A LOW BACKGROUND LIQUID SCINTILLATION COUNTER FOR ^{14}C

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Abstract

A liquid scintillation counter for ^{14}C with an E^2/B of over 1800 has been built and operated on a routine basis for over a year. It has a background of 1.96 ± 0.03 c.p.m. and an efficiency of 60.3% ± 0.5% has been measured using 5 ml of ^{14}C benzene prepared from N.B.S. Contemporary Standard Oxalic Acid (14.24 ± .07 d.p.m./g of C).

Signals from the last dynodes of the two EMI 9635QB photomultiplier tubes are fed through amplifiers, discriminators and a coincidence system which are entirely contained on three small printed circuit boards mounted near the tube bases. The anode signals of the two tubes are fed into a single N.I.M. preamplifier, amplifier, linear gate (controlled by the coincidence unit) and to a pulse height analyser. As the system gain is high, an EHT of less than 1000 volts can be used.

The sources of background are discussed. Optical and electronic methods of substantially reducing crosstalk, the major component of background, without reducing counting efficiency are described.

Introduction

A high figure of merit (% efficiency^2/background c.p.m.) is necessary for a counter used for ^{14}C dating. Commercial liquid scintillation counters have a typical figure of merit of 600, but this may be easily increased to 1200 by simple modifications to reduce the background (1). To reduce the background further special counters with anticoincidence shields have been built (2).

The counter described in this paper achieves a figure of merit of 1800 without the need for anticoincidence shielding, by reducing the crosstalk between the two photomultipliers by optical and electronic means.

Sources of Background

The background of a coincidence type liquid scintillation counter may be divided into three components:

(a) Accidental coincidences between the two channels.

(b) Coincidences from light pulses in the sample itself, i.e. in the part of the system which is common to both channels.

(c) Coincidences from light pulses which originate in one channel and which are seen by the other channel.

Component (a) arises mainly from thermionic emission from the photocathodes and may be reduced to well below 0.1 c.p.m. by using a short resolving time. Component (b), light pulses in the sample, is caused by external radiation. It may be reduced by shielding, preferably with materials selected for low radioactivity. Little improvement will be obtained beyond 10 cm of lead or equivalent. A window discriminator almost eliminates the high energy cosmic ray components and further reduces the γ background. Component (c) is usually the major one. It originates from two sources, namely, light pulses associated with the operation of the photomultipliers, which may be minimised by using a low operating voltage (3), and those caused by cosmic rays and radioactivity of the photocathode window. Some of the light from these pulses will reach the other photomultiplier and may trigger the coincidence circuit causing a background count to register. Background arising from this process will be referred to as cross talk background, and the fraction of light leaving one photomultiplier which reaches the other as the cross talk ratio. Cross talk background is directly but not linearly related to cross talk ratio. If the ratio is minimised without affecting the light collecting efficiency the figure of merit will be improved. Even if light collecting efficiency is reduced along with the cross talk ratio an improved figure of merit may still result, especially with higher energy β emitters. Cross talk background may also be reduced by increasing the coincidence thresholds. Most instruments have fixed thresholds, but the same effect may be achieved by lowering the tube voltage and increasing the main (sum) amplifier gain.

Reduction of Cross Talk Ratio

The cross talk ratio may be reduced without reducing light collecting efficiency by using a vial made from a material which reflects back light from the photomultipliers but does not absorb any light from the scintillator. Consider a material which diffusely transmits a small fraction μ of the light incident on it and diffusely reflects all the remainder. A vial of this material is mounted between two photomultiplier tubes so that a fraction δ of its surface is coupled to the cathode of each photomultiplier with negligible loss. (This can be done with a light guide or mirror system which has constant or increasing cross section from vial to photocathode (4).) If absorption in the scintillator is negligible and μ is small enough for each photon to be reflected several times before leaving the vial, then the fraction of the total light emitted by the scintillator reaching each photocathode is δ and the light collecting efficiency is 2δ (5). Light originating from the photomultiplier will be reflected back by the vial and absorbed, and only a fraction μ will be transmitted to the scintillator. A fraction δ of this will then be transmitted to the other photomultiplier. The cross talk ratio is therefore $\mu\delta$ if there is no light leakage around the vial. It can be seen that a low μ and low light absorption are desirable properties for a vial material. μ for 1 mm thick Teflon is about 0.17 and for 2 mm or thicker about 0.1. Teflon has a very low light absorption and is unaffected by scintillator solutions, making it an ideal vial material. It is possible to fabricate a vial from Teflon with a light collection efficiency close to 100% and a cross talk ratio of less than .1.

Description of Counter

The counter is based on an early model Tracerlab liquid scintillation counter of which only the freezer and manual sample changer have been retained. The sample changer has been automated and a new lead shield with the photomultipliers mounted coaxially has been fitted. The shield which has an average thickness of about 5 cm encloses the photomultipliers as well as the sample. The

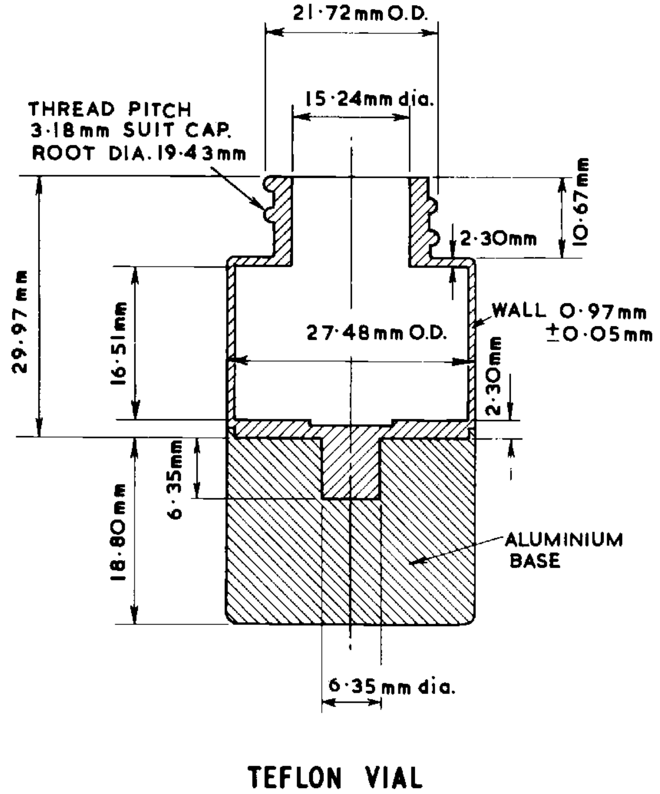

Figure 1 Teflon counting vial

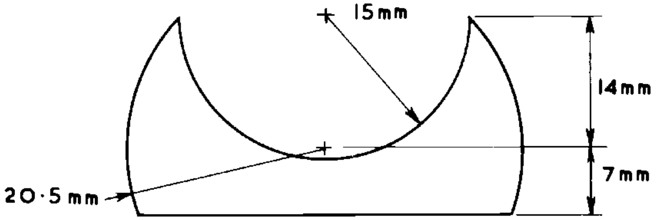

Figure 2 Plan view of one light guide. The light guide is made from 13 mm thick perspex. The outer curved surface is coated with evaporated aluminium.

sample vials which are shown in figure 1 are made of Teflon and have a volume of 5 ml. The vial is coupled to two EMI type 9635QB photomultipliers by two perspex light guides (figure 2) supported by a copper block which provides some additional shielding. Black paint and tape eliminate any stray light travelling from one tube to the other. μ for the optical system is .17, and δ is 0.274. The calculated light guide efficiency is .83, giving a light collecting efficiency of .46 and a cross talk ratio of .039. Figure 3 shows a block diagram of the electronics. The photomultipliers are operated with 150 V from cathode to first dynode and equal voltage distribution over the remaining stages. Signals from the last dynodes of the two photomultipliers are fed through specially designed amplifiers, discriminators and a coincidence gate with a 30 ns resolving time. The anode signals of the two tubes are fed through a single N.I.M. preamplier, amplifier and linear gate (controlled by the coincidence unit) and then to a single channel pulse height analyser and print out scaler, or to a multichannel analyser (figure 3). Alternatively, the linear gate may be omitted and the output of the single channel analyser gated by the coincidence unit.

Coincidence System Circuit Description (Figure 4, 5)

Amplifier

A charge sensitive amplifier with a field effect transistor (FET) Q1 in a folded cascode circuit is used as the input stage. The load resistor of Q2 is bootstrapped by the emitter followers Q3 and Q5 to increase the preamplifier open loop gain to approximately 2,000. With the feedback resistor R2 and the capacitor C3 connected, the preamplifier has an output of 1.6×10^{-7}V per electron applied to the input. This gives a 1V output at the emitter of Q6 for a 10^{-12} coulomb input. With a 7 cm input lead of 50 ohm coaxial cable the output rise time at Q6 is less than 30 ns and the fall time, determined by R2 and C3, is 100 ns.

Discriminator

The output of the preamplifier is buffered by Q7 which drives the monostable multivibrator Q8, Q9 and Q10. The transistor Q8 is normally held cut off by the positive voltage (1-3 V) set on RV1; when the negative pulse from

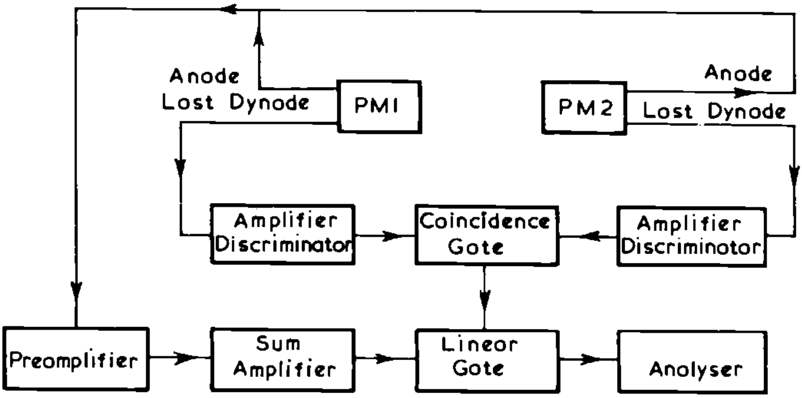

Figure 3 Block diagram of the counting system

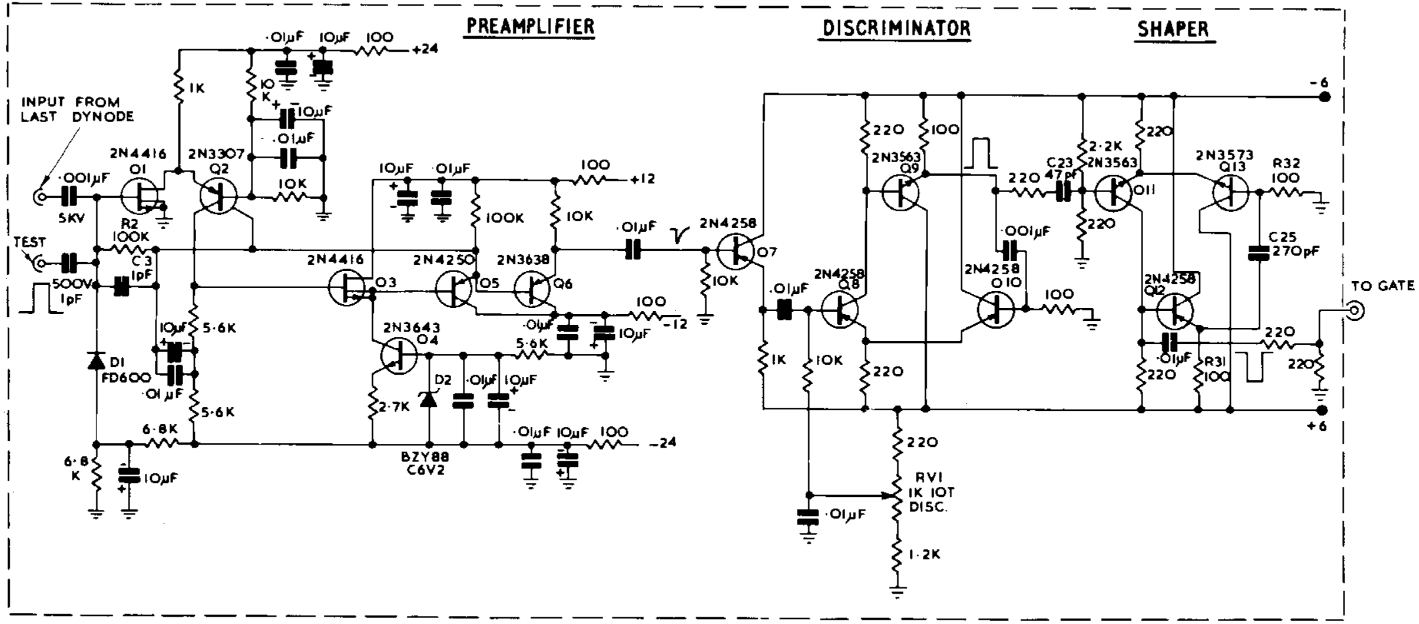

Figure 4 Amplifier - Discriminator circuit diagram

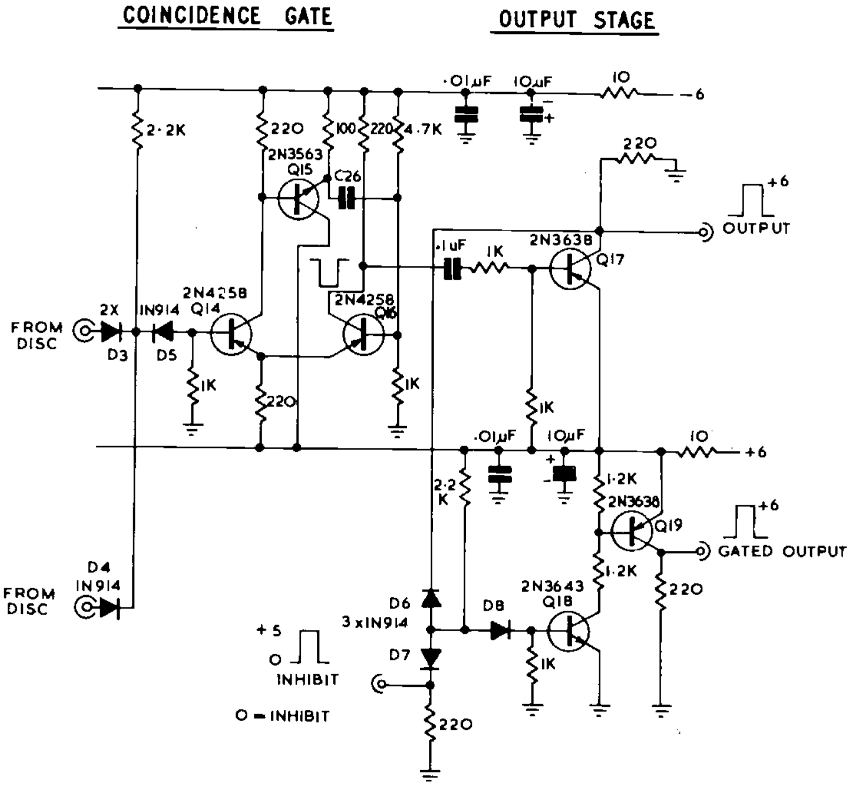

Figure 5   Coincidence gate circuit diagram

Q7 exceeds this preset voltage the monstable triggers giving a positive 100 ns wide pulse at the emitter of Q9.

Shaper

The output of Q9 is differentiated by C23 and the positive edge triggers the monstable Q11, Q12 and Q13. The width of the negative output pulse on the emitter of Q12 is set to 30 ns by C25 and R32.

Coincidence Gate

A diode AND gate is formed by D3, D4 and D5; when the outputs from Q12 in each channel are in coincidence D3 and D4 cut off and D5 conducts. This gives a positive trigger signal to the monstable Q14, Q15 and Q16, the width of the output at the collector of Q16 can be varied by selecting C26. If a coincidence does not occur only D3 or D4 will cut off and the monstable will not trigger.

Output Stage

The negative output pulse from the collector of Q16 saturates Q17 giving a positive 6V pulse capable of driving a 50 ohm cable. When Q17 saturates it cuts off D6 and if a positive strobe pulse of greater than 2V is present D8 will conduct allowing Q18 to saturate which in turn saturates Q19 giving a 6V output pulse to the gated output. Holding the INHIBIT input to O V or open circuit will prevent an output at the gated output. Both output pulses have less than 0.1 microsecond rise times.

Setting up Procedure and Results

A ^{14}C sample is loaded and the high voltage on each photomultiplier is set separately (with the linear gate held open) to give a maximum pulse height of about 5 volts. The linear gate is then returned to normal and a sample and background spectrum taken using the multichannel analyser. The cut off channels to obtain maximum E^2/B are then determined. The main amplifier gain is then changed (by a factor of 2) and the procedure repeated until the maximum E^2/B is obtained. The single channel analyser is then set to correspond to the optimum cut off channels using a mercury pulser. With the optimum settings (HV 945V and 1120V, gain 12, window .5 - 8.5 volts) a background of 1.96 ± 0.5 c.p.m. and an efficiency of 60.3 ± 0.5% has been measured using 5 ml of ^{14}C benzene prepared from N.B.S.

Contemporary Standard Oxalic Acid (14.24 ± .07 d.p.m./g of C).

Further Improvements

The background could probably be further reduced by using thicker shielding. Replacement of the light guides by a mirror system would reduce the amount of material in which cosmic ray induced Cerenkov radiation could occur. The optical efficiency could be increased by using a near spherical vial with a δ of close to .5, while the cross talk ratio could be kept about the same by using 2mm thick Teflon. If each of these vials were built into their own light guide assembly an automatic sample changer could still be used and light leakage around the vial would be completely eliminated.

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