

# PROPORTIONAL COUNTER WITH AUTOMATIC GAIN CONTROL

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In aid of a solar X-ray experiment aboard the earth satellite ESRO-II a proportional counter was developed, at the Utrecht Space Research Laboratory, of which the gas gain can be monitored. There are different factors that can influence the gas gain of a proportional counter, of these the gas pressure and supply

voltage are the most important. This paper describes the electronic circuitry that makes use of this monitor voltage to control the high voltage supply of the proportional counter so that a constant output pulse height distribution of the X-ray detector can be achieved.

## 1. Introduction

A detailed description of the ESRO-II soft X-ray detector will be given elsewhere. Here the relevant details for the present application will be mentioned.

In view of the fact that a detector in a space vehicle has to operate over a long period of time without the possibility of recalibration, it was thought necessary finding a way to check the performance. Therefore a detector was built consisting basically of a twin-proportional counter. The two parts of the detector are fed from the same power supply and the gas pressure and gas composition are identical because there is a connection between the two gas volumes.

One proportional counter is used for detecting solar X-rays, the second, called the monitor counter, is constantly irradiated by a  $^{55}\text{Fe}$  source (fig. 1). The output pulses of this monitor counter are amplified and the amplitude of the pulses is converted to a dc voltage, by means of a "semi-peak detector" circuit. A pre-flight calibration can be made to correlate the monitor voltage and the gas gain. Fig. 2 shows the monitor output voltage vs an E.H.T.-supply change.

## 2. Block diagram of a proportional counter with stabilized output

Fig. 3 shows the block diagram of the proposed system. The output pulses of the "monitor detector" are

amplified and integrated. The output voltage is then compared with a reference voltage  $V_R$  and the voltage difference  $V_3 - V_R$  controls the high voltage supply of the detector. We demand that the output pulse height distribution of the X-ray detector should be constant. If one assumes that the monitor and the X-ray counter behave in the same way, this requirement can be stated as: the pulse height distribution of the monitor counter has to be constant. Although the output pulse height distribution of a proportional counter irradiated by a relatively soft monochromatic source, is a very broad one, it is possible to find a straightforward relation between the integrator output voltage and the peak of the distribution, provided the time constants are very long.

For the loop one can write the following equations:

$$V_1 = T_1 V_5, \quad V_2 = A_1 V_1, \quad V_3 = T_2 V_2, \\ V_4 = A_2 (V_3 - V_R), \quad V_5 = A_3 V_4,$$

where  $V_1$ ,  $V_2$ ,  $V_3$ ,  $V_4$  and  $V_5$  are the output voltages of the detector, the pulse amplifier, the integrator, the comparator-regulator and the high voltage for the proportional counter respectively.

$V_R$  is the reference voltage.

$A_1$ ,  $A_2$  and  $A_3$  represent the amplification factors of the pulse amplifier, the comparator-regulator and the converter respectively.

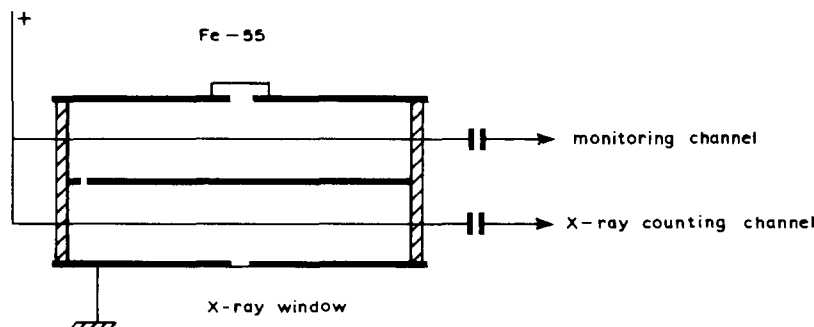


Fig. 1. Twin-proportional counter used in the Utrecht X-ray experiment in the ESRO-II spacecraft.

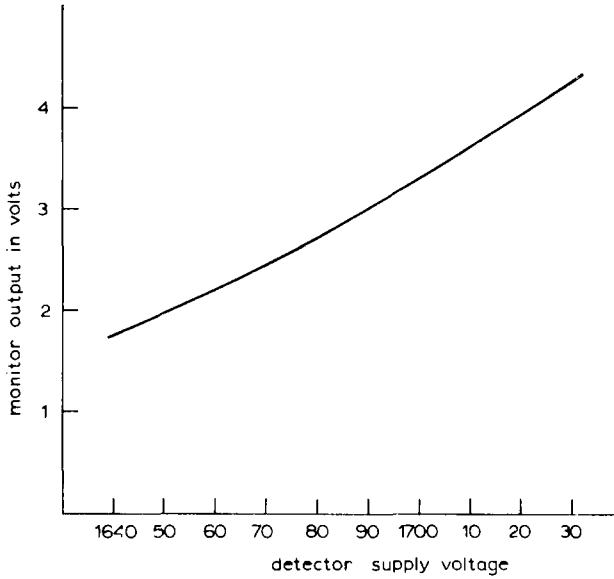


Fig. 2. Monitor output as a function of detector supply voltage.

$T_1$  and  $T_2$  are the transfer functions of the proportional counter and the integrator.

With the above defined quantities one derives,

$$(V_R - V_3)A_{2d} \cdot A_{3d} \cdot T_{1d} \cdot A_{1d} \cdot T_{2d} = \Delta V_3,$$

where the subscripts d indicate differential gain.

This can be rearranged to:

$$V_3 = V_R - \Delta V_3 / G_L, \quad (1)$$

where  $G_L = A_{1d} \cdot A_{2d} \cdot A_{3d} \cdot T_{1d} \cdot T_{2d}$ .

For  $V_3$  one can also write:

$$V_3 = A_1 T_2 V_1. \quad (2)$$

Eqs. (1) and (2) give:

$$V_1 = \{V_R / (A_1 T_2)\} - \{\Delta V_3 / (G_L A_1 T_2)\}. \quad (3)$$

For a non-varying pulse height distribution  $V_1$ , one requires therefore a stable  $V_R$ ,  $A_1$  and  $T_2$ .

In addition,  $G_L$  should be large so that the term  $\Delta V_3 / (G_L A_1 T_2)$  can be neglected.

For this case the dynamic open loop gain was mea-

sured and found to be 1400. Due to this rather high gain, it is not possible to open the loop and to measure the gain directly. Therefore, the gain was determined in three successive steps.

First  $\Delta V_3 / \Delta V_5$  was measured, the value of which is  $3.7 \times 10^{-2}$ .

This was done by disconnecting the output of the converter from the detector and supplying the power for the detector from a separate unit.

The value of  $\Delta V_4 / \Delta V_3$  was measured in the loop and was 300.

The dynamic gain of the converter was  $\Delta V_5' / \Delta V_4 = V_5 / V_4 = 125$ .

### 3. Description of electronic circuitry

The pulse amplifier used consists of a charge sensitive pre-amplifier, followed by a voltage amplifier.

As the amplification factor  $A_1$  appears in the expression  $V_1 = V_R / (A_1 T_2)$ , the gain  $A_1$  should be therefore constant. However, if the pulse amplifier of the X-ray proportional counter and the pulse amplifier of the monitor part are of an identical type, and therefore have the same dependence on temperature, supply voltage etc. the requirement can be relaxed so far that the difference in gain of the two pulse amplifiers should be constant. This requirement is obviously much easier to fulfil.

The circuit diagram of the integrator is given in fig. 4. The circuit can readily be understood if we make the following assumptions. The amplitude of the input pulses is  $H$ . The pulses appear at regular intervals, the rise time of the pulse is very short and the trailing edge decays exponentially. As soon as the momentary value of the input pulse is greater than  $V_3'$ , transistor  $T_3$  will conduct and  $T_4$  is saturated. The resulting  $T_4$  collector current,  $i_C$  which charges  $C_3$ , is  $(V_B - V_3' - V_{CE}) / R_6$ .

It can be shown easily that the current pulse duration is a logarithmic function of  $H / V_3'$ .

The voltage  $V_3'$  will be stabilized at a point where the charge lost by leakage through  $R_7$  and  $R_8$  is equal to the charge supplied by the current pulses (fig. 5).

Where in reality the input pulses appear at random

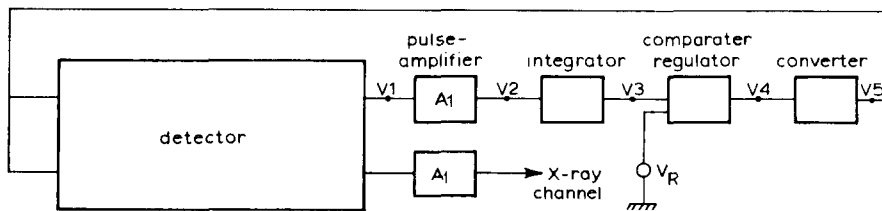


Fig. 3. Block diagram of twin-proportional counter with automatic gain control circuitry.

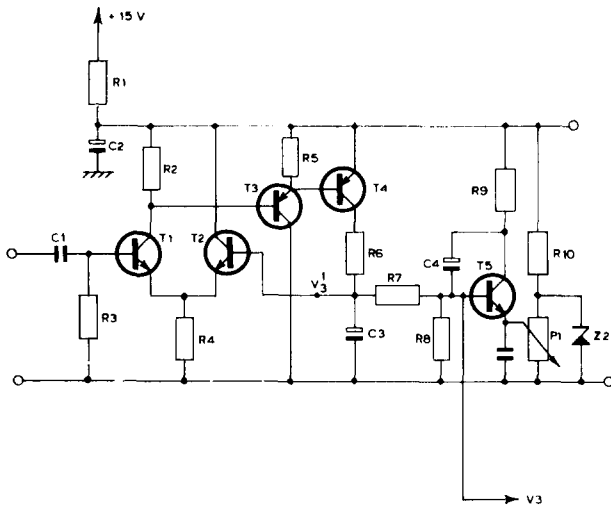


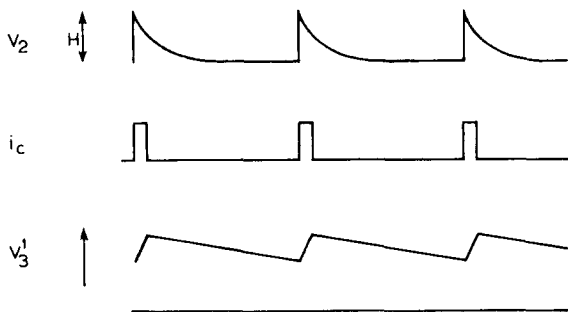
Fig. 4. Integrator circuit diagram.

and the pulses form a pulse height distribution, it is necessary to have this circuit followed by a low pass filter. This is done by  $R_7$  and  $C_4$ .

The capacitance is a virtual capacitance with a value  $A_0 C_4$ , where  $A_0$  is the voltage amplification factor of this stage for very low frequencies. The voltage  $V'_3$  is controlled by the discharge  $RC$ -time of capacitor  $C_3$  and by the size and duration of the charge current pulses. As only input pulses from the distribution  $V_1$  which are greater than  $V'_3$ , do open transistor  $T_4$  and therefore do contribute to the voltage  $V'_3$ , it is clear that the discharge time and the charge current pulses decide which part of the input pulse height distribution will be used.

If the  $RC$ -time of this filter is long, only the biggest input pulses of the distribution will cause a  $C_3$ -charge current. The larger the current pulses the higher the resulting  $V'_3$  will be, this is controlled by resistor  $R_6$ . In order to keep the ripple on  $V'_3$  low it is desirable to have a long  $RC$ -time and therefore a large  $R_8$ .

From a temperature stability point of view there is

Fig. 5.  $V_2$ ,  $i_c$  and  $V'_3$  as a function of time.

a contradictory requirement for the value of  $R_2$ .  $R_2$  should be small to ensure equal collector currents for transistors  $T_1$  and  $T_2$ , at the trigger point, which is necessary for equal  $V_{BE}$ 's. On the other hand,  $R_2$  should be large to ensure a stable trigger level. A good compromise was a value for  $R_2$  of 82 k $\Omega$ .

Fig. 6 shows the circuit diagram of the comparator-regulator. In the comparator-regulator circuit the voltage  $V_3$  is compared with a reference voltage  $V_R$ . The difference voltage controls via transistor  $T_9$ , the series regulator transistor  $T_{10}$ .

The comparator is a long tail pair circuit, with the emitter resistor replaced by a transistor, as a constant current source. Diodes  $D_1$  and  $D_2$  are added to compensate the temperature characteristic of  $V_{BE}$  of transistor  $T_8$ .

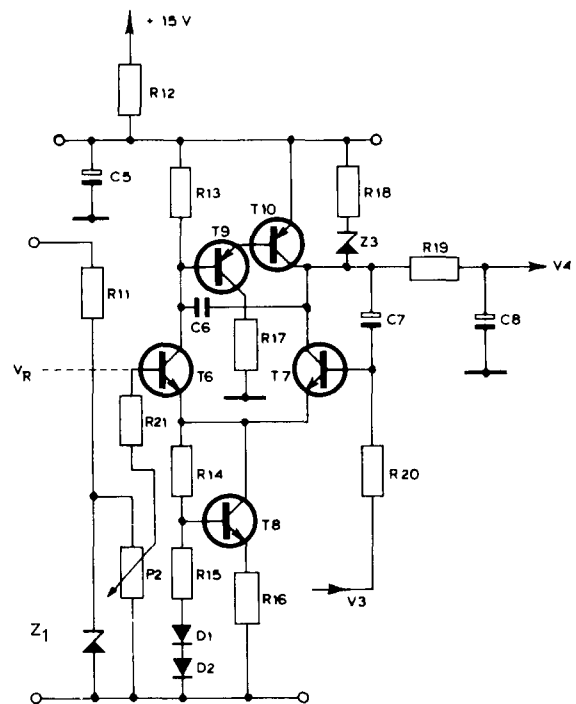


Fig. 6. Comparator-regulator circuit diagram.

$T_6$  and  $T_7$  is a dual transistor, 2 N3680, with a  $\Delta(V_{BE1} - V_{BE2})$  of 5  $\mu V$  per  $^{\circ}C$ .

In order to decrease the influence of the base currents the value of the base resistors is made of the same order.  $Z_1$  is a reference element, 1N4572<sup>A</sup>, with a temperature coefficient smaller than 0.002%/ $^{\circ}C$ . To prevent amplification of any low frequency component of  $V_3$  the output of the regulator is coupled to the input by capacitor  $C_7$ . This can be regarded to be a low pass filter with  $RC$ -time of tens of minutes. The output is

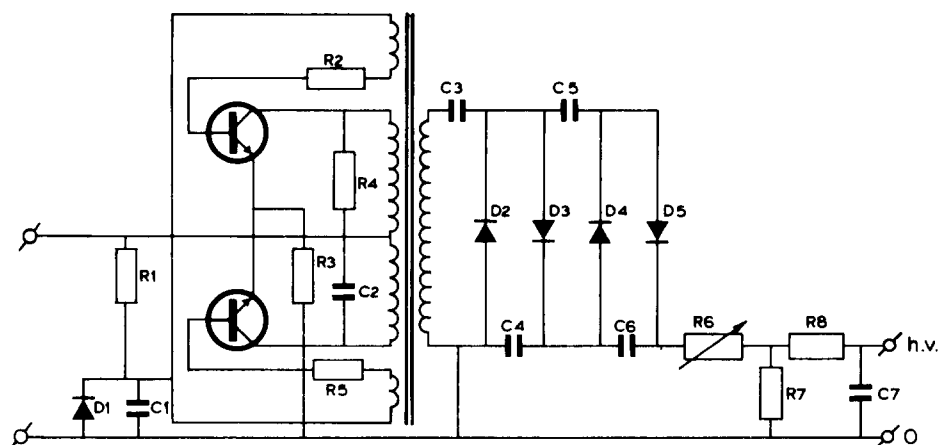


Fig. 7. Converter circuit diagram.

coupled to the converter via  $R_{10}$  and  $C_8$ . The capacitor supplies the charge for the current spikes drawn by the converter.

The circuit diagram of the converter is given in fig. 7. A push-pull circuit is used for the oscillator, followed by a voltage quadrupler. The resistor  $R_1$  in series with the parallel diode-capacitor network, form the starter circuit.

#### 4. Results

In order to simulate a gas gain change of the detector by a factor of two, e.g., caused by a gas leak, the amplification factor of the pulse amplifier was changed by the same amount.

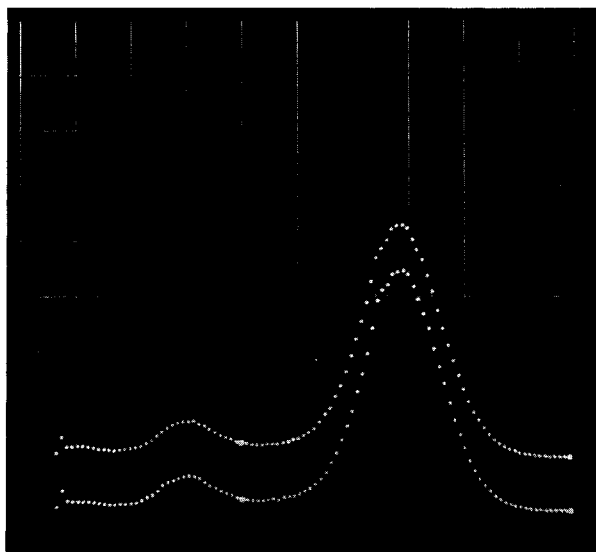


Fig. 8. 2.1 Å pulse height distributions made with a multichannel pulse height analyser. The top curve has been taken before, the lower one after the simulated gain change of a factor two.

Fig. 8 shows two 2.1 Å distributions, measured at the output of the pre-amplifier with a 100 channel pulse height analyser. Along the abscis are the channel numbers, about ten channels per division. The bottom curve is taken before, the top one, after the simulated gain change. As can be seen from the picture the change in the distribution is less than one channel (the peak is in channel 65), therefore the resulting relative change of gas gain is less than 1.5%.

#### 5. Some additional considerations on circuitry

A decrease in the number of pulses from the  $^{55}\text{Fe}$  source after a long period of time will result in a decrease in the voltage  $V_3$ . The circuit will compensate this and the result is an undesired shift of the pulse height distribution. The size of this shift greatly depends on the number of pulses from the distribution that contribute to the voltage  $V_3$ .

However, as long as the trigger level for the integrator is set in such a way that only the part of the pulse height distribution at the right of the peak is used, the shift will be rather small.

A decrease in the number of pulses of 30% (corresponding with a period of more than  $1\frac{1}{2}$  year for a  $^{55}\text{Fe}$  source) causes a shift of one channel in fig. 8, or about 1½%.

A temperature test of the whole circuitry including the detector shows a change of 1 channel over a temperature range of 70°C, (−10°C to +60°C). The spectral resolution was measured by comparing the full width at half maximum (fwhm) of a spectrum from the  $^{55}\text{Fe}$  source with the circuits described and the fwhm of a spectrum with the same detector, but with a separate stable high voltage supply. No difference could be detected.

The power consumption of the integrator, compara-

tor-regulator and converter was 150 mW. A fixed voltage output converter utilizing a voltage stabiliser tube would consume about 80 mW.

## 6. Conclusions

A circuit has been built which, compared with a conventional proportional counter circuit with a fixed power supply, compensates for changes in gas gain and supply voltage.

Changes of a factor two in gain can by application of the proposed circuit be reduced to changes in the order of one per cent.

Although no attempt has been made yet to minia-

turize the circuits and economize on power, the application would be in the field of space research etc. where proportional counters have to work for a long period of time, typically one year, without access for recalibration. Gain shifts could cause false readings, particularly where on board pulse height analysis is carried out.

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