EVALUATION OF
WRIGHT AND WRIGHT
OIL FILM MONITOR
FOR DETECTION OF OFFSHORE
CHRONIC OIL DISCHARGES

EE-98

EVALUATION OF WRIGHT AND WRIGHT OIL FILM MONITOR FOR DETECTION OF OFFSHORE CHRONIC OIL DISCHARGES

by

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Abstract

A Wright and Wright model DX250 Oil Film Monitor was procured, modified and installed aboard a semi-submersible drilling rig. The modifications included, in part, the connection of a micro-computer to the Oil Film Monitor for the purpose of processing and recording signals internal to the instrument during the experiment. The instrument was evaluated for its suitability as a sensor of chronic or low level oil discharges from an offshore rig. It was concluded that the instrument could function adequately in this role but that it would require further development to make it suitable for operational use. Recommendations are given for such further development.

RÉSUMÉ

On a fait l'acquisition d'un détecteur Wright et Wright, modèle DX250, de pellicules d'hydrocarbures qu'on a modifié puis installé sur une plate-forme de forage semi-submersible. Une partie des modifications a concerné sa connexion à un micro-ordinateur afin de traiter et d'enregistrer les signaux internes de l'expérience. L'appareil a été évalué pour sa capacité de détecter les rejets chroniques ou faibles d'hydrocarbures d'une plate-forme de forage hauturier. On a constaté que l'appareil fonctionnnait bien, mais qu'il exigeait d'être perfectionné d'avantage avant de pouvoir servir de façon suivie. Des recommandations sont donné à cette fin.

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1.0 BACKGROUND

1.1 Program Objectives

It is not unusual to monitor oil refinery effluent outlets, settling ponds and other such locations for the presence of oil. A number of devices for accomplishing this are available off-the-shelf. As offshore oil exploration and production activities intensify, there is a growing need to perform similar monitoring at the rig locations. There is, as yet, no off-the-shelf device suitable for offshore oil monitoring. The ideal offshore oil discharge detecting instrument would be environmentally and physically rugged, able to monitor a large area (several tens of square meters) and capable of detecting a variety of types of oil under a wide range of weather conditions at a distance of up to 30m from the water (typical deck height on a large jackup drilling rig).

This ideal instrument would function in much the same way as a domestic smoke alarm; the instrument would function continuously with minimal maintenance and would trigger an alarm whenever oil enters its field of view.

1.2 Review of Previous Phases

This is Phase IV of a project whose aim is to evaluate the suitability of various alternative technologies for the detection of offshore oil discharges. Phase I, completed in 1984 by F.G. Bercha and Associates, was a paper study of available instruments and technologies and the capabilities of each. The following excerpt from the Phase I report states quite nicely the nature of the hazard which is being monitored.

"A major or catastrophic spill, large in both area and volume, could occur from a blow-out or tanker accident. Methods of detection, monitoring and identification of this type of discharge are well

documented and include both aircraft and satellite mounted sensors. This type of oil spill is not considered in this study.
This study is oriented towards those spills that are limited in both volume of pollutant and areal extent, and are virtually confined to the area directly around the source. These spills occur, and reoccur, at facilities where petroleum products are handled. They are most often accidental and minor in nature. They occur due to negligence, human and design errors, operation errors, and mechanical failures. Sources of concern include oil/water separators, spillover and slop from exploration rigs and drilling material debris. In addition, there is an increasing interest on the part of operators in the use of petroleum and mineral oil-based drilling muds in offshore exploration and development occurring off the east coast. Several trial uses of mineral oil-based muds have already been approved by regulatory agencies. Oil-based muds are used extensively in production drilling in some parts of the world.

When spills occur frequently and over an extended period of time, they are considered chronic. Although singularly, they have no significant impact on the environment, over time, their impact increases. The spill volumes of significance to this study are from less than one barrel per day to about five barrels per day. Often the spill amounts constitute less than fifty parts per billion in the water column."

Based upon the recommendations from Phase I, Martec Limited undertook in Phase II to conduct field testing of five candidate remote sensing systems. The Wright and Wright Oil Film Monitor was not tested during Phase II but was identified as a promising system for further work.

Phase III, completed in May 1986 by Seakem Oceanography Limited, extended the laboratory and field evaluation of improved versions of two of the instruments tested in Phase II and of the Wright and Wright Oil Film Monitor. Only the Wright and Wright Oil Film Monitor was considered worthy of further consideration.

1.3 Object of This Phase

The object of this Phase IV of the study program is to purchase a Wright and Wright Oil Film Monitor and to test and evaluate it in actual use aboard an oil rig.

The evaluation would ideally have been conducted aboard an operating rig, but none was available at the time of the study and the work was done aboard a semi-submersible stacked in Halifax Harbour. While stacked, the rig main deck was 26m above water level, instead of the 14 m which would be the case if the rig were at drilling draft (see Figure 2.) This placed the Oil Film Monitor at the extreme limit of its operating range which was a major difficulty throughout the course of the study. Although not representative of expected conditions aboard a semi-submersible rig, the 26m operating height is typical of deck elevations for a jackup.

2.0 OBJECTIVES

2.1 Procurement

- To procure a Wright and Wright Oil Film Monitor.
- To modify it to incorporate extra transmitters, thermoelectric cooling of the detector and to bring out extra signal lines, in order to enhance and to monitor its performance.

2.2 Installation

- To fabricate suitable fixtures and to install the instrument aboard an oil rig.

2.3 Testing

- To observe and record the performance of the instrument under field conditions.
- To note other factors which bear upon the suitability of the instrument for offshore use.

2.4 Evaluation

- To establish the boundaries within which the instrument's performance is acceptable. It is anticipated that this will be a multi-dimensional space whose independent variables are:

  - lighting....... day/night, cloud cover
  - visibility..... rain, snow, fog
  - water surface.. swell, wind waves
  - contaminants... drilling mud, oil types and quantity

- The dependent variables will be:
  - operating range...maximum round trip distance from transmitter to receiver at which discernible signal is detected.
  - discriminating ability....false alarm rate, ability of the receiver to distinguish between oil and water.

- Other evaluation factors will include:
  - ease of installation and use
  - criticality of alignment
  - power consumption
  - power line transient tolerance
  - maintenance requirements
  - susceptibility to being damaged in installation/use
  - potential interference with rig operations

2.5 Strategy

The task of this study can be regarded as answering the question "Does the Wright and Wright Oil Film Monitor function effectively from a drilling rig repeatedly under as wide a range of environmental conditions as possible?" This may be restated as:

Question 1: Does the instrument detect a signal from the transmitter?

Question 2: Does the received signal successfully distinguish between oil and other materials?

The Oil Film Monitor can be considered to function effectively if and only if the answer to both of these questions is affirmative.

3.0 THEORY OF OPERATION

The Wright and Wright Oil Film Monitor is an active sensor; i.e. it transmits radiation which is reflected by the water surface and monitored by the instrument's receiver. The receiver is able to distinguish between oil and water because of the differences between the infrared reflectance spectra of the two materials (see Figure 1). In particular, the instrument indicates the presence of oil in the absence of the 2.7 micron absorption peak which is characteristic of water.

The transmitter portion of the Oil Film Monitor comprises one or more (in our case, four) lamps which project infrared light onto the surface of the water. The receiver monitors the reflected intensity in each of the two wavebands of interest by means of a chopped detector. The chopper is an opaque disc containing two optical filters, one for each of the wavebands of interest. The disc spins in front of the detector so as to admit light through each of the filters as they pass in front of the detector in rapid succession. The signal generated by the detector therefore consists of an alternating series of pulses, the amplitudes of which represent the intensity of the light received through the corresponding filter.

The detected pulses are de-commutated into two channels - one for each of the wavebands filtered - and low-pass filtered in the receiver. Finally, a ratio of the two signals is computed and used as the oil/water indicator. The ratio signal is compared to an adjustable threshold and the result is used to drive an alarm relay. There is also provision for an instrument status alarm which is signalled whenever the received signal strength in both channels drops below a preset threshold.

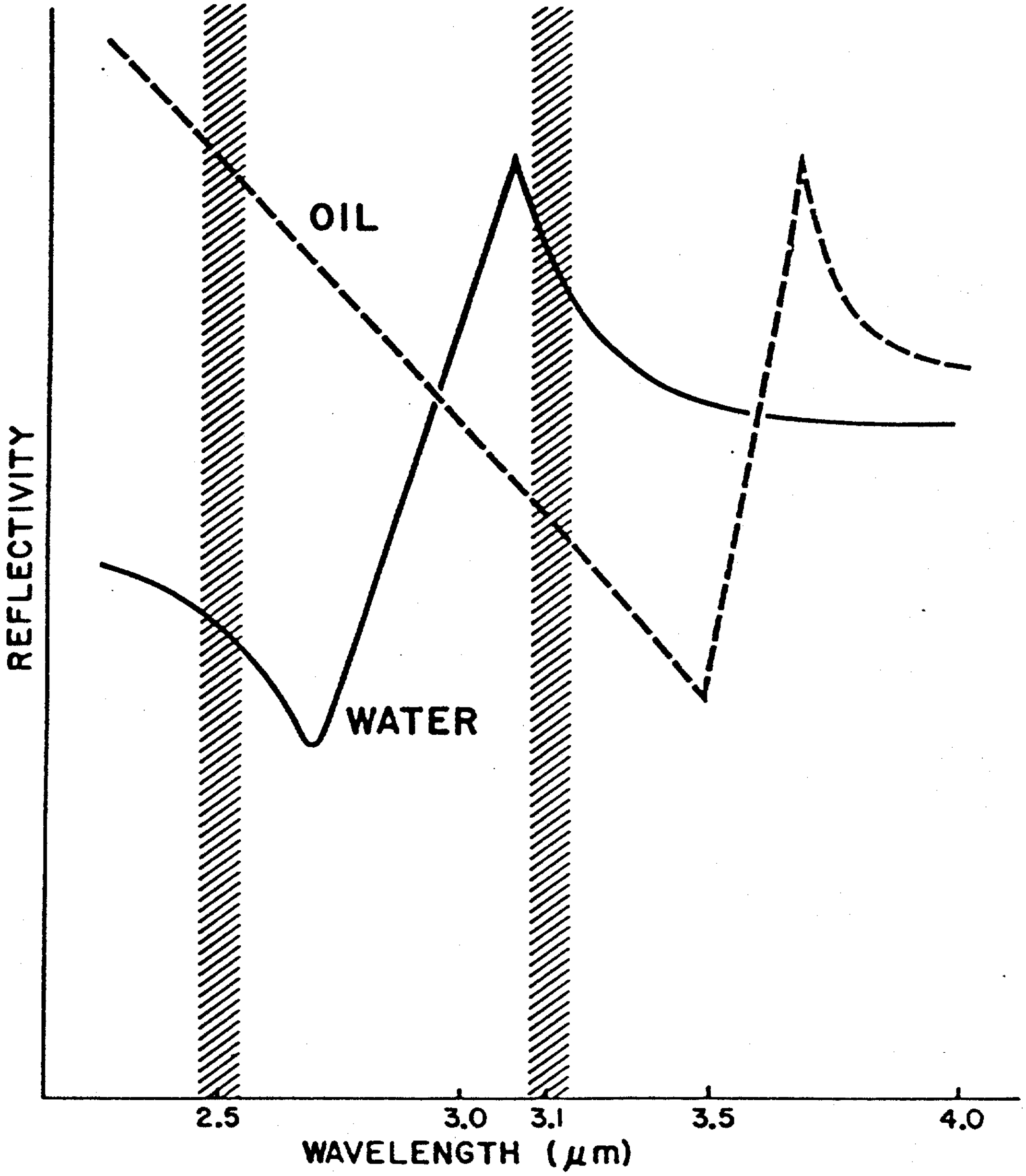


Figure 1: Spectral reflectance of water and oil (wavebands used by Wright and Wright Infrared Oil Film Monitor are shaded areas) (from phase III report - see References, Section 11.0).

4.0 SIGNAL PROCESSING

4.1 Active Systems

The Wright and Wright Oil Film Monitor was identified early in this series of studies as being one of the most promising oil remote sensing systems. A major reason for this is that it is an active system. An active system is one in which the user has control over the transmitted signal.

This control can be used to optimize the performance of the system in many ways. One of the most basic means is selection of the operating frequency and bandwidth. The system may also modulate the transmitted signal in phase, frequency and/or amplitude and detect in a manner coherent with that modulation. This is a standard technique in measurement systems and has the effect of dramatically reducing the noise bandwidth since presumably only a very small portion of the noise happens to be coherent with the modulating signal.

The Wright and Wright Oil Film Monitor takes less than optimum advantage of the fact that it is an active sensor. The features which the system does indeed incorporate include:

1. The ability to increase the number of transmitters, which in principle can increase the signal to noise ratio (SNR) without limit.

2. Chopping (and subsequent detection in synchronization with the chopping signal) of the received signal.

Phase and frequency modulation are not practical for this system. Amplitude modulation would appear to hold promise for substantial improvements in SNR but is not used in the Wright and Wright system. This is to avoid infringement of a patent held by Texas Instruments (Dave Wright, personal communication, March 1987).

(Amplitude modulation means the process of causing a signal to vary in amplitude, so as to convey information. In a broad sense it was used during this project inasmuch as the transmitters were switched on and off at times in order to confirm that some portion of the received signal was attributable to the transmitters. When only a very small noisy signal is present, this is the only means by which it can be confirmed that a meaningful signal is being received.)

It may be possible to accomplish coherent detection using amplitude modulation in the Wright and Wright instrument without infringing any patents. This would be done by reflecting a pilot signal, probably microwave, from the Oil Film Monitor's target area and then using the received microwave signal intensity to modulate the gain of the infrared detector. The beauty of this technique is that it would not only produce a significant improvement in the SNR, but also that the improvement would be largest in the presence of waves - the very circumstance where improvement is probably needed most. To implement this modulation scheme would require substantial development effort and would approximately double the cost of the instrument. Such an effort may not be justifiable.

4.2 Chopping

The chopping scheme used in the Wright and Wright is sub-optimal from a signal processing point of view. Ideally, the detector should spend 100% of the time looking at signals - 50% for each channel. Instead the instrument actually spends only about 25% of its time measuring meaningful signal, and the rest of its time looking at background noise. The reason for this has to do with practical realities concerning the price and availability of optical filters of particular sizes.

Wright and Wright are currently developing a modification to the Oil Film Monitor which involves installing additional filters in the filterwheel. This will not only provide a signal to the detector 100% of time but will also provide information about the reflected signal at additional wavelengths. The result should be a significant improvement in SNR. The reader is referred to Wright and Wright for further details on this modification.

4.3 Data Logging

Recognizing that SNR would be a major factor in the instrument's ability to function from a rig deck, it was decided that enhanced signal processing should be one of the principal thrusts of this project. To this end, several extra signal lines were brought out of the Wright and Wright (see Table 4.1) and all signals - both raw and processed - were digitized and logged on a microcomputer. This allowed us to not only monitor the performance of the instrument and its internal signal processing, but also to replay the raw signal repeatedly through other candidate algorithms to see what improvements might be made.

Sychronization of data logging was accomplished through the use of the "window pulses". These are waveforms provided by the Wright and Wright receiver each of which consists of a train of pulses whose timing and duration coincide with the presence of one of the filter windows in front of the detector. There are, accordingly, two such waveforms, one corresponding to each of the two wavebands received. By using these waveforms to trigger the computer's ADC board, the output signal from the Wright and Wright's detector was broken down into two signals called ch2 and ch3, each representing the received light intensity in one of the two wavebands.

4.4 Data Processing

The signal processing algorithms tested were various combinations of weighting functions and averaging schemes applied to both the ch2 and ch3 signals. The purpose of the weighting function is to emphasize the importance of the signal during the time when the filters are positioned in front of the detector and to de-emphasize it at other times. The purpose of averaging is to smooth out signal fluctuations (primarily due to waves).

Wright and Wright Oil Film Monitor		Multi-conductor Cable (twisted pairs)	Metrabyte DASH 8 ADC Board	
Receiver Terminal No.	Designation	Conductor Colour	Pin No.	Channel No.
1	ch. 1 (ratio)	black	31	6
3	ch. 3 (reference)	white	32	5
2	signal ground	black	18	LL GND.
4	preamp output	red	37	0
5	ch. 2 "window"	black	35	2
7	ch. 3 "window"	green	34	3
6	ch. 2 (hydro-carbon)	blue	33	4
		jumper	6	COUNTER OUT
			24	INTERRUPT IN
	N/C	shield		LL GND.

TABLE 4.1: RECEIVER - COMPUTER WIRING

All of these algorithms were implemented in BASIC on an IBM-PC compatible microcomputer (see Section 6.0 Software).

4.4.1 Weighting Function

Three weighting functions, W(t) were tried:

flat: W(t) = no weighting

square:W(t) = 1 while window pulse is high
.1 while window pulse is low

peaked: W(t)= f(t) while window pulse is high
.1 while window pulse is low

where f(t) is a function whose shape is intended to approximate the intersection of the areas of the filter and the detector as a function of time.

4.4.2 Averaging

The ideal averaging scheme would be a so-called "moving average". What was tested instead was a geometrically decaying average of the form.

$$X(t_n) = \frac{X(t_{n-1})}{D} + A(t_n)$$

where $X(t_n)$ = average at n'th time step
$A(t_n)$ = raw signal at n'th time step
D = delay constant (≥ 1)

The above reduces to a simple arithmetic sum for the case D=1.

The advantage in using this geometric average is that it is a far simpler algorithm to implement and requires considerably less memory than does the moving average. While this is of no great concern for our experimental purposes, it would definitely be a deciding factor in any ultimate operational system.

4.4.3 Ratio vs Difference

As mentioned in Section 3.0, Theory of Operation, the Oil Film Monitor uses the ratio of ch3 to ch2 as its oil-no oil indicator. This is done as a simple means of indicating the relative amplitudes of the reflected signal in the two wavebands. The individual amplitudes of the two channels are an indication of such things as range, flatness of the reflecting surface and output of the transmitter; only the relative amplitude contains the oil-no oil information.

One difficulty of the ratio as indicator of relative amplitude is that it becomes unstable if either of the signals goes negative or if the channel 2 signal becomes small. In order to avoid this, there is provision in the instrument for adding an adjustable offset to each of the two channels. This does not decrease the information content in the signals because they are already AC coupled. The tradeoff is that the offsets must be made large enough to keep both channels always positive, but small enough that the ratio is sufficiently sensitive as an oil indicator.

In order to circumvent these shortcomings of the ratio technique, one might instead use the difference, channel 3 minus channel 2, as the oil-no-oil indicator. The price paid is that the magnitude of the difference depends upon the amplitudes of the individual channels. This means that a decrease in range to the target could create a false "oil" alarm.

As it is not clear which choice of difference or ratio is the better one, both were implemented and tested on the micro-computer. It may be that the best approach is some combination of the two. For more on this issue, see Section 8.10, Signal Processing.

5.0 SUMMARY OF EVENTS

The Wright and Wright Oil Film Monitor was received in Halifax in late November 1986. Due to the low level of offshore exploration activity at that time, there were no longer any rigs active on the Scotian Shelf.

In early February permission was granted by Petro-Canada to conduct our tests aboard the SDS Vinland which was anchored in Halifax Harbour.

The interval between November and February was used to prepare for the Field tests by experimenting with the Oil Film Monitor in the MacLaren Plansearch warehouse. Several signal lines were brought out of the instrument's receiver and connected to a DASH8 ADC board. This board was used in conjunction with an Eagle PC to analyze and record the various signals.

On 6 February 1987, the Oil Film Monitor together with associated tools, mounts, cabling and logging computer were transported to the Vinland and hoisted to deck level. By the end of the day installation was complete and the instrument was ready for testing.

On 9 February 1987, the receiver and transmitter, mounted together on a single frame, were lowered and raised from a lifeboat davit at the bow of the Vinland. (See Figure 2) It became clear that it would be necessary to switch the transmitters on and off to establish that the detected signal was real.

On 13 February, the wiring was re-arranged and the Oil Film Monitor operated at several ranges to establish the relationship between signal strength, range and number of transmitters. Misalignment of optical axes of transmitters with their housings was discovered and corrected. Alignment of receiver was impossible due to necessity of lowering it well below deck level to get a detectable signal.

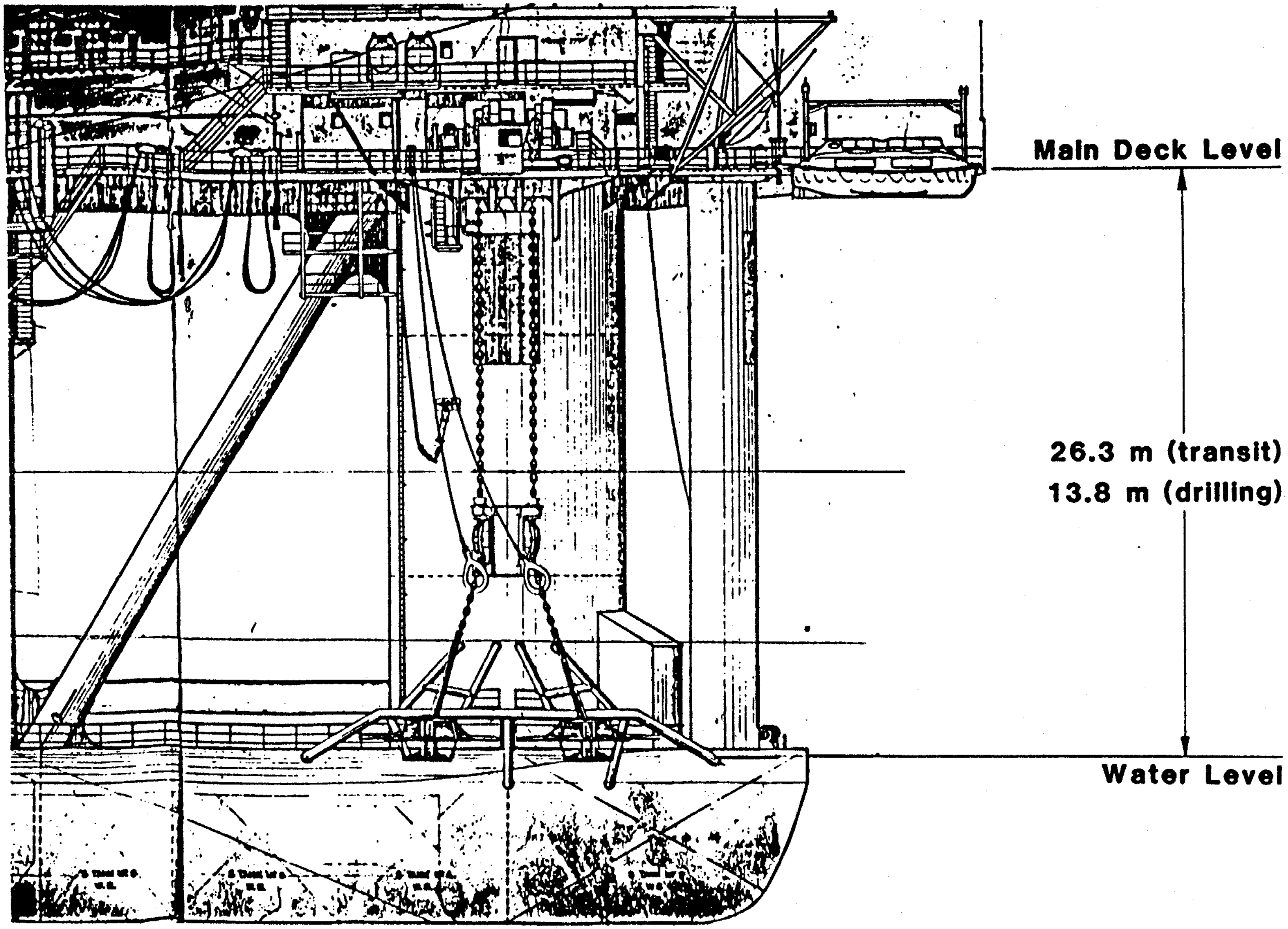


Figure 2 Bow of SDS Vinland (viewed from starboard side and showing deck height above water).

On 27 February, the receiver was mounted on a fixed bracket at deck level so that it could be aligned while transmitters were lowered from the davit. A small plastic children's swimming pool measuring 117 cm in diameter by 23 cm deep had been mounted on a sheet of plywood. This pool was floated on the water tethered to the rig pontoons. By causing the pool to pass in and out of the Oil Film Monitor's field of view, it was used to test the instrument's response to different oil types.

Periods of data acquisition alternated with data analysis and equipment modifications as the field tests continued through to their completion in mid-March.

6.0 SOFTWARE

The hard disc and floppy diskettes included with the deliverables for the project (see section 10.0) contain MS-DOS files of three basic types.

1. Utilities supplied by Metrabyte for use with the DASH8 ADC board. Some are in assembler, some in BASIC. The DASH8 is a very versatile device and, with the aid of these utilities, can readily be configured to a wide variety of digital and/or analog data gathering tasks. Most of these utilities are well-documented in the DASH8 manual; some are self-documenting. Still others were supplied without documentation, but their function can readily be determined simply by trying them.

2. Utilities written by MacLaren Plansearch for use with the Wright and Wright receiver. They are called WWALIGN, WWTEST, WWLOG, WWREAD, and SCOPE. These are all program files written in BASIC. Documentation sufficient for following or modifying program flow is included in the source code. The programs provide the user with instructions on how to proceed as they run. All programs can be terminated by CTRL BREAK.

   All programs require trigger signals from the Wright and Wright receiver in order to function properly. If the receiver is not connected the computer will "hang up" until either trigger signals are received or the computer is turned off.

3. Data files created by WWLOG. These are packed binary files written in a format which can be read by WWREAD. File names are in the form MMDDHHNN.DAT where

   MM is month number
   DD is day of the month

HH is hour of the day (Atlantic Standard Time)
NN is minute of hour

In this way the file is tagged with the time at which the data were logged.

Further description of some of the programs follows:

WWALIGN continuously monitors the channel 3 (reference channel) output of Oil Film Monitor and displays the result in three separate ways simultaneously:

1. As a voltage which is printed numerically on the screen;

2. As an asterisk whose distance from the left margin of the screen is proportional to the measured voltage;

3. As a tone whose pitch increases with increasing signal level.

This program is useful for aligning the Oil Film Monitor as well as for confirming that it is responding to infrared light.

WWTEST is useful for a more exhaustive examination of receiver operation. This program monitors all seven data lines connected to the Oil Film Monitor and displays the results on the screen. The monitoring and displaying is done in bursts, the results of each burst occupying the full screen. Each burst is triggered by the operator from the keyboard. Channels 1, 2 and 3 of the receiver are slowly varying and are each displayed simply as a count printed across the top of the screen. The preamp output is demultiplexed into channel 2 and channel 3 half-cycles which are both displayed as time series plots and as columns of numbers. Increasing time runs from the top to the bottom of the screen and increasing signal level runs from left to right.

WWLOG monitors all outputs in the same manner as WWTEST but logs the data to a disk file instead of to the screen. The disk files are named using the date and time according to the scheme described above. Each file comprises a number of (non-contiguous) bursts of data gathered over approximately a one minute period and packed into binary format. Data collection is triggered automatically every hour on the hour but can also be triggered manually from the keyboard by pressing "T".

SCOPE allows the computer to function as a simple general purpose digital oscilloscope. The program incorporates an adjustable trigger level and can sample at rates of up to 4000 samples per second in either single shot or repetitive modes.

WWPROC reads, processes and displays data files created by WWLOG. The data are read into scan vectors A2 and A3 corresponding to Wright and Wright channels 2 and 3 respectively. These vectors are multiplied by a weight vector W and running totals are kept in the display vectors X2 and X3 according to the following formula:

$$X = \frac{X}{D} + A . W$$

where D is a decay constant. D and W are user selected interactively. (For more on this, see the chapter on signal processing). X2 and X3 are displayed in the form of time series plots on the computer screen.

7.0 DATA ANALYSIS

All of the data files recorded by WWLOG were saved on floppy diskettes. A total of 216 data files were saved on six diskettes labelled Volumes I through VI. Of this total, 36 files on three diskettes were not readable due to disk drive malfunctions. (The reason for these malfunctions is not known. It may be attributable to rig power line transients. At any rate, it does not reflect negatively upon the performance of the Wright and Wright.) The remaining 180 files were analyzed at the MacLaren Plansearch office using programs WWPROC and WWPLOT on a second computer.

Once the optimum processing scheme had been derived, all 180 data sets were plotted. Representative samples of these plots are in Appendix B. The processing used for these plots was:

1) Demultiplex the preamp signal into channel 2 and channel 3 signals synchronously with the "window" pulses;

2) Calculate arithmetic averages for each channel of the 50 scans which constitute each data file.

These averages, together with their ratio, ch3/ch2, and their difference, ch3-ch2, are all plotted on each graph. By visual examination of each graph, a subjective decision was made as to the presence or absence of a discernible signal in plots of channels 2 and 3.

The tables in Appendix C summarize the plotted data (see Appendix B) together with the meteorological observations of wind speed, air temperature and cloud cover corresponding to each of the data logging events. (The meteorological observations were made on site aboard the Vinland until 5 March. After 5 March meteorological observations from Shearwater airport were regularly taken from the AES circuit and logged in the MacLaren Plansearch weather office). All times are Atlantic Standard Time.

The following is intended as a guide to aid the reader in interpretation of the plots and tables using data file 02271529 as an example:

The interval between 0 and 2 milliseconds in the plotted data corresponds to the time when one of the filters is positioned in front of the detector. The plot of data file 02271529 shows clearly the peaks in the responses of channels 2 and 3 during this interval. The relative amplitude of the peaks is the "oil/no oil" indicator. In this case, the channel 2 peak is higher than the channel 3 peak, indicating a stronger reflection in the 3.1 micron waveband than in the 2.5 micro waveband. Referring to Figure 1, it can be seen that this is a clear "no-oil" indication.

The difference plot (ch3 - ch2) displays a distinct dip, a clear "no-oil" signal, during the 0-2 msec time interval. The ratio plot (ch3/ch2) is not so readily interpreted, but, by comparison with plots having definite "oil" responses (see, for example, graph #02271657), it can be seen that the ratio is also giving a "no-oil" response.

Both the difference and the ratio plots are digitally generated by the computer from the ch2 and ch3 signals which it captures from the Oil Film Monitor. The Oil Film Monitor also computes a ratio signal using its own internal circuitry. Due to filtering, this is a slowly varying signal and its amplitude is represented by the single number printed in the top right of each plot. Experience with use of the Oil Film Monitor during this study indicates that the ratio channel is usually greater than 1.0 in the presence of oil. The reading of .3 for data file 02271529 is therefore a clear "no-oil" indication, confirming the two computer-generated indicators.

During the time interval between 2 millisceonds and 8 milliseconds, there is no filter in front of the detector. The detector is looking at the opaque portion of the filter wheel during this dead period. The plotted data during the dead period should be regarded as noise. It is worth noting that the difference signal, "ch3 - ch2", is much better behaved than is the ratio signal, "ch3/ch2", is which gives spurious "oil" signals during the dead period.

Referring to the tabulated data in Appendix C, the reader will find the entry corresponding to the data discussed above indicated by 02271529 in the left most column. The next two columns indicate the observed wind speed and cloud cover at the time when the data were recorded. The third column shows the round trip range from transmitter to receiver and the fourth column shows the number of transmitters turned on at the time in question. The judgement of discernible signal is a subjective one made by studying the plotted data in Appendix B. This decision is made on the basis of whether or not there is a peak in either of the ch2 or ch3 plots which rises significantly above the background noise level in the 0-2 millisecond time interval.

The final two columns of Appendix C are voltage readings taken directly from the Oil Film Monitor. The reference channel is an indicator of the amount of infrared light reaching the detector and thus gives an indication of the level of confidence which can be placed in the Oil Film Monitor's verdict of "oil" or "no oil". In this study it was found that a reference channel output of 0.13V generally indicated reception of a discernible signal. The column headed "ratio channel" gives the output of the Oil Film Monitor's internal signal processor. Interpretation of this number was discussed above.

Further discussion of the plotted and tabulated data is given in Section 8 - conclusions.

8.0 CONCLUSIONS

8.1 Signal to Noise Ratio

Most of the effort in this experiment was directed at obtaining a discernible signal. Due to the high operating height, the criticality of the receiver alignment and the presence of waves (albeit small ones), the occasions on which any meaningful signal was detected (less than 10% of the time) were so few, and the data so noisy, that quantitative conclusions about the performance of the Oil Film Monitor are difficult to make. There can be little doubt that we are pushing the operating limits of the instrument.

Improvement of the signal to noise ratio (SNR) is the answer to virtually all of the limitations of the Oil Film Monitor. A higher SNR would increase the useful range, improve performance in limited visibility and waves, simplify alignment, permit coverage of a larger area, and shorten response time, to mention only a few of the areas of improvement.

8.2 Mounting

A number of modifications to mounting, alignment and wiring were performed during the course of the field testing. It is therefore fortunate that the testing was conducted in Halifax Harbour as such modifications would be impractical or impossible on an operating rig located offshore.

The aluminum mounting brackets included with the deliverables for this project performed remarkably well considering that they were intended only for temporary use. The second shelf-type bracket would serve as a good model from which to make something more permanent.

The alignment mounts provided by Wright and Wright could stand some improvement as discussed in Section 8.4 - Alignment.

8.3 Siting

Factors to be considered in locating the instruments include the following:

1. prevailing wind direction (i.e. direction of oil drift);
2. proximity of suitable power connection;
3. potential for collision with fuel lines, crane hooks and other movable machinery;
4. elevation above the water;
5. accessibility of the instrument for alignment and servicing;
6. exposure of the instrument to sources of contamination such as diesel exhaust (reduced light transmission through receiver window);
7. clear view of the water directly below.

In most cases it should be possible to find at least one suitable location at deck level on the outboard side of the rail. If carefully chosen, such a siting should permit the instrument to function properly and present minimal interference to rig operations. In the vast majority of rigs, it will not be practical to mount the Oil Film Monitor below deck level. (see discussion in Section 9.3 - Siting).

8.4 Alignment

8.4.1 Transmitters

There are two parts/aspects to transmitter alignments:

Part A: Making all transmitters point in same direction.

Part B: Making sure that mutual direction coincides with the desired direction.

It was found that the Part A alignment could be accomplished as follows: Cause the transmitters to shine on a convenient flat surface. Note the bright spots corresponding to the centres of the beams. Adjust the lamps until the spatial arrangement of the bright spots on the flat surface is the same as the arrangement of the lamps themselves. A photograph of this process in practice is included in Appendix A.

It is worth noting that the lamps in the non-explosion proof housings are substantially mis-aligned with their housings. This can be somewhat disconcerting as it causes the properly aligned array of transmitters to appear somewhat askew.

The transmitters cast a fairly broad beam. This makes their alignment non-critical. It was found that in most cases, alignment by eye is adequate and the alignment mount may even be superfluous.

8.4.2 Receiver

In striking contrast to the transmitters, the receiver alignment is extremely sensitive. When the receiver is properly aligned, a 1/4 turn on any of the alignment screws can cause a 15% drop in the received signal. The diligence required to properly make this alignment under field conditions cannot be over-emphasized. This is in striking contrast to the findings of the Phase III study. This is probably attributable to the greater range and more complex mounting arrangement therefore necessitated in the present study.

The alignment mount was found to be adequate but could stand improvement in the areas of corrosion resistance, interaction of the adjusting screws and immunity to jarring and vibration. More specific recommendations are made in Section 9.4 - Alignment.

Receiver alignment is easiest at short ranges and with a flat reflecting surface. Given the extreme ranges involved in working from a rig, and the roughness of the water surface, averaging periods of as long as one minute or more were required for each turn of the adjustment screw to discern whether the signal had improved or not. Indeed, it can be stated that alignment is impossible at a range of 50m or more or whenever the wind speed is higher than 10 knots. This is because the effectiveness of water as a reflecting surface is determined primarily by the presence or absence of small wind-induced ripples. This implies that alignment is easier at night, when the water is calm and also when there is oil on the water surface to dampen these ripples. In fact, the only way in which alignment was successfully accomplished in this study was as follows:

1. With the receiver mounted within easy reach at deck level, lower the transmitter close enough to the water surface that a significant (at least .13V in our case) signal is received on the reference channel.

2. Using at least a five second averaging period, align the receiver for maximum signal.

3. Gradually raise the transmitters back to deck level taking care to continuously align the receiver so that the peak is not lost in the process.

Obviously, the above process, which can take several hours, is not very practical and indeed is not even possible in anything but the calmest seas and winds. One must cope not only with the motion of the reflecting surface, but also with the swaying of the suspended transmitters.

Another more practical trick which might be used - as was discovered by accident during this study - is to float a sheet of plywood into the instrument's field of view; plywood floats awash and appears to the Oil Film Monitor as a flat sheet of water. This increases the amplitude and decreases the variability of the received signal, greatly simplifying alignment.

According to Wright and Wright, the receiver can be equipped with a sighting scope to aid in alignment. It is not clear that such a device would actually make alignment much easier in the presence of waves. In any event, if the signal-to-noise ratio is improved, as may be necessary for other reasons, alignment will become correspondingly easier.

It remains unclear whether or not initial alignment is in practice an important issue. Over a long term deployment, things such as vibration, bumps, temperature changes and waves may well smear the peak so much that fine tuning for that last 15% in signal strength is pointless.

8.5 Power Requirements

The Wright and Wright Oil Film Monitor is designed to operate on 60 Hz 110VAC. While 110 VAC is not widely available on the deck of a drilling rig, it is always possible to run a power cable from the distribution panel to the desired location.

Although the power demands of the receiver are moderate, the four transmitters used in this study consume a total of 1000W. While this may seem excessive for a device which is in continuous operation - especially as there may be several such devices aboard each rig - it would represent a negligibly small fraction of the base load served by a rig power plant. Given this level of power consumption, wiring the instruments for a 220 volt supply may be a good idea. This may also improve the power availability situation.

The electrical design of the Wright and Wright Oil Film Monitor is very robust; it can survive all manner of power blackouts or brownouts without damage or "hang up". Indeed the instrument survived an actual power failure during this study on 07 March 1987. Some of the receiver circuitry may temporarily cease functioning if the power supply deviates too far from nominal, but the system would resume normal operation once the power supply has been restored. Some of the more delicate portions of the receiver circuitry might be damaged by severe power line transients but the Wright and Wright is far less sensitive to such "glitches" than are any of the microprocessor-based electronic devices widely used offshore today. It is standard procedure to install power line conditioning with such devices offshore; if such conditioning is needed for the Wright and Wright, it would only be needed for the 8W consumption of the receiver.

It is worth noting in this regard that our logging computer apparently suffered a number of power line transients during this experiment as evidenced by the fact that several of the floppy disc data files were not readable. The Oil Film Monitor itself appears to have suffered no ill effects from these transients.

8.6 Field of View

The acceptance angle of the Wright and Wright receiver is remarkably small; at the 26m maximum operating height used in this study, the receiver was found to be sensitive to oil within a circle of approximately 1.2 m diameter. Coverage of an area one or two orders of magnitude larger would be the ideal for application aboard a drill rig. According to Wright and Wright (Dave Wright, personal communication, 12 March 1987), it may be possible to enlarge the field of view by a factor of five, but an order of magnitude or more seems unlikely.

8.7 Visibility

Next to sea state, visibility would seem to be the biggest environmental threat to the successful operation of the Wright and

Wright. Thick fog or heavy rain or snow could conceivably attenuate the light from the transmitters sufficiently to render the monitor inoperative. It was not possible during this study to isolate the effect of poor visibility.

Similarly, accumulations of salt, soot, grease and/or oil pose a threat to the transparency of the receiver window. Although a slight encrustation of salt was apparent on the window at the end of the study, it was probably too slight to cause any significant attenuation nor was any signal attenuation attributable to it.

8.8 Range

This section addresses the answer to Question 1 identified in Section 2.5. Strategy - "Does the instrument detect a signal from the transmitter?".

The data gathered on 11, 12, and 13 March clearly establish that the Oil Film Monitor can receive discernible signals at a range of 52.8m (total round trip from transmitter to receiver). This is high enough for use at deck level on most oil rigs. These data also establish that the instrument can function in wind speeds of up to at least 8 knots, in daylight or at night and in cloud cover ranging from 0 to 100%.

It is also clear from the above-referenced data, as well as from the majority of the data gathered during this experiment, that most of the time the Oil Film Monitor did not register a discernible signal. It is not certain which of the various independent variables are responsible for this lack of success. Given the delicate nature of the alignment process - which can take several hours to complete - it is probable that the alignment degraded slightly due to slight movement in the supporting structures following the instrument's lastalignment on 11 March and that this was sufficient to render the signal undetectable.

Multiple correlation analyses were run amongst the various variables. Using the reference channel (channel 3) output as a measure of signal strength and hence maximum operating range, the findings were:

- There is a strong correlation of signal strength with presence of a discernible signal. A discernible signal was present only at times the signal strength was higher than .13V. Whenever the signal strength registered higher than .16V (20 occasions), a discernible signal was detected. (While it may seem that the existence of this positive correlation is intuitively obvious, it is worth checking in order to confirm that the data "makes sense". Indeed the fact that this correlation is not even stronger is evidence for the presence of a great deal of noise in the data. Furthermore, it should be kept in mind that the "discernible signal" decision is based upon the output of the synchronous demodulation scheme implemented in the computer while the reference channel is taken at the output of the synchronous demodulator built into the Wright and Wright receiver.)

- There is an inverse correlation of signal strength with wind speed. All events with a signal strength of higher than .13V occurred at winds speeds of less than nine knots. All events with discernible signal occurred at wind speeds of less than 10 knots. (The median wind speed was approximately 11 knots during the observing period.)

- There is a slight correlation of signal strength with time of day; signal strength tends to be higher at night. (This is probably simply another manifestation of the correlation with wind speed, since wind speed tends to be lower at night.)

The influence of wind speed upon signal strength is to be expected as the small ripples created by even slight breezes greatly reduce the effectiveness of the water surface as a reflector. This effect is clearly demonstrated during the process of alignment. Indeed the highest signal strength by far was observed when a flat surface (a sheet of plywood) was introduced into the instrument's target area on the surface of the water.

8.9 Response to Various Substances

The following addresses the answer to Question 2 identified in Section 2.5, Strategy - "Does the received signal successfully distinguish between oil and other materials?".

The following subsections 8.9.1 through 8.9.3 draw principally upon written correspondence from Wright and Wright, with supporting observations from the present work.

8.9.1 Response to Oil Type

Wright and Wright has over 15 years experience with this instrument in environments ranging from oil refineries to the bow of a research workboat. Every imaginable type of oil has been tested at one time or another in that 15 year period. The results have consistently shown that the oil type is not as important as the physical distribution of the oil on the water's surface. That is, if the oil spreads out into a thin sheen on the water's surface, the instrument's response to all oil types is roughly the same. If the oil makes lenses or striations on the water's surface and does not sheen, the instrument's response will be significantly affected. Lenses or striations allow considerable water surface to show around the oil surfaces. In such cases, the instrument sees much more water than oil, and gives a corresponding weak response to the oil. Because a sheen gives a thin layer of oil over a large water surface, the instrument sees only oil (infrared light does not penetrate through the thin oil) and gives a very strong response. A good disertation on this is in Schwartzberg, 1970. It should be noted that oils generally form sheens on the ocean.

In the present work, a much stronger oil response was registered from crude oil than from condensate. Since the crude oil formed conspicuous globs, while the condensate formed a sheen, there is an apparent contradiction. Upon closer examination of the crude oil slick it was observed that it consisted of a thin sheen in addition to the obvious globs. Since the globs float very low in the water, it is probable that the Oil Film Monitor was actually responding only to the thin sheen component of the crude oil and not to the globs at all.

The observed apparent discrepancy between crude and condensate responses can also be attributed to variation in alignment of the swimming pool with the receiver's field of view and/or to rapid evaporation of the relatively high volatility condensate.

Between 1300 hours and 1800 hours on 12 March, there is an apparent "oil" event detected by the Oil Film Monitor (as evidenced by ratio channel readings of 1.1V, 1.2V, 1.3V and 1.2V respectively on data files 03121300, 03121400, 03121700 and 03121800. See tables in Section 7.0, Data Analysis). However, the reference channel output is relatively low being .13V and lower on the same occasions. This suggests that the high ratio channel readings are merely an artifact of the low signal strength. As confirmation of this, the plots in Appendix B reveal no discernible signal at any of the times in question.

As a further check, Canadian Coast Guard personnel at the Halifax Vessel Traffic Centre were asked to consult their Operations Log; only one oil slick was reported in Halifax Harbour on 12 March and that was at least a mile seaward of the Vinland's location. The rig Captain advised that slicks are frequently observed at the rig's location when the wind blows from the east. The winds were NE at 4-10 knots on the morning of 12 March, veering to SE at 8 knots at noon local time.

Regardless of the presence or not of a slick at the time in question, the low output registered on the reference channel clearly indicates that the receiver is receiving insufficient signal and hence cannot determine whether or not it is looking at oil.

In other words, the "oil" signal registered by the ratio channel is a false alarm. The difference signal, channel 3 minus channel 2, gives no false alarm registering zero volts (meaning "no discernible signal") the entire time.

The data in the tables in Section 7.0, Data Analysis, shows an interesting inverse correlation between reference channel and ratio channel outputs, especially on 11 and 12 March. The proper interpretation of this is probably that channels 2 and 3 hover around their bias settings when signal strength is low, thus causing the ratio channel to hover around 1V. When signal strength rises, as indicated by a level of .13V or more on the reference channel, channels 2 and 3 begin to rise from their bias settings yielding a clear "no oil" signal of about .5V on the ratio channel.

8.9.2 Response to Oil Thickness

"The instrument has the strongest response to a thin oil sheen (less than one micrometer) and a weaker response to thick oil sheens (greater than ten micrometers). The response between one and ten micrometers follows a complex, damped sinusoid, caused by optical interference effects of thin films. The difference between the response to a thin film and a very thick film is about a factor of X2. The instrument was designed to have an optimum response to thin oil films to maximize its usefulness as an oil spill detector. This response to thickness cannot be changed or adjusted within the instrument." (Source Dave Wright, personal communication.)

The present data bears this out in that the response from crude, which produced an extremely thin sheen (barely visible to the eye) was higher than the response to condensate, which produced a slick approximately .2mm thick.

8.9.3 Interfering Materials

"The measurement technique employed by the instrument is quite good at ignoring the presence of foreign substances in the water. The only exceptions are surfactant-type substances that alter the surface tension, as noted above. The technique looks for the water molecule resonance at 2.7 micrometers. Oil films have the unique property of completely covering water molecules and preventing the instrument from viewing any resonance at 2.7 microns. Other non-hydrocarbon foreign substances in the water do not have this property. They mix with the water molecules and permit the instrument to still observe the 2.7 micron resonance. The instrument responds only when it does not see the 2.7 micron resonance." (Source Dave Wright, personal communication)

This is confirmed by the strong "no oil" response given by the clean swimming pool (containing water to a depth of approximately .5cm) before introduction of any oil.

8.10 Signal Processing

As was noted in the Phase III report, the raw preamp signal is so noisy as to be quite useless in the presence even of small waves. Time averaging proved to be remarkably effective at extracting signals from this noise. This would seem reasonable if wave induced variations in reflected light intensity are assumed to be the main source of interference. The decay constant implemented in the averaging scheme was of little use with the short (less than one minute) sampling durations used here. In other words, the longer the averaging period, the better.

The weighting functions are of no utility with the present scheme of plotting data for visual presentation as the weighting function does nothing that the eye cannot do at least as well. The weighting function(s) will only be useful in assisting a machine - rather than a human - to make the oil/no oil decision.

As mentioned earlier in Section 4.4.3, Ratio vs Difference, the Wright and Wright receiver uses the ratio, ch3/ch2, of the signals in the two wavebands as its oil-no oil indicator. The plots in Appendix B show for comparison purposes what the ratio and difference signals calculated by the computer look like as functions of time. The plots show clearly that the difference signal is much more stable than the wildly fluctuating ratio signal. This is a direct result of the low signal strength received, and might possibly be eliminated by increasing the ch2 and ch3 biases. The difference has the nice property that it is negative for "no oil", positive for "oil" and zero at other times (i.e. when signal strength is low). This eliminates the need for the separate "instrument status" line currently provided in the receiver.

The fact that the amplitude of the difference signal is range-dependent is of little consequence as no significance is attached to the amplitude of the signal; it is only necessary to know whether it is positive, negative or zero.

9.0 RECOMMENDATIONS

9.1 Signal to Noise Ratio

Further improvement in the SNR of the Oil Film Monitor is essential in order to make it practical for use offshore. The easiest way to improve SNR is to simply add more transmitters, but these pose an explosion hazard unless protected by heavy, unwieldy and expensive explosion proof housings.

Slightly less easy, but probably more effective, would be the installation of additional filters in the filter wheel together with modification of the synchronous demodulator circuitry to make use of the extra information gained. The present design incorporates features which allow for such enhancements.

If necessary, more dramatic improvements in SNR could probably be accomplished by using a ranging device to modulate the detector gain in synchronism with the waves. This would be a major development project; the cost may not be justifiable.

9.2 Mounting

The transmitter and receiver must both be rigidly mounted to prevent their movement relative to each other or relative to the rig. Given the necessity in the present work to move at least one of the packages in the alignment process, this also implies a requirement for a simpler alignment process.

Further work must be done to establish how well the instrument maintains its alignment when properly and rigidly mounted over an extended period.

An additional feature which might be considered for inclusion in a more permanent mounting arrangement is an inverted metal box. This box would be constructed so as to shield the instrument from rain, snow, etc., as well as from paint, grease and other substances which might otherwise foul the workings. In addition, the box could be made strong enough to guard against the monitor being knocked out of alignment or damaged through collision with a crane or any one of a number of other such hazards to be found aboard an oil rig.

9.3 Siting

Consideration should be given to the use of a supply boat, instead of a rig, as a mounting platform. The main advantage in doing this would be the reduced range from the instrument to the water. Coverage would also be improved in that supply boats usually stand by downwind of the rig where oil is most likely to be encountered. Additional benefits include less stringent safety requirements and improved accessibility of the instrument for servicing through the frequent visits of the supply boats to port. Although the boat would present a much livelier platform, this penalty may be worth the price.

It is essential that the Oil Film Monitor be installed in a location where it is readily accessible for alignment, cleaning and servicing. Regular maintenance requirements will probably include checking alignment, replacing burned out transmitter bulbs and cleaning accumulated grease and salt from the receiver window.

Many rigs vent their engine exhausts downwards under the main deck. This causes greasy soot to deposit on all exposed surfaces under the rig. For this reason, as well as in consideration of accessibility, the Oil Film Monitor must be located no lower than main deck level. This varies from 20m to 30m above sea level depending upon rig size and type.

9.4 Alignment

The alignment mount incorporates a variety of metals, including both steel and aluminum. A more careful selection of materials, with due regard to galvanic couples, is necessary in a marine environment.

The adjustments screws are currently arranged in a triangular pattern. This causes the adjustment axes to be non-orthogonal and creates interaction among the adjusting screws. Perpendicular adjusting axes, which match the axes of the universal joint, would be more user-friendly.

The process of tightening the adjustment locking screw disturbs the adjustment. Some better locking mechanism should be found.

The alignment mount should be made more immune to impact and vibration which can too easily disrupt the alignment.

The current system suffers from jerkiness and hysteresis (or backlash) in its action. This should be eliminated.

A simpler alignment procedure must be found. Floating a sheet of plywood on the water may be all that is needed.

9.5 Field of View

Modification of the instrument to enlarge the field of view by up to a factor of ten may be necessary to make the coverage area large enough for offshore use to be practical.

9.6 Transmitters

The four transmitters used comprise a bulky, heavy, unwieldy and non-explosion proof package. A way must be found to assemble 1000W of illumination in some more compact and convenient package. The largest lamps currently available in an explosion proof package are 250W.

Since explosion proof requirements become significantly less stringent as the wattage of individual bulbs decreases, it may be worth considering an array of a large number of low wattage lamps. An additional benefit would be the narrower beam possible with lower wattage lamps.

9.7 Junction Boxes

The junction boxes must be altered so as to avoid their tendency to admit rain water. This would be a simple matter of rotating them by 180° and greasing the threads on the lids. Quite apart from the obvious electrical hazard which they pose, the existing junction boxes render maintenance in winter very difficult.

10.0 ACKNOWLEDGEMENTS

This work has been performed under the terms of DSS Contract No. KE201-6-0385/01-SC with the invaluable guidance of Mr. Roger Percy, Regional Environmental Emergencies Coordinator, as Scientific Authority. The work was funded by PERD (Program for Energy Research and Development).

The work would not have been possible without the assistance of SDS Drilling who kindly allowed the use of the Vinland drilling rig and her facilities in the performance of this study. The generous hospitality of Captains Loken and Salsbratten and the crew of the Vinland are gratefully acknowledged.

11.0 REFERENCES

Phase I Report, "Remote Sensing Equipment for Chronic Oil Discharges", report EE-54, prepared by F. G. Bercha and Associates Ltd. for Environmental Protection Service, August, 1984.

Phase II Report, "Evaluation of Remote Sensing Technology for Monitoring Chronic Oil Discharges from Offshore Well Sites", prepared by Martec Ltd. for Environmental Protection Service, May, 1985.

Phase III Report, "Remote Sensing Chronic Oil Discharges", report EE-80, prepared by Seakem Oceanography Ltd. for Environmental Protection Service, May 1986.

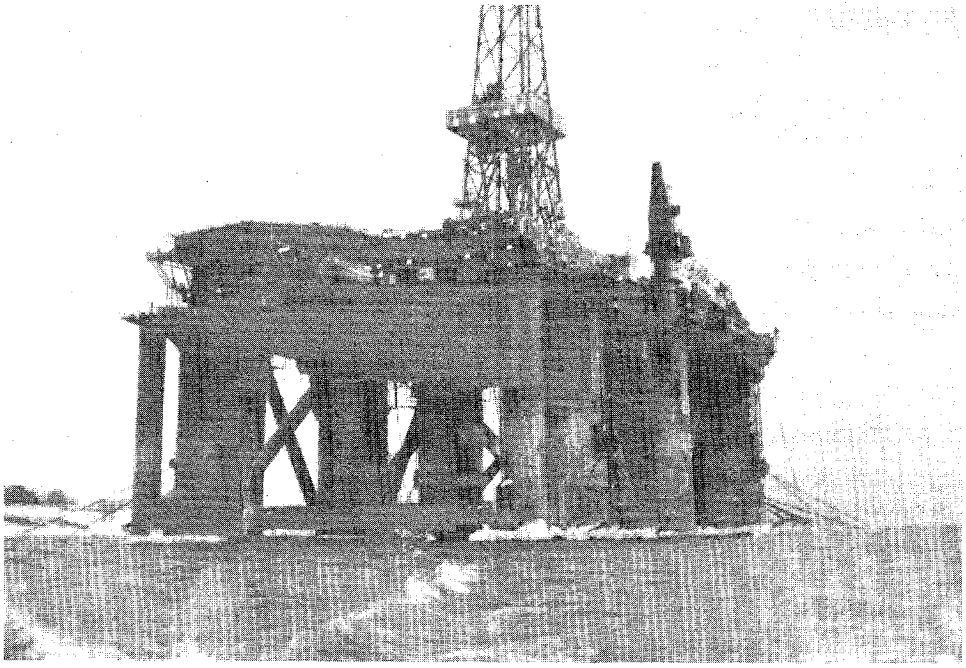
Dave Wright, Wright and Wright, personal communications, February and March 1987.

"Spreading and Movement of Oil Spills", H.G. Schwartzberg, New York University, Report 150-80-EPL, April, 1970.

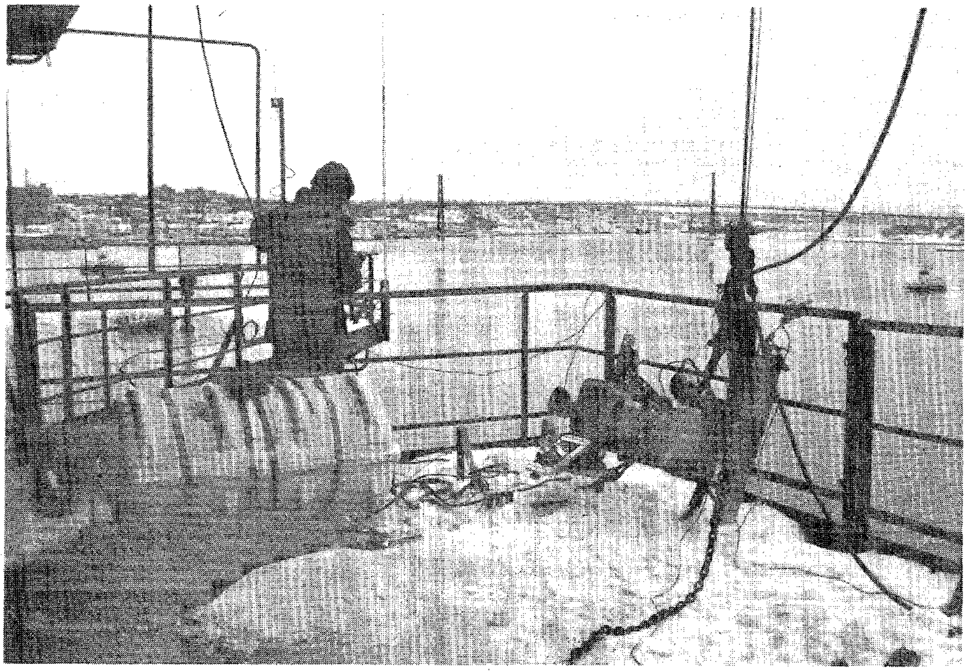
Halifax Vessel Traffic Operations Log, maintained by Canadian Coast Guard, Halifax.

APPENDIX A

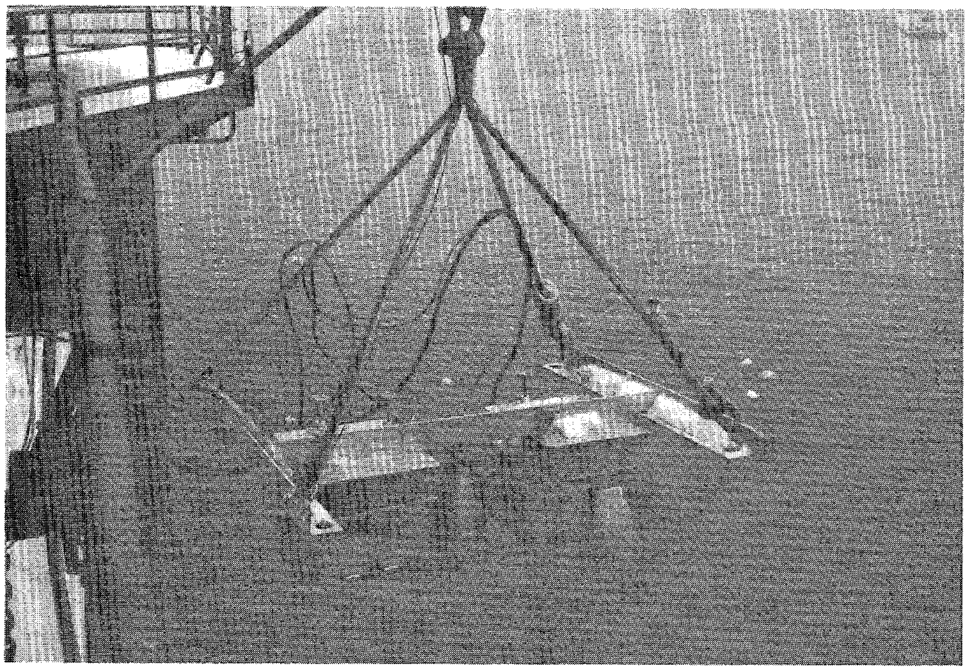
PHOTOGRAPHS OF INSTALLATION



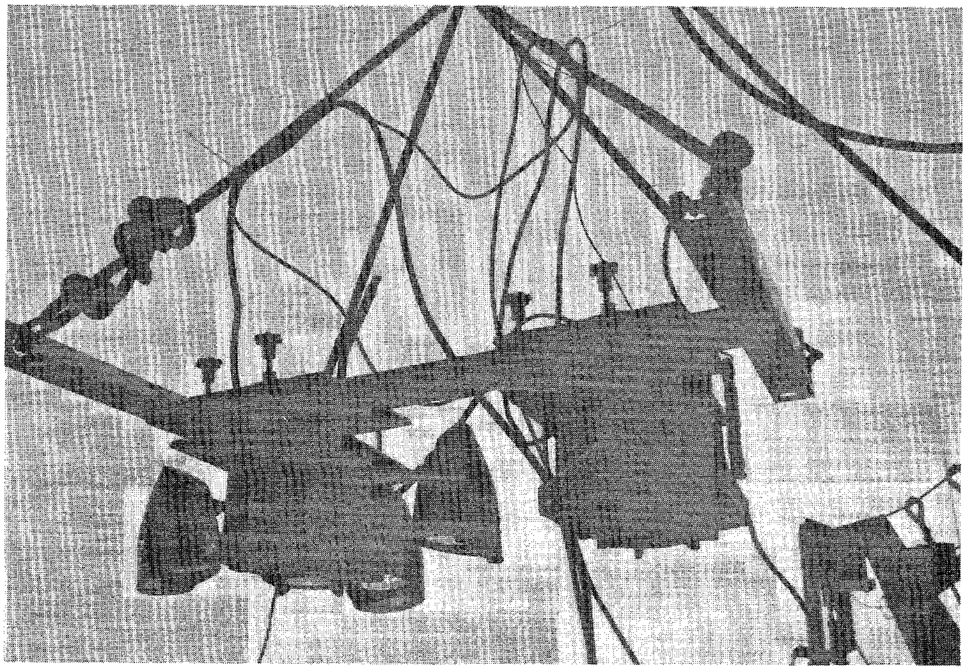
Bow of the SDS Vinland. The white square immediately to the right of the lifeboats at main deck level marks the location of the Oil Film Monitor. For extended periods of data logging, the computer was installed in the bridge which can be seen just above and to the right of the white square.



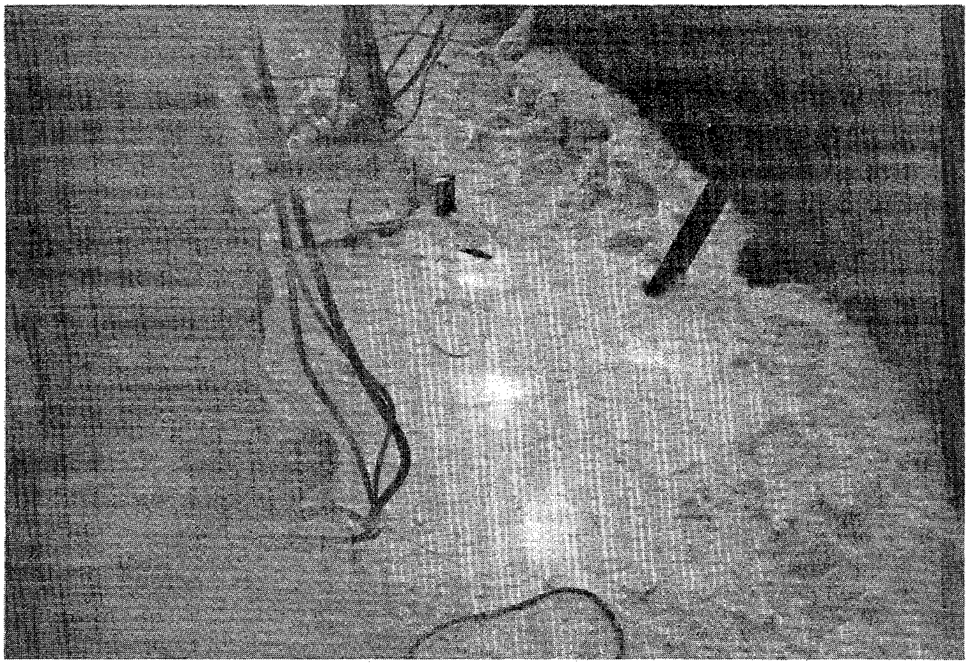
Setting up on the deck of the Vinland.



Complete Wright and Wright Oil Film Monitor mounted on hoistable frame and suspended over the rail of the Vinland. Chunks of ice from municipal snow clearing operatings are visible in the water.

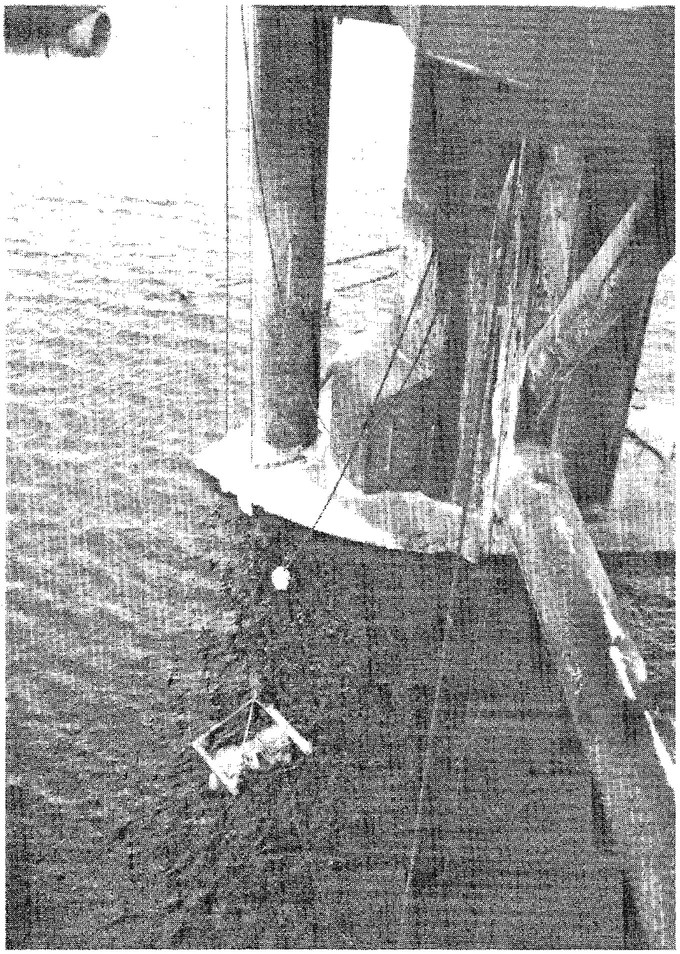


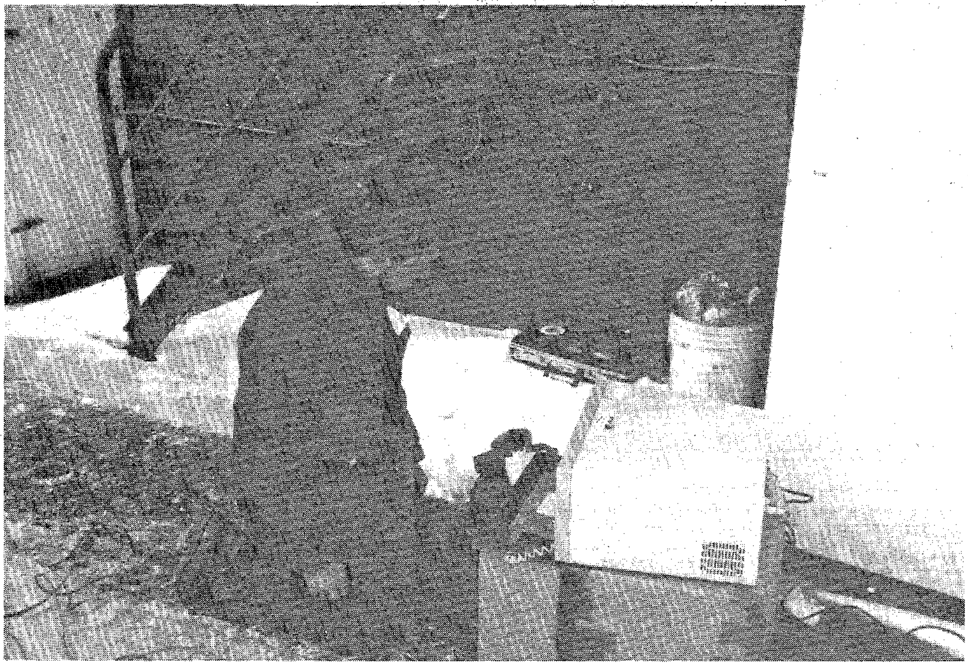
Closeup of complete Wright and Wright Oil Film Monitor mounted on hoistable frame.



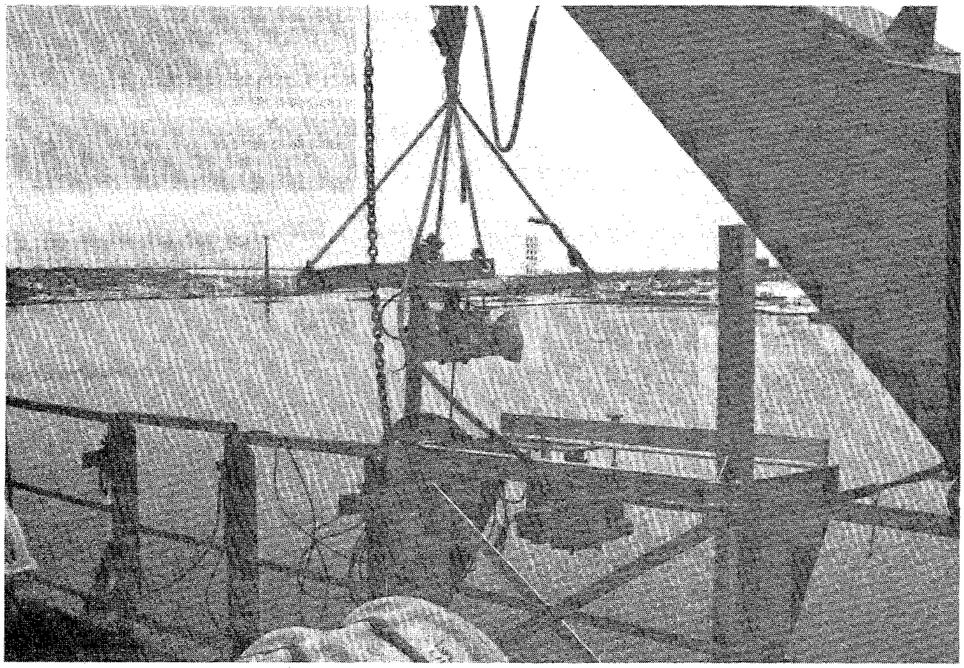
Checking alignment of transmitters. Discrete spots for each of the 4 transmitters can be seen in the snow on the deck.

View looking east across the bow of the Vinland showing receiver and transmitters all mounted on hoistable frame.

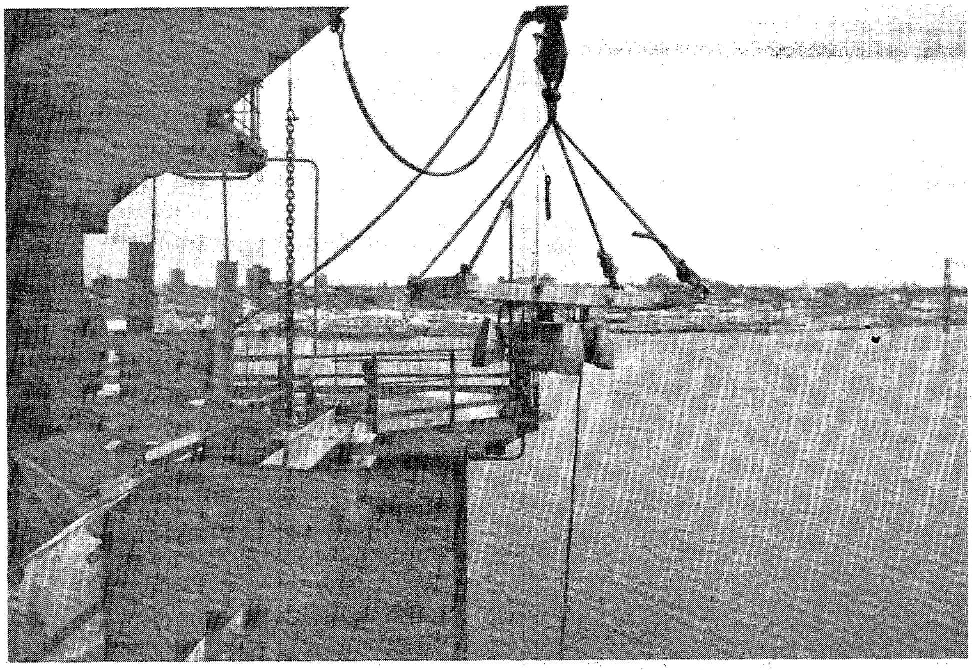




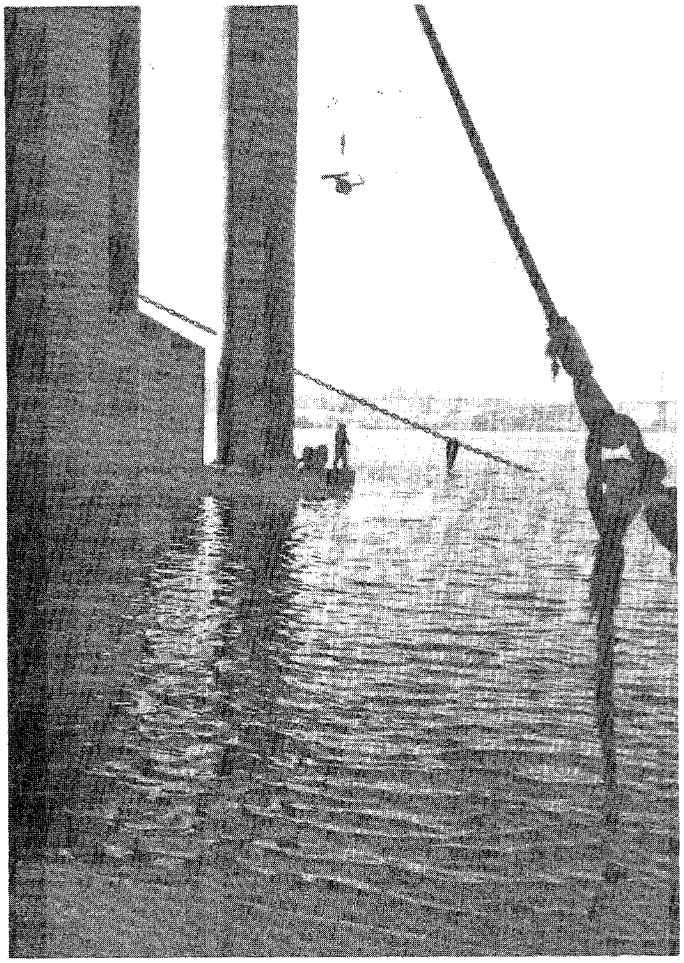
Data loggers - animate and inanimate. Eagle PC shown at lower right.



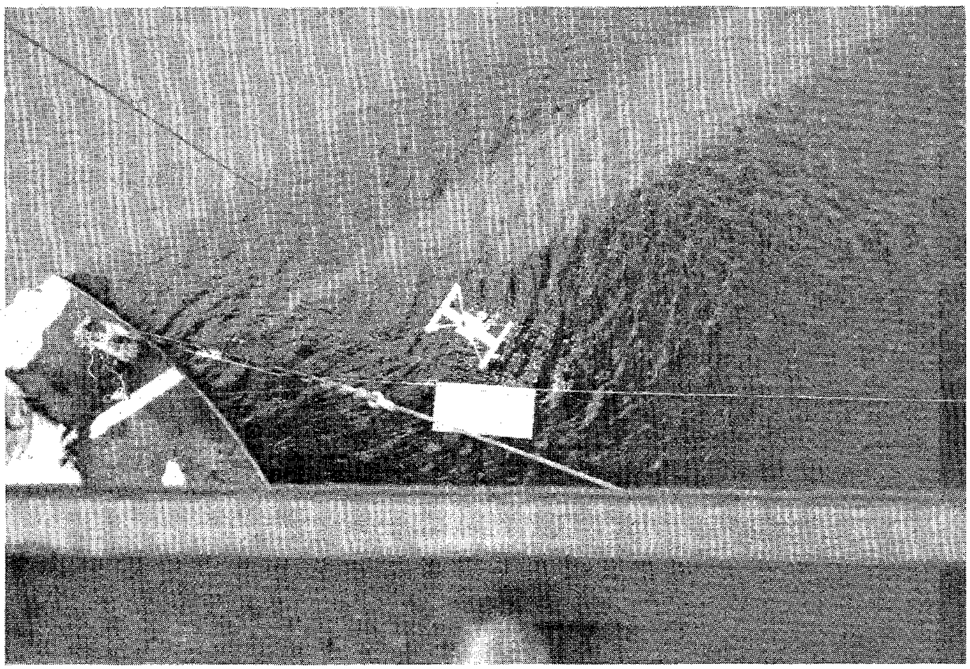
View looking NW from the bow of the Vinland at main deck level. Transmitters are shown mounted on hoistable frame at centre of photograph. Receiver can be seen mounted on fixed frame at lower right.



View from main deck of Vinland looking west across the bow. The 4 transmitters can be seen mounted on the hoistable frame in the centre of the photograph The receiver is mounted on the fixed bracket at lower left.



View from bow of starboard pontoon of Vinland looking westward towards bow of port pontoon. Swimming pool can be seen floating on the water below transmitters.

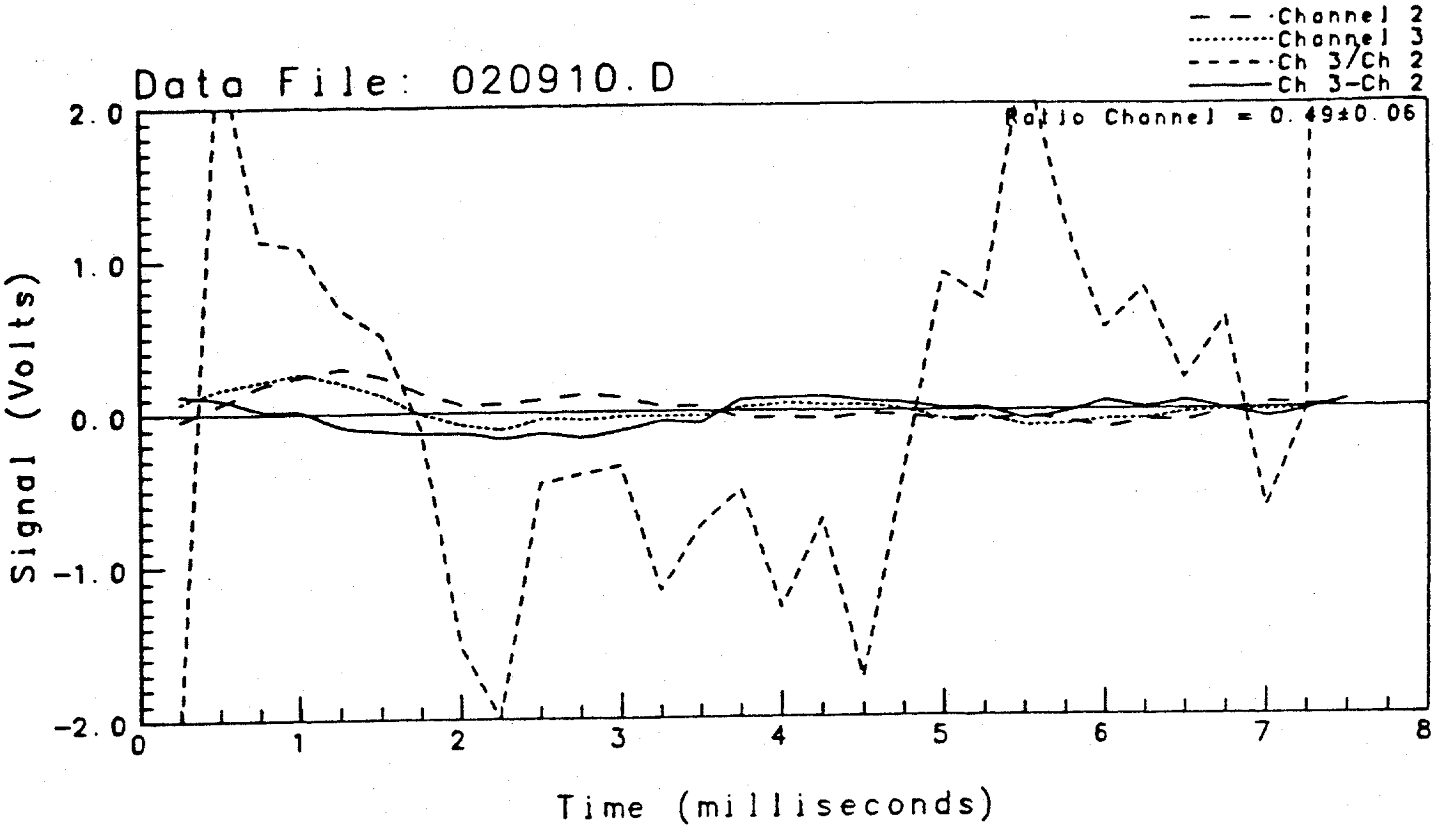


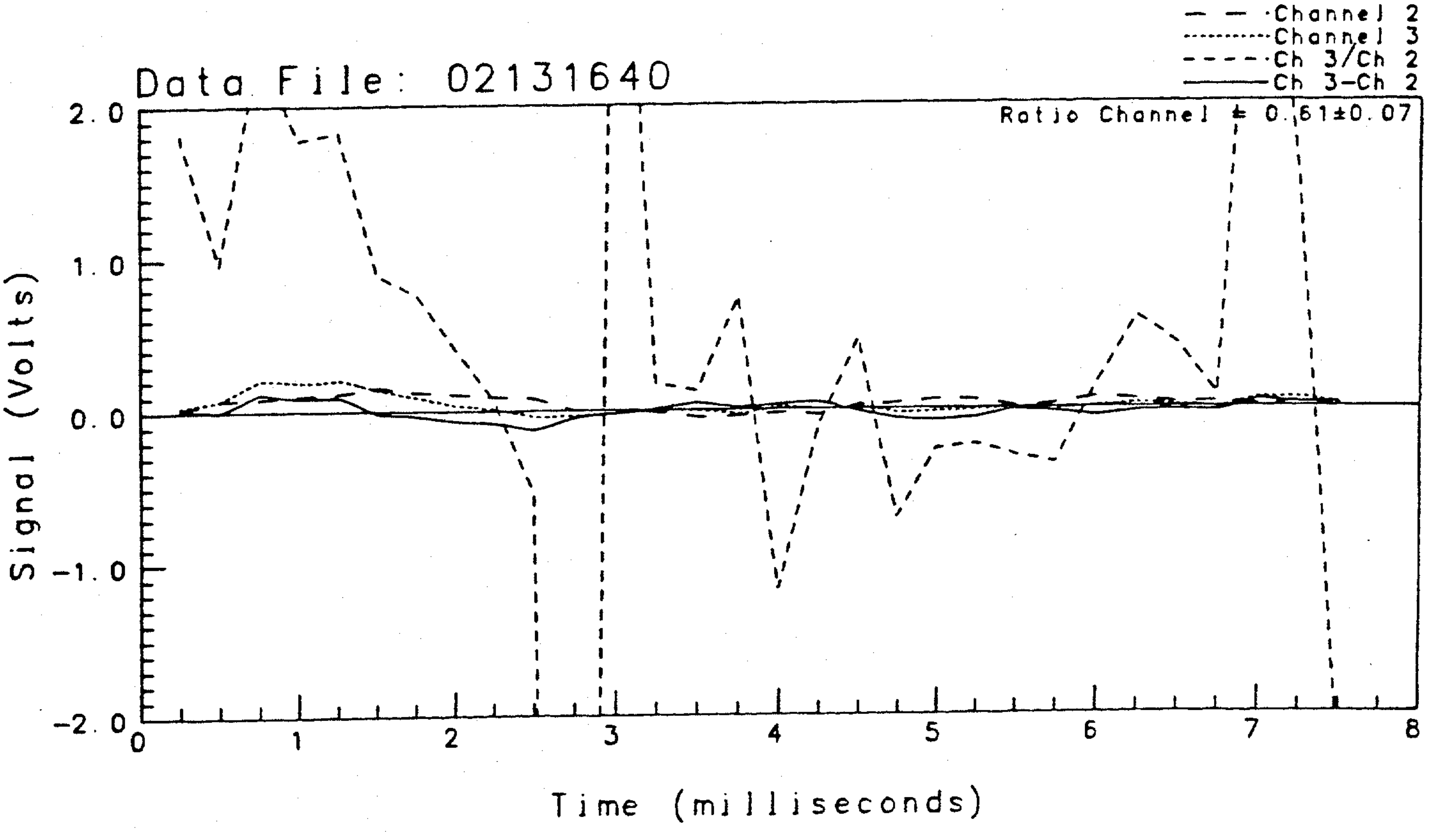
View from deck of Vinland looking down on swimming pool and transmitters mounted on hoistable frame. Reflection from transmitters can be seen on water surface.

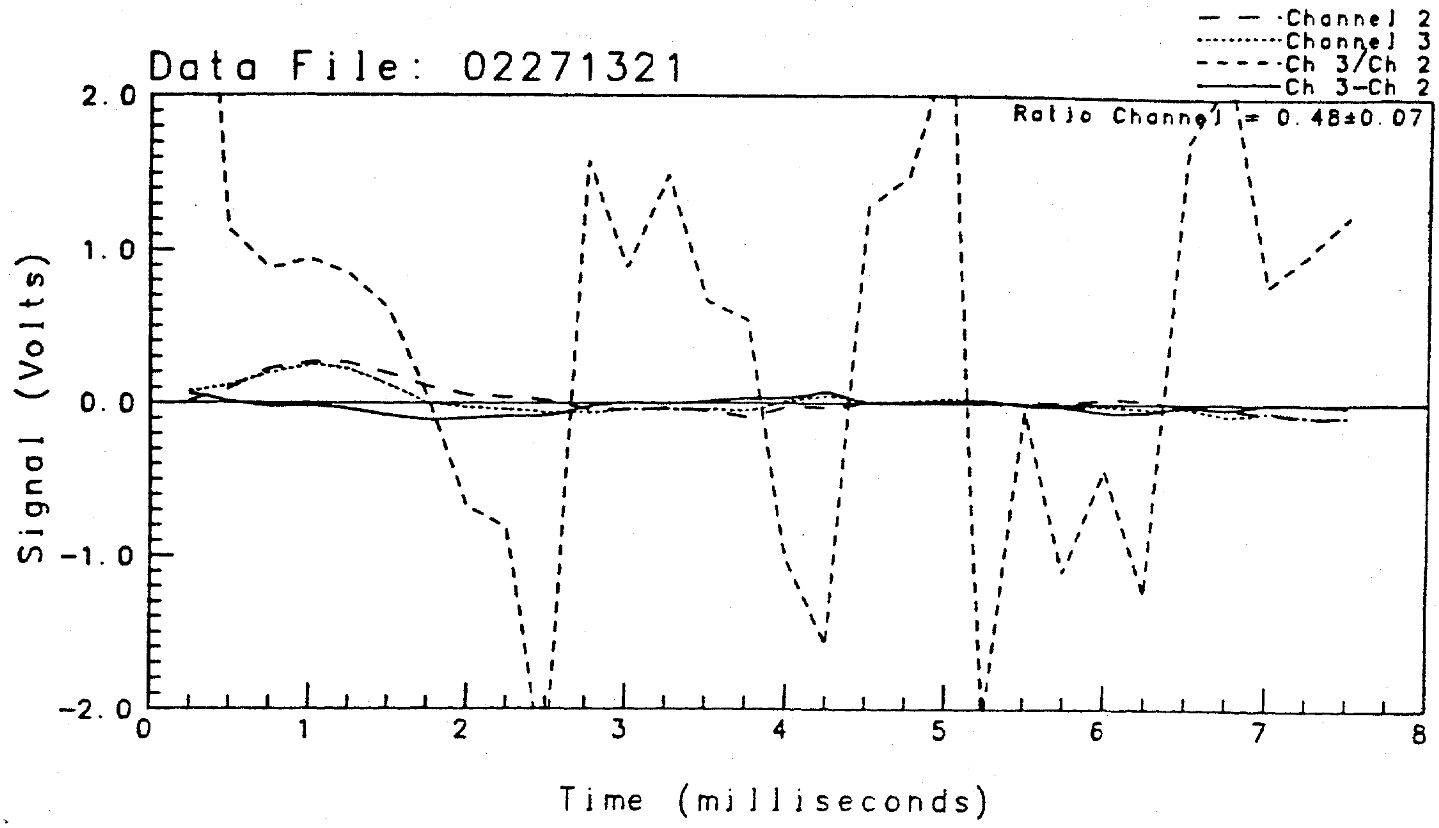
APPENDIX B

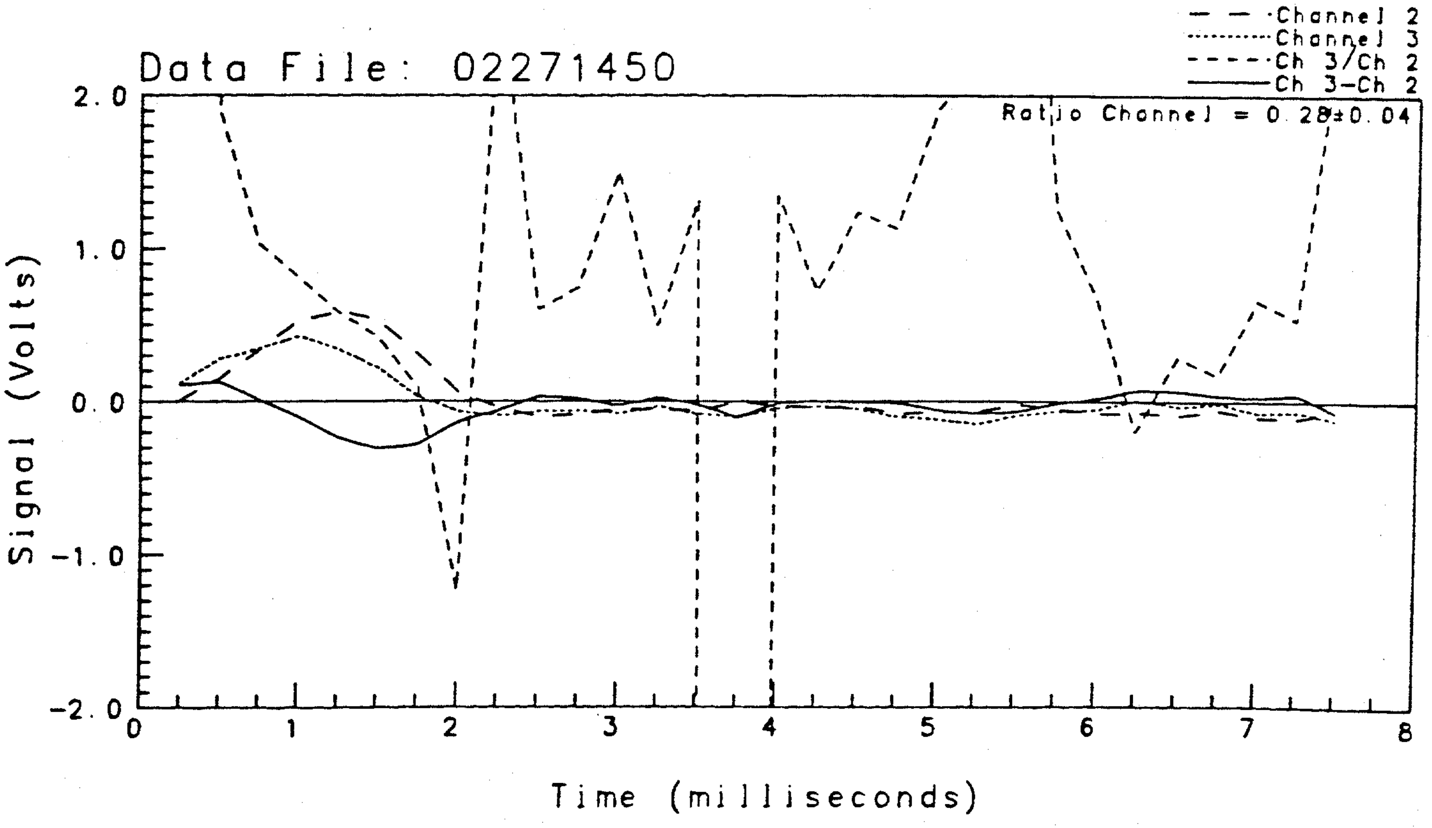
PLOTTED DATA

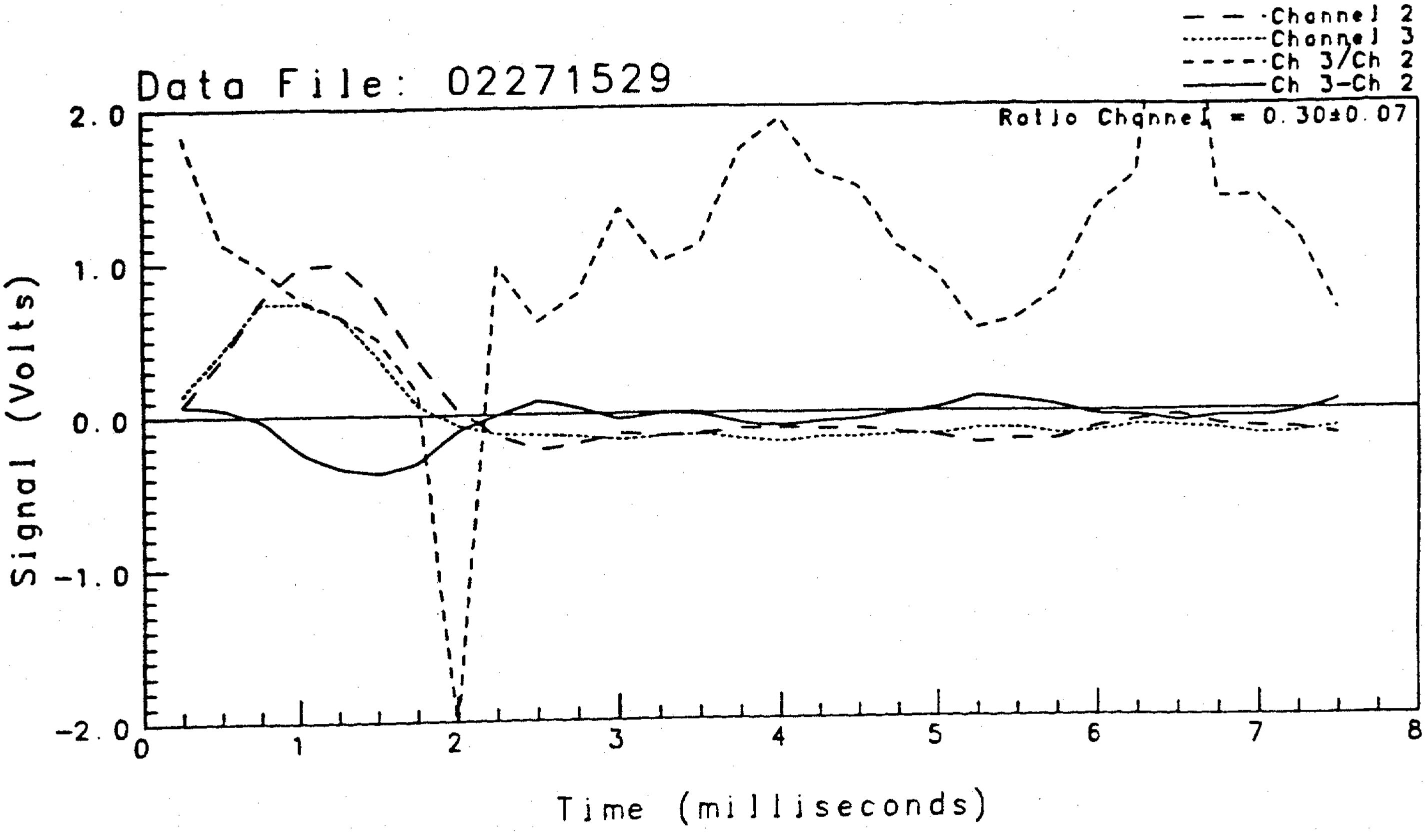
Each of the following plots represents the average of 50 non-contiguous rotations of the filter wheel sampled over a one minute interval. The plots are labelled in the upper left-hand corner with the name of the disk file in which the data are stored. The file name gives the data and time at which the data were logged according to the scheme described in Section 6.0, Software. Printed in the upper right-hand corner of each plot is the output of the Wright and Wright ratio channel observed at the same time. The tolerance limits indicated for the ratio channel are ± one standard deviation. Superimposed on the same sets of axes are plots of channel 2, channel 3, the ratio ch3/ch2, and the difference ch3 - ch2, all derived by the computer directly from the raw preamp output signal as described in Section 7.0 Data Analysis.

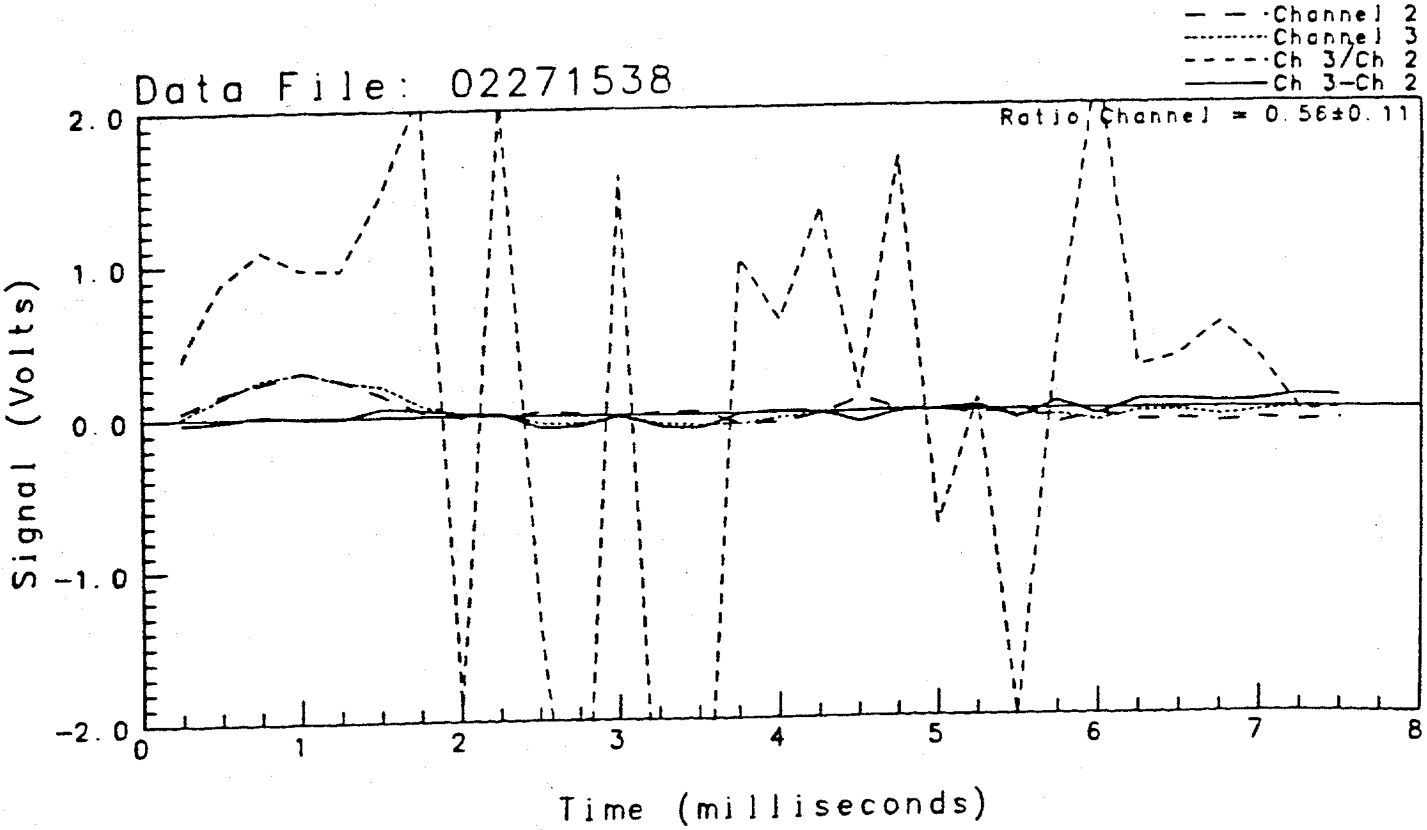

Data File: 020910.D
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.49±0.06
2.0
1.0
0.0
-1.0
-2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

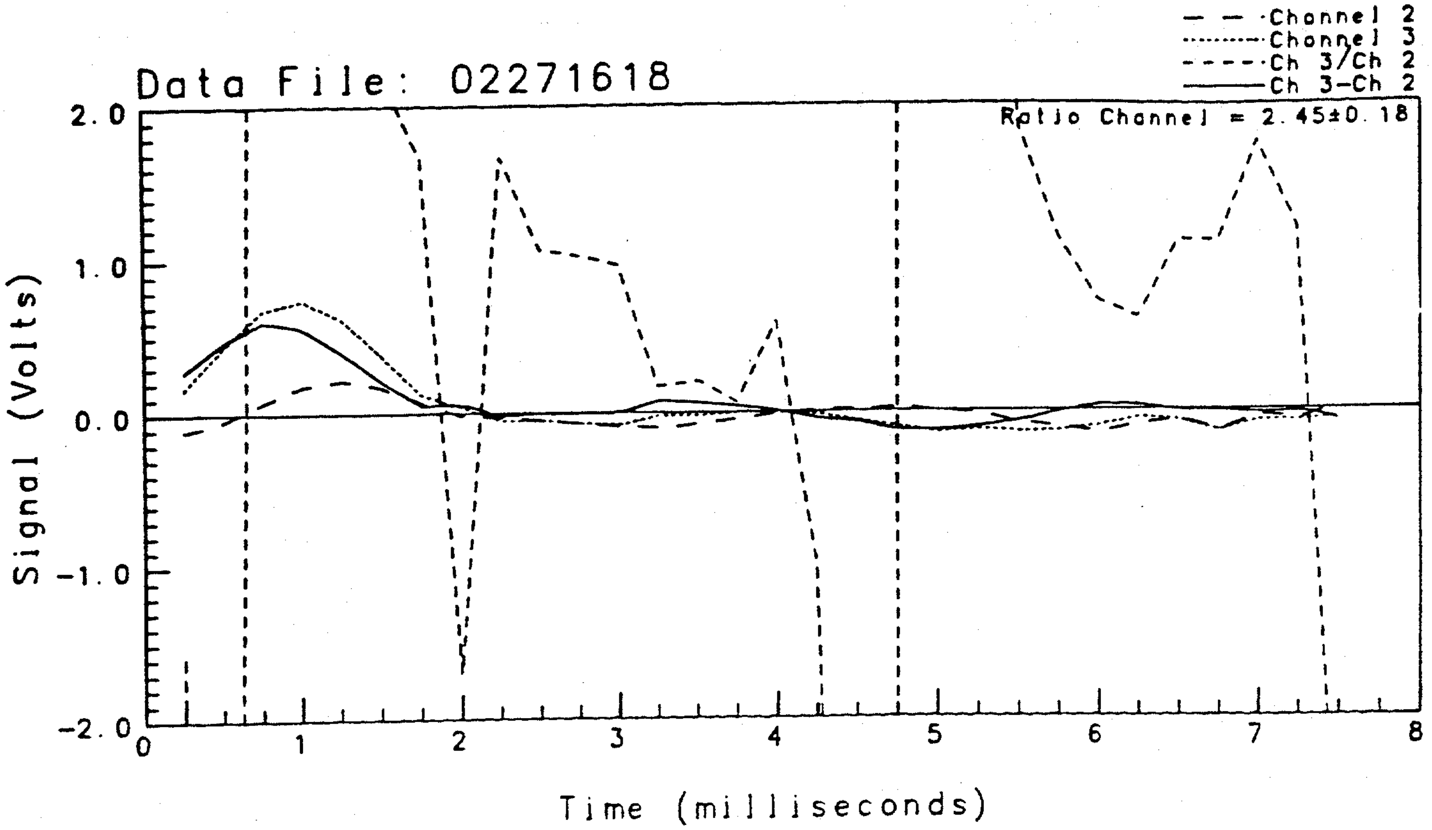

Data File: 02131640
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.61±0.07
2.0
1.0
0.0
-1.0
-2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

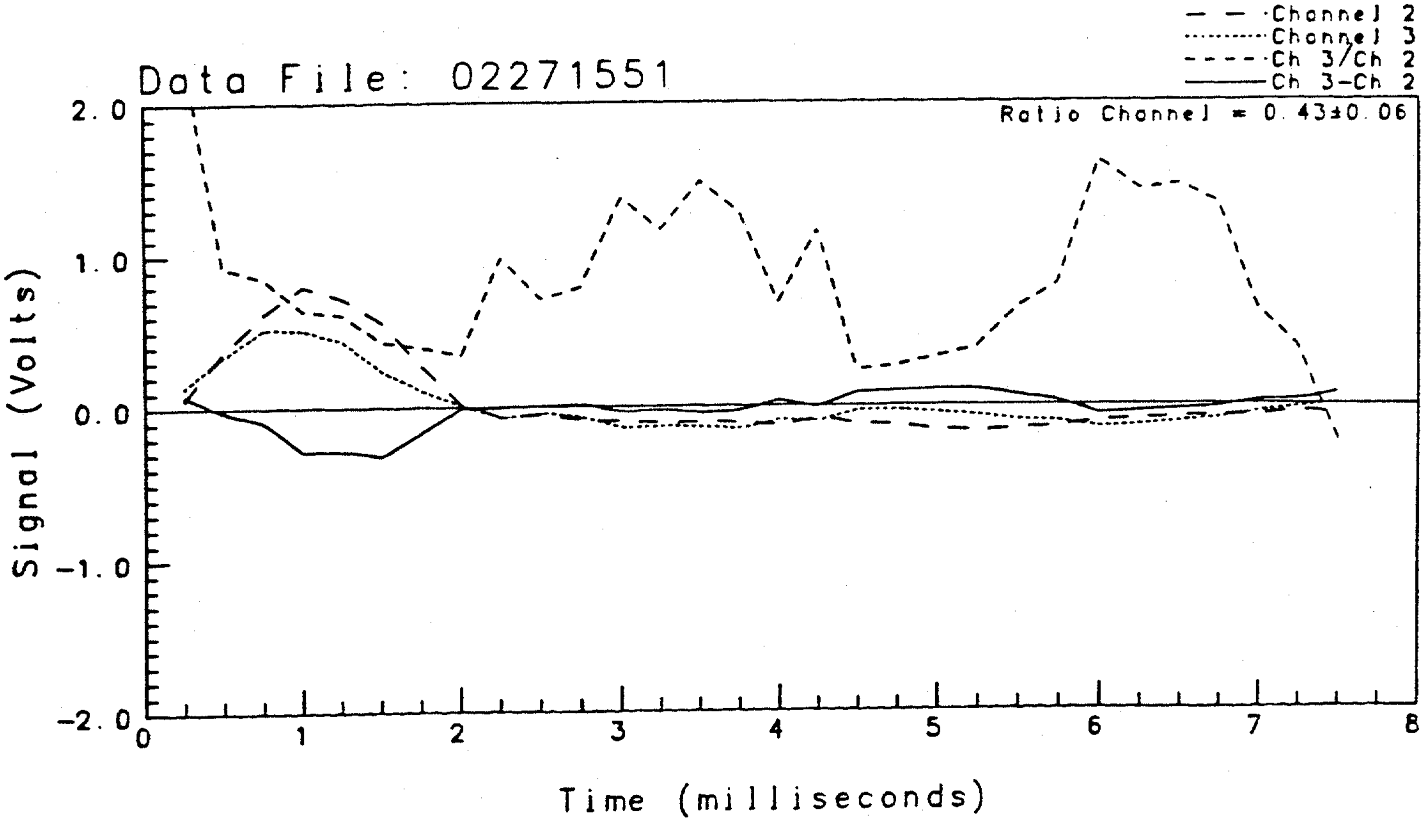

Data File: 02271321
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 0.48±0.07
2.0
1.0
0.0
−1.0
−2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

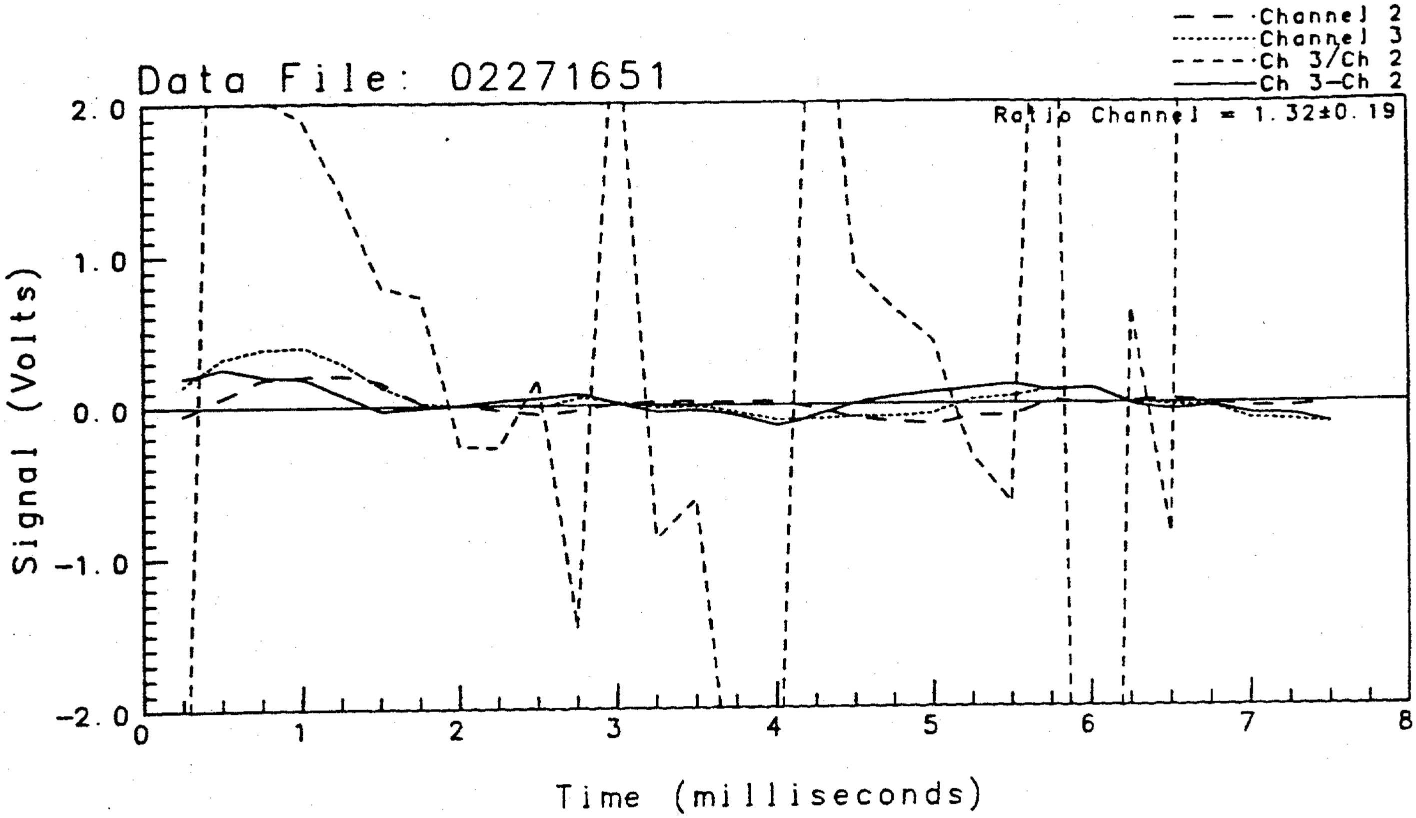

Data File: 02271450
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 0.28±0.04
2.0
1.0
0.0
−1.0
−2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

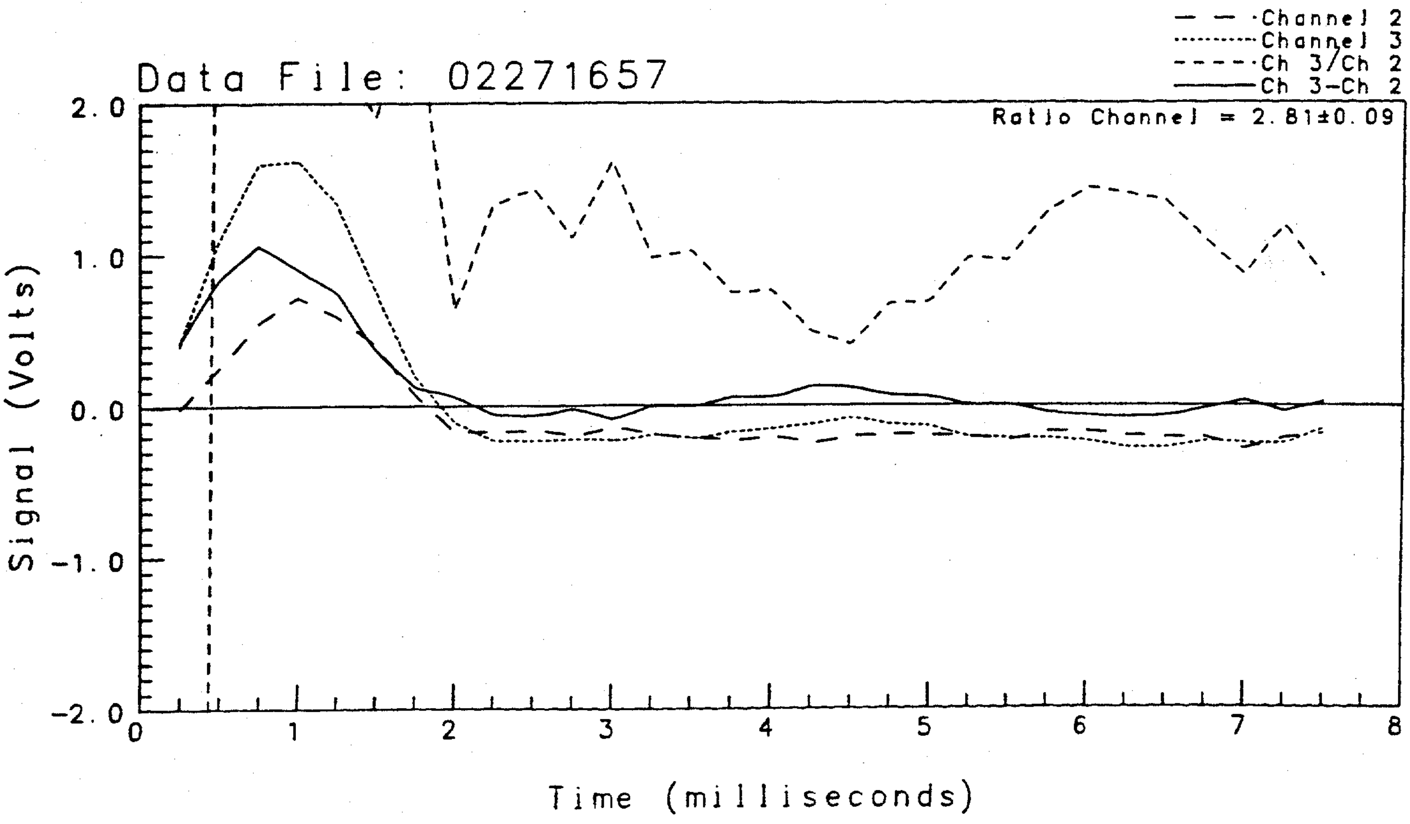

Data File: 02271529
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.30±0.07
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)

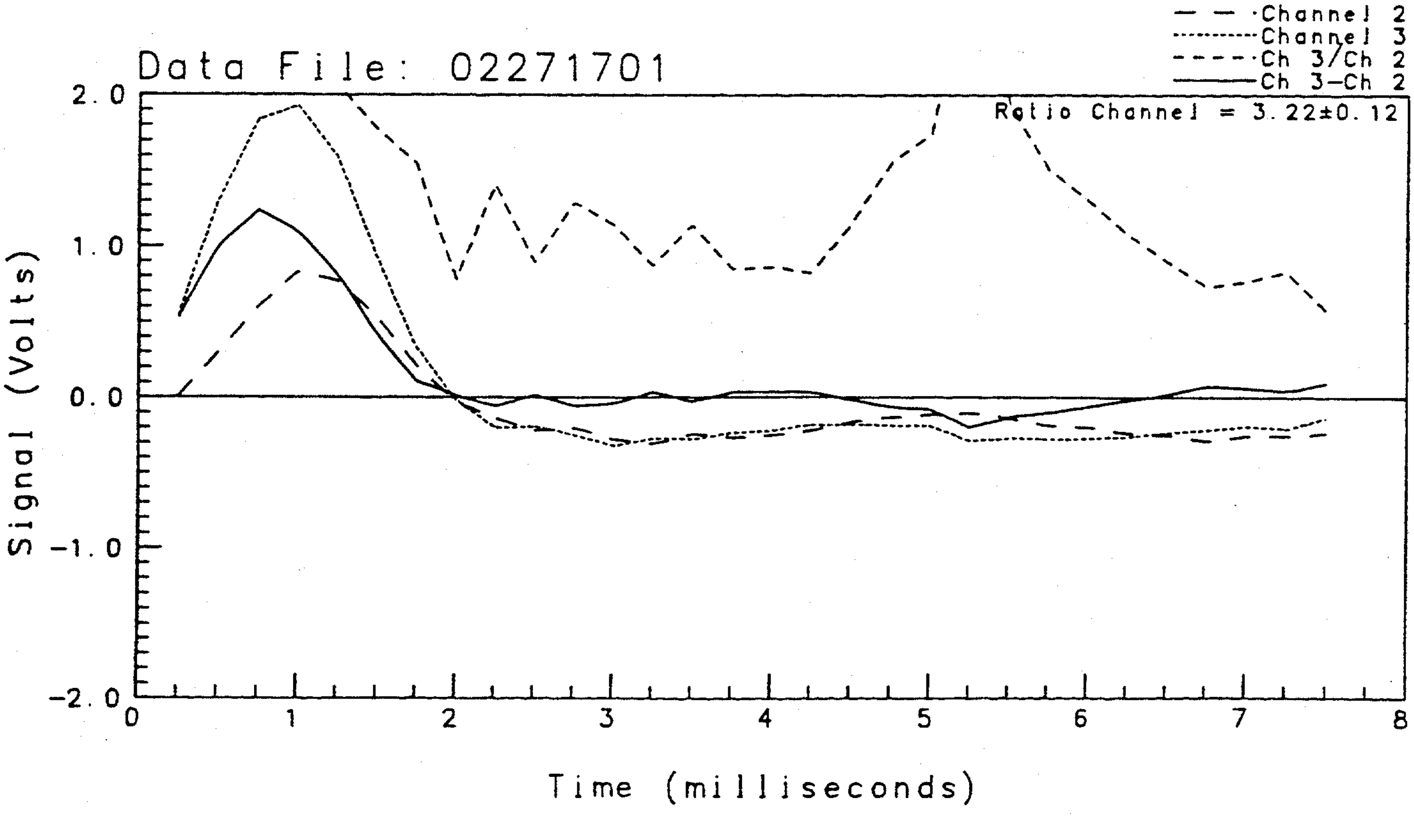

Data File: 02271538
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.56±0.11
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Data File: 02271618
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 2.45±0.18
2.0
1.0
0.0
-1.0
-2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

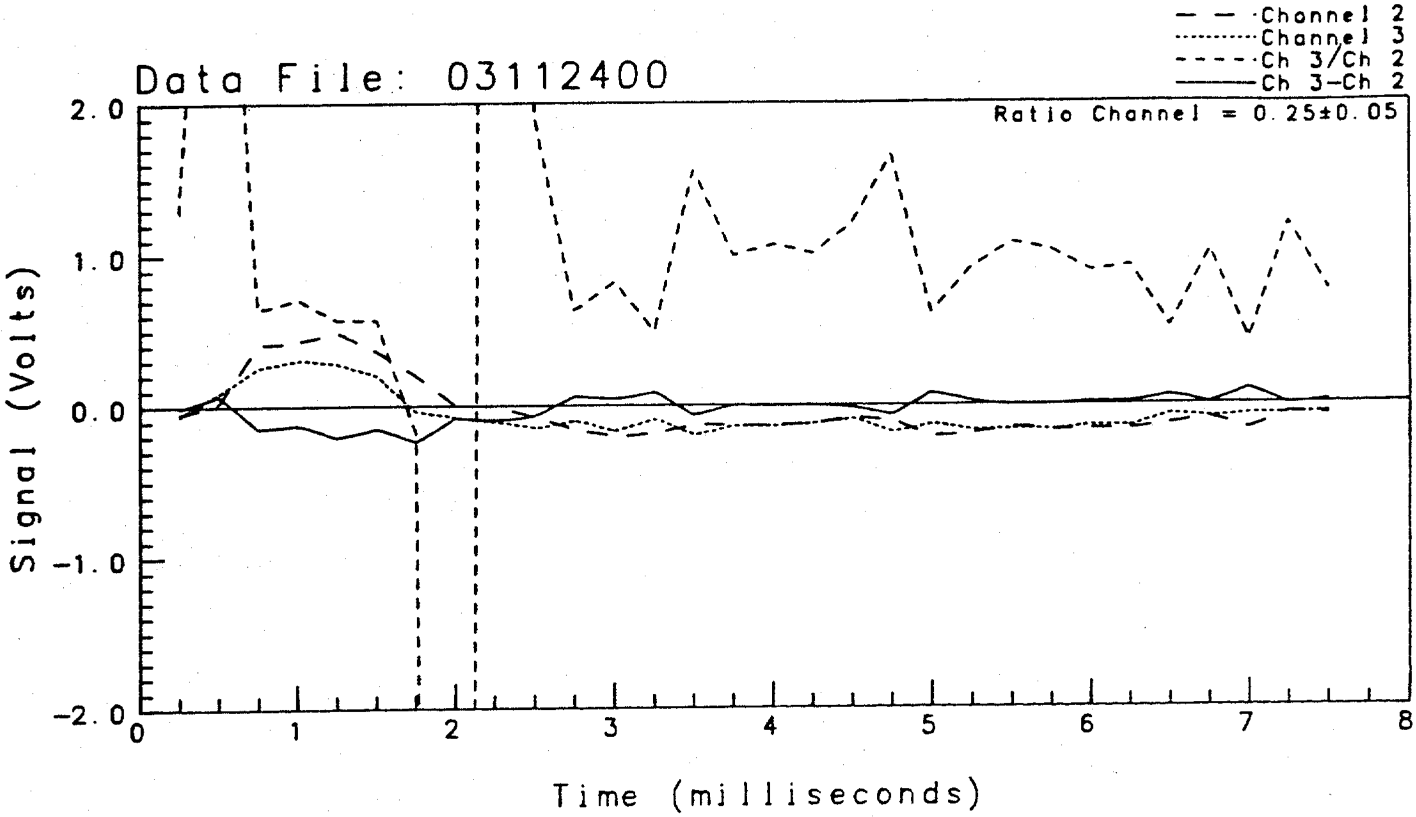

Data File: 02271551
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.43±0.06
2.0
1.0
0.0
-1.0
-2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

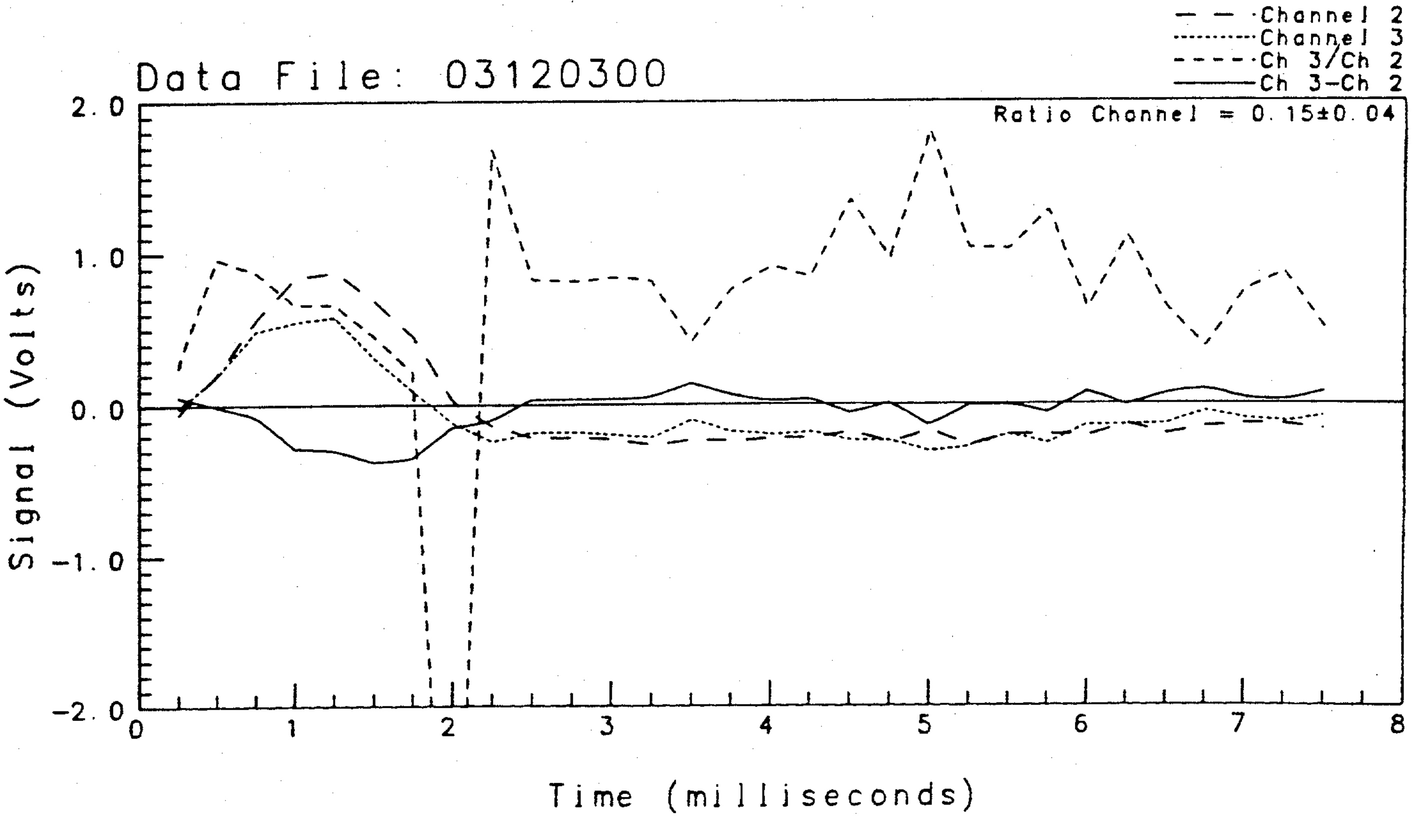

Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Data File: 02271651
Ratio Channel = 1.32±0.19
2.0
1.0
0.0
−1.0
−2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

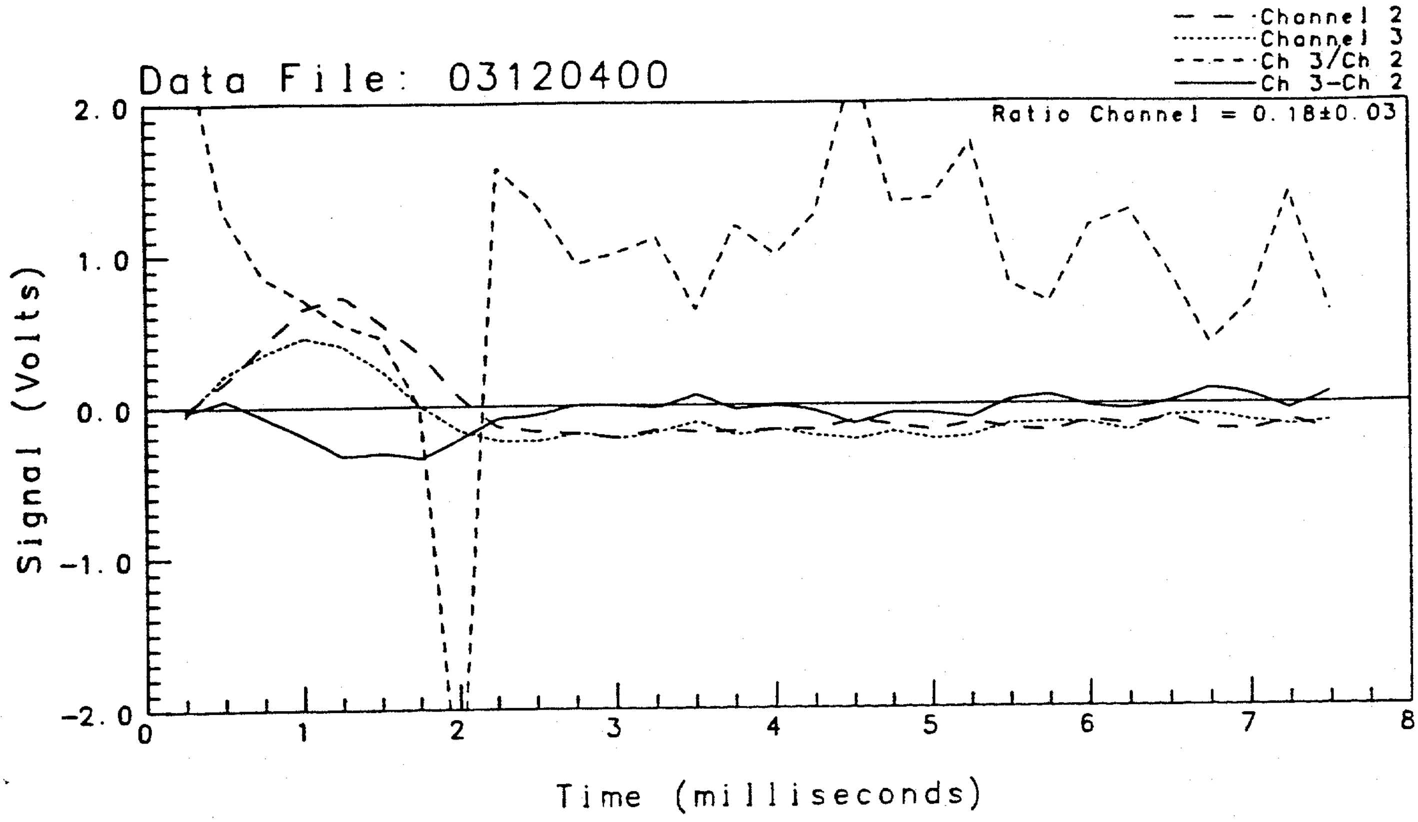

Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Data File: 02271657
Ratio Channel = 2.81±0.09
2.0
1.0
0.0
−1.0
−2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

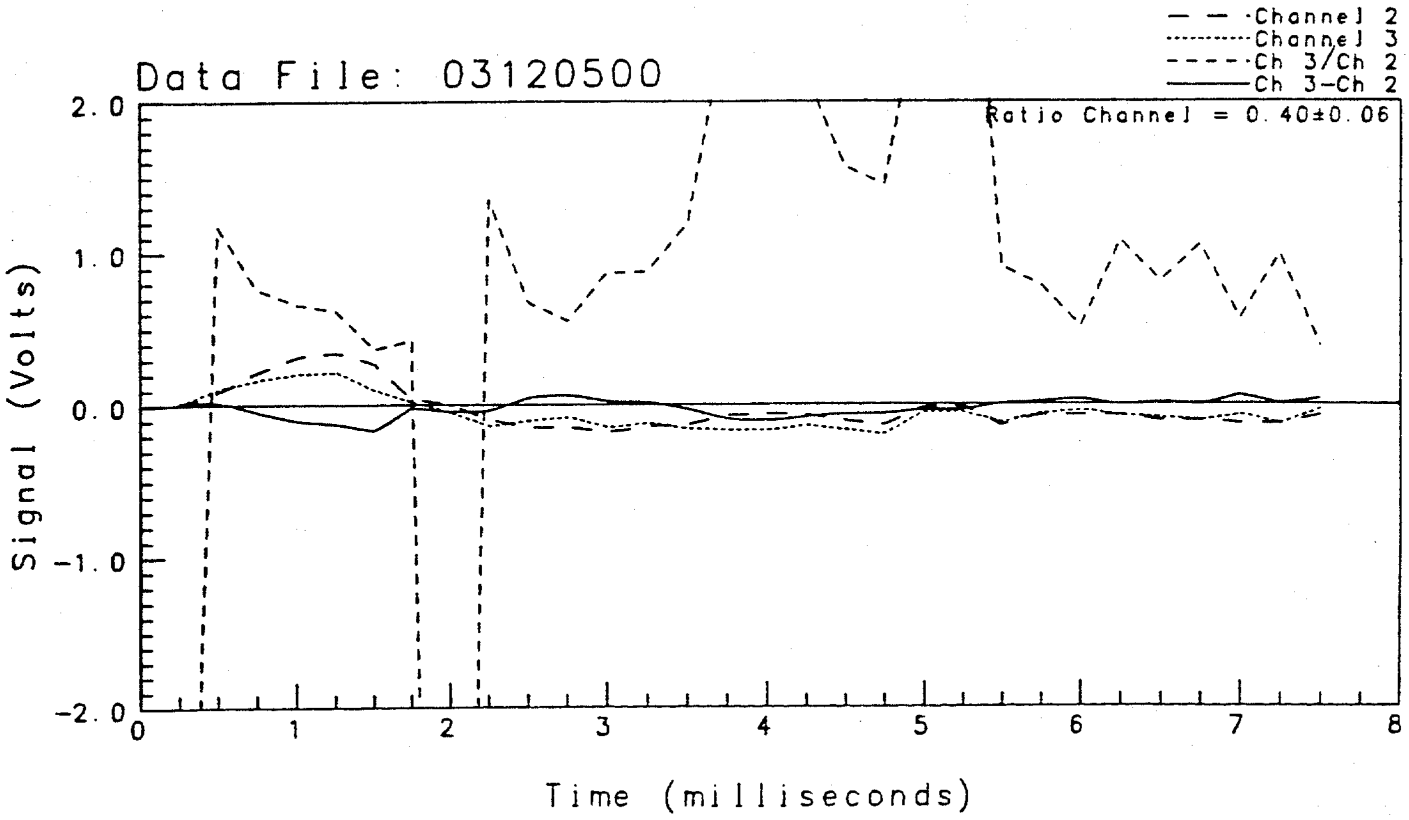


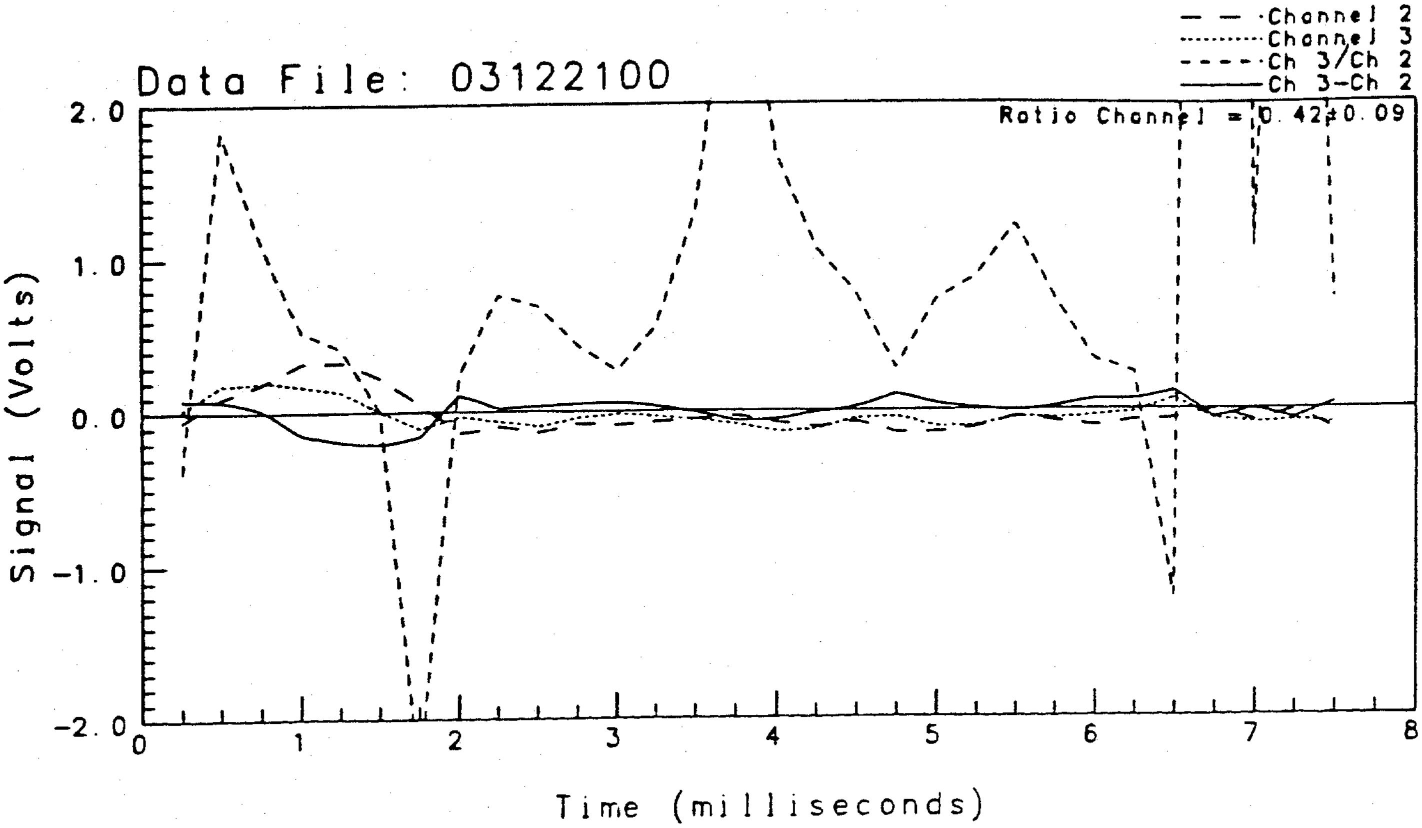
Data File: 02271701
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 3.22±0.12
2.0
1.0
0.0
−1.0
−2.0
Signal (Volts)
0
1
2
3
4
5
6
7
8
Time (milliseconds)

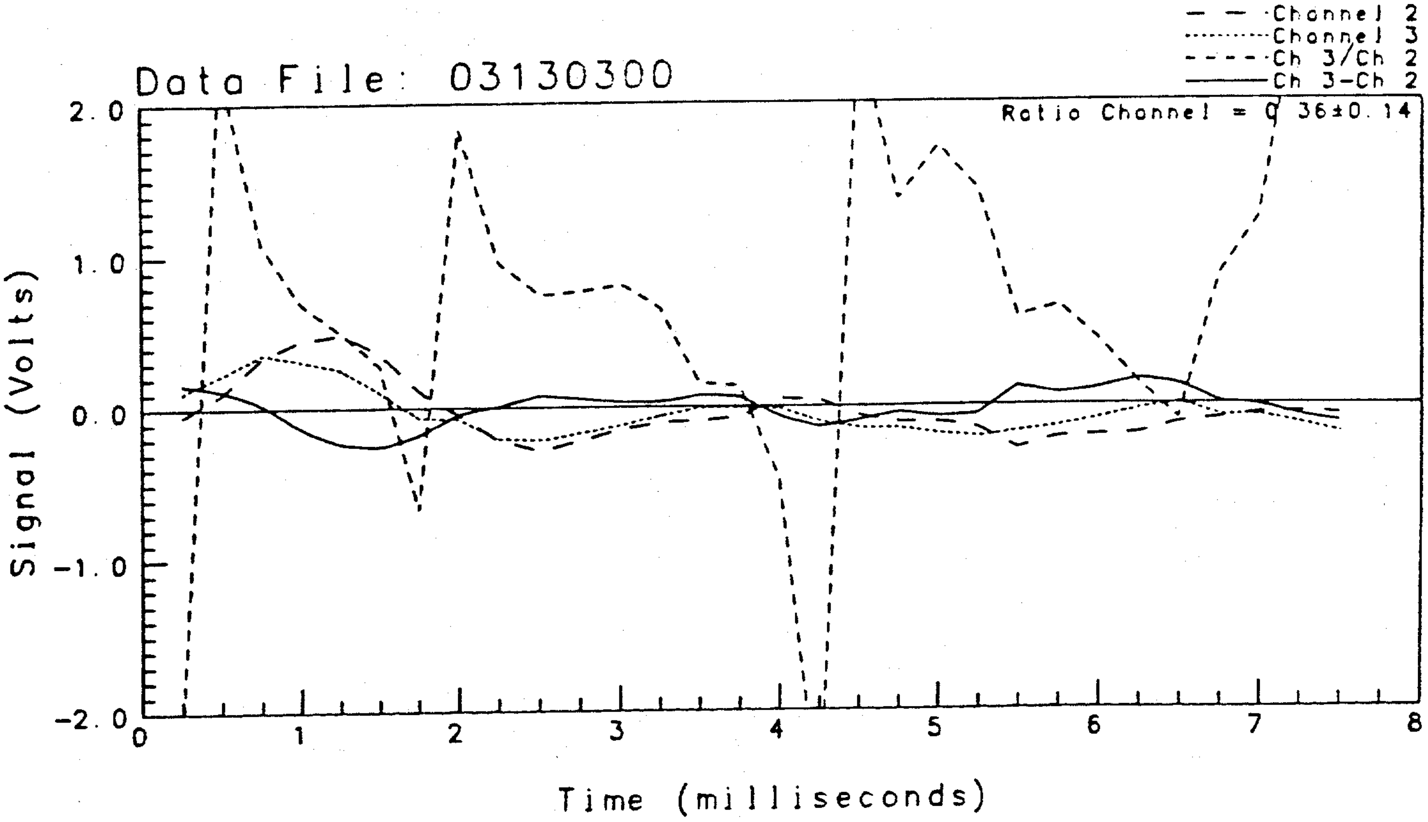

Data File: 03112400
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.25±0.05
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)

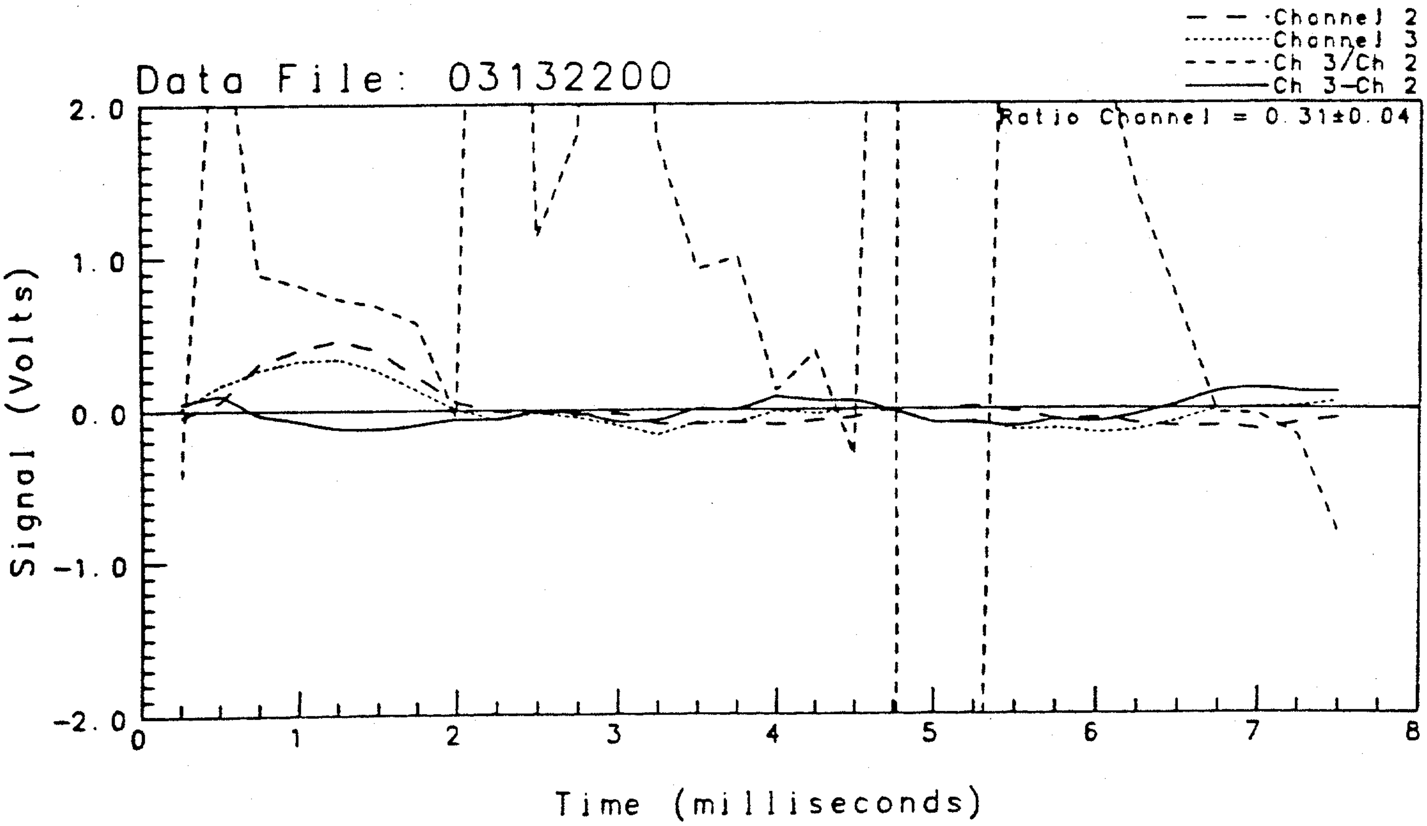

Data File: 03120300
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.15±0.04
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)

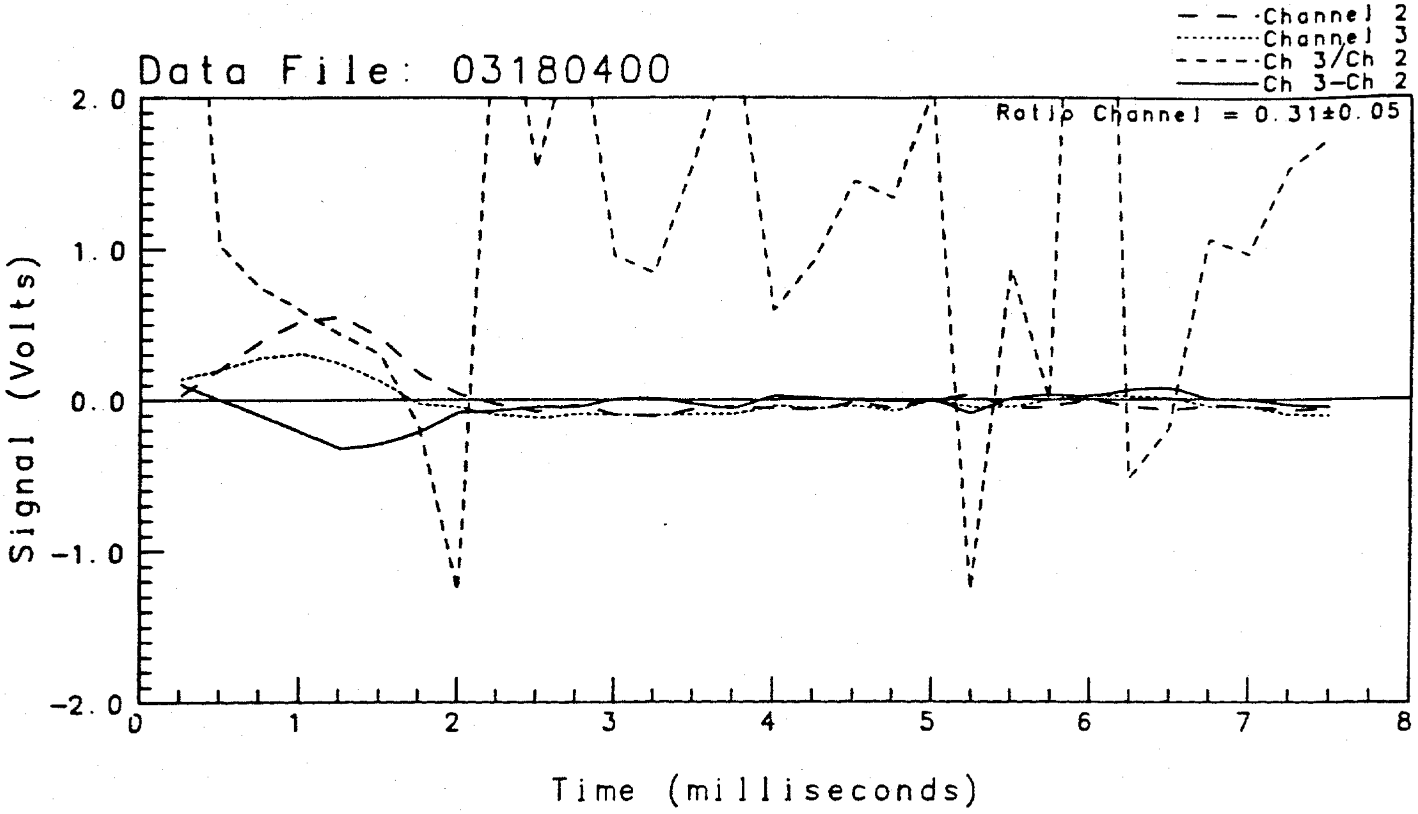

Data File: 03120400
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.18±0.03
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)

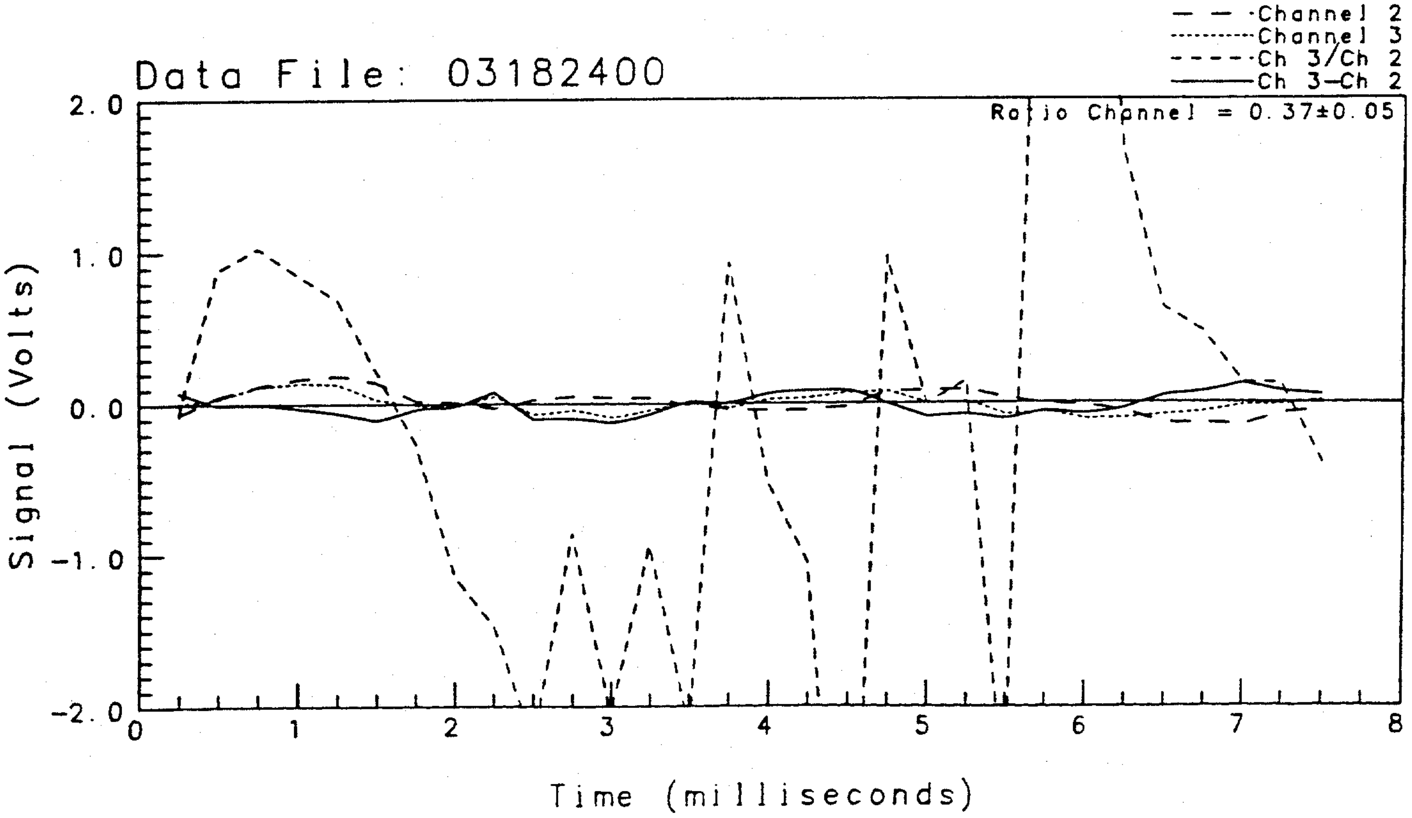

Data File: 03120500
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Ratio Channel = 0.40±0.06
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Data File: 03122100
Ratio Channel = 0.42±0.09
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Channel 2
Channel 3
Ch 3/Ch 2
Ch 3-Ch 2
Data File: 03130300
Ratio Channel = 0.36±0.14
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Data File: 03132200
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 0.31±0.04
Signal (Volts)
2.0
1.0
0.0
−1.0
−2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Data File: 03180400
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 0.31±0.05
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)


Data File: 03182400
Channel 2
Channel 3
Ch 3/Ch 2
Ch 3–Ch 2
Ratio Channel = 0.37±0.05
Signal (Volts)
2.0
1.0
0.0
-1.0
-2.0
0
1
2
3
4
5
6
7
8
Time (milliseconds)

APPENDIX C

The tables in Appendix C summarize the plotted data (see Appendix B) together with the meteorological observations of wind speed, air temperature and cloud cover corresponding to each of the data logging events. (The meteorological observations were made on site aboard the Vinland until 5 March. After 5 March meteorological observations from Shearwater airport were regularly taken from the AES circuit and logged in the MacLaren Plansearch weather office). All times are Atlantic Standard Time.

NAME OF DATA FILE MMDDTIME	WIND SPEED kt.	CLOUD COVER %	ROUND TRIP RANGE m	NUMBER OF LAMPS	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
020910	5	100	7.8	4	Y	.17	.5	
02131419	10	100	52.8	3	N	.09	.6	Snowing
02131421	10	100	52.8	0	N	.11	.7	Snowing
02131425	10	100	42.8	3	N	.09	.6	Snowing
02131427	10	100	42.8	0	N	.10	.6	Snowing
02131437	10	100	32.8	0	N	.10	.7	Snowing
02131439	10	100	32.8	3	N	.11	.7	Snowing
02131447	10	100	22.8	0	N	.09	.7	Snowing
02131449	10	100	22.8	3	?	.11	.6	Snowing
02131453	10	100	12.8	3	?	.12	.6	Snowing
02131455	10	100	12.8	0	N	.10	.7	Snowing
02131640	15	80	12.8	4	Y	.13	.6	
02131642	15	80	12.8	0	N	.11	.7	
02131648	15	80	22.8	4	N	.13	.6	
02131650	15	80	22.8	0	N	.12	.7	
02131657	15	80	32.8	0	N	.11	.8	
02131659	15	80	32.8	4	N	.12	.7	
02131703	15	80	42.8	4	N	.12	.7	
02131705	15	80	42.8	0	?	.11	.7	
02271321	10	50	35.3	4	Y	.16	.5	
02271323	10	50	35.3	0	N	.12	.8	
02271400	10	MD	35.3	4	Y	.17	.4	

MD indicates "missing data"

NAME OF DATA FILE MMDDTIME	WIND SPEED kt.	CLOUD COVER %	ROUND TRIP RANGE m	NUMBER OF LAMPS	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
02271450	10	0	35.3	4	Y	.20	.3	Clean swimming pool.
02271508	10	0	35.3	4	?	.13	.5	Condensate in pool.
02271529	10	0	35.3	4	Y	.36	.3	Condensate in pool.
02271531	10	0	35.3	0	N	.10	.6	
02271538	10	0	42.8	4	Y	.20	.6	Condensate in pool.
02271551	10	0	47.8	4	Y	.31	.4	Condensate in pool.
02271605	5	0	47.8	4	?	.15	.6	Condensate on water.
02271610	5	0	47.8	4	N	.13	.6	"Clean" pool.
02271618	5	0	47.8	4	Y	.35	2.5	"Clean" pool.
02271651	0	0	47.8	4	Y	.23	1.3	Crude in pool.
02271657	0	0	37.8	4	Y	.67	2.8	Crude in pool.
02271701	0	0	37.8	4	Y	.71	3.2	Crude in pool.

NAME OF DATE FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03111937	7	0	-6	N	.12	1.1	
03112000	8	0	-7	N	.10	1.1	
03112100	9	0	-8	?	.11	1.1	
03112300	7	0	-10	N	.10	1.0	
03112400	3	0	-11	Y	.20	.3	
03120300	3	0	-13	Y	.26	.2	
03120400	6	0	-13	Y	.23	.2	
03120500	6	0	-15	Y	.16	.4	
03120600	5	0	-15	N	.12	.6	
03120700	7	30	-13	Y	.17	.3	
03121100	4	80	-5	N	.15	.8	
03121200	8	80	-4	N	.15	.7	
03121300	8	30	-3	N	.13	1.1	
03121400	6	30	-3	N	.11	1.2	
03121700	6	80	-4	N	.11	1.3	
03121800	8	80	-4	N	.10	1.2	
03122100	4	80	-6	Y	.17	.4	
03122400	4	100	-5	?	.16	.5	
03130200	4	100	-5	?	.15	.6	
03130300	6	100	-6	Y	.20	.4	
03130400	7	100	-7	Y	.17	.5	
03130500	3	100	-7	N	.13	.8	
03130600	4	100	-7	N	.10	1.0	
03131000	6	30	-7	N	.13	.9	
03131100	4	30	-4	Y	.17	.4	

All at round trip range of 52.8m with four lamps on.

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03131300	5	30	-2	N	.15	.7	
03131400	6	30	-1	N	.10	.9	
03131500	8	0	-2	N	.10	.7	
03131600	8	30	-3	N	.10	.8	
03131700	6	30	-3	N	.11	.8	
03131800	5	30	-4	N	.10	.7	
03131900	0	30	-5	N	.13	.6	
03132000	0	30	-4	N	.11	.7	
03132100	4	30	-7	Y	.14	.5	
03132200	8	30	-6	Y	.19	.3	
03132300	9	100	-5	N	.12	.7	
03132400	9	80	-6	N	.13	.7	
03140100	9	80	-7	N	.12	.8	
03140200	8	100	-7	?	.13	.8	
03140300	7	100	-7	?	.12	.8	
03140400	2	100	-7	?	.13	.7	
03140500	6	80	-7	N	.13	.8	
03140700	12	80	-8	N	.13	.9	
03140800	14	30	-7	N	.12	1.0	
03140900	12	100	-5	N	.12	1.0	
03141000	12	100	-3	N	.10	.8	
03141100	13	100	-1	N	.11	.9	

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03141200	14	100	0	N	.11	.9	
03141300	12	30	1	N	.11	.8	
03141400	12	100	2	N	.11	.7	
03141500	13	80	1	N	.11	.7	
03141600	14	80	1	N	.10	.8	
03141700	14	80	0	?	.10	.8	
03141800	16	80	-2	N	.11	.8	
03141900	13	80	-3	N	.11	.8	
03142000	16	80	-3	N	.11	.9	
03142100	12	30	-5	N	.11	.9	
03142200	12	100	-5	N	.13	.9	
03142300	14	100	-5	N	.13	.9	
03142400	13	100	-6	N	.11	.9	
03150100	13	100	-6	N	.12	.9	
03150200	11	100	-6	N	.10	.9	
03150400	13	80	-7	N	.10	.9	
03150500	15	80	-7	N	.11	.9	
03150600	15	100	-6	N	.12	1.0	
03150700	14	100	-6	N	.12	1.0	
03150900	13	100	-5	N	.11	.9	
03151000	15	100	-3	N	.12	1.0	
03151437	17	100	-2	N	.11	1.0	

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03151500	18	100	-2	N	.11	.9	
03151600	17	100	-2	N	.10	.9	
03151700	15	100	-2	N	.11	.9	Very light snow
03151800	16	100	-2	N	.11	.9	Drizzle, fog
03151900	12	100	-2	N	.12	.9	Drizzle, fog
03152000	14	100	-2	N	.12	.9	Drizzle, fog
03152100	16	100	-3	N	.12	.9	Very light drizzle
03152200	18	100	-3	N	.13	.9	Very light snow
03152300	20	100	-3	N	.12	.9	Light snow
03152400	18	100	-3	N	.12	.9	Light snow
03160100	15	100	-3	N	.12	1.0	Snowing
03160200	20	100	-3	N	.12	.9	Snowing
03160300	17	100	-3	N	.11	1.0	Snowing
03160400	20	100	-3	N	.10	.8	Snowing
03160500	23	100	-3	N	.12	1.0	Snowing
03160600	21	100	-3	N	.10	1.0	Snowing
03160700	21	100	-3	N	.11	1.0	Snowing
03160800	17	100	-3	N	.11	.9	Light snow
03160900	21	100	-3	N	.12	.9	Light snow
03161000	17	80	-3	N	.11	1.0	Light snow
03161100	22	100	-2	N	.11	.9	Light snow
03161200	18	80	-1	N	.10	.9	Light snow

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE ^{0}C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03161300	15	80	-1	N	.10	.9	Light snow
03161400	14	100	-1	N	.12	.8	Light snow
03161500	13	80	0	N	.11	.9	Light snow
03161600	15	100	0	N	.11	.8	Light snow
03161700	14	100	0	N	.10	.9	Light snow
03161800	16	80	-1	N	.12	.9	Light snow
03161900	13	100	-1	N	.11	.9	Light snow
03162000	13	100	-2	N	.11	.9	Light snow
03162100	14	100	-2	N	.10	1.1	Light snow
03162200	MD	MD	MD	N	.11	.9	
03162300	16	80	-2	N	.12	.9	Light snow
03162400	15	80	-2	N	.10	1.0	Light snow
03170100	15	80	-2	N	.10	.9	Light snow
03170200	15	100	-2	N	.11	.9	Light snow
03170300	16	100	-2	N	.11	.8	Light snow
03170400	12	80	-2	N	.11	1.0	Light snow
03170500	8	80	-2	N	.11	.9	Light snow
03170600	8	80	-3	N	.11	.9	Light snow
03170700	6	80	-2	N	.12	.9	
03170800	6	80	-2	N	.11	.8	
03170900	5	90	-1	N	.11	1.0	
03171000	7	100	0	N	.10	.8	

MD indicates "missing data"

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03171100	4	100	0	N	.12	.7	
03171200	6	100	1	N	.11	.8	
03171300	4	100	1	N	.11	.7	
03171400	3	100	1	N	.10	.7	
03171406	3	100	1	N	.12	.7	
03171700	4	100	1	N	.11	.6	
03171900	7	100	0	N	.11	.8	
03172100	7	90	-1	N	.10	.8	
03172200	6	90	-1	N	.11	.8	
03172300	8	90	-1	N	.11	.7	
03180100	6	100	-2	N	.12	.8	Very light snow
03180300	4	100	-2	N	.12	.7	Very light snow
03180400	3	100	-2	Y	.19	.3	
03180600	10	100	-2	N	.11	.8	
03180700	8	90	-2	N	.10	.8	
03180800	8	90	-1	N	.10	.7	
03181000	8	100	1	N	.08	.9	Very light snow
03181100	12	100	2	N	.10	.9	
03181200	7	100	2	N	.10	.8	
03181300	11	100	2	N	.12	.8	Very light snow
03181400	13	90	2	N	.11	.8	
03181600	11	80	1	N	.12	.8	Light snow

NAME OF DATA FILE MMDDTIME	WIND SPEED kt	CLOUD COVER %	AIR TEMPERATURE °C	DISCERNIBLE SIGNAL Y/N/?	REFERENCE CHANNEL V	RATIO CHANNEL V	REMARKS
03182100	5	80	0	N	.11	.8	Light snow
03182200	4	100	0	N	.11	.8	Light snow
03182400	2	80	-1	Y	.14	.4	Light snow
03190200	2	80	-1	Y	.13	.5	Light snow
03190300	4	80	-1	?	.10	.8	Light snow and fog
03190500	6	100	-1	N	.12	.8	Light snow and fog
03190700	8	80	-1	N	.11	.7	Light snow and fog
03190800	8	100	-1	N	.11	.8	Fog
03190900	9	100	0	N	.11	.8	
03191000	9	100	0	N	.09	.8	
03191100	11	100	0	N	.12	.9	