Mid-Semester Test

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Course No./Title : EEE F472/Satellite communications
DATE: Nov. 3rd, 2022. Test duration: 90 Mins. Max. marks: 30.

(*Note*: You may use standard results or formulae by stating them explicitly. Highlight your final answers in rectangular boxes. Simplify your response to the extent possible. Use notation consistently.)

Part-I: Answer the following. (10 points)

Note: Each question carries 1 point. Just write down the final simplified answer. There is no partial marking.

1. Recall a satellite receiver's figure-of-merit. Assume an antenna with a circular aperture. Write down the analytical expression for the receiver figure of merit in terms of the following parameters: i) antenna efficiency parameter η ii) antenna diameter $\mathcal{D}$ iii) operating frequency f iv) noise figure $\mathcal{F}$ v) reference physical temperature (≈ 290 K) vi) background noise temperature T_b.

2. Consider an FM satellite communication receiver that uses wideband FM. Suppose that the demodulated SNR is 40 dB, and the frequency demodulation requires a threshold CNR of 15 dB. Determine approximate modulation index β_f (provide the value of β_f up to two decimal places.). *Hint:* $3 < \beta_f < 4$.

3. Refer to Q.2. Compute the approximate RF (bandpass) transmission bandwidth needed to transmit the baseband signal band-limited to 4 KHz.

4. Consider the channel decoder in a digital satellite receiver. In it, each $k-$bit block is encoded to a block of $n-$ bits (often called chips). Suppose that a Hamming code $(4, 7)$ is used. Determine the chip decoding error probability if the equivalent $\frac{E_b}{N_0} = 10$ dB. *Note:* Use the standard $Q-$ function table.

5. Refer to Q.4. Let us denote the chip decoding error by ϵ. The chip cut-off rate, denoted by r_c, is defined as $r_c = 1 - \log_2\left(1 + \sqrt{4\epsilon(1-\epsilon)}\right)$. Compute $\frac{r}{r_c}$, where r denotes the code rate of the Hamming code.

6. Suppose a digital satellite radio downlink has a transmission bit rate of 3 Mbps. If 9 bit errors are found in a period of 10 min, determine the bit error rate.

7. Suppose that a digital satellite transmission link handles a 1.544 Mbps transmission rate. The transmission link uses QPSK modulation, forward error correction with rate $\frac{1}{2}$, and square root raised cosine filter with roll-off factor 0.36 are employed. Compute the occupied bandwidth.

8. Refer to Q. 7. If the same Guard bands of 36 KHz are used on both sides of the channel, compute the overall occupied bandwidth required.

9. Suppose that an earth station transmitter uses an antenna with a circular aperture. The operating frequency is 11.5 GHz, and the aperture efficiency is 65%. Further, the antenna gain is 45.5 dB. Treating the diameter as the maximum dimension of the antenna, compute the Rayleigh distance.

10. Suppose that a satellite telemetry link operating in $S-$band uses FM to transmit the value of a continuous-time voltage signal on the satellite to a receiving earth station. The voltage signal ranges from -1000 millivolts to $+1000$ millivolts and has a maximum frequency of 4 KHz. The FM modulator on the satellite has a frequency sensitivity of 9000 Hz per volt. Compute the modulation index.

Part-II: Valid or Invalid (5 points)

Note: Write down Valid/Invalid. Justify in one or two sentences. No credit for incorrect justification.

1) An earth station transmitter's baseband signaling uses $16-$bit pulse code modulation (PCM). Suppose a voltage waveform is sampled and quantized into 65536 different levels. If the sampling rate is 32000 samples per second, the resultant bit rate is 256 kbps.
2) Consider a digital satellite receiver that uses a BPSK decoder with imperfect phase referencing. Suppose that phase reference error (PRE) is ψ_e. A PRE causes the bit error rate to increase from its minimal value. *Note:* Justification should include bit error rate expression in terms of the standard Gaussian Q$-$function.
3) Recall the modulation schemes used in analog satellite communications. Examples of useful analog modulation schemes are amplitude-comapanded SSB and offset-quadrature phase shift keying.

TABLE I
DATA PERTAINING TO PROBLEM 1 (PART-III).

Quantity	Value
Operating carrier frequency	8.42 GHz
Space vehicle amplifier power level	10 W
Propagation loss (9.5×10^8 KM)	**?** dB
Atmospheric, pointing losses	1.2 dB
Receive antenna gain	71.7 dB
Noise PSD ($T_{\text{eq}} = 26°$K)	**?** dB/Hz
Received $\frac{C}{N_0}$	**?** dB-Hz
Additional receiver losses	1.55 dB
Data rate	0.13 Mbps
bit energy−to−PSD ratio $\frac{E_b}{N_0}$	**?** dB

4) Suppose that a linear systematic block code $(6, 3)$ has a minimum Hamming distance of two. The error correction capability of the $(6, 3)$ linear block code is one.
5) The Rayleigh distance is the demarcation boundary between the near-field (Fresnel) zone and the far-field (Fraunhofer) zone. The Rayleigh distance is directly proportional to the operating frequency.

Part III: Answer the following questions. (15 points) [*Note:* Provide key intermediate steps.]

1. [Deep-space downlink budget][6 points]

i). Refer to the table shown. Complete the table by determining the quantities required (unknown–"?"). *Note:* Boltzmann's constant $= 1.38 \times 10^{-23}\ J/°K$.

ii). If the code rate of the block code is 0.9016, determine the coded bit energy-to-PSD (in dB).

iii). Determine the difference between uncoded bit energy−to−PSD ratio and coded bit energy−to−PSD ratio.

2. [Wideband-FM SNR Computation] [5 points]

Refer to Q.10. in Part−I. *Answer the following:*

i). Suppose that the CNR at the receiver input is 9 dB. Determine the approximate transmission bandwidth. What is the unweighted baseband SNR at the earth station receiver's output for the recovered analog signal?

ii). Suppose the FM satellite link uses pre−emphasis (PE) and de−emphasis (DE). Let the filter cutoff frequency $f_0 = 0.45$ KHz. Determine the improvement in the baseband SNR (in dB). Further, compute the overall baseband SNR after employing PE and DE.

iii). Suppose that the subjective improvement factor is 9 dB. Compute the overall baseband SNR.

3. [Equivalent noise temperature and noise powers] [2 + 2 points]

Let $T_{\mathcal{B}}$ denote the brightness temperature of the troposphere. Along a path length ℓ, $T_{\mathcal{B}}$ has the following profile: $T_{\mathcal{B}} = \alpha T_{\mathcal{A}} \exp(-\alpha r), 0 \leq r \leq \ell$, where α denotes the attenuation constant, $T_{\mathcal{A}}$ is the absorber temperature.

Answer the following:

i). Derive the simplified analytical expression for the effective noise power in terms of the temperature profile parameters, bandwidth B_n, and Boltzmann's constant.

ii). Comment on the effective noise power for very large $\alpha\ell$. Suppose that (in the presence of heavy rain) $T_{\mathcal{A}} = 290$ K and (in the absence of rain) $T_{\mathcal{B}} = 10^4$ K. Compute the ratio of noise powers ($\frac{N_{\mathcal{B}}}{N_{\mathcal{A}}}$) in dB. Assume the same noise bandwidth at an ideal receiver.

□ END OF QUESTION PAPER □