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Communications Interview Questions

INSIDE

- 22 questions with short answers
- 5 numericals with the working
- Grouped by topic

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Random processes, power spectral density and noise

1. What is the power spectral density of a random process, and how is it related to the autocorrelation function?

The power spectral density shows how the average power of a wide-sense stationary process is spread over frequency. It is the Fourier transform of the autocorrelation function. Its integral over all frequency equals the total average power, which is the autocorrelation at zero lag, $R_X(0)$.

2. Why is white noise called an idealisation, and why is it still used?

White noise has a flat PSD $N_0/2$ at all frequencies, so its total power would be infinite, which no physical source can have. Thermal noise is flat only up to very high frequencies. It is treated as white because it is flat over the whole bandwidth of the system being analysed.

3. A wide-sense stationary random process is passed through a linear time-invariant filter. How is the output PSD found?

Multiply the input PSD by the squared magnitude of the frequency response: $S_Y(f) = |H(f)|^2 S_X(f)$. Only the magnitude response matters, and the phase response does not change the PSD. The output power is the area under $S_Y(f)$.

4. White noise with two-sided PSD 10^{-12} W/Hz is applied to an ideal low-pass filter with voltage gain 2 and cut-off 1 MHz. Find the output noise power.

The output noise power is 8 µW.

WORKING

1. Output PSD: $S_Y = |H|^2 S_X = 4 \times 10^{-12}$ W/Hz for $|f| < 1$ MHz.
2. The band covers -1 MHz to $+1$ MHz, a width of 2×10^6 Hz.
3. Power $= 4 \times 10^{-12} \times 2 \times 10^6 = 8 \times 10^{-6}$ W.

Amplitude and angle modulation, receivers and multiplexing

5. What is the difference between conventional AM and DSB-SC?

Conventional AM transmits a carrier along with the two sidebands, so a simple envelope detector can recover the message, but much of the power goes into the carrier. DSB-SC suppresses the carrier, so all power is in the sidebands, but it needs a coherent detector with a synchronised local carrier.

6. A carrier of power 100 W is amplitude modulated by a single tone with modulation index 0.6. Find the total transmitted power.

The total transmitted power is 118 W.

WORKING

1. Total power: $P_t = P_c\left(1 + \mu^2/2\right)$.
2. $\mu^2/2 = 0.36/2 = 0.18$.
3. $P_t = 100 \times 1.18 = 118$ W, of which 18 W is in the sidebands.

7. An FM signal has a peak frequency deviation of 75 kHz and a message bandwidth of 15 kHz.

Estimate the transmission bandwidth using the usual FM bandwidth rule.

The estimated FM bandwidth is 180 kHz.

WORKING

1. The rule gives $B_T = 2(\Delta f + f_m)$.
2. $B_T = 2(75 + 15)$ kHz.
3. $B_T = 180$ kHz.

8. Why does a superheterodyne receiver convert every station to a fixed intermediate frequency?

A fixed intermediate frequency lets the main gain and selectivity be built into one set of filters and amplifiers tuned to a single frequency. Only the local oscillator and the RF stage need tuning. This gives better selectivity and stability than tuning a high-gain amplifier across the whole band.

9. What is the image frequency in a superheterodyne receiver, and how is it rejected?

The image frequency is a second input frequency that mixes down to the same intermediate frequency as the wanted station. With a high-side local oscillator it equals the wanted frequency plus twice the intermediate frequency. It is rejected by a tuned RF filter ahead of the mixer, because the IF stage cannot separate it.

Information theory

10. What does the entropy of a discrete source measure, and when is it largest?

Entropy is the average information per symbol, in bits when the logarithm is base 2. It also gives the least average number of bits per symbol needed to code the source without loss. For M symbols it is largest, $\log_2 M$ bits, when all symbols are equally likely.

11. A source emits four symbols with probabilities 1/2, 1/4, 1/8 and 1/8. Find its entropy in bits per symbol.

The entropy is 1.75 bits per symbol.

WORKING

1. $H = -\sum p_i \log_2 p_i$.
2. Terms: $\frac{1}{2}(1) + \frac{1}{4}(2) + \frac{1}{8}(3) + \frac{1}{8}(3)$.
3. $H = 0.5 + 0.5 + 0.375 + 0.375 = 1.75$ bits/symbol.

12. Why is the capacity of a binary symmetric channel zero when the crossover probability is 0.5?

The capacity is $C = 1 - H(p)$, and $H(0.5) = 1$ bit, so $C = 0$. At $p = 0.5$ each output bit is equally likely to be 0 or 1 whatever was sent. The output is independent of the input, so it carries no information about it.

13. What does the channel capacity formula $C = B \log_2(1 + S/N)$ tell an engineer?

It gives the highest rate, in bits per second, at which data can be sent over a band-limited channel with white Gaussian noise and arbitrarily small error. Rates below C are achievable with suitable coding, and rates above it are not. With fixed signal power, raising bandwidth does not give unlimited capacity, because noise power grows with it.

PCM, digital modulation and detection

14. Why must a band-limited signal be sampled at no less than twice its highest frequency?

Sampling makes copies of the signal spectrum around every multiple of the sampling frequency. If the rate is below twice the highest frequency, neighbouring copies overlap, which is aliasing, and the original cannot be recovered. Above that rate the copies stay apart and a low-pass filter recovers the signal. At exactly that rate they touch: only an ideal filter could separate them, and a tone at exactly the highest frequency can be lost.

15. A full-scale sinusoid is encoded by a uniform PCM quantiser with 8 bits per sample. Find the signal to quantisation noise ratio in dB.

The signal to quantisation noise ratio is about 49.9 dB.

WORKING

1. For a full-scale sinusoid, $\mathrm{SQNR} = 6.02n + 1.76$ dB.
2. With $n = 8$: $6.02 \times 8 = 48.16$.
3. $\mathrm{SQNR} = 48.16 + 1.76 = 49.92$ dB.

16. What is the difference between BPSK and coherent BFSK in error performance?

BPSK uses two antipodal signals, giving error probability $Q\left(\sqrt{2E_b/N_0}\right)$. Coherent BFSK uses orthogonal signals with the same energy, giving $Q\left(\sqrt{E_b/N_0}\right)$. So BPSK needs about 3 dB less E_b/N_0 for the same bit error rate, and BFSK also needs more bandwidth.

17. What does a matched filter do, and what is its impulse response?

A matched filter maximises the output signal to noise ratio at the sampling instant when a known pulse is received in white noise. Its impulse response is the pulse reversed in time and delayed by the symbol duration. The peak output SNR is $2E/N_0$, where E is the pulse energy.

18. Why are raised-cosine pulses used instead of rectangular pulses for baseband data transmission?

Pulses overlap in a band-limited channel and cause inter-symbol interference. A raised-cosine pulse is zero at every other symbol's sampling instant, so there is no interference at the decision points, and it has a finite bandwidth of $(1+\alpha)R_s/2$, where α is the roll-off factor. A rectangular pulse needs unlimited bandwidth.

Error detection and correction

19. How does the minimum distance of a block code set its error detecting and correcting ability?

A code with minimum Hamming distance d_{min} detects up to $d_{min} - 1$ errors and corrects up to $\lfloor (d_{min} - 1)/2 \rfloor$ errors in a codeword. For example, $d_{min} = 5$ detects 4 errors or corrects 2. Correction needs a larger distance because the received word must stay closer to the sent codeword than to any other.

20. How does the (7,4) Hamming code locate a single bit error?

The code adds 3 parity bits to 4 data bits, giving minimum distance 3. The receiver multiplies the received word by the parity-check matrix to get a 3-bit syndrome. For a single error, the syndrome equals the column of the matrix at the error position, so the receiver flips that bit. A zero syndrome means no detected error.

21. Why is a CRC better at catching burst errors than a single parity bit?

A single parity bit only catches an odd number of flipped bits, so an even number of errors passes unnoticed. A CRC divides the message by a generator polynomial over GF(2). With a generator of degree r and a nonzero constant term, it detects every burst of length r or less.

22. What is the difference between forward error correction and ARQ?

Forward error correction adds enough redundancy for the receiver to repair errors itself, so no return path is needed, but the code rate falls. ARQ only detects errors and asks the sender to retransmit the block. It needs a feedback channel and adds delay, but needs less redundancy when the channel is fairly clean.

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227A Rash Behari Ave, Ballygunge, Kolkata 700019

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