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X-Ray Tubes Control Devices

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X-Ray Tubes Control Devices

There are many fields in which X-ray tubes are commonly used. Not only traditional radiology makes wide use of this type of devices but also many research and industrial activities.

Together with the large use of X-ray tubes, increases the necessity of the control of the emitted radiation in order to evaluate both the good functioning of the tube as, often more important, the characteristics of the emitted radiations.

While in radiotherapy is mandatory the control of X-ray emission and the measure of the dose, in diagnostic radiology, for example, have been proposed various devices that while controlling X-ray emission permit to measure patient's dose, in industrial radiography is necessary to record radiation exposures, etc.

The aim of the present paper is to give some elements for the design and realization of some devices for the control of X-ray tubes emission.

1.Ionization Chambers

In these brief notes on ionization chambers we assume that the Bragg- Gray cavity ionization theory is known, so that our attention may be devoted mainly to some elements of the design of ionization chambers.

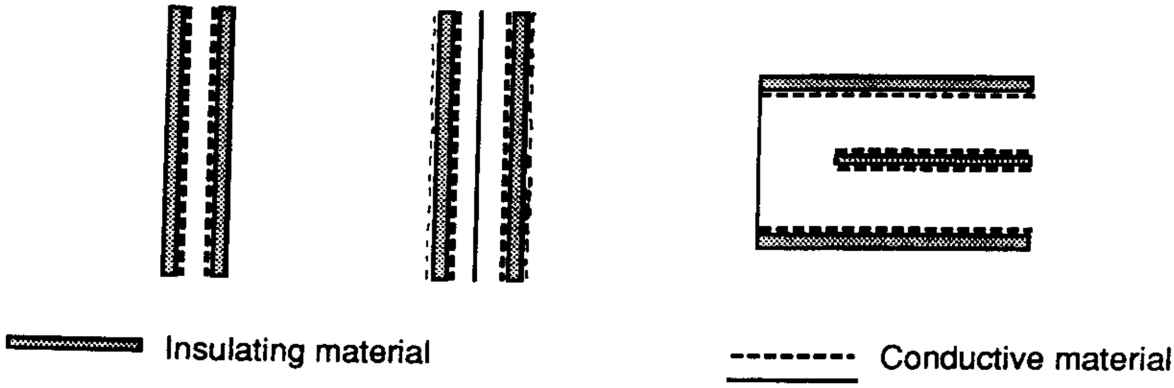


Fig.1.1. Various configurations of ionization chambers

Ion chambers may be constructed with parallel plates, coaxial cylinders, or other configurations and with a wide choise of materials. Metals and plastics are the more used but waxes and other materials have been successfully utilized.

In radioprotection practice often ionization chamber are cylindrical with the outer cylinder at positive high voltage and the collector electrode insulated from ground by a high impedance insulator. Teflon is for its volume and surface high resistivities and for very low igroscopicity among the materials more used, but polystirene, perspex, plexiglass and other plastics are conveniently used.Table I reports the characteristics of various materials commonly used in construction of ionization chambers.

Table I
Insulating characteristics of various insulating materials

	Vol.Resistivity	Resistance to water absorption
Teflon	10^{17}- 10^{18}	good
Polyethylene	10^{14}- 10^{18}	moderate
Polystyrene	10^{12}-10^{18}	moderate
Ceramic	10^{12}-10^{14}	weak
Nylon	10^{12}- 10^{14}	weak
PVC	10^{10}- 10^{15}	good
Phenolic	10^{5}- 10^{12}	weak

A grounded guard electrode generally surround the collector electrode. The function of this guard ring is to preserve the central electrode from the high voltage leakage currents, to define the collecting volume of the chamber and to shield from electrostatic charges the signal insulator.

Of course this guard ring must be properly insulated from the high voltage electrode with an insulation like the signal electrode insulation.

We need now to resume some useful definitions indispensable for the design of ionization chambers.

Saturation. For a ionization chamber the first requirement is that the ions formed by the radiation should be collected by the applied electric field.A chamber is said to be saturated when the voltage on its electrodes is sufficient to collect all the ions formed within its volume.

The geometry of the chamber, the gas pressure inside the chamber, the intensity of the radiation and the type of gas determinates the saturation voltage. The ionization current plotted vs collecting potential shows an asymptotical trend as in Fig.1.2.When no current increase is appreciated versus increasing voltage, the chamber is operating in a saturated condition.

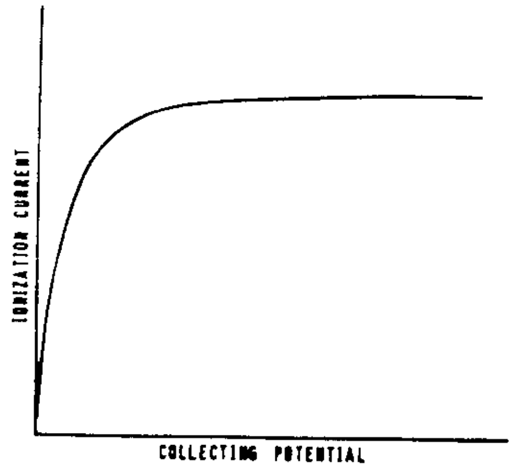


Fig.1.2. The saturation curve for an ion chamber.

Current from an Ion Chamber. The current from an ion chamber in saturation state is directly proportional to the incident radiation.If we refer to the old radiological units in which the roengen (R) was defined as the radiation of X or gamma ray which produces one electrostatic unit of charge per cubic centimeter of air at standard condition of temperature and pressure, it can be deduced that the current output in a ionization chamber is given by:

$$I = \frac{k\,V\,P\,R \times 10^{-13}}{1.08}$$

where I = output current (A)

k= constant of the gas (air =1)

V= chamber volume (cc)

P = gas pressure (atm)

R = radiation intensity (R/hr)

In Fig.1.3 is shown the ionization current for various type of gas at different pressures at a fixed radiation field.The gas used include air, xenon, boron, krypton, helium and gas mixture like those used in health physic to make tissue equivalent ionization chambers.

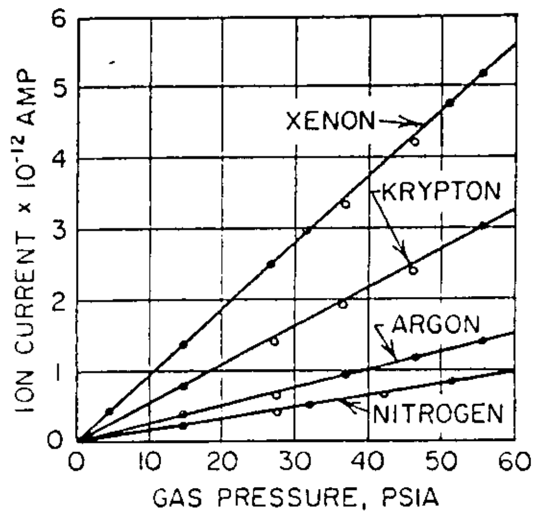


Fig.1.3. Effect of gas and gas pressure on ion chamber current. Volume of the ion chamber 36 cc.

Collection Efficency of an Ion Chamber. The ratio of the measured current to the ideal saturation current for a parallel plate chamber is said collection efficency.

To design a ionization chamber with a expected efficiency is necessary to refer to Boag's saturation curves which applies to all parallel plate ionization chamber filled with air exposed to continuous or pulsed radiation. In these curves the percentage of formed ion measured (ion efficency) is plotted as a function of the dimensionless quantity

$$\xi = m\frac{d^2\sqrt{R}}{V}$$

where :

V= voltage between the electrodes (V)

d= spacing between the electrodes (cm)

R= exposure rate (R/sec)

m= constant, depending on the type of gas used in the chamber (air at 1 atm, 20°C, m= 36.7)

Construction of a ionization chamber. The ionization chamber which we have designed and realized is air vented and was manufactured using perspex 1 mm thick foil coated with graphite and a central electrode of aluminium 50 μm thick. The electrodes have an area of 14 x 14 cm and spacing between the conductive layers is 2 mm while the high voltage supply is 200 V.

In Fig.1.5. is shown a cross section of the chamber.

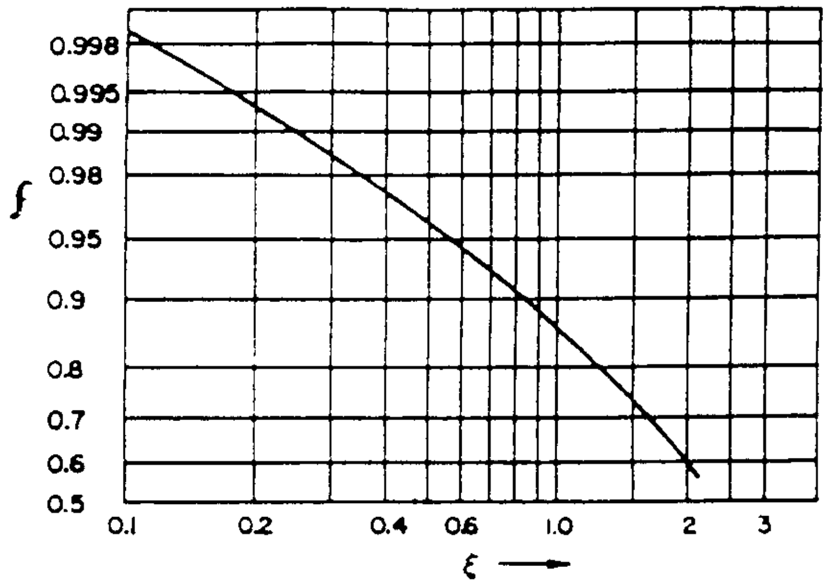


Fig.1.4 Collection efficiency of a parallel plate ionization chamber filled with air

For a good collection efficiency in the chamber we must refer to Boag curve as before outlined. If we wish an ion efficiency f>99% the value of ξ as shown from Boag curve should be <0.2, at m=366.7, V= 200V and d=0.2cm. The exposure rate R in this case is limited to 750 R/sec.This value is never reached in our tube.

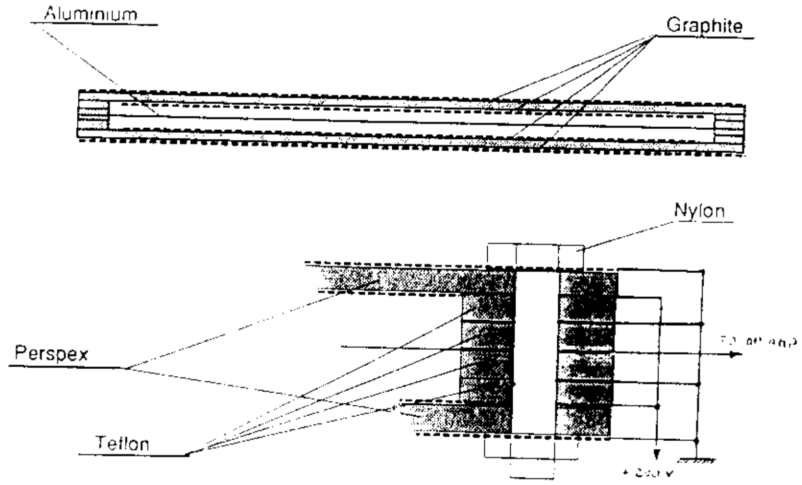


Fig.1.5. Cross section of the ion chamber

The electrometer circuit that amplifies the signal coming from the ionization chamber is based on a TEXAS - TL O81 FET input operational amplifier. The characteristics of this op-amp are quite suitable for this type of application in which the radiation fields to measure are rather intense. The drawing of the circuit proposed is shown in Fig.1.6.

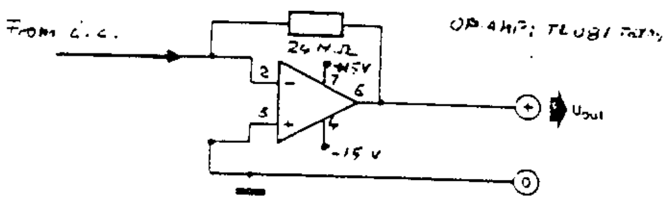


Fig.1.5. Drawing of the measuring circuit.

2. Silicon Photodiode for X-Ray Tubes Emission Control

In the previous chapter we have briefly described the principles of operation of a ionization chamber and we have given some constructive elements. In this second chapter we are taking into consideration the use of silicon photodiodes in the control of the radiation emitted from an X-ray tube.

The use of silicon diodes in X-ray tube emissions measurements is reccomended because its high density, 1800 times that of the air, and the energy required to produce an electron-hole pair (3.5 eV compared to 35 eV for the production of an ion pair in air). Further, it produces a current nearly 18000 times that of an ionization chamber of the same sensitive volume.This obviously requires an less sophisticated electronics to amplify the current.

In Fig.2.1 are shown three possible electrical configurations for a photodiode. The configuration of Fig.2.1b is used for nuclear spectroscopy while generally the circuit in Fig.2.1c for dosimetric purposes.

The photodiode in this last connection, Fig.2.1c, is used without reverse bias (photovoltaic mode). In this mode it acts as a current source and exhibits a linear response versus exposure rate.The circuit of Fig.2.1c is a current-to-voltage transducer and the output voltage is equal to the radiation induced current i circulating in the photodiode and the feedback resistor R

$$V = i\ R$$

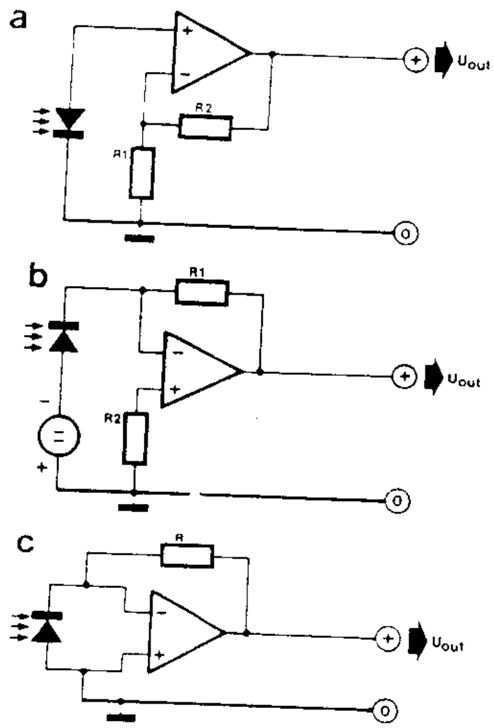


Fig.2.1. Wiring diagrams for photodiodes

Let us see now briefly the mechanism of current production.When two materials p and n type are in contact to form a pn junction at their interface produces a zone called depletion region in which is present an electric field. Under effect of irradiation the electron-hole pairs produced in this region are immediately separated and swept out by the intense electric field producing part of the radiation induced current.Not only the pairs produced in the depletion region contribute to radiation induced current, also the minority carriers (electron in p-type region and holes in n-type region) generated outside the depletion zone, within about one diffusion length, may diffuse into the depletion region and can be collected producing a further contribution to the radiation induced current.Then the length of the sensitive region of the diode is

$$L = w + L_n + L_p$$

with: L = Length of sensitive region
w = width of the depletion zone
L_n = diffusion length of electrons in p region
L_p = diffusion length of the holes in n region.

w is in general small compared to diffusion lengths.

For an uniformly irradiated photodiode the radiation induced current is

$$i = e\, g\, A\, (w + L_n + L_p)$$

where: e = electronic charge
g = electron-hole pairs/cm per second in the silicon

A= area of the junction

From the last formula it is possible to observe that the radiation induced current may be increased both increasing photodiode area (A) both increasing diffusion lengths$L$ defined as the distance through which the minority carriers diffuse in its lifetime (before the capture and recombination at a recombination center) it can be shown that

$$L=\sqrt{D\tau}$$

with: D = diffusion coefficient;
τ = minority carrier lifetime

The radiation induced current may be increased selecting photodiodes having large minority carriers lifetimes.

In the selection of the photodiodes for radiation measurements a great care must be put to choose diodes with a low "dark current", i.e. the current due to thermally generated carriers in the absence of radiation.This current is strongly temperature dependent. In Table II are summarized some photodiodes with different characteristics at 20°C at a reverse bias of 20 V. The "dark current" increases with bias, but for our purposes, diode without reverse bias, the only bias applied will be the small input offset voltage in the range of the μV-mV due to the operational amplifier of the measuring circuit. An adeguate choice of the operational amplifier having moreover a small bias current solves the problem.

Table II

Photodiode	Type	Area (mm)	Dark current (n A)
Siemens BPX 12	pn	20	48
Siemens BPX 65	pin	1	1
Siemens BPX 60	pn	9	3
Siemens BPX 61	pin	9	1
Siemens BPX 34	pin	7.6	.6
Honeywell SD 4478	pin	2.2	.04
Hamamatsu 1722	pin	13.2	.7

In Fig.2.2. and 2.3. are shown respectively the reverse current vs temperature and reverse current vs reverse bias for the photodiode Siemens BPW 34 that we have used in the circuit shown in Fig.2.4.

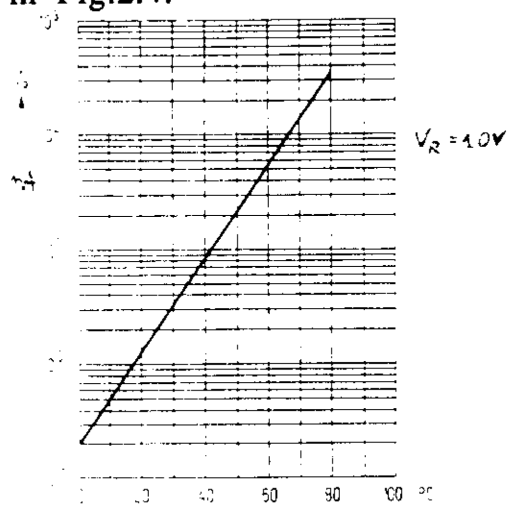


Fig.2.2.Reverse current vs temperature for SIEMENS BPW 34 photodiode

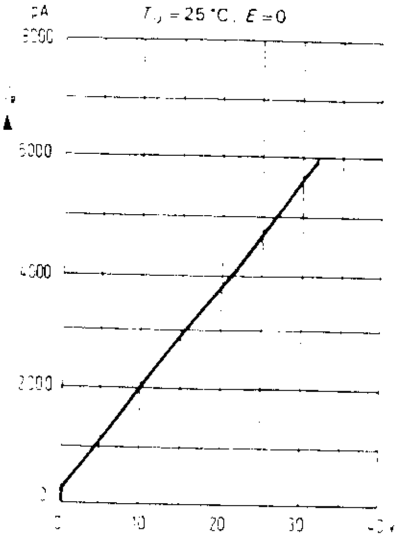


Fig.2.3.Reverse current vs reverse biasing for SIEMENS BPW 34 photodiode

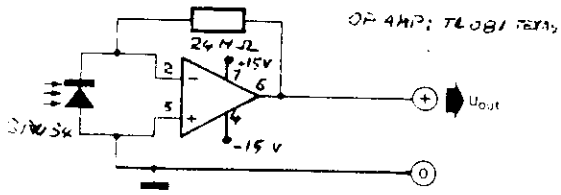
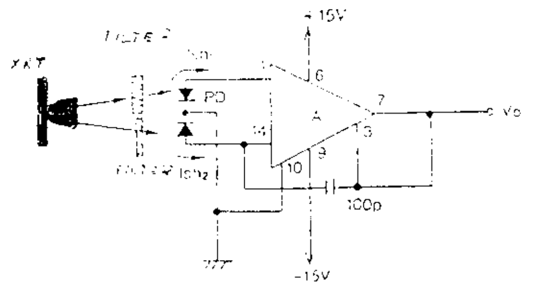


Fig.2.4.Wiring diagram of the measuring circuit for X-ray tube emission control

Fig.2.5. shows how the photodiode BPW 34 may be used for the control of kV of X-ray tube.If an adequate filter is used V_{out} is a direct measure of kV of the tube.



$$V_{out}=\log(I_{sh1}/I_{sh2})\ V$$

Fig.2.5. Circuit for kV meter. A = LOG 100 (Burr Brown), PD = BPW 34

In many cases the signals coming from ionization chambers adequately amplified must be integrated over the time. The simplest method for that to convert the signal, with a voltage to frequency converter, and to count the pulse obtained after conversion.In Appendix I is reported a low cost devices that, designed for noise measurements, can find convenient application.

Photodiodes may be also used for measurement of X-ray spectra and this application provide a very useful, low cost , method for the control of X-ray tube emission. Resolutions of 2.0 keV FWHM for 60 keV photons have been obtained at room temperature.

Good results we have obtained with the photodiode Hamamatsu 1722 G.This results will be reported in other part of the course in which will be explained pulse mode operation for the detection of X radiations.

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A very simple electronic integrator for true noise dosemeters

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Abstract. An electronic integrator for true noise dosemeters was made using reasonably inexpensive devices. The proposed circuit can easily be used, with minor variations, as a basic circuit for many other applications, such as in personal alarms.

1. Introduction

The control of some physical variables, such as noise, radiation or the concentration of chemical or radiochemical substances inhaled, where levels of these parameters vary constantly, requires the use of appropriate dosemeters and alarms, to avoid health risks and comply with regulations. Many circuits for the integration of these variables with respect to time have been proposed (Carra *et al* 1973, Meier and Widmer 1988) and are in common use.

The purpose of this note is to describe a very simple and economical circuit for the realisation of an integrator for true noise dosemeters, which can be assembled from readily available components.

2. Circuit description

The permissible daily noise exposures as recommended by many national and international authorities are shown in table 1. In accordance with the limits of table 1, an instrument has been designed and its block diagram is presented in figure 1. In particular, the integrator, the object of the present note, was made using a voltage-to-frequency converter (VFC) and a digital alarm clock, identified in the figure.

Figure 2 shows a detailed drawing of the circuit. The working principle of the circuit is as follows: when an electrical signal from the microphone, adequately amplified and filtered, is present at the input of the VFC (Burr Brown VFC 42), the output of the converter 'pulses' down. Pulses, with a frequency proportional to the input current, are sent to the input of the digital alarm clock (National Semiconductor MM5402) whose time-keeping function operates from DC to 10 kHz. The advancement rate of the clock is a function of the input frequency; thus the 'time' will pass more quickly if the signal is higher.

In practice, it is necessary to zero the clock and to set the alarm, for example at 8.00, then the alarm will ring when the product of the signal intensity and the real time has reached the fixed maximum daily limit that has been previously set for the clock. The use of a clock instead of a conventional counter satisfies legal requirements for noise dosemeters, gives an immediate use for the circuit as an alarm and, moreover, simple variations of the alarm settings allow a wide choice of integration levels appropriate for the particular conditions in which the dosemeter operates. The same circuit may also be used for electronic integration of all those physical or chemical variables whose time-dependent expo-

Table 1. Permissible daily noise exposure.

Duration per day (h)	Sound level (dBA)
8	90
4	95
2	100
1	105
1/2	110
1/4	115

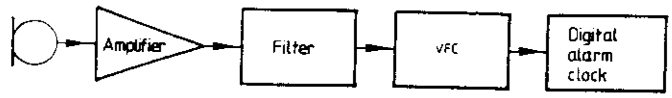

Figure 2. Integrator circuit.

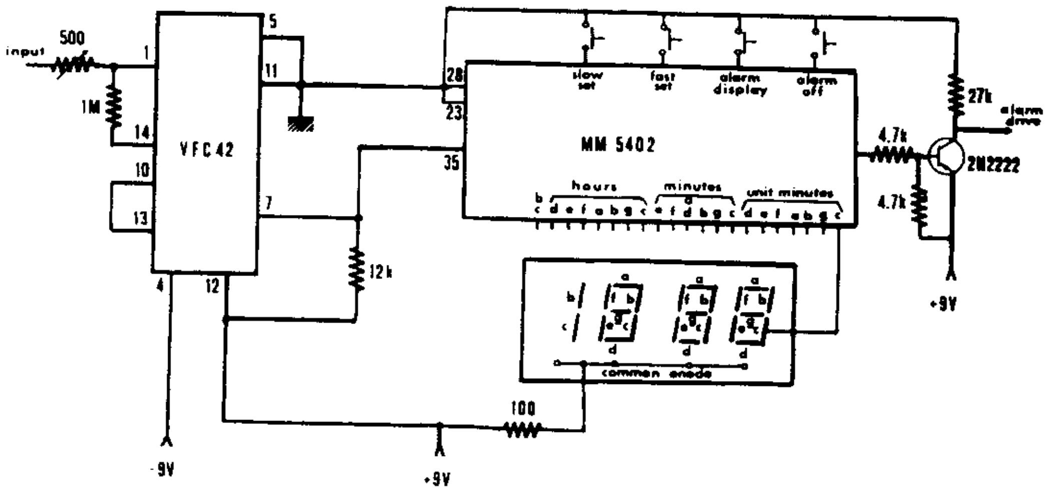

Figure 1. Block diagram of a noise dosemeter.

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sure needs to be limited, the type of variable investigated naturally depending upon the choice of the transducers used.

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