

**No materials, no calculator. Prepared by and return to: Mikko Valkama**

NB 1: If you wish to take the Full Exam, answer to all the questions 1-6. If you wish to take only the Second Midterm Exam, answer only to the questions 4-6.

NB 2: Please pay special attention to clear handwriting. If I cannot read your text with reasonable effort, your paper cannot be unfortunately graded. So, please, try to write in a clear manner. Thank you. Stay safe.

1. Explain and characterize (in both time and frequency domains) the concept of distortionless (distortion-free) transmission. What kind of different distortions are commonly encountered in communication systems? As an example, consider a system where the transmitted signal  $x(t)$  is received as  $y(t) = x(t) + ax(t - \tau)$ . Determine the impulse and frequency responses of this system and illustrate them graphically. What kind of distortions does this system cause (if any)? How do these distortions depend on the values of  $a$  and  $\tau$  and on the input signal bandwidth?
2. Explain the concepts of thermal noise, white noise and Gaussian noise. Explain also how the observable thermal noise power is calculated and how does it depend on the observation/receiver bandwidth.
3. Explain the general concept of I/Q modulation. Illustrate the principle by drawing a block-diagram of an I/Q modulator, and some example spectral contents of the relevant signals in different stages. How does I/Q modulation utilize the structure of a general bandpass signal, sketched below. Explain also how the receiver can recover the I and Q components. Finally, explain the concept of lowpass or baseband equivalent and how is it related to I/Q modulation.

$$x_{BP}(t) = A(t) \cos(\omega_c t + \varphi(t)) = x_I(t) \cos(\omega_c t) - x_Q(t) \sin(\omega_c t)$$

4. Explain the basic principles of Nyquist pulse-shape filtering based baseband pulse amplitude modulation (PAM) and I/Q modulated single-carrier PAM/QAM/PSK techniques, in the context of digital communication. How are the bandwidth and bit-rate calculated in the two techniques (baseband system and I/Q modulated system)? Give also a feasible numerical example. What does intersymbol interference (ISI) mean?
5. Explain briefly the basic ideas of multicarrier modulation / OFDM and multi-antenna / MIMO communications. Discuss also shortly the benefits of OFDM compared to single-carrier PAM/QAM/PSK and the corresponding benefits of multi-antenna/MIMO compared to single-antenna systems.
6. Explain shortly what is meant by (i) information, (ii) entropy and (iii) mutual information, in the context of electrical or electromagnetic communications. Explain also what is meant in this context by channel capacity. Assuming a bandlimited additive white Gaussian noise (AWGN) channel, what factors are determining the channel capacity?

Maximum points, Full Exam: 5+5+5+5+5+5 = 30p

Maximum points, Second Midterm Exam: 5+5+5 = 15p