

Jan. 11, 1966

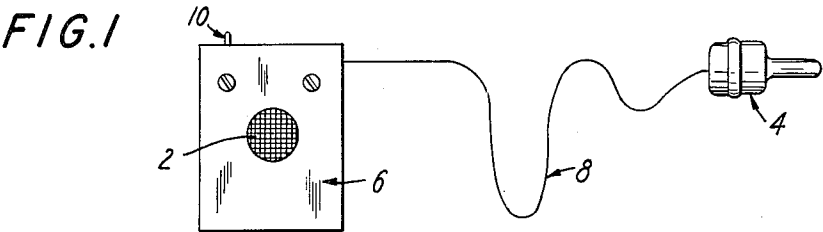
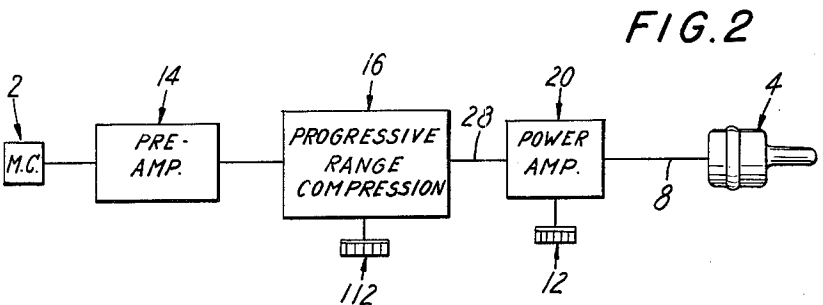
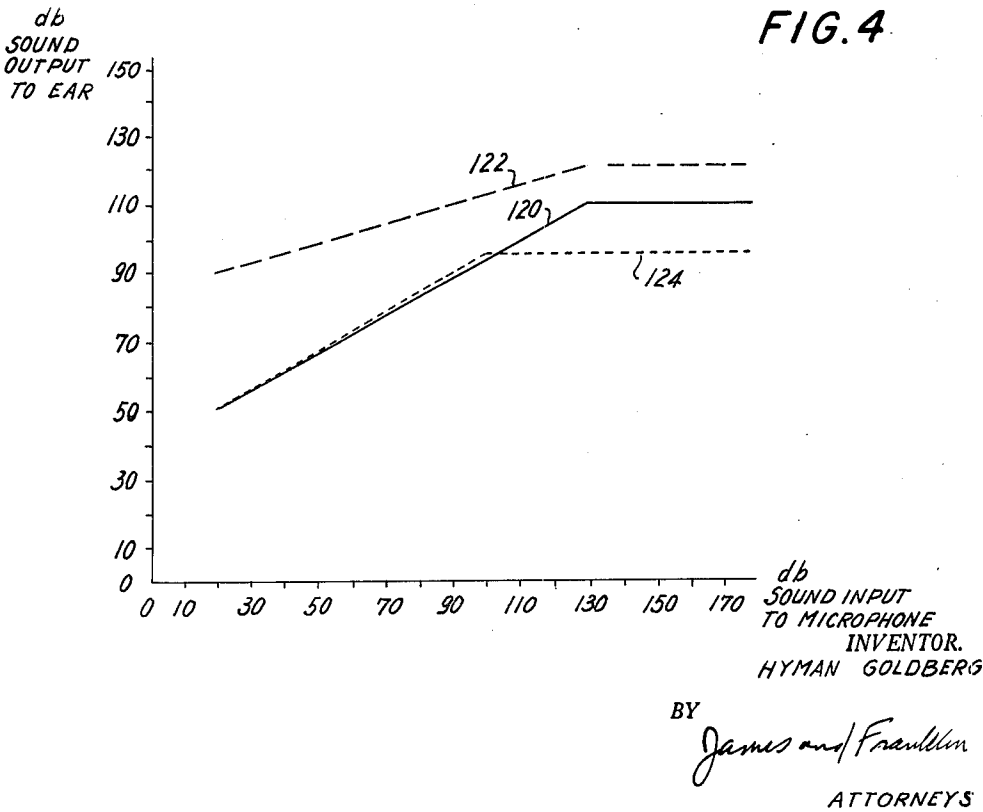
H. GOLDBERG

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HEARING AID

Filed Aug. 4, 1960

2 Sheets-Sheet 1



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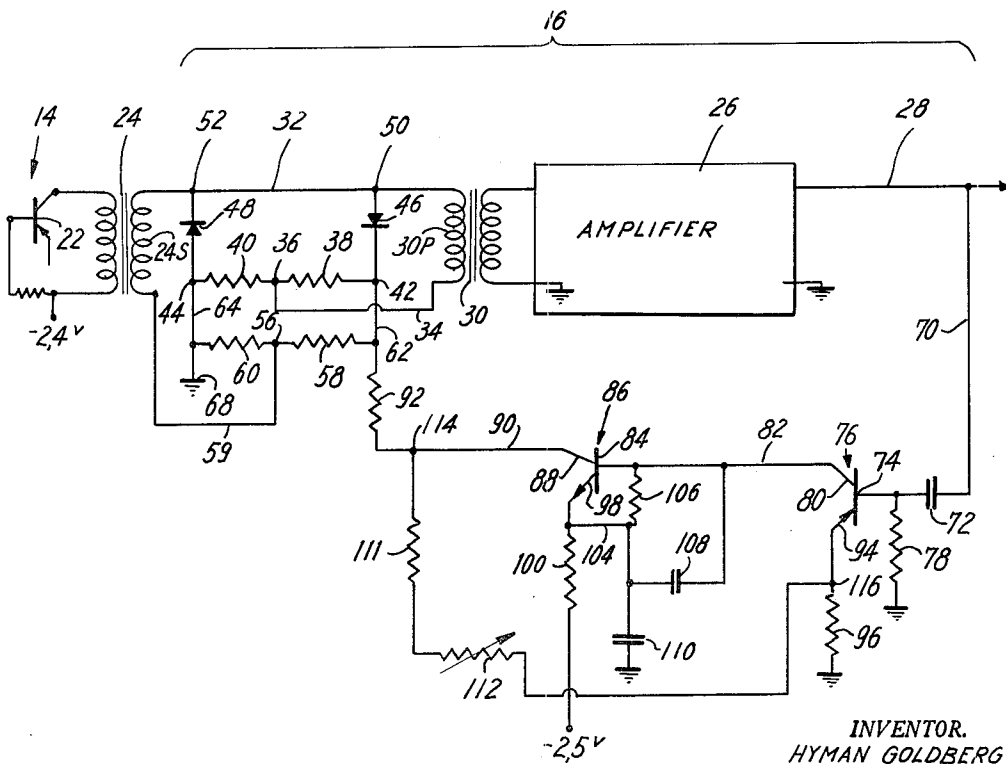
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HEARING AID

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2 Sheets-Sheet 2

FIG. 3



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HEARING AID

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The present invention relates to an improved hearing aid for use by those with hearing deficiencies.

There is much more to the design of a truly effective hearing aid than merely providing for amplification of sounds. The complexities involved derive in part from the complex acoustic nature of speech, and in part from the physiological peculiarities attendant upon most forms of deafness.

It is commonly recognized that sounds are composed of a plurality of frequencies, so that a hearing aid must be capable of amplifying frequencies throughout the audible range. It is further generally recognized that there are soft sounds and loud sounds. What is not generally appreciated by the layman is that a given spoken word considered as having been uttered with a given sound intensity or amplitude is in fact not of uniform intensity, but instead is composed of a plurality of sounds the intensities of which usually vary markedly. It has moreover been ascertained that intelligibility is in large part determined by these variations in sound intensity within a given spoken word, and any failure on the part of a hearing aid to produce in its output a complex sound having variations in intensity in direct relationship to the intensity variations of the detected sound will result in loss of intelligibility.

From a physiological point of view, the normal ear will hear sounds in a range between approximately 20 db and 130 db. Sounds having an intensity below 20 db will normally not be audible, and sounds having an intensity about 130 db will cause actual pain. The lower level of 20 db is called the audibility threshold, and the level of 130 db is called the pain threshold. Sounds having intensities somewhat below 130 db may well cause discomfort. The upper limit of comfortable hearing will vary as between normal individuals.

Moreover, the normal human ear will distort sounds received above 100 db. Fortunately, sound intensities above that value are not needed for intelligibility, at least as far as speech is concerned, although the human ear can distinguish and identify coarse sounds above 100 db. (For purposes of comparison, a yell is usually below 100 db in intensity, while a full symphony orchestra heard very close may produce sounds at the ear above 100 db.)

It has been found that with most types of deafness the upper limit of hearing, the pain threshold, is substantially the same as for a healthy ear, and the upper limit of comfortable hearing will vary with individuals and may in some instances be lower than that for a normal ear. The minimum audibility threshold for a deaf ear, is, of course, considerably higher than that for a normal ear. Thus, while a normal ear will hear sounds within the range of 20—130 db, a deaf ear may, depending upon the degree of deafness, hear sounds only above 50 db and comfortably only below 110 db, or, in an extreme case, only above 90 db and comfortably only below 120 db. It has been found, however, that even though the range of audibility of a deaf ear is less than that for a normal ear, the deaf ear is capable of distinguishing between differences in intensity, even within its limited audibility range, to a truly surprising degree, and with more acuity than a normal ear.

Hearing aids as they have been known heretofore, even in the relatively sophisticated forms which they have come to assume in the course of the development of the art, have not taken advantage of this characteristic of the

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deaf ear, and as a result have not been truly or universally effective. It is well known that two hearing aids of equal quality, but manufactured by different concerns, will affect a given individual differently. With one he will be able to understand speech, but with the other he may have a great difficulty in understanding speech. The more acute the deafness, the more critical does the choice of a hearing aid become, and it is not uncommon for an individual to try many different hearing aids in search of one which will provide him with satisfactory hearing.

This situation has come about in large part because of the prior art approach to amplification of sound in order to make that sound sensible to the deaf ear. Ordinarily the hearing aid is provided with a conventional adjustable volume control so that the hearing aid can be adapted to the particular degree of deafness of its individual user and to his personal preferences. The user will tend to adjust the volume control to a position giving him maximum comfort in a given situation. If he is conversing with a person who speaks softly, he will turn the volume control up to get increased amplification. If there should be a loud sound, such as a door slamming, that loud sound will also be greatly amplified, and may well pass the pain or discomfort thresholds. In order to prevent this latter effect, many hearing aid amplifiers have been provided with maximum amplitude limitation; no matter what the setting of the volume control. This is sometimes accomplished by "clipping" the tops of sound waves in the output of the hearing aid which exceed a given value, such as 130 db—the pain threshold. In other systems conventional automatic volume control is used to accomplish the same result, that automatic volume control becoming effective only when the output of the hearing aid to the ear reaches the predetermined magnitude. This type of approach will prevent the pain or discomfort thresholds from being exceeded, but it often results in great loss of intelligibility. When the volume control is set for high amplification, as during normal conversation, the louder individual sounds of a given word, normally necessary for intelligibility, are "clipped" or distorted, so that the ear of the user is presented with unfamiliar sound patterns. If the volume control is set low enough so that this distortion of high intensity normal sound does not take place, it may often occur that low intensity sounds will not be amplified sufficiently to pass the audibility threshold of the particular user. In both cases there is loss of intelligibility.

Thus, the "limiting" approach which amplifies all sound intensities up to a given value substantially similarly and then, for sound of greater intensities, produces an output which is substantially uniform in intensity, leaves much to be desired.

The hearing aid of the present invention is based upon a new approach to the problem, which I have termed "progressive range compression." I realize that the term "compression" has sometimes been used to describe that type of prior art operation set forth above, which functions on a "limiting" principle, amplifying all sounds over a range of intensities equally and amplifying all sounds above that range in such a way as to produce a substantially uniform output. As thus used "compression" is a misnomer. My "progressive range compression," by way of contrast, is truly compressive in nature—it provides for compression of a given normal intensity range—20—130 db, or some other selected range—to a range having a smaller width, depending upon the nature of the deafness of the individual user, in which smaller or compressed range the detected sound intensities of the original range are all present and retain their original intensity relationship. In other words, minimum intensity sound is amplified a great deal, maximum intensity sound may not be amplified at all, and each sound intensity,

moving from minimum to maximum, is amplified to a decreasing degree.

This I accomplish in part by providing my amplifier with an automatic amplification control of specialized character. An output intensity adjustment is located in the circuit after the automatic amplification control has had its effect, so that the automatic amplification control is in reality determined by the input to the system, and is independent of the system output volume or amplitude. In addition, the automatic amplification control itself varies in effectiveness depending on the intensity of the sound involved. Conventional automatic volume control is designed to come into effect when the signal reaches a predetermined value, thereafter maintaining that signal at said predetermined value. The type of automatic amplification control which I employ differs in that the effect of the automatic amplification control varies with different sound intensities, and in a substantially gradual manner as the sound intensities increase, providing minimal automatic amplification control (maximum amplification) for low intensity sounds, maximum automatic amplification control (minimum amplification) for high intensity sounds, and intermediate degrees of automatic amplification control for intermediate sound intensities.

The hearing aid of the present invention therefore functions to take sounds within a predetermined range of intensities, which may be the entire normal audibility range of 20-130 db, and compress all of the intensities of that entire range of sounds in a graduated or proportional manner, into a range having a smaller width selected in accordance with the particular dynamic intensity audibility range of the individual user. The signals within this smaller width range are then modified by the output intensity adjustment so that they are fed to the ear of the user at absolute intensities such as to make for maximum comfort and intelligibility for that particular individual. Since sounds of different intensities within the complete range of normal audibility maintain their proportional intensity relationships, those differences in intensity are sensed by the deaf ear even though the quantitative or absolute intensity differences are smaller than in the original sounds. Because of the increased acuity of the deaf ear in detecting differences in sound intensity, intelligibility of the amplified sound is exceptionally high.

A very significant advantage of the hearing aid of the present invention, and one which radically differentiates it from hearing aids of the prior art, is the fact that the provision of an adjustable volume control, adapted to be actuated by the user, is neither necessary nor desirable. Once the progressive range compression has been suited to the particular needs of the user of the device and the output intensity adjustment has been set to produce a range of vibration intensities at the ear of the user corresponding to his individual requirements (both of these adjustments being permanent in nature for a given individual), nothing further need be done. The hearing aid will provide for accurate, comfortable and intelligible hearing of all of those sounds to which the normal ear accurately responds.

From an electronic point of view the design of a truly progressive compression amplifier operable without appreciable distortion and with adequate stability over a range having a width as great as 110 db—from 20 to 130 db—has heretofore eluded the art. Nevertheless, through the use of novel circuit arrangements, I have been able to accomplish this result and still produce a device sufficiently light and compact to be truly practical as a hearing aid. Among its important features are the following: the feed-back circuit which provides automatic progressive range compression, and which is connected between the output and the input of a primary amplifying stage, is itself an amplifier, and is provided with an additional feed-back means between its output and its input which modifies its amplification, and thus

the magnitude of the automatic amplification control which it produces, directly with respect to the input to the feed-back circuit.

The feed-back signal is applied to the primary amplifier which it controls by varying the characteristics of a voltage divider connected across the main signal input to the primary amplifier, one of the voltage divider elements having the characteristic that its resistance varies with the current passing through it. The output from the feed-back amplifier is fed to that voltage divider element, thereby to vary its resistance and control the magnitude of the input signal to the primary amplifier. The voltage divider is preferably in the form of a balanced bridge circuit to reduce undesired A.C. effects. The primary amplifier is followed by a power amplifier, the amplification of which is substantially uniform for all signal intensities and the amplification of which can be manually adjusted (output intensity adjustment) in order to control the absolute amplitude of the output of the hearing aid to the ear. Since the output intensity adjustment is located in the circuit after the progressive range compression feed-back circuit, the effect of that latter circuit will be independent of the actual output volume, and will be controlled only by the intensity of the input sounds. It is preferred that the voltage divider bridge be preceded by a pre-amplifier at least the last stage of which is defined by a transistor and which is preferably transformer-coupled to the bridge circuit, this particular arrangement increasing the width of the range of operation of the progressive range compression circuit without adversely affecting stability.

The general discussion as set forth above has been based upon the premise that the entire normal audibility range of 20-130 db is to be progressively compressed, and it is entirely feasible to do this. However, because of the fact that sounds having intensities about 100 db are distorted by the normal ear and are not truly required for intelligibility I have found that it is unnecessary to compress that full 110 db width range. Instead it is eminently satisfactory to provide for progressive range compression only for detected sounds within the range of 20-100 db. To accomplish this I limit the input to the primary amplifier which provides the progressive range compression to signals having a maximum amplitude corresponding to detected sounds of 100 db. This limiting can be accomplished in any of the various ways known to the prior art. Only the sound intensities between 20 and 100 db are subjected to the progressive range compression of the present invention. (This limiting of the range of input intensities is to be distinguished from, and is independent of, the output intensity adjustment which controls the intensity of the sounds fed to the user's ear by the hearing aid. The latter adjustment is made solely to conform to the hearing characteristics of the individual user.)

To the accomplishment of the above, and to such other objects as may hereinafter appear, the present invention relates to a hearing aid as defined in the appended claims, and as described in this specification, taken together with the accompanying drawings, in which:

FIG. 1 is an idealized elevational view of a hearing aid assembly such as might be employed in conjunction with the present invention;

FIG. 2 is a block diagram of the hearing aid arrangement of the present invention;

FIG. 3 is a circuit diagram of the progressive range compression circuit and associated circuit parts; and

FIG. 4 is a graphical representation of the mode of operation of the system of the present invention.

The hearing aid of the present invention may comprise, as is conventional, a microphone generally designated 2 for detecting sound and transducing it into electrical signals, an ear piece generally designated 4 for transducing the signals which reach it into vibrations sensible to the person using the device, and appropriate electrical cir-

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cuitry between the microphone 2 and the ear piece 4. That circuitry is contained within a casing generally designated 6, which also may contain the microphone 2, and which may be carried somewhere on the person of the user, a wire generally designated 8 electrically connecting the circuitry in the casing 6 to the ear piece 4. The casing may be provided with an on-off switch 10, which may constitute the only control made available to the user.

As may be seen from FIG. 2, the circuitry of the preferred embodiment of the hearing aid of the present invention here specifically disclosed comprises a pre-amplifier 14 to which the electrical signals produced in the microphone 2 are conveyed, the output of the pre-amplifier 14 being fed to the circuitry generally designated 16 which provides for the progressive range compression, and which is provided with an adjustment means 112 for controlling the scope of the compressed range of signal intensities. The output from the progressive range compression circuit 16 is fed to a power amplifier 20, which is provided with an adjustable intensity control 12, and the output from the power amplifier 20 is fed to the ear piece 4. The nature of the microphone 2, pre-amplifier 14, power amplifier 20 and ear piece 4 may all be relatively conventional, and consequently no detailed showing thereof is here set forth. It may be noted, however, that when, as is preferred, the progressive range control is made effective only over a selected portion of the normal dynamic range of audibility, as over the range of 20-100 db, the pre-amplifier 14 should be so designed as to limit its output to a maximum value corresponding to detected sounds of 100 db, as through the use of a "clipping" circuit of a type heretofore used and well known. It is further preferred, for reasons which will be set forth hereinafter, that at least the last stage of amplification of the pre-amplifier 14 be defined by a transistor 22 (see FIG. 3), and that the output of that transistor 22 be connected to the automatic range control circuit 16 by means of the transformer coupling 24.

The automatic progressive range control circuit 16 comprises one or more primary amplifier stages 26 (which may be of conventional form and which, therefore, are only schematically represented), the output from which is fed along lead 28 to the power amplifier 20. The input to the primary amplifier stages 26 is by means of transformer 30, the upper end of the primary winding 30P of which is connected by lead 32 to the upper end of the secondary winding 24S of the transformer 24 which couples the pre-amplifier 14 thereto. The lower end of the primary winding 30P is connected by lead 34 to point 36, from which two resistors 38 and 40 branch, those resistors being connected at points 42 and 44 respectively to oppositely oriented diodes 46 and 48 respectively, the other ends of those diodes being connected at points 50 and 52 respectively to lead 32. The lower end of the transformer winding 24S is connected by means of lead 54 to point 56 from which resistors 58 and 60 branch, the ends of those resistors 58 and 60 being connected by means of leads 62 and 64 respectively to points 42 and 44 respectively. The point 44 is connected to ground at 68. The diodes 46 and 48 are high conductance junction diodes, selected to have the same operating characteristics over the range of circuit conditions to which they will be subjected.

From the above it will be seen that a balanced bridge circuit is interposed between the pre-amplifier 14 and the primary amplifier 26, and that the bridge functions as a voltage divider between the two. Thus, the output of the pre-amplifier 14 is connected across the bridge defined on one side by the resistor 58 and the diode 46, and on the other side by the resistor 60 and the diode 48. The input to the amplifier 26 is connected across a bridge one side of which is defined by the resistor 38 and the diode 46, and the other side of which is defined by a resistor 40 and the diode 48. The proportion of the output from the pre-amplifier 14 which is fed to the amplifier 26 will depend

upon the relative resistance of the diodes 46, 48 and the resistors 58, 60. The diodes 46, 48 have the characteristic that their resistance will vary in accordance with the current which passes therethrough.

Lead 70 extends from the output line 28 of the primary amplifier 26 to a coupling condenser 72, the other side of which is connected to the base 74 of a PNP transistor 76, a resistor 78 being connected between the transistor base 74 and ground. The collector 80 of the transistor 74 is connected via lead 82 to the base 84 of the NPN transistor 86, the collector 88 of which is connected via lead 90 and resistor 92 to the point 42. The emitter 94 of the transistor 74 is connected to ground via resistor 96 and the emitter 98 of transistor 86 is connected, via resistor 100, to a biasing potential of -2.5 volts. Lead 104 and resistor 106 are connected between the emitter 98 and the base 84 of the transistor 86, capacitor 108 is shunted across the resistor 106, and capacitor 110 is connected between the lead 104 and ground.

The resistor 111 and adjustable resistor 112 are connected between a point 114 on the output line 90 from the transistor 86 and point 116 between the emitter 94 of transistor 76 and the resistor 96 connected thereto.

The circuitry designated by the reference numerals 70-116 constitutes the means for producing proportional range compression. A portion of the output from the amplifier 26 is coupled by the condenser 72 to transistor 76, which functions as a rectifier, and the output of which is fed to transistor 86, which functions as a D.C. amplifier. The output from the transistor 86 is applied across the terminals 42 and 44 of the bridge circuit previously described. The passage of the output current from the feed-back amplifier 76, 86 through the bridge, and particularly through the diodes 46 and 48, will cause the resistance of those diodes to change, the amount of change being dependent upon the amount of current passing therethrough. A change in the resistance of the diodes 46 and 48 will cause a change in the voltage division as between those diodes on the one hand, and the resistors 58 and 60 respectively on the other hand, thus causing a greater or lesser proportion of the output from the pre-amplifier 14 to be applied to the input of the primary amplifier 26, it being borne in mind that the input circuit for the amplifier 26 is only connected across the diodes 46 and 48 and not across the resistors 58 and 60.

The additional feed-back defined by the resistors 111 and 112 modifies the amplification of the feed-back amplifier in accordance with the output thereof in a signal-reducing sense. Without the circuit defined by the resistors 111 and 112, the feed-back amplifier would be progressively effective only over a very small width range at the low-intensity and of the normal intensity spectrum, and above that range all input intensities would produce output signals of the same intensity, this in effect "limiting" the output of the primary amplifier 26 to a constant value for sound input intensities over most of the range necessary for proper audibility. This would, of course, result in great loss of intelligibility. However with the additional feed-back circuit defined by the resistors 111 and 112, a portion of the output of the feed-back amplifier 86 is fed back to the rectifier transistor 76, providing a bias for that transistor which reduces its output, and therefore reduces the output from the amplifier transistor 86. The amount of this additional feed-back, for a given setting of resistor 112, will vary in a manner corresponding to variations in the output of the feed-back amplifier itself, which will in turn vary in a manner corresponding to the amplitude of the signals on lead 28. The overall effect is to spread the graduated action of the feed-back amplifier 86 over the required extended range. The extent of the range over which the feed-back circuit is gradually effective may be varied by the setting of the resistor 112, the setting of that resistor therefore controlling the amount to which the predetermined

range of input intensities (intensities of detected sound) is progressively compressed.

Hence, within the range of amplitudes passed by the pre-amplifier 14, the lower amplitudes will be amplified to a greater degree than the higher amplitudes, and this different degree of amplification will be progressively effective upon signals corresponding to sound intensities throughout the range involved.

The use of a bridge circuit makes any A.C. component in the feed-back signal ineffective, within limits, so that A.C. modulation of the overall circuit is inconsequential.

The effect of the bridge circuit in proportionally varying the amplification of signals of different intensities is accentuated when, as is here specifically disclosed, the last stage of the pre-amplifier 14 is defined by a transistor 22 which is transformer-coupled, at 24, to the bridge circuit. Increase in the signal-reducing feed-back signal applied to the bridge circuit causes the impedance across the output transformer 24 of the pre-amplifier 14 to decrease, thus lowering the gain of the pre-amplifier transistor 22 and also lowering the efficiency of the output transformer 24.

One problem involved in circuitry of the type under discussion is recovery time, that is to say, the time sensitivity of the circuit. If amplification is reduced because of the detection of a sound of high intensity, it is necessary that the circuit be capable of changing to a high amplification state with sufficient rapidity to provide that high amplification for low intensity sounds. If the recovery time is too fast, the hearing aid will pick up echoes; and thus produce a reverberatory effect antithetical to proper intelligibility. Conversely, if the recovery time is too slow the device will not be able to accommodate itself to those sounds of high intensity and low intensity which follow closely upon one another in normal speech. An optimum value is at least 70% recovery within 100 milliseconds. The condenser 108 in the feed-back circuit serves the dual function of controlling in part the recovery time of the feed-back circuit and also the filtering out of A.C. ripple components. If it were fully effective as a filter it would produce a recovery time much too great for optimum operation. The value of the condenser 108 is therefore chosen to give the desired recovery time, and such A.C. components as are not filtered out by the condenser 108 are balanced out by the bridge circuit.

Purely by way of exemplification the circuit elements of the bridge circuit and progressive range compression circuit of FIG. 3 may have the following values:

Resistors 38 and 40	ohms	300
Resistors 58 and 60	do	1000
Capacitor 72	mf	4
Resistor 78	ohms	10,000
Resistor 92	do	22
Resistor 96	do	47
Resistor 100	do	47
Resistor 106	do	4700
Capacitor 108	mf	80
Capacitor 110	mf	20
Resistor 111	ohms	100
Resistor 112	do	0-1000

In use, when a given person is to fitted with the hearing aid of the present invention he will be tested to determine the particular dynamic intensity range which he is capable of hearing. If, for example, individual A can hear sounds comfortably between 50 and 110 db—a range of 60 db—the resistor 112, which controls the variation of feed-back in accordance with signal intensity, will be set so that detected sounds having an intensity range between 20 and 130 db, the normal dynamic acoustical range, will produce outputs to the power amplifier 20 over a 60 db width range. Then, by proper setting of the intensity control 12 in the power amplifier 20, the amplification of the output from the progressive range

compressor 16 is adjusted so that the ear piece 4 produces sensible vibrations within the desired hearing range of 50-110 db. If the hearing of individual B is more greatly impaired, so that he can only hear comfortably in the range between 90 and 120 db—a range of 30 db—the resistor 112 will be set to compress the normal 110 db width dynamic audibility range into a 30 db range, and the signals within that 30 db range will be amplified in the power amplifier 20 according to the setting of the intensity control 12 so as to produce an ear piece output within the actual audibility range of that individual, i.e., 90-120 db. These situations are graphically represented in FIG. 4, the solid line 120 representing the characteristic of the system of the present invention as applied to individual A, and the broken line 122 representing the characteristics of the present system for individual B.

It will be noted that the setting of the intensity control 12 is independent of, and does not affect the operation of, the setting of the progressive range compression control resistor 112. The setting of the resistor 112 is determined by the desired width of output range, and therefore would be the same for an individual having an audibility range between 50 and 110 db and an individual having an audibility range between 60 and 120 db—both having an audibility range 60 db wide. The setting of the intensity control 12 would, however, vary as between these two individuals, so that the upper intensity limit of the vibrations emanating from the ear piece 4 would be 110 db or 120 db respectively.

However, as soon as both of these adjustments have been made, thereby to bring the characteristics of the hearing aid into conformity with the characteristics of the individual concerned, no further adjustments are necessary, and the person using the hearing aid will be able to hear all of the sounds that a normal ear can hear, with the various intensities of the sounds heard substantially in proper proportional relationship. The user of the device will therefore be able to hear and intelligibly distinguish the same sounds as a person with normal hearing.

Because of tendency of the human ear to distort sounds having an intensity above 100 db, because accurate detection and reproduction of sounds above that intensity level is unnecessary for accurate intelligibility, and because sounds above that intensity usually result in discomfort, if not actual pain, it may be desired to limit the selective input of the hearing aid to a maximum value of 100 db. This has the additional advantage that the width of the input intensity range to be compressed by the progressive range compression circuit is reduced from 110 db (20-130 db) to 80 db (20-100 db). As set forth by way of example, this limiting may be accomplished by suitable conventional limiting circuitry in the preamplifier 14. When this is done, the normal dynamic intensity range of 20-100 db may, for a person like individual A mentioned above, whose comfortable audibility range is from 50-110 db, be compressed into a 60 db range (50-110 db) through adjustment of the resistor 112, that range then being so located by setting the adjustable intensity control 12 that the maximum output to that individual's ear is 110 db. However, a person such as individual A might well find it more comfortable not to have sounds applied to his ear above 95 db, this value being approximately 20 db above the intensity value for normal conversation. Under such circumstances, and as indicated by the dotted line curve 124 of FIG. 4, the pre-selected 20-100 db range for detected sound will, for that individual, be progressively compressed into a range having a width of 45 db through the setting of resistor 112, and that range will then be amplified in power amplifier 20, through the setting of intensity control 12, so that the actual intensity of vibrations applied to the ear is in the 50-95 db range.

The above exposition has been based upon a limited

number of examples but it will, it is believed, make clear the manner in which the hearing aid of the present invention can, through the use of the two adjustments 112 and 12, be tailored to the requirements or desires of a particular individual and will impart to that individual the ability to hear and to accurately distinguish sounds over the same range as is available to a person with normal hearing.

All of the circuitry of the hearing aid of the present invention may utilize transistors, to the end that the circuitry, as well as the microphone 2 and the power supply, may be included within a casing having a length and breadth of only a few inches, and a thickness of only a fraction of an inch, so that it may be carried conveniently and unobtrusively, even in a shirt pocket. The only manual control which is really required is the on-off switch 10. With the use of this hearing aid initial adjustment of the device to correspond to the dynamic intensity range of audibility of the particular individual will result in a device which will impart to that individual the ability to hear and to distinguish the full range of sounds within the normal intensity range without any appreciable distortion. If desired, appropriate tone control circuits may be built into the apparatus to conform to the hearing peculiarities of the individual insofar as differences in frequencies of sound are concerned, as is well known. The device of the present invention can be used by practically all persons with hearing defects, and is of particular value to those persons whose threshold of minimum audibility is quite close to the pain threshold.

The circuitry specifically disclosed is believed to represent a significantly efficacious way of achieving the result desired, and particularly the broad scope of progressive range compression, and the adjustability thereof without appreciable distortion, instability and noise, but it is believed that the basic manner in which the overall system operates, independently of the specific circuitry used, is highly advantageous.

While but a single embodiment of the present invention has been here disclosed, particularly insofar as circuitry is involved, it will be apparent that many variations may be made therein, all within the scope of the following claims.

I claim:

1. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for detecting sound over a given range of intensities extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof and for transducing said sound of said given range of intensities into electrical signals the intensities of which are related to the intensities of said detected sound, means for converting said signals into modified signals the intensities of which vary substantially in accordance with the variations in intensities of said sounds but over a range substantially less than said given range, and means for transducing said modified signals into human-sensible vibrations of intensities varying substantially in accordance with the intensities of said signals, said converting means comprising an amplifier having gain-varying means to which said signals are connected so as to vary said gain in an inverse sense in accordance with the magnitude of said signals over a substantial portion of the entire range of said signals including a portion of said range remote from the upper region thereof, said last mentioned transducing means being of the type adapted to be applied to and carried by the head of the user.

2. In the hearing aid of claim 1, manually adjustable amplifying means in advance of said transducing means and after said detecting and converting means for amplifying said modified signals, thereby to produce, via said transducing means, human-sensible vibrations having

a range of intensities with an upper intensity-level below the pain-threshold of the user and a lower intensity level above the minimum audibility level of the user.

3. In the hearing aid of claim 1, amplifying means in advance of said transducing means and after said detecting and converting means for amplifying said modified signals, thereby to produce, via said transducing means, human-sensible vibrations having a range of intensities with an upper intensity level below the pain-threshold of the user and a lower intensity level above the minimum audibility level of the user, and means in said detecting and converting means for limiting the maximum intensity value of said signals to a value corresponding to detected sound intensities on the order of 100 db.

4. In a hearing aid or the like, a transducer and an amplifier, a normally balanced bridge circuit having first and second sets of opposed terminals, means connecting one pair of legs of said bridge circuit to a terminal of said first set, said legs having resistance which varies with current, means connecting said transducer and said amplifier to one another with said first set of terminals of said bridge circuit in shunt across said connection, and a feed-back circuit electrically connected between the output of said amplifier and said second set of terminals of said bridge circuit.

5. The hearing aid of claim 4, in which a transistor amplifier is connected between said transducer and said bridge circuit.

6. The hearing aid of claim 4, in which a transistor amplifier is connected between said transducer and said bridge circuit and is transformer-coupled to said bridge circuit.

7. The hearing aid of claim 4, in which said feed-back circuit comprises a feed-back amplifier having input and output, and an additional feed-back means connected between said output and said input of said feed-back amplifier.

8. The hearing aid of claim 7, in which said additional feed-back means is adjustable.

9. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual a first amplifier having an output, feed-back means operatively connected between said output and said amplifier for varying the amplification of said amplifier inversely with respect to the amplitude of said output, and means for gradually varying the effectiveness of said feed-back means in accordance with its output, thereby to amplify signals of low intensity more than signals of high intensity over an extended range comprising substantially the normal audibility range, said last mentioned means being effective over a substantial portion of said entire extended range including a portion thereof remote from the upper region thereof.

10. The hearing aid of claim 4, in which said feed-back circuit comprises rectifying means connected to the output of said amplifier, D.C. control means connected between said rectifying means and said amplifier and effective to amplify the output of said rectifying means and vary the amplification of said amplifier section in accordance therewith, and means connected between said rectifying means and said control means, sensitive to the output of said rectifying means, and effective to vary the amplification of said control means in accordance with the output of said rectifying means.

11. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the

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normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduately amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, and means for transducing said amplified signals into sound, said amplifying means comprising gain-varying means to which said signals are connected so as to vary said gain inversely in accordance with the magnitude of said signals over a substantial portion of said given range including a portion thereof remote from the upper region thereof, said last mentioned transducing means being of the type adapted to be applied to and carried by the head of the user.

12. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduately amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, second amplifying means for further amplifying said previously amplified signals substantially uniformly for all intensities thereof, and means for transducing said amplified signals into sound, said first amplifying means comprising gain-varying means to which said signals are connected so as to vary said gain inversely in accordance with the magnitude of said signals over a substantial portion of said given range including a portion thereof remote from the upper region thereof, said last mentioned transducing means being of the type adapted to be applied to and carried by the head of the user.

13. In a hearing aid, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduately amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, and means for transducing said amplified signals into sound, and, in combination therewith, means in advance of said amplifying means for limiting the maximum intensity of input of said amplifying means to a value corresponding to sound intensities on the order of 100 db at said means for transducing received sounds into electrical signals.

14. In a hearing aid, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduately amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range

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but compressing said range of intensities, second amplifying means for further amplifying said previously amplified signals substantially uniformly for all intensities thereof, and means for transducing said amplified signals into sound, and in combination therewith, means in advance of said first amplifying means for limiting the maximum intensity of input of said first amplifying means to a value corresponding to sound intensities on the order of 100 db at said means for transducing received sounds into electrical signals.

15. In a hearing aid, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduately amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, second means for adjustably further controlling the intensity of said amplified signals, and means for transducing said amplified signals into sound, and in combination therewith, means in advance of said amplifying means for limiting the maximum intensity of input of said first amplifying means to a value corresponding to sound intensities on the order of 100 db at said means for transducing received sounds into electrical signals.

16. In a hearing aid, means for detecting sound over a given range of intensities extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof and for transducing said sound of said given range of intensities into electrical signals the intensities of which are related to the intensities of said detected sound, means for converting said signals into modified signals, the intensities of which vary substantially in accordance with the variations in intensities of said sounds but over a range substantially less than said given range, and means for transducing said modified signals into human-sensible vibrations of intensities varying substantially in accordance with the intensities of said signals, and, in combination therewith, means in said detecting and converting means for limiting the maximum intensity value of said signals to a value corresponding to detected sound intensities on the order of 100 db.

17. In a hearing aid or the like, a first amplifier having an output, feed-back means operatively connected between said output and said amplifier for varying the amplification of said amplifier inversely with respect to the amplitude of said output, and means for graduately varying the effectiveness of said feed-back means in accordance with its output, thereby to amplify signals of low intensity more than signals of high intensity over an extended range, and in which said feed-back means comprises a second amplifier having input and output, said effectiveness-varying means comprising additional feed-back means electrically connected between said input and said output of said second amplifier.

18. The hearing aid of claim 17, in which said additional feed-back means is adjustable.

19. In a hearing aid or the like, a first amplifier having an output, feed-back means operatively connected between said output and said amplifier for varying the amplification of said amplifier inversely with respect to the amplitude of said output, and means for graduately varying the effectiveness of said feed-back means in accordance with its output, thereby to amplify signals of low intensity more than signals of high intensity over an extended range, and in combination therewith, means in advance of said first amplifier for limiting the maxi-

mum intensity of the input to said first amplifier to a value corresponding to detected sound intensities on the order of 100 db.

20. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduatly amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, and means for transducing said amplified signals into sound, in which said amplifying means comprises an amplifying section having an input and an output adapted to carry a fluctuating signal, means for rectifying a portion of said output, D.C. control means connected between said rectifying means and said amplifying section and effective to amplify the output of said rectifying means and vary the amplification of said amplifying section in accordance therewith, and means connected between said rectifying means and said control means, sensitive to the output of said rectifying means, and effective to vary the amplification of said control means in accordance with said output of said rectifying means.

21. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduatly amplify signals of lower intensities to a greater degree than signals of higher intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, second amplifying means for further amplifying said previously amplified signals substantially uniformly for all intensities thereof, and means for transducing said amplified signals into sound, in which said first amplifying means comprises an amplifying section having an input and an output adapted to carry a fluctuating signal, means for rectifying a portion of said output, D.C. control means connected between said rectifying means and said amplifying section and effective to amplify the output of said rectifying means and vary the amplification of said amplifying section in accordance therewith, and

means connected between said rectifying means and said control means, sensitive to the output of said rectifying means, and effective to vary the amplification of said control means in accordance with said output of said rectifying means.

22. In a hearing aid of the type designed to compensate for the hearing deficiencies of a particular individual and comprising parts adapted to be carried on the person of that individual, means for transducing received sounds into electrical signals the intensities of which are related to the intensities of said received sounds, means for amplifying said signals, said amplifying means being effective, over a given range of signal intensities corresponding to sound extending over a substantial portion of the normal sound audibility range and including at least a portion of said normal audibility range remote from the upper region thereof, to graduatly amplify signals of lower intensities to a greater degree than signals of high intensities, thereby substantially maintaining the intensity relationship of said signals of said given range but compressing said range of intensities, second means for adjustably further controlling the intensity of said amplified signals, and means for transducing said amplified signals into sound, in which said amplifying means comprises an amplifying section having an input and an output adapted to carry a fluctuating signal, means for rectifying a portion of said output, D.C. control means connected between said rectifying means and said amplifying section and effective to amplify the output of said rectifying means and vary the amplification of said amplifying section in accordance therewith, and means connected between said rectifying means and said control means, sensitive to the output of said rectifying means, and effective to vary the amplification of said control means in accordance with said output of said rectifying means.

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