PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventors: ROBERT JOSEPH PACKER and EDMUND RAMSEY WIGAN

1,096,196

1,096,196

Date of filing Complete Specification: Nov. 12, 1965.

Application Date: Nov. 13, 1964. *No. 46362/64.*

Complete Specification Published: Dec. 20, 1967.

Index at acceptance: —**H4** R18AX

Int. Cl.: —**H 03 g 7/06, H 03 g 11/00**

COMPLETE SPECIFICATION

Means for Controlling the Amplitude of Electrical Signals

We, THE BRITISH BROADCASTING CORPORATION, a British Body Corporate, of Broadcasting House, London, W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

The present invention relates to means, including a photo-controlled varistor (or P.C.V.), for controlling the amplitude of electrical signals. A photo-controlled varistor is an assembly comprising a photo-sensitive resistor arranged to receive radiation (such as visible light) from an electrically driven source of radiation.

A number of proposals have been published which employ P.C.V. assemblies for limiting compressing and expanding electrical signals. In such processes it is the signal envelope which is modified while the spectral content of the signal waveform contained within the envelope is not altered significantly.

The various devices employed are described as input-controlled or output-controlled according to whether the control signal is derived from the input signal or output signal respectively.

One difficulty that has been met with in such assemblies is that it has not been found possible to maintain the compression (or expansion) ratio N, which is defined as the ratio of the decibel increments of output signal amplitude to the decibel increments of input signal amplitude, constant over any considerable range. The continual variation of N, whenever the input signal level changes, has been found disadvantageous. It is one of the objects of the present invention to overcome, or at least substantially reduce, this difficulty.

It has been proposed to use as radiation source a filamentary light source having a thermal inertia sufficient to prevent it from following current fluctuations having frequencies in excess of the syllabic rate of voice frequency signals in a communication system. For many purposes such thermal inertia is not acceptable.

According to the present invention, there is provided a circuit having between input and output terminals the photosensitive resistor of a photo-controlled varistor arranged to control the attenuation between the input and output terminals, the source of radiation of the varistor being a semiconductor diode arranged to be driven in dependence upon signals at the output or input terminals, and the parameters of the circuit elements being so chosen that, at least over a substantial range of amplitude levels above a limiting value, the ratio N of the decibel increments of the output signal amplitude to the decibel increments of the input signal amplitude remains substantially constant at a value of substantially 1/2 or 2/1 or zero, according to whether the circuit operates as a compressor, an expander, or a limiter, respectively, over said range.

Although for most purposes it is preferred that the light-generating semiconductor diode (e.g. Ga.P), should be one having a linear relation between the driving current and the radiation generated, and that the photo-sensitive resistor (e.g. a Cd.Se photo-conductive cell) should be one having a linear relation between its conductance and the light flux, the invention is not limited to such linear devices. In the following description, however, linear devices will be assumed.

The invention will be described, by way

of example, with reference to the accompanying drawings in which

Fig. 1 is the block schematic diagram of an output-controlled compressor or limiter according to the invention,

Figs. 2, 3 and 6 show curves used in explaining the operation of the circuit of Fig. 1, Figs. 2(a) and 6 illustrating the input/output signal relationship obtained with the circuit of Fig. 1 when $N=1/2$ and $N=0$ respectively,

Fig. 4 is the block circuit diagram of an input-controlled expander according to the invention,

Fig. 5 shows curves of the input/output relationships obtained with the circuit of Fig. 4,

Fig. 7 is a block circuit diagram of a circuit arrangement according to the invention including a light-controlled gate, a compressor and a limiter,

Figs. 8 and 9 show curves illustrating the operation of the circuit of Fig. 7,

Fig. 10 is the block circuit diagram of an input-controlled limiter according to the invention, and

Fig. 11 shows curves of the input/output signal relationships obtained with the circuit of Fig. 10.

Referring to Fig. 1, the circuit between input terminals 1, 1′, to which a signal of amplitude e_1 is assumed to be applied, and output terminals 2, 2′, at which the signal amplitude is e_2, contains a fixed series resistor A. The output terminals are shown connected to a load B which represents the input impedance of equipment that follows the circuit of Fig. 1 in a signal chain. The load B will be assumed to be resistive. It is desirable that the ratio A/B should be small, say 1/100.

Across the output terminals 2, 2′ is connected the photo-sensitive resistor r (for example a Cd.Se diode cell) of a varistor V. The light source of the varistor (for example a light-generating Ga.P diode) is excited from the output signal through a chain including a high gain amplifier 3, a rectifier 4 and a smoothing circuit 5. The signal threshold at which gain reduction begins is determined by a reverse bias S_o applied to the light source of the varistor V by means of an adjustable resistor 6. This bias prevents any rectified current flowing to the varistor light source until the output voltage e_4 of the smoothing circuit 5 exceeds a predetermined value.

The effective resistance of the resistor r of the varistor V to alternating current is assumed to vary inversely as the light flux L falling on it and L is assumed to be proportional to the current in the light source of V. These conditions can be met with sufficient accuracy by a P.C.V. assembly as already described consisting of a Ga.P diode light source and a Cd.Se diode cell.

Referring to Fig. 2, the value N remains constant at 1/1 until the input reaches a threshold value S_{th} determined by the setting of the resistor 6 in Fig. 1. Up to this point the resistance of r remains effectively infinite.

Above the threshold S_{th}, three curves are shown: curve (a) where $N=1/2$ is the desired curve which is substantially a straight line, and curves (b) and (c) which show substantial variations of N with input signal amplitude. The way in which the parameters of the components in Fig. 1 can be chosen in order to obtain the curve (a) will be understood from the following analysis. In this the elements A, B and r will be assumed to have the values A, B and r respectively.

K_1 and K_2 are constants such that

$$K_1=e_4/e_2$$

$$\text{and } K_2=(1/r)/(e_4-S_o). \qquad (1)$$

Fig. 3 illustrates the relationship between 1/r and e_4.

It is clear that when e_4 is less than S_o (or e_2 less than S_o/K_1), the lamp of the varistor V will not be lit, the resistance r will be very high and no compression will occur. Thus equation (1) establishes the threshold input level S_{th} below which the system will behave as a simple, linear, amplifier.

Assuming that e_4 is equal to or greater than S_o, then from general considerations we have:—

$$e_1/e_2=1+A/B+A/r \qquad (2)$$

Substituting from (1) into (2):—

$$e_1/e_2=(1+A/B-A.K_2.S_o)+(A.K_1.K_2).e_2 \qquad (3)$$

Whence

$$e_1=(1+A/B-A.K_2.S_o).e_2+(A.K_1.K_2)(e_2)^2 \qquad (4)$$

Now, by adjusting A, B or K_2, the term (e_2) in equation (4) can be eliminated. This happens when

$$A.K_2.S_o=1+A/B \qquad (5)$$

i.e. when

$$e_1=(A.K_1.K_2)\,(e_2)^2$$

or

$$e_2=\sqrt{e_1/(A.K_1.K_2)} \qquad (6)$$

Equation (6) implies that the circuit will act as a compressor having a compression ratio N of 1/2.

From equation (4), it can be shown that:—

$$e_1/A.K_1.K_2=e_2^2+[1+A/B-A.K_2.S_o]\;e_2/A.K_1.K_2 \qquad (4a)$$

If this circuit is to be used as a limiter, N is required to be 0, i.e. e_2 is to be independent of e_1. Assuming that S_o has been made large, the term in e_1 can be made 0 by making K_1 comparable with S_o, whence from equation (4a):—

$$e_2 = S_o/K_1 \quad (7)$$

Fig. 6 shows the input/output signal relationships of the circuit of Fig. 1 arranged to satisfy equation (7).

Fig. 10 shows a circuit for operation as an input-controlled limiter; the function of the photosensitive resistor r is the same as in Fig. 1 and like parts in the two Figures have the same reference. In Fig. 10, the control chain supplying current to the Ga.P diode is fed from the input signal e_1 making $K_1 = e_4/e_1$, so that

$$e_1/e_2 = (1+(A/B) - A.K_2.S_o) + A.K.K_2.e_1 \quad (8)$$

which may be contrasted with equation (3).

Again, by adjusting A, B, or K_2, the constant term in equation (8) can be eliminated. This happens when

$$A.K_2.S_o = 1 + A/B$$

Whence

$$e_1/e_2 = A.K_1.K_2.e_1 \quad (9)$$

and

$$e_2 = 1/(A.K_1.K_2) \quad (10)$$

Fig. 11 shows the input/output signal relationships of the circuit of Fig. 10, curve (a) being an ideal curve with a slope of N=0 and curves (b) and (c) showing varying degrees of misadjustment of the components in the circuit.

Fig. 4 shows the circuit of Fig. 1 modified to convert it into an expander with N=2/1. Like parts in the two Figures have the same reference. In this case the light-sensitive resistor r is connected in parallel with a fixed resistor C connected in series between the input and output terminals. A fixed resistor D is connected between the output terminals 2, 2′. The light source of the varistor V is excited by the input signal e_1.

Fig. 5 shows the relation between input and output signal amplitude, curve (a) being the desired curve with a substantially constant slope of 2/1 and curves (b) and (c) being non-linear.

The correct design of the circuit of Fig. 4 to produce the curve (a) of Fig. 5 can be seen from the following analysis:—

We have from general considerations:—

$$e_1/e_2 = 1 + 1/D[(1/C) + (1/r)] \quad (11)$$

We again have

$$K_1 = e_4/e_1$$

$$1/r = [K_2(K_1.e_1 - S_o)] \text{ provided } e_1 > S_o/K_1 \quad (12)$$

Substituting (12) into (11)

$$e_1/e_2 = 1 + 1/D\ [(1/C) + K_2(K_1.e_1 - S_o)] \quad (13)$$

To obtain an expansion ratio of 2/1, we so arrange the circuit constants that

$$K_2.S_o = 1/C \quad (14)$$

Then, substituting (14) into (13)

$$e_1/e_2 = 1 + 1/(DK_2.K_1.e_1)$$

$$e_2 = DK_1.K_2.e_1^2/(1 + DK_1.K_2.e_1) \quad (15)$$

As before, $D.K_1.K_2$ is made small, so that

$$e_2 = D.K_1.K_2.e_1^2 \quad (16)$$

which shows that the expansion ratio will be N=2/1 for all input levels greater than S_{th} at which $e_1 = S_o/K_1$.

The broken line G in Fig. 5 indicates the point on the graphs at which the performance suddenly changes because the threshold S_{th} has been passed.

The choice of the resistance C and D is important. For efficient expander action the ratio C/D must be large (for example 100/1); the choice of their ohmic values depends on the parameters of the P.C.V. assembly and is decided as follows:—

When the lamp varistor V is unexcited, and the cell in complete darkness, the cell resistance r rises to a very high value r_{max} (in some cells r may reach 10 or more megohms). In this regime the cell response to light changes is usually too sluggish for use. On the other hand when the lamp gets brighter and r has been reduced to some 100's of kilo-ohms, the response is rapid and the expander system is usable. The value of C has to be chosen to make a suitable compromise between a resistance low enough to swamp the higher values of r (where response is sluggish) and a resistance so low that an excessively high light intensity is called for from the lamp before any expander action starts.

Values of C and D near 300 k. ohms, and 3 k. ohms, respectively, have been found suitable for a typical expander employing a Cd.Se cell.

It is to be borne in mind, however, that the transition from the linear to the expander regime can be made more sudden simply by increasing the input voltage e_1 at which the threshold S_{th} is set. For if e_1 is made larger, any given percentage of e_1 will also be larger. The price paid for the more rapid transit of the signal through the threshold point (where the lamp will be very faint, and the cell response sluggish) is that any rise of threshold level brings both the lamp and its driving amplifier by that much nearer to their point of overload.

All other considerations however demand that for efficient operation an expander of the type described should have the lowest possible threshold level; in Fig. 4 for instance the "no-signal-loss" of the circuit is 40 dB (the ratio 1+C/D).

It will be evident that by using circuits according to Figs. 1 and 4 in cascade there can be obtained a circuit with N=1.

Fig. 7 shows the circuit embodying a compressor as in Fig. 1, an amplitude limiter as in Fig. 10, and other refinements.

The compressor part of the circuit includes the varistor V and a control chain the gain of which is controlled by a variable attenuator 10, whilst a component 11, represented for simplicity as an amplifier, performs the functions of parts 3, 4, 5 and 6 in Fig. 1.

In the circuit of Fig. 7, the threshold S_{th} can be controlled by the attenuator 10, which has the effect of altering e_1 in Fig. 1. It is to be noted, however, that the attenuator 10 is mechanically coupled to an attenuator 12 in the signal chain after the variable gain stages, in such a way that when the attenuation produced by 10 increases by x dB, the attenuation produced by 12 is increased by $x/2$ dB. This ensures that for signals having sufficient amplitude to produce compression, the output at 2 shall remain unchanged when 10 is used to alter the value of S_{th} from S_{th1} to S_{th2} as is shown in Fig. 8. If 12 were not ganged to 10, a decrease in attenuation by y dB at 10 (introduced in order to decrease S_{th} by y dB from S_{th1} to S_{th2}) would reduce the output at 2 by $y/2$ dB.

It can be seen from Figs. 8 and 9 that the output signal is a compressed version of the input signal.

The circuit of Fig. 7 also includes a limiter comprising a further varistor V_1 having its light source driven from the output of the variable gain stage of the compressor, through a control chain, fed from the same point, in which a variable attenuator 13 controls the gain of a component 14, represented for simplicity as an amplifier, but performing the functions of parts 3, 4, 5 and 6 in Fig. 10. An ideal limiter acts as a compressor of compression ratio N=0. The circuit shown in Fig. 10 will produce a compression ratio which is zero when the input voltage e_1 is just above the limiting threshold S_{th}, N remaining very small until the control chain overloads. When the output of the attenuator 13, amplified and rectified by 14, is sufficient to overcome the reverse bias S_o, the Ga.P diode is excited and the limiting action sets in. Thus, by means of the attenuator 13, which can conveniently be calibrated in dB, the limiting level can be adjusted as required.

The circuit of Fig. 7 also includes a light-controlled gate, or gate-step, including a varistor V_2 having its resistor connected in parallel with a variable resistor 15 in the main signal path between input and output terminals 1, 2. The light source of this varistor V_2 is fed with signals from the input terminal 1, through a variable attenuator 17, an amplifier 18, a further variable attenuator 19 by means of which the gate threshold can be adjusted, and a component 20 represented for simplicity as an amplifier, but performing the functions of parts 3, 4, 5 and 6 in Fig. 4.

The gate can be regarded as an expander, such as that of Fig. 4, carried to the limit of performance, the "step" control being the resistor 15 which corresponds to C in Fig. 4. The gate acts virtually as a two-position switch; when the input is insufficient to operate the gate, the gate has a loss fixed by 15 and there is no compression (N=1); when the input rises the resistance of the resistive element of the varistor V_2 is reduced sharply and the standing loss of the system is reduced, the amount of reduction depending on the setting of 15.

The gate-step may be introduced, for example, to prevent the studio background noise from becoming obtrusive in the pauses in the programme signal, e.g. between sentences and movements of a musical composition.

In the absence of the gate-step, noise signals, either when alone or when associated with the programme signal, will always be too small to influence the compressor, for the compressor operates in terms of the major signal components and thus ignores the minor. It follows that when speech starts the compressor operates to reduce (by some quantity L_o dB) the level of the composite signal-plus-noise, that is to say the signal-to-noise ratio at the input and output of the compressor. When speech stops, the gain of the system immediately rises by precisely the amount L_o that it fell when speech started; the noise level follows the rise of gain and the impression is given that the output signal-to-noise ratio has been reduced by L_o dB.

The gate-step can be adjusted to correct this effect; when properly adjusted the gate-step reduces the system gain by exactly the amount L_o, thus maintaining the effective output signal-to-noise ratio during pauses in the programme. To achieve this the gate-step must be adjusted to agree with the value of L_o; L_o will, of course, depend upon the user's choice of programme level at the input of the compressor.

It will be appreciated that the threshold, at which the gate operates, must be set slightly above the studio noise level, otherwise the noise signal will operate the gate.

In the optically-controlled systems described which use semiconductor diode lamps, the response time of the lamps (much less than 1 ms) is so short that the overall time-constant of the P.C.V. assembly plus driving amplifier can be decided almost completely by the electrical components in the control loop.

In systems used for controlling the amplitude of audio frequency signals the "operate" time constants of the limiter, compressor and expander may be made about 1 ms; on the other hand the "release" time constant of the gate, limiter and compressor (namely the rate at which the P.C.V. element is allowed to revert to its un-excited state) may be 500 ms. Unless the closure of the gate is somewhat delayed, the after-reverberations of speech and music are cut-off unnaturally short at the ends of sentences and musical phrases.

It should be noted that all the equations given in this description relate to the steady state condition.

Although the invention has been described with particular reference to audio frequency signals, the circuits can be adapted to operate with signals of higher frequencies by suitable choice of component values.

In Specification No. 967,152 there is claimed, inter alia, an amplitude compression and/or expansion arrangement for voice frequency electrical signals in a communication system comprising a variable loss network including a photo-electric element, a source of light acting upon said element and means to modulate said source of light in accordance with the syllabic rate of said voice frequency signals.

WHAT WE CLAIM IS:—

1. A circuit having between input and output terminals the photo-sensitive resistor of a photo-controlled varistor arranged to control the attenuation between the input and output terminals, the source of radiation of the varistor being a semiconductor diode arranged to be driven in dependence upon signals at the output or input terminals, and the parameters of the circuit elements being so chosen that, at least over a substantial range of amplitude levels above a limiting value, the ratio N of the decibel increments of the output signal amplitude to the decibel increments of the input signal amplitude remains substantially constant at a value of substantially 1/2 or 2/1 or zero, according to whether the circuit operates as a compressor, an expander, or a limiter, respectively, over said range.

2. A circuit according to claim 1, wherein said photosensitive resistor is connected in parallel with said output terminals.

3. A circuit according to claim 2, having its output terminals connected to a load and having a resistor connected in series between an input terminal and the photo-sensitive resistor, said series resistor having a resistance which is much smaller than the impedance of said load over the operating frequency range.

4. A circuit according to any preceding claim, comprising means for applying a variable bias to the light source of the varistor in such a manner as to vary the said limiting value.

5. A circuit according to claim 1, wherein said photo-sensitive resistor is connected in series between the input and output terminals.

6. A circuit according to claim 5, comprising a resistor connected in parallel with said photo-sensitive resistor.

7. A circuit according to claim 6, wherein the parallel-connected resistor is variable.

8. A circuit according to claim 2, in which the source of radiation of the varistor is driven in dependence on signals at said output terminals and comprising a variable attenuator arranged to control the amplitude of the signals applied to the said source and a further variable attenuator ganged to the first-named attenuator and so arranged that the amplitude of the output signals remains substantially unaffected by variation of the first-named attenuator over a substantial range.

9. A circuit substantially as hereinbefore described with reference to Fig. 1, or Fig. 4 or Fig. 7 or Fig. 10 of the accompanying drawings.

REDDIE & GROSE,
Agents for the Applicants,
6, Bream's Buildings, London, E.C.4.

Leamington Spa: Printed for Her Majesty's Stationery Office by the Courier Press.—1967
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

Fig. 1.

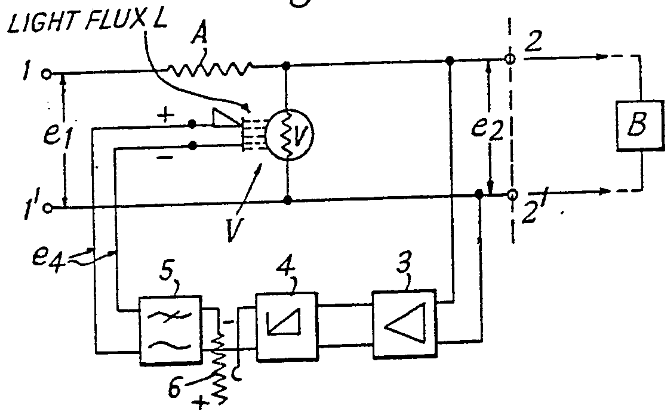
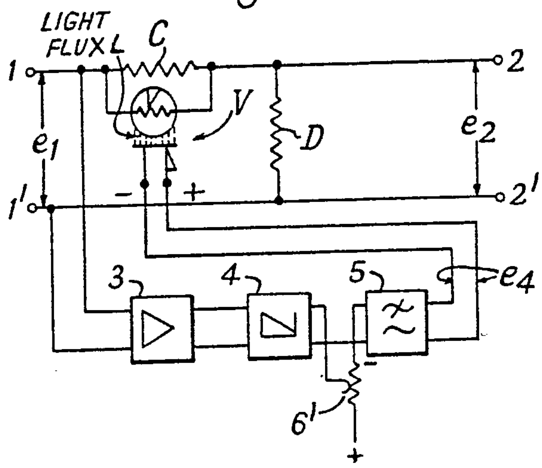

LIGHT FLUX L
A
1
2
+
−
V
e_1
e_2
B
1'
2'
V
e_4
5
4
3
6
+

Fig. 4.


LIGHT FLUX L
C
1
2
V
D
e_1
e_2
1'
2'
−
+
3
4
5
e_4
−
6'
+

1096196 PROVISIONAL SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 1 & 2

Fig. 2.

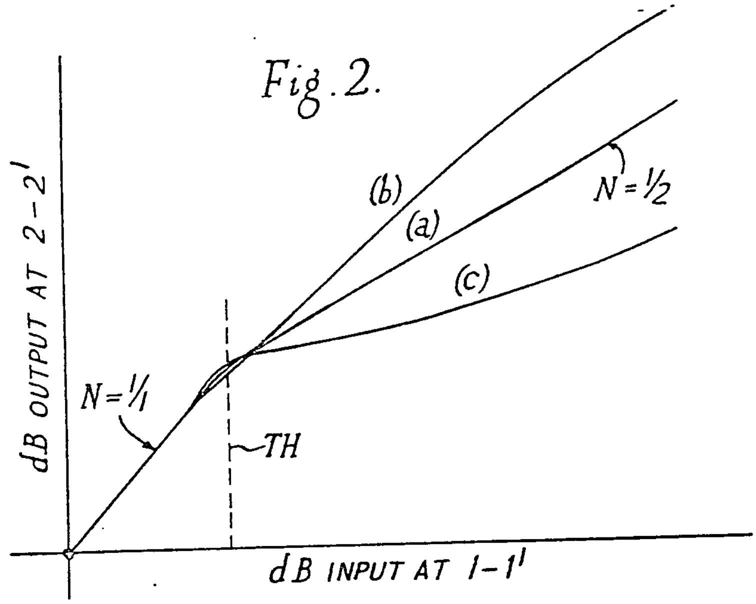
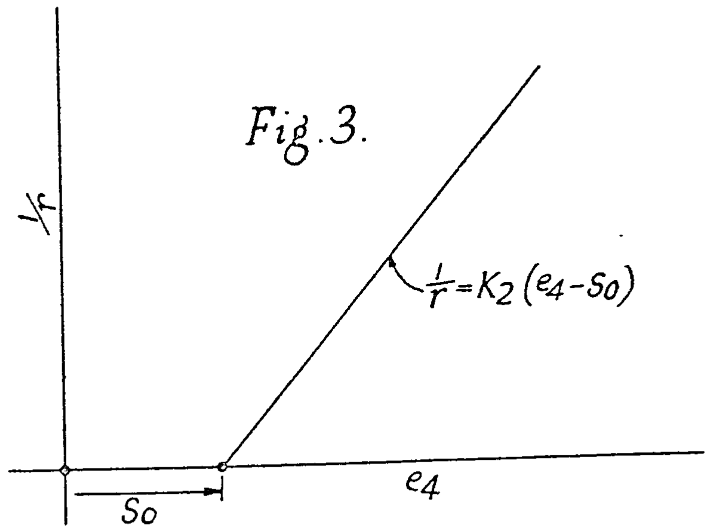


Fig. 3.



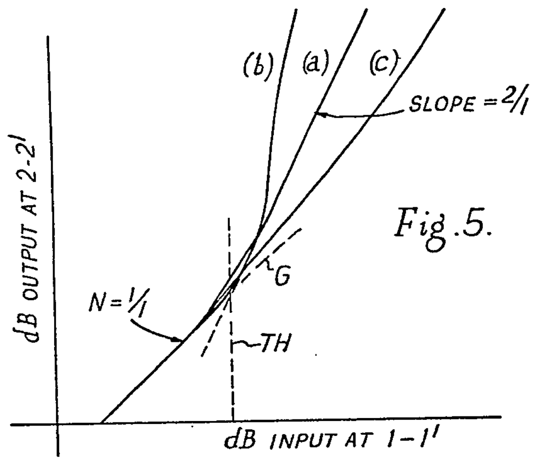


Fig.5.

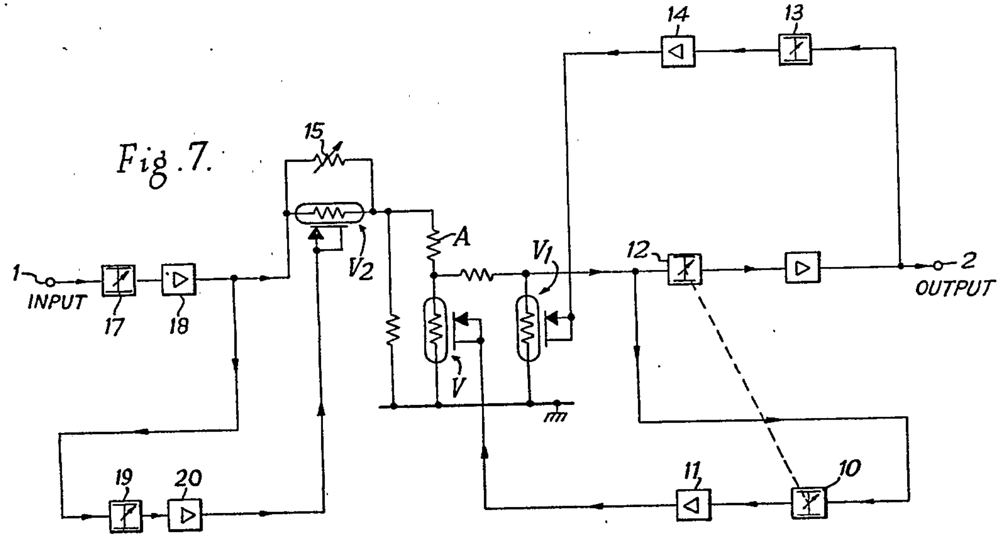


Fig.7.

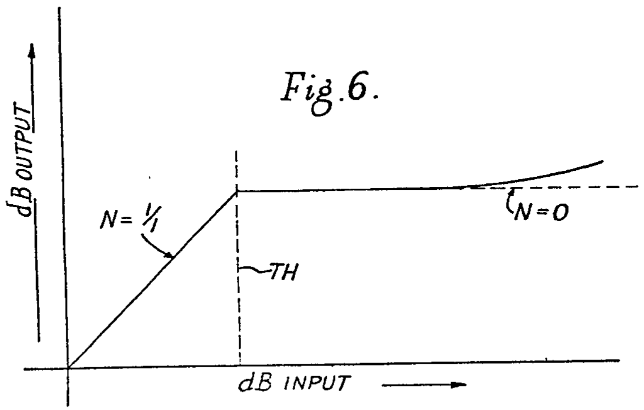


Fig.6.

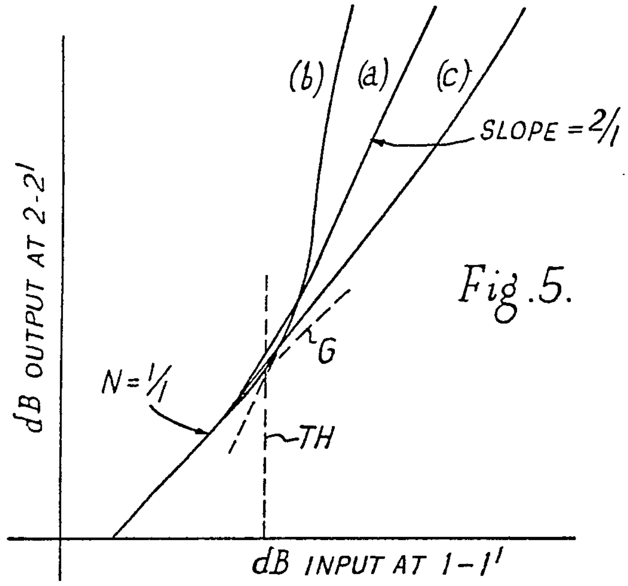


Fig.5.

Fig.7.

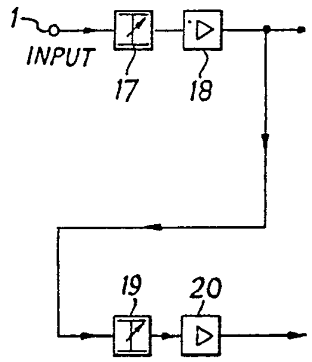
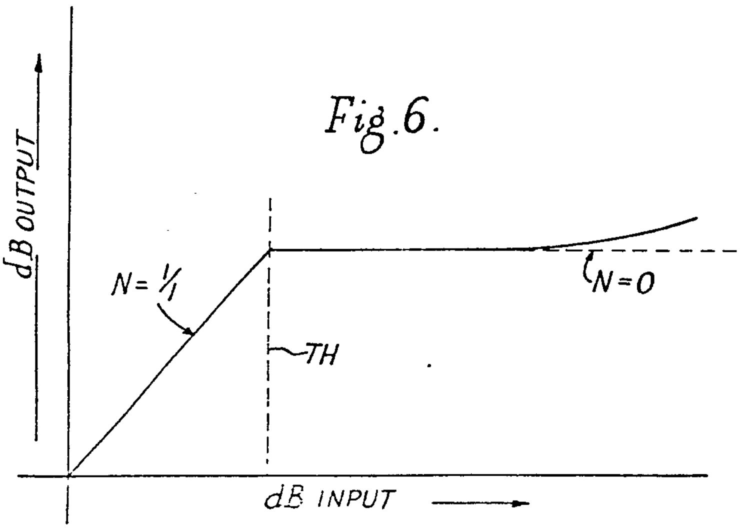


Fig.6.



1096196 PROVISIONAL SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

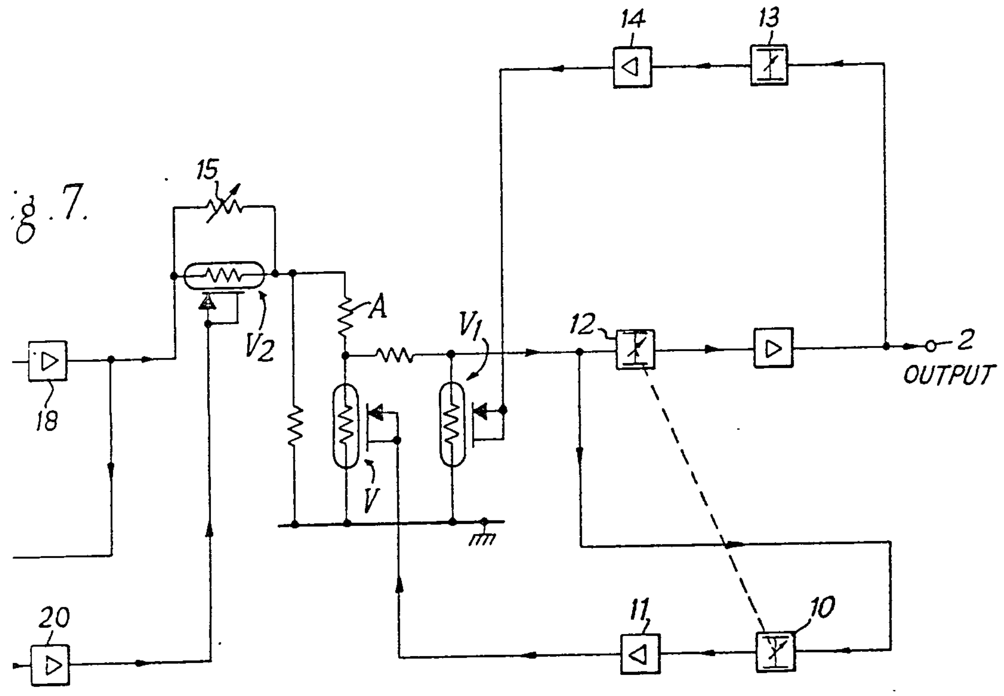


Fig. 1.

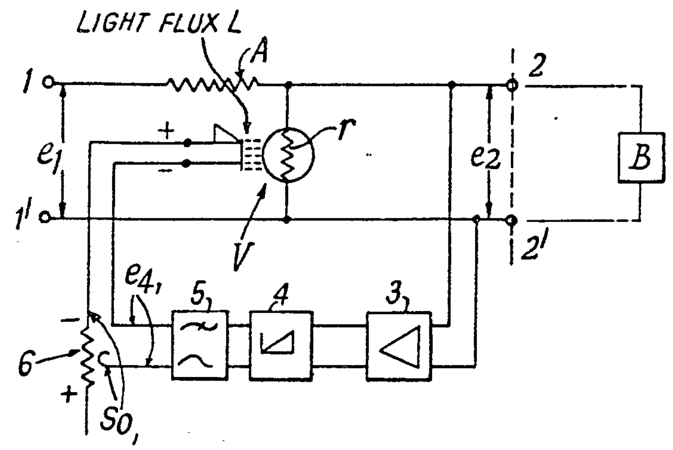
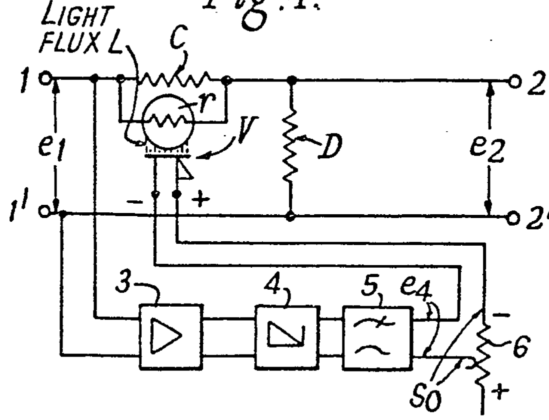

LIGHT FLUX L
A
1
2
r
+
−
e_1
e_2
B
$1'$
$2'$
V
e_4
5
4
3
−
6
+
So

Fig. 4.


LIGHT FLUX L
C
1
2
r
V
e_1
D
e_2
$1'$
$2'$
−
+
3
4
5
e_4
−
6
So
+

1096196 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 1 & 2

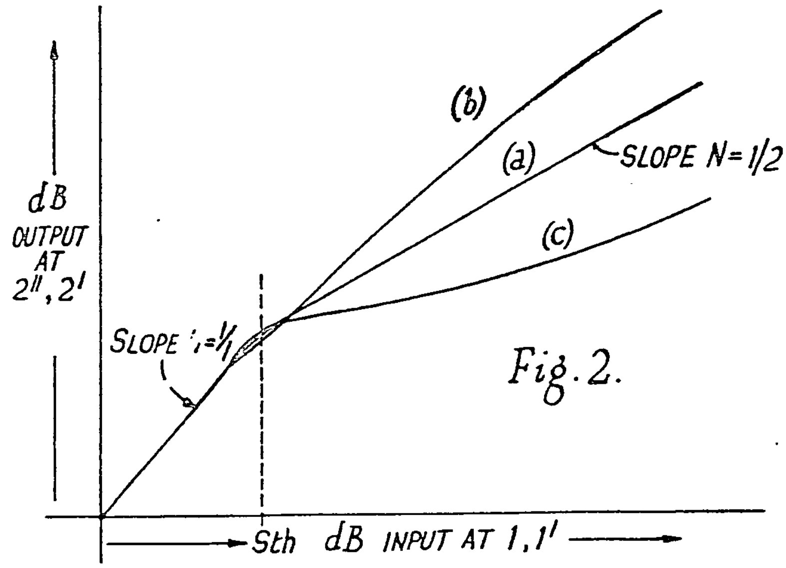


Fig. 2.

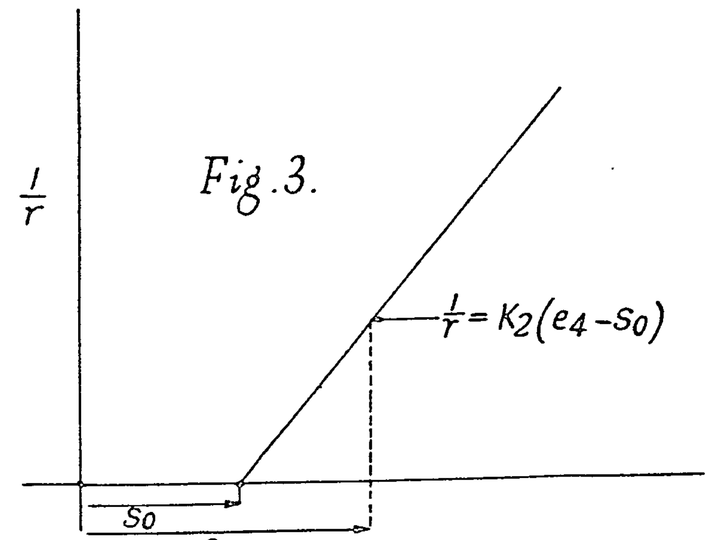


Fig. 3.

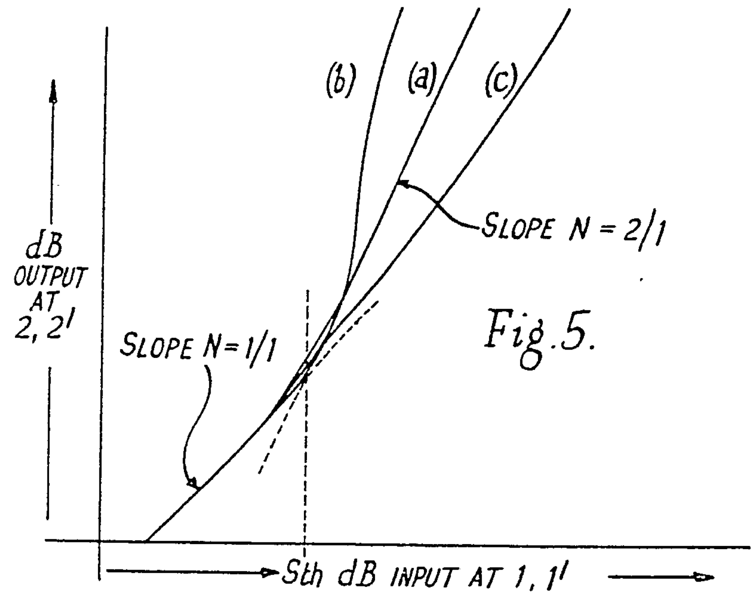

(b)
(a)
(c)
SLOPE N = 2/1
dB OUTPUT AT 2, 2'
SLOPE N=1/1
Sth dB INPUT AT 1, 1'

Fig.5.

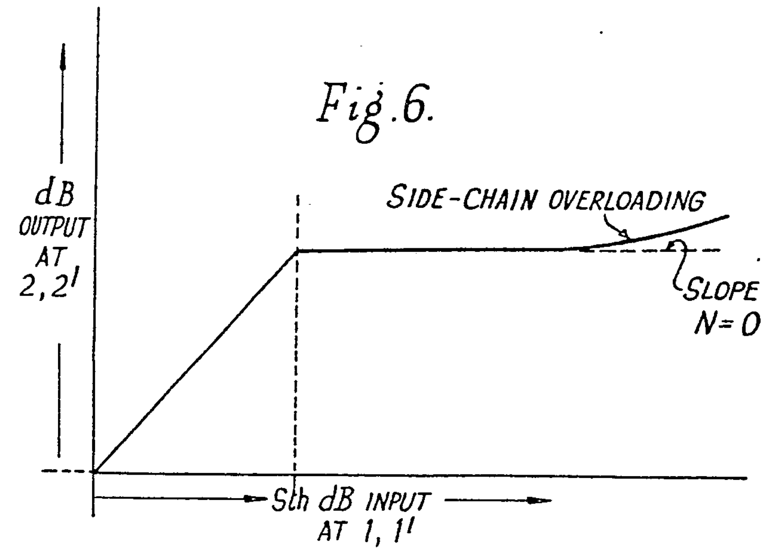

dB OUTPUT AT 2,2'
SIDE-CHAIN OVERLOADING
SLOPE N=0
Sth dB INPUT AT 1, 1'

Fig.6.

1096196 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 3 & 4

Fig. 7.

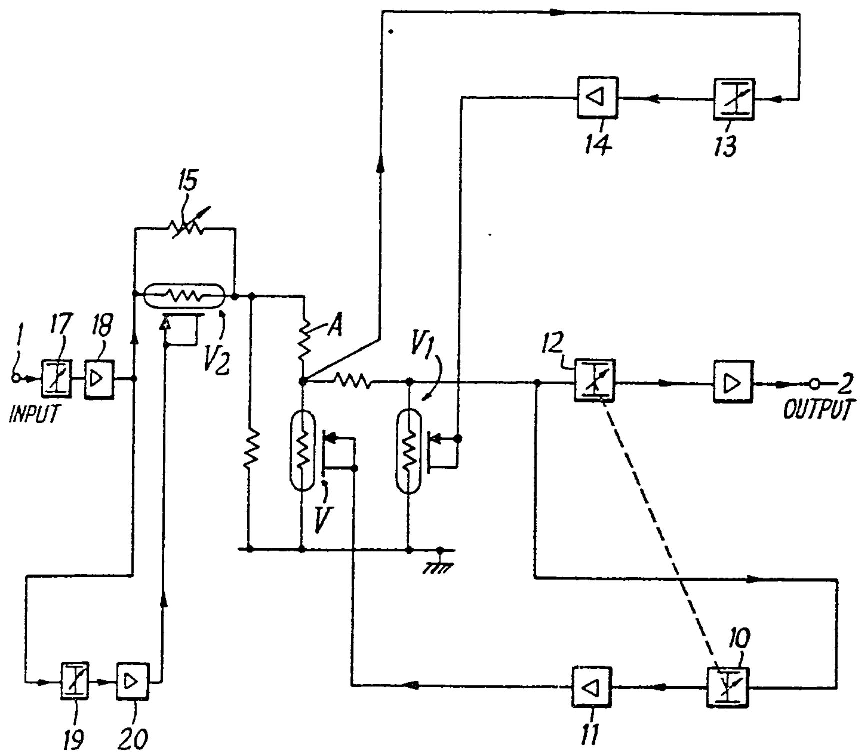
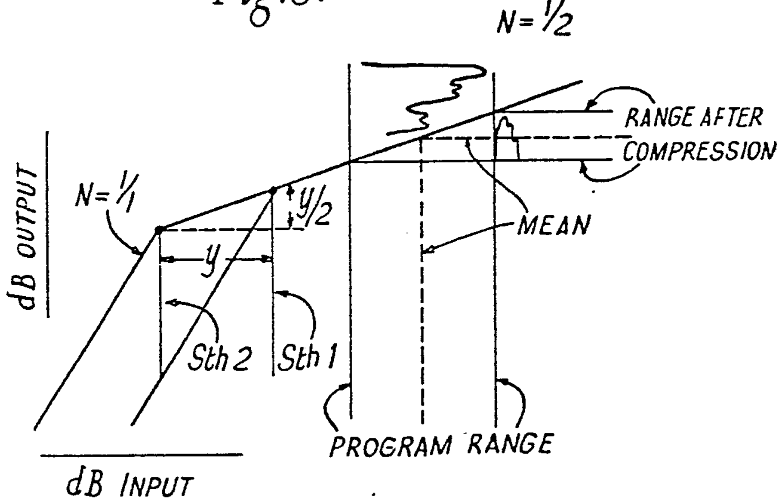


Fig.8.


N=½
RANGE AFTER
COMPRESSION
N=1/1
y/2
MEAN
dB OUTPUT
y
Sth 2
Sth 1
PROGRAM RANGE
dB INPUT

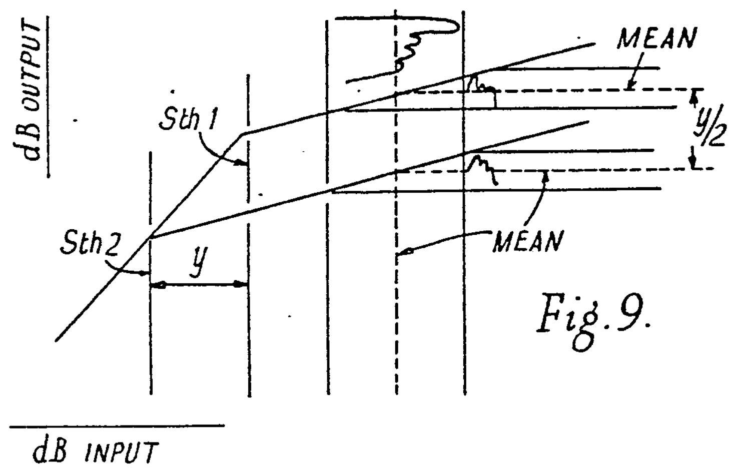

MEAN
dB OUTPUT
Sth 1
y/2
Sth 2
MEAN
y
dB INPUT

Fig.9.

1096196 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 5 & 6

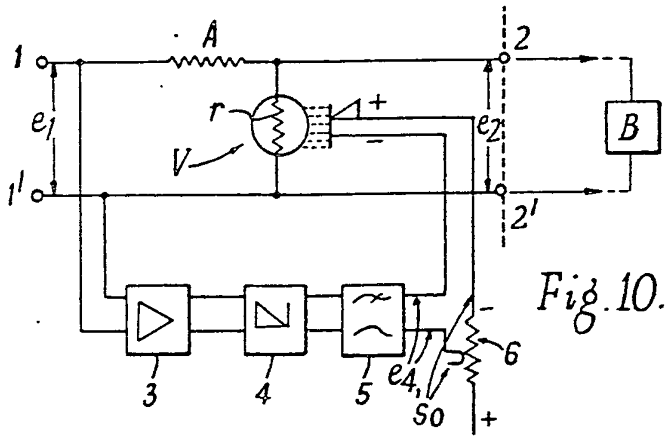


Fig. 10.

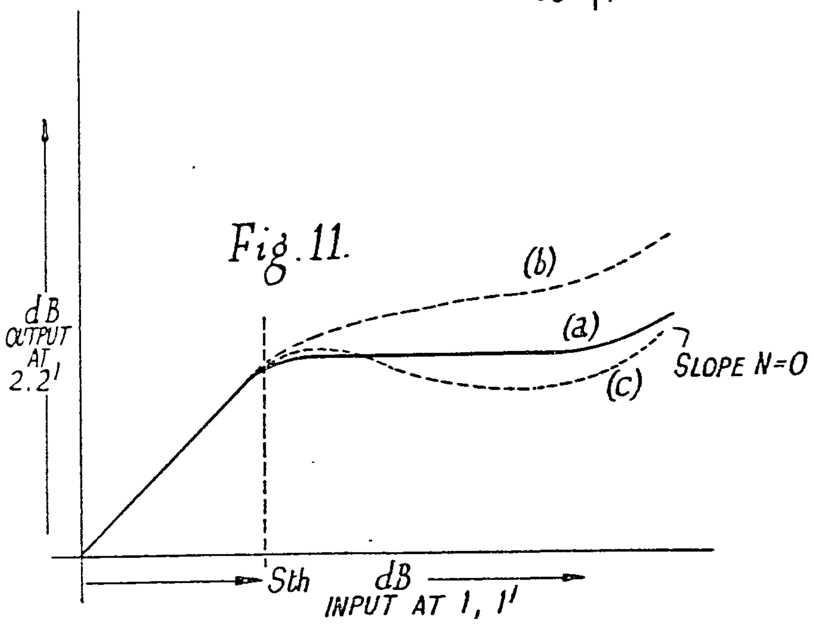


Fig. 11.

1096196 PROVISIONAL SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

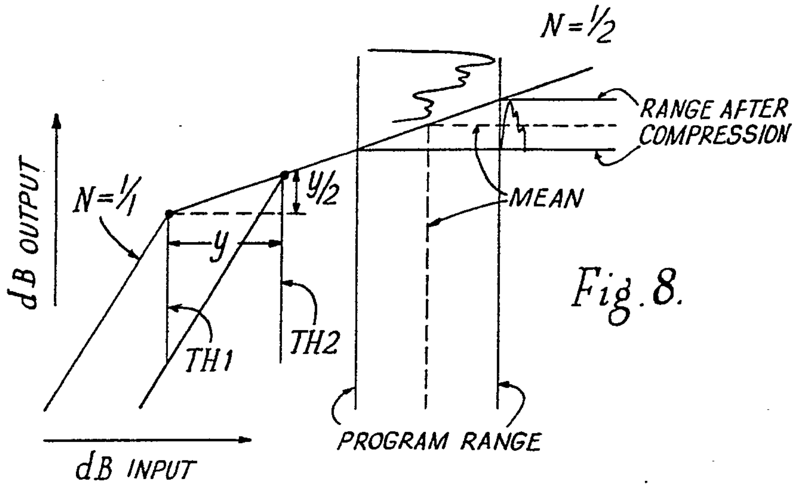


Fig. 8.

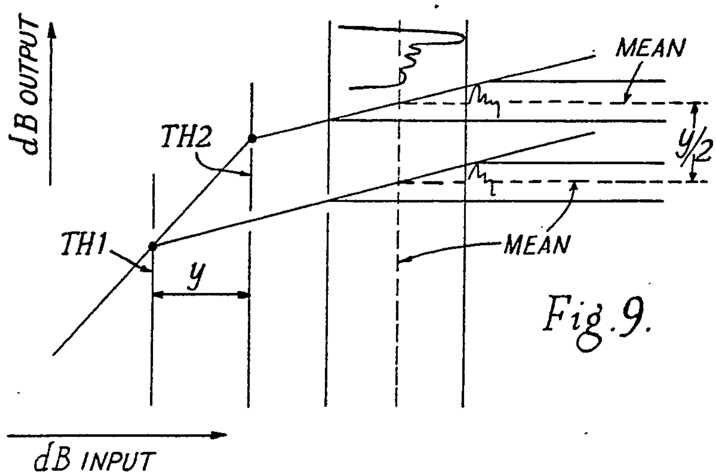


Fig. 9.