Paper Number(s): **E2.4**

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
UNIVERSITY OF LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2000

EEE PART II: M.Eng., B.Eng. and ACGI

COMMUNICATIONS II

Friday, 23 June 2000, 2:00 pm

There are FIVE questions on this paper.

Answer ANY THREE questions.

All questions carry equal marks.

Please use a separate answer book for Sections A and B.

Corrected Copy

None

Time allowed: 2:00 hours

Examiners: Dr R.H. Clarke, Dr J.A. Barria, Dr M.K. Gurcan

NOTE:-

Boltzmann's constant $k = 1.38 \times 10^{-23}$ J / K

Use can be made of the asymptotic form for the Q function, when its argument ν is greater than 3, of

$$Q(\nu) \approx \frac{1}{\sqrt{2\pi}\nu} \exp\left(-\frac{\nu^2}{2}\right)$$

which is the area under the upper tail, from ν to ∞, of a standardised Gaussian random variable, namely $N(0,1)$.

SECTION A Communication Principles

1. Define the effective noise temperature T_e of a device, and show that

$$T_e = T_0 (F - 1)$$

where T_0 is the standard room temperature, and F is the noise figure of the device.

[3]

Briefly explain the advantages of using the effective noise temperature rather than the noise figure to describe the noise performance of a device.

[3]

A TV receiver, with a bandwidth of 8 MHz and a noise figure of 9 dB, is directly connected to a receiving antenna via a coaxial cable whose loss is 3 dB. If the signal input power at the antenna terminals is 500 pW, calculate the signal-to-noise ratio at the output of the receiver's IF amplifier. Assume that the effective antenna noise temperature is 180 K, and that all the components are matched.

[8]

What steps could you take to increase the signal-to-noise performance of this TV receiver, without requiring that the signal power is increased? Give some rough quantitative estimates.

[6]

2. Justify the representation

$$v_n(t) = \sum_k \sqrt{2\eta\Delta f} \cos(2\pi f_k t + \theta_k)$$

for white noise of power spectral density η over a band of frequencies B, of which a representative frequency is f_k, and the θ_k are random phases which are uniformly distributed in 0 to 2π. Show that the mean-square value (σ^2) of the noise is ηB.

[6]

By referring $v_n(t)$ to the centre frequency f_c of the band of frequencies B, show that $v_n(t)$ can be expressed as a time-varying random phasor

$$V_n(t) = X(t) + jY(t)$$

whose zero-phase reference is $\cos(2\pi f_c t)$. Describe the statistics of this "complex noise envelope" $V_n(t)$.

[10]

If now a carrier sinusoid $A_c\cos(2\pi f_c t)$ is added to $v_n(t)$, and if $A_c >> \sigma$, describe the statistics of the resulting complex envelope.

[4]

3. Two computers are directly connected by a coaxial cable of negligible loss and may be assumed to be matched to the characteristic impedance of the cable which is 50 Ω,. A binary bit stream consisting of a series of pulses of amplitude A V or 0 V are transmitted at baseband over the cable. Calculate the value of A that will ensure a probability of error in the received bit stream of at most 10^{-8} when the bit rate is 2×10^{8} bits per second. Assume the use of a maximum-likelihood detector, that the **1**'s and **0**'s in the bit stream are equiprobable and that the transmission bandwidth is equal to the bitrate.

[12]

What would the bandwidth be of an analogue video signal that could be transmitted at the same bit rate over the cable by using 16-bit, uniformly quantized PCM? What is the quantization signal-to-noise ratio, if the video signal is random but uniformly distributed over the full range of the quantizer?

[8]

4. (a) Deduce a formula for the entropy $H(\boldsymbol{S})$ of a memoryless source alphabet $\boldsymbol{S}$. What is the entropy for the binary-source alphabet $\boldsymbol{S} = \{\mathbf{0},\mathbf{1}\}$, when the probability of **0** being sent is p?

[6]

By what fraction is it theoretically possible to compress a binary bit stream if the probability of a **1** is (i) 0.05 and (ii) 0.5?

[5]

(b) Identify, and give the dimensions of, all the terms in Shannon's channel capacity formula:

$$C = B\log_2\left[1+\tfrac{S}{N}\right]$$

and state Shannon's channel capacity theorem.

[6]

Briefly discuss the usefulness, or otherwise, of this theorem.

[3]

SECTION B Networks (Please use separate answer book.)

5. Answer **any two** of the following subsections (a), (b) and (c).

   (a) Discuss briefly the evolution and characteristics of present public switched telephone networks. [10]

   (b) Explain and state the differences between virtual circuit packet switching and datagram packet switching. Use event timing charts when necessary.

   [10]

   (c) Briefly describe the function associated with the seven layers of the OSI reference model.

   [10]

Q.1

Effective noise temperature is that temperature T_e at the input of the network which would account for the added noise ΔN at the output. Thus

$$\Delta N = kT_e BG$$

So from the definition of noise figure,

$$F = \frac{kT_0 BG + kT_e BG}{kT_0 BG} = 1 + \frac{T_e}{T_0}$$

$$\Rightarrow T_e = T_0(F-1)$$

where T_0 is the standard temperature. 3

Advantages of using T_e:

- it is a finer measure, particularly for small F
- S/N at input (with T_e) same as S/N at output
- the only way to incorporate antenna noise

3

Noise figure of attenuator and Rx combined is LF_R, i.e., 3+9 = 12 dB, which is 15.85.

Hence $T_e = 14.85 \times 290 = 4306$ K

With $T_a = 180$ K, the system temperature

$$T_s = 4306 + 180 = 4486 \text{ K}$$

Hence the effective input noise at the antenna terminals is $N_{in} = kT_s B = 4.95 \times 10^{-13}$ W.

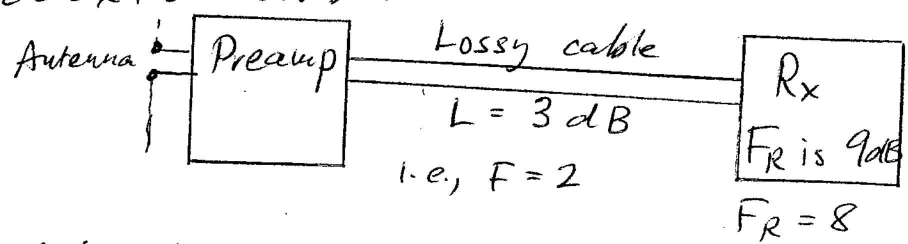
Q1 (cont'd.)

If signal power at antenna terminals is 500 pW, then

$$SNR_{out} = SNR_{in} = \frac{500\times10^{-12}}{4.95\times10^{-13}}$$

$$= 1010 \text{ (i.e., } \underline{30\ dB}\text{)}$$ 8

To increase this (it should be more like 50 dB) introduce a preamplifier (low noise figure, high gain) at the antenna terminals, ahead of the lossy coaxial cable:



We should aim to increase SNR by a factor of 100 (i.e., 20dB). This would mean reducing the system temp. to 45 K. This is not practical – it would need liquid helium cooling. A more reasonable preamp noise figure would be 2 dB, i.e., 1.585, or an equivalent first stage noise temperature of 580, which with the 180 antenna noise would give a SNR of 5960 or 37.8 dB 6

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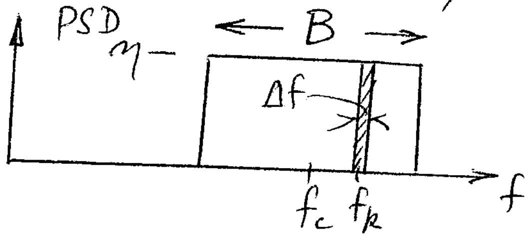
Q2 White noise has a flat PSD of η W/Hz, assumed to be normalised, i.e., into a $1\,\Omega$ resistor.



Hence shaded region of width Δf can be represented by a randomly-phased sinusoid of frequency f_k and random phase θ_k; and amplitude A such that $A^2/2 = \eta \Delta f$, the power in the sinusoid. Then summing over the band B, the noise voltage

$$v_n(t) = \sum_k \sqrt{2\eta\Delta f}\cos(2\pi f_k t + \theta_k)$$

The phases for different k are statistically independent. Hence, the m.s. noise is

$$\overline{v_n^2(t)} = \sum_k \tfrac{1}{2}\left(\sqrt{2\eta\Delta f}\right)^2 \quad \text{over } \frac{B}{\Delta f} \text{ "slices"}$$

$$= \eta B = \sigma^2, \text{ the variance.}$$ 6

Now write $f_k = (f_k - f_c) + f_c$, resulting in

$$v_n(t) = \sum_k \sqrt{2\eta\Delta f}\cos\left[2\pi(f_k - f_c)t + \theta_k\right]\cos(2\pi f_c t)$$

$$- \sum_k \sqrt{2\eta\Delta f}\sin\left[2\pi(f_k - f_c)t + \theta_k\right]\sin(2\pi f_c t)$$

$$= X(t)\cos\omega_c t - Y(t)\sin\omega_c t$$

Q2 (cont.d)

in which $X(t) = \sum_k \sqrt{2\eta \Delta f} \cos(\omega_k' t + \theta_k)$

and $Y(t) = \sum \sqrt{2\eta \Delta f} \sin(\omega_k' t + \theta_k)$

which are the sum respectively of randomly phased cosines and sines, slowly varying $(-B/2 \leq \omega_k' \leq +B/2)$ compared to the carrier f_c.

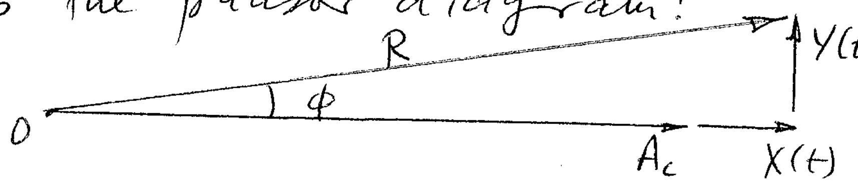
Checking the noise phasor $V_n(t) = X(t) + jY(t)$,

$$Re\left[V_n(t) e^{j\omega_c t}\right] = Re\left[\{X(t)+jY(t)\}\{\cos \omega_c t + j\sin \omega_c t\}\right]$$

$$= X(t) \cos \omega_c t - j\, Y(t) \sin \omega_c t.$$ 6

By the central limit theorem (since the θ_k are independent) $X(t)$ and $Y(t)$ are approximately Gaussian (hence "white Gaussian noise"), clearly zero-mean, with variances $\eta B = \sigma^2$, and uncorrelated and therefore independent of each other. 4

Adding a large carrier $(A_c >> \sigma)$, gives the phasor diagram:



where, to a good approximation the complex envelope $Re^{j\phi}$ has a Gaussian magnitude, i.e., $R \sim N(A_c, \sigma^2)$ and Gaussian phase, i.e., $\phi \sim N(0, (\sigma/A_c)^2)$ 4

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Q3

Probability of error at baseband for a maximum likelihood detector is

$$P_e = Q(A/2\sigma)$$

where the pulse varies between 0 and A, and hence the threshold is at A/2, and the rms noise (in 1Ω) is σ.

The bandwidth B ≈ bitrate = 2×10^8 Hz.

Hence the noise power is

$$kTB = 1.38 \times 10^{-23} \times 290 \times 2 \times 10^8 = 8 \times 10^{-13} \text{ W.}$$

The corresponding root-mean-square noise voltage is given by

$$\overline{v_n^2} = \sigma^2 = 50 \times 8 \times 10^{-13} = 4 \times 10^{-11} \ (V^2)$$

and hence

$$\sigma = 6.3 \times 10^{-6} \ (V)$$

Now $P_e \simeq \dfrac{e^{-v^2/2}}{\sqrt{2\pi}\, v}$ with $v = \dfrac{A}{2\sigma}$

By trial and error, when $v = 6$, $P_e \simeq 10^{-9}$

but with $v = 5.5$, $P_e = 2 \times 10^{-8}$.

Hence choose $v = \dfrac{A}{2\sigma} = 6$, i.e.,

$$A = 12\sigma$$
$$= 12 \times 6.3 \times 10^{-6}$$
$$= \underline{75.6 \ \mu V}$$

12

Q3 (cont'd.)

For the analogue video signal, choose the sampling rate to be 2.5 times video bandwidth. But the transmission consists of 16 bits per sample, and so with 2×10^8 total bits / second,

$$\text{sampling rate} = \frac{2 \times 10^8}{16}$$

$$\text{and video bandwidth} = \frac{2 \times 10^8}{2.5 \times 16}$$

$$= \underline{5\ MHz}$$ 4

If the signal is assumed to be random, but uniformly distributed over the whole range of the quantizer, the quantization SNR = 2^{2n} (or $6n$ dB) so with $n = 16$, quant S/N = $\underline{96\ dB}$ 4

Q4(a)

If the alphabet of the discrete memoryless source is $\mathcal{S} = \{s_0, s_1, \ldots s_{K-1}\}$ with probabilities $p_0, p_1, \ldots p_{K-1}$, then the information associated with each symbol, such as s_k, is

$$I(s_k) = \log_2 \frac{1}{p_k} \quad \text{bits/symbol}$$

then the expectation gives the average information

$$H(\mathcal{S}) = E[I(s_k)] = \sum_{k=0}^{K-1} p_k \log_2 \frac{1}{p_k}$$

which is known as the entropy of the source. 6

For the binary source alphabet $\{\underline{0}, \underline{1}\}$ if the probability of $\underline{0}$ is p, then that of a $\underline{1}$ is $1-p$, and the (binary) entropy (function) is

$$H(p) = p \log_2 \frac{1}{p} + (1-p) \log_2 \frac{1}{1-p}$$

3

Entropy can be shown to give the fraction by which a bit stream can be compressed. So $H(0.05) = 0.286$ which is the fractional compression, but for $p = 0.5$ $H(0.5) = 1$, and compression is not possible. 2

E2.

Q4(b)

In Shannon's formula,

$$C = B \log_2 [1 + \frac{S}{N}]$$

C is the rate of information transmission in bits per second, B is the bandwidth in Hertz, S is the signal power and N is the noise power, both in Watts. Shannon's theorem states that if the rate of transmission of information in the channel is less than C, then it is theoretically possible to find a method of coding which will transmit the information without error, otherwise it is not possible. 6

Shannon's ~~formula~~ theorem is widely applicable, and therefore provides a practical limit. But it does not indicate how a method of coding can be found. 3

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(5a) Answer should include the following elements

- Invention of pulse code Modulation (PCM) opened the way to the convergence of all communication network systems

- From manual, step by step and cross bar switches to electronic and digital switching exchanges.

FDM: frequency division multiplexing. Possible when the useful bandwidth of the medium exceeds the required bandwidth of the signal to be transmitted. Each signal is modulated onto a different carrier frequency...

TDM: time division multiplexing. Commonly used for multiplexing digitised voice streams. possible when data rate of medium is bigger than data rate of digital signals to be transmitted. Data streams are interleaved.

- changes from in band signalling to out of band signalling (1976): i.e. common channel inter office signalling (CCIS)

(5a) Cont

CCIS:

- Call set-up, routing and termination
- Internet database access
- Network operation and support
- accounting and billing

Most of current telephone system have three distinct components:

- Analogue public circuit switching: i.e. dedicated path, set-up a call and use the network resources along the path throughout the length of the communication.

- CCIS: (Control of voice: control plane) Discuss introduction of the Intelligent Network (IN).

- packet switched Network: i.e. no dedicated transmission capacity. Share resources, data may be delayed, intermediate storage of data. ...

ISDN: Integrated service digital Network: the idea is that of a digital bit pipe, between the customer and carrier. ISDN model and devices: NT1, NT2, TE1, TE2 and TA. Also reference points R, S, T, V between various devices

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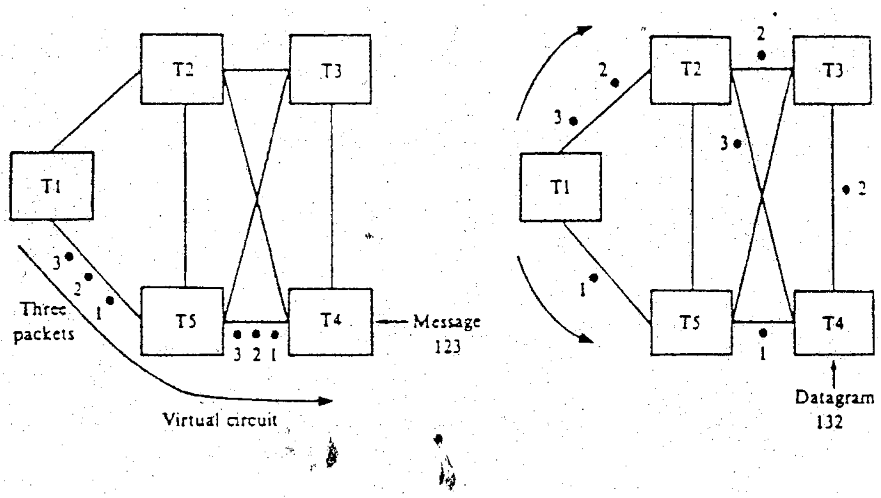
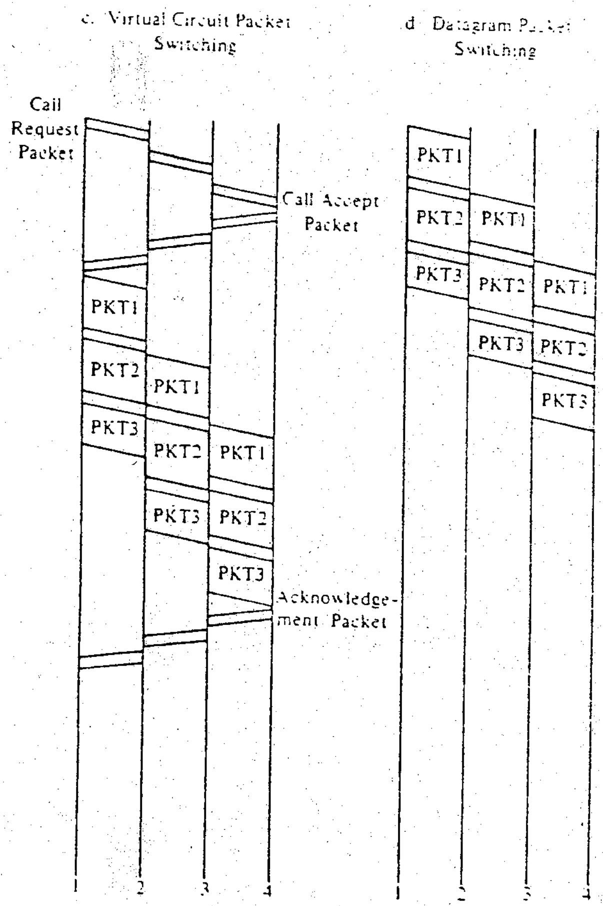
(5b) The answer should be based on the following two figures:





(5ii) cont

VC: co
- connection set up
- packet follow same path
- connection termination
- No reordering of packets

Datagrams:
- Each packet follow different routes
- The receiver will have to deal with re-ordering of packets

Other issues:
- packet overheads (DG > VC)
- connection oriented vs. connectionless services (at network layer)
- Reliability issues

10

(5c)

Physical layer: Provides for the transmission of bits over a physical medium, including procedures to activate and deactivate a physical circuit

Data link layer: Provides relatively error free transmission of data between ends of a physical link

Network layer: Provides the network specific signalling information and procedures required to enable the network to route data between systems containing transport layer entities

Transport layer: Provides transport of data between end systems in a manner which isolates its users from the specifics of the particular network(s) supporting the transport data

Session Layer: Establishes association between communicating presentation layer entities (session users) and negotiates the dialogue discipline to be used

(5c) continues

Presentation layer: Represents information to application layer entities such that the meaning of the information is preserved while syntax differences (between communicating application entities) are resolved

Application layer: Provides all services directly accessible by applications, all exchange of information meaningful to applications occurs via the application layer

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E24