

Electronic Methods in the Physical Laboratory

Design Exercises

part 1: 22th October – 2nd November 2012

Aim: The aim of this exercise is to help you to apply what you have learnt on this course to the sort of lab problems you will encounter next, in particular, in Junior Honours Experimental Physics. The exercise will also assess your understanding of the lectures and the lab checkpoints. **In total it is worth 40% of the total course mark.** There are three exercises: the second is split across part 1&2 as you will need to attend the remaining lectures to work on its second half. The first two exercises focus on specific experimental situations, in the third exercise you can demonstrate your JAVA skills obtained in the Computational Physics course(or use Labview).

Please attempt all parts of all questions. Use the (green) answer book which can be picked up in the lab. There is no penalty for including too much information in your answers: in circuit designs include enough details for someone to be able to build your circuit. Take care to make all diagrams and graphs complete (e.g. the labels). You are free to consult lecture notes, text books etc. but you must acknowledge any sources which helped you to answer the questions. For example at the beginning of a solution:

Ref: Horowitz & Hill, The Art of Electronics, 2nd edition, 1989, pp.11-13.

At the end of your answers you must sign and date a declaration, "The above answers are my own work except where otherwise acknowledged". **Hand in part 1&2 to the Undergraduate Secretary, JCMB 4315, no later than 17:00 on Friday 7th December 2012.**

Stephan Eisenhardt, September 2012

Exercise 1: Pulses

^{22}Na decays with a half-life of 2.6 years by positron emission. The positron annihilates an electron giving rise to a pair of 0.51 MeV γ -rays. Coincidence measurements can easily show that the 0.51 MeV γ -rays are produced in pairs with the two photons travelling in opposite directions. A schematic illustration of the apparatus you might use to study the pairs of photons is shown below:

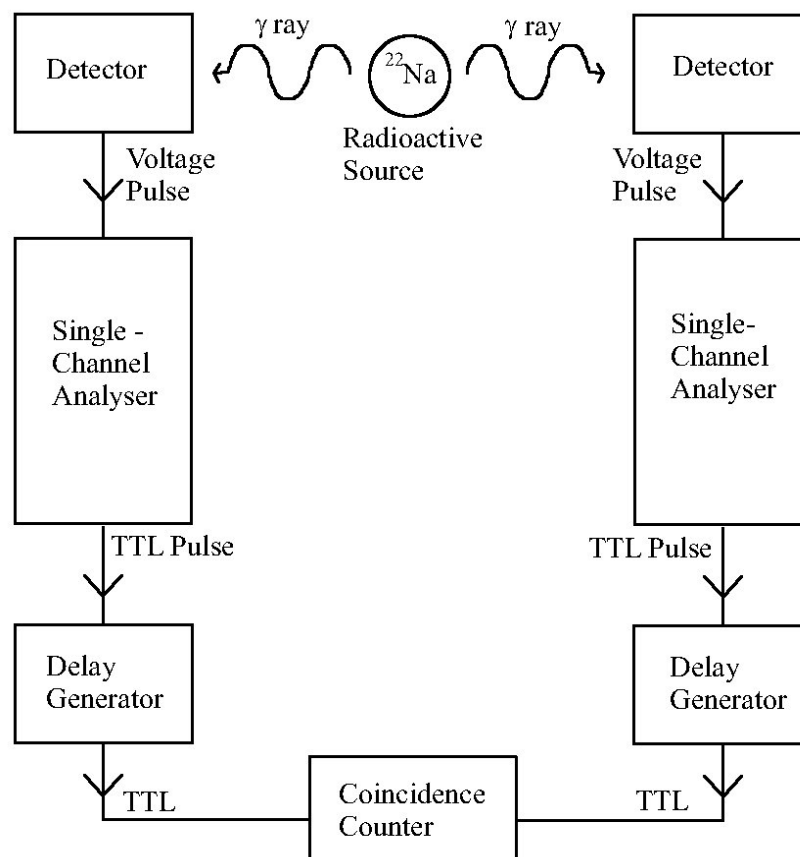


Figure 1: Layout of apparatus for observing coincident photons from electron-positron annihilation.

The pulses from the detector have a peak voltage that is proportional to the energy of the γ -ray that hit them. A single-channel analyser produces a TTL pulse whenever the amplitude of the input pulse lies within a specific voltage range (chosen by the experimenter).

a) What does TTL stand for? What does it imply about the pulses coming out of the single-channel analyser?

Delay generators can be used to delay the time at which one of the pulses reaches the coincidence counter.

b) Explain why it might be necessary to delay one of the pulses.

c) To determine whether two pulses are coincident, what logic operation would you use?

By systematically adjusting the delay generators it is possible to plot a graph of the coincidence resolving time curve that looks like this:

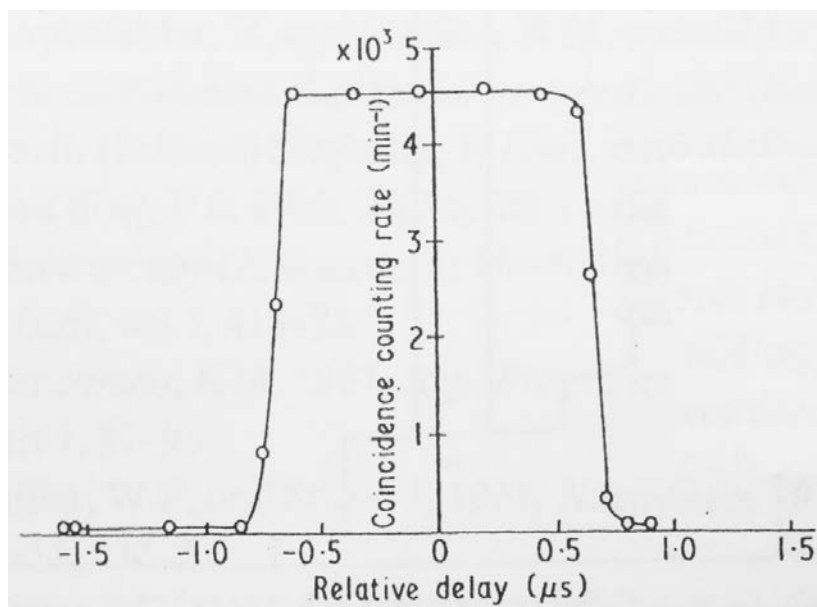


Figure 2:
Coincidence
resolving
time curve.

d) Estimate the time resolution for coincidence detection of this apparatus.

e) How does the duration of the TTL pulses influence this?

The single-channel analyser can also output a linearly amplified version of the input pulse. This pulse can then be viewed on an oscilloscope or be input to a data acquisition card in a computer. Let's say that the maximum voltage that can be accepted by this acquisition card is 10V and the input signal is digitized using 10 bits. The resulting discrete spectrum of measured voltages is referred to as *channels*, the acquisition card as *multi-channel analyser (MCA)*:

f) What is the error induced when the analogue voltage is converted into a channel number?

g) When viewed on the oscilloscope the pulses corresponding to a 0.51 MeV photon are 2.4V in amplitude. If the computer is configured to draw a pulse height spectrum (number of pulses versus channel number) which channel number would you expect to contain the peak from the 0.51 MeV photons?

h) Actually the peak is observed in channel 82. The output impedance of the single-channel analyser is 100 Ω . What is the input impedance of the acquisition card? Neglect any effect due to the intervening wires.

Now, let's turn back to counting:

i) Design a counter which accepts the output from the delay generators and counts and indicates the number of pairs of coincident pulses up to a maximum of 7. Explain the considerations involved. Draw a circuit diagram showing how you would assemble the apparatus on a breadboard.

Exercise 2: Frequency Dependence

A very basic loudspeaker consists of a conical diaphragm with a circular coil of wire concentrically mounted at its (relatively free) narrow end. The rim of its outer end is fixed to a rigid circular frame and the diaphragm between the frame and coil is sufficiently flexible to deform slightly, when the coil moves axially. The coil is placed in the cylindrical gap of a permanent magnet producing a radial magnetic field B . Axial movement of the coil occurs when a current in the coil produces a magnetic field which interacts with that of the magnet.

If the loudspeaker coil is prevented from moving (for example, by holding the cone with your hand) the current in the coil is produced only by the voltage from your audio amplifier. For acoustical frequencies, the electrical capacitance of the coil can be ignored, and the electrical impedance Z_e of the loudspeaker coil has resistive and inductive parts only:

$$Z_e = R_e + i\omega L_e$$

where R_e is the electrical resistance, L_e the electrical inductance, ω the angular frequency ($\omega = 2\pi f$). This is described by Ohm's law: $V = IZ_e$, with all quantities in complex form. If you now let go of the cone the coil will begin to move. Because the coil is moving in a magnetic field, "crossing" the magnetic field lines, an induced emf ε (sometimes called a back emf) is set up. The net voltage is now $V - \varepsilon$ and is related to the current by:

$$V = IZ_e + \varepsilon = IZ$$

The total impedance Z has an electrical component Z_e and a component with which must be related to the mechanical properties of the loudspeaker. The same V as before now produces a different I from before because the total impedance is now different from Z_e . The total impedance can be written:

$$Z = Z_e + \frac{T^2}{Z_m} = R_e + i\omega L_e + \frac{T^2}{R_m - i\left(\left(\frac{1}{\omega C_m}\right) - \omega L_m\right)}$$

where R_m , C_m and L_m are actually mechanical characteristics of the loudspeaker and T is proportional to the magnetic field strength. Plausible values for the loudspeaker characteristics are:

$$\text{electrical: } R_e = 3.4 \Omega \quad L_e = 1.0 \times 10^{-4} \text{ H,}$$

$$\text{magnetic: } T = 2.5 \text{ N/A}$$

$$\text{mechanical: } R_m = 1.2 \text{ kg/s} \quad C_m = 1.1 \times 10^{-4} \text{ s}^2/\text{kg} \quad L_m = 4.7 \times 10^{-3} \text{ kg}$$

Assume the range of audible frequencies is 20 Hz – 50 kHz (even though non-K9s fail badly at the top end).

- Convince yourself that the capacitance of the coil can be neglected.
- Find the expression for the resistive component of Z and hence show that the resistance is now frequency dependent.
- Using a spreadsheet package and the above values, plot a 'locus' graph with the resistive component on the x-axis and the reactive component on the y-axis over the given frequency range. You should find a locus of points that looks something like a circle or a spiral. Take note of the ranges of the resistive and reactive part.
- In addition plot a graph with the amplitude of the impedance on the y-axis and the frequency range on the x-axis.
- Correlate the two plots: which features of the two graphs correspond to each other?
- Hence or otherwise determine how many resonances this loudspeaker has in the given range and give their resonance frequencies, phases and widths (FWHM).
- Interpret the plots: Explain why the lowest frequency point on your plot approaches the x-axis close to the point $(R_e, 0)$. Where is the loudspeaker capacitive or inductive dominated? Why is that asymmetric? What happens at the high frequency end? How does all that correlate to the mechanical nature of the loudspeaker?

This exercise is to be continued with a design of a corresponding amplifier in the second period...