Communication and Information Technology

Test Your Prior Knowledge

The Master of Science program Communication and Information Technology builds upon prior knowledge, which you should have acquired at the courses you have taken at your Bachelor studies. In order to assess your prior knowledge and to judge by yourself whether you are familiar with the background material required and presume at the Communication and Information Technology program, please carefully work through the following questions.

Basic Calculus

1) What are complex numbers? Why and when are they required? Give the rules for computing (addition, subtraction, multiplication, and division) with complex numbers!

2) Write down Euler’s formula! Describe the Cartesian form and the polar form of complex numbers! How can both forms be converted into each other?

3) What are absolute value (magnitude) and argument (phase) of a complex number?

4) Differentiate (w.r.t. the variable $t$; $c \in \mathbb{R}; j^2 = -1$) the following functions:
   \[ f(t) = c, \quad f(t) = t^2, \quad f(t) = \cos(ct), \quad f(t) = e^t, \quad f(t) = e^{jct} \]

5) Integrate (w.r.t. the variable $t$; $c \in \mathbb{R}; j^2 = -1$) the following functions:
   \[ f(t) = c, \quad f(t) = t^2, \quad f(t) = \cos(ct), \quad f(t) = e^t, \quad f(t) = \begin{cases} 1, & |t| < 1/2 \\ 0, & \text{else} \end{cases} \]

6) How is the product of a matrix with a vector defined? Which requirements do both quantities have to fulfill, such that the product exists?

7) How is the scalar product of vectors defined? How is the cross product between two vectors defined?

8) What is the Euclidean norm of a vector?

9) Let a basis, i.e., a set of vectors spanning a space, be given. How can we calculate an orthonormal basis from the given one?

10) Explain the meaning of eigenvalues and eigenvectors! How are they calculated given a (square) matrix?

11) What is the meaning of curl, div, and grad? Express them in Cartesian, polar, and cylindrical coordinates!
Basics on Electronics

12) What are the Kirchhoff’s circuit laws?
13) State Ohm’s law! Is it applicable in AC systems?
14) Can you write the Node Admittance Matrix for a circuit?
15) How are the complex impedances of a capacitor and an inductor defined?
16) How are a node-voltage analysis and a branch-current analysis being carried out to find the currents and/or voltages of an electrical network?
17) Can you convert a resistive voltage source into an equivalent current source?
18) Can you determine the output voltage of a resistive source loaded with a diode?
19) What is the DC operating point of an electrical network?
20) How can the nonlinear state-space description of a network be linearized around a DC operating point?
21) What is the small signal equivalent circuit of an electrical network?
22) What is a 4-pole and what is a 2-port? How are the Y- and Z-parameters of a linear 2-port defined?
23) Can you calculate the step response for first order RLC networks?
24) What is the time constant \( \tau \) of a first order low-pass filter (comprised of a resistor and a capacitor)?
25) What are the characteristics of an ideal OPAMP (impedances, gain)?
26) Can you draw an analog adder, a low-pass, and an ideal integrator using an OPAMP?

Fields and Waves

27) How large is the voltage at a short circuit? How large is the current at an open end?
28) What is a plane wave?
29) Concerning electromagnetic waves explain the term “interference”.
30) What do Maxwell’s Equations describe? Write them down! Which vectorial field quantities are contained? Which relationships exist between these fields in a linear medium?
31) Which quantity describes the energy transport of an electromagnetic wave?
32) What is the Biot-Savart law?
33) What is the relationship between DC-voltage and E-field of a capacitor?
34) What electrical loss mechanisms do you know?
35) What is larger 3 mW or 3 dBm; 0 dBW or 0.5 W?

36) How are linear quantities expressed in *decibels (dB)*?
   Give the quantities 2, 3, 4, 10, 100, and 1000 in dB.

**Electronic Devices and Optoelectronics**

37) Explain the concept of *holes* (in addition to electrons) in a semiconductor!

38) What is the *Fermi energy*? What are quasi-Fermi energies?

39) Explain the flow of electrical current over a *pn-junction*.

40) What is the *depletion region* in a pn-junction and how does it depend on the applied voltage?

41) What is the expression for the *drain current* of a MOSFET transistor in strong inversion as a function of its gate, drain, and source voltage ignoring all second-order effects?

42) What is the expression for the *emitter current* of a bipolar transistor as a function of its base voltage and its reverse saturation current according to the *Ebers-Moll model*?

43) What are the *DC small signal equivalent circuits* of a MOSFET and a BJT?

44) What is a common *source/gate/drain amplifier* for a MOSFET transistor?

45) What is a common *emitter/base/collector configuration* for a bipolar transistor?

46) Which frequency does *green light* have approximately?

47) How large is the *velocity of light* in a material?

48) What happens when a light ray hits an interface between two different media?

49) What is a *photon*? Does it have a mass? What is its momentum?

50) What is “coherence” of a light field?

**Signals and Systems**

51) What are *signals* and what are *systems*?

52) Characterize *continuous-time* and *discrete-time* signals!

53) Under which conditions is a *continuous-time signal* completely specified by a *discrete-time signal*?
   How is the discrete-time signal obtained from the continuous-time signal? How is the continuous-time signal recovered from the discrete-time signal?

54) What is the *Dirac delta “function”*?

55) Give the definition of the *convolution* of two signals!
56) What is the energy and what is the average power of a signal?

57) What is a linear time-invariant (LTI) system? How is such a system completely characterized? Given the input signal, how is the output signal calculated?

58) When is a system stable? How can the stability of a system be determined from the location of its poles? When is a system minimum phase?

59) What is an ideal low-pass filter?

60) How is the Fourier transform of a (continuous-time) signal defined? What are the properties of the Fourier transform of a i) real-valued signal, ii) real-valued even signal, iii) purely imaginary odd signal?

61) Let a signal with its corresponding Fourier transform, i.e., spectrum, be given. How is the spectrum modified if the time-domain signal is i) scaled with a constant, ii) temporarily shifted, iii) multiplied by $e^{j\omega t}$, iv) multiplied by $\cos(\omega t)$?

62) What operation in frequency domain corresponds to convolution in time domain? What operation in time domain corresponds to convolution in frequency domain?

63) What is the Hilbert transform of a (continuous-time) signal? Give the impulse response and the transfer function of the Hilbert transform!

64) How is the $z$ transform of a discrete-time signal defined? Given the $z$ transform of a signal, how is the spectrum (discrete-time Fourier transform) of this signal obtained?

65) What is the discrete Fourier transform (DFT)? For which signals is the DFT suited?

66) How are the spectra of a continuous-time signal and that of a discrete-time signal, thereof generated via sampling, related?

67) How can the simplified Nyquist stability criterion, which uses the open loop Bode plot of a plant, be used to assess the stability of a closed loop system?

68) How are gain margin and phase margin defined?

Random Variables, Stochastic Processes, and Estimation

69) Describe the axioms of probability!

70) State Bayes’ Theorem. For what is it useful?

71) What is a random variable?

72) Give the meaning of the cumulative distribution function (cdf) and the probability density function (pdf) of a random variable!

73) How is the expected value (expectation) of a random variable defined? What is the intuition behind the expected value?
74) What are mean and variance of a random variable?

75) Let two zero-mean normal (Gaussian) distributed random variables $X_1$ and $X_2$ with variances $\sigma_1^2$ and $\sigma_2^2$, respectively, be given. What is the variance of the random variables i) $Y_1 = X_1 + X_2$, ii) $Y_2 = X_1 - X_2$, iii) $Y_3 = X_1 \cdot X_2$, and iv) $Y_4 = X_1/X_2$?

76) What is the notion of a stochastic process?
   What are the most important quantities characterizing a stochastic process?

77) Which conditions must a process fulfill such that it is stationary?
   What is an ergodic process?

78) What is the power spectral density (psd) of a stochastic process?
   Knowing the psd, how is the power of the process calculated?

79) Let a stochastic process (with given autocorrelation function (acf) and psd) be the input to an LTI system (impulse response/transfer function). How are acf and psd of the output process related to the quantities of the input process?

80) A continuous-time stochastic process (with given acf and psd) is sampled. How are acf and psd of the obtained discrete-time process related to the quantities of the input process?

81) We want to estimate a random variable $x$ via the (indirect) observation of a random variable $y$, which depends on $x$.
   Explain the maximum a-posteriori rule and the maximum-likelihood rule for estimating $x$ based on $y$.

Fundamentals on Communications

82) An analog signal is converted into a (binary) data stream by means of pulse-code modulation (PCM). How is the data rate related to the sampling frequency and the resolution? If uniform quantization is used, by how much dB does the signal-to-noise ratio increase if the number of quantization levels is doubled? By which amount does the date rate increase?

83) What are the bandwidth and the power of a (transmit) signal?

84) Let a continuous-time (source) signal be given. How is such a signal transmitted using amplitude modulation (AM)? What are the required operations in transmitter and receiver?

85) Let a continuous-time (source) signal be given. How is such a signal transmitted using frequency modulation (FM)?

86) What are the advantages and disadvantages of FM compared to AM?

87) What is the main difference of digital transmission schemes compared to analog schemes? What are the main advantages of digital transmission over analog transmission?
88) What are the main performance measures for any type of communication systems? In other words, the utilization of which resources is typically quantified?

89) What is the main principle of pulse-amplitude modulation (PAM)? How is the (binary) information to be communicated represented in the transmit signal if we consider the simplest form of amplitude-shift keying?

90) What is the difference between baseband transmission and carrier-modulated (passband) transmission?

91) What is a quadrature modulator/demodulator?

92) What is an additive white Gaussian noise (AWGN) channel? Explain the meanings of additive, white, and Gaussian!

93) What is the optimum receive filter for PAM transmission over an AWGN channel?

94) Why do we characterize digital transmission schemes via their bit error rate (BER)? How (qualitatively) is the BER related to the signal-to-noise ratio?

95) Given a discrete source with a finite alphabet and known probabilities of the symbols. How is the entropy of such a source calculated and what is their meaning?

96) What is the aim of source coding? Give an example for a specific source coding scheme and explain how it works!

97) What is the meaning of the capacity of a channel!

98) Let a discrete-time AWGN channel with some signal power and noise power be given. Calculate the capacity of this channel!

99) Let a continuous-time AWGN channel with some bandwidth, signal power and noise power spectral density be given. Calculate the capacity of this channel!

100) What is the aim of channel coding? Give an example for a specific channel coding scheme and how the corresponding decoder works!