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Department of Physics

Examination paper for TFY4190 Instrumentation

Examination date: June 1 , 2023

Examination time (from-to): 15:00 to 19:00

Permitted examination support material:
C: Specified printed support material is allowed. A specific basic calculator is allowed.
Allowed: Mathematical formulas (Rottmann or equivalent). English dictionary.

Academic contact during examination: Steinar Raaen
Phone: 482 96 758

Academic contact present at the exam location: No

OTHER INFORMATION

Get an overview of the question set before you start answering the questions.

Read the questions carefully and make your own assumptions. If a question is unclear/vague, make your own assumptions and specify them in your answer. Only contact academic contact in case of errors or insufficiencies in the question set. Address an invigilator if you wish to contact the academic contact. Write down the question in advance.

Weighting: *IF THE QUESTION SET CONTAINS QUESTIONS/SECTIONS WITH A SPECIFIC WEIGHT, YOU MAY WANT TO SUGGEST EXPECTED TIME SPENT PER QUESTION OR SPECIFY THE MAXIMUM ACHIEVABLE SCORE.*

Notifications: If there is a need to send a message to the candidates during the exam (e.g. if there is an error in the question set), this will be done by sending a notification in Inspera. A dialogue box will appear. You can re-read the notification by clicking the bell icon in the top right-hand corner of the screen.

Withdrawing from the exam: If you become ill or wish to submit a blank test/withdraw from the exam for another reason, go to the menu in the top right-hand corner and click “Submit blank”. This cannot be undone, even if the test is still open.

Access to your answers: After the exam, you can find your answers in the archive in Inspera. Be aware that it may take a working day until any hand-written material is available in the archive.

1 P1-TFY4190v2023

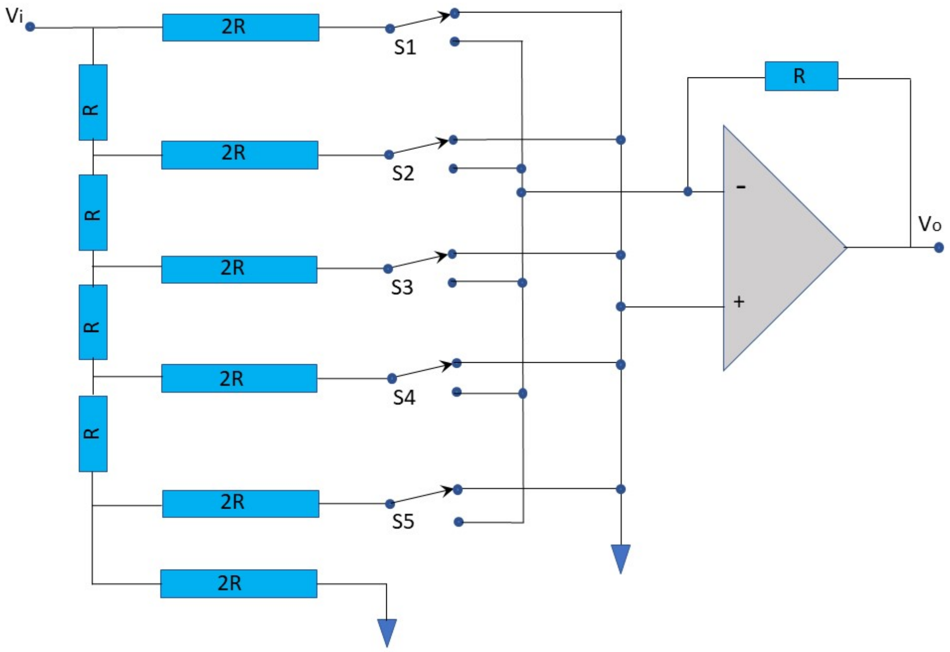
The 2-complement representation of the decimal number -314 .

Select one alternative:

- 1011010110
- 1001000110
- 1010111001
- 1010000110
- 1011000110

Maximum marks: 2

2 P2-TFY4190v2023



The DAC circuit shown above consists of resistors with resistances R and 2R as indicated, switches S1 to S5, and an ideal operational amplifier. The reference voltage is V_i = 8V and the output voltage is V_o.

What is the ratio of currents running through S4 and S1 ?

Enter the answer here: [ ] .

What will the output voltage V_o be for a digital input corresponding to the number 29 ?

Enter the answer here: [ ] V.

Maximum marks: 4

3 P3-TFY4190v2023

A single precision binary number consists of 32 bits. The MSB gives the sign, the next 8 bits the exponent, and the 23 remaining bits give the fraction. A bias of 127 is used for the exponent. What is the decimal value of the double precision number given in hexadecimal form by BCEA 8000 ?

Enter the **decimal number** here: [ ]

Maximum marks: 2

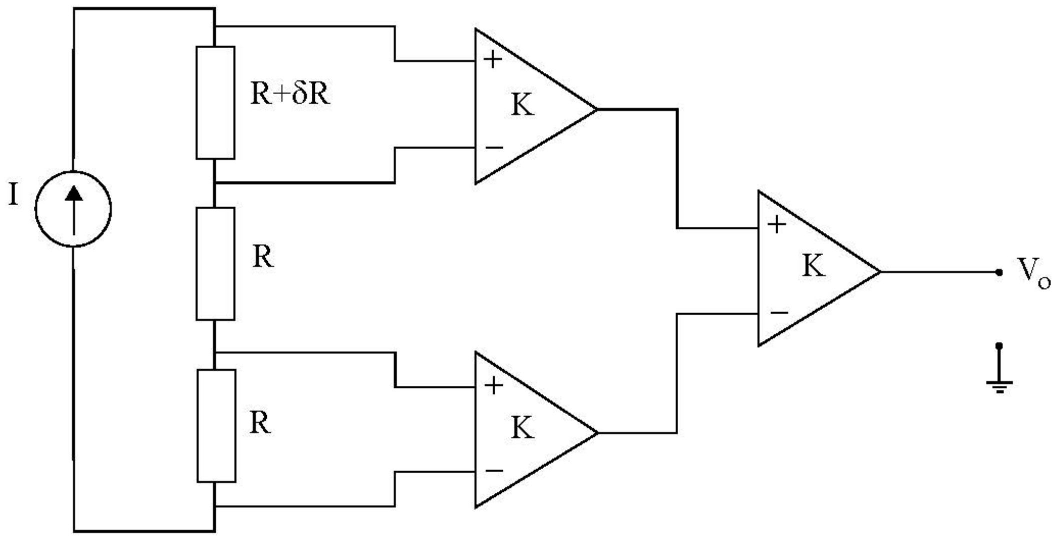
4 P4-TFY4190v2023

Convert the decimal number 27.456 to binary format.

Enter the answer here: [ ] .

Maximum marks: 2

5 P5-TFY4190v2023



The above figure shows an “Anderson loop” circuit having three differential amplifiers of gain K and resistors of values R and R+δR and a current source of current I.
What is the output voltage V_o for K = 8, I=0.1A, R = 1000Ω, and δR= 0.1Ω?

Enter the answer here: V_o = [ ] V

Maximum marks: 2

6 P6-TFY4190v2023

A 14bit AD converter operates in a voltage range from -10 to 10 V.
What is the resolution of the ADC?

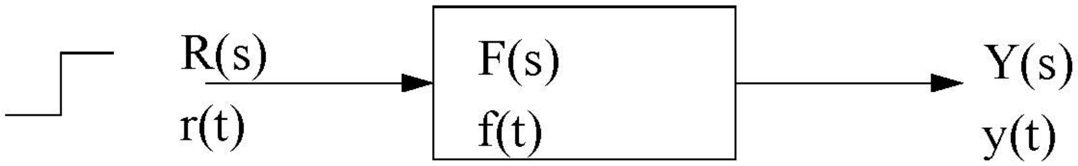
Enter the number here: ____ V

The output voltage is given in binary 2-complement form. What is the analogue input voltage when the output is given by the binary number 11 1111 1101 0000?

Enter the number here: ____ V

Maximum marks: 4

7 P7-TFY4190v2023



A unit step signal is impinging on a system of transfer function F(s). The voltage output from the sensor is measured in mV. The transfer function of the sensor is given by $F(s) = \frac{1}{s(s+1)(s+2)}$.

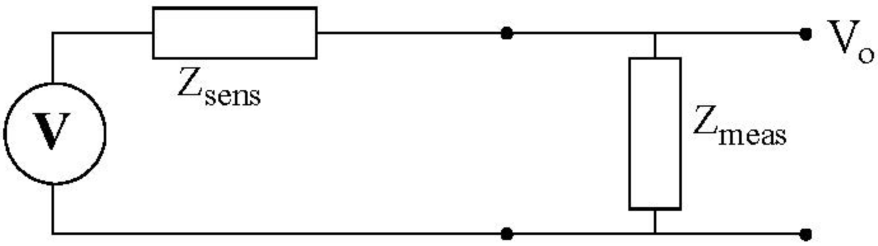
What is the value of the output signal y(t) after time t=1s?

Select one alternative:

- 0.02 mV
- 0.08 mV
- 0.10 mV
- 0.32 mV
- 1.22 mV
- 1.05 mV

Maximum marks: 4

8 P8-TFY4190v2023



The figure above show an equivalent circuit for a voltage source and a measurement circuit. The impedance for the source $Z_{sens} = (200 + 50i)\Omega$.
What should the amplitude of the impedance Z_{meas} be for transfer of maximum power from the source to the measurement circuit?

Enter the answer here: ____ Ω

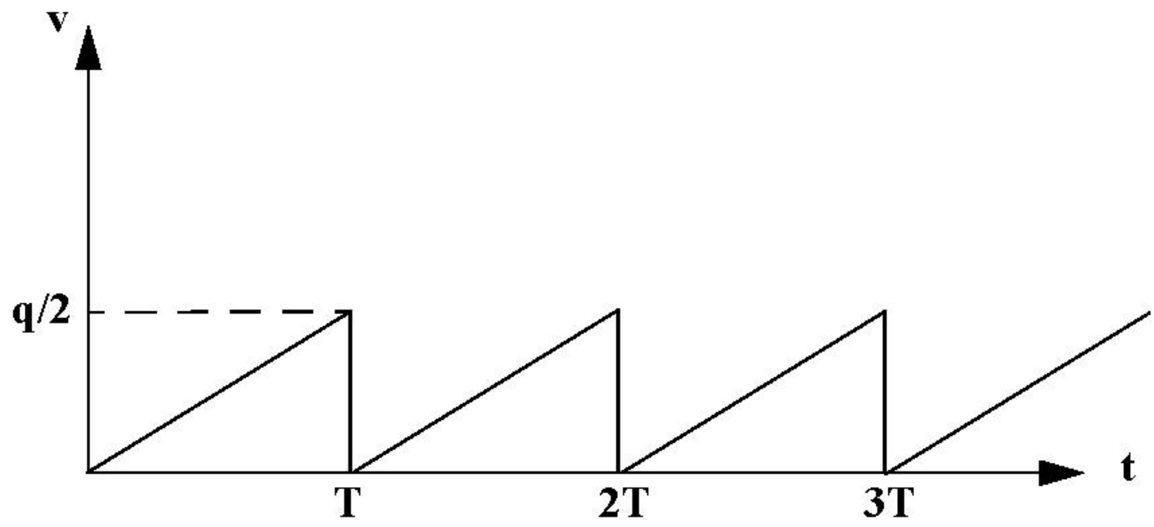
To obtain high accuracy of the output signal $\boldsymbol{V_o}$ the impedance $\boldsymbol{Z_{meas}}$ should be:

Select one alternative

- $Z_{meas} >> Z_{sens}$
- $Z_{meas} = Z^*_{sens}$ $(complex\ conjugate)$
- $Z_{meas} = Z_{sens}$
- $Z_{meas} << Z_{sens}$

Maximum marks: 4

9 P9-TFY4190v2023



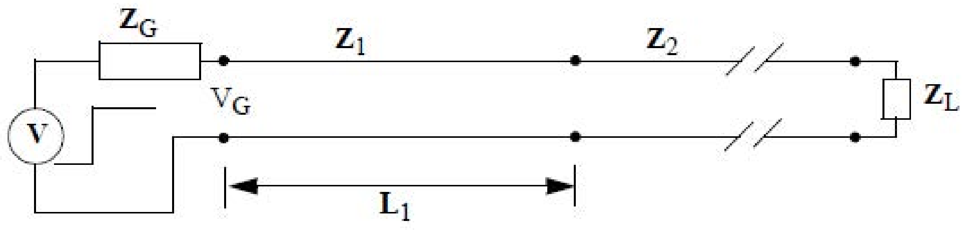
A noise signal v of period T and amplitude q/2 (as shown in the figure above) is superposed on a voltage signal V. What is the RMS value of the noise signal (quantization noise)?

Use for the resolution q = 0.01V and calculate a number.

Enter the answer here: ______ V.

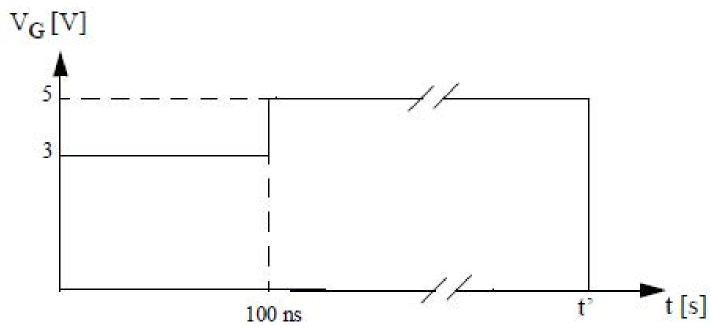
Maximum marks: 2

10 P10-TFY4190v2023



A voltage step of 3V is sent from a source of impedance $Z_G = 50\Omega$ to a transmission line of impedance $Z_1 = 50\Omega$ and length $L_1 = 10m$, as shown in the figure above. The first transmission line is connected to a second line of real impedance $\mathbf{Z_2}$. At the end of the second transmission line is a load impedance $\mathbf{Z_L}$.

The figure below shows the voltage $\mathbf{V_G}$ as a function of time.



What is the impedance $\mathbf{Z_2}$ in units of Ω of the second transmission line?

Select one alternative:

- 100
- 133.3
- 250
- 150
- 83.3

What is the speed in units of km/s of the signal in the first transmission line?

Select one alternative

- 50k
- 200k
- 150k
- 120k
- 20k

What is the significance of the signal going to zero at time **t'**?

Select one alternative

- $Z_L = Z_2$
- $The\ transmission\ line\ is\ broken$
- $There\ is\ a\ short\ in\ the\ transmission\ line$

Maximum marks: 3

11 P11-TFY4190v2023

The transfer function of a regulated system is given by $F(s) = \frac{10}{0.01s^3+0.1s^2+s}$.
Consider proportional control and harmonic frequency response and find the frequency ω_0 where the phase shift is 180 ^{o}.

Select one alternative:

- $30s^{-1}$
- $3s^{-1}$
- $10s^{-1}$
- $200s^{-1}$
- $100s^{-1}$

Find the amplitude of the transfer function at frequency ω_0.

Select one alternative

- 0.25
- 0.32
- 0.5
- 1.0
- 2.0

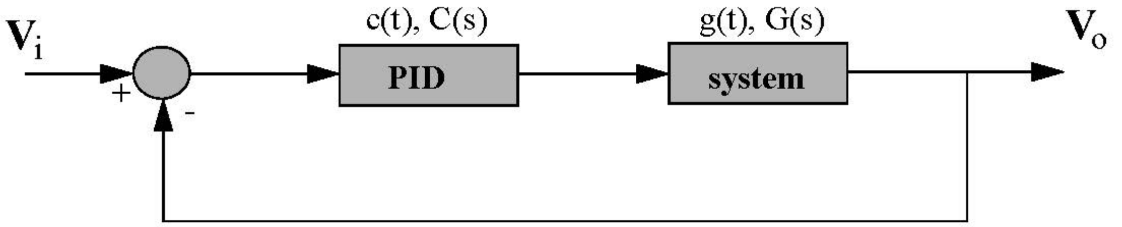
What is the proportional control parameter where the system starts to oscillate?

Select one alternative

- 0.24
- 0.5
- 1.0
- 1.46
- 2.0

Maximum marks: 6

12 P12-TFY4190v2023



A system is controlled by use of a PID controller as shown in the figure above.

Write down the expression for the transfer function C(s) of the PID controller in the frequency (Laplace) domain. Use parameters Kp=2, Kd=4, and Ki=5, and s=1 and calculate a number.

Enter the answer here:

Find the transfer function for the total system (PID controller and system) in the frequency (Laplace) domain. Use parameters C(s) = 2 and G(s) = 3 and calculate a number.

Enter the answer here:

Maximum marks: 4

13 P13-TFY4190v2023

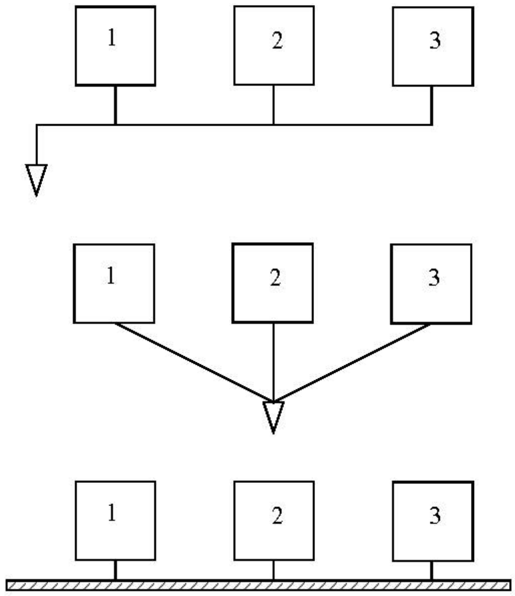
In the figure to the right below are shown three grounding schemes.
Which statement belongs to each figure?

Place the statements on top of the correct figure (drag and drop):

Low ground currents

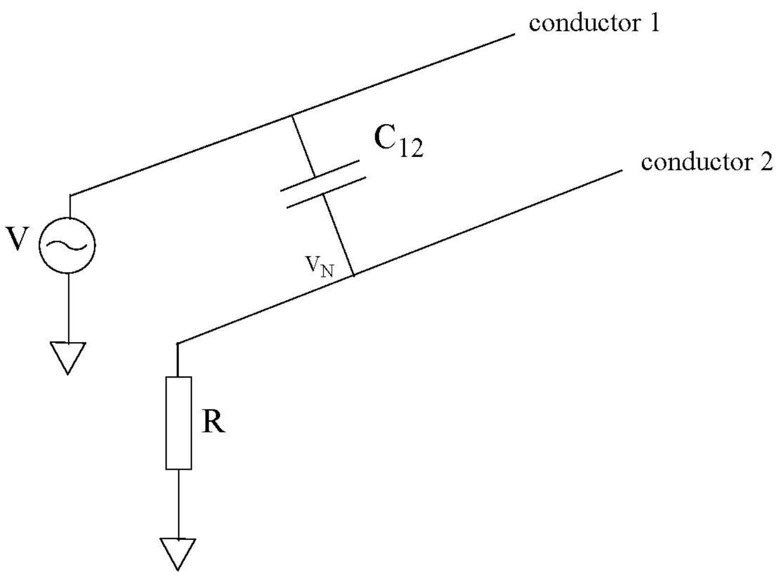
High frequency signal

High ground currents and low frequency



Maximum marks: 3

14 P14-TFY4190v2023



A high frequency voltage signal V is transmitted on "conductor 1". Due to capacitive coupling which is modelled by the capacitor C_{12} the signal is picked up by a nearby "conductor 2", as shown in the figure above. The signal on "conductor 2" may be considered as a noise signal V_N. The resistance to ground of conductor 2 is given by the resistor R.

Estimate the amplitude of the noise signal V_N for the following parameter values: AC voltage of amplitude V = 100 V and angular frequency ω = 10000 1/s, stray capacity C_{12} = 100 pF, and resistance R = 1000 Ω.

Enter the answer here: ☐ V

Maximum marks: 2

15 P15-TFY4190v2023

A harmonic signal $u(t) = 5cos\omega t\ [V]$ is to be sampled by using a 14 bit ADC. The frequency of the signal is given by $f = 1kHz$. The signal should not increase by more than 25% of the resolution between samplings. Find the maximum sampling time that may be used for digitizing the signal.

Enter the maximum sampling time here: ☐ ns.

Maximum marks: 2

16 P16-TFY4190v2023

A sound signal has bandwidth from 25 to 22000Hz. Only frequencies up to 18000Hz are of interest for a particular application. Assume that a digital sampling is to be done of the signal. What should the minimum sampling frequency be to avoid aliasing?

Select one alternative

- 36000 Hz
- 18000 Hz
- 44000 Hz
- 22000 Hz

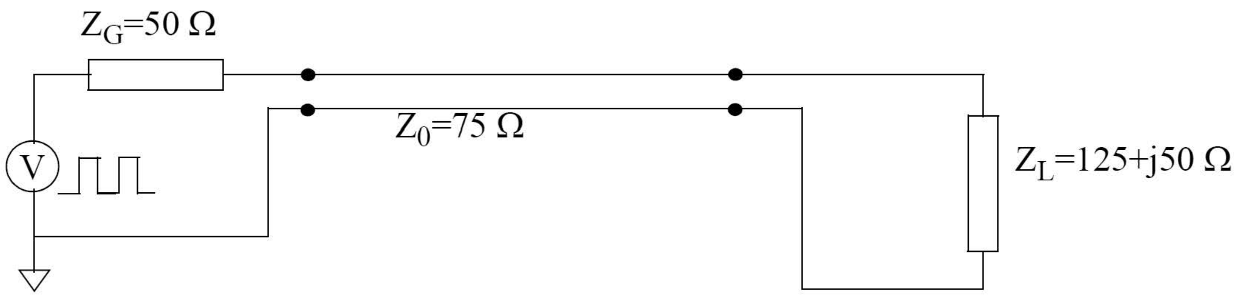
What should the cut-off frequency be for the low-pass filter?

Select one alternative

- 44000 Hz
- 36000 Hz
- 18000 Hz
- 22000 Hz

Maximum marks: 2

17 P17-TFY4190v2023



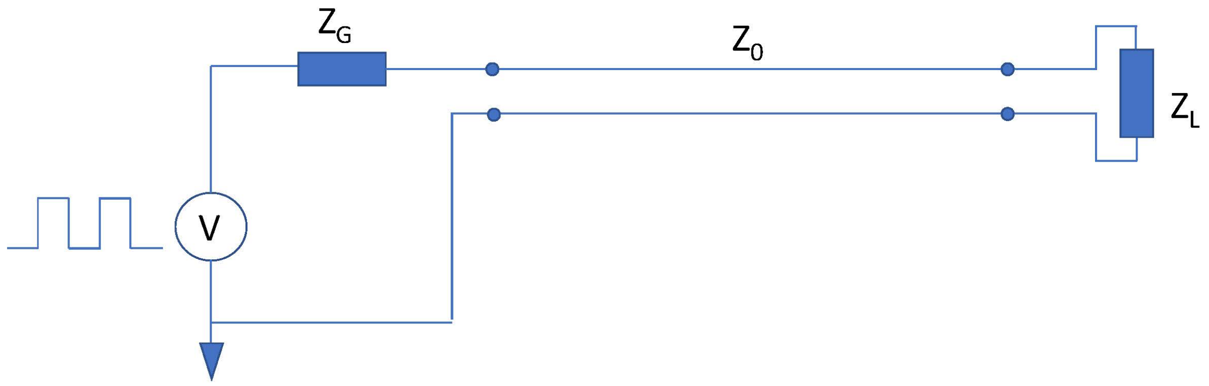
A high frequency pulse train enters a transmission line as shown in the figure. At the end of the transmission line is a complex load that consists of a serial coupling of a resistor and a solenoid. Find the reflection coefficients at the load. Give the answer in amplitude and phase angle. Assume loss-less transmission line.

The amplitude of the reflection coefficient is: ____ .

The phase of the reflection coefficient is: ____ ° (degrees).

Maximum marks: 4

18 P18-TFY4190v2023



The figure above shows a high frequency transmission line with inductance and capacitance give by $L = 300nH$ and $C = 120pF$.
What is the characteristic line impedance Z_0 of the transmission line?

Select one alternative:

- 85Ω
- 50Ω
- 100Ω
- 75Ω

The voltage and current along the line measured from the load impedance $Z_L = 200\Omega$ may be written:

$V(d) = Be^{\gamma d}[1 + \Gamma_R\, e^{-2\gamma d}]\ \ and\ \ I(d) = \frac{Be^{\gamma d}}{Z_0}[1 - \Gamma_R\, e^{-2\gamma d}]$

Assume low loss transmission line $\gamma = \alpha + j\beta \approx j\beta = j\omega\sqrt{LC}$.
The angular frequency of the signal is $\omega = 1 \cdot 10^8 s^{-1}$.
Find the line impedance ***Z(d)*** at distance d = 2.618m from the load.

Select one alternative

- 25.0Ω
- 12.5Ω
- 8.5Ω
- 10.0Ω

Maximum marks: 4

Solution Exam TFY4190 June 1, 2023

Problem1

-314=-(256+0+0+32+16+8+0+2+0) =-100111010-> (add MSB) 0100111010 ->(2komp) 1011000110

Problem2

DAC R-2R ladder, Is4/Is1=0.125; Vi=8V, I1=Vi/2R,

29 = 11101, I=I1+I2+I3+0+I5=I1(1+1/2+1/4+1/16) = -Vo/R

=> Vo=-(Vi/2)*(16+8+4+1)/16 = -Vi*(29/32) -7.25V

Problem3

BCEA 8000 = 1|011 1100 1|110 1010 1000 0000 0000 0000
sign -, exponent 0111 1001 = 121 -bias(127)=-6, fraction=1/2+1/4+1/16+1/64+1/256= 0.83203125
number= -1.83203125*2^{-6} = -0.0286255

Problem4

Concert decimal 27.456 to binary:

27/2 =13+1/2, 13/2=6+1/2, 6/2=3+0, 3/2=1+1/2, 1/2=0+1/2 -> binary 11011

.456*2 = .912+0, .912*2=.824+1, .824*2=.648+1, .648*2=.296+1, .296*2=.592+0, .592*2=.184+1

-> binary .011101 => 11011.011101…..

Problem5

Vo = (K*(R+dR)*I-K*R*I)*K = K^2*I*dR= 0.64

Problem6

resolution=LSB=$\frac{10-(-10)}{2^{14}-1}$= 0.001221 V

Binary number is: 11 1111 1101 0000
sign is negative, 2komp = 0 0000 0011 0000 = 2^5+2^4= 48
input voltage= -48*0.001221V= -0.0586 V

Problem7

Transfer function $F(s) = \frac{1}{s(s+1)(s+2)}$, unit step has transfer function $R(s) = \frac{1}{s}$, and $Y(s) = R(s)F(s)$

From Laplace table we get $f(t) = Inv\{F(s)\} = \frac{1}{2} - e^{-t} + \frac{1}{2}e^{-2t}$, and $y(t) = \int_0^t f(t)dt$

We then get $y(t) = \left[\frac{1}{2}t + e^{-t} - \frac{1}{4}e^{-2t}\right]_0^t = \frac{1}{2}t + e^{-t} - \frac{1}{4}e^{-2t} - 1 + \frac{1}{4}$, and $y(t=1) = 0.084$

Problem8

Maximum power transfer: $Z_{meas} = Z_{sens}^* \Rightarrow |Z_{meas}| = \sqrt{R^2 + X^2} = \sqrt{200^2 + 50^2}\Omega = 206.2\Omega$

High accuracy of output signal requires that: $Z_{meas} \gg Z_{sens}$

Problem9

Quantization error: $E_q = \sqrt{\langle y^2 \rangle} = \sqrt{\frac{1}{T}\int_0^T \left(\frac{qt}{2T}\right)^2 dt} = \frac{q}{\sqrt{12}} = 0.289q = 0.00289$

Problem10

Reflection coefficient at the junction of the two transmission lines is: $\Gamma_{1\to2} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$ after time t=100ns the voltage V_G goes from 3 to 5V, which means that the reflection coefficient must be $\Gamma_{1\to2} = \frac{2}{3}$.

1) We can solve for Z_2 and get $Z_2 = 250\Omega$
2) Speed (phase velocity) of signal is $v = \frac{2L_1}{t} = \frac{20m}{100ns} = 200\ 000\ km/s$
3) The signal will go to zero if there is a short in the transmission line ($\Gamma = -1$).

Problem 11

$$F(s) = \frac{10}{0.01s^3 + 0.1s^2 + s} \quad \xrightarrow{s=j\omega} \quad F(\omega) = \frac{10}{-0.1\omega^2 + j(\omega - 0.01\omega^3)}$$

$$|F(\omega)| = \frac{10}{\sqrt{10^{-2}\omega^4 + (\omega - 10^{-2}\omega^3)^2}}$$

$< F(\omega) = tan^{-1}\left(\frac{\omega - 0.01\omega^3}{0.1\omega^2}\right)$ we see that $tan(180°) = 0$ -> $\omega_{180} = 10s^{-1}$

Proportional control and phase shift 180° -> $K_0 \cdot |F(\omega_{180})| = 1$

1) Angular frequency where the phase shift is 180° is $\omega_{180} = 10s^{-1}$
2) Amplitude of transfer function $|F(\omega_{180})| = 1.0$
3) The proportional gain is $K_0 = 1.0$

Problem 12

1) $u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt}$, and $U(s) = \left\{K_P + \frac{1}{s}K_I + sK_D\right\}E(s) = C(s)E(s)$

Inserting $K_P=2$, $K_D=4$ and $K_I=5$, and s=1 we get C(s)= 11

2) $\big(V_i(s) - V_0(s)\big)C(s)G(s) = V_0(s) \Rightarrow \frac{V_0(s)}{V_i(s)} = \frac{C(s)G(s)}{1+C(s)G(s)}$

Inserting C(s)=2 and G(s)=3 we get $\frac{V_0(s)}{V_i(s)} = \frac{6}{7} = 0.86$

Problem 13

Low currents -> use serial coupling
High ground currents and low frequency signal -> use star coupling (parallel coupling)
High frequency signal -> use ground plane

Problem14

We have that $\frac{V - V_N}{\frac{1}{j\omega C_{12}}} = \frac{V_N}{R}$, if we assume $V_N << V$ we get $V_N \approx j\omega R C_{12} V \Rightarrow |V_N| = 0.1V$

(Using V=100V, C_{12}=100pF, R=1000Ω, ω=10000s^{-1})

Problem15

$u(t) = 5\ cos\omega t \Rightarrow \frac{du}{dt} = -5\omega\ sin\omega t\ \ \Rightarrow \left|\frac{du}{dt}\right|_{max} = 5\omega = 10\pi f$, which is maximum rate of change of *u(t)*

Resolution $q = \frac{5-(-5)}{2^{14}-1}V = 0.61mV$, and we have that $\frac{0.25q}{\tau} = 10\pi f \Rightarrow \tau = \frac{q}{40\pi f} = 4.86ns$

Problem16

1) Sampling frequency is 2*maximum frequency of the signal $f_s = 2f_{max} = 44000Hz$
2) Cut-off frequency $f_{cut\text{-}off} = 18000Hz$

Problem17

$$\Gamma_R = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{1+j}{4+j} = \frac{(1+j)(4-j)}{(4+j)(4-j)} = \frac{5}{17} + j\frac{3}{17}$$

$$|\Gamma_R| = \frac{\sqrt{25+9}}{17} = 0.343\ \ and\ \ \angle\Gamma_R = \tan^{-1}\frac{3}{5} = 30.96°$$

Problem18

$V(d) = Be^{\gamma d}[1 + \Gamma_R e^{-2\gamma d}] \qquad and \qquad I(d) = \frac{Be^{\gamma d}}{Z_0}[1 - \Gamma_R e^{-2\gamma d}]$, where $\gamma = \alpha + j\beta \approx j\beta = j\omega\sqrt{LC}$

1) $Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{300n}{120p}}\Omega = 50\Omega$
2) $Z(d) = \frac{V(d)}{I(d)} = Z_0\frac{1+\Gamma_R e^{-2\gamma d}}{1-\Gamma_R e^{-2\gamma d}}$, and $\Gamma_R = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{3}{5} = 0.6$
   $\omega = 10^8\ s^{-1}\ ,\ d = 2.618\ m\ \ \Rightarrow 2\beta d = 2\omega\sqrt{LC}d = 2\cdot 10^8 \cdot 6 \cdot 10^{-9}\cdot 2.618 = 3.1416 \approx \pi$
   We get $Z(d) = Z_0\frac{1+\Gamma_R e^{-2\gamma d}}{1-\Gamma_R e^{-2\gamma d}} = Z_0\frac{1+\Gamma_R e^{-j2\beta d}}{1-\Gamma_R e^{-j2\beta d}} = Z_0\frac{1+\Gamma_R e^{-j\pi}}{1-\Gamma_R e^{-j\pi}} = 50\cdot\frac{1-0.6}{1+0.6}\Omega = 12.5\Omega$