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A simple pulse spectrograph

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The usual saw-tooth time-base of an oscilloscope is replaced by one in which the spot moves with acceleration. Pulses from a radiation detector are displayed as bright dots which occur mainly on the side of the screen where the spot is moving slowly. Integration by time exposure with stationary film gives a record in which a constant-density line is a graph of pulse frequency against pulse height. Visual observation of the spectrum is possible with abundant pulses. The two simple circuits used employ only four tubes between them.

Various methods have been adopted for deriving a pulse spectrum from the displacement of an oscilloscope spot by incoming pulses. In one, employed by Curran in many published investigations,[1] the time-base is not used but the spot movements (in the *y*-direction) are recorded on film moved in the *x*-direction; the pulse distribution is then found by projection of the film on to a screen divided into appropriate channels. Hunt and others[2] brightened the tops of the pulses so that the film showed an array of dots, photo-electric scanning giving the pulse spectrum. This method was fully automatic but involved elaborate circuitry.

Two methods have been described for photographing the spectrum directly from the oscilloscope screen on stationary film, giving a record similar to optical absorption wedge-spectrograms. The pulse, on arrival, triggers the time-base, is stretched and is displayed as a horizontal line displaced

DESCRIPTION OF INSTRUMENT

In the present method each pulse appears as a dot on the oscilloscope screen. The time-base is non-linear but is not triggered. Provided that the occurrence of the pulses is random in time, the dots will occur most frequently at the side of the screen where the *x*-velocity of the spot is small. Time exposures (usually a few minutes) give records similar to those of Bernstein or Muzdeka. (See Fig. 3.)

The pulses are made to appear as dots by the following method. A pulse, assumed negative, is applied to the *y*-plates of the oscilloscope and also to the circuit shown in Fig. 1. (If the pulses are positive, small changes in the connexions to the second tube will be required.) Here it is differentiated and the resultant pulse amplified in the first tube, a type 6AK5, before being applied to the second tube, a type 6J6. In the quiescent state the right-hand half of the second and
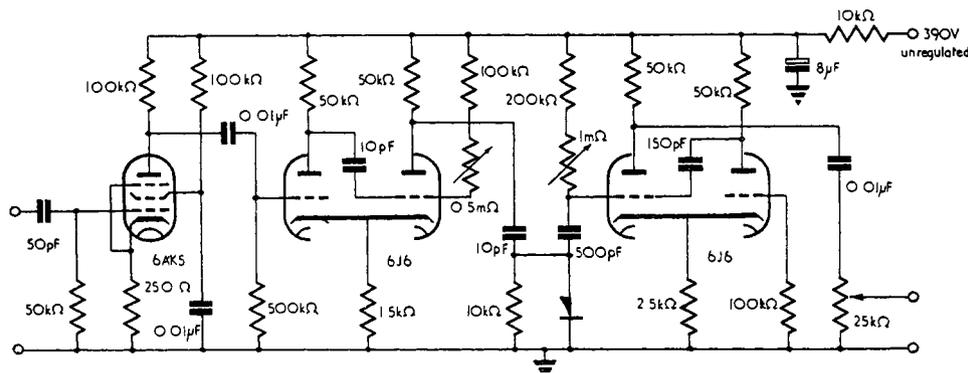

Fig. 1. Pulse-brightening circuit

from the time-base by a distance proportional to the pulse height. If the screen is photographed through an optical "wedge," the density of which varies in the *x*-direction, exposures of a few minutes give the spectrum,[3] preferably by high-contrast photography. Muzdeka[4] has described another method in which a triggered exponential time-base gives the same final effect as the optical wedge.

the left-hand half of the third tube are conducting, the other halves being cut off.

The arrival of the differentiated pulse from the first tube raises the potential of the grid of the second tube (left) and this half begins to conduct. The plate of the second tube (left) falls and with it the grid of the same tube (right) which ceases conducting until the central 10 pF capacitor discharges,

through the 0.5 MΩ variable resistor, whereupon the tube reverts suddenly to its quiescent state.

The flat-topped pulse resulting from the switching on and off of the second tube (right) is now differentiated, giving two new pulses, one positive, the other negative. The positive one is rejected through the rectifier between the second and third tubes and the negative one initiates a similar temporary change in the condition of the third tube In the quiescent state the left-hand side of this tube conducts, the right is cut off

Hence a positive pulse is applied to the z-axis of the oscilloscope for an interval dependent upon the setting of the 1 MΩ potentiometer. Thus the spot is made brighter at an arbitrary short time after the sharp rise of the pulse and is kept bright for another arbitrary interval.

The settings of the two potentiometers are made subjectively until the pulses give the sharpest possible dots on the screen. This is facilitated by temporarily using a high sweep frequency; the pulses now appear as short arcs which are adjusted until they approximate to short horizontal lines at the pulse maxima.

If all pulses are to appear as small dots it is desirable that they should all be of the same shape. If there is a large range of rise times some of the pulses will appear as vertical smears instead of dots, resulting in loss of resolution in the pulse-height spectrum. Should this loss be serious it will be necessary to resort to pulse-stretching. This, of course, means complicating the instrument and also reducing the rate at which pulses may be accepted.

Resolution is also impaired by lack of "squareness" in the brightening pulse from Fig. 1. Stray capacitance in the cable connecting this circuit to the oscilloscope was found to have adverse effects. In addition, the oscilloscope used (Dumont type 208B), not being designed for high-frequency work, exhibited undesirable capacitance to earth in the fly-back suppressor cable. This cable was superfluous in the present application and was disconnected.
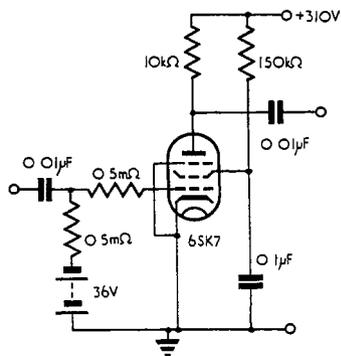

Fig. 2. Time-base circuit

The non-linear time-base may be produced in various ways. Approximately exponential variation of voltage with time is given by the ordinary thyratron time-base circuit, the capacitor being allowed to charge more fully than usually, thus giving marked departure from linearity. This method permits measurement of only a limited range of spectrum line intensities, for reasons discussed later.

This range may be greatly extended by use of an alternative method. In this the saw-tooth voltage which provides the oscilloscope with its normal time-base is tapped off and applied (Fig. 2) to the grid of a heavily biased remote-cut-off

tube. The plate voltage of this tube is then applied to the x-plates of the oscilloscope and yields a time-base permitting line intensities having a ratio of some hundreds to be measured.

THEORY OF TIME-BASE

The following considerations give some guidance in selecting a wave-form for the time-base voltage. If the oscilloscope spot moves in such a way that the displacement x is related to time by the equation

$$t = f(x) \tag{1}$$

then, to move a distance Δx the spot requires time $f'(x)\Delta x$. If dots due to pulses of a given height are being produced at the rate of N per second, the number of dots ΔN occurring in the interval Δx is $Nf'(x)\Delta x$. That is, the linear density of dots at the height concerned is $Nf'(x)$. The spectrum is a constant density locus, so, for points on this locus,

$$N \propto 1/[f'(x)] \tag{2}$$

If, as mentioned above, an exponential wave-form is used,

$$x = a\,e^{-bt} \tag{3}$$

Then, since

$$t = (1/b) \log_e (x/a) = f(x) \tag{4}$$

Therefore

$$f'(x) = -1/bx \tag{5}$$

and

$$N \propto x \tag{6}$$

Hence the height of a peak in the spectrum is proportional to the intensity of the line. This restricts the range of intensities that may be measured.

If

$$x = a \log_e bt \tag{7}$$

we find

$$x \propto \log_e N \tag{8}$$

A time-base operating according to this law therefore permits a large range of intensities to be measured and also has the advantage that ratios of spectrum line intensities are measured as differences and the zero for x-measurements does not need to be known.

USE OF INSTRUMENT

The black-white transition marking the spectrum profile, or, more generally, a line of constant photographic density, is a locus of points where the number of dots per unit area on the film is constant. Since the dots are assumed random in time this number is statistically variable, the variance being the number itself. Hence if the dot density is large the spectrum profile is more reliable. For maximum accuracy, therefore, two procedures present themselves. One is to increase the exposure time, the other to work with a constant density line as near as possible to the "slow" end of the time-base. In either case it may be found desirable to decrease the blackness of the film, which may be done by stopping down the camera, using slower film or different development or by reducing the spot brightness with the final potentiometer in Fig 1.

Slight defocusing, if it can be tolerated, also gives statistical smoothing out. Rather more useful is astigmatic defocusing by means of a cylindrical lens (say three dioptres) in front of the camera lens. According to its orientation this lens permits better measurement of spectrum "line" position at the expense of line intensity, or *vice versa*.

The method retains some of the limitations of grey-wedge and other oscilloscope methods. These include non-linearity

due to curvature of screen, hum and noise effects and channel broadening due to imperfect focusing. Methods of dealing with these are discussed by Bernstein.[3] Some of the difficulties of the grey-wedge method, including failure of reciprocity law and intermittency effect, do not arise here. Calibration of both pulse height and pulse frequency scales is empirical.

Fig. 3 is a spectrum of the radiation from ^{65}Zn, observed with a commercial scintillometer. The small peak on the left is the time-base, broadened somewhat by hum and exhibiting a tail in the negative energy direction because the cathode-ray spot slightly overshoots the time-base on completion of pulses. Two prominent peaks (0·20 and 1·14 MeV) and various minor peaks are discernible. By reflexion photometry on a print it has been found possible to fix the ordinate of a constant density line to an accuracy of about 3%. In
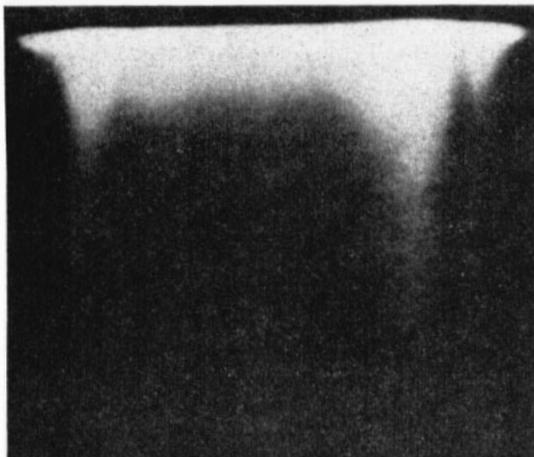

Fig. 3. Spectrum of ^{65}Zn

the present case the source was of the order of 1 μc located about 5 cm from the crystal. The exposure time was five minutes at $f/2\cdot8$ on Kodak Plus X film. The more prominent spectrum lines were easily visible on the screen. With more intense sources, and particularly with long-persistence screens, the instrument may prove a useful visual spectroscope for nuclear radiations.

In Fig. 4 is displayed a spectrum produced by supplying the spectrograph with artificial pulses of constant height.

These were initially of length 1·5 μs, but were rounded somewhat in amplification. Half-way through the exposure the height was changed by 1%, so that two spectrum lines appear. (The time-base is at the left, broadened by halation.) It appears that energy resolution of the order of 1% may be expected of the spectrograph.

Fig. 4. Test of resolution

The author has chiefly used the instrument in the display of X-ray fluorescence spectrograms using a proportional counter as analyser of the soft fluorescence radiation. In this application the counter itself limits resolution to a much greater degree than does the pulse-brightening device described here.

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