MACHAKOS UNIVERSITY

University Examination 2018/2019

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

FIFTH YEAR SECOND SEMESTER EXAMINATION FOR

BACHELOR OF SCIENCE (ELECTRICAL AND ELECTRONICS ENGINEERING)

BACHELOR OF SCIENCE (TELECOMMUNICATION)

EEE 519: FIBER-OPTIC COMMUNICATION

DATE: 14/5/2019 **TIME: 8.30-10.30 AM**

INSTRUCTIONS

Answer Question ONE and any other TWO Questions.

QUESTION ONE (30 MARKS).

a) A Raman amplifier is pumped in the backward direction using a pumping power $P_p(L) = 1$ W. The fibre length L = 5km, a signal is injected into the amplifier: $P_s(0) = 1\ \mu W$. The Raman gain is $g_R = 6 \times 10^{-14}$m/W; the cross section area $A_{eff} = 50\mu m^2$; the losses are α_p(dB/km) = 0.25dB/km and α_s = (dB/km) =0.2dB/km. Find the output signal power $P_s(L)$. (7 marks)

b) A fibre transmission system has the following data:

Transmitter output	: - 6 dBm
Receiver sensitivity	: - 60 dBm
Fibre loss	: 4 dB/km
Fibre link length	: 10 km
Connectors	: one interconnection every 2 km ; 1dB loss per splice connection.

Determine the system margin. (6 marks)

c) The rms pulse broadening resulting from intermodal dispersion within a multimode optical fiber is 0.6 ns km^{-1}. Assuming this to be the dominant dispersion mechanism, estimate the dispersion–equalization penalty over an un-repeatered fiber link of length 8 km at bit rates of

i. 25 Mbit s^{-1};

ii. 150 Mbit s^{-1}

In both cases evaluate the penalty without and with mode coupling.

The pulses may be assumed to have a Gaussian shape. (10 marks)

d) An optical fiber system is to be designed to operate over an 8 km length without epeaters. The rise times of the chosen components are:

Source (LED)	8 ns
Fiber: intermodal	5 ns km^{-1}
(pulse broadening) intramodal	1 ns km^{-1}
Detector (*p–i–n* photodiode)	6 ns

From system rise time considerations, estimate the maximum bit rate that may be achieved on the link when using an NRZ format. (7 marks)

QUESTION TWO (20 MARKS)

a) A compact disc (CD) has several levels of error detection and correction. Provide a very brief description of the following and explain their purpose:

i. Eight to Fourteen Modulation (EFM)

ii. Reed-Solomon Code

iii. Interleaving (6 marks)

b) A DVD is a storage technology which provides sufficient data capacity and data rate to store high quality standard-definition video. Given that a conventional audio compact disc (CD) can store up to 73 minutes of audio, derive the approximate number of hours of standard definition TV (SDTV) video that a DVD can store using all its available layers. (5 marks)

c) Assume that one day we will have 10 billion homes on planet earth, each home having one phone on average. If these phones were to transmit simultaneously over one 4 MHz line, using frequency division multiplexing (FDM), what is the bandwidth required? Could a single optical beam, with a spectral wavelength $\lambda = 1\ \mu m$, carry this multiplexed signal? (3 marks)

d) Still using the same case of 10 billion phones and some spectral frequency, now assume digital modulation, with time division multiplexing (TDM) and a data rate of 64 kbps for each voice message. Demonstrate whether the single optical beam can carry this frequency or not. (2 marks)

e) A fibre telephone cable contains 144 fibres, at the T3 standard, implying each fibre is capable of carrying 672 voice messages. A conducting telephone cable contains 900 copper twisted pairs, and each pair can carry 24 messages. Compare the capacities of the fibre and conducting cables. How many of the conducting cables are required to equal the capacity of the fibre cable? Repeat the calculation if each fibre operates at the DS-4 standard which allows up to 4032 voice messages per fibre. (4 marks)

QUESTION THREE (20 MARKS)

a) Consider a heterodyne receiver for a digital optical fibre communications system. Briefly explain how a heterodyne receiver detects a phase, given that photo-detectors can only detect amplitude or optical power. (2 marks)

b) What type of modulation scheme can a heterodyne system permit that is not otherwise achievable with direct detection using a standard receiver? (1 mark)

c) State the key advantage of phase detection over amplitude detection. (1 mark)

d) Heterodyne receivers offer increased sensitivity. Briefly explain why. (1 mark)

e) Using a heterodyne receiver, compute the local-oscillator (LO) power required to make the SNR 1 dB less than the quantum limit. You may assume the IF bandwidth is 500 MHz and the received optic power is constant at 5 nW when a binary "1" is received. The dark current of the photo-detector is $I_D = 2$ nA, and its responsivity is $\rho = 0.5$ A/W. Assume the temperature is 27° C and the load resistance of 100 Ω. (11 marks)

f) If this were not a heterodyne system, then the receiver's bandwidth could be as small as 250 MHz. For this case determine the signal power required to achieve a SNR equal to that in part (e) (4 marks)

QUESTION FOUR (20 MARKS)

a) Consider a single mode fibre operating at 1550 nm. The specification is to transmit 400 Mbps NRZ data over a 100 km fibre link with a bit error rate (BER) of 10^{-9} or better. Given that $\tau = 1/R_{NRZ}$ and allowing for the system rise time to be 70% of τ, compute the system rise time τ_{S}; (1 mark)

b) Given a material dispersion of M = -20 ps/nm/km and a waveguide dispersion of M_g = 4.5 ps/nm/km, compute the fibre rise time, τ_F. The spectral line-width is given as 0.15 nm. (1 mark)

c) If the rise time of the light source is t_{LS} = 1 ns, find an upper limit on the photo detector rise time t_{PD}; (4 marks)

d) Assume a basic BJT amplifier circuit at the receiver. If the photo detector has a transit time limited rise time of t_{TR} = 0.5 ns and a junction capacitance of C_d = 1 calculate an upper limit on the load resistor. (2 marks)

e) Given that the fibre loss is 0.25 dB/km, the coupling efficiency to the fibre is 3 dB, there are two connectors with 1 dB loss each, there are 50 splices with 0.1 dB loss each and the source power is 5 dBm, find the power at the receiver. (2 marks)

f) Calculate the optical power needed to achieve the specified BER assuming a quantum limited system. Comment on the result. You may assume dark current is negligible and therefore the expression for probability of an error $P_e = e^{-ns}$ holds. The quantum efficiency of the detector is $\eta = 0.7$; (4 marks)

g) Now calculate the optical power needed to achieve the specified BER assuming a thermal limited system. Comment on the result. You may assume a detector responsivity of $\rho = 1$ A/W and a noise figure of F = 2. Room temperature conditions hold, thus T = 300 K. (6 marks)

QUESTION FIVE (20 MARKS)

a) A silicon *p–i–n* photodiode has an intrinsic region with a width of 20 µm and a diameter of 500 µm in which the drift velocity of electrons is 10^5 ms^{-1}. When the permittivity of the device material is 10.5×10^{-13} Fcm^{-1}ms, calculate:

i. the drift time of the carriers across the depletion region;

ii. the junction capacitance of the photodiode (5 marks)

b) A germanium *p–i–n* photodiode with active dimensions of 100×50 µm has a quantum efficiency of 55% when operating at a wavelength of 1.3µm. The measured dark current at this wavelength is 8 nA. Calculate the noise equivalent power and specific detectivity for the device. It may be assumed that dark current is the dominant noise source. (7 marks)

c) The quantum efficiency of a particular silicon RAPD is 80% for the detection of radiation at a wavelength of 0.9 µm. When the incident optical power is 0.5 µW, the output current from the device (after avalanche gain) is 11 µA. Determine the multiplication factor of the photodiode under these conditions. (8 marks)