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PERFORMANCE OF AN ABSOLUTE VELOCITY PROFILER
BASED ON ACOUSTIC DOPPLER AND ELECTRO-
MAGNETIC PRINCIPLES

by

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TECHNICAL REPORT

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Abstract

This report describes the performance of a freely-falling velocity profiler called the Absolute Velocity Profiler (AVP). The AVP is distinguishable from our previously developed velocity profiler the Electro-Magnetic Velocity Profiler (EMVP) in that acoustic Doppler measurements are used to determine the reference velocity for the EMVP profiles. The AVP contains the essential measurements of the motional electric currents in the sea as implemented in the EMVP and in addition, collects acoustic Doppler measurements of frequency-shifted bottom echoes. The former measurements yield a profile of the horizontal components of velocity relative to a reference velocity, independent of depth, while the latter measurements determine the absolute velocity of the AVP vehicle with respect to the sea floor. The EM profile is obtained from the sea surface to bottom, and the acoustic Doppler measurements are made within about 300 m of the sea floor. The combination of the EM and acoustic Doppler measurements yields an absolute velocity profile throughout the water column. Performance analyses included in this report set method uncertainties of between 1 and 2 cm/s r.m.s. Measurements of temperature and its gradient are also made.

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I. INTRODUCTION

I.1 Background

A freely-falling instrument, the Absolute Velocity Profiler (AVP), has been developed for measuring horizontal water velocity as a function of depth in the deep ocean. The design and construction of the AVP are described in a previous technical report (Drever and Sanford, 1976). The purpose of this report is to discuss the performance of the AVP during sea tests in December 1976.

The AVP consists of two, independent velocity measuring systems. One, denoted as the EM system, operates on the principles of motional induction and provides a profile of horizontal velocity from the sea surface to the bottom relative to an unknown but depth-independent reference velocity (Sanford, 1975; Sanford, Drever, and Dunlap, 1978). The other, denoted as the AD system, operates on the principles of the acoustic Doppler effect and determines the absolute motion of the instrument within several hundreds of meters of the sea floor. The novel aspect of the present work is that the absolute velocities obtained from the AD system near the bottom are combined with the relative velocities from the EM method. In this way the unknown reference velocity in the EM method is determined near the bottom. This reference velocity is assumed to be the same at all depths prior to and after the encounter with the sea floor.

In December, 1976, the AVP was used in support of a multidisciplinary study of cold core, Gulf Stream rings aboard cruise 62 of the R/V KNORR (Schmitz, et al. 1977). Results from these deployments are presented later in this report.

The next scientific usage of the AVP will be in the Local Dynamics Experiment of the joint US-USSR POLYMODE experiment. For this work we wish to collect absolute velocity profiles at 10 sites in the western North Atlantic using two instruments simultaneously whenever possible.

The goal of this work is to investigate the spatial and temporal structure of velocity profiles. Knowledge of the absolute velocity is vitally important to estimate terms in the conservation of potential vorticity equation and to relate profiles to the two-depth SOFAR float, moored current meter, and density programs.

I.2 The Acoustic Doppler Effect

The acoustic Doppler effect results when there is relative motion between a signal source and receiver or between a source-receiver and scattering or reflecting elements. In the present situation we consider the Doppler frequency changes due to a source-receiver system moving relative to a sound-scattering sea bottom. As the instrument moves toward reflecting elements on the sea floor, the received signal return will be "up Doppler" shifted in frequency. Suppose the instrument, as shown in Figure 1, has a vertical speed of W and is moved sidewise by the local current with horizontal speed U . Then for a periodic signal transmitted and returned along a ray making the angle ϕ_1 with respect to the vertical in the U, W plane, the measured Doppler shift is (Berger, 1957):

$$f_{D1} = \frac{2f_1}{c} (U \sin \phi_1 - W \cos \phi_1), \quad (1)$$

where

f_{D1} = Doppler frequency shift on beam number one

f_1 = transmitted frequency on beam number one

c = speed of sound.

The factor of two results from the fact that both the source and receiver are moving. However, this simple relation applies only when the velocity components and angles are constant during the time between signal transmission and reception. A more general relation is obtained when we recognize that U and W at the time of transmission (t_0) are

Figure 1. A freely-falling instrument moving with velocity components of U and W in the horizontal and vertical directions while projecting ultrasonic beams in the directions ϕ_1 and ϕ_2 .

different when the echoes return ($t_0 + \tau$). In general, the Doppler frequency shift is given as:

$$f_{D1} = \frac{f_1}{c} \{ [U(t_0) + U(t_0 + \tau)] \sin \phi_1(t_0) - [W(t_0) + W(t_0 + \tau)] \cos \phi_1(t_0) \}. \quad (2)$$

One would also expect an effect due to changes in ϕ_1 with time. In the case of the AVP the receiving hydrophone is nearly omnidirectional in its response and, hence, not very sensitive to small ϕ_1 changes.

No mention in the literature has been found of the above time dependent effects. This oversight probably results because previous work concerned radar and short range sonar application where τ is usually less than 1 ms. In our approach τ is as large as 0.5 second, a value large enough to be of concern. However, for simplicity in our discussion, we will ignore changes which occur during the propagation delay. The expected errors will be discussed later.

I.3 Motional Induction

Motion of the sea and instruments through the geomagnetic field induce electric currents and fields. These electrical effects, although exceedingly weak ($\sim 10 \mu V$), are measureable and can be interpreted in terms of the generating velocity distribution. The EMVP instrument, based on the principles of geomagnetic induction, has been in use for several years (Sanford, Drever, and Dunlap, 1978). The EM system of the AVP is essentially the electronics of the EMVP.

The EMVP is a freely-falling device which senses and records the horizontal components of induced electric currents in the water arising from induction between the water motion and the earth's magnetic field. The electric measurements are converted to the equivalent velocity required to generate the electric currents in the local geomagnetic field. The velocity profile which is derived is a relative one, being arbitrary to within a depth-independent velocity. If we denote the local velocity at some depth as $\vec{v}(z)$ and the unknown but depth-independent velocity as $\vec{v}^*$, then the EMVP yields a profile of

the form $\tilde{v}(z) - \bar{v}^*$ (Sanford, 1971). Because $\bar{v}^*$ is independent of depth, it is possible, in principle, to determine $\bar{v}^*$ from a measurement of $\tilde{v}(z)$ at one depth by an independent method.

In reality, it is necessary to measure $\tilde{v}(z)$ at many depths in order to eliminate $\bar{v}^*$. Measurements of the velocity at one depth, say, at the surface from ship drift, are too inaccurate; even velocity values from several levels by moored current meters are not sufficient. To reduce the uncertainty in the determination of $\bar{v}^*$ to about 1 cm/s requires that $\tilde{v}(z)$ be measured over a depth interval of at least 50-100 m. As discussed in the next section, an acoustic Doppler method is used to determine $\bar{v}^*$.

I.4 Absolute Velocities from Combined EM and AD Measurements

The AD system is an ultrasonic transceiver able to determine the velocity of the AVP at several levels or averaged over a vertical distance from Doppler frequency shifts of bottom-scattered echoes (Drever and Sanford, 1976). The EM system is essentially a version of the EMVP (Sanford, Drever, and Dunlap, 1978). The absolute velocity profile results from the combination of the AD and EM data sets:

$$\text{AD} - \text{EM} = \tilde{v}(z) - [\tilde{v}(z) - \bar{v}^*] = \bar{v}^* . \quad (3)$$

Once $\bar{v}^*$ is known the whole EM profile can be adjusted so that it is an absolute velocity profile.

The success of the combined method depends not only on accurate measurements of $\tilde{v}(z) - \bar{v}^*$ and of $\tilde{v}(z)$ but also on the assumptions that $\partial/\partial z \bar{v}^* = 0$ and $\partial/\partial t \bar{v}^* = 0$. The vertical gradient of $\bar{v}^*$ is discussed by Sanford (1971) and should produce profile errors of less than 1 cm/s. The time derivative of $\bar{v}^*$ consists of changes due to fluctuations in the ambient electric field and in the barotropic component of the water motion. Changes to the barotropic or depth averaged flow over a drop time of 1-1/2 hours are thought to be negligible. However, fluctuations to the ambient electric field due to variations in the

geomagnetic field can be significant during geomagnetic storms. From bottom-mounted electric field measurements in MODE-I (Filloux, personal communication), the expected error is about 1 cm/s except during brief periods of magnetic disturbances.

II. THE INSTRUMENTATION

The construction and operation of the AVP are essentially as described by Drever and Sanford (1976). As previously described and as shown in Fig. 2, the AVP is a hybrid technique composed of two measurement techniques on the same vehicle.

The EM system consists of equipment to measure and record the electric current density in the surrounding sea water. The potential difference across a diameter of the vehicle is served by electrodes and amplified and filtered. Every 1/2 second the potential difference pressure, compass coil voltage (used to determine orientation), and 2 tilt measurements are digitized and recorded.

The AD system is an ultrasonic transceiver operating at a frequency of about 300 kHz. Every 1/2 second a pulse of sound is emitted from each of two narrow beam transducers oriented in the same vertical plane but directed at angles of $\pm 30^\circ$ with respect to the vertical (Fig. 2). The one transducer operates at 300 kHz and the other at 286 kHz. The echoes backscattered from the sea floor undergo Doppler frequency shifts. The backscattered energy is received by an omnidirectional hydrophone, amplified and coherently demodulated with the carrier. The resulting Doppler-shifted signals are band-pass filtered and recorded on an analog tape recorder. In addition, a 10-kHz pilot signal is recorded which contains an amplitude modulation encoding the instant of pulse transmission and the instant that the instrument pointed toward geomagnetic north and which permits compensation during playback for tape wow and flutter.

Figure 2. System block diagram of the Absolute Velocity Profiler.

The principle change made to the AVP since its first trials in November 1975 (Drever and Sanford, 1976) was to correct a wiring error at the ultrasonic transducer array. During the first trials each acoustic beam was operated at both frequencies simultaneously. As a result of this operation it was not possible to determine the Doppler shift separately on each beam.

III. KNORR 62 CRUISE DESCRIPTION

In December 1976 we had the opportunity to join the first of four interdisciplinary cruises planned to study the physical, biological, and chemical structure of newly formed cyclonic Gulf Stream rings. Our goals were to test the operation of the AVP and to deploy it in several different regions of a ring, especially the center and high velocity zone. Other activities and measurements of this cruise are reported by Schmitz et al. (1977).

The first AVP (AVP8) deployment was made just south of the Gulf Stream, denoted by the long solid and dashed lines on Figure 3. On board data analysis using a Rockland FFT spectrum analyzer and the computer showed that the AD system functioned well, but that pressure was not recorded. Approximately correct pressure values were synthesized from the instrument rotation data since the rate of change of pressure is a function of the rotation rate to within an uncertainty of $\pm 2\%$ (Sanford, Drever, and Dunlap, 1978). The problem with the pressure channel was corrected.

After several days spent locating and surveying a ring (Fig. 4), two drops, AVP 9 and 10, were made one-half an inertial period apart at the center of the ring. Averaging such a pair provides a good estimate of the mean profile, because most of the variability is at the inertial frequency.

Figure 3. Chart of double ring structure and Gulf Stream as found on KNORR Cruise 62.

Figure 4. 15° C isotherm depths and drop locations.

Likewise, AVP 11 and 12 were to provide a mean profile in the high velocity core. However, AVP 12 EM data starts to have tape recorder-caused gaps near the bottom so the EM data cannot be shifted to make it absolute. This problem was finally found to be a sticky supply spool bearing and corrected in AVP 15.

AVP 13 is a special drop with a 1-ms tone-burst to verify the projector beam pattern and to make estimates of the bottom reflectivity function vs. grazing angle. This analysis is deferred to a later section. Because of the short tone-burst the frequency resolution is not sufficient to obtain Doppler information. The EM tape recorder problems became so serious that no EM data is available either.

AVP 14 was deployed in the wake of the ring during a break in the weather. However, the EM tape recorder still did not perform well and the AD recording was missing the 10-kHz pilot modulation which encodes timing and North pulse times. Thus the only AD data available from AVP 14 is speed which we did not attempt to recover.

AVP 15 and 16 are another half-inertial pair in the slope-water, north of the stream. The AD data from AVP 15 is again missing timing and North pulses so it is not useful. This problem was corrected in AVP 16. The EM data is good for both.

In conclusion, AVP 9, 10, 11, 16 provide good absolute profiles. That for AVP 8 can be reasonably estimated. EM but not absolute data is available for parts of 12 and 14, and all of 15.

Table 1 summarizes times, positions, and comments.

IV. DATA PROCESSING

IV.1 Analog Tape Playback System

The single track, analog tape from the AVP contains three frequency bands of information. In the band 0-1 kHz is the Doppler frequency of

Table 1

Summary of KNORR 62 Drop Information

AVP Drop No.	Date Dec. 1976	Run time (min)	Time (GMT)	Latitude	Longitude	Other obs. (KNORR-62)	Comments
8 L R	2 2	- 149	0150 0433	37°51.83' 37°50.99'	67°22.39' 67°20.94'	SCIMP #1 CTD #1	Good AD data but pressure not recorded so EM must use rotation instead
9 L R	5 5	- 153	1030 1330	36°13.00' 36°13.16'	65°36.47' 65°36.63'	SCIMP #2 CTD #2 & 3	Good EM & AD data
10 L R	5 6	- 153	2126 0023	36°13.52' 36°13.90'	65°32.54' 65°32.81'	SCIMP #3 CTD #4	Good EM & AD data
11 L R	6 6	- 149	1748 2222	36°00.68' 35°59.93'	65°50.94' 65°47.63'	SCIMP #4 CTD #5	Good EM & AD data
12 L R	7 7	- 153	0500 0745	35°59.11' 35°58.87'	65°49.72' 65°48.91'		Good AD, but gappy EM data - none at bottom
13 L R	11 11	- 158	1445 1821	36°20.82' 36°22.27'	64°45.32' 64°45.52'	SCIMP #6 CTD #16	1-ms tone burst No Doppler or EM data
14 L R	15 15	- 161	0935 1310	37°15.23' 37°15.15'	63°13.43' 63°13.01'	SCIMP #7 CTD #24	EM tape stopped before bottom. No timing or North pulses on AD tape
15 L R	20 20	- 101	0912 1142	38°48.10' 38°48.72'	68°55.56' 68°54.81'	SCIMP #8 CTD #25	Good EM. No timing or North pulses on AD tape
16 L R	20 20	- 102	2020 2248	38°48.1' 38°49.3'	68°55.3' 68°52.6'	CTD #26	Good EM & AD data

Note: L,R = Launch, Recovery

the 300 kHz channel. At 10 kHz is the pilot signal which is amplitude-modulated to encode the main and North pulses. The doppler frequency from the 286 kHz beam is in the third band, $14.3 \pm .5$ kHz. An oscilloscope picture of the signals on the analog tape is presented in Fig. 5.

The tape play-back system separates the three frequency bands, demodulates the 14 kHz channel at 14.286 kHz, forms the envelope of the main and North pulses and generates a 25 kHz signal from the 10 kHz pilot. A block diagram of the play-back system is shown in Fig. 6.

The demodulation of the 14 kHz channel is necessary to conform to the sampling rate of the digitizer in the next stage and is desirable so that the signal is the actual Doppler shifted return. Since the 285.714 kHz beam was mixed with 300 kHz within the AVP, the true Doppler shift was itself shifted 14.286 kHz. The demodulation at the play-back stage eliminates this frequency shift and yields in-phase and quadrature-phase components.

The 14.286 kHz mixing frequency and 25 kHz sampling rate are generated from the 10 kHz pilot by phase-lock, frequency multiplier circuits.

The analog signals separated by the play-back system are then digitized into four channels: (1) timing pulses and North pulses, (2) demodulated 300 kHz in-phase returns, (3) demodulated 286 kHz in-phase returns, (4) demodulated 286 kHz quadrature-phase plus in-phase returns. The 25 kHz sampling rate of the digitizing system is shared among the 4 channels resulting in a 6.25 kHz sampling rate for each channel. A plot of 3 channels of the digitized data is presented in Fig. 7.

Figure 5. Oscilloscope picture of all signals from the analog tape recording on an individual 0.5-second interval. A denotes the timing pulse (TP) at the start of tone burst emission, region B consists of spillover during the 50-ms long transmission, C denotes the Doppler signal returns, and D is the north pulse (NP). Scales are 50 ms per division on the abscissa and 50 mV per division on the ordinate.

Figure 6. Block diagram of the analog tape playback and signal conditioning system.

AVP 9D 181 m

Figure 7. Digital plot of the three main channels from the playback system. See Fig. 11 for more examples of the digitized data.

IV.2 Interpretation of Acoustic Doppler Spectra

It is not readily apparent precisely how to utilize the Doppler frequency shifts. Similar devices to the AVP use different spectral characteristics, such as the frequency of maximum energy, the normalized first moment or average frequency of a spectrum, or the normalized second moment. For example, many acoustic Doppler wind measuring systems determine the average Doppler frequency from a cloud of scatters along a narrow beam (Beran et al., 1974). Some airborne and marine Doppler velocimeters compute the normalized second moment or centroid of the frequency spectrum and define that as the "Doppler frequency." We choose to use the frequency of the maximum component in the Doppler spectrum.

The different definitions of the Doppler frequency result from differing scattering models and from technical or hardware considerations. The Doppler wind measuring systems are dealing with returns from a cloud of distinct scatters which are being advected as a whole by some ensemble-averaged flow having random velocities among the individual scatterers. In this case, single peaks in the Doppler spectrum may have little significance because it is the average frequency shift which is physically meaningful. The average frequency, f_{AVE} , is

$$f_{AVE} = \frac{\int_0^{\infty} fE(f)df}{\int_0^{\infty} E(f)df} \quad (4)$$

where $E(f)$ is the energy density function of the acoustic Doppler spectrum.

Marine Doppler systems frequently operate continuously (CW) and determine the Doppler shift as the average number of zero crossings of the back-scattered signal. The average number of zero crossings has

been shown by Rice (1945) to be the same as the centroid of the spectrum:

$$f_{ZC} = \left[\frac{\int_0^{\infty} f^2 E(f) df}{\int_0^{\infty} E(f) df} \right]^{1/2} \quad (5)$$

We have decided to use simply the frequency, f_{MAX} , at which $E(f)$ is largest. The three definitions of the Doppler frequency are most equivalent when the spectrum is highly peaked; clearly if $E(f) = \delta(f - f_D)$ where δ is the Dirac delta function then $f_{MAX} = f_{AVE} = f_{ZC}$. However, the AVP spectrum is not dominated by a narrow band peak. Figure 8 shows two averaged spectra formed by averaging all spectra from pulses sent out in sectors 0-40° (CW from N) and 200-240°. The locations of the two spectral peaks are different because the horizontal motion of the water produces an increased frequency shift in the 0-40° sector (i.e., water motion toward north) and a decreased shift in the 200-240° sector. The important aspect of this figure is that the spectra are not symmetric about the peaks. Because the main beams are 5° in width with significant side lobes (see Drever and Sanford, 1976, fig. 8) the spectra contain contributions from scattering at many locations not just those insonified by the main beam. Thus we find that using the frequency of the peak, which corresponds to the returns from the main beams, is not only physically reasonable but also yields the best profile results.

IV.3 Acoustic Doppler Signal Analysis

A single FORTRAN computer program, AVPTWO, determines the Doppler frequency shifts from the received tone-burst returns. AVPTWO uses digitized tapes generated by the play-back system and saves signal return spectra for other processing. More refined methods of using the spectra to determine velocity are incorporated into AVPVEL. Average spectral shapes versus instrument direction are computed in AVSPEC. A

Figure 8. Average of a number of spectra when the 300 kHz main lobe beam pointed in the sectors 0-40° and 200-240° clockwise from geomagnetic north. Intensity is in terms of digitizer counts squared.

plotting program AVPPLT shows selected signal returns as shown in fig. 7.

In AVPTWO the timing pulses and North pulses on channel 1 are found by threshold detection. The pulses are distinguished by their time duration. Spurious and missing pulse times are detected by requiring tight tolerances on time intervals. Timing pulse errors are corrected immediately in AVPTWO, while North pulse errors are corrected later in AVPVEL. These errors arise because the pulses are amplitude modulations of a 10-kHz pilot tone which itself experiences significant amplitude fluctuations during tape playback.

A timing pulse indicates the beginning of a projected tone-burst and occurs precisely every 0.5 second. Projector directions with respect to geomagnetic North are interpolated between North pulses.

Two signal channels are used for processing: the in-phase demodulation of the 300 kHz and the 286 kHz returns. The quadrature-phase demodulation of the 286 kHz returns is not presently used.

Following the receiver recovery (typically 30 ms) after a projected tone-burst (typically 50 ms) the absolute value of each signal is compared with a preset threshold. This method is very reliable when within 250 m of the sea-floor. No return-to-return averaging is necessary. The first return is assumed to be from the sea floor directly beneath the AVP and yields the height, h , above the seafloor: $h = \frac{c}{2} \tau_0$ where c is the sound speed and τ_0 is the two-way travel time. The time delay of the projector's main-lobe return at 30° from the vertical, τ_{30} , is computed assuming a level seafloor: $\tau_{30} = \tau_0 / \cos 30^\circ$. The returns following τ_{30} are loaded into processing arrays for Doppler-shift determination. Usually the return duration used is equal to that projected, 50 ms in the present case.

The returns are filtered to reduce subsequent aliasing, subsampled by a factor of six, and adjusted to have zero mean. The resulting data is thus sampled at 1042 Hz having a 521 Hz Nyquist folding frequency - well above the maximum expected return frequency. For a 50 ms data window, the 52 data points are followed by

204 zeroes so a fast Fourier transform (FFT) will compute 128 estimates with 4-Hz frequency resolution. This is actually done using a 128-point complex FFT followed by term re-arrangement to get the real transform. Subsampling reduces the FFT time significantly with little spectral change. The Doppler frequency is usually chosen to be the frequency (FMAX) with maximum energy (EMAX). Other choices include various spectral energy moments, but these haven't proved as useful as discussed in the results and analysis section. Every half-second the computed variables, such as height above bottom, FMAX, EMAX and a histogram of both spectra are listed by the line printer. The histogram digits indicate the energy at each frequency normalized by EMAX on a scale from 1 to 10 where @ indicates the peak (i.e., FMAX or 10). An example of this display is shown in Fig. 9 where a dot has been used to emphasize the location of FMAX.

The quality of each spectrum is clearly revealed in Fig. 9. Single, sharp, energetic peaks usually indicate the correct Doppler frequency; broad, double-peaked or weak spectra indicate noisy or poor quality data. Also, the sinusoidal variation of FMAX with time is evident for both channels. This occurs because the AVP is rotating as it falls. Channel 3, which points in the opposite direction from Channel 2, is 180° out of phase with Channel 2 as expected.

A time series of FMAX frequencies are analyzed to determine the corresponding velocity components. The average frequency of the FMAX series determines the W component, while the amplitude and phase of the sinusoidal variations yield the U and V components. The procedure is to fit about 50 values of FMAX to mean and sinusoidal components by a least-squares method. The arguments for sine and cosine fitting functions are the directions (clockwise from geomagnetic north) the projector pointed at the mid-time of each projected tone burst. To obtain good results, data with low EMAX are excluded from the fitting. This criteria eliminates low-amplitude returns, which also tend to be broad-band spectra having no significant Doppler peak. The fitting routine also recomputes the fits excluding those data with deviations

AVP 9D HISTOGRAMS: RELATIVE ENERGY vs. DOPPLER FREQUENCY (Hz)

Figure 9. Histograms of relative energy vs. Doppler frequency between 119.8 and 150.1 m above the sea floor on drop 9D. A dot has been placed at the frequency of the maximum energy on each return. Each line contains the results for the two beams every 0.5 s. Note that the peak energy frequency on each beam oscillates with time and is about 180° out of phase with the other beam. Velocity components based on the two frequencies and on FMAX and FCEN (F_{2C}) for 4 average heights above the sea floor are presented at the bottom of the figure (units are cm/s, W is listed as positive to save space).

from the fit larger than 2.0 times the standard deviation. This data analysis is very similar to the treatment of the electric field measurements and is extensively discussed in Sanford, Drever, and Dunlap (1978).

IV.4 Spectral Broadening and Error Sources

Several characteristics of the AD system cause frequency shifts and broadening of the Doppler spectra. Translations or shifts in frequency of the Doppler signal cause measurement errors, while severe spectral broadening will increase the uncertainty in the estimation of the Doppler frequency shift. Listed below are sources of spectral broadening. Wherever possible the spectral width between half-power points are estimated.

1. Beam characteristics

- a) According to Equation 1, the 5° width of the main lobe causes a return of width

$$\Delta f_{D1} = \frac{2f_1}{c}(U \cos \phi_1 + W \sin \phi_1)\Delta\phi_1 \quad (6)$$

$$= 21 \text{ Hz}$$

for $U = 10$ and $W = 100 \text{ cm/s}$, $\phi_1 = 30^\circ$, $\Delta\phi_1 = 5^\circ$, and $2f_1/c = 4 \text{ Hz/cm/s}$.

- b) Differential absorption and spreading within the 5°-wide main lobe has the effect of making the main lobe slightly narrower. Absorption and spreading losses are greater along the 32.5° ray than along the 27.5° one. The effective beam width depends upon height above the sea floor and has the value of 4° at 200 m. That is, at 200 m above the bottom the 27.5° and 31.5° rays are -3 db relative to 30.0°.
- c) Side lobes produce Doppler returns at many frequencies. The effect of side lobe interference is simulated by the computer model described by Drever and Sanford (1976), but its effect on actual Doppler-shifted spectra is difficult to assess because it is

dependent on velocity and actual beam patterns. The beam pattern is not accurately known and the velocity field changes from drop to drop. A rather qualitative discussion of this effect is deferred to Section V.2.

2. Motion and tilt of acoustic transducer

- a) Due to a difference in the motion of the instrument in the time interval between transmission and reception there will be a slight broadening and a measurable shift in the center frequency. According to Equation 2 the center frequency will be due to the average of the motion of the instrument at t_0 and $t_0 + \tau$.
- b) Rotation of the transmitter causes a small broadening since part of the transducer is moving toward the direction of transmission and part is moving away. The transmitter is 6.5 cm in diameter and rotates at about 1 radian/second. About a 4 Hz spectral broadening results from transducer rotation.
- c) Tilt of the instrument will produce errors principally at the time of transmission, since it is at this time that the sound is produced by the transducer. The receiving hydrophone is essentially insensitive to small tilts since it is more omnidirectional. The frequency shifts due to tilt can be estimated from Equation 6 which for the parameters used gives

$$\Delta f_1 / \Delta \phi_1 = 0.061(U + 0.57W) = 0.6 + 3.5 \text{ Hz/}^\circ \text{ tilt} . \quad (7)$$

For a steady instrument tilt in the presence of the assumed flow the error will consist of a steady and sinusoidally varying frequency shift. The steady frequency shift produces errors of about 1.0 cm/s/ $^\circ$ tilt in the estimation of W and 0.3 cm/s/ $^\circ$ tilt in the estimation of U. The influence of small ($<1^\circ$) random tilts on vertically averaged estimates of U and W is negligible.

3. Modulation and demodulation characteristics

- a) Modulation of the outgoing pulse by a uniform amplitude envelope of duration τ , results in a Doppler spectrum of bandwidth $1/\tau$. Hence a 50 ms duration pulse will yield a spectrum of 20 Hz bandwidth.
- b) Coherent demodulation requires that the carrier frequency be stable between pulse transmission and echo reception. The crystal oscillator and phase lock loops are sufficiently stable to limit frequency shift errors and spectral broadening to less than 0.1 Hz. However wow and flutter of analog tape during playback degrades the 14 kHz signal purity, producing a 10 Hz bandwidth to what was recorded as a single frequency signal. This effect is not significant on the 400 Hz channel.

IV.5 Electromagnetic Signal Analysis

The electric field, pressure, and orientation data collected on a drop are processed to yield a profile of horizontal velocity. Data analysis follows the procedures described by Sanford, Drever, and Dunlap (1978). For the recent data 22 measurements from the electric field and compass coil are used to compute a value of horizontal velocity. Because of larger quantization noise, pressure and pressure rate (i.e., fall speed) are computed over 80 points.

IV.6 Instrument Tilt Analysis

The outputs from the two tilt indicators are processed since the tilt and its rate of change influence the frequency of Doppler returns. Usually the mean value, the component synchronous with the rotation of the AVP and the r.m.s. residues are computed and listed. Table 2 contains the means and standard deviations for the 4 drops having usable digital data. According to section IV.4, these tilts are responsible for velocity errors of about 1 cm/s in W and 0.3 cm/s in U.

Table 2

Mean and Standard Deviations of α and β Tilt Measurements

<u>Drop No.</u>	<u>Tilt α (deg)</u>	<u>Tilt β (deg)</u>
9D	-0.93 ± 0.12	-0.05 ± 0.04
9U	-1.05 ± 0.10	-0.08 ± 0.11
10D	-0.27 ± 0.14	-0.60 ± 0.06
10U	-0.87 ± 0.10	0.03 ± 0.07
11D	-0.71 ± 0.08	0.39 ± 0.02
11U	-0.90 ± 0.10	0.23 ± 0.09
15D	-0.56 ± 0.13	-0.90 ± 0.10
15U	-0.57 ± 0.13	0.06 ± 0.10
16D	-0.61 ± 0.14	-0.06 ± 0.10
16U	-0.62 ± 0.16	-0.14 ± 0.12

However, the angular relationship between the tilt indicators and the axes of the main lobe are not known to an accuracy of 1° . Hence the data of Table 2 mainly show that tilt introduces only small errors between down and up traverses.

V. AVP PERFORMANCE

V.1 Introduction

All EM and AD data from KNORR Cruise 62 have been processed according to the procedures of Section IV. Results from the two AD frequencies and down and up traverses of the water column have been separately analyzed since they represent redundant measurements.

V.2 Comparisons of Echo Levels and Computer Simulations

One of the principal uncertainties in predicting energy levels of backscattered sound is the backscattering strength of the sea floor as a function of grazing angle. The shape of pulse returns as shown in Fig. 7 indicate a relatively large return from side lobe transmission in the direction directly beneath the AVP. In the previous report on the AVP (Drever and Sanford, 1976), the backscattering strength was taken to be independent of grazing angle, a result consistent with the wide scatter of data presented by McKinney and Anderson (1964). Results from the last experiments indicate that this assumption is not correct.

Figure 10 presents the amplitude envelopes of 1-ms pulses received at a variety of heights above the sea bottom. The amplitudes grow rapidly at the start of pulse reception, decrease somewhat later and increase again at the time of arrival for the main lobe returns. Clearly the first arrivals are of comparable strength to the main beam, a condition which makes for accurate detection of the bottom echo (for height determination) but allows undesirable side-lobe interference.

The data of Fig. 10 can be used to calculate a more realistic bottom scattering function than used previously for computer simulations. To increase the energy level of the nadir returns we have

AVP 13D AVERAGE ENVELOPES

Figure 10. Average amplitude envelopes for 10 successive 1-ms duration pulses (5 seconds) for both beams from 244-75 m above the sea floor. Usually the energy of the main lobe can be seen as a separate bump arriving after the first bottom arrivals

linearly increased the bottom scattering strength from -30 db at 60° grazing angles to -21 db at 90° while leaving it at -30 db for the range 0-60°. With the modified bottom scattering the pulse envelopes computed are quite similar (± 2 db) with those observed (Fig. 11).

Although the average envelopes of the two beams are about equal the individual pulses may be very unequal. For example in Fig. 12 are presented a sequence of pulses for one instrument rotation at a height above bottom of over 200 m. There is considerable reciprocal amplitude modulation evident in these data, since when the 300 kHz channel is energetic the 286 kHz channel is weak and vice versa. This effect seems to come from the mixer stage (Fig. 2) in a manner not well understood as yet. The reciprocal amplitude modulation does seem to be dependent on signal strength, since it does not occur for the much less energetic (2%) 1-ms pulse.

To estimate the contributions from side lobe radiation the computer simulations were run for 50-ms pulses with and without side lobe contributions. At heights of 300, 200, and 100 m above the bottom the contributions from side lobes are shown in Fig. 13. Model computations were made for 50-ms pulses emitted as the beam pointed in a sequence of directions with respect to the motion of the AVP. These results are presented in Fig. 14 and show how the spectral shape and width change with beam orientation.

V.3 Comparison of the Two Acoustic Doppler Channels

The complimentary figure to that of the average pulse shapes shown in Figs. 10 and 11 is the average spectral shape shown in Fig. 15. Because the spectra change as the AVP rotates the average spectra is shown for two azimuth intervals. There is more energy in the 286 kHz beam in the 0-40° interval but less in the 200-240°. Since by Fig. 10 the energies of the two beams are on average equal the difference between beams in Fig. 15 indicates the effect of anisotropic back-scattering. More energy is reflected

Figure 11. a) Comparison of measured average envelope (Drop 13D) with simulated envelopes using either a constant (with grazing angle) and an adjusted bottom scattering strength (chosen to achieve a good fit to the observation (see text)).
 b) Ratio in dB of observed and simulated envelopes for the adjusted reflectivity as a function of grazing angle (see text).

AVP 9D DIGITIZED DATA

Figure 12. Timing and Doppler return signals for the 300 and 286 kHz beams for a complete instrument rotation. Note the undesirable reciprocal amplitude modulation between channels 2 and 3.

$\tau_p = 50$ ms $U = -7.07$ cm/s $V = 7.07$ cm/s $W = -100$ cm/s

Figure 13. Comparisons at three heights (H) of the simulation spectra using the measured beam pattern (a) and only the main lobe of the measured beam pattern (b). The left diagrams depict the amplitude versus time of the bottom scattered returns. The peak amplitudes in (a) are about 88, 4.5, and $0.25 \mu V$ at heights of 100, 200, and 300 m respectively. The center diagram is a sonogram where relative energies are contoured in steps of 3dB (regions of energy greater than -3dB are hatched) as a function of time. The ordinate is Doppler frequency from 250 to 450 Hz and the abscissa is two-way travel time. The two vertical lines are 50 ms apart with the first one at 150, 300, and 450 ms for $H = 100, 200,$ and 300 m respectively. Data from between the vertical lines are used to give average frequency spectra as presented in the right-most diagrams. Adjusted bottom scattering coefficient (Fig. 11) is used.

SONOGRAMS (3 dB CONTOUR INTERVALS)

AVERAGE SPECTRA

Figure 14. Simulated sonograms and spectra for one-half instrument rotation. This is a similar display to that shown in Fig. 13 but at one height and at various orientations. Note the strong spectral changes as a function of beam direction. Adjusted bottom scattering coefficient is used.

Figure 15. (a) Averages of a number of spectra obtained when the 300 kHz main lobe beam pointed in the sectors 0-40° (a) and 200-240° (b). The 286 kHz main lobe beam was pointed in the sectors 180-220° and 20-60° since it was oriented 180° with respect to the 300 kHz beam. Intensity is in terms of digitizer counts squared.

by the bottom when the 300 kHz beam points between 200 and 240° than when the 286 kHz beam points the opposite direction (i.e., 20-60°).

The average spectra of Fig. 15 are useful for estimating the average spectral shape of the Doppler returns but they are not used to determine velocity values. Velocity determinations are made by fitting to the individual spectra from each return as discussed previously in Section IV.3 and illustrated by the computer listing shown in Fig. 9.

The near bottom velocity profiles are shown in Fig. 16 and summarized in Table 3 for the AVP drops having usable AD data (see Table 1). The frequency of the spectral peak (FMAX) was used in the sinusoidal fit, and both beams were assumed to be directed 30° with respect to the vertical. Sound speed was computed from nearby CTD stations. From these calculations one sees that

1. there is no significant difference in the vertical means of U and V between the two beams;
2. the individual profiles differ by about 1 cm/s r.m.s. (i.e., down 300 kHz vs. down 286 kHz);
3. the vertical velocities differ with $|W_{300} - W_{286}| \approx 2.5$ cm/s.
4. The average standard deviation between the 4 mean components (e.g., East for all data; both beams and Down + Up) is 0.6 cm/s.

V.4 Results of Electromagnetic Measurements

The profiles computed from usable EM data are shown in Fig. 17. The down versus up EM profiles differ by less than 0.5 cm/s r.m.s. and indicate that there was very little vertical shear in the region of interest. The exception is drop 16 which has a 1 cm/s offset in both components between down and up. Clearly the electrode arms on the AVP have been rotated with respect to the compass coil some time between drop 11 and drop 16. The same calibration was used for all of the drops. Nonetheless, this offset does not matter; the profiles are relative anyway.

EAST VELOCITY COMPONENT (cm/s)

NORTH VELOCITY COMPONENT (cm/s)

VERTICAL VELOCITY COMPONENT (cm/s)

Figure 16. Velocity components determined from the 300 kHz (solid lines) and 286 kHz (dashed lines) acoustic data.

Figure 17. Horizontal velocity components determined from the EM data. The down profile is drawn as a solid line and the up as a dashed line.

The lack of vertical shear in the EM profiles suggests that the fluctuations evident in the AD profiles of Fig. 16 are largely due to noise. Thus we choose to average all of the AD data together to obtain one East and one North velocity determination.

V.5 Combined AD and EM Data

Now with EM and AD derived velocity components averaged over comparable height interval it is possible to determine the offset velocity in the EM profile. According to Equation 2,

$$\overline{V}_{AD \text{ profile}} - \overline{V}_{EM \text{ profile}} = \overline{V}^* . \quad (8)$$

These data are plotted in Fig. 18 and listed in Table 4.

The average and standard deviation of the difference in $\overline{V}^*$ between down and up determinations are -0.5 ± 0.6 for the east and 0.8 ± 0.8 for the north component.

Plotted in Fig. 18 are results from AVP8 which lacked pressure measurements. Special analysis using time and rotation rate allowed us to estimate the EM data with reduced accuracy.

The comparison of $\overline{V}$ and $\overline{V}^*$ is presented in Table 5. The difference between these two quantities (<1.5 cm/s r.m.s.) occur not only from measurement errors but also from the physics of motional induction. Sanford and Schmitz (1971) discuss the relationship between $\overline{V}^*$ and the contributions due to $\overline{V}$, large-scale electric currents of a non-local source and the vertical distribution of electrical conductivity. The observed differences are within the expected amount from the above sources.

There are four independent methods for determining the vertical speed of the vehicle near the sea floor. The two-beam AD system yields W from the 300 kHz beam (W_{300}), from the 286 kHz beam (W_{286}), and from the rate of change of the round trip travel time (τ) to

Figure 18. Vertically-averaged velocity determinations from the acoustic Doppler (AD) and electro-magnetic data. The data plotted is from Table 4 and the vector joining the AD and EM data is $\vec{V}^*$.

Table 4

Combination of EM and AD Measurements

Drop No.	Height (m)		EM Data (cm/s)			AD Data (cm/s)			AD-EM or $\bar{v}^*$				
			u	v	w	u	v	w	$\bar{u}^*$	$\bar{v}^*$	Δw		
9D	85-253	Mean	-0.2	5.8	-103.5	-4.3	9.4	-104.7	-4.1	3.6	-1.2		
		σ	0.7	0.3	0.5								
9U	77-248	Mean	0.0	5.9	109.7	-3.7	9.1	110.8	-3.7	3.2	1.1		
		σ	0.7	0.5	0.8								
		D-U	-0.2	-0.1	-	-0.6	0.3	-	-0.4	0.4	-		
10D	82-250	Mean	-3.0	5.5	-103.6	-6.4	13.2	-104.4	-3.4	7.7	-0.8		
		σ	0.6	0.4	0.7								
10U	78-223	Mean	-3.3	5.7	110.3	-6.2	13.3	111.7	-2.9	7.6	1.4		
		σ	0.6	0.6	0.7								
		D-U	0.3	-0.2	-	-0.2	-0.1	-	-0.5	0.1	-		
11D	78-187	Mean	-4.7	16.2	-103.7	5.0	11.5	-104.4	9.7	-4.7	-0.7		
		σ	0.6	0.4	0.6								
11U	78-263	Mean	-5.0	16.4	109.4	4.5	9.8	110.9	9.5	-6.6	1.5		
		σ	0.6	0.7	0.6								
		D-U	0.3	-0.2	-	0.5	1.7	-	0.2	1.9	-		
16D	91-238	Mean	-9.0	-4.4	-105.3	-0.8	-1.9	-105.9	8.2	2.5	-0.6		
		σ	0.7	0.7	0.4								
16U	74-258	Mean	-10.4	-3.1	107.8	-0.9	-1.3	108.5	9.5	1.8	0.7		
		σ	0.8	1.0	0.7								
		D-U	1.4	-1.3	-	0.1	-0.6	-	-1.3	0.7	-		
									$\bar{u}^*$	$\bar{v}^*$	Δw_D	Δw_U	
D-U									Mean	-0.5	0.8	-0.8	1.2
S.Dev.										0.6	0.8	0.3	0.4

Table 5
Comparison of $\bar{V}^*$ and $\bar{V}$

<u>Drop No.</u>	<u>East Component</u>	<u>North Component</u>
8DN	$\bar{U}^* = 15$ $\bar{U} = \underline{18}$ -3	$\bar{V}^* = -16$ $\bar{V} = \underline{-17}$ 1
9DN	$\bar{U}^* = -3.5$ $\bar{U} = \underline{-3.2}$ -0.3	$\bar{V}^* = 3.5$ $\bar{V} = \underline{4.0}$ -0.5
10DN	$\bar{U}^* = -3.4$ $\bar{U} = \underline{-3.4}$ 0.0	$\bar{V}^* = 7.6$ $\bar{V} = \underline{8.5}$ -0.9
11DN	$\bar{U}^* = 9.7$ $\bar{U} = \underline{8.8}$ 0.9	$\bar{V}^* = -4.7$ $\bar{V} = \underline{-2.5}$ -2.2
16DN	$\bar{U}^* = 8.2$ $\bar{U} = \underline{9.9}$ -1.7	$\bar{V}^* = 2.5$ $\bar{V} = \underline{2.4}$ 0.1

the bottom (i.e., $W_E = \frac{c}{2} \frac{\partial \tau}{\partial t}$). The fourth measurement comes from the rate of change of pressure (i.e., $W_P = -\frac{\alpha}{g} \frac{\partial p}{\partial t}$). These four measurements are presented in Table 6. As we saw in Fig. 16 $|W_{300}| < |W_{286}|$, which may be caused by a systematic error in the elevations of the two beams (i.e., $|\phi_1| > |\phi_2|$ by about 1°). The average of the two beams (W_{AVE}) differs from the travel time and pressure rate estimates by 1 cm/s or less.

All of the profiles, absolute and relative, are plotted in Fig. 19. Whenever possible the zero velocity component line is given.

V.6 Comparison of Time Integrated AVP Velocities and LORAN-C Displacements

The analysis to this point has emphasized expected error sources and the intercomparison of the two acoustic measurements and the down and up traverses. Such analyses reveal the internal consistency of the measurements but determine nothing about the absolute accuracy. The only test of absolute accuracy available is the comparison of the time averaged velocities or displacements obtained from the AVP data with the difference in launch and recovery positions.

Let $V(t)$ be the AVP velocity profile. Then

$$\int_{T_L}^{T_R} V(t) dt = \int_{T_L}^{T_S} V(t) dt + \int_{T_S}^{T_R} V(t) dt = \Delta \tilde{x} \quad (9)$$

where T_L , T_S , and T_R are the times of launch, surfacing, and recovery respectively, and $\Delta \tilde{x}$ is the displacement of the AVP between launch and recovery.

Displacement calculations were made for drops 8, 9, 10, and 11. Drop 8 has no pressure record, and, as mentioned previously, the velocity profile is less accurate than the other ones. The LORAN-C positions are from Table 1 which were taken from the digitized values recorded automatically every 10 min rather than from

Table 6

(a) Comparison of W from Doppler, Bottom Echo Delays and Pressure Measurements

AVP Drop	C m/s	W ₃₀₀ cm/s	W ₂₈₆ cm/s	W _{AVE} cm/s	W _E cm/s	W _P cm/s
8D	1540	-103.1	-104.8	-104.0	-103.5	-
U		109.7	112.8	111.3	111.1	-
9D	1544	-103.3	-106.1	-104.7	-104.5	-103.5
U		109.1	112.4	110.8	110.8	109.7
10D	1544	-103.5	-105.2	-104.4	-104.3	-103.6
U		110.4	113.0	111.7	112.1	110.3
11D	1540	-103.2	-105.6	-104.4	-103.2	-103.7
U		109.9	111.8	110.9	111.5	109.4
12D	1540	-102.0	-104.9	-103.5	-103.4	-
U		109.3	112.4	110.9	111.0	-
16D	1515	-105.0	-106.7	-105.9	-106.7	-105.3
U		107.3	109.7	108.5	109.7	107.8

(b) Mean and Standard Deviations for Differences of Absolute Value of W Measurements in Table 6a.
Differences are Columns minus Rows.

	W ₃₀₀	W ₂₈₆	W _{AVE}	W _E	W _P
W ₃₀₀	0	-	-	-	-
W ₂₈₆	-2.35 ±0.56	0	-	-	-
W _{AVE}	-1.18 ±0.28	1.18 ±0.28	0	-	-
W _E	-1.39 ±0.72	0.98 ±0.86	-0.19 ±0.74	0	-
W _P	-0.23 ±0.35	2.15 ±0.52	1.01 ±0.34	1.19 ±0.84	0

Figure 19. All velocity profile data with absolute zero when available.

positions entered by the mates in the LORAN log. The digitized LORAN-C tape is missing for drop 16, so it was not included in the comparison.

Figure 20 presents the displacements and Table 7 lists the average velocities computed as the displacements in east and north (geomagnetic coordinates, 15° W of true north) divided by the time between launch and recovery. For the best drops, 9, 10, and 11, there is no significant difference in velocities when expressed either in polar or Cartesian coordinates. The present sample is too small to firmly establish absolute method errors. Also no error analysis has been made on the expected LORAN-C errors. Nonetheless these results are very encouraging and suggest that the method errors are less than 2 cm/s r.m.s.

V.7 Summary of Results

The differences in vertically averaged velocities from the two acoustic Doppler channels (Table 3) have r.m.s. values of 0.9, 0.4, and 2.6 cm/s for u , v , and w respectively.

The differences in EM-derived velocities between down and up profiles (Table 4) have r.m.s. values 0.9 cm/s for u and 0.8 for v . It should be emphasized that the difference between down and up EM velocities can be largely eliminated by a simple adjustment of the calibration parameters as discussed by Sanford, Drever, and Dunlap (1978).

The r.m.s. differences between down and up velocity determination for the combined AD and EM (Table 4) data are 0.8 cm/s for $\bar{u}^*$ and 1.1 cm/s for $\bar{v}^*$. Thus the AVP gives internally consistent results to an uncertainty of about 1 cm/s r.m.s.

Finally, average velocities computed from time integrated velocity profile data and from launch and recovery positions differ by about 1.6 cm/s r.m.s. This difference is probably an upper bound on system errors.

Figure 20. Comparisons of time integrated AVP velocities and LORAN-C displacements between launch and recovery.

Table 7

Comparison of Time Averaged Velocities betweenAVP and LORAN Measurements

<u>Drop No.</u>	<u>Type</u>	<u>Speed (cm/s)</u>	<u>Dir (°T)</u>	<u>U (cm/s)</u>	<u>V (cm/s)</u>
8	AVP	27.0	112	25.0	-10.1
	LORAN	<u>26.8</u>	<u>125</u>	<u>22.0</u>	<u>-15.4</u>
	DIFF.	0.2	-13	3.0	5.3
9	AVP	3.1	310	-2.4	2.0
	LORAN	<u>3.5</u>	<u>322</u>	<u>-2.2</u>	<u>2.8</u>
	DIFF.	0.4	-12	-0.2	-0.8
10	AVP	9.0	333	-4.1	8.0
	LORAN	<u>6.7</u>	<u>341</u>	<u>-2.2</u>	<u>6.3</u>
	DIFF.	2.3	- 8	-1.9	1.7
11	AVP	33.6	104	32.6	-8.1
	LORAN	<u>31.9</u>	<u>106</u>	<u>30.7</u>	<u>-8.8</u>
	DIFF.	1.7	- 2	1.9	0.7
9, 10 & 11	DIFF. AVE.	1.2	-7.3	-0.1	0.5
	σ	1.4	5.0	1.9	1.3

In summary, the reproductability of velocity values between down and up traverses near the sea floor indicates measurement uncertainties of about 1 cm/s r.m.s. This is a relative error level since it is only based on reproductability of results. Comparisons of absolute velocities obtained from LORAN observations indicate absolute errors of about 1.6 cm/s. Until more intercomparison data is available a method of uncertainty of 2 cm/s r.m.s. is assumed even though this is probably an over estimate.

VI. CONCLUSIONS AND DEVELOPMENTS

The AVP has performed to the design specifications: reproductability of horizontal velocity determination by the acoustic Doppler system to within 1 cm/s r.m.s. Moreover, several performance limitations have been identified which if eliminated should permit improved performance. Certain of these limitations, such as the beam pattern of the transducers and the rotation rate of the vehicle, cannot be altered at this time. Other problems, those relating to electronic noise, mixer performance, and data recording, are being eliminated or, at least, reduced.

The mixer stage (Fig. 2), which demodulates the back-scattered returns, suffers from cross-channel amplitude modulation and non-linear gain. These characteristics are evident in the small dynamic range of average pulse envelopes versus height on Fig. 10 and in the reciprocal amplitudes of individual returns on Fig. 12. This behavior limits the signal to noise ratio of the recorded data and broadens the pulse spectra shown on Fig. 9. A new mixer (demodulator) has been developed to eliminate the above problems.

Because the 286 kHz signals are demodulated at 300 kHz the Doppler shifted returns are frequency shifted by 14 kHz. The quality of the Doppler data when recorded at 14 kHz (Channel 3) is significantly worse than the data recorded at lower frequency, 200-600 Hz (channel 2). The degradation in data quality is clearly

shown in Fig. 12 and is due to the poorer high-frequency performance of the analog tape recorder. The procedure now used is to separately demodulate the 300 kHz and the 286 kHz returns with their respective carrier, and then to modulate the 286 kHz channels with a 1 kHz signal. The 300 kHz Doppler signal occupies the frequency band of about 200-600 Hz and the other channel resides between 600 and 1000 Hz. The two demodulated signals are then combined and recorded on the analog tape. As a result of this scheme the peaks of the spectra will oscillate in time, due to U and the rotation of the vehicle, as before, but will now be in phase rather than 180° out of phase as seen on Fig. 9. Besides improving the quality of the recorded signals, the peak frequency for both channels can be determined from a single, 1 kHz wide spectrum. Presently individual spectra are calculated for each channel (Fig. 9). The principal advantage of this approach is that a real-time FFT analyzer can be used to determine the spectra of both channels in real-time as the analog tape is played on the ship.

The present digitizer and analysis system cannot be taken to sea. Yet the amount of digital data and required computations is too much for the shipboard computer system. We intend to use a Rockland FFT analyzer (model FFT 512/S) to digitize the desired portions of the signal, to calculate a FFT over the band 0-1 kHz and to transfer the spectra to the shipboard computer for storage on a 9-track magnetic tape. This system must complete the full cycle of operations twice per second. Later the 9-track tape will be analyzed to determine the probe velocities. We expect to complete the analysis of the AD data between 1/2 to 1 hour after recovery of the AVP analog tape.

The EM functions of the AVP have been improved with the addition of a second electrode system and a 3-axis magnetometer. The second electrode line is orthogonal to the first and will permit higher quality EM profiles to be made. The magnetometer yields good orientation data which, when combined with the orthogonal

electric field measurement, permits the determination of high quality EM velocity profiles.

Temperature and temperature gradient are measured but electrical conductivity is not. The temperature measurements will only be accurate for up profiles because of where the sensors are mounted.

The vehicle (Fig. 21) has been modified to make it shorter and more easily handled. Additional buoyancy has been installed beneath the nose cone and the flasher and radio have been given more protection (compare with Fig. 5 of Drever and Sanford, 1976). Otherwise we have used as much of the EMVP vehicles as possible, including the pressure cases.

ABSOLUTE VELOCITY PROFILER (AVP)

Figure 21. The AVP as built for profile work in 1978 in the Local Dynamics Experiment of POLYMODE.

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