# nucleonics for the EXPERIMENTER

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## 6—STRACE GAMMA RAY SPECTROMETER UNIT (Continued)

Last month's article terminated with details of the calibration procedure for the bottom and top limit controls VR2 and VR3 of Fig. 5.3.

### ENERGY RESOLUTION

The setting accuracy of an ordinary carbon potentiometer calibrated in the manner described is about $\pm 1$ per cent, so that the complete range from 0·1 to 3·6MeV can be resolved into some 100 sequential chanels. It is thus convenient to select any spectrum interval of width 0·5MeV, and to record this in 12 steps of about 0·05MeV each, although this need be no hard and fast rule.

This degree of resolution, which has proved very stable and reproducible with the prototype, is well matched to the other limiting factors, such as the inherent resolution of the specified detector and circuit gain tolerances, so that there is no point in using improved potentiometer types.

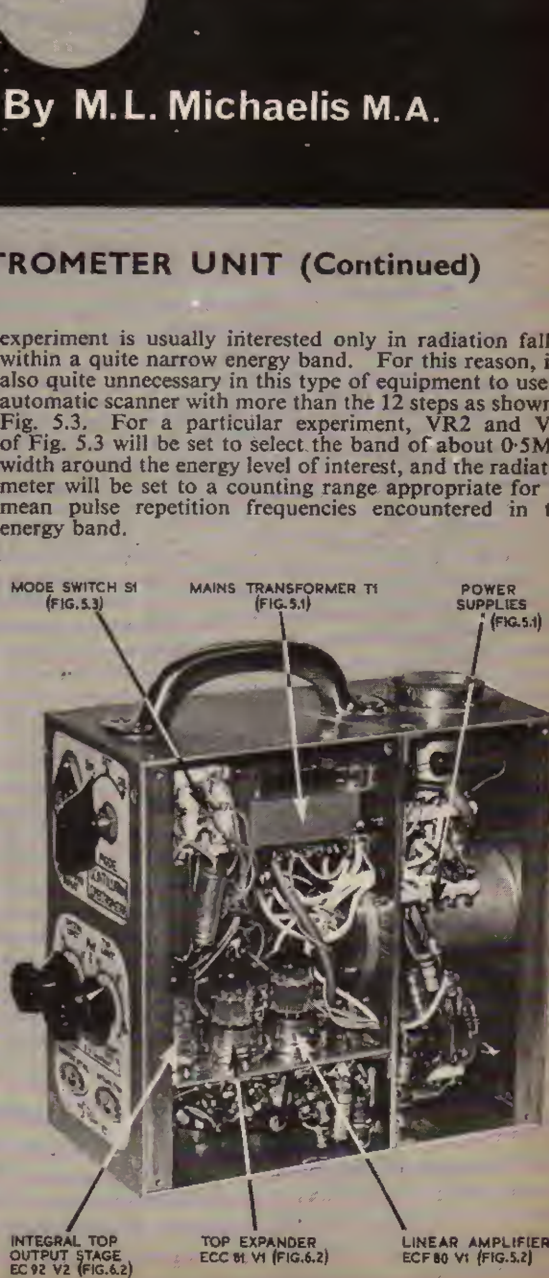
Professional equipments with resolutions of many hundreds of channels employ so-called helical potentiometers. These are spiral-track devices wound with close-tolerance resistance wire. The entire track is covered by several revolutions of the spindle, and suitable gearing and a cyclometer-type counter mechanism show the actual setting. Such potentiometers are expensive, and unnecessary for the amateur design here described.

### OVERALL COUNTING RATE

The overall counting rate, apart from the peak counting rates at the respective energy levels, drops logarithmically with increasing energy. Thus typical samples as recommended for this work give counting rates of thousands per minute for peaks falling around 0·5MeV, hundreds per minute for peaks falling around 1·5MeV, and only a few dozen per minute for peaks at still higher energies. This is because the proportion of incident quanta of nuclear radiation which are absorbed totally in the crystal becomes smaller at higher energies, since some of the energetic radiation can escape again.

With a linear scale radiation meter, the entire range of the main potentiometers can thus not be recorded properly anyway, and although logarithmic scaling is often found in professional equipment, it adds unnecessary complexity to an amateur design.

Whilst the entire available energy range from 0·1MeV to 3·6MeV will be required at different times for various experiments with various substances, any *particular* experiment is usually interested only in radiation falling within a quite narrow energy band. For this reason, it is also quite unnecessary in this type of equipment to use an automatic scanner with more than the 12 steps as shown in Fig. 5.3. For a particular experiment, VR2 and VR3 of Fig. 5.3 will be set to select the band of about 0·5MeV width around the energy level of interest, and the radiation meter will be set to a counting range appropriate for the mean pulse repetition frequencies encountered in this energy band.



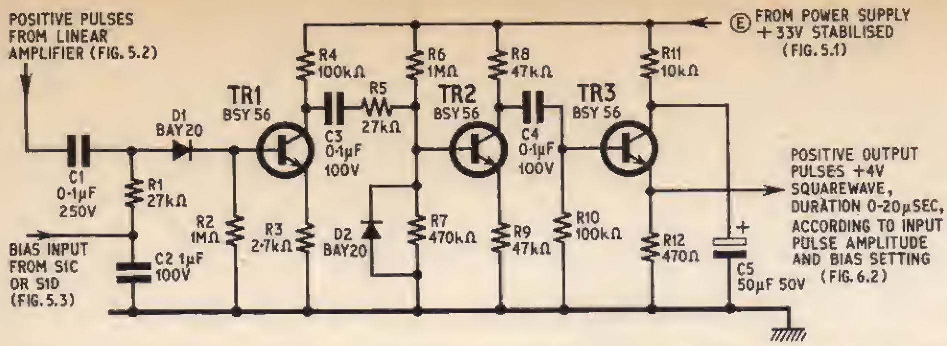



*Fig. 6.1 STRACE Gamma Ray Spectrometer: Circuit diagram of the amplitude discriminator (there are two such units in STRACE—"bottom" and "top" discriminators repectively—and they use this identical circuit)*


## RADIOACTIVE SAMPLES

Suitable radioactive samples may be purchased from the Radiochemical Centre, Amersham, Bucks. The Caesium-137 solution specified for the energy calibration should have a volume of about 4ml, in a sealed glass ampule fitting the sample well in the sodium iodide crystal, and it should contain a total activity of about 350nCi. Similarly for the specified Cobalt-60 solution. These amounts of these particular substances are less than those permitted to be sold without special permit, and are quite safe with reasonable care. They should never be carried on the person, e.g. in pockets.

## AMPLITUDE DISCRIMINATOR

The circuit of the STRACE amplitude discriminator is given in Fig. 6.1. D1 is the actual discriminator. The inverse bias is applied via R1 from the scanner to the anode of the diode, whilst the pulse mixture from the linear amplifier is fed in via C1 and establishes a positive pulse voltage spectrum across R1 as load resistor. Only those pulses greater than the applied bias can cause D1 to conduct on their tips, causing TR1 to conduct in turn. Due to the very large collector load R4 of TR1, this transistor saturates already with a very slight excess of pulse voltage above the bias threshold of D1.

R5 and D2 prevent blocking, TR2 is a polarity inverter to restore positive polarity of the pulses, and finally TR3 is an emitter follower to produce low output impedance for driving the next functional stages.

The overall function of the circuit is thus that of a diode gate feeding a high-gain amplifier which normally rests cut off. A very slight excess above the gate threshold already saturates the amplifier and produces full output of 4V. Thus we have now obtained *constant* amplitude output pulses which carry a "yes/no" information. The presence of an output pulse implies "yes, the input pulse was greater than the chosen threshold", whilst the absence of an output pulse implies "no, the input pulse was not greater than the chosen threshold".

However, the output pulses are still not of uniform duration, since their duration depends upon the time spent by the input pulse above the bias threshold, which is obviously a function of the pulse amplitude in relation to the bias level. The energy information, which was originally contained in the amplitude of the input pulses to Fig. 6.1, has been transferred to the width of the output pulses. Some professional circuits make use of this feature, but in our case it is unwanted; we desire discriminator output pulses which are strictly identical in amplitude and duration, carrying solely the yes/no threshold information.

## THE EXPANDERS

Turning now to Fig. 6.2, we see that the unwanted pulse width information is "killed" by feeding the output of each discriminator to a respective expander. Each expander is fired by an input pulse to produce a standard

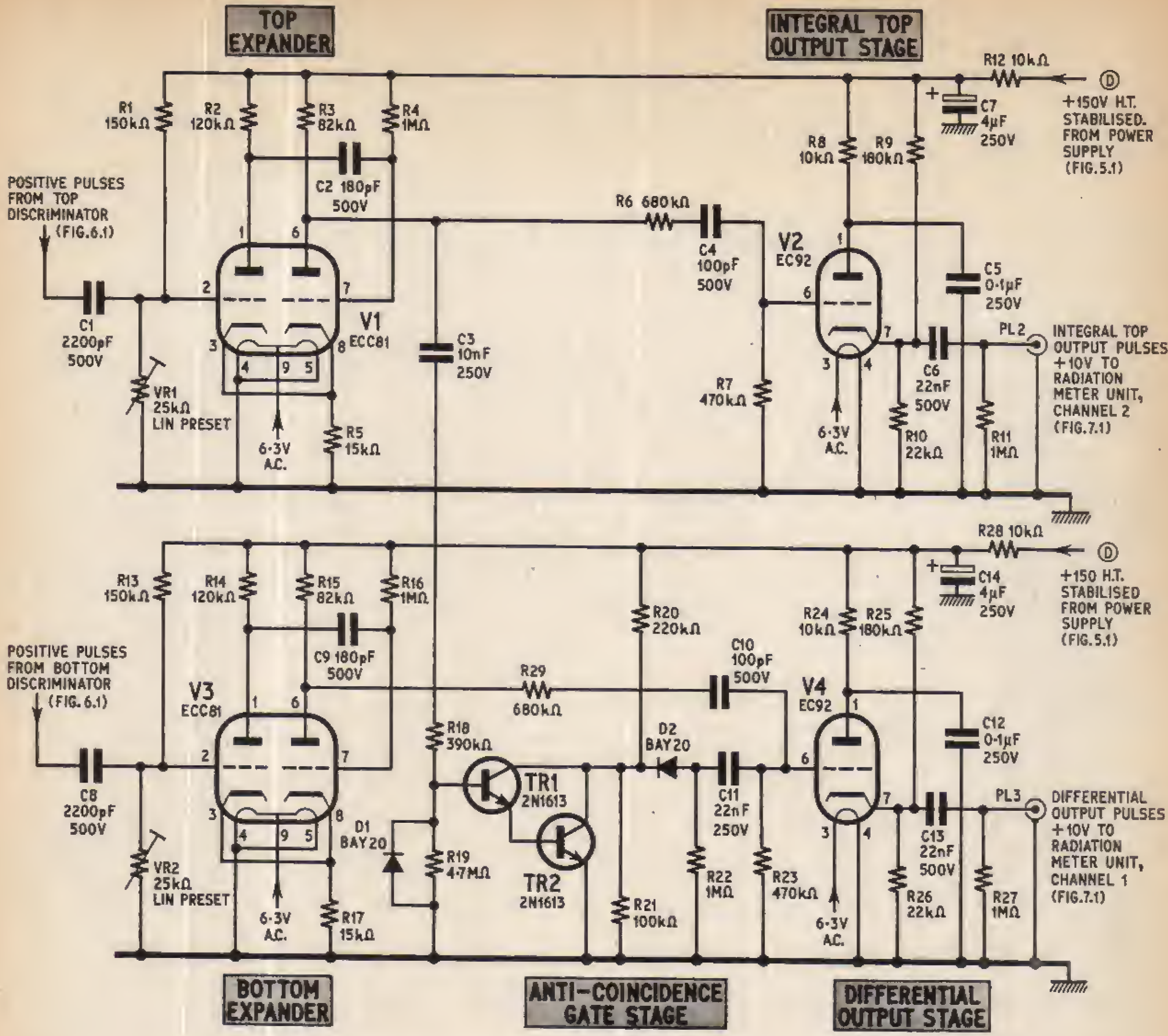



*Fig. 6.2.* ***STRACE Gamma Ray Spectrometer:*** ***Circuit diagram of the pulse channel amplifiers***

response pulse of fixed amplitude and duration determined solely by the characteristics of the expander circuit. It is called an expander because the standard response pulse is longer than the longest input trigger pulse.

The section pins 1, 2, 3 of each double triode rests cut off, whilst the other triode section rests conducting. A positive input pulse greater than a certain threshold amplitude determined by the setting of VR1/VR2 in Fig. 6.2, changes over the roles of the two triode sections by cumulative multivibrator action, for a brief time determined by C2, R4 and C9, R16. After the elapse of this relaxation time, the circuit drops back into its former resting state of its own accord. Positive square pulses of about 70μs duration thus appear at the respective anode pins 6. These are fed to respective conventional cathode follower output stages, V2 and V4, via the voltage dividers R6/R7 and R29/R23.

## ANTI-COINCIDENCE GATE

The anti-coincidence gate simply shorts-out the bottom end R23 of the voltage divider feeding the bottom cathode follower, if the top discriminator has also produced a pulse simultaneously.

The diode D2 is normally cut off by the standing bias on the bleeder R20, R21. A pulse from the top expander is fed via C3 to make TR1, TR2 conduct and thus effectively remove the bias from D2, so that D2 then shorts-out the pulse voltage across R23 from the bottom expander, giving no output from V4. Any residual pulse voltage at V4 grid is suppressed by the positive bias applied to the cathode via R25.

V4 thus gives an output pulse only when the bottom, but not the top discriminator has responded. It is thus called the differential output stage. The output from V2 contains all pulses greater than the upper limit of the differential interval of V4, whilst original pulses smaller than the lower limit of the differential interval of V4 are entirely suppressed.

## SOME GENERAL FEATURES

The diode D2 is necessary in Fig. 6.2 in addition to the two transistors, because the collector capacitance of transistors is too high in the resting state, distorting the wanted pulses from the bottom expander. It is common practice to use low-capacitance silicon diodes for the actual gating and discriminator functions in nucleonic equipment, with separate drive stages.

The expanders V1 and V3 in Fig. 6.2 are theoretically complete amplitude discriminators in themselves, and one may ask why they are not used as such and fed directly from the linear amplifier and scanner. Some circuits do actually work on this principle, but then at higher pulse amplitude ranges of about 100V peak from the linear amplifier. Numerous other derivatives of multivibrators and paraphase amplifiers can also be used as high-level amplitude discriminators. In our equipment concept, this is inconvenient, because the lower pulse peak values of 15V are too small compared with drifts of the trigger threshold level of the expanders with valve ageing and other factors. A multivibrator type amplitude discriminator is also prone to erratic performance on trigger pulses much greater than the trigger threshold level, as would be the case when working near the bottom end of the spectrum.

This brings us to the question of signal level planning for the complete kick-sorter amplifier, which is intimately connected with the adoption of hybridisation (mixed valves and transistors).

## HYBRID DESIGN

Whilst modern professional equipment increasingly tends to be fully transistorised in all stages, hybridisation often permits a better compromise between stability and complexity, if no extreme demands are placed on accuracy. This is best illustrated by the underlying ideas in the present STRACE design.

The most vulnerable point is the discriminator voltage stability. Using biased semiconductors, this stability is determined solely by precision resistors in the scanner and a stabilised voltage supply, irrespective of the active devices as long as the pulse amplitude levels are large compared to silicon barrier layer threshold voltages (the latter being some hundreds of millivolts). This must hold for the smallest pulse voltages, so that the input pulse spectrum to the discriminator is required to be inconveniently large compared to the linear drive range of transistor amplifiers. But it is very easily provided by a valve amplifier. Hence a valve was used for the simple linear amplifier.

Similar considerations led to the adoption of valves for the expanders and output stages, but transistors for the anti-coincidence gate. Sufficiently fast response of the gate is difficult to obtain in a simple circuit, except by brute force of driving it with massive pulse amplitudes readily obtainable only from a valve circuit.

## CONSTRUCTIONAL DETAILS

The entire kick-sorter circuitry of Figs. 5.1, 5.2, 5.3, 6.1 and 6.2 can be accommodated in an aluminium casing measuring 8in × 8in × 4in with a carrying handle and the socket for the plug-in scintillation detector on the upper side, as shown in the photographs. Layout is not critical, and constructors can use any convenient form, larger if necessary.

Almost any type of silicon *npn* transistor is suitable in all positions, provided the voltage rating is adequate. The pulse diodes may be any silicon type with at least 100 p.i.v. rating and at most 4pF self-capacitance.

The narrow face panel carries the threshold potentiometer controls VR2, VR3, and the mode switch S1 of Fig. 5.3; the power and command input plug PL1 of Fig. 5.1 and the two pulse output plugs PL2 and PL3 of Fig. 6.2. The latter are coaxial, for feeding the processed pulses through coaxial cables to the radiation meter unit.

## IMPORTANT

### ADDENDA AND CORRECTIONS TO DIAGRAMS IN PART 5

***Fig. 5.1 Power supply and scintillation detector.***

The Zener diode voltages of D9, D10, D11 and D12 are equal to the nominal output voltages of their respective circuits. The Zener diode voltage of D13 is 120V, and of D14 to D23 inclusive, 60V each.

The correct value of C16 is 47nF (0.047μF).

The correct value of C17 is 10nF (0.01μF).

***Fig. 5.3. Sequential scanner circuit diagram***

The correct voltage rating for C3 is 9V and not as shown.

**Next month: Radioactivity measurement; a ratemeter design**