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"The Stethophone," An Electrical Stethoscope

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1. Acoustic Stethoscopes

AUSCULTATION is commonly practiced by means of the ordinary stethoscope, a device with which the physician is able to study sounds produced within the heart, lungs, or other portions of the body and to determine whether such abnormal conditions exist as are evidenced by abnormal sounds. Of particular importance are the characteristics of the normal heart sounds, heart murmurs, breathing sounds and râles.[1] It is well known that the intensity of certain of these sounds is not in itself of fundamental significance, that, for example, certain very faint murmurs may represent serious organic lesions; hence it is of pathological importance that these sounds be heard and understood.

Most acoustic and mechanical vibratory systems introduce distortion by discriminating in favor of certain frequency bands. Extreme distortion may alter a sound beyond recognition. If a moderate amount of distortion is unavoidable, it may be possible to control it judiciously so as to give most accurate reproduction in the frequency region of major importance.

From this standpoint it is of interest to consider the frequency characteristics of the two common types of stethoscopes shown in Figs. 1 and 2. The stethoscopes used in these tests were equipped with thick-walled soft rubber tubing such that the distance from the chest piece to the ear pieces was approximately 55 cm. The characteristic of the open bell stethoscope was obtained by picking up sound from the surface of a piece of fresh beef and measuring the relative intensity of sound on a condenser transmitter[2] with and

[1] The presence of any one of several types of lesions in or near the valves of the heart "gives rise to eddies in the blood current and thereby to the abnormal sounds to which we give the name murmurs." "No one of the various blowing, whistling, rolling, rumbling or piping noises to which the term refers, sounds anything like a 'murmur' in the ordinary sense of the word." (R. C. Cabot—Physical Diagnosis, pp. 182-3, 1923.)

"The term 'râles' is applied to sounds produced by the passage of air through bronchi (windpipes) which contain mucus or pus, or which are narrowed by swelling of their walls." (R. C. Cabot—Physical Diagnosis, p. 163) Râles may appear either as bubbling sounds, occurring singly or in showers, or as musical squeaks and groans.

[2] E. C. Wente, "The Sensitivity and Precision of the Electrostatic Transmitter for Measuring Sound Intensities," *Phys. Rev.* 19, No. 5, p. 498, 1922.

without the test stethoscope inserted in the sound path. In this experiment, it was impracticable to set up pure vibrations in the human body. A piece of fresh beef was a convenient substitute and one which for the purposes of such physical analysis appeared satisfactory.

The frequency characteristic of the open bell stethoscope is shown

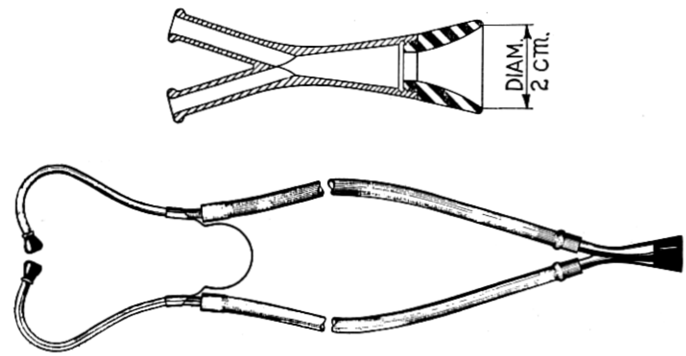


Fig. 1—The open bell stethoscope

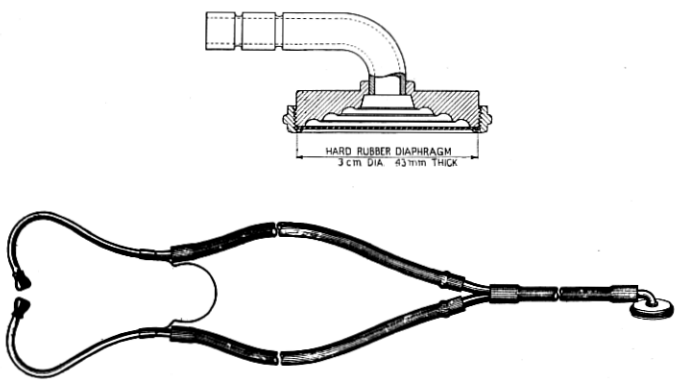


Fig. 2—One type of Bowles stethoscope

in Fig. 3, in which the "sensation value" as interpreted by the ear is plotted in transmission units,[3] TU,—convenient units used to

[3] The transmission unit used in this paper is a logarithmic function of power ratio. The number of transmission units N corresponding to the ratio of two amounts of power P_1 and P_2 is given by the relation $N=10 \log_{10}\frac{P_1}{P_2}$. The power ratio corresponding to N units is therefore $10^{\frac{N}{10}}$. For example, an increase of 10 TU signifies 10 times as much power; of 20 TU, 100 times as much power, etc. See W. H. Martin, "The Transmission Unit," *Journal A. I. E. E.*, Vol. 43, p. 504, 1924; *B. S. T. J.* Vol. 3, p. 400, 1924.

express relative loudness. A power ratio scale is also shown at the left and the power at 100 cycles is assumed equal to unity as a reference point.

This curve shows the relative efficiency of transmission for frequencies up to 2,000 cycles. The successive peaks are due primarily to resonance of the air columns and are partly determined by the length of the stethoscope tubing. Resonance thus increases the

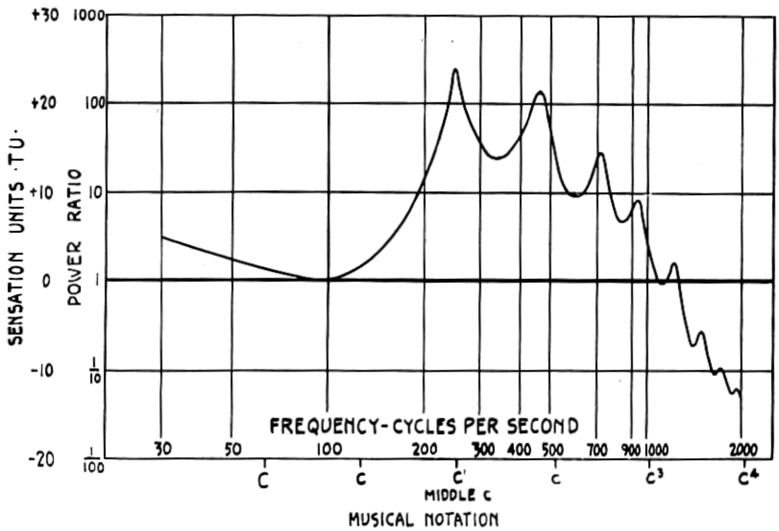


Fig. 3—Frequency characteristic of open bell stethoscope

efficiency of transmission at and above the fundamental peak frequency. As the frequency scale is ascended from this point, the transmission falls off gradually.

In a subsequent test, the open bell and Bowles types of stethoscopes (Figs. 1 and 2) were compared directly with one another. For this test, a vigorous sound was imparted to the sternum of a patient and the sound was picked up over the apex of the heart. Below 150 cycles, the Bowles stethoscope averaged approximately 15 *TU* less efficient, whereas, disregarding the somewhat different arrangement of the resonance peaks, between 300 and 1,000 cycles, it varied from 5 to 10 *TU* more efficient than the open bell type. These features of the Bowles stethoscope are due to the chest piece diaphragm. As will be shown in another paper, much of the energy of systolic and diastolic murmurs is made up of frequencies between 120 and 660 cycles per second. Thus, concurring with observations made by Dr. R. C. Cabot,[4] it is to be expected that many of the moderately high and high pitched murmurs can be heard more distinctly with the Bowles than with the open bell stethoscope. On the other hand, for many faint pathological sounds such as presystolic murmurs which are composed primarily of relatively low frequencies, the open bell stethoscope is more satisfactory for observation. The latter introduces less distortion so that with it all sounds are retained more nearly at their original relative intensities. These remarks are, of course, confined to the particular designs of stethoscopes shown in Figs. 1 and 2. It should be noted that as the length of the rubber tubing is increased, the fundamental peak of Fig. 3 moves downward in frequency, and the transmission at higher frequencies becomes poorer. In order to retain the very high pitched components of certain heart and chest sounds, the use of long rubber tubing should, therefore, be avoided.

The common stethoscope serves as a convenient means of observing body sounds. If the available energy from a single chest piece is subdivided in order to supply several individuals, however, the sounds observed by each are much fainter. In cases where the sounds of pathological interest are sufficiently near the threshold of audibility the use of a multiplicity of observing tubes renders these sounds inaudible. This is often the case.

For teaching purposes or for consultation, it is extremely desirable to have multiple listening units. In the past, it has been necessary to handle the students of large classes either singly or in small groups. This method naturally limits the number of cases that can be demonstrated and makes it impossible to give each student as much practice as has been found necessary for him to become familiar with the more obscure sounds. Aside from these factors, it has not been feasible for a large group to observe simultaneously with the instructor the peculiarities and changes in murmurs of a transient or evanescent character.

With the development of vacuum tube amplifiers, the possibilities of reproducing and magnifying body sounds electrically were considered. It appeared that a device might be provided which would be useful not only in teaching but also in diagnosis, as an aid to physicians of subnormal hearing, in the reproduction of the very faint fetal heart sounds or even in fields beyond the scope of the ordinary stethoscope.

[4] R. C. Cabot, "Physicial Diagnosis," Chap. VI, 1923.

2. Early Development of the Electrical Stethoscope

The earliest development work on electrical stethoscopes was naturally centered about the carbon transmitter and other microphonic contact devices. In 1907, Einthoven [5] made records of normal heart sounds and murmurs. In 1910,[6] heart sounds were reproduced by a tuned mechanical relay consisting of a single microphonic contact and an electromagnetic element. With this device, heart sounds were transmitted audibly but evidently with a considerable amount of distortion, over a commercial telephone line in London. The normal heart sounds were amplified by Squier [7] for a group of physicians by means of a carbon transmitter in 1921. It is readily possible to amplify the fluctuations in current in a carbon microphone by means of vacuum tube amplifiers. However, the carbon microphone also introduces a certain amount of noise inherent in the use of loose contacts. This noise is below the threshold of audibility for the normal use of the microphone, as in the telephone plant, but when it is amplified along with the faint sounds of interest, in auscultation it becomes very annoying and tends to obscure these other sounds. This "microphone roar" contains components throughout the range of audible frequencies and hence cannot be eliminated. Various experimenters have, however, attempted to perfect such a device.[8,9] As far as we have been able to determine, such devices have not satisfactorily reproduced faint heart murmurs or chest sounds.

Of the other possible types, the electromagnetic has thus far appeared to offer the greatest promise. In design, this resembles closely the ordinary telephone receiver. This type requires a more powerful amplifier than the carbon microphone but this is not a serious limitation. Such a combination has been used with promising results to obtain graphical records of heart murmurs.[10] The progress made with this type of equipment for teaching purposes has been outlined.[11] The successful application of the electromagnetic

[5] W. Einthoven, "Die Registrierung der menschlichen Herztöne mittels des Saitengalvanometers," *Arch. f.d. ges. Physiol.*, 117:461 April 1907; "Ein dritler Herzton," ibid. 120:31 Oct. 1907

[6] S. G. Brown, "A Telephone Relay," *Journal I. E. E.* May 5, 1910.

[7] S. W. Winters, "Diagnosis by Wireless," *Scient. Amer.* 124:465 June, 1921.

[8] R. B. Abbott, "Eliminating Interfering Sounds in a Telephone Transmitter Stethoscope," *Phys. Rev.* 21:200 Feb., 1923.

[9] Jacobsohn, "Amplified Audibility of Heart Sounds," *Berlin Letter J. A. M. A.*, 80:493 Feb. 17, 1923.

[10] H. B. Williams, "New Method for Graphic Study of Heart Murmurs," *Proc. Soc. Exper. Biol. and Med.*, 18:179 March 16, 1921.

[11] R. C. Cabot, "A Multiple Electrical Stethoscope for Teaching Purposes," *J. A. M. A.*, 81:298 July 28, 1923.

transmitter to teaching was due largely to the work of Dr. R. C. Cabot and Dr. C. J. Gamble at the Massachusetts General Hospital where a successful multiple electrical stethoscope was first employed for classroom lectures in June, 1923. The equipment consisted of an electromagnetic transmitter provided with a special form of mouthpiece for picking up the body sounds, a three-stage vacuum tube amplifier and a distribution system to accommodate as many as 125 students with single head receivers on which individual ordinary stethoscopes were held.[12]

The experience gained with this equipment indicated certain improvements to increase the sensitivity to body sounds, and at the same time decrease the disturbances caused by extraneous noises. Greater sensitivity required a better transference of sound energy from the body to the transmitter. Reduced room noise required that we couple the transmitter as closely as possible with the human body and at the same time make it insensititive to sound vibrations in the air. A preliminary analysis with electrical filters of the frequency characteristics of sounds of pathological interest to the physician showed that these sounds were composed largely of frequencies below 1,000 cycles. Inasmuch as the frequency characteristics of these various sounds are different, it has been found very useful to permit concentration on the sounds of interest by the use of electrical filters.

These factors led to the development of the electrical stethoscope called the "stethophone" which is described in the following paragraphs. This development was undertaken at the request and with the active cooperation of Dr. H. B. Williams of the College of Physicians and Surgeons, New York, Dr. Richard C. Cabot [11] of the Massachusetts General Hospital, Boston, and Dr. C. J. Gamble [12] of the School of Medicine of the University of Pennsylvania, Philadelphia. The cooperation of these physicians permitted the instrument to be given practical tests at every stage of its development.

3. General Description of the Stethophone

The stethophone consists essentially of the following elements:

1. An electromagnetic transmitter.
2. A three-stage amplifier with a potentiometer control.
3. A selected group of electric filters.
4. A multiplicity of output receivers for observers.

The whole is assembled in a substantial cabinet on wheels re-

[12] A detailed description of the apparatus used in this installation was presented in a recent paper. See Gamble and Replogle, "A Multiple Electric Stethoscope for Teaching," *J. A. M. A.*, Vol. 82, p. 387, 1924.

sembling a "tea-wagon." It requires for its operation a six-volt storage battery and a 130-volt "B" battery. These are housed in compartments in the lower part of the cabinet. Ten jack positions are provided to permit this number of persons to listen simultaneously

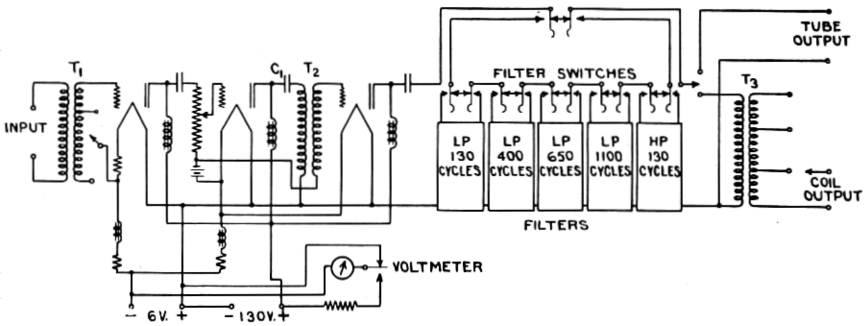


Fig. 4—Circuit diagram of stethophone

around the stethophone. All controls are conveniently placed on a single panel to facilitate operation.

A schematic circuit diagram is shown in Fig. 4.

4. Transmitter

The transmitter employed with greatest success with the stethophone thus far is of the electro-magnetic type equipped with a special vibratory element which is placed in direct contact with the flesh of the patient.

One of the features of the transmitter is its insensitiveness to sound waves in the air. Thus, the ratio of extraneous noise picked up by the transmitter to the body sounds is greatly reduced so that observations can be made with a minimum amount of interference from room noise.

The transmitter construction provides efficient transfer of vibrational energy from the flesh or bony framework of the body to the vibratory steel element. It provides a means for coupling which serves as a mechanical transformer for body sound energy and avoids an abrupt change in the path of the waves and large attendant losses by reflection. The system is highly damped and minimizes the distortion of the sounds of interest.

Since the transmitter is a contact device, the physician may vary the pressure of application at will. Firm but light contact is desirable. The human flesh contributes damping to the vibratory system of the transmitter. Undoubtedly this damping is not only variable for different individuals but depends upon the pressure and the nature of the flesh and bone structure in the vicinity of the point of application for any one individual. Thus the frequency characteristic of the transmitter is somewhat dependent on the conditions of use. The frequency of maximum response is slightly above 200 cycles, and the nature of the response-frequency curve indicates that the vibratory system is highly damped. A discussion of the overall frequency characteristic of the stethophone, including the transmitter, is given in a later section of the paper.

It is obvious that variations in the pressure of application will introduce disturbing noises in the audible frequency range. Suitable means have, therefore, been provided to eliminate the communication to the vibratory system of hand tremors, slight movements of the patient, and friction noises of the fingers on the case of the transmitter.

Another source of extraneous noise is the rubbing of the transmitter cord on the clothing or on other surfaces. A stiff cord is very objectionable from the standpoint of transmission of friction noises. Insulation from these noises has been provided by a very flexible section of cord at the transmitter end.

5. Amplifier

The three-stage amplifier employs one Western Electric 102-D and two Western Electric 101-D vacuum tubes. As shown in Fig. 4, the input transformer *T*1 connects the transmitter to the grid of the first tube which is coupled to the second tube through a resistance potentiometer. The second and third tubes are coupled through a transformer *T*2. The output circuit of the last tube may be connected to the load directly from its plate circuit for high impedance loads, or through an output transformer *T*3 for low impedance loads. The plate circuit of the second tube is tuned by means of a condenser *C*1 in order to retain high amplification at the low end of the frequency scale.

A very flat characteristic is obtained over the range of interest, the maximum variation being only about 3 *TU* (See Fig. 5). A total gain of about 80 *TU* is provided, that is, a power amplification of about one hundred million times. With an amplification of 50 *TU*, about the same loudness is observed in a single receiver in the output circuit of the stethophone as is heard by the direct use of the open bell stethoscope. This leaves a reserve amplification of about 30 *TU* available for obtaining greater intensity of sounds or for supplying a large number of individual listening units.

The potentiometer between the first and second tubes makes it possible to adjust the amplification in small steps, each step giving

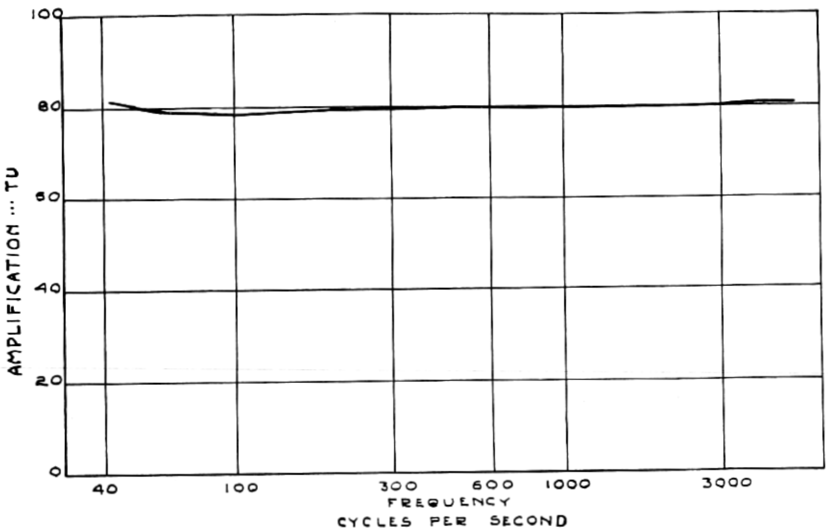


Fig. 5.—Amplifier characteristics—maximum amplification

approximately twice the energy of the preceding one. This is an essential element of a flexible system.

6. Electric Filters

An electric filter is a combination of coils and condensers capable of separating electrical waves characterized by a difference in frequency.[13]

The three fundamental forms of filters are commonly termed "low-pass," "high-pass," and "band-pass." A low-pass filter is one which passes currents of frequencies below a particular "cut-off frequency" and attenuates or weakens very greatly currents of higher frequencies. A high-pass filter does the opposite—attenuates below the cut-off frequency and passes above this frequency. A band-pass filter is one which passes currents of frequencies within a definite band fixed by two cut-off frequencies. A low-pass and a high-pass filter connected in series constitute one form of band-pass filter. For any type of filter, the sharpness of cut-off and the amount of attenuation can be controlled at will by suitable design constants.

[13] G. A. Campbell, "Physical Theory of Electrical Wave Filters," *Bell System Tech. Journal*, Nov., 1922.

The stethophone is equipped with five filters whose cut-off frequencies are based on careful analyses of about 100 hospital cases of heart murmurs, râles and breathing sounds. These analyses showed that the sounds of pathological interest to the physician can be grouped into fairly definite frequency regions. When sounds in a particular range of frequencies are of immediate importance, they may be emphasized by suppressing sounds outside of this band.

The frequency characteristics of the filters are shown in Fig. 6.

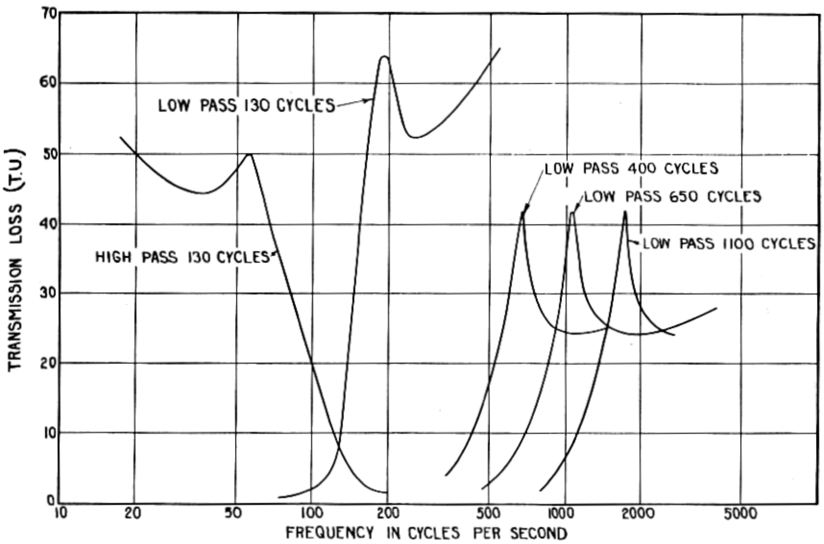


Fig. 6.—Loss characteristics of the five filters

For convenience, the cut-off frequency has been defined as that frequency at which the energy is reduced to approximately 1/10 of its original value.

The low-pass filter with a cut-off frequency of 130 cycles is of primary use for reproducing the normal heart sounds and fetal heart sounds in cases where the rate alone is desired. Most of the energy of these sounds is below 100 cycles. With this filter most of the common interfering noises, including the sounds of the human voice, are excluded.

The low-pass 400 cycle filter is particularly useful for observing presystolic and certain low-pitched systolic and diastolic murmurs.

The low-pass 650 cycle filter has been found the most valuable of all five filters. With it, most high-pitched murmurs, low-pitched râles and certain types of breathing sounds can be observed to the greatest advantage.

The low-pass 1,100 cycle filter passes the higher frequency components of very high-pitched murmurs and high-pitched râles in a majority of cases.

The high-pass 130 cycle filter serves a unique and important purpose. It may be regarded as in value second only to the low-pass 650 cycle filter. In many cases, the loud normal sounds tend to mask or obscure the faint higher-pitched murmurs. The high-pass 130 cycle filter serves to weaken greatly the normal heart sounds so that the murmur sounds occurring in the intervals between the beats appear with its use to be relatively much louder. In this filter, the amount of attenuation in the low frequency region has been made such that the residual low frequency energy and the higher frequency components of the normal heart sounds are just sufficiently audible so that the murmurs may be timed with relation to their positions in the cardiac cycle. This filter is also very useful for weakening the heart sounds when râles or pericardial friction sounds are to be observed in areas where the heart sounds are loud.

The high-pass 130 cycle filter may be connected into the circuit jointly with any one of the low-pass filters, thus making available a group of band-pass filters with a lower cut-off frequency of 130 cycles.

7. Output Receivers

When the stethophone is used for teaching or consultation purposes, a number of high impedance receivers are connected in parallel in the output circuit. Each observer is provided with a single receiver to which the ordinary stethoscope earpieces may be readily

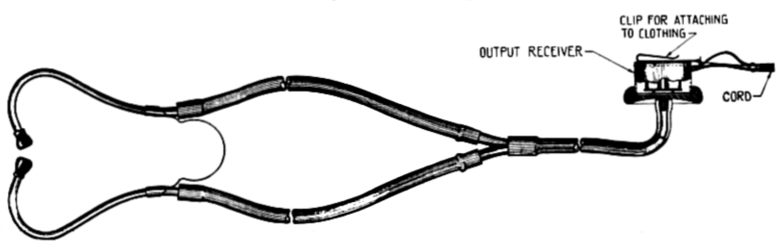


Fig. 7—The output receiver

attached as shown in Fig. 7. This method of transmitting sounds from the receiver diaphragm to the ears minimizes leakage loss of sound energy and serves effectively to shut out room noises and other annoying sounds. This result could be even better obtained and with less distortion by providing the receivers with small tips to insert in the ears but at a greater cost for additional receivers. It is perhaps better to use the tubing and earpieces of the ordinary stethoscope as this is the equipment to which physicians are most accustomed and to which the student must accustom himself for future practice. The receiver case is provided with a spring clip for attachment to the clothing. This allows full freedom of both hands for manipulating the transmitter and the control switches of the amplifier, taking notes, etc.

The impedance of the output circuit depends upon the number of receivers in use and, for parallel connection, decreases as the number of receivers is increased. To care for the variable number that may be used at different times, the output transformer has been tapped and a three-way switch provided. By operating this switch, the apparatus can be adjusted to a load varying from 1 to 600 receivers with a maximum transmission loss of 2.5 *TU*.

8. Frequency Characteristics of the Stethophone

The overall frequency characteristics of the stethophone, including the transmitter, the amplifier, and the output receivers, are given in Fig. 8. Two curves are shown. The solid line curve represents

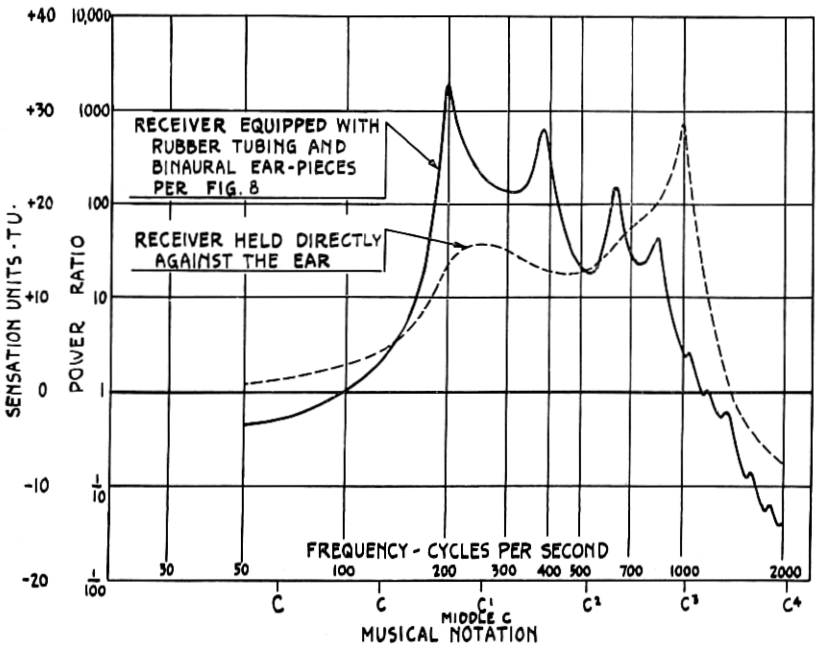


Fig. 8—Frequency characteristics of the stethophone

operating conditions when the output receivers are equipped with rubber tubing as in Fig. 7, and with the binaural ear-pieces held in the ears. The peaks in this curve are due principally to the resonance in the air columns of the rubber tubing, and correspond to the similar peaks of Fig. 3 for the open bell stethoscope. In order to point out the effect of the stethoscope attachment of the output receiver, a second characteristic is shown by a dotted curve which represents conditions when an output receiver of the same type is held directly against the ear. It is noted that the stethoscope attachment increases the transmission between 150 and 500 cycles per second, and damps the sharp resonant peak of the receiver.

The overall characteristic of the stethophone as employed for auscultation is quite similar to that of the open bell stethoscope. It is desirable that the body sounds as observed by the stethophone should appear the same as in the ordinary stethoscope, particularly in teaching work since the latter is used almost universally in regular practice. If it were deemed desirable for special purposes to avoid the distortion introduced by the stethoscope attachment, receivers with small tips to insert in the ears could be used. For such an arrangement, the overall characteristics could be further improved by using damped receivers which would practically eliminate the sharp peak of the dotted curve in Fig. 8.

9. Installation for Teaching Purposes

When the stethophone is to be used for teaching purposes a permanent wiring or distribution system should be installed with outlets distributed among the seats of the amphitheatre or lecture room.[11] A schematic diagram of such a system is shown in Fig. 9. A distributing pair of feeder wires, preferably shielded, is run between alternate rows of seats below the floor casing, or suitably sheathed to prevent damage. An outlet block "A" of six double contact jacks is mounted on the back of each third seat of alternate rows. Thus, one outlet block will supply six seats, three in front and three in back of the block. Substantial jacks should be used throughout and all receivers should be equipped with rugged plugs. In addition to furnishing jack outlets among the seats, two or three multiple outlet blocks may be installed at the center of the amphitheatre as shown at "B" for the use of guests or others on the floor of the amphitheatre. The output of the stethophone can be connected to the distributing system of the amphitheatre at any one of these outlets. Switch boxes should be installed at various points as at "C" to facilitate the localization of an accidental short circuit. If a short circuit should occur in any part of the system this section can thus be disconnected and the balance used independently.

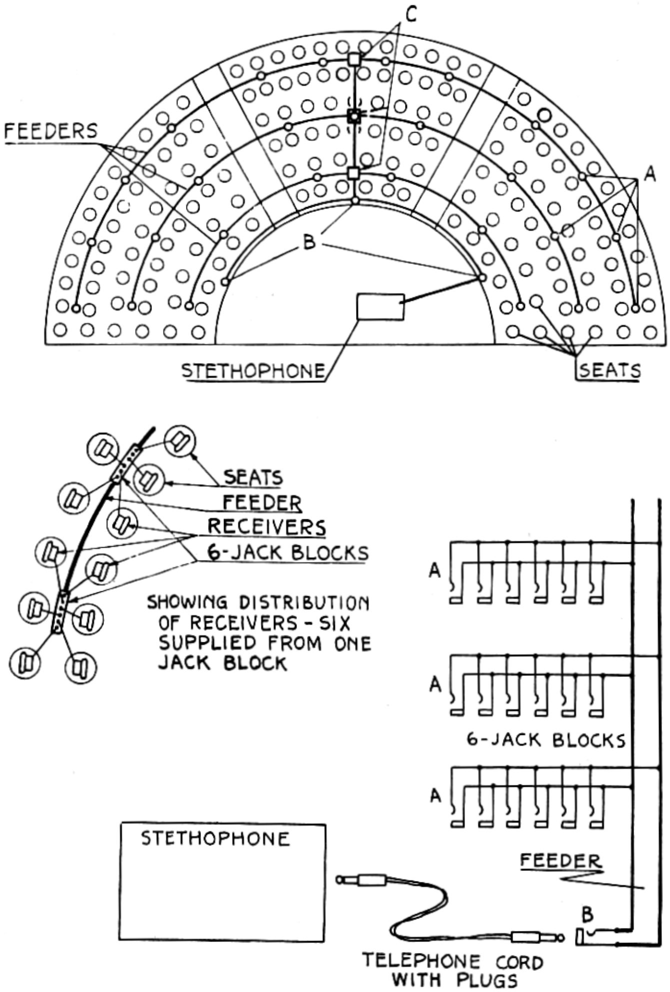


Fig. 9—Wiring installation in an amphitheatre for teaching purposes

In class room lectures, the instructor can make announcements to the students and point out features of particular interest in a convenient and somewhat novel manner without requiring the removal of the stethoscope tubes from their ears. The human body acts as a sounding board for sounds in air—that is, when words are spoken in the vicinity of a patient, the flesh and bone structure vibrates to these sounds. This is particularly true of the areas commonly used in auscultation. The transmitter, resting on the flesh, will pick up these vibrations together with those originating in the body of the patient. The instructor may, therefore, talk to his students by directing his words at that portion of the body to which the transmitter is applied. Best results are obtained with a talking distance of about ten inches. During such announcements, it is essential,

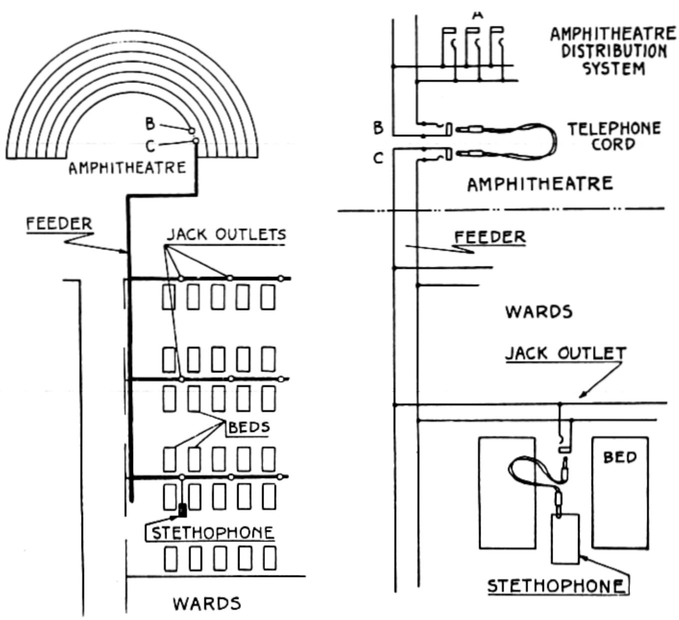


Fig. 10—Wiring installation for the rooms or the wards of a hospital

of course, that the electrical filters be removed from the circuit in order that the important higher frequency components of speech may be transmitted to the receivers. Because of this operating feature, it is obviously necessary to have the patient in a reasonably quiet place.

It is often desirable to reproduce in the lecture hall, the heart and chest sounds of confined patients too ill to be moved. For this purpose, the rooms or the wards of a hospital may be connected by a pair of wires to the lecture room. Such an installation is shown in Fig. 10. Terminal outlets are distributed throughout the rooms or the wards as desired and all are connected to the main feeder wires which communicate with the lecture hall. It is necessary to take the stethophone to the bedside. Long wires from the transmitter to the amplifier cannot be tolerated on account of inductive disturbances from neighboring telephone or other electrical circuits. If desirable, announcements may be made as before by talking close to the body of the patient under observation. In cases where exposure of a patient is inadvisable or where accurate statements pertaining to the seriousness of a disease are preferably withheld from the patient, announcements may be made by talking in a low tone of voice at about one inch distance from the transmitter itself. Reasonably satisfactory reproduction is obtained by this means.

10. Other Applications

Aside from its application to teaching purposes, the stethophone appears to have possibilities in fields which have not yet been thoroughly studied. Further experimental investigation by the medical profession can alone bring out these possibilities.

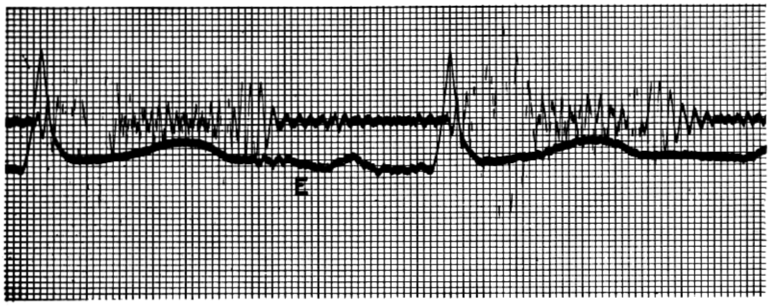
The possibility of substituting a loud speaker for the individual receivers in the output circuit has been investigated in a preliminary manner. This problem involves certain very fundamental factors relating to the sense of hearing which must be considered carefully. To a remarkable extent, the ear is capable of selective observation. Ordinarily we listen to sounds through a sea of noise to which we become so accustomed that we fail to notice it. However, when listening to sounds near the threshold of audibility, such as the body sounds under consideration, this noise may render the sounds of interest inaudible. In order to hear them, it therefore, becomes necessary to increase the loudness to a point well above that commonly observed by the physician with his stethoscope. This increase in loudness brings within the audible range, sound components ordinarily not heard and changes the quality of the whole as judged by the ear. Such alteration of quality is obviously very unsatisfactory for diagnosis or teaching purposes. Assuming that we had available a perfect loud speaker, one that would transmit the very low and the higher frequency components of faint body sounds without distortion, difficulties would still be presented by the acoustic characteristics of the room in which the loud speaker was placed. All rooms are more or less reverberant. When these sounds are reproduced by a good loud speaker in a small heavily damped sound-proof room, they appear quite natural, but such a room is seldom available practically. None of the ordinary loud speakers with horns will transmit the low frequencies here of interest and would sound very unnatural even with ideal room conditions. While a loud speaker has been used under proper acoustic conditions to reproduce faint pathological sounds, as murmurs and râles, this does not appear in general to be a practical arrangement. Most arguments, except perhaps that of economy, tend to favor the use of individual output receivers for practically all purposes where critical analysis of sounds is the objective.

Fetal heart sounds as heard through the mother's abdomen are much fainter and require considerably higher amplification than adult heart sounds. Preliminary data indicate that the energy of fetal heart sounds is approximately only 1/50 to 1/500 of the energy of average normal heart sounds. The low pass 130 cycle filter is not only useful for suppressing the extraneous sounds and electrical disturbances which usually attend the use of high amplification, but serves most effectively to eliminate the voice sounds of the patient. At Sloane Hospital in New York City it has been found possible to reproduce clearly on a loud speaker and with a negligible amount of interference, fetal heart sounds which were barely audible in the physician's stethoscope. In these cases no interference was experienced from the maternal heart sounds. However, even in surgical work where the rate of the adult or fetal heart is alone of importance, it is felt that the best plan is to equip an attendant with earpieces attached to a receiver and to make it his chief duty to observe the heart action.

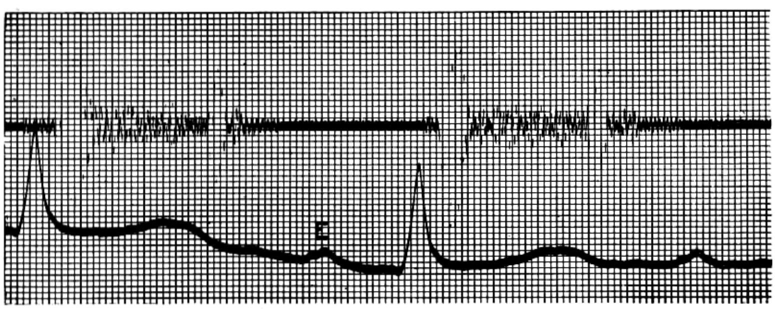
A very important application of the electrical stethoscope is its association with a recording galvanometer for making photographic records of heart and chest sounds. Permanent records of this sort might constitute a valuable addition to the history records of important cases in large hospitals. Some excellent graphical records have already been made.[10] It has been found that such records can be obtained much more easily with the stethophone, principally because of the part played by the electrical filters. The low-pass filter suppresses largely the current fluctuations caused by mechanical vibrations and noise at the apparatus. The high-pass 130-cycle filter is also valuable for bringing out very faint murmurs. By its use, the amplitude of the normal heart sounds can be greatly reduced. When this is done, the amplitude of the faint murmur sounds may be magnified relatively and hence shown very nicely on the record.

This is illustrated in the two charts of Fig. 11, which are presented through the courtesy of Dr. H. B. Williams. The stethophone records are accompanied by simultaneous electro-cardiograms (E) for timing the events. The first record was made with a low pass

650 cycle filter and the second with a band pass 130–1,100 cycle filter and increased amplification. The latter shows the systolic murmur very clearly. With the *LP* 650 filter, the murmur is more or less obscured by very low pitched sounds which may really be a part



Low pass 650 cycle filter



Band pass 130–1100 cycle filter

Fig. 11—Records of a systolic murmur taken with the stethophone and a recording galvanometer

of it, but certainly play a subordinate role in producing the audible sound. The effect of suppressing the low pitched sounds by using the high pass filter is more pronounced in charts of this sort for murmurs which have negligible sound components below 130 cycles per second.

Phonograph records of heart sounds have been made previously.[14] With the stethophone and a special electrical recorder, records of some 15 cases of murmurs and chest sounds have recently been made. The results are very encouraging. All of the characteristics of these sounds, such as the relative intensities of the different components

[14] G. F. Keiper, *Letter J. A. M. A.*, 81:679 Aug. 25, 1923.

and their quality, have been retained remarkably well. The problem of subsequent reproduction of these records has been met satisfactorily in two ways, in both of which the factor of particular concern is the elimination of "needle scratch" noises. First, an electromagnetic reproducer has been used in conjunction with the stethophone. In this case, low-pass filters serve to reduce the scratching noises. Second, the records have been reproduced by attaching the earpieces of the ordinary physician's stethoscope to a special adapter used with a commercial phonograph reproducer. To reduce needle scratch in this case it is only necessary to introduce some form of air passage between the reproducer and the binaural earpieces which acts as a low-pass acoustic filter. The ordinary commercial phonograph is quite unsatisfactory for reproducing these records partly for the same reasons mentioned above relative to the use of loud speakers.

Phonograph records of heart and chest sounds can be employed to some extent for preliminary teaching purposes and do not require much equipment if reproduced acoustically. No patients are required in this case, and the records can be accompanied by the analysis or diagnosis of an expert. It is suggested that phonograph records might be used to advantage as permanent records to follow the progress of disease in important cases.

11. Summary

A summary of the applications and limitations of a new form of electrical stethoscope has been given. However, the extent of its usefulness can be brought out only after it has been placed at the disposal of experienced men in the medical profession. With it, heart murmurs and râles can be magnified and observed with greater clearness than with the ordinary stethoscope. Extremely faint sounds may be heard clearly without great acuity of hearing by inexperienced observers, a thing which has not hitherto been possible. In several instances, murmurs have been discovered with the stethophone which were not discerned initially with the ordinary stethoscope although discernible after having heard them with the more powerful apparatus. In a few of these cases, very faint murmurs, although undoubtedly present could not be heard at all with the ordinary stethoscope. It is felt that the electrical filters have played an important part in such cases. These facts lead us to believe that the stethophone may have real value for diagnosis.

The field of physical research of body sounds has been touched upon but lightly. For special purposes, an endless variety of electrical filters can be used with the stethophone.