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TECHNICAL REPORT No. 135

MICROBAROGRAPHS FOR MEASUREMENTS OF ATMOSPHERIC WAVES

by
C. S. Clay
and
D. W. Kraft

February 16, 1967

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Hudson Laboratories
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Dobbs Ferry, New York 10522

Alan Berman
Director

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ABSTRACT

Microbarographs may be divided into two classes, the very sensitive absolute "dc" instruments and "high-pass" instruments. Most meteorological measurements are made by means of absolute instruments. These instruments are used for very low-frequency atmospheric fluctuations, i.e., cycles/month, cycles/day and a few cycles/hour. High-pass instruments are generally used in the frequency range above a few cycles/hour. It has been necessary to choose the type of response to suit the desired measurements because the noise power spectrum density is much larger at low frequency than at high frequencies. The specifications and range of operation are summarized.

INTRODUCTION

On initially entering the field of atmospheric waves, one knows that people have been measuring the atmospheric pressure and its fluctuations for a very long time and thus assumes that much instrumentation should be available. However this does not appear to be the case, and many experimenters have resorted to making their own microbarographs.

Experimenters tailor their instruments to operate in a particular frequency range. In Fig. 1, the spectrum measurements of Gossard[1] show that the spectrum level increases rapidly at low frequencies. Note that the figure shows the product of the frequency, n, times the spectrum level, S, vs n. Thus it is evident that very different sensitivities of instrument are required to make measurements below 0.01 Hz or above 0.01 Hz. Generally microbarographs may be divided into two classes: "absolute" instruments that have a flat response from zero to cut-off frequency, and "high-pass" instruments that measure the difference between the present pressure and a weighted average of the prior pressures. (The specifications of several different instruments are compared in Tables I and II.)

The barometers used for weather observations are usually absolute instruments and measure the pressure without phase shifts. But to be useful for our purpose, the measurements would probably have to have about five significant figures. "Absolute" microbarographs are manufactured by Askania-Werke and Texas Instruments.

As shown in Fig. 2, "high-pass" microbarographs generally consist of a transducer T that compares the pressure of the atmosphere to that in

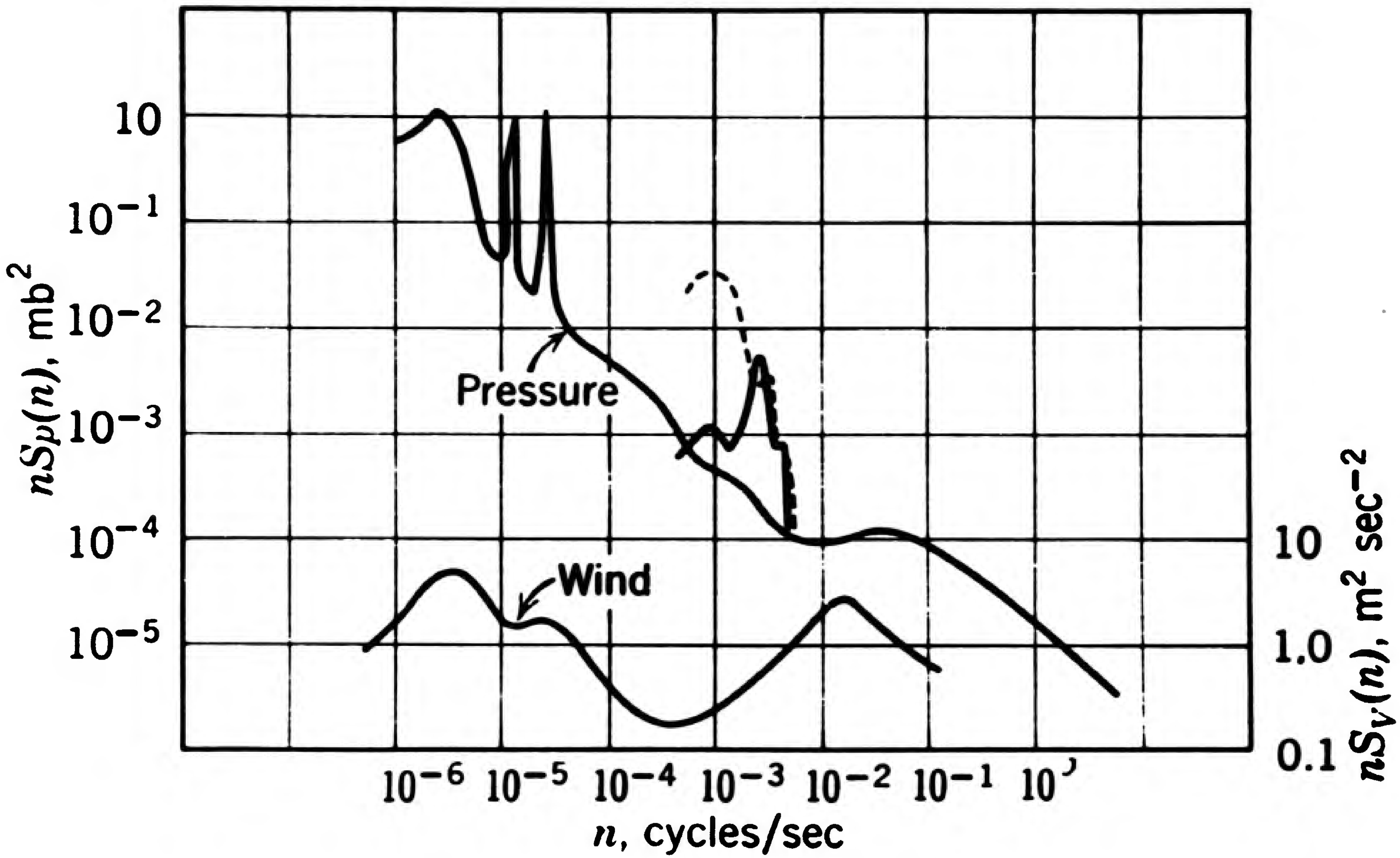

Fig. 1 Power spectrum density times frequency vs frequency for atmospheric fluctuations and for wind (Gossard[1]).

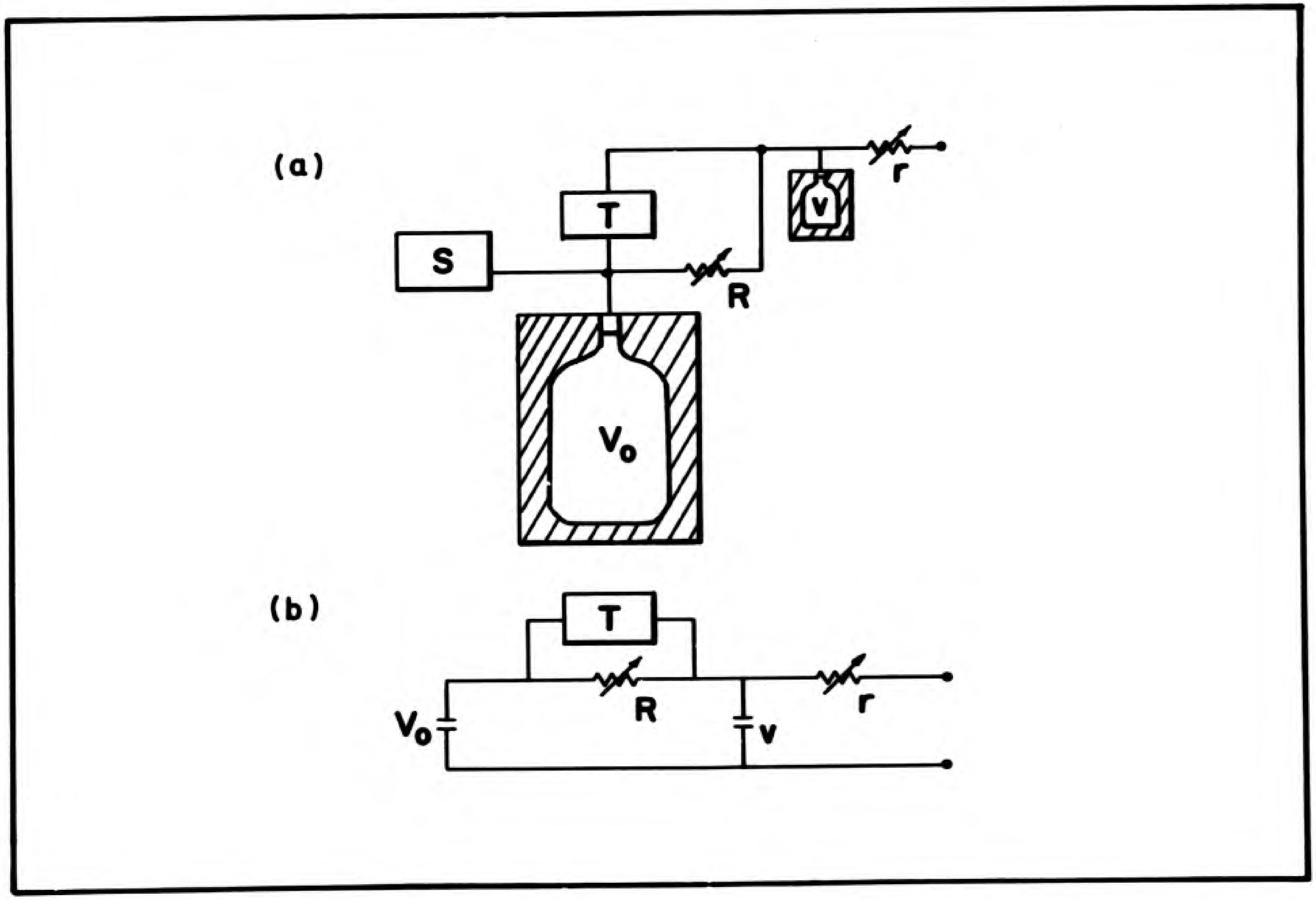

Fig. 2 (a) Design of microbarograph.
(b) Equivalent electrical circuit for the transducer T. The high-pass time constant is governed by R and V_o, while r and v set the low-pass time constant.

a reference volume V . The reference volume is connected to the atmosphere by a slow leak R . Often an acoustic low-pass filter (a leak r in series with a volume v) is included so as to filter out turbulence and other high-frequency noise. The equivalent electrical circuit of a microbarograph (in which the leaks are represented as resistances and the volumes as capacitors) is also shown in Fig. 2. Most of the available transducers have a limited dynamic range so the transducer must be chosen on the basis of the noise spectrum and the high- and low-pass points of the particular microbarograph.

ABSOLUTE MICROBAROGRAPHS

The standard microbarograph used by the U. S. Weather Bureau is made by Bendix Corporation. The instrument is not useful because of its poor sensitivity. Both the Texas Instruments and the Askania microbarographs use a mirror on a Bourdon tube as the sensing element. Deflections of the mirror depend upon the atmospheric pressure and are measured optically. The Askania instrument yields an analog voltage that is proportional to the deflection. The Earth Science Observatory of the Geology Department, University of Oklahoma, has been using an Askania microbarograph for several years.

The Texas Instruments microbarograph uses a quartz Bourdon tube and the deflections of the mirror are followed by means of an optically controlled, servo balancing loop. Our relatively early model was not initially equipped to give a recordable digital output. The analog output could be obtained by opening the servo loop and recording the error voltage. However, the normal daily pressure variations greatly exceeded the error-sensing system's range, and the error voltage was not useful for our purpose. The factory replaced the decade indicator with an indicator that also had decade switches (Veeder Root). The decade switch positions are converted to BCD (binary coded decimal) by means of diode logic networks. We encountered one difficulty in the procedure, namely, when the switch wiper was between contacts it was read as zero. Memory or hold circuits were built to store the previous reading until the wiper made contact with the new switch position. The result is not completely satisfactory, but it works. The BCD readings are recorded on punch tape. The two most sensitive decades are converted to analog voltages and recorded on a strip chart recorder.

The instrument indicates the atmospheric pressure to one part in 10^4 or to 100 μb. A sample of analog data is shown in Fig. 3. The range of daily variation is about 10 mb and the least count is 0.1 mb. An improved means of indicating the position of the mirror could increase the sensitivity to about 10 μb.

"HIGH-PASS" MICROBAROGRAPH

The Columbia University-Pace microbarographs are patterned after instruments built by the National Bureau of Standards. Our initial design was built around the Pace Model P1 transducer. A large reference volume (18,000 cc) was used with fixed capillary lengths serving as leaks. The current design employs the more sensitive Pace Model P90D, a smaller reference volume (900 cc), and a continuously adjustable leak.* The smaller reference volume has enabled the whole instrument to be packaged as a small suitcase, as shown in Fig. 4.

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* The adjustable-leak feature is modeled after an instrument built by Wallace and Tiernan for Lamont Geological Observatory. Manufacture of this instrument has been discontinued. Professor W. Donn of Lamont kindly lent us one of his instruments.

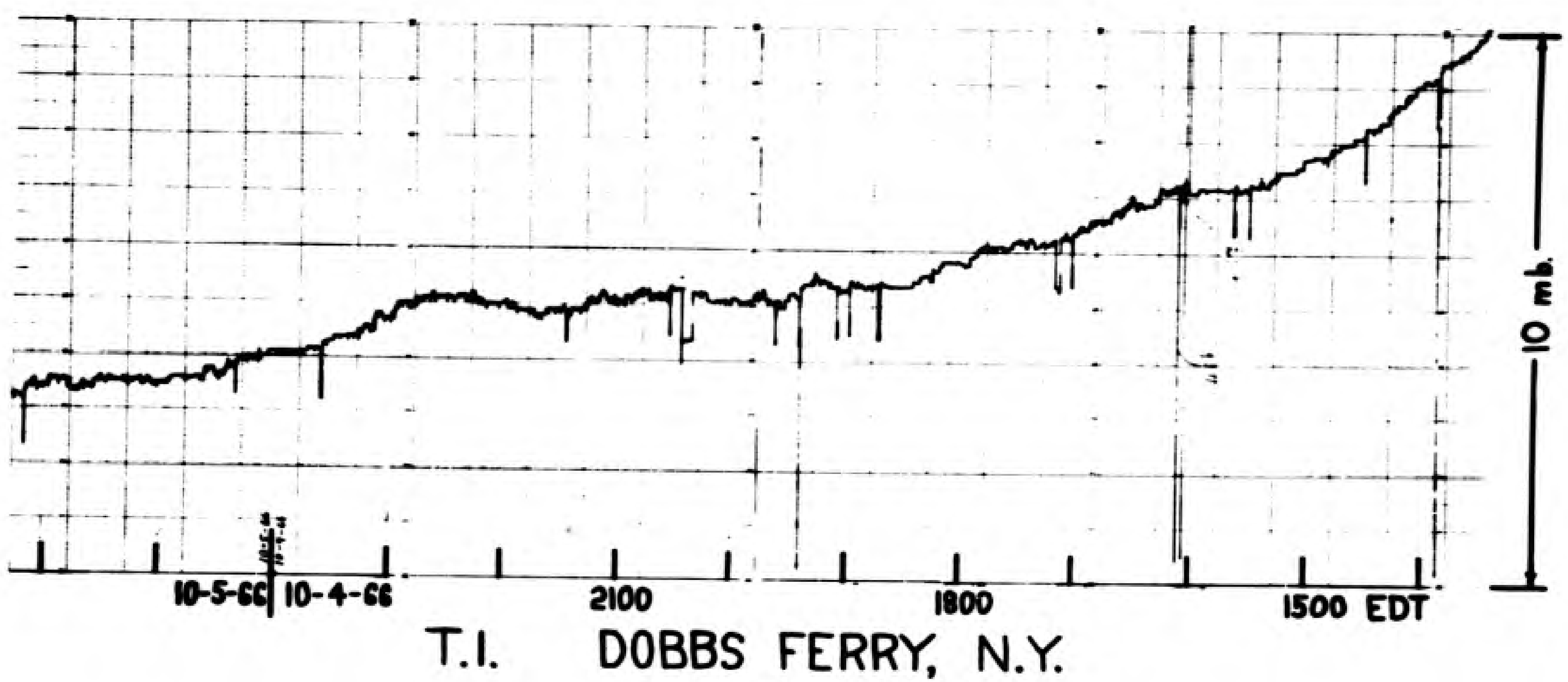

Fig. 3 Sample of record from Texas Instruments microbarographs.

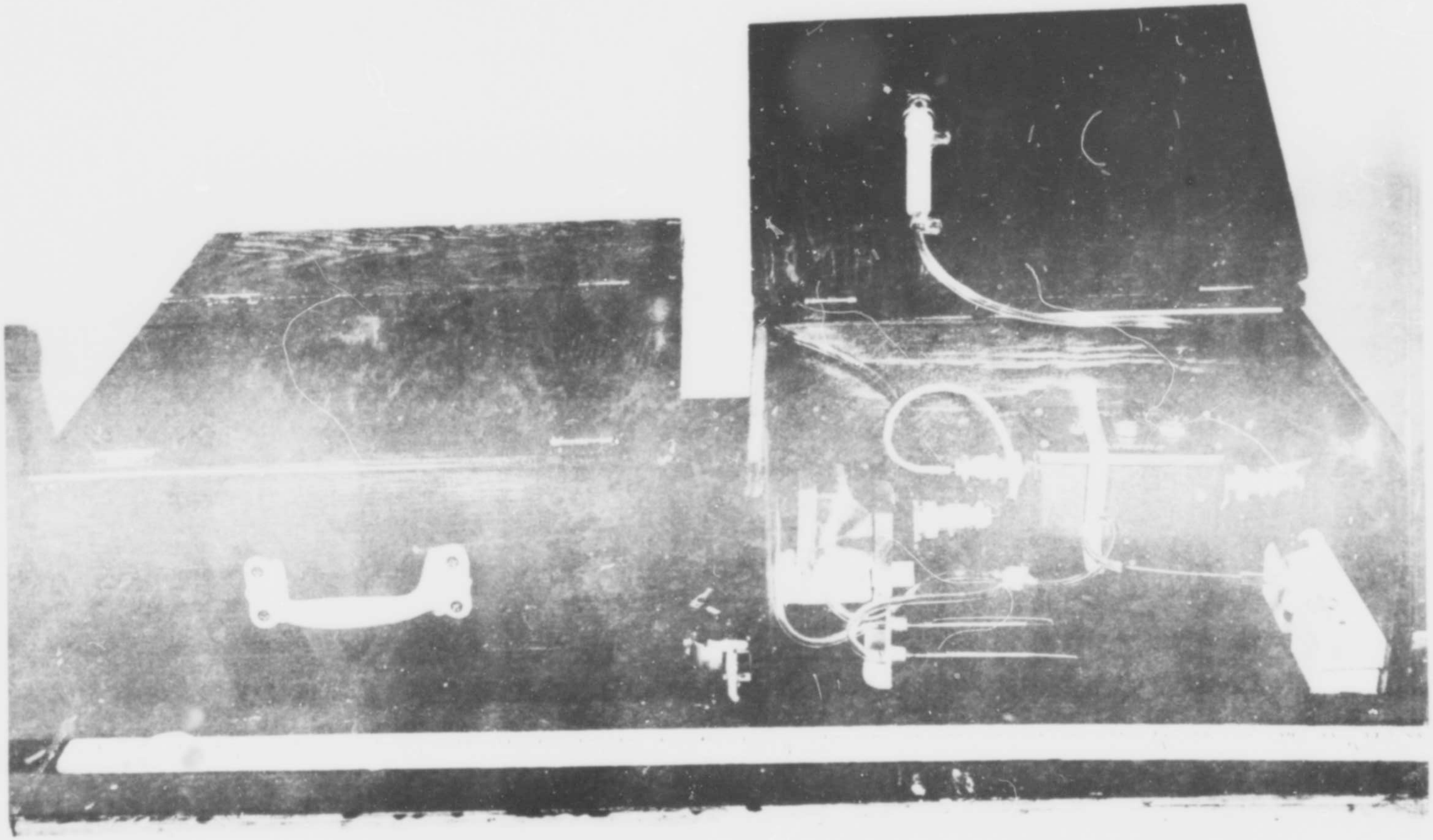

Fig. 4 Photograph of most recent Columbia-Pace microbarographs. The time constants are adjustable and have been set for 600 sec (high pass above ~ 1 cycle/hour) and 6 sec (low pass below 1 cycle/sec). The transducer and amplifier are standard Pace Engineering Co. equipment.

Low-mode gravity and internal waves are of low frequency. In order to observe these waves, the leak-reference volume time constants were chosen for the instrument to have a flat response above 1 cycle/hour. Figure 5 shows some typical data: the daily pressure fluctuations are generally less than ± 500 μb (uncorrected for instrument response).

The instrument is calibrated by measuring its response to a step function in pressure. Following the technique demonstrated by J. Young, of the National Bureau of Standards, a small, measured quantity of air is injected into the reference volume. The step and its decay yield both the amplitude calibration constant and the time constant.

The two Pace transducers mentioned above have ± 7-mb and ± 2.5-mb ranges, respectively. The manufacturer states the linearity as being ± 0.5 percent of best straight line, and the hysteresis as ± 0.1 percent of the pressure excursion. The temperature sensitivity of the transducer and its amplifier are given as being about 0.01 percent scale/deg F. Figure 6a shows the response of one instrument to different amplitudes of the pressure step function: the linearity appears to meet the manufacturer's specifications for the Model P90D.

Six instruments are currently in operation; they appear to be reliable, free of obvious drift, and to hold calibration. The data of Fig. 5 for four instruments at a single location indicate a uniformity of phase response among them.

Frequency-modulated signals are being used for analog-to-digital conversion and for the transmission of a single channel of data over telephone lines. The conversion of pressure to frequency appears to be linear over a

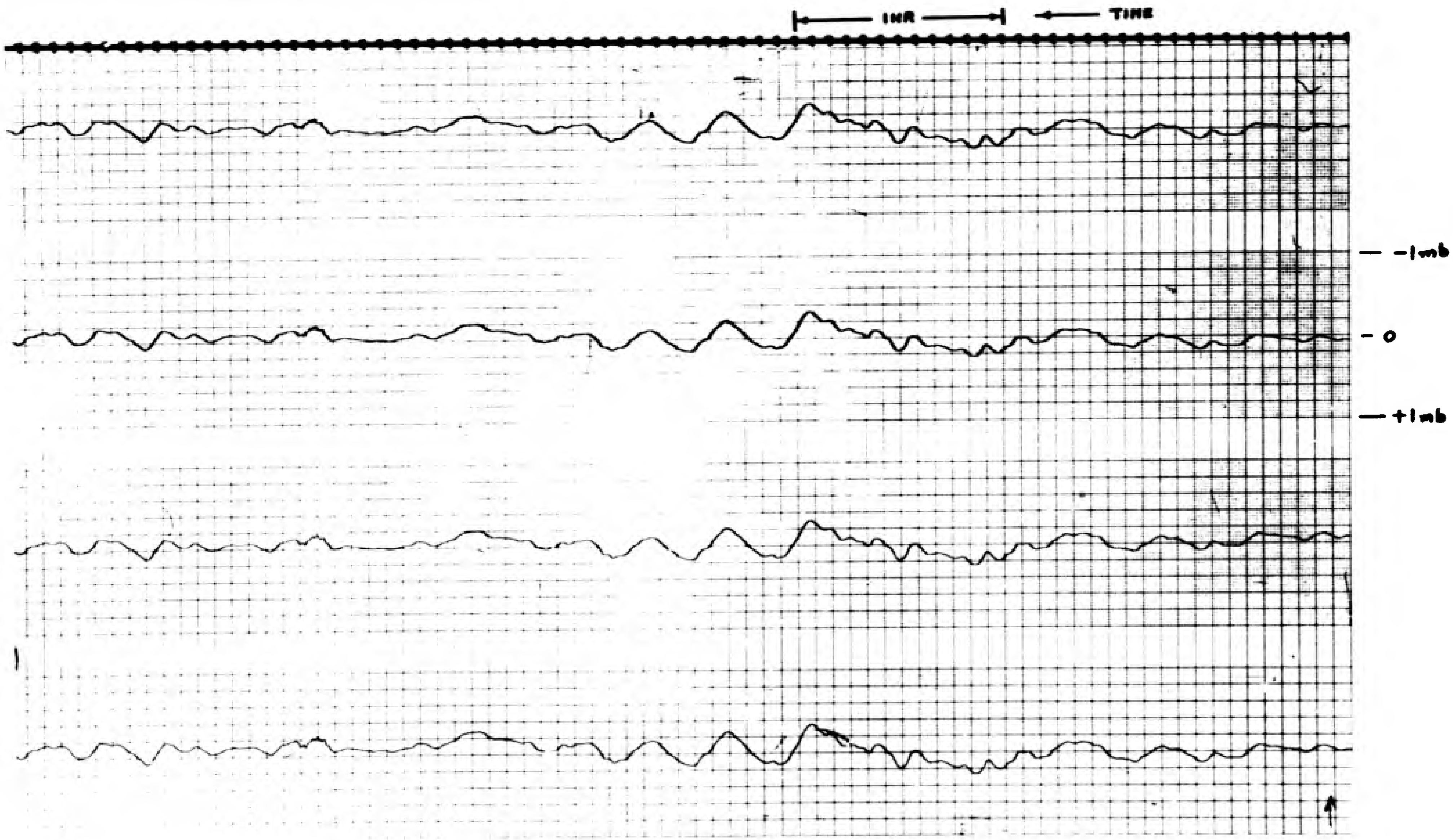

Fig. 5 Sample of record from four Columbia-Pace microbarographs at Dobbs Ferry, N. Y. Each has a high-pass time constant of 600 sec.

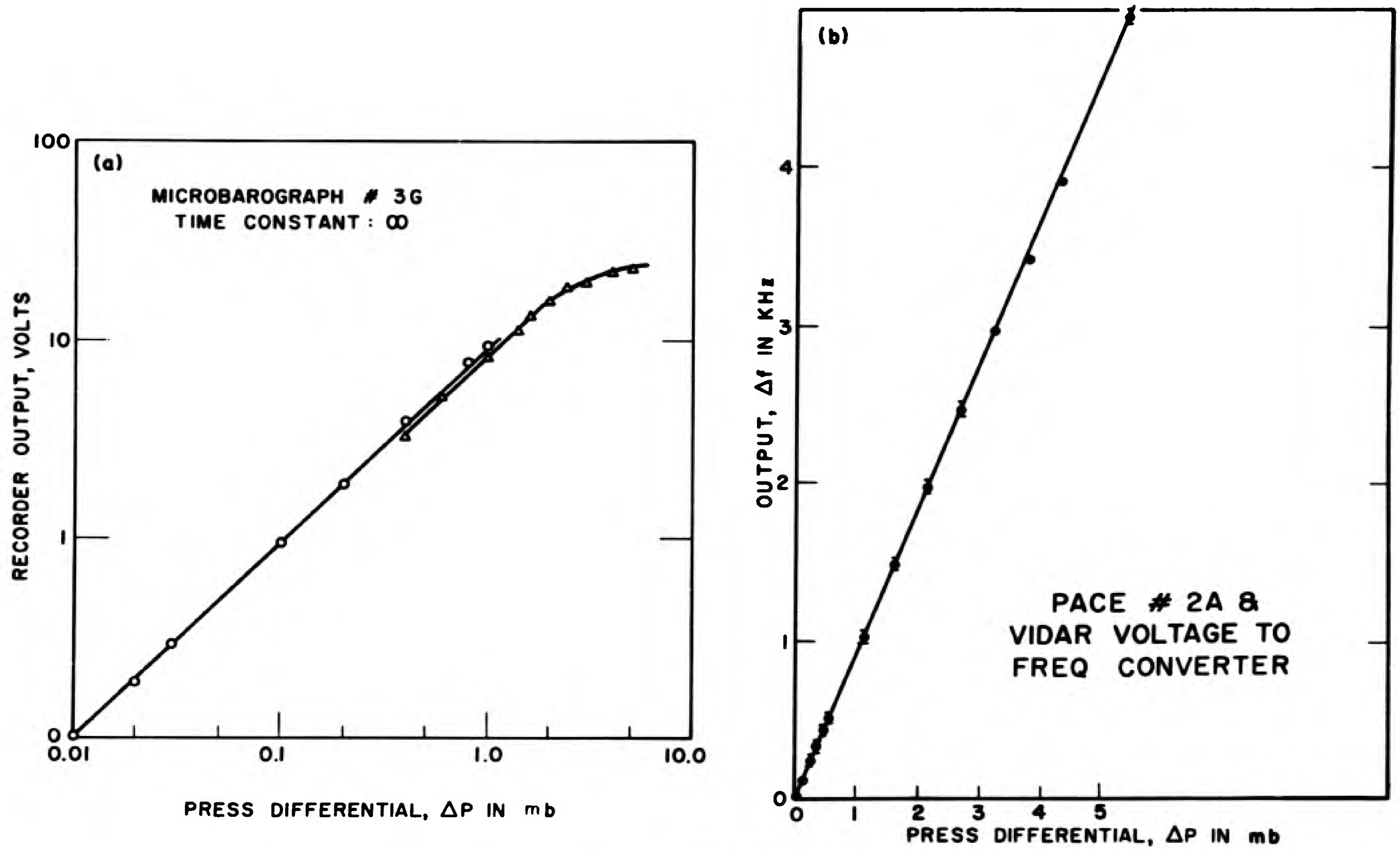

Fig. 6 (a) Linearity of Pace P90D transducer. The two sets of points correspond to different gain settings.
(b) Linearity of Pace Pl transducer together with Vidar voltage-to-frequency converter.

wide range of pressures; the calibration curve of frequency (Vidar voltage-controlled oscillator) vs difference pressure (± 7 mb Pace transducer) is shown in Fig. 6b. The equipment is usually adjusted to give frequency swings of over ± 500 Hz for a ± 500 μb pressure change. The 1000 Hz bandwidth is sufficient to make the telephone transmission noise less than the instrument noise.

The instrument noise levels of the microbarograph and the voltage-to-frequency converter were measured as follows: both sides of the transducer were opened to atmospheric pressure (the slow leak was bypassed by a large tube), and the output frequency from the voltage-controlled oscillator was counted and recorded on punch tape. Since we are interested in low-frequency phenomena, the signal is counted for 29 sec and the counter is read and recorded during the 30th sec. Twenty-four hours of data and a maximum lag of 100 min were used in a Blackman and Tukey spectrum analysis routine.[2] The transducer calibration and system response have been included in the instrument noise-level spectrum shown in Fig. 7.

The power spectra of pressure fluctuations have been measured. Two spectra are shown in Fig. 8 together with spectrum levels reported by Gossard.[1] Comparison of Figs. 7 and 8 shows the instrument noise spectrum levels to be much lower than the atmospheric noise levels.

SUMMARY

A number of different barographs and microbarographs have been built. Each of these instruments is designed to operate in a particular

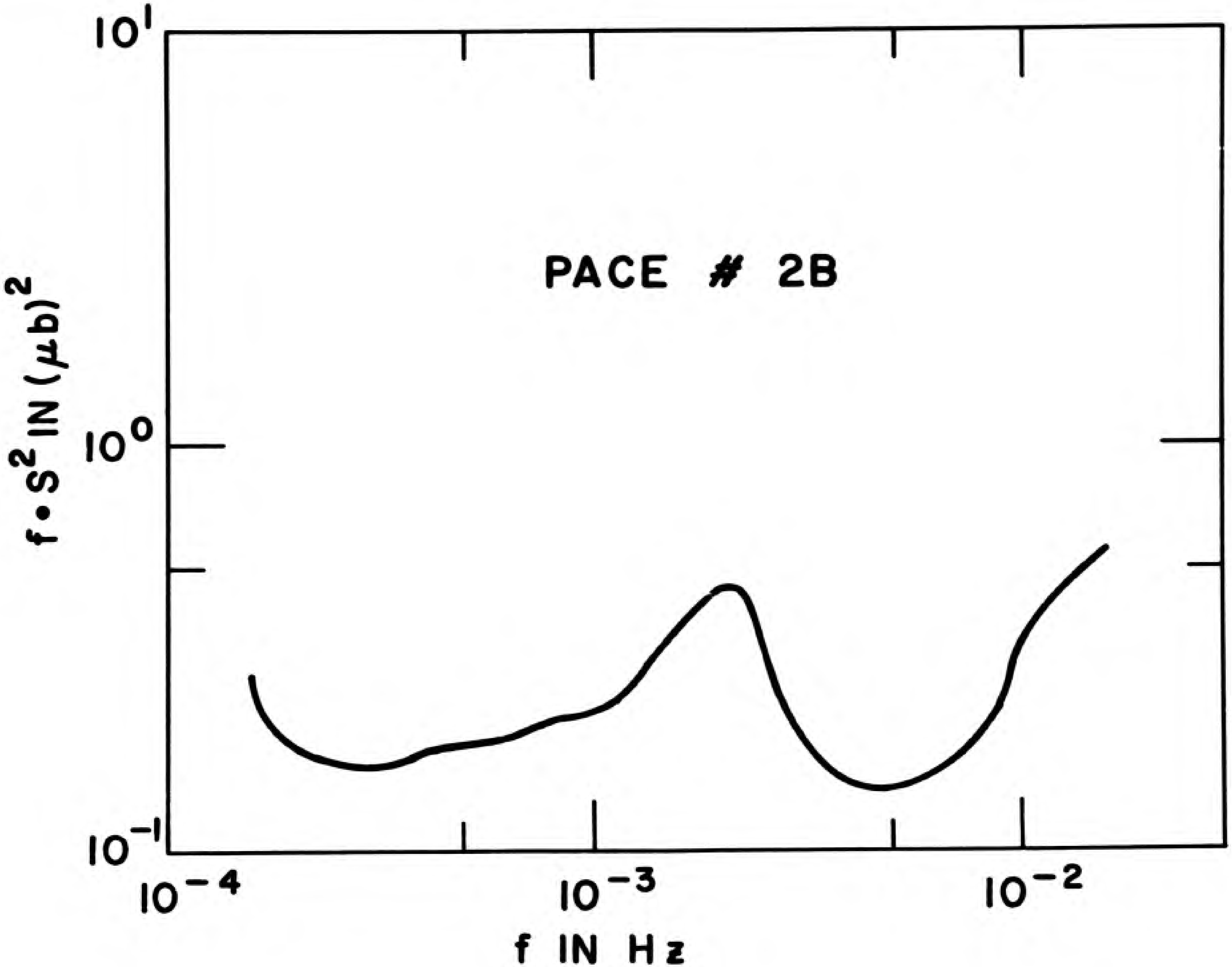

Fig. 7 Power spectrum density times frequency vs frequency for instrument noise level, referred to the input.

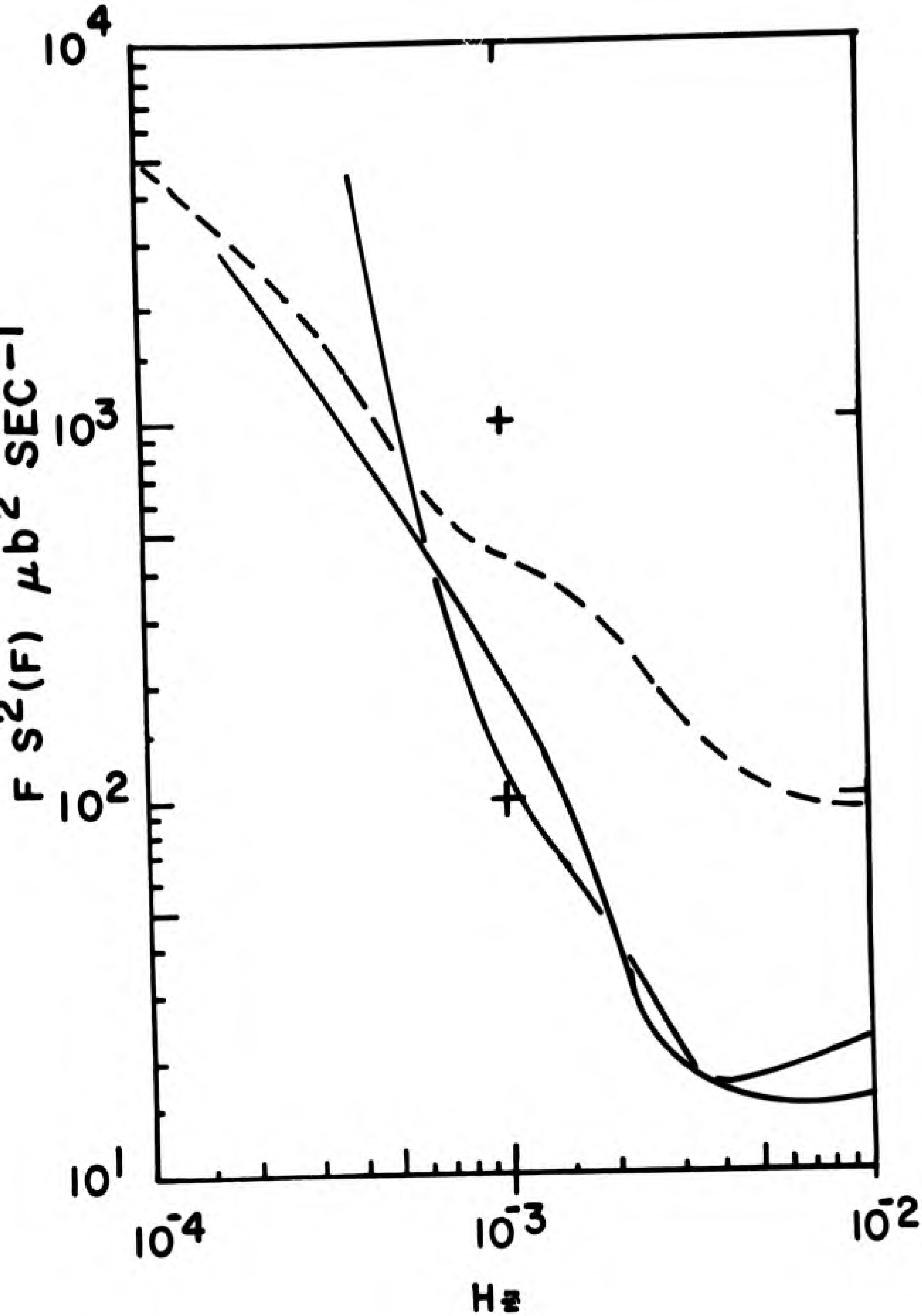

Fig. 8 Power spectrum density times frequency vs frequency for instruments at Dobbs Ferry, N. Y. The dashed line is from Gossard[1] (see Fig. 1).

frequency range. The sensitivities are correspondingly selected. Several types are compared on Tables I and II. (The specifications are basically those of the manufacturers.)

The importance of linear response and hysteresis has not been discussed, but we mention that the transducer's linearity can set the limit of usefulness of spectrum studies based upon the transducer outputs.

It is evident that the ideal instrument does not exist. At the present, one instrument cannot be used over a large range of frequency and signal levels.

ACKNOWLEDGMENT

We are indebted to Drs. R. Cook and J. Young of the National Bureau of Standards for their helpful comments.

REFERENCES

1. Earl E. Gossard, "Spectra of atmospheric scalars," J. Geophys. Res. 65, 3339-3351 (1960).
2. R. B. Blackman and J. W. Tukey, The Measurement of Power Spectra, (Dover Publications, 1959).

Table I. Absolute Instruments

Type	Range	Estimated smallest reading or chart division	Output	Record
Bendix Friez (aneroid bellows)	~45 mb	1 mb	pen deflection	cylinder 1, 4 or 7 days
Askania (beryllium alloy Bourdon tube)	± 7-mb display chosen in 400-mb range	0.04 mb	voltage	strip chart
Texas Instruments (quartz Bourdon tube)	500 mb	0.1 mb	digital	- - - - - - - -

Table II. High-Pass Microbarographs

Type	Frequency range	Maximum pressure	Thermal time constant	Linearity	Output	Estimated instrument noise
Globe (capacitor microphone-amplifier)	0.1 to 400 Hz ~ flat	of order of 500 μb	- - - - -	<5% nonlinear up to 400 μb input	voltage 20 V peak to peak [illegible] V/μb	- - - - - -
Teledyne (variable capacitance-oscillator)	2×10^{-2} to 1 Hz ~ flat	± 100 μb	- - - - -	~ 5% straight line	frequency-modulated signal (7 Hz/μb)	0.03 μb
Columbia-Pace (variable reluctance bridge and amplifier)	3×10^{-4} to 1 Hz ~ flat	± 2500 μb	~9 hours	0.5% best straight line	voltage, max ± 10 V dc (4×10^{-3} V/μb)	~ 3 μb

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