**19 through 2**0.

Seismic data format

The least significant 14 bits of any seismic data word are the digitized representation of the sensor analog data signal and the 1 most significant bits of the word are encoded by the element processor to indicate the GAIN SELECT value as follows:

BIT 15	14	
0	0	GAIN SELECT = 128
0	1	GAIN SELECT = 32
1	0	GAIN SELECT = 8
1	1	GAIN SELECT = 1

BB frame format

15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 00
FRAME SYNC WORD 1 (F325 HEX)
FRAME SYNC WORD 2 (OCDA HEX)
2^{0} TIME WORD 1 2^{15}
2^{16} TIME WORD 1 2^{23} / 2^{07} BB CHANNEL STATUS 2^{0}
10 WORDS OF IPZ DATA APPEARING IN ORDER COLLECTED
10 WORDS OF IPN DATA APPEARING IN ORDER COLLECTED
10 WORDS OF IPE DATA APPEARING IN ORDER COLLECTED
LPZ DATA WORD
LPN DATA WORD
LPE DATA WORD
GTSOH STATUS
DH SOH STATUS WORD
DH SOH STATUS WORD
DH SOH STATUS WORD
4 UNUSED WORDS, ALL = 0
2^{15} COMMAND 2^{0}
COMMAND 2^{19} – 2^{16} / AID 2^{03} – 2^{0} / TIME WORD 2 2^{27} 2^{26} 2^{25} 2^{24} 2^{19} 2^{18} 2^{17} 2^{16}
2^{15} TIME WORD 2 2^{00}
CID / FA HEX
6 BITS UNDEFINED / 10 BIT AUTHENTICATION NUMBER

HUB status frame format

15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
FRAME SYNC WORD 1 = F325 HEX															
FRAME SYNC WORD 2 = OCDA HEX															
0	0	MASTER FRAME NUMBER													
GMT WORDS 1, 2, 3, 4, 5															
HUB ANALOG STATUS WORD 1 THRU 10															
HUB DIGITAL STATUS WORD															
PORT 1 STATUS BYTE								PORT 0 STATUS BYTE							
PORT 3 STATUS BYTE								PORT 2 STATUS BYTE							
PORT 5 STATUS BYTE								PORT 4 STATUS BYE							
PORT 7 STATUS BYTE								PORT 6 STATUS BYTE							
PORT 9 STATUS BYTE								PORT 8 STATUS BYTE							
PORT 11 STATUS BYTE								PORT 10 STATUS BYTE							
PORT 13 STATUS BYTE								PORT 12 STATUS BYTE							
PORT 15 STATUS BYTE								PORT 14 STATUS BYTE							
PORT 17 STATUS BYTE								PORT 16 STATUS BYTE							
PORT 19 STATUS BYTE								PORT 18 STATUS BYTE							
PORT 21 STATUS BYTE								PORT 20 STATUS BYTE							
PORT 23 STATUS BYTE								PORT 22 STATUS BYTE							
PORT 25 STATUS BYTE								PORT 24 STATUS BYTE							
GENERAL STATUS WORD															
UPLINK TIME POSITION WORD															
LAST HUB COMMAND WORD															
LAST COMMAND BYTE								LAST COMMAND ELEMENT							
13 WORDS OF MULTIPLEXED DIGITAL STATUS															
1 WORD, CONTENT UNDEFINED THIS WORD IS RESERVED FOR SCARS USE AND CANNOT BE USED BY HUB															

GMT TIME CODE INTERFACE

This interface consists of three 16-bit ports which provide time of year (GMT) to the millisecond which is inserted into HUB status frame GMT words 1 through 5. Format of each word is shown in the following.

GMT word formats

Bit	Word 1	Word 2	Word 3
0	Units of millisec. 1	Units of sec. 1	Units of min. 1
1	Units of millisec. 2	Units of sec. 2	Units of min. 2
2	Units of millisec. 4	Units of sec. 4	Units of min. 4
3	Units of millisec. 8	Units of sec. 8	Units of min. 8
4	Tens of millisec. 1	Tens of sec. 1	Tens of min. 1
5	Tens of millisec. 2	Tens of sec. 2	Tens of min. 2
6	Tens of millisec. 4	Tens of sec. 4	Tens of min. 4
7	Tens of millisec. 8	0	0
8	Hund. of millisec. 1	0	0
9	Hund. of millisec. 2	0	0
10	Hund. of millisec. 4	0	0
11	Hund. of millisec. 8	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0

Bit	Word 4	Word 5
0	Units of hours 1	Units of days 1
1	Units of hours 2	Units of days 2
2	Units of hours 4	Units of days 4
3	Units of hours 8	Units of days 8
4	Tens of hours 1	Tens of days 1
5	Tens of hours 2	Tens of days 2
6	0	Tens of days 4
7	0	Tens of days 8
8	0	Hund. of days 1
9	0	Hund. of days 2
10	0	0
11	0	0
12	0	± 1 millisecond accuracy
13	0	± 5 millisecond accuracy
14	0	± 50 millisecond accuracy
15	0	± 500 millisecond accuracy