JANUARY 1998 EXAM

Question 4

Speech Signals are to be recorded digitally using an analogue interface incorporating a sample and hold. The bandwidth of the signals are from 100Hz to 4kHz and have a dynamic range of 44dB. The Analogue to Digital converter has a conversion time of 7µs + 7µs per bit, a full range of 10V and 1 LSB error during conversion.

i) Sketch a suitable system stating the function of each of the components. (5 marks)

Calculate:
ii) A suitable sampling frequency
iii) the number of bits required in the converter
iv) the conversion time

(4 marks)

v) the ratio of minimum signal (rms) to quantisation noise (rms) (5 marks)
vi) the maximum aperture time and acquisition time of the sample and hold (6 marks)

Question 5

In an experiment physiological signals are to be sampled and digitised. A data acquisition system consists of an 8 channel multiplexer made from CMOS switches to the following specification:

ON state:	$R_{DS} = 75\Omega$ $C_{DS} = 1pF$
OFF state:	$R_{DS} = 4x10^9\ \Omega$ $C_{DS} = 1pF$
LOAD:	$R_L = 4M\Omega$ $C_L = 50pF$

a) Explain what is meant by the following terms for this multiplexer:

Attenuation, Offset, Glitches, Settling Time, Crosstalk (8 marks)

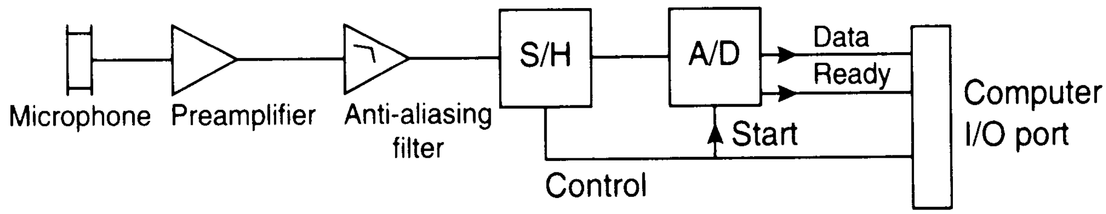
b) Calculate the crosstalk attenuation at d.c. and at 10kHz. (8 marks)

c) With a full-range signal of 10kHz, show that the crosstalk is lower than one least significant be of a 12-bit Analogue to Digital converter. (2 marks)

d) Would you consider these switches suitable for an 8 channel multiplexer at 10kHz or would reed relays give better performance? (2 marks)

Solution to Question 4

i)



ii) 2 times max input frequency = 2x4000 = 8kHz

iii) dB = 20log V_2/V_1

therefore 44/20 = log V_2/V_1

hence $V_2/V_1 = 10^{44/20} = 158$

2^8=256 therefore at least 8 bits are required

iv) conversion time is 8 + 8x8 = 72μs

v) RMS quantisation noise

LSB/√12	= 0.289 LSB
maximum signal	= 256 LSB pk to pk
minimum signal	= 256/158 LSB pk to pk
	= 256/(158x2√2) LSB rms
Signal to noise ratio	= (256x√12)/(158x2√2)
	= 1.98

vi) Aperture Time:

Maximum rate of change of maximum frequency signal is:

$2\pi \times f_{max} \times V_{max} = 2\pi \times 4000 \times 2^7$

$= 3216991$ LSB s^{-1}

The signal should not change more than 1 LSB during the aperture time, so the maximum aperture time is $(3216991)^{-1}$ = 0.31μs

Acquisition Time:

The aperture time + the conversion time + the acquisition time should not exceed the sampling interval:

$t_{AQ} \le t_{SAM} - t_{CON} - t_{AP}$

therefore:

$t_{AQ} \le 10^6/8000 - 72 - 0.31 = 52.69$ μs

Solution to Question 5

a) **Attenuation**: ON resistance of the channel in use and the load resistance form a voltage divider, if the load resistance is not sufficiently large a buffer will be required
Offset: If V_G and V_D are very different in the OFF state, leakage current through the R_{GD} of the OFF channels can flow through the load and cause an offset. Leakage currents increase rapidly with temperature.
Glitches: As a switch is turned ON and OFF, the step function change of V_G can transmit a spike through C_{GD} and cause a glitch on the output
Settling time: The settling time is made up of the time to turn the current on and the time to charge the stray capacitances, including the input capacitance of the load and is in the range 50ns to 3μs
Crosstalk: Crosstalk is the leakage of signals between channels. With all switches off, the output voltage should be zero, if not then whatever voltage is measured has come through the OFF channel and produced an error.

b) crosstalk attenuation = $20\log[Z_{OFF}/Z_{ON}(N-1)]$ dB
N = number of channels
Z_{OFF} = is the impedance of the switch in the OFF state
Z_{ON} = is the impedance of the switch in the ON state
At d.c.

crosstalk attenuation = $20\log(4\text{x}10^9/ 75 \text{ x } 7) = 7.619 \text{ x } 10^6 = 137.6$ dB

At 10kHz:

$X_{DS} = 1/2\pi 10^4 C_{DS} = 10^8/2\pi = 15.92$ MΩ

Now X_{DS} is much less than R_{DSOFF} so $Z_{OFF} = 15.92$ MΩ
The load reactance X_L is:

$X_L = 1/2\pi 10^4 C_L = (2\pi 10^4 \text{ x } 50 \text{ x } 10^{-12})^{-1} = 0.3183$ MΩ

so Z_L is still much greater than Z_{ON} therefore:

$V_{TEST}/V_{OUT} = (15.9 \text{ x } 10^6)/(75 \text{ x } 7) = 30286$
and crosstalk attenuation = 89.6dB

c) The rms of the full-range signal is $V_{FS}/2\sqrt{2}$, at 10kHz:

crosstalk = $V_{FS} /(2\sqrt{2} \text{ x } 30286) = V_{FS} / 85662$

one least significant bit is: LSB = $V_{FS} / 4096$
Solution to question 2 continued:

Therefore the crosstalk is less than 1 LSB

d) A 10kHz signal would have to be sampled at 20kHz minimum, if the multiplexer changes channel after each sample then the switching rate would be 8 x 20000 operations per second which is much too fast for reed switches.