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A MICROPROCESSOR CONTROLLED INSTRUMENT FOR MEASURING THE TRANSMITTANCE AND REFLECTANCE OF OCEAN WATERS

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Abstract

The factors contributing to the visibility of submerged targets are discussed and the data requirements for calculating submerged contrast and contrast transmittance are developed. An instrument capable of making the measurements of the optical properties of seawater needed for visibility calculations is described. The instrument incorporates proven features of previous spectral transmissometers and oceanographic illuminometers into a single unit that can be operated through standard STD cables up to 8000 meters in length. It can, as a result, be used on most oceanographic vessels without requiring the addition of a special winch and cable. The instrument system utilizes a unique microprocessor-controlled, digital data acquisition and command system. This system performs the control and data transmission functions for eight underwater data channels through the armored, single wire STD cable. The total instrument system includes an HP9830B desk-top computer for data processing and recording, with an interconnected plotter for the real-time plotting of the measured variables.

Introduction

An instrument has been developed for the U.S. Naval Oceanographic Office which performs the measurements necessary to determine the water reflectances and attenuation coefficients that are significant to the assessment of submerged visibility. The determination of the visibility of a submerged object requires knowledge of the contrast of the object against its water background, the extent to which this contrast is attenuated by the water between the object and the observer, and, if the viewer is above the surface, the contrast loss at the water surface. While contrast is defined in terms of the luminance of the object and the luminance of the surrounding background against which it is viewed, it is more generally useful to express the contrast in terms of the ratio of the reflectance of the object to the appropriate water reflectance. Such reflectances are dimensionless and have the advantage over luminances that they are essentially invariant with depth in vertically homogeneous water. The contrast attenuation of the water may be determined from the diffuse attenuation coefficient, K, and the volume (or beam) attenuation coefficient, c. These concepts will be further discussed under "Data Requirements for Submerged Visibility Calculations."

The instrument has been designed to work through standard STD or CTD wires up to 8000 meters in length, thereby making it readily usable on most major oceanographic vessels without the need for additional special winches and cables. Although the instrument functions through cables capable of reaching abyssal depths, the determination of visibility of submerged objects is primarily a matter or concern in the upper regions of the ocean. Consequently, the instrument has been designed to operate to maximum depths of 500 meters.

The following variables are measured:

- Downwelling illuminance, E_d, in the water;
- Upwelling illuminance, E_u, or alternatively, upwelling luminance, L_u, in the water;
- Downwelling illuminance, E_o, above the water surface;
- Beam transmittance, T, at any of 5 operator selectable wavelengths;
- Instrument depth, Z;
- Water temperature, t;
- Pitch and roll of the instrument.

The purpose of measuring E_d, E_u, L_u, E_o and T will be discussed below. The requirement for knowledge of the instrument depth is obvious. The water temperature is useful in interpreting the vertical optical structure in the water column since variations in the optical properties are frequently correlated with thermal features. The pitch and roll information is used only to determine the attitude of the irradiance sensors. Should the collecting surfaces of these sensors depart from horizontal to a significant extent due to instrument wire angle, it would be necessary to discard the data until the attitude could be corrected by adding additional weight to the instrument or by adjusting its suspension bridle.

The data from the instrument is provided to an HP9830B desk-top computer used by the Oceanographic Office for a variety of shipboard data acquisition and processing tasks. The data may be recorded, listed, plotted, and computations of the reflectances and attenuation coefficients performed in real-time by the 9830B and its associated plotter.

A microporcessor (Motorola 6800) has been incorporated in the instrument to perform various housekeeping and logic functions, read front panel switch commands, apply calibration factors to the data from the various channels, select channel gains (auto ranging), change data formats as required for the front panel displays and by the 9830B, and to handle the general interfacing requirements between the instrument and the 9830B.

The general philosophy of the instrument design was to provide a single instrument that would serve the functions of the separate transmissometer and the dual illuminometer previously used for acquiring visibility data, but in an automated, state-of-the-art system that would provide higher quality data with significantly less time on station. The underwater sensor package uses elements from previous spectral transmissometers[1,2] oceanographic illuminometers[3] and digital data and command transmission systems[4]. Optical and mechanical components similar to those used in the new instrument have proven to be rugged and free of alignment and adjustment problems over prolonged periods of field use.

Figure 1 shows the components of the instrument system. The underwater unit is 117 centimeters (46 inches) in length, 31 centimeters (12.25 inches) between upwelling and downwelling sensor surfaces, and weighs 44.5 kilograms (98 pounds) in air. The weight in water is reduced to 17.25 kilograms (38 pounds) Table 1 lists the specifications of the instrument.

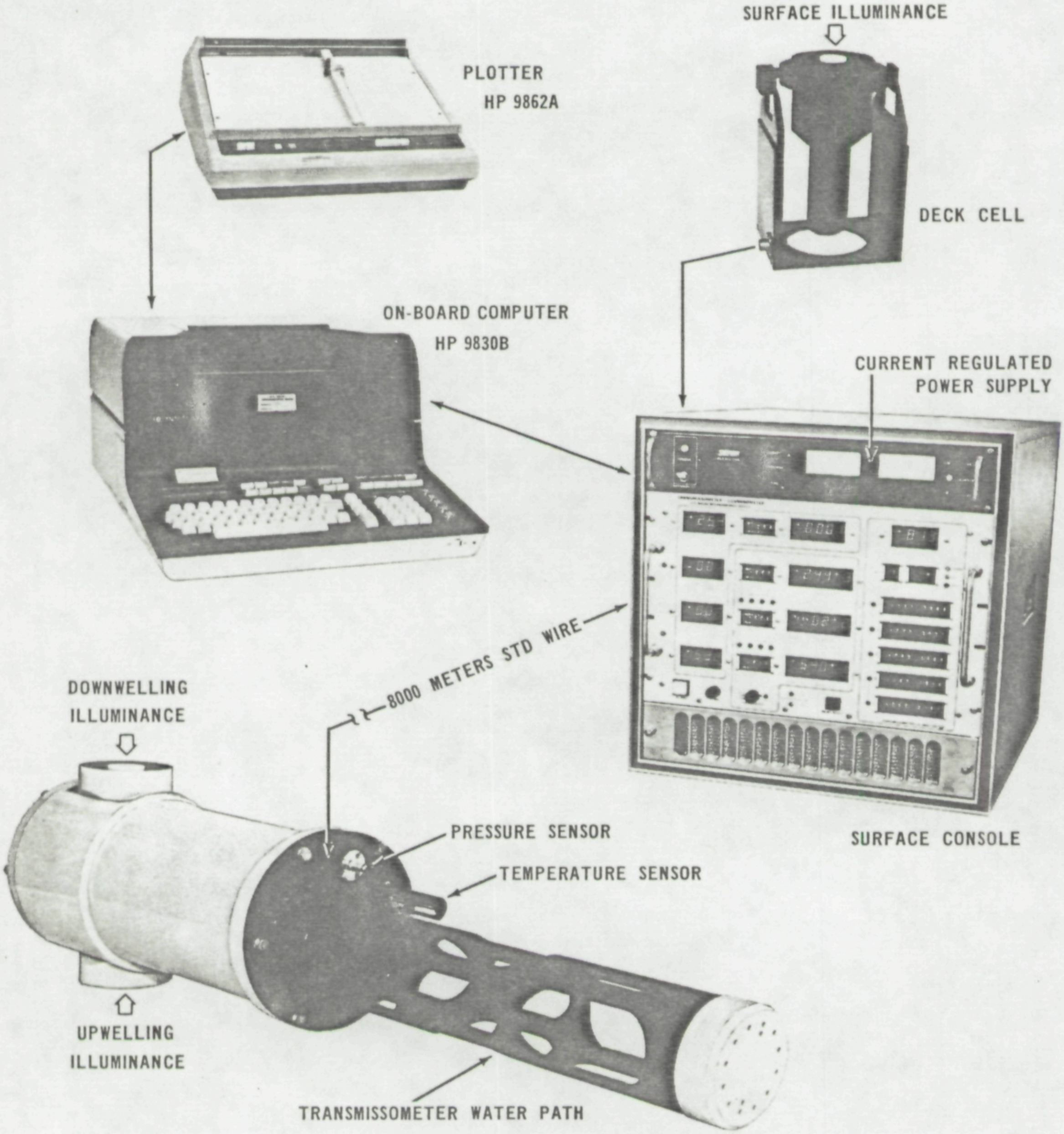

Fig. 1. The integrated oceanographic transmissometer, dual illuminometer instrument system.

Table 1. Specifications for Combined Transmissometer/Illuminometer Design

Sensor	Units	Ranges	Accuracy	Resolution
1. Downwelling Illuminance, E_d	{candelas·foot^{-2}} {(foot-candles) }	12,000 cd·ft^{-2} 1,200 120	10% of reading or 1 cd·ft^{-2} whichever is greater	6 cd·ft^{-2} 0.6 0.06
2. Upwelling Illuminance, E_u	{candelas·foot^{-2}} {(foot-candles) }	1,200 cd·ft^{-2} 120 12	10% of reading or 0.6 cd·ft^{-2} whichever is greater	0.6 cd·ft^{-2} 0.06 0.006
2a. Upwelling Luminance, L_u	{candelas·foot^{-2} } {steradian^{-1} }	12,000 cd·ft^{-2}·sr^{-1} 1,200 120	10% of reading or 1 cd·ft^{-2}·sr^{-1} whichever is greater	6 cd·ft^{-2}sr^{-1} 0.6 0.06
3. Surface Downwelling Illuminance, E_o	{candelas·foot^{-2}} {(foot-candles) }	12,000 cd·ft^{-2}	10% of reading or 20 cd·ft^{-2} whichever is greater	10 cd·ft^{-2}
4. Transmittance, T (5 spectral channels)	dimensionless	1.000	0.003	0.001
5. Depth, Z	meters	500.0 m	2.5 m	0.25 m
6. Temperature, t	Celcius	0-40.0°C	0.5°C	0.1°C
7. Pitch and Roll, Θ_p, Θ_r	angular degrees	±30°	3°	1°

Data Requirements for Submerged Visibility Calculations:

The contrast of an object may be defined as follows:

$$C = \frac{L_t - L_u}{L_u} \qquad (1)$$

where C is the universal contrast,
L_t is the luminance of the object or "target",
and
L_u, is the luminance of the surrounding water background against which the object is viewed.

The contrast of the object when viewed from close aboard is called the inherent contrast, C_o, and that when viewed over a path of length r is called the apparent contrast, C_r. The ratio C_r/C_o, is the contrast transmittance, τ_r , for the path. It can be shown (e.g., see Ref 5) that

$$\tau_r = e^{-(c+K\cos\Theta)r} \qquad (2)$$

where c is the volume attenuation coefficient
K is the diffuse attenuation coefficient
and Θ is the angle between the path of sight (direction of flux travel) and the zenith (see Fig 2).

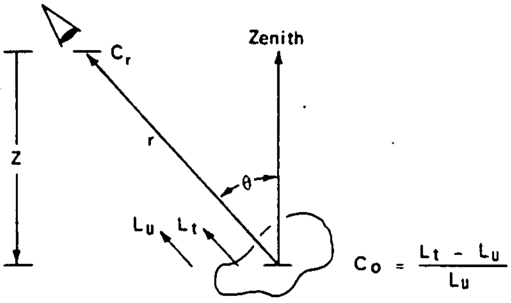

Fig. 2. Contrast Concepts

It is helpful to rewrite Eq(2) in terms of the depth difference, Z, between the point of observation and the target (depth increases positively in the downward direction). Thus, since $Z = r \cos\Theta$

$$\tau_r = e^{-(cr+Kz)} . \tag{2a}$$

We see that contrast transmittance is composed of two components, the first, e^{-cr}, is the beam transmittance, T, for the path of sight, i.e., $T = e^{-cr}$), and the second is the illuminance transmittance e^{-KZ} for the depth difference, Z, between the ends of the path.

The visibility of a submerged target will depend on the apparent contrast, C_r, which it makes with its background. This, as we have seen, is the product of the inherent contrast, C_o, of the object and the contrast transmittance, τ_r, of the intervening path.

The luminance of the target, L_t, may be determined from the reflectance of the target surface, R_t, and the illuminance incident on this surface. We will restrict our concern to targets that are viewed from above, hence are illuminated by the downwelling illuminance, E_d. It will be further assumed that the target surface is a lambertian reflector, i.e., that the target luminance may be determined from

$$L_t(Z) = E_d(Z) \frac{R_t}{\pi} \tag{3}$$

The water also has a reflectance that can be used to determine the water background luminance. The most commonly measured water reflectance is the illuminance ratio

$$R_w = E_u/E_d \quad . \tag{4}$$

It is not sufficient, however, to assume that the water is a lambertian reflector since measurements of the angular radiance (or luminance) distribution in water have shown that there is a significant departure from the uniform angular distribution that obtains for lambertian surfaces.

The upwelling illuminance $E_u(Z)$ is related to the upwelling luminance $L_u(z,\theta,\phi)$ by

$$E_u(Z) = - \int_{\phi=0}^{2\pi} \int_{\theta=\pi/2}^{\pi} L_u(Z,\theta,\phi) \cos\theta d\omega \tag{5}$$

where θ and ϕ are the zenith and azimuth angles of L_u, respectively, and the solid angle, $d\omega = \sin d\theta d\phi$. In the case where $L_u(z,\theta,\phi)$ is the same for all θ & ϕ, i.e., L_u is uniformly distributed,

$$E_u(Z) - \pi L_u(Z) \quad . \tag{6}$$

In the general case where $L_u(Z,\theta,\phi) \neq$ constant there is, of course, no single factor that can be used to relate $E_u(Z)$ and $L_u(Z,\theta,\phi)$. It is helpful, however, to consider the special, but important, viewing geometry where the observer is looking directly downward. In this case the background is $L_u(Z,\pi)$, i.e., the nadir luminance, and we can define a factor, Q, which relates $E_u(Z)$ to $L_u(Z,\pi)$ in a manner similar to Eq.(6). Thus

$$E_u(Z) = Q \, L \, (Z,\pi) \; , \tag{7}$$

and when $L_u(Z,\theta,\phi)$ = constant, $Q = \pi$ and Eq.(6) reduces to Eq.(7). Austin[6], using radiance distributions obtained by Tyler[7,8] in Lake Pend Oreille and recent unpublished measurements of upwelling spectral radiances and irradiances, has found that Q as defined in Eq.(6) generally has a value close to 5 in water deep enough to preclude significant return from the bottom.

The nadir luminance may be determined by combining Eqs.(4) and (7). Thus

$$L_u(Z,\pi) = \frac{E_u(Z)}{Q} = \frac{R_w}{Q} \; E_d(Z) \tag{8}$$

The inherent contrast at depth Z may be expressed as

$$C_o(Z) = \frac{L_t(Z)}{L_u(Z)} - 1 \quad , \tag{9}$$

and using Eqs.(3) and (8) we obtain

$$C_o(Z) = \frac{R_t}{R_w} \cdot \frac{Q}{\pi} -1 \quad . \tag{10}$$

Finally combining Eqs.(2a) and (10) we obtain the relationship for the apparent contrast of an object a distance Z below the observer in the nadir direction, i.e., $\theta=\pi$,

$$C_r = \frac{R_t}{R_w} \cdot \frac{Q}{\pi} -1 \quad e^{-(c+K)Z} \quad . \tag{11}$$

From Eq.(11) we see that the water properties which determine the apparent contrast are:

a) R_w, the water reflectance or illuminance ratio
b) Q, the ratio of upwelling illuminance to upwelling luminance
c) c , the volume attenuation coefficient for the water, and
d) K , the diffuse attenuation coefficient for the water.

The water reflectance, R_w, may be determined in accordance to Eq.(4) from the measurements of upwelling and downwelling illuminances. The Q-determination may be made by measuring the upwelling luminance at the nadir and the upwelling illuminance in accordance with Eq.(7). However, since R_w and Q appear as a ratio in Eqs.(10) and (11) there is little merit to making separate determinations and the preferred procedure would be to determine their ratio, R_w/Q, directly by measuring $E_d(Z)$ and $L_u(Z,\pi)$ since,

$$\frac{R_w}{Q} = \frac{L_u(Z,\pi)}{E_d(Z)} \quad . \tag{12}$$

The volume attenuation coefficient, c, may be determined from the beam transmittance, T. Thus

$$c = \frac{1}{r} \ln T \ (m^{-1}) \tag{13}$$

and since r, the measurement path length in the transmissometer, is 1.0 meter, this reduces to simply

$$c = \ln T \ (m^{-1}) \tag{13a}$$

The diffuse attenuation coefficient, K, that is required for the contrast transmittance equation is that associated with the upwelling luminance $L_u(Z)$. Thus if the luminance is measured at depths Z_1 and Z_2, then

$$L_u(Z_2) - L_u(Z_1) \ e^{-K_L(Z_2-Z_1)} \tag{14}$$

and

$$K_L = \frac{1}{Z_2-Z_1} \ln \frac{L_u(Z_2)}{L_u(Z_1)} \ (m^{-1}) \quad . \tag{14a}$$

An alternative expression

$$K = \frac{1}{L(Z)} \ \frac{dL(Z)}{dZ} \ (m^{-1}) \tag{15}$$

is rigorously correct but does not lend itself to the computation of K as readily as Eq(14a). Expressions similar to Eqs(14) and (14a) may be written for the downwelling and upwelling illuminance fields and the three resulting K's will rapidly converge to a common asymptatic value as the depth increases beyond Z = 1/K meters. Now since the amount of flux available to the instrument in the upwelling luminance measurement is 1000 to 3000 times smaller than in the downwelling illuminance measurement, it is possible to determine a satisfactory K for contrast transmittance computations from the $E_d(Z)$ profile to significantly greater depths from the $L_u(Z,\pi)$ profile. It is expected, therefore, that the most of the diffuse attenuation coefficient determinations will be made from the downwelling illuminance profiles and only when there is reason to expect a significant difference in K near the surface would the luminance profiles be used. Such a situation might be indicated, for example, if the transmissometer profile showed the presence of a distinct change in water properties in the first 1/K meters of water.

Measurement Sub-Systems

The subsurface sensor unit performs three basic measurements of the underwater optical environment: downwelling and upwelling illuminance, and beam transmittance. Alternatively, with the addition of a baffled Gershun tube to limit the field of view of the upwelling illuminometer, that sensor can be used to measure the upwelling (nadir) luminance. The underwater sensor unit contains, in addition, transducers to sense ambient water pressure and temperature and the pitch and roll (attitude) of the underwater unit. On deck, a gimbal-mounted illuminometer measures the illuminance incident on the water surface. The power for operating the subsurface unit is provided by a current regulated dc supply in the surface console. Figure 3 presents the elements of the instrument system in a combined schematic and block diagram.

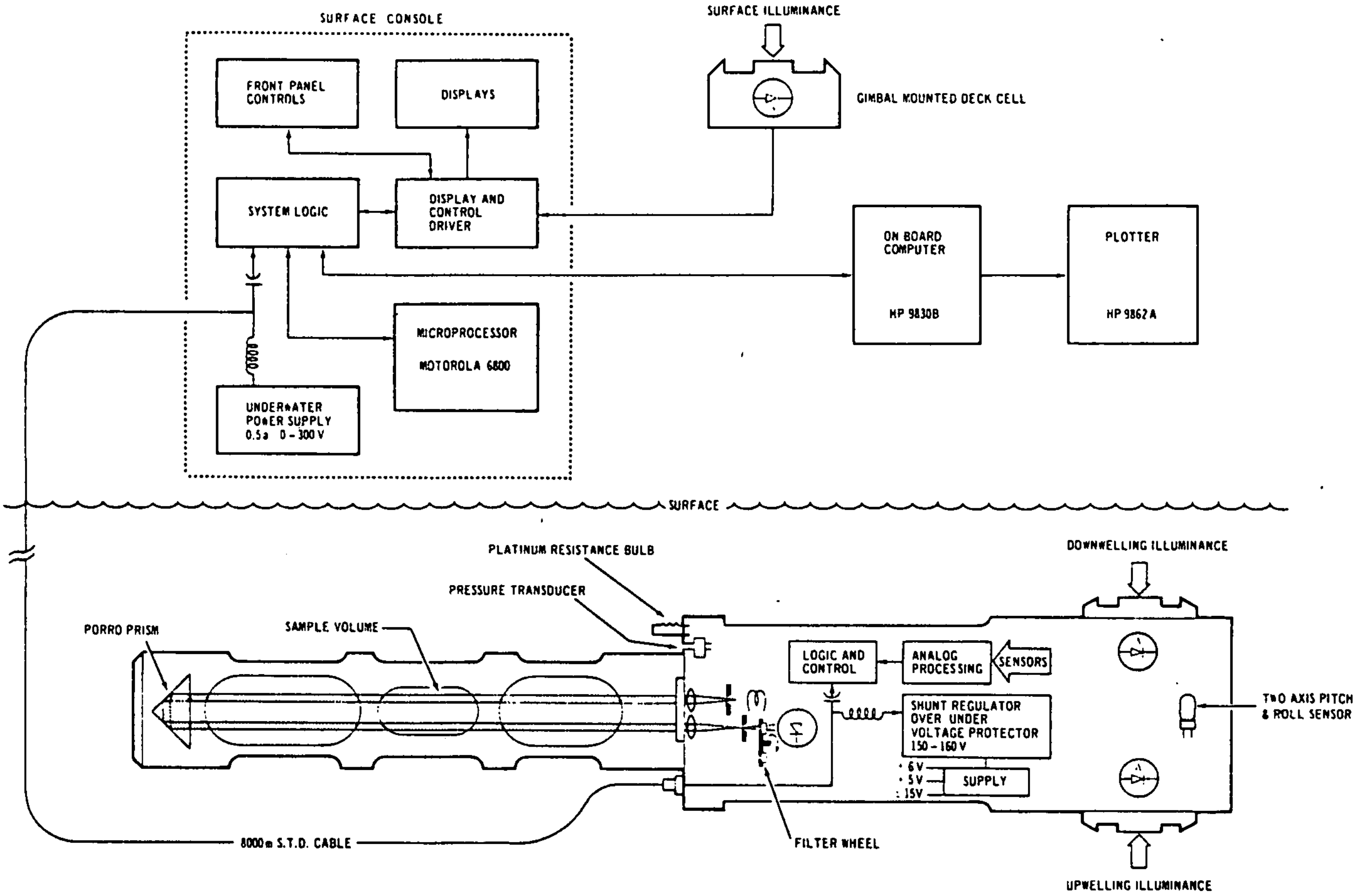

Fig. 3. Schematic and block diagram of the instrument system.

Subsurface Illuminometers

The measurements of downwelling and upwelling illuminance, E_d and E_u, are performed with illuminometer sensor units identical in design to those used previously[3] for visible light penetration and reflectance studies in ocean water. They consist of selenium photovoltaic detectors (Weston Model 856) fitted with a spectral correction filter to give them spectral responses matching the photopic luminous efficiency function. With this sensitivity the sensors can then be calibrated in photopic units such as candelas per square foot (foot-candles), candelas per square meter (lux) etc. The photodector is mounted behind a specially designed underwater collector surface which provides the sensor with an angular response proportional to the cosine of the angle of incidence of the incoming light, as required for the measurement of illuminance or irradiance. This collector design was first described by Austin and Loudermilk[3]. Additional details on a variant of this collector are provided by Smith[9].

The dynamic range of a sensor for illuminance measurements in water determines the useful range of depths over which the instrument can be used. For example in clear ocean water with a diffuse attenuation coefficient for visible light of 0.04 m^{-1}, a dynamic range of 10^4 (e.g., from 10,000 $cd \cdot ft^{-2}$ to 1 $cd \cdot ft^{-2}$) would be required to perform E_d measurements from the surface to a depth of 230 meters. In water with a K of 0.20 m^{-1} the same dynamic range would be required to attain equivalent measurements to 46 meters. The upwelling illuminance, E_u will be 10 to 60 times smaller than the downwelling illuminance since the water reflectance (or illuminance ratio) will vary from about 0.016 for very clear water to 0.10 for turbid water. As a result it is possible to limit the maximum value for E_u to one tenth that used for E_d. Since the instrument must operate at the surface and the maximum downwelling illuminance at the surface (with the sun at the zenith) is 12,000 candelas per square foot, the maximum scale values for both illuminometers are determined. Thus the full scale value for E_d is 12,000 $cd \cdot ft^{-2}$ and for E_u is 1200 $cd \cdot ft^{-2}$. Both illuminometer subsystems have amplifiers with remotely adjustable gains in the subsurface unit that are under microprocessor control to provide decade gain changes, automatically, as the light level requires. This auto-ranging feature assures the optimum performance of the illuminometers over the maximum light range allowed by the basic photodetector.

The measurement of the nadir (upwelling) luminance, $L_u(Z,\pi)$ may be accomplished with the upwelling illuminometer by attaching to it, a Gershun or radiance tube having a circular field of view subtending a solid angle of 0.1 steradians (10.25° half vertex angle, cone). The luminance then can be determined by dividing the displayed illuminance value by the solid angle (i.e., in this case by dividing the upwelling illuminance by 0.1). The full scale nadir luminance value becomes 12,000 $cd \cdot ft^{-2} \cdot sr^{-1}$ since the full scale E_u was selected to be 1200 $cd \cdot ft^{-2}$.

Spectral Transmissometer

The spectral transmissometer is an improved version of the instrument described by Petzold and Austin[1] and incorporates a remotely operated spectral filter changer first used in an instrument built for the Naval Air Development Center[2]. The optical path in water is one meter in length, folded at the middle by means of a porro prism. The beam diameter is 19 millimeters at all positions along the path as a result of the "cylindrically limited" optical design. Thus all rays, both in air and in water, pass through all stops and, as a consequence, the transmissometer may be calibrated by adjusting the instrument gains in air to obtain the appropriate reading to account for the increased window reflectance losses that occur in air over those occurring in water. The five spectral bands cover the range from 450 to 630 nanometers with bandwidths from 28 to 56 nanometers. Channel zeros and gains are individually adjustable.

Underwater Environmental Sensors

The depth sensor is an absolute pressure transducer of the low-level strain-gage type with an overall accuracy of 0.35 percent. An instrumentation amplifier in the subsurface sensor unit provides a voltage analog of the instrument depth to the data acquisition system. Full scale output corresponds to a depth of 500 meters. The resolution imposed by the digitization is 0.25 meters and the accuracy limit of the pressure transducer results in ±1.75 meter depth accuracy. Overall depth measurement accuracy is expected to be within the specified ±2.5 meters.

The ambient water temperature is sensed with a platinum resistance thermometer. The full scale range is from 0 to 40.0° Celcius, and the resolution is 0.1° Celcius. The accuracy should be well within the specified 0.5°C. It is limited by the calibration procedure and the stability of the associated circuitry and not by the platinum resistance sensor. The purpose of the temperature measurement, however, is to detect changes in water temperature rather than the high accuracy, absolute temperature determinations which generally interest the physical oceanographer.

The attitude of the underwater sensor unit is determined by a two-axis electrolytic roll and pitch sensor. This device has a systematic non-linear response. The non-linearity has been measured and a look-up table is stored in the microprocessor memory to perform the necessary corrections to the measured value before it is displayed or recorded. The pitch and roll are measured over the range ±30° with a resolution of 1° and accuracy of ±2°.

Surface Illuminometer

A gimballed illuminometer measures the illuminance incident on the ocean surface. It is intended that this unit be mounted on deck in a location providing an unshadowed view of the full sky. Its purpose is to record the absolute level of E_o, the illuminance input into the top of the water column, and its variations during the period of underwater measurements. With this information, corrections may be made to the E_d and E_u readings to account for the effects of solar zenith angle changes and thin clouds during the measurements. Major changes in surface illuminance, as caused by dense clouds, would indicate the need to use particular caution in analyzing the data or, possibly, discarding it.

The dynamic range requirements for surface illuminance are much less than for the underwater illuminances. It is doubtful, for example, that the illuminometer portion of the instrument system would be used when the surface illuminance falls much below 1000 $\text{cd}\cdot\text{ft}^{-2}$ since such levels occur only when the solar zenith angle exceeds 80° or in the presence of dense clouds. Neither of these conditions is suitable for obtaining data of good quality. Only one range is provided for E_o as a result. This is 0-12,000 $\text{cd}\cdot\text{ft}^{-2}$ with a resolution of 6 $\text{cd}\cdot\text{ft}^{-2}$ and an accuracy of 10% of reading or 20 $\text{cd}\cdot\text{ft}^{-2}$, whichever is greater.

The sensor is the same type of selenium photovoltaic detector with photopic spectral response used in the underwater illuminometers.

Analog-to-Digital Interface

Because switching regulator power supplies were used in the subsurface unit, with their concomittant pervasive electrical noise, particular care was exercised in the design and selection of analog circuits to reduce the system sensitivity to high frequency switching transients. (See Fig. 4.)

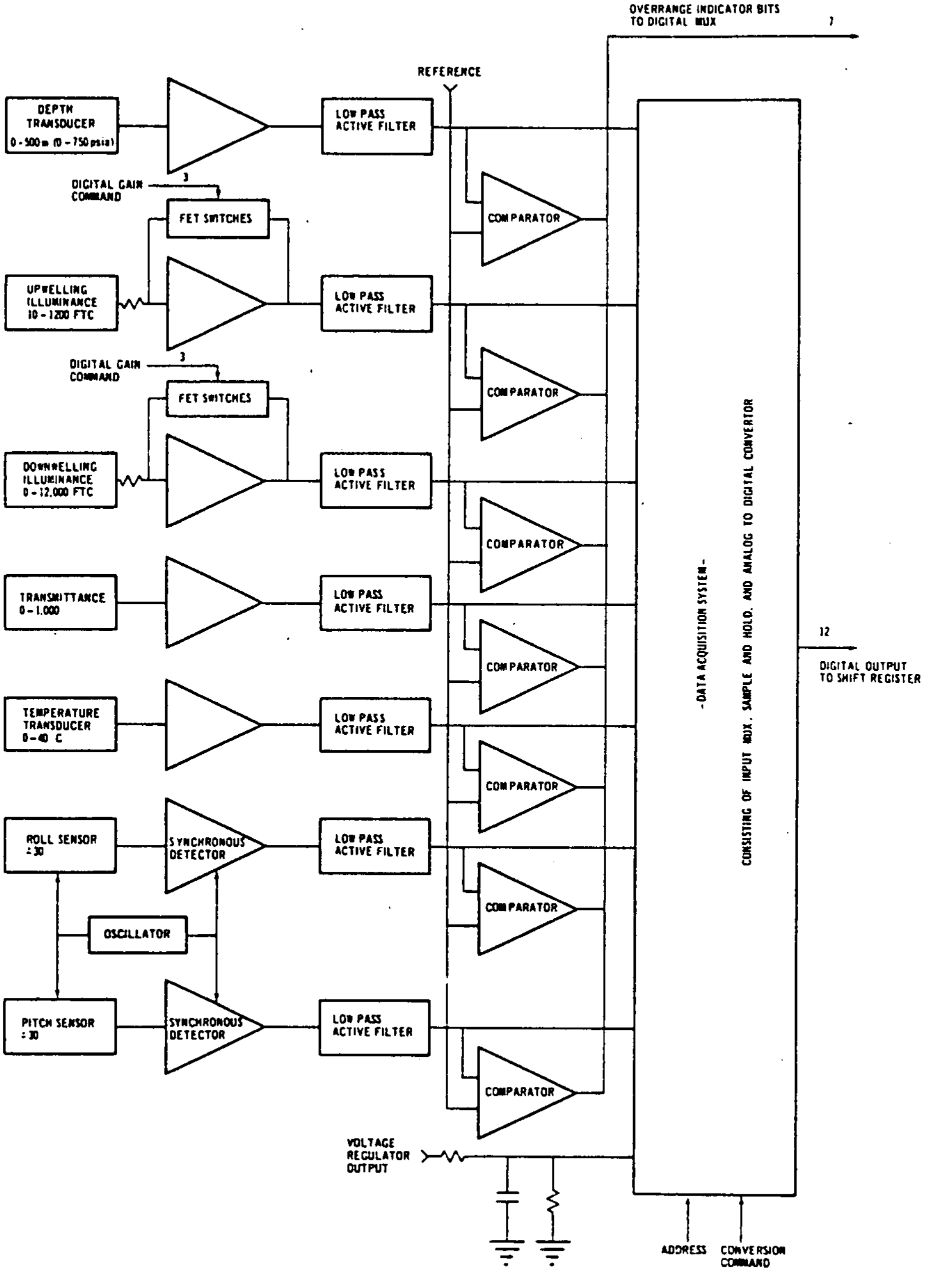

Fig. 4. Instrument Subsurface Analog Signal Block Diagram.

Each underwater analog channel has an active, two-pole low-pass filter to reject frequencies above 3.75 Hz. A modular data acquisition system (Datel Systems, Model MDAS-8D) having a differential input multiplexer was used to provide further isolation from noise induced in the ground circuits. This unit incorporates sample and hold circuits, the eight channel differential multiplexer, and a 12 bit bipolar, analog-to-digital converter, in a single miniature module. The maximum error for the unit is stated to be ±0.025% (±1 bit in the 12 bit binary range) and the common mode rejection is 70 dB at 1 HKz.

The bipolar mode of operation is essential for the roll and pitch sensors since these variables are bipolar. Although the other variables are unipolar, the ability to set zeros on all channels requires a bipolar system to be able to sense whether a zero offset is positive or negative.

Subsurface Power Supply System

The system design was based on the use of a direct current primary underwater power supply. The amount of power which could be made available to the underwater unit was determined by the electrical characteristics of the STD cable and its maximum length. The maximum operating voltage for the cable was taken to be 300 volts and the round trip cable resistance for the 8000 meter length was given as 300 ohms. The maximum power deliverable to the underwater unit was, therefore, 75 watts. Since the cable length is variable from installation to installation and the resistance of the cable will vary with temperature, the desirable mode of operation was to use a current regulated supply on the surface with a 300 volt compliance. The underwater unit had requirements for ±15 volts, 5 volts, and 6 volts at 20 watts (for the transmissometer lamp). In order to have a high conversion efficiency from primary to secondary power, a single switching regulator unit with the three secondaries was obtained. Because of size restrictions the power supply manufacturer was only able to provide the required efficiency and output operating characteristics by restricting the input voltage to 150 to 160 volts. To protect the supply and the underwater circuits from under- and over-voltage excursions beyond the rated range, a shunt regulator and protective relay disconnect were placed in the underwater unit. As a diagnostic aid to the operator, the primary dc voltage is sensed and transmitted to the surface where it is displayed on the surface console.

Digital Data Acquisition and Command Transmission System

Data is sent and received serially over the STD cable at a 2400 baud rate--send cycles alternating with receive cycles. A frequency shift keying (FSK) method of modulation was employed, with the mark/space frequencies being 5.486 KHz and 9.6 KHz, respectively. The baud rate selected was a compromise between achieving an acceptable data package rate and suffering an unacceptably large attenuation in the STD cable. Time division multiplexing of the send-receive cycles was used to avoid crosstalk problems between a receiver and its local transmitter.

Figures 5 and 6 show, respectively, block diagrams of the subsurface and digital transmission systems. The subsurface unit sets up the basic send-receive cycle, turning off its transmitter at the appropriate time to allow for the surface transmission cycle. The surface unit, on the other hand, remains in the receive mode until synchronization is established. The surface unit then proceeds to transmit a channel address and command to the subsurface unit. It then switches to the receive mode while the subsurface unit sends the digitized value of the analog signal for that channel, a confirmation word, and finally a unique frame sync word.

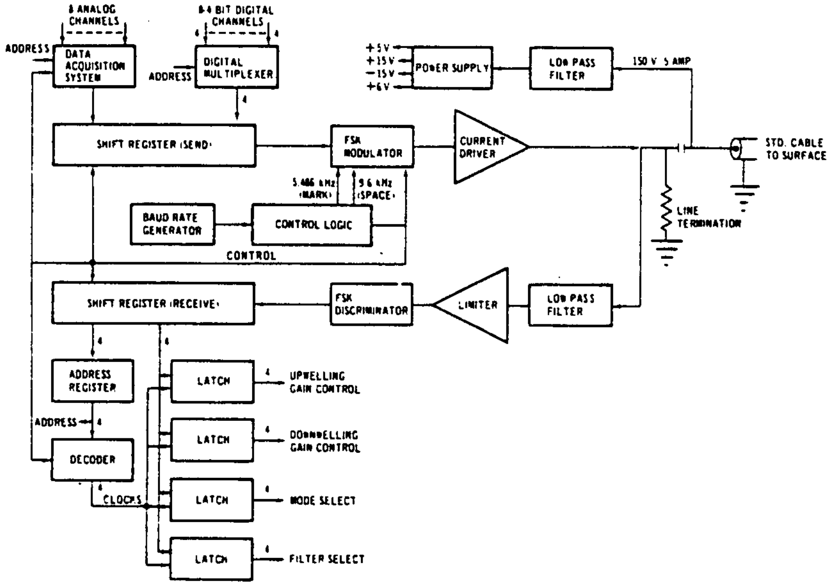

Fig. 5. Block diagram of data transmission and control system. (subsurface unit)

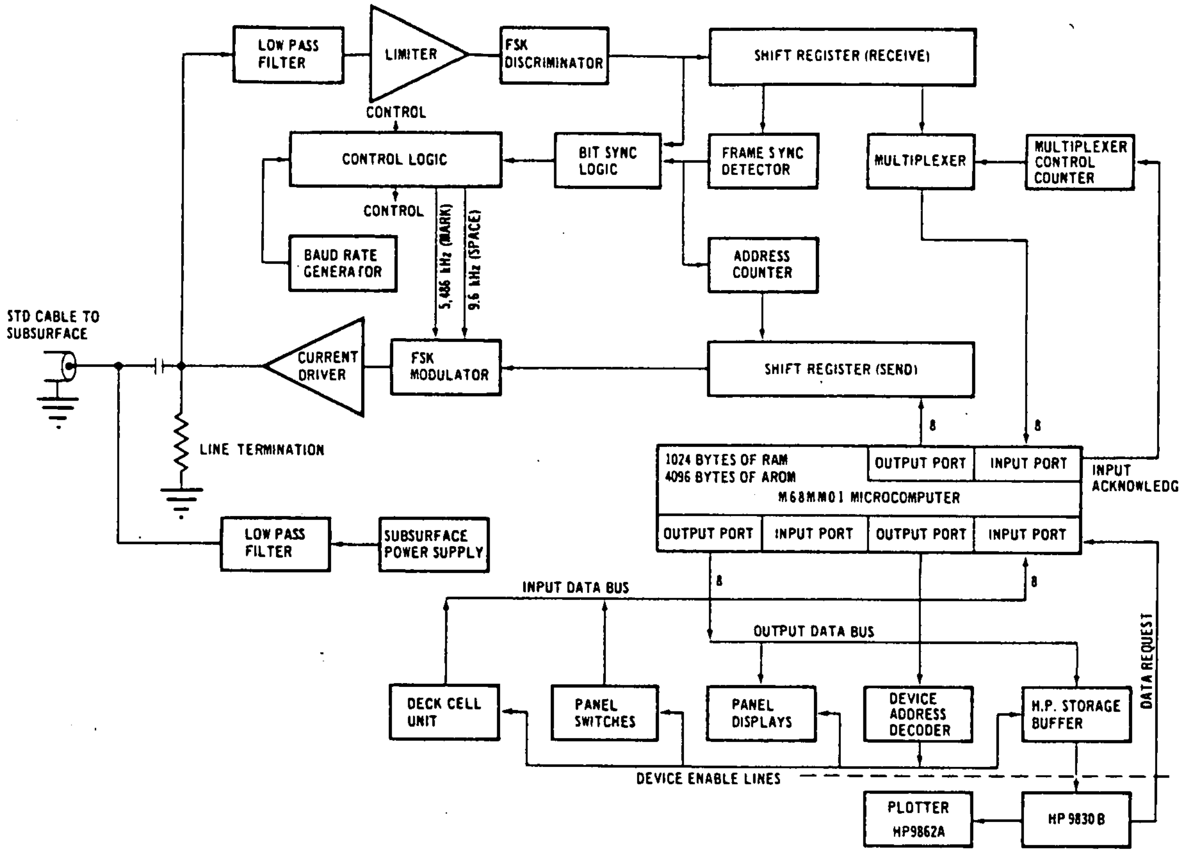

Fig. 6. Block diagram of data transmission and control system (surface unit).

Figure 7 illustrates the basic timing of the system. The basic send-receive cycle is called a frame and is forty clock cycles in duration resulting in a 16.67 millisecond period. A set of eight frames makes up a data package. Hence all displays are updated every 133.3 milliseconds.

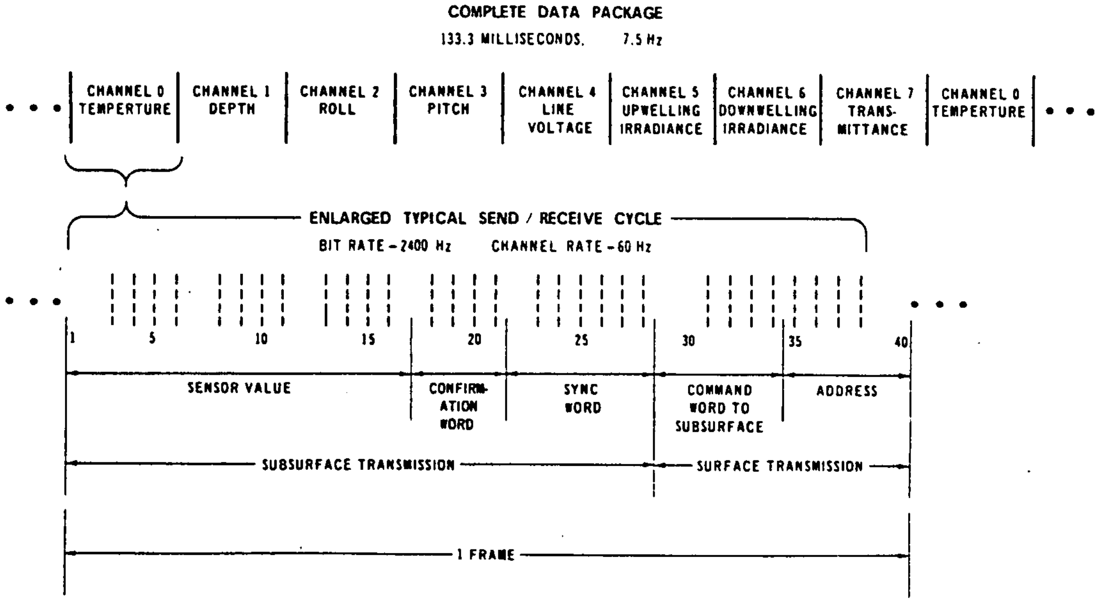

Fig. 7. Digital data acquisition and control system timing diagram.

Subsurface System

Referring to the subsurface block diagram, system operation can best be described by starting at the point in the subsurface transmission cycle when the received data from the surface has just filled the receive shift register. At this time the channel address is latched in the address register and decoded to route the command word to its proper location. The digitized output from the previous channel along with the confirmation word is then transferred into the send shift register for subsequent serial transmission to the surface. The Data Acquisition System (DAS) is then presented with a new channel address and given a convert command by the control unit. The FSK modulator generates a Read Only Memory (ROM)-derived sinusoid having a value of 5.486 KHz for a mark and 9.6 KHz for a space. Since these frequencies are derived from the crystal controlled baud rate generator there is no jitter with respect to the basic clock rate of 2,400 Hz. The resultant FSK signal drives a voltage-to-current converter which is AC coupled to the STD cable. The low pass filter connected between the STD cable and the power supplies presents a high impedance to the FSK frequencies.

The subsurface receiver consists of a low pass filter, limiter, and frequency discriminator - the output of which directly drives the receiver shift register. The frequency discriminator must be tuned precisely to the center frequency of the FSK band. Any appreciable drift in this setting can cause a loss of signal, hence, components with good temperature stability are used in this part of the circuitry.

Surface System

The surface system is analogous to the subsurface with respect to the modulator-demodulator and up through the shift registers. One added task imposed upon the surface unit consists of establishing the bit and frame sync. This is accomplished by a comparator circuit that looks for the sync word. At this time bit sync is established by clearing the counter used to count down the local 2400 Hz from the crystal oscillator. Bit sync is established only once per frame to prevent a false synchronization on transients that can occur during transmitter switching between alternate send and receive cycles. The crystal stability is adequate to insure against appreciable drift in the clock rate during the frame time.

Commands and sensor data enter and leave the transmission system via the 6800 Microprocessor. The transmission systems runs at a predetermined rate, as described, and independent of the microprocessor. At a fixed point in the cycle, under direction of the multiplexer control unit, the processor is directed to multiplex in, through an eight bit input port, the data received from the subsurface unit together with the surface address. The processor has already assembled the command for the next surface transmission cycle, and this is subsequently loaded into the surface send register. During the following frame time the processor, under direction of its program, loads the panel displays, reads the panel switches, performs scaling and formatting operations and transmits data to the 9830B if requested.

Only one input port is devoted to inputting switch data from the panel as well as deck cell data. Hence a multiplexer is employed, driven by a second eight bit output port. In a similar fashion, all output data for the displays and the HP9830B buffer is generated via a third output port. Here again the same address decoder directs the data to the appropriate location. A third input port is available for future expansion of the 9830B capability to permit interaction between it and the 6800.

Command and Verification

In transmissometer operation the operator may select one of five spectral filters and one of three transmission modes. The microprocessor continually reads the panel switches which control these functions and sends their digitized values below. Comparators in the subsurface unit cause the filter and mode wheels to servo to the condition requested. The actual position of these filter and mode wheels is sensed and transmitted topside. Should any discrepancy occur, as would be the case during the executions of a change from one condition to another, all F's appear in the transmittance display and blinking mode lights are displayed by the mode condition indicators. Thus the operator knows the exact state of the subsurface unit.

Each wavelength channel can be independently adjusted for zero and gain. Individual thumbwheel switches are available for each wavelength channel. The processor reads these each data package cycle and applies these factors to the data received from the subsurface unit. With the instrument on the surface, the operator would command the dark condition and then apply the zero correction for each wavelength channel. A transmittance mode would then be selected and the gain switches adjusted to obtain the required air path transmittances.

In a similar fashion the depth channel can have a front panel zero correction applied to it.

Both of the up and down illuminance channels employ variable gain amplifiers in the subsurface unit. Gain can be changed in decade steps from x1 to x1000. The gain setting of these programmable amplifiers is continually being transmitted to the surface. During a calibration cycle the operator selects each channel in turn and zeroes it with the front panel switches. The processor then stores the value selected and applies it to the data whenever that gain setting is employed by the auto-ranging routine.

When not in the calibration mode, the processor engages in an auto-ranging operation and automatically commands the highest gain possible without overload. A number of readings are averaged by the program before the command to switch gain is given by the processor. This is done to insure against an oscillatory condition or the selection of a gain setting based upon noisy signal conditions.

Each analog channel is fed into a voltage comparator as a check for an over-voltage or saturated condition. This information is relayed to the surface by turning on a bit in the status word that is reserved for this purpose. Upon receipt of this condition, the processor in turn displays all F's for that channel as a flag to the operator.

Microprocessor Function

As the design for the system progressed it became evident that a hard wired logic system would have to be exceedingly complex in order to fulfill all of the system requirements. First, all data is transmitted in binary to minimize transmission time yet all of the displays and thumbwheel switch inputs are in Binary Coded Decimal (BCD) for operator convenience. In some cases, the data format differs between the HP9830B and the front panel; the former being in scientific notation whereas some channels are displayed as integer plus decimal.

In addition to formatting, a scale factor is applied to each channel so that data can be displayed in engineering units. If this scaling were performed in the analog domain at the input to the DAS in the subsurface unit there would be a loss in resolution in most cases. As an example, the DAS output range is 0 to ±2047 whereas full scale on the depth channel is 500 meters. If the scaling were done in the analog domain, resolution would only be one meter as contrasted to the one quarter of a meter achieved by utilizing the entire digital range of the DAS and performing the scaling in the processor.

As previously mentioned, the processor controls the calibration of the irradiance channels and their autoranging. Zero and gain factors are also applied to the transmittance channels in the five spectral bands.

An additional function performed by the microprocessor is the management of data transfer between the instrument and the 9830B. The two devices operate asynchronously--the channel rates being 60 Hz and 18 Hz respectively. Of the 9 channels of information sensed by the instrument not all have the same significance or time rate-of-change. The supply voltage in the underwater instrument, for example, is of interest to the operator but there is no requirement for its permanent recording. The roll and pitch are likely to be slowly changing and are used only as an aid to assessing data quality. The surface downwelling illuminance, E_o, should vary slowly under most conditions suitable for data acquisition. Water temperature is usually a slowly varying variable at the normal rates of descent and is of secondary importance to the overall instrument mission. The remaining four channels, E_d, E_u, T and Z are the primary variables of interest and are the ones expected to show the greatest rates of change. The rate at which the instrument can be deployed and retrieved will depend on the vertical variability of E_d, E_u and T in the water column. With these different data recording requirements in mind, it was possible to optimize the recording by the 9830B in the following manner. A basic five channel multiplexing cycle was used with a 3.6 Hz cycle rate. The four primary variables, downwelling illuminance, E_d, upwelling illuminance, E_u, transmittance, T, and depth, Z, were included in each cycle and the four remaining variables were submultiplexed into the fifth channel. A total of four cycles is required in order to update all of the eight data channels to be recorded. Thus the complete data recording rate is 0.9 Hz, while a 3.6 Hz rate is obtained for the primary variables. Figure 8 illustrates this sequence.

HP 9830B DATA CYCLE

CHANNEL RATE – 18 Hz MAX. CYCLE RATE – 3.6 Hz MAX

ADDRESS		FUNCTION	
MAIN CYCLE	1	DEPTH	
	5	UPWELLING IRRADIANCE	
	6	DOWNWELLING IRRADIANCE	
	7	TRANSMITTANCE (Filter 1)	ONE OF THESE (DEPENDENT UPON MODE FILTER SELECTION)
	8	TRANSMITTANCE (Filter 2)	
	9	TRANSMITTANCE (Filter 3)	
	10	TRANSMITTANCE (Filter 4)	
	11	TRANSMITTANCE (Filter 5)	
	12	ZERO	
	13	REFERENCE	
SUB CYCLE	2	ROLL	ONE OF THESE (IN TURN)
	3	PITCH	
	6	TEMPERATURE	
	4	SURFACE IRRADIANCE	

Fig. 8. Data multiplex and submultiplex cycle.

Data Acquisition and Recording

Data storage and presentation are handled by the 9830B under program control. Thus great flexibility is available for calculating, formatting, plotting and recording the data obtained with the instrument. In addition to recording and plotting the measured variables, E_d, E_u, L_u, T, and t, in real-time, it is also a relatively simple matter to calculate, record, and plot the derived variables such as c, K_u, K_d, R_w,/Q, and τ_z.

A preliminary program for the 9830B, prepared by the U.S. Naval Oceanographic Office for use with this instrument, functions in the following manner. The operator first enters recordkeeping information pertinent to the data station. He then can request either a single data scan of all eight channels or a vertical profile of transmittance versus depth. If a record of the transmittance in the five spectral bands at a fixed depth is required, for example, five single data scans would be requested with the operator changing wavelength between each scan. An example of two such scans is shown in Fig. 9. If the operator requests a vertical profile, the computer prepares a running tabulation of all of the values of the measured variables until the underwater sensor reaches a prestated maximum depth. Simultaneously, the HP9862A plotter prepares a plot of transmittance versus depth. At the termination of the cast, the data may be permanently stored on the cassette tape in the 9830B for archiving purposes.

```
DATE: 7     24    78

FILTER: 1
        N     DEPTH     ILL-UP    ILL-DOWN TRANSM
              METERS    FT CAN     FT CAN
        1     300.7      156      1987     0.920      2444  DECK CELL FT. CANDLES

        2     300.6      156      1982     0.920         3  ROLL DEG

        3     300.7      156      1987     0.920         0  PITCH DEG

        4     300.7      156      2003     0.920      2762  TEMP DEGX100

FILTER: 2
        N     DEPTH     ILL-UP    ILL-DOWN TRANSM
              METERS    FT CAN     FT CAN
        1     300.6      156      1963     0.802      2460  DECK CELL FT. CANDLES

        2     300.7      156      1967     0.803         3  ROLL DEG

        3     300.7      156      1967     0.802         0  PITCH DEG

        4     300.7      156      1963     0.802      2762  TEMP DEGX100

FILTER: 3
        N     DEPTH     ILL-UP    ILL-DOWN TRANSM
              METERS    FT CAN     FT CAN
        1     300.7      156      1963     0.786      2460  DECK CELL FT. CANDLES

        2     300.7      156      1967     0.786         3  ROLL DEG

        3     300.7      156      1963     0.786         0  PITCH DEG

        4     300.7      156      1963     0.786      2742  TEMP DEGX100

FILTER: 4
        N     DEPTH     ILL-UP    ILL-DOWN TRANSM
              METERS    FT CAN     FT CAN
        1     300.6      162      2106     0.641      2448  DECK CELL FT. CANDLES

        2     300.6      162      2084     0.641         3  ROLL DEG

        3     300.6      162      2082     0.642         0  PITCH DEG

        4     300.6      162      2060     0.642      2742  TEMP DEGX100

FILTER: 5
        N     DEPTH     ILL-UP    ILL-DOWN TRANSM
              METERS    FT CAN     FT CAN
        1     300.6      162      2088     0.557      2448  DECK CELL FT. CANDLES

        2     300.6      162      2082     0.556         3  ROLL DEG

        3     300.6      162      2088     0.556         0  PITCH DEG

        4     300.6      162      2082     0.556      2748  TEMP DEGX100
```

Fig. 9. Single data scans (simulated data).

Figure 10 shows a section of a tabulation prepared in a laboratory simulated vertical profile and Fig. 11 shows the corresponding plot.

```
DATE: 7      24    78

FILTER: 1
         N      DEPTH    ILL-UP   ILL-DOWN TRANSM
                METERS   FT CAN    FT CAN
CAST TO STOP AT 300
START TIME: 1015     Z

 N      DEPTH    ILL-UP   ILL-DOWN TRANSM
        METERS   FT CAN    FT CAN
 1       0.3      144     1880     0.782        4  ROLL DEG
 2       0.3      144     1885     0.782        0  PITCH DEG
 3       0.3      144     1885     0.782     2728  TEMP DEGX100
 4       0.3      144     1908     0.782     2462  DECK CELL FT. CANDLES
 5       0.3      150     1920     0.782        4  ROLL DEG
 6       0.3      150     1927     0.782        0  PITCH DEG
 7       0.3      150     1944     0.782     2726  TEMP DEGX100
 8       5.1      150     1939     0.782     2528  DECK CELL FT. CANDLES
 9       8.8      150     1939     0.782        4  ROLL DEG
10      12.2      150     1946     0.782        0  PITCH DEG
11      16.0      150     1946     0.782     2720  TEMP DEGX100
12      19.8      150     1939     0.782     2520  DECK CELL FT. CANDLES
13      22.6      150     1939     0.782        4  ROLL DEG
14      24.8      150     1939     0.764        0  PITCH DEG
15      26.6      150     1939     0.683     2729  TEMP DEGX100
16      28.6      150     1946     0.584     2502  DECK CELL FT. CANDLES
17      30.6      150     1962     0.562        4  ROLL DEG
18      32.2      150     1963     0.515        0  PITCH DEG
19      34.2      150     1980     0.565     2728  TEMP DEGX100
20      36.2      150     1986     0.575     2522  DECK CELL FT. CANDLES
21      38.2      150     1932     0.600        4  ROLL DEG
22      40.0      150     1967     0.609        0  PITCH DEG
23      42.0      150     2003     0.629     2728  TEMP DEGX100
24      44.0      156     1993     0.648     2586  DECK CELL FT. CANDLES
25      45.8      156     1999     0.660        4  ROLL DEG
26      47.8      156     2006     0.662        0  PITCH DEG
27      49.6      156     2006     0.664     2726  TEMP DEGX100
28      51.6      156     2006     0.652     2688  DECK CELL FT. CANDLES
29      53.6      156     1999     0.666        4  ROLL DEG
30      55.2      156     2002     0.666        0  PITCH DEG
```

Fig. 10. Vertical profile listing (simulated data).

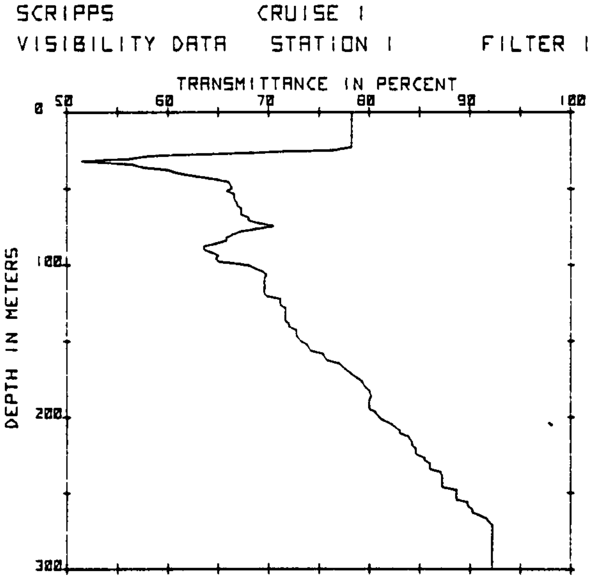

Fig. 11. Vertical transmittance profile (simulated data).

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