Answer THREE questions

The numbers in square brackets in the right hand margin indicate the provisional allocation of marks per sub-section of a question.

You may need the following Laplace transforms, where *L{f(t)}=F(s),*

f(t)= $\delta(t)$*;*	*F(s) =1*
f(t)= unit step;	*F(s) =1/s*
f(t)= e^{-bt} *;*	*F(s) =1/(s+b)*

1. Draw a charge integrating circuit based on an operational amplifier. Explain with reference to the properties of the amplifier how the feedback mechanism ensures that one point on the circuit is kept at virtual ground potential and that the output voltage is accurately proportional to the input charge. Where would you put a switch to set the output to zero before integration begins? How can the circuit be modified to introduce an exponential decay at the output with time constant τ ? [8]

   Three separate input transmission lines with 50 ohm characteristic impedance deliver square pulses which are summed by a single charge integrating operational amplifier circuit. On the first line the pulses are 100 ns long and 50 mV high. On the second they are 50 ns long and 20 mV high. On the third line they are 200 ns long and 10 mV high. When there is a pulse on any one of the lines alone the output signal is 1 V. Sketch a circuit which will properly terminate all three of the lines and perform the summing and integration as specified. Give the values of all the components. Briefly suggest one reason for making the input resistances as low as possible. [9]

   Sketch the variation of the output voltage from this circuit when pulses come in successively on the first, second and third lines with gaps between them of 500 ns. [3]

2. A linear control system has input (reference) signal *r(t)* and output (controlled) signal *c(t).* Write down the definition of the Laplace transform which takes these time-domain signals into the frequency domain. How is the transfer function *G(s)* of the system defined? [4]

   Derive, using the relevant transforms, the time domain response of a system with transfer function $G(s) = A/(s+a)$ to an input impulse (delta function) and to an input step function. Explain, with reference to what you have derived, the range of values of the constant *a* for which the system will be stable.
   For an input sinusoidal function of frequency ω, write down (without derivation) expressions which relate the system gain and the phase advance to the transfer function. [9]

   A system has a transfer function $G(s) = Ks/(s+a)$,with $K = 10^3$ and $a = 2\pi.10^6$. How many poles and how many zeros are there in this function? Sketch both parts of its Bode plot, labelling the rates of change of gain. What is the gain in dB at 10^6 Hz and at 10^8 Hz? [7]

3. The general expression for a voltage pulse in a nondispersive transmission line can be written $\mathrm{v}(x,t) = f(t \pm x / c_p)$ with the related current pulse given by $i(x,t) = \mp \mathrm{v}(x,t) / R_t$. In which direction is the pulse travelling when the upper or the lower sign is chosen? Write down a formula relating the characteristic resistance R_t of the line to the inductance L per unit length and the capacitance C per unit length of the line? Give a brief definition of what is meant by dispersion in a transmission line and write down an expression for the speed of propagation of signals of angular frequency ω in a nondispersive line. [6]

Explain, with sketches of pulses, what happens to a short pulse when it reaches the end of three different transmission lines which are terminated with:

a short-circuit link
an open circuit
a resistor equal to R_t.

How could these effects be demonstrated by using an oscilloscope? [6]

A detector with a very small signal of a few nanoseconds pulse-length is working in an environment with a great deal of electromagnetic noise and has to be read-out in a control room some tens of metres away. Describe the prudent steps to be taken in transmitting the signal to the control room with the minimum of noise and distortion. Sketch the system and give reasons for each feature shown. Why might a twisted pair cable be preferable to a co-axial cable? What are typical values for the characteristic impedance in each case? Why is it impossible to operate such a system without significant power dissipation at the signal transmission stage? [8]

4. Give brief explanations of three of the following terms in the context of signal processing:

Signal compression
Wavelets
Fast Fourier Transform
Nyquist critical frequency [11]

An audio signal lasting 5 seconds, with significant frequency components up to 20 kHz, is digitally sampled and transmitted. What is the minimum number of samples required to make it possible to completely reconstruct the transmitted signal? [6]

Describe how the reconstructed signal may be distorted if only alternate sampled values are transmitted. [3]

5. Sketch the possible layout of electrodes for a drift chamber which could be used to measure the positions in one dimension of the tracks of high energy charged particles. Explain briefly step by step the processes by which the initial ionisation is converted into an electrical pulse which can give the position of a track. Why is the chamber gas normally a mixture of a rare gas with a molecular gas? [10]

A chamber with maximum drift distance 13 cm has its anodes at ground and its cathode at 13 kV. It operates at ambient atmospheric pressure. The drift velocities of electrons in two possible chamber gas mixtures are given in the following table.

E/p kV.cm^{-1}.atm^{-1}	$\mathbf{v_{drift}}$ (Ar-CO_2) cm/μs	$\mathbf{v_{drift}}$ (Ar-CH_4) cm/μs
0.75	0.60	9.4
0.85	0.68	9.8
0.95	0.76	10.0
1.05	0.84	10.0
1.15	0.92	9.8

The time resolution of the Flash ADC readout system is ±5ns rms. Neglecting diffusion, how well can the position be resolved in each gas for a particle track crossing the chamber at right angles? If the atmospheric pressure changes by 0.5%, by how much does the apparent position of a track 10 cms from the anode move for each gas? [10]

END OF PAPER