PHOTO-SENSITIVE RESISTOR IN AN OVERLOAD-PREVENTING ARRANGEMENT

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PHOTO-SENSITIVE RESISTOR IN AN OVERLOAD-PREVENTING ARRANGEMENT

(J. Rodrigues de Miranda) *)

Summary. The signal from a pre-amplifier or tuner is supplied to the input terminals of the power amplifier by means of a voltage-dividing network, the element in parallel to these input terminals being a photo-sensitive resistor of new design. Facing this photo-resistor in a lightproof enclosure is a neon lamp connected to the output voltage of the amplifier. Because a neon lamp ignites at a fixed voltage, the value of the photo-resistor resistance will be decreased as soon as this voltage is reached. Consequently the input signal to the amplifier will be decreased as well, making overload substantially impossible.

Properties of the CdS Photo-resistor

One of the more recent photo-sensitive devices is the sintered cadmium sulphide (CdS) photo-resistor. The properties of these resistors and some of their applications have been described extensively elsewhere. Therefore I will confine myself here to some general informations.

As is the case with all non-conductive solids, practically all electrons of CdS (in dark) are bound to nuclei of the atoms which make up the crystal. However when radiation (light) falls on the substance, the energy of this radiation is absorbed by some of the outer electrons with the result that their binding force becoming so much smaller that they behave as free electrons. Electricity transport is now possible, the CdS has become conductive. The conductivity will depend on the amount of radiation absorbed as can be understood as follows:

After some time the "free" electrons are recaptured; if radiation continues to fall on the material an equilibrium is reached where just as many electrons are recaptured as are set free. With stronger radiation the equilibrium will move towards a higher average number of free electrons.

We thus see that CdS can be used as a variable resistor, the value being controlled by the amount of light falling on it. The variation in resistance can be quite considerable: a typical execution of the photo-resistor has a "dark" resistance of 100 Megohm and a "light" resistance of 100 Ohm; a variation ratio therefore of $1:10^6$. Another property which is of importance for the subject of this paper is the speed of variation.

The variation of resistance against time as a result of a certain illumination follows a law which is very complicated (because of the action of so-called electron traps) but resembles somewhat an exponential law. The initial rising is very steep, the steepness depending on the amount of impinging light. When the light is taken away the resistance increases and here again the initial increase is very quick whereas the final "dark" value is reached only after a relatively long time.

Be setting the working range of the resistance values appropriately we can obtain within this range, a relatively quick drop in resistance and a relatively slow rise. We can say that we make use of the fact that radiation sets the electrons free almost immediately, whereas, when the radiation disappears, the electrons will not recombine with the ions all at the same moment and immediately so that a considerable time is required to reach the "dark" value. The time of decrease and increase of the resistance is shown in fig. 1 and 2 respectively. (Note: the time-scales are different.) The curve of fig. 1 has been taken with relatively weak light as is obvious from the relatively high final resistance.

Application of a photo-resistor as a volume control.

From the above it can be seen that, among other applications, the CdS cell can be readily applied as a volume control device for an amplifier by combining with a small lamp, the current through which can be regulated. The circuit diagram of a simple device of this kind is shown in fig. 3.
The time which is needed to decrease the resistance to 1/10th of a certain value depends on the initial value as is shown in fig. 1. It takes about 1 millisecond for the resistance to drop from 10 Megohm to 1 Megohm, but another 5 milliseconds to reach the value of 0,1 Megohm.
The recovery time, including the tail, is much longer and can, depending on the treatment of the material during production, be anywhere between 0,1 sec and 2 sec (see fig. 2). It will be clear that if the photo-resistor R_2 is illuminated the input signal drops noticeably as soon as the value of R_2 becomes smaller than that of R_1.

In this figure the manual control is obtained by means of variation of R_3, which controlls the amount of light falling on R_2. Resistor R_3 can obviously be at a considerable distance from the photo-resistor, a distance not restricted by factors influencing audio frequency considerations. As a matter of fact an additional advantage of a CdS volume control would be that the controlled resistor can be located at the most favourable point from a circuit point of view whilst the controlling resistor R_3 can be mounted at a place for most convenient handling. More detailed information on a manual volume control of this type can be found in the quoted publication of the Philips Technical.

The CdS photo-resistor in an amplitude limiting device.

We come now to another application of this CdS photo-resistor which application will be the main subject of this paper, viz an amplitude-limiting device. Some of the properties of CdS photo-resistor make an element of this kind very suitable for preventing overload of an audio amplifier. The characteristics of the device to be described are comparable to those of arrangements usually referred to as peak limiters.
There might be a difference of opinion about some of the required properties of a limiter, but I believe that the following characteristics will always be considered as advantageous.

1. The device shall have no influence whatsoever below a certain predetermined output level.
2. Above this threshold it shall decrease the output very rapidly below the overload level.
3. When the signal drops below the value which necessitates the functioning of the device, it shall become slowly inoperative.

The demands 2 and 3 can be described as a short attack time and a long decay time respectively.
Now a photo-sensitive resistor like a CdS cell used in the properly chosen resistance range has by its own nature these properties 2 and 3 as will be clear from the account given of the phenomenon of photo-conductivity.
We can make use of these properties in the following way.
Control of the output of an amplifier can be effected by the volume control at the input, e.g. in fig. 3 by changing the value of R_2. And, if this resistance is a CdS cell, a lowering of the output level may be obtained by illuminating this cell. In order to get a limiting action, we have to lay a connection between the output power-

or voltage- and the illumination of this cell. It was found that this link can be realised in a very simple way by using a neon lamp, ignited by the output voltage.

Quasi-static conditions.

As is well known, a neon lamp has a fixed, very constant ignition voltage and an extinguishing voltage which has a slightly lower value. If the photo-electric CdS cell and the (small) neon lamp are built together in a lightproof enclosure, the CdS cell being connected as R_2 in fig. 4, the full input voltage will be applied the first grid of the amplifier as long as the neon lamp is not ignited, i.e., as the output voltage does not exceed a certain predetermined value. As soon as this value is reached and the lamp ignites, the resistance of the CdS cell drops. As a consequence the input voltage decreases to a value which corresponds to an output voltage just a little above the ignition voltage such that the light will just keep burning. If the initial input voltage increases still further, the output voltage rises only very little. In other words a rigid limit is set to the output voltage as is illustrated in fig. 5.

Rapid changing conditions.

The decrease of the input voltage occurs very quickly due to the almost immediate ignition of the neon lamp and the rapidly following decrease of resistance of the CdS cell. The return to the original setting (when the input voltage to the complete system is decreased) goes relatively slowly for reasons explained earlier.
The behaviour of this limiting device under "rapid changing" conditions such as occur during a music program in which rapid peaks are followed by weaker passages is almost completely determined by the properties of the CdS cell and not as is the case with other limiting devices, by RC elements. If a sudden peak reaches the output terminals the control action takes place in a couple of milliseconds, before the ear can detect any distortion. The amplifier continues to work with a turned down volume control as it was. If no further peaks follow, the regulation becomes non effective, the volume is "turned back", relatively slowly, to its original setting. Therefore this device operates as an almost ideal limiter: No influence whatsoever before overload starts to take place. Rapid action is taken analogue to turning down a volume control. When overload conditions no longer exist, this action is slowly returned to normal.

Eindhoven, 5th September 1959

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Literature:

N.A. de Gier, W.v. Gool, J.C. v. Santen
"Photo-resistors made of compressed and sintered Cadmium Sulphide",
Philips Technical Review, Volume 20, page 277-308.

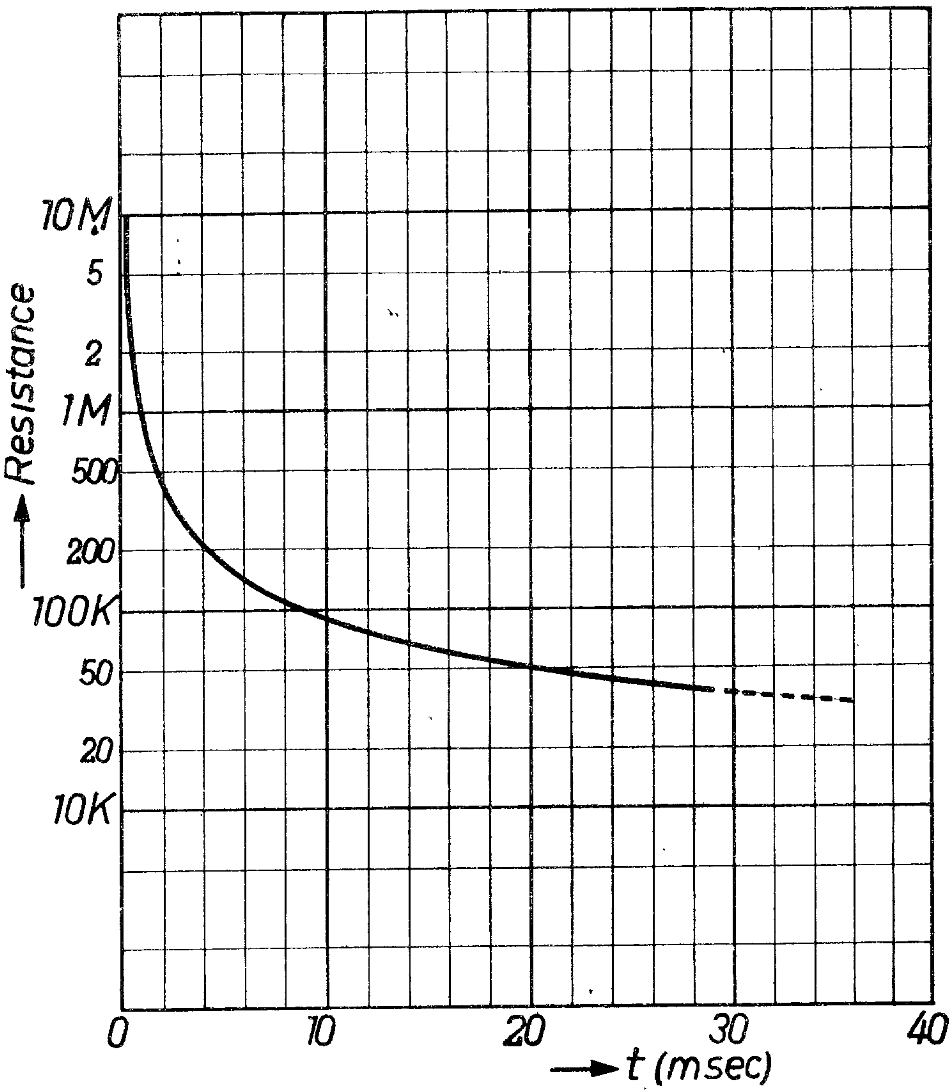

Fig. 1

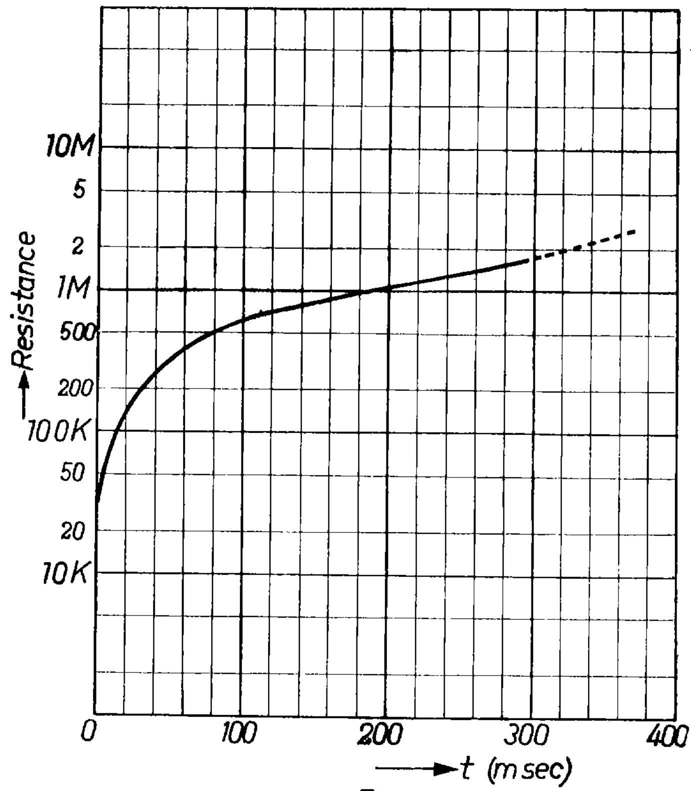
10M
5
2
1M
500
200
100K
50
20
10K
Resistance
0
100
200
300
400
t (msec)

Fig. 2

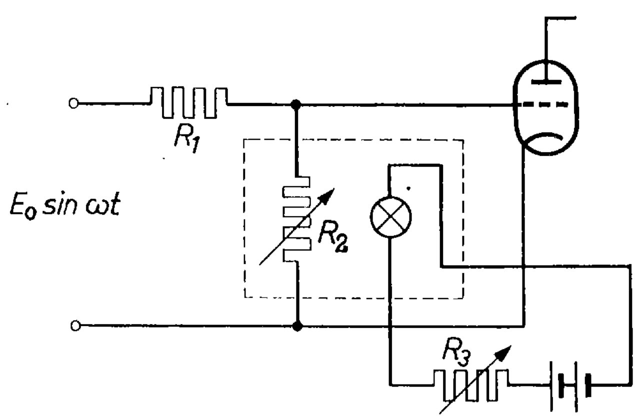
R1
R2
R3
E0 sin ωt

Fig.3

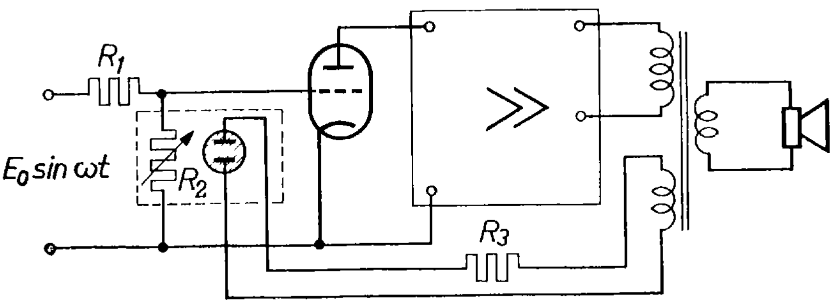
R1
E0 sin ωt
R2
R3

Fig. 4

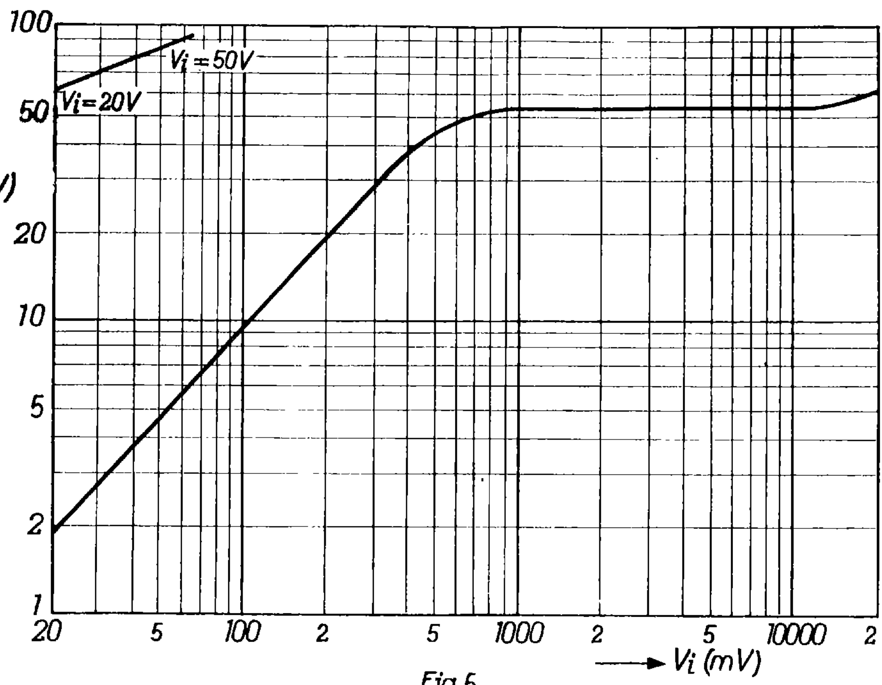
100
50
20
10
5
2
1
V0 (V)
Vi = 50V
Vi = 20V
20
5
100
2
5
1000
2
5
10000
2
Vi (mV)

Fig.5