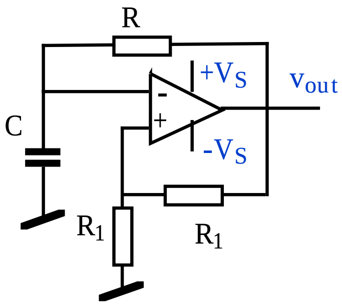
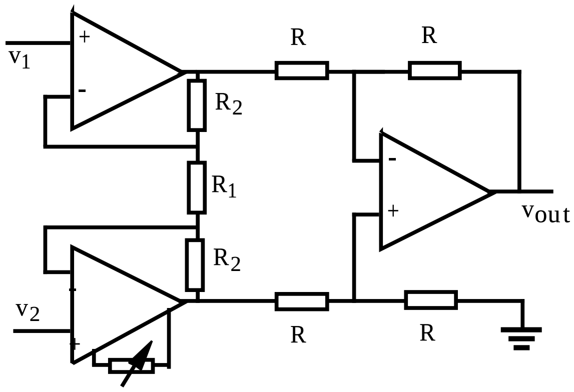
Instrumentation Problem Sheet 5

(1) Show that the period of the relaxation oscillator is $T \approx 2.2RC$



(2) A classical instrumentation amplifier is illustrated. What is the function of the offset null?

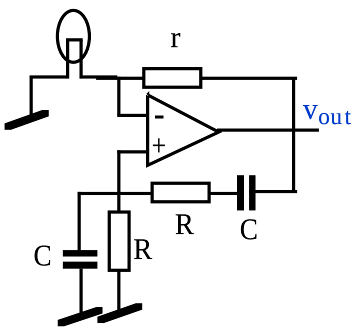


Show that the differential and common mode gains for the input stage of the amplifier are

$G_{diff} = (1 + 2R_2/R_1)$ $G_{cm} = 1$

Find G_{diff} and G_{cm} for the output stage.

(3) Calculate the non-inverting gain of the Wien bridge oscillator and show that positive feedback occurs at a frequency $\omega = 1/RC$. A lamp rated as 6V, 40mA is available for the temperature dependent resistor and values of C = 1.5nF and R = 100kΩ are chosen. Suggest a suitable value for r.
The Wien bridge is favoured for audio applications because of its low harmonic distortion. Why does this work well at audio frequencies but not at much higher values?



(4) A 200m long coaxial cable has a capacitance of 100 $pF.m^{-1}$ and inductance of 0.5 $\mu H.m^{-1}$. A single 10ns FWHM Gaussian voltage pulse, amplitude 10V, is introduced into one end of the cable. The input to the cable is terminated in a 10Ω resistor, the output with a 100Ω resistor.

(i) What is the impedance of 10, 20 and 30m lengths of this cable, and at what velocity do electrical signals propagate in the cable ?

(ii) If a cable could be fabricated with the same inductance/meter, but 10x less capacitance/meter what would the signal velocity now be? Is it physically achievable?

(iii) How much signal is reflected from the output of the cable on the first transit of the pulse through this transmission line? Is the reflected signal inverted or not?

(iv) How long does it take for the first and second ***reflections*** of the voltage pulse to reach the output end of the cable. What are the amplitudes and signs of these pulses ?

(v) A high impedance scope is connected to the output. What is actually observed there, at the respective times of arrival?

(5) What is the maximum allowable rms noise in the comparator threshold of a 10 bit ADC with 1V range?

(6) An amplifier used for a precise time measurement of the arrival of a signal has a pulse shape v(t) = at for the leading edge of the output pulse, where a = 0.04V/ns. The threshold for a signal to be observed is set at 200mV but the rms noise at the amplifier output is 80mV. What precision can be achieved on the time measurement? How does the time precision depend on the choice of threshold?

(7) A detector system which generates a binary count when a 10mV threshold is crossed is observed to be counting at 200kHz in the absence of signals. If the noise is measured as 5mV, what would be the count rate if the threshold were increased to 25mV? What would you do if the noise count rate did not fall as much as you predict?

(8) A bipolar preamplifier with a 10kΩ feedback resistor is used with a detector of capacitance 20pF and a dark current of 10nA. The current gain of the input transistor (β) = 100 and the collector current is 0.4mA. What is the noise corner frequency and corner time constant? The preamplifier is used with a pulse shaping circuit whose impulse response (of preamp and filter) can be approximated by a symmetric triangular pulse shape peaking after 15nsec with a baseline of 30nsec. Assuming a delta impulse as input, calculate the Equivalent Noise Charge.

(9) What are the advantages and disadvantages of digital data transmission compared to analogue? Due to chromatic dispersion in an optical fibre the rms width of a gaussian pulse increases with fibre length L as $\sigma^2(t) = \sigma^2(t{=}0) + D^2\sigma^2(\lambda)L^2$. Show that
$\sigma(\lambda) = (2\pi c\omega^{-2})\sigma(\omega)$ and hence calculate the maximum rate of digital data transmission which can be achieved in a 10km fibre at λ = 1550nm. In the wavelength range of interest, the fibre manufacturer quotes

$$D(\lambda) = S_0[\lambda - \lambda_0^4/\lambda^3] \text{ with } S_0 = 0.023 \text{ ps.nm}^{-2}\text{km}^{-1} \text{ and } \lambda_0 = 1310\text{nm and } n = 1.47.$$

How could the data transmission rate be improved?

(10) An x-ray photon counting system is designed using an integrating detector, where the photons arrive too close together in time to count them individually. (Analogous to counting water molecules in a jar by weighing the water.) Assume negligible noise from the amplification, so all noise is statistical. The largest signal to be measured is $6.55\ 10^8$ photons and the goal is to achieve 1% resolution on photon number. For cost reasons, a 10bit ADC with a range from 0-1V must be used to digitise signals.
Ignoring the effect of the ADC, what is the smallest signal which can be distinguished from statistical noise at the 1% level? What is the dynamic range in dB of the system? What is it expressed in bits? What is the resolution of the largest signals to be measured?
The output from the detector-amplifier is V_{out} = GxN, where G= gain (V/photon) and N = number of photons in a spot. If the system is operated with a single gain, why is a 10-bit ADC insufficient?
To improve on this, it is decided to split the signal range into two parts and amplify smaller signals. What is the gain, G_2, which should be used? Is 1% resolution achieved over the full dynamic range? If not, what should be done?