A portable impedance pneumograph

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The difficulties of measuring respiratory movements during speech have been widely recognized. The National Advisory Neurological Diseases and Stroke Council (1969), for instance, has pointed out that in such measurements problems "arise from the fact that speech is a rapidly varying dynamic activity ... easily modified and disrupted by instrumental intervention." At the present time many of the systems available to the researcher or clinician for measurement of respiratory movements have one or more disadvantages: slowness of response, loading of the respiratory system, interference with the speech act, severe restriction of portability, and — in many instances — high cost.

These disadvantages presented serious impediments to a contemplated series of studies of thoracic and abdominal movements during vegetative and phonatory respiration in infants. It was therefore necessary to design and construct new equipment with these specifications:

1. capable of independent and simultaneous measurement of the circumference of several levels of the thorax and abdomen;
2. sensitive to a change in the circumference of the region being measured of 0.1 inches or less, with accurate and reliable recording of such change;
3. non-disruptive of respiratory or vocal behaivor, either by loading the respiratory system or by restricting orofacial activity;
4. capable of simultaneously recording both respiratory information and a vocal signal;
5. sufficiently portable to permit the entire system to be moved from the laboratory to other areas of the speech clinic, hospital nursery,

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child's home, etc.;

6. innocuous to the subject and acceptable to the parents of very young children;

7. easy to construct, calibrate, and operate, permitting use and maintenance by professional personnel untrained in engineering; and

8. of the lowest possible construction and operating cost.

The portable impedance pneumograph (PIP) described meets these criteria and has been field tested at the Teachers College Speech Science Laboratory during several studies on infants (age 3 days to 9 months), and on juvenile gorillas.

Functional description and basis of operation

Impedance pneumography, which is a well-known technique, takes advantage of the fact that as the thorax or abdomen expands and contracts an electrical pathway lengthens and shortens. The pathway involved may be the skin of the subject or some external transducer. Because of calibration and other difficulties inherent in using the subject's skin, and also because such a method is often unacceptable to the parents of an infant, the PIP employs a strain-gauge transducer.

Figure A is a functional block diagram of a two-channel PIP. Each channel measures the circumference of a single level of the torso; both channels are identical in function and basic circuitry. Channel 1 uses a carrier frequency of 1000 Hz while channel 2 uses 440 Hz. Each channel is composed of a sine-wave oscillator which excites a wheatstone bridge, of which the transducer forms one arm. The output of the bridge is an amplitude-modulated signal carrying information concerning the magnitude of the circumference of the level of the torso under observation. After amplification the outputs of the two channels are summed in a mixer and are recorded on one channel of a stereo tape recorder for storage and later analysis. Vocal signals are simultaneously recorded on the other tape channel. Respiratory information is retrieved from the tape by playback through a filter system which separates the composite signal into distinct signals of 1000 Hz and 440 Hz. These are then rectified and demodulated by means of a low-pass filter, thereby extracting the electrical analog of circumference. The output of the demodulator may be applied to a pen recorder, oscilloscope, or

Abstract

A miniature, lightweight device for simultaneous measurement and recording of thoracic and abdominal movement and vocal output is described. The circuit is inexpensive, easily constructed, reliable, and applicable to clinical and research work.

Resumé en français

Un appareil miniature et léger, qui mesure et enregistre simultanément les mouvements thoraciques et abdominaux ainsi que la production vocale, est décrit. Le circuit est peu couteux et se construit facilement; il est sûr et s'applique aussi bien au travail clinique qu'à la recherche.

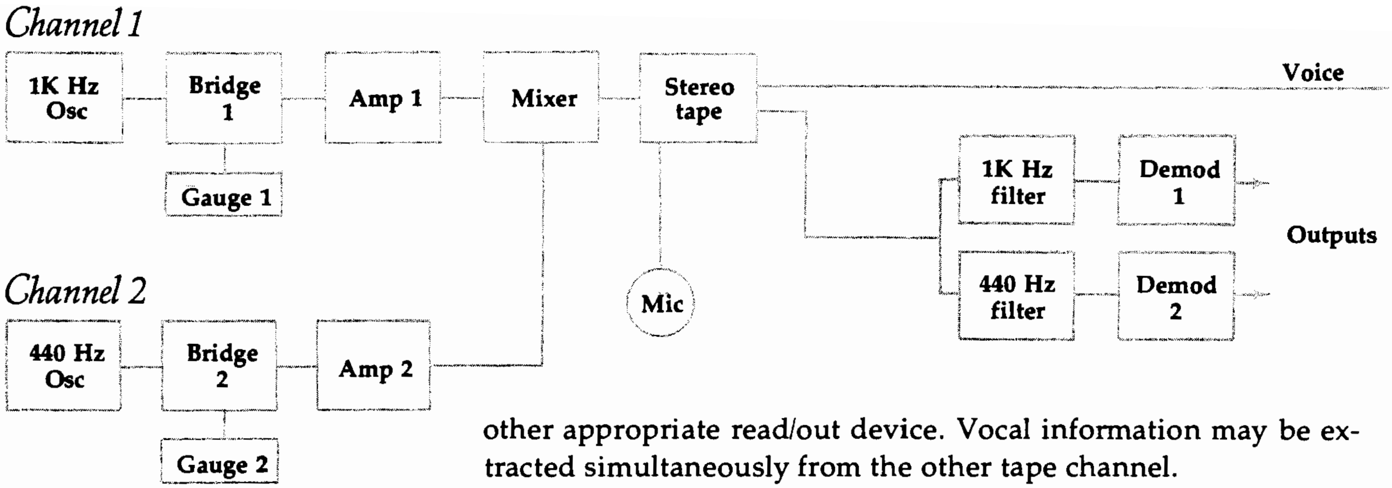


Figure A. *Functional block diagram of a two-channel portable impedance pneumograph.*

other appropriate read/out device. Vocal information may be extracted simultaneously from the other tape channel.

Circuitry and construction

The transducer employed in the PIP is a mercury-filled silastic capillary tube known as a Whitney gauge. The relaxed-state impedance of such a four-inch gauge is on the order of 1.25 ohms but, when the gauge is subjected to stretch, increased length and decreased cross-sectional area of the mercury column result in a relatively large increase in impedance. The gauge is inexpensive, long-lasting, rapidly responding, and, for all practical purposes, electrically non-reactive.*

The schematic diagram for a two-channel PIP is shown in Figure B. The oscillator used to excite the bridge is of the phase shift type. Frequency of oscillation (f_O) is determined by component values of the RC filter network in the feedback line and, if all filter sections are identical,

$$f_O = \frac{1}{2\pi\sqrt{6}\,RC}$$

A variable resistance ("frequency") permits precise adjustment of the frequency of oscillation, while the feedback potentiometer ("waveform") is used to adjust the amplitude and to reduce feedback in case of distortion. Phase shift oscillators are somewhat touchy in their behavior; when wiring, keep all leads short. The feedback potentiometer should be carefully adjusted while observing the waveform on an oscilloscope; a distorted wave indicates too much feedback. Failure to

*Whitney gauges of almost any length may be ordered from: Parks Electronics Laboratory, 12770 South West First, Beaverton, Oregon 97005, USA.

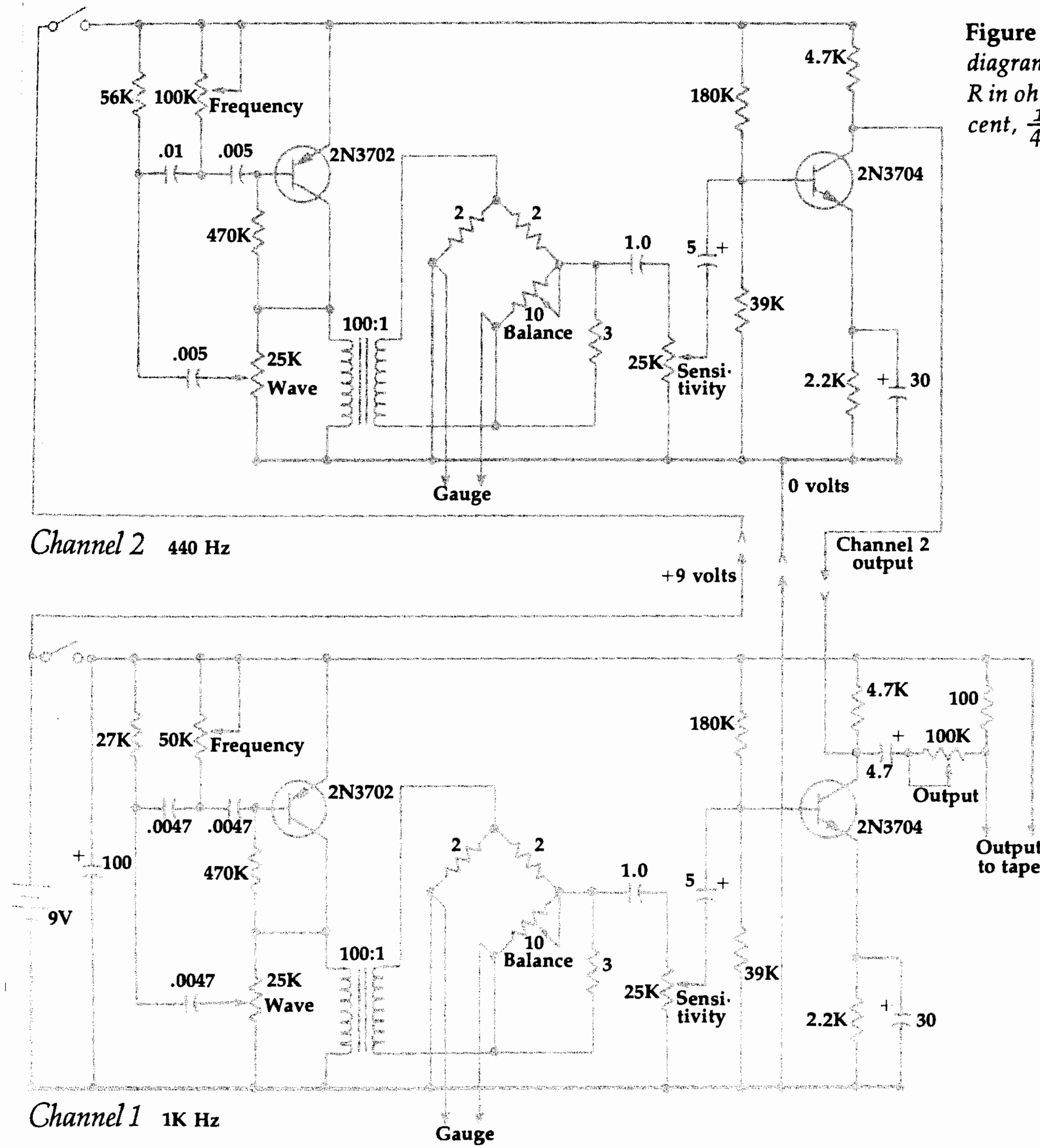
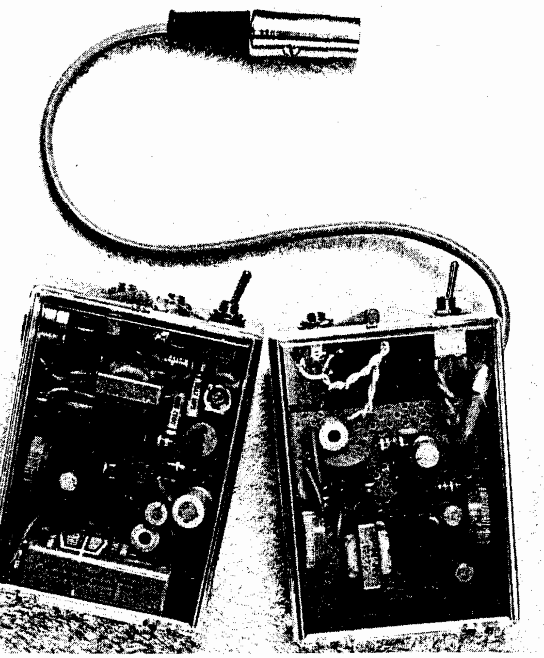


Figure B. *Schematic diagram. All C in μf, R in ohms ±10 per cent, $\frac{1}{4}$W.*

oscillate may be due to insufficient feedback or to inappropriate setting of the "frequency" resistance. Note that adjustment of frequency may require readjustment of feedback, and vice versa.

A step-down transformer couples the oscillator to the bridge, which is balanced with a 10 ohm variable resistor ("balance") in the arm opposite the transducer. A parallel 3 ohm resistor aids in achieving balance; it should be changed (and may be eliminated) if a transducer of relatively high impedance is to be used. The output of the bridge (which is the millivolt range) is AC coupled to the single-stage amplifier; a potentiometer ("sensitivity") at the amplifier input serves as a voltage divider and controls the final output level. The output is taken across a resistance in the collector circuit; this serves to minimize output variations due to any change in battery voltage. The output of the second channel's amplifier is added to the first as shown. If the output of more than one other channel is to be added it may be necessary to decrease the value of the collector resistor. Because the output level may be too high for some applications, a voltage divider ("output") is used in the output line.

Figure C. *Current version of the portable impedance pneumograph. Each channel is housed in its own case.*



The schematic shown calls for a 9 volt battery (Eveready #216 or equivalent) but the circuit will function well at lower voltages should this be desirable. Also, transistors other than the 2N3702 and 2N3704 may be used if biasing is appropriately adjusted. In theory any general purpose audio frequency transistor will serve if it is a high-gain type.

In the current version of the PIP (as shown in Figure C) each channel is housed in its own plastic case. In order to conserve weight, however, channel 2 is "slaved" to channel 1. That is, when wired as shown, it is possible to operate either channel alone, but channel 2 must be connected to channel 1 in order to draw operating current. Also, the only output connector provided is on the case housing channel 1. Each of the cases shown in Figure C measures 3.75 by 2.75 by 1.125 inches, and the combined weight of the two channels, including a battery, is approximately 8.5 ounces. The circuit draws less than 5 milliamps and will function on a transistor radio battery well in excess of 30 hours.

The separator/demodulator circuit used in extracting data is shown in Figure D. The demodulator outputs may be DC coupled to an oscilloscope for observation, amplified and applied to pen motors for

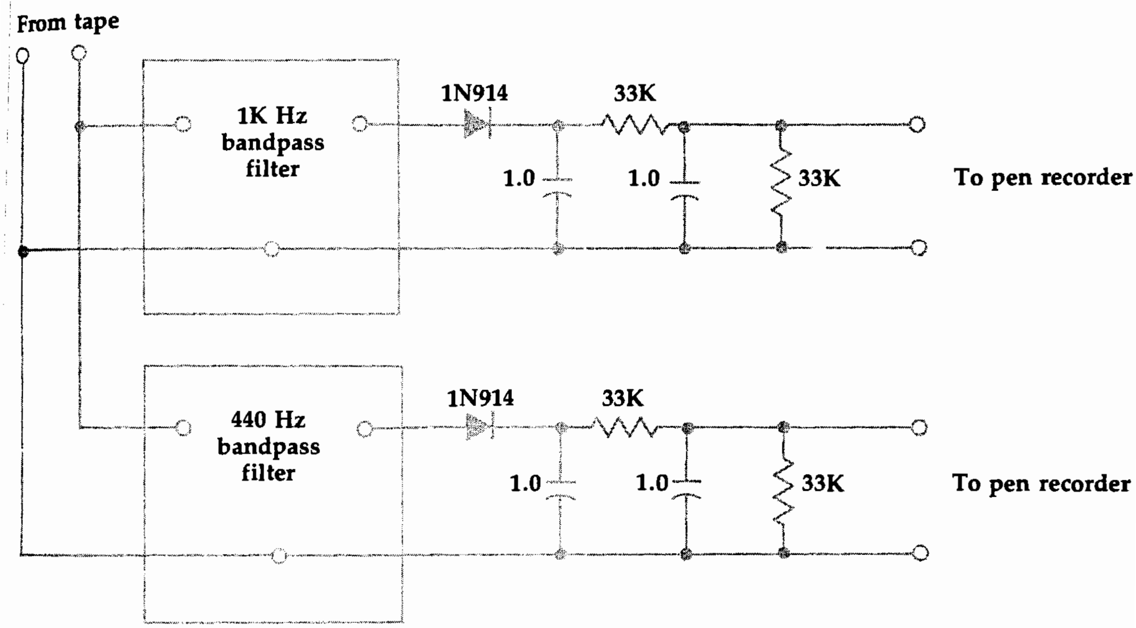


Figure D. *Separator-demodulator circuit. C in μf, R in ohms ±10 per cent.*

Figure E. *Five month old infant with transducers in place around the thorax and abdomen. Note location of the microphone.*

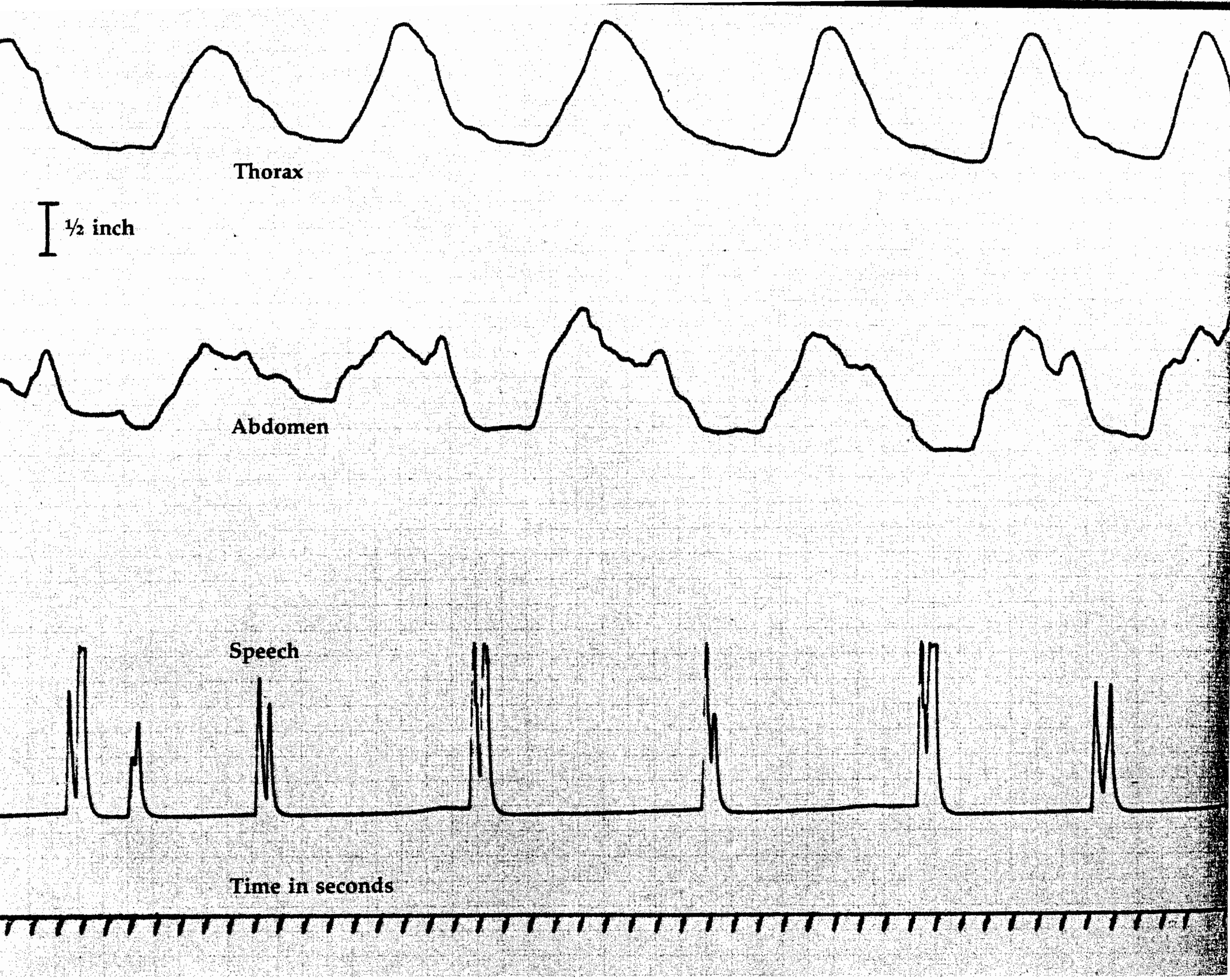


Figure F. *Pneumogram obtained with the portable impedance pneumograph. The top line represents the thorax; the second line, the abdomen. Calibration mark indicates one half inch circumference change; expansion is indicated by upward pen deflection. Third line shows speech (SPL), and the bottom line shows time, in one second intervals.*

write-out, or handled in other ways to extract derived data. Circuitry for this portion of the total array may have to be modified to suit the particular readout devices used.

Calibration and operation

It is important that the frequency of oscillation be carefully controlled, and therefore it is wise to check it periodically against a known standard. Each channel should have its own transducer for which its bridge is balanced. Calibration graphs showing each channel's output as a function of transducer length are easily generated; these will demonstrate the region of linear response within which each transducer should be used. These data should be rechecked periodically over the life of the gauge since its characteristics will change slightly with aging. At the start of each recording made with the system the transducers to be used are held together and stretched to known lengths and the resultant output of the system recorded. This provides a scale by which the readout system may be adjusted and calibrated for each set of data.

Transducers may be held on the subject by the use of Velcro strips. A band of the material should partially encircle the torso at the level to be measured; the transducer completes the circle and is attached by patches of complementary Velcro material. The transducer should always be slightly stretched, and enough tension will be generated to keep the assembly in place in most instances. If slippage occurs (as it occasionally will, especially in infants) the Velcro band may be lightly taped to the skin. Do not place tape on the transducer.

The cases containing the circuitry may be held on the subject by means of a small harness, may be placed in pockets attached to a loose-fitting shirt, or may be simply placed in the crib with an infant. With young infants it is best to have the child in a commercially-available infant seat, with a microphone on a goose-neck above the head, as in Figure E. If maximum freedom of subject movement is desired, a miniature FM transmitter may be used to broadcast the PIP output to a receiver which is connected to the tape recorder some distance away. An example of a pneumogram obtained with the PIP is shown in Figure F.

Reference

National Advisory Neurological Diseases and Stroke Council. 1969. *Human communication and its disorders: an overview*. Bethesda, Maryland: National Institutes of Health.

Acknowledgement

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