FrontpageTFY4190

Department of Physics, NTNU

Examination paper for **TFY4190 Instrumentation**

Examination date: **June 10, 2021**
Examination time (from-to): **9-13**

Permitted examination support material: A / All support material is allowed

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Accessing your answer post-submission: You will find your answer in Archive when the examination time has expired.

1

p1v2TFY4190v2021

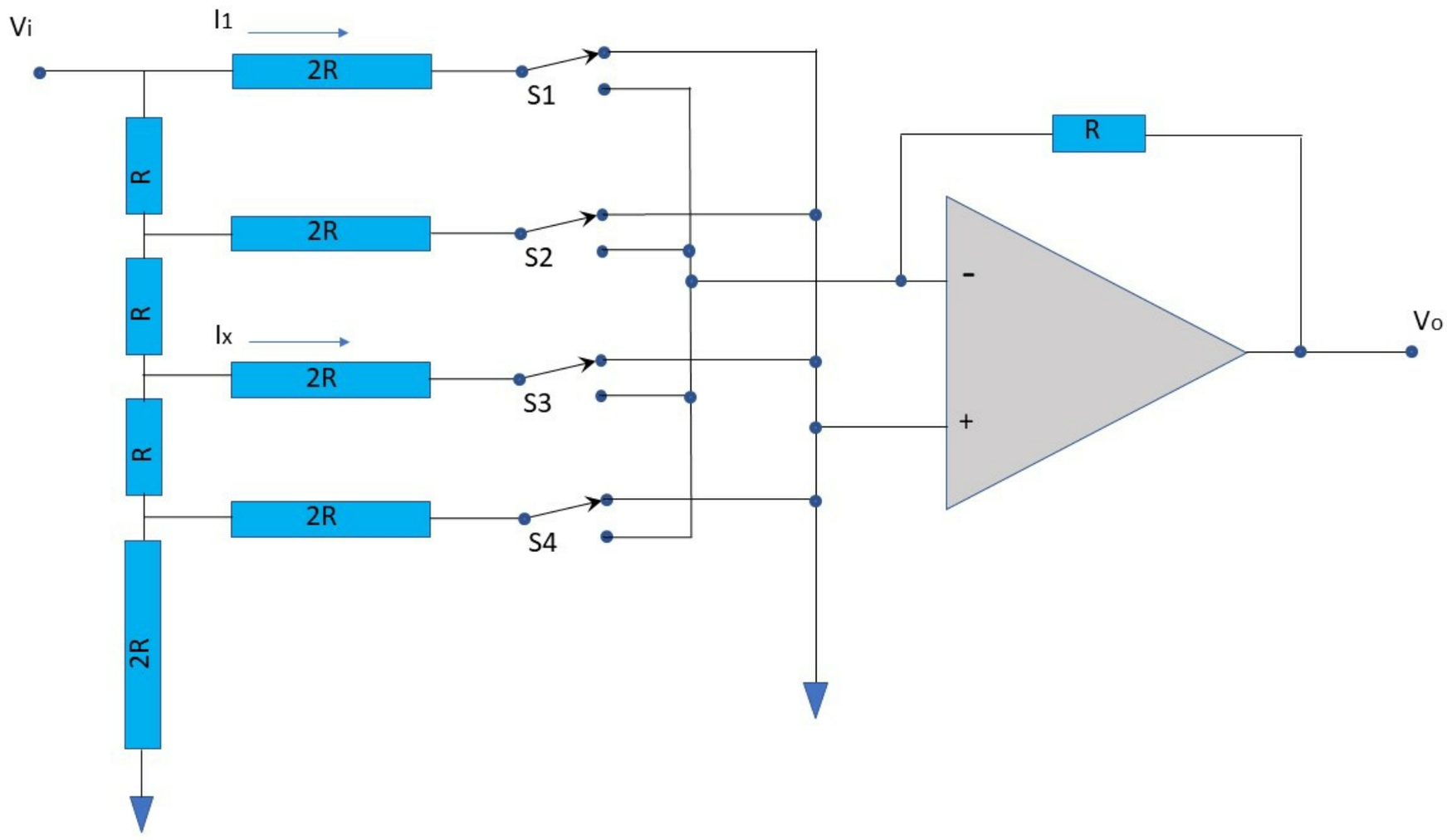
The 2 complement representation of the decimal number -213 is:
Select one alternative:

- 1010111
- 1101011
- 11010101
- 100101011
- 110101

(2 points for correct answer)

Maximum marks: 2

2 p2v2TFY4190v2021



The DAC circuit shown above consists of resistors with resistances R and 2R as indicated, switches S1 to S4, and an ideal operational amplifier. The reference voltage is V_i and the output voltage is V_o. Currents I_1 and I_x are indicated in the figure.

What is the ratio I_1/I_x between currents I_1 and I_x?

Enter the answer here: .

What is the analogue output if switches S1, S2, and S3 are in the lower positions, and switch S4 is in the upper position? Assume a reference voltage V_i of 5 V.

Enter the answer here: V.

(2 points for each correct answer)

Maximum marks: 4

3 p3v1TFY4190v2021

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 single precision number given in hexadecimal form by C2380000 ?

Enter the answer here: .

(2 points for correct answer)

Maximum marks: 2

4

p4v2TFY4190v2021

A physical quantity is measured 10 times. The results are:
5.1, 5.2, 5.0, 5.3, 4.9, 5.1, 5.2, 5,0, 4.8, 5.0 (in arbitrary units).
What is the precision in % for the second measurement (value 5.2) ?
Select one alternative:

- 98%
- 97%
- 96%
- 95%
- 99%

(2 points for correct answer)

Maximum marks: 2

5

p5v2TFY4190v2021

Assume the following time dependent signal $y(t) = sin(\omega t)$.

Find the RMS (root mean square) average of the signal.
The RMS average is:

- 0.67
- 0.83
- 0.71
- 0.5
- 0.64

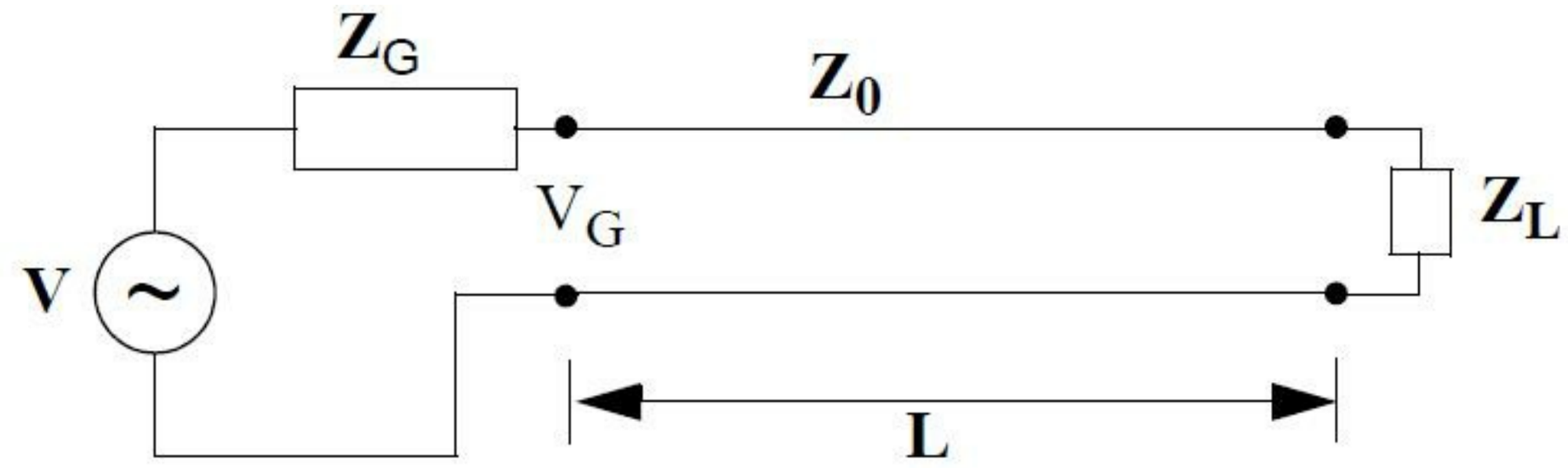
Find the rectified average of the signal.
The rectified average is:

- 0.67
- 0.71
- 0.64
- 0.83
- 0.5

(1 point for each correct answer)

Maximum marks: 2

6 p6v3TFY4190v2021



The figure above shows a generator circuit that transmit a high frequency signal on a transmission line of characteristic impedance Z_0. At the end of the line is a load impedance $Z_L = 1000\Omega - i300\Omega$.

Which statement is correct?

Select one alternative:

- the voltage signal is a maximum at the load
- the voltage increases when moving away from the load
- the voltage decreases when moving away from the load
- the voltage signal is a minimum at the load

The voltage standing wave ratio (VSWR) at the load is given by $VSWR = 4$.

What is the magnitude of the reflection coefficient at the load?

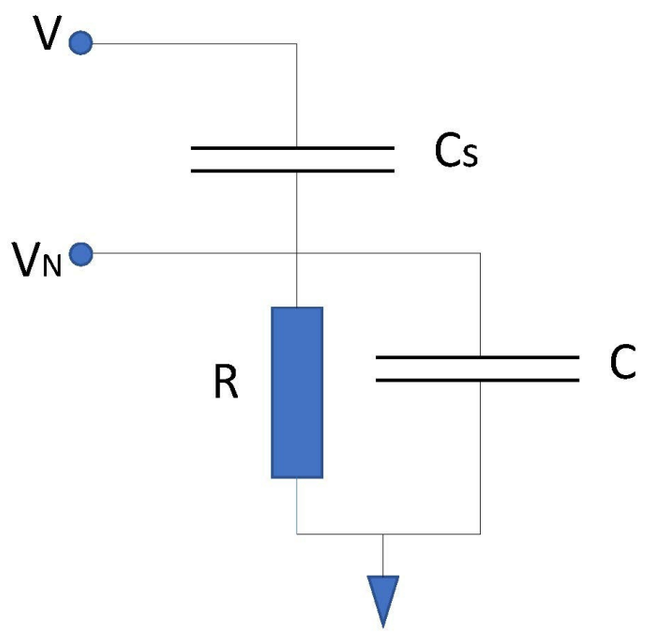
Select one alternative

- 0.4
- 0.5
- 0.6
- 0.7
- 0.8

(2 points for each correct answer)

Maximum marks: 4

7 **p7v2TFY4190v2021**



The input circuit of an amplifier can be considered to consist of a $R = 10M\Omega$ resistor in parallel with a $C = 100pF$ capacitor as shown in the figure above. A power line of frequency $f = 50Hz$ and peak to peak voltage $V = 320V$ results in a noise voltage of $V_N = 1V$ at the input of the amplifier due to capacitive coupling.

Find the capacitance C_S between the power line and the input circuit.

Select one alternative:

- 0.62 pF
- 1.04 pF
- 0.89 pF
- 0.52 pF
- 1.24 pF

(4 points for correct answer)

Maximum marks: 4

8 **p8v2TFY4190v2021**

A 16 bit ADC has operating range from -15 to +15V. The output signal is given in 2 complement binary format in hexadecimal representation V_{out} = 9DE3.

What is the resolution of the ADC?

Enter the answer here: mV.

What is the input voltage?

Enter the answer here: V.

(2 points for each correct answer)

Maximum marks: 4

9

p9v2TFY4190v2021

Convert decimal 4038.356 to hexadecimal format.
The answer is given by:
Select one alternative:

- FC6.5B22...
- FC6.6011...
- FC6.5B30...
- FC6.5C1E...
- FC6.4FF3...

(2 points for correct answer)

Maximum marks: 2

10

p10v1TFY4190v2021

A sound signal has bandwidth from 10 to 24000Hz. 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
- 24000 Hz
- 18000 Hz
- 48000 Hz

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

- 24000 Hz
- 18000 Hz
- 48000 Hz
- 36000 Hz

(1 point for each correct answer)

Maximum marks: 2

11 p11v1TFY4190v2021

A disturbance in form of a sharp voltage pulse (delta pulse) is impinging on a system of transfer function F(s) as shown above. The transfer function of the measurement system is given by: $F(s) = \frac{s}{(s+1)(s+2)}$.

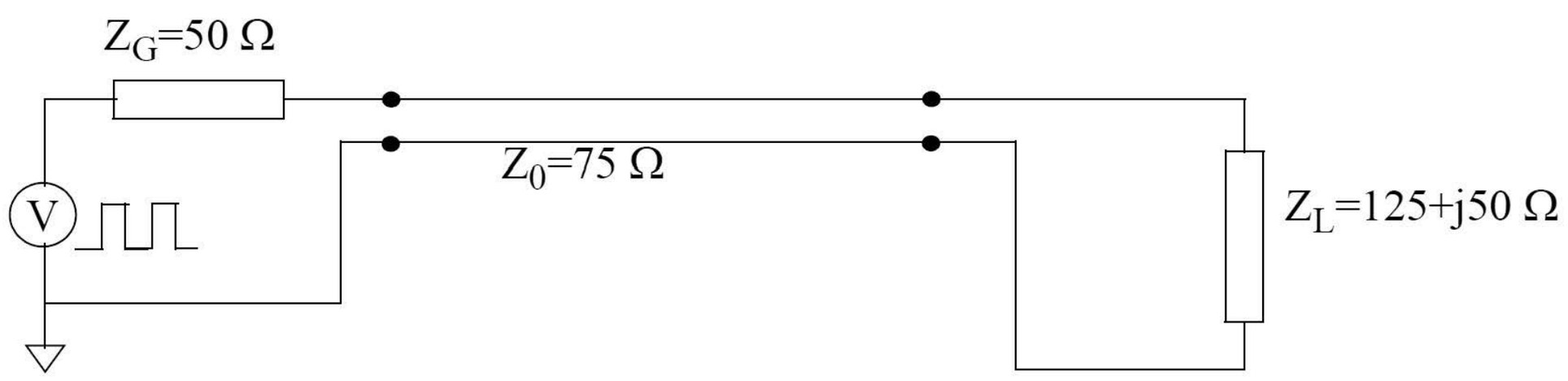
How large is the effect of the disturbance on the output signal y(t) after t = 0.5s ?

Enter the answer in % of the maximum disturbance: [ ] %.

(4 points for correct answer)

Maximum marks: 4

12 p12v1TFY4190v2021



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.

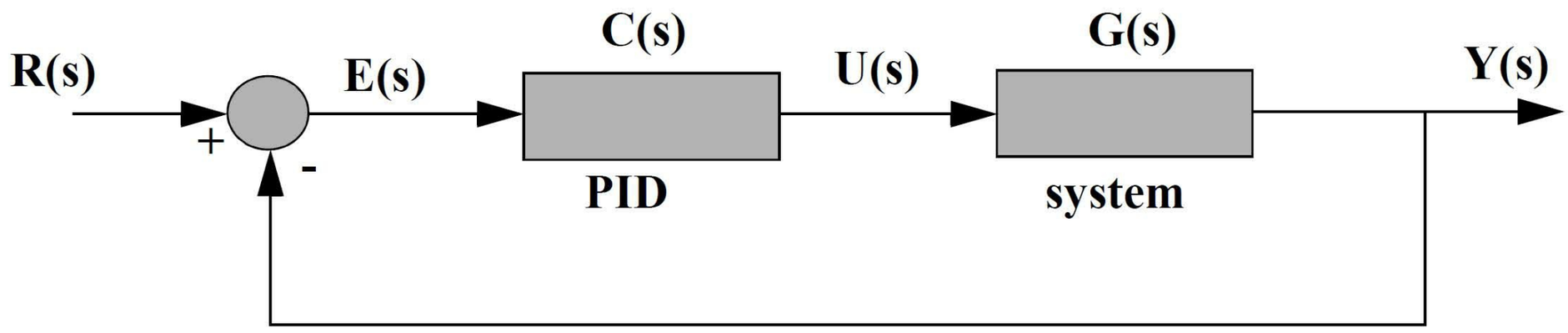
The amplitude of the reflection coefficient is: [ ] .

The phase of the reflection coefficient is: [ ] ^{o} (degrees).

(2 points for each correct answer)

Maximum marks: 4

13 p13v1TFY4190v2021



A PID regulated system is shown in the figure above.

The transfer function of the system is given by $G(s) = \frac{1}{0.01s^3+s+1}$

Assume proportional control and harmonic signal and find the angular frequency where the regulated system starts to oscillate.

Enter the answer here: [ ] rad/s.

Find the period of the oscillations at this point.

Enter the oscillation period here: [ ] s.

(1 point for each correct answer)

Maximum marks: 2

14 p14v1TFY4190v2021

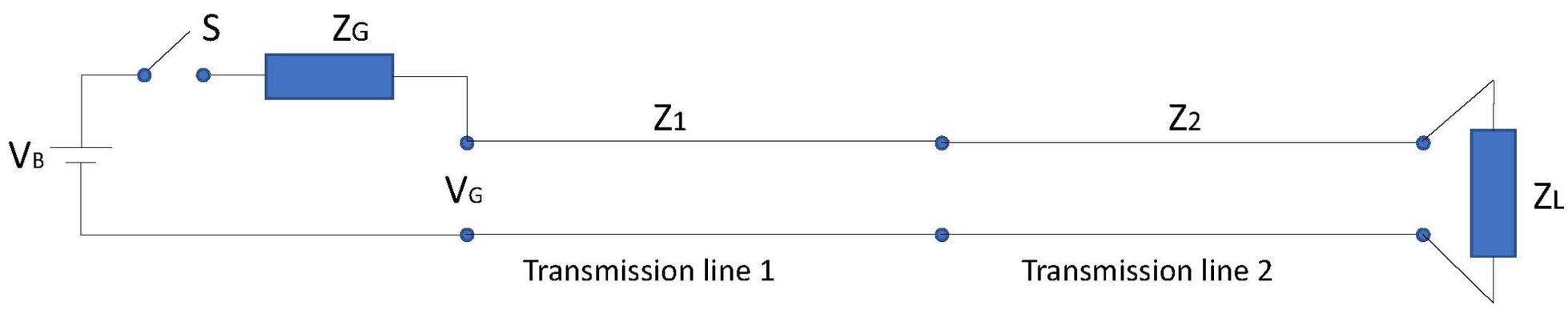
A harmonic signal $u(t) = 5cos\omega t\ [V]$ is to be sampled by using a 14 bit ADC. The frequency of the signal is given by $f = 1kHz$. The signal should not increase by more than 25% of the resolution between samplings. Find the maximum sampling time that may be used for digitizing the signal.

Enter the maximum sampling time here: [ ] ns.

(2 points for correct answer)

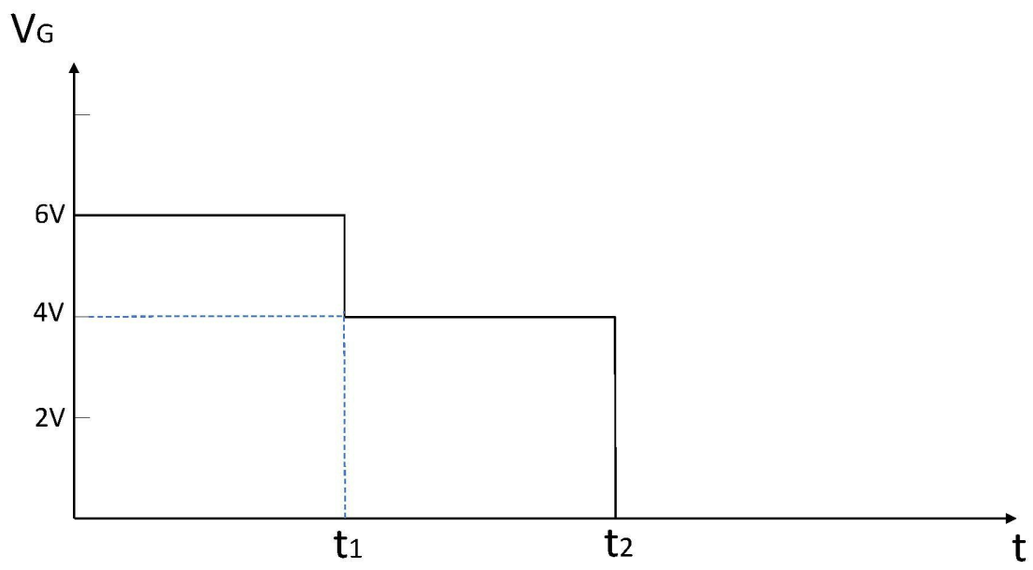
Maximum marks: 2

15 **p15v1TFY4190v2021**



A battery of voltage **V_B** and a switch **S** generates a step voltage $V_G = 6V$ at the start of transmission line 1.
Impedances are given by $Z_G = 75\Omega$ and $Z_1 = 75\Omega$.
What is the voltage **V_B** of the battery ?

Enter the voltage here: [ ] V.



How V_G varies with time is shown in the figure above.
Find the line impedance of transmission line 2.

Enter the line impedance **Z_2** here: [ ] Ω.

Use the curve above to estimate the size of the load at the end of transmission line 2.

Enter the value of **Z_L** here: [ ] Ω.

(2 points for each correct answer)

Maximum marks: 6

16 **p16v1TFY4190v2021**

We want to sample the signal $u(t) = sin(\omega t)$. The angular frequency $\omega = 56520\, rad/s$. We will use sampling frequency $f_s = 25\ kHz$.

Which of the following frequencies may be reproduced in the sampled signal in the absence of a low-pass filter?

Select one or more alternatives:

- 18000 Hz
- 30000 Hz
- 40000 Hz
- 50000 Hz
- 20000 Hz
- 25000 Hz

(2 points for each correct answer, -2 points for each wrong answer, minimum score is 0 points)

Maximum marks: 6

17 **p17v2TFY4190v2021**

Consider a semiconductor junction of resistance $R = 100k\Omega$ which is at temperature $T = 300K$. A frequency dependent current $I = 1nA$ of bandwidth $\Delta f = 1000Hz$ flows through the junction.

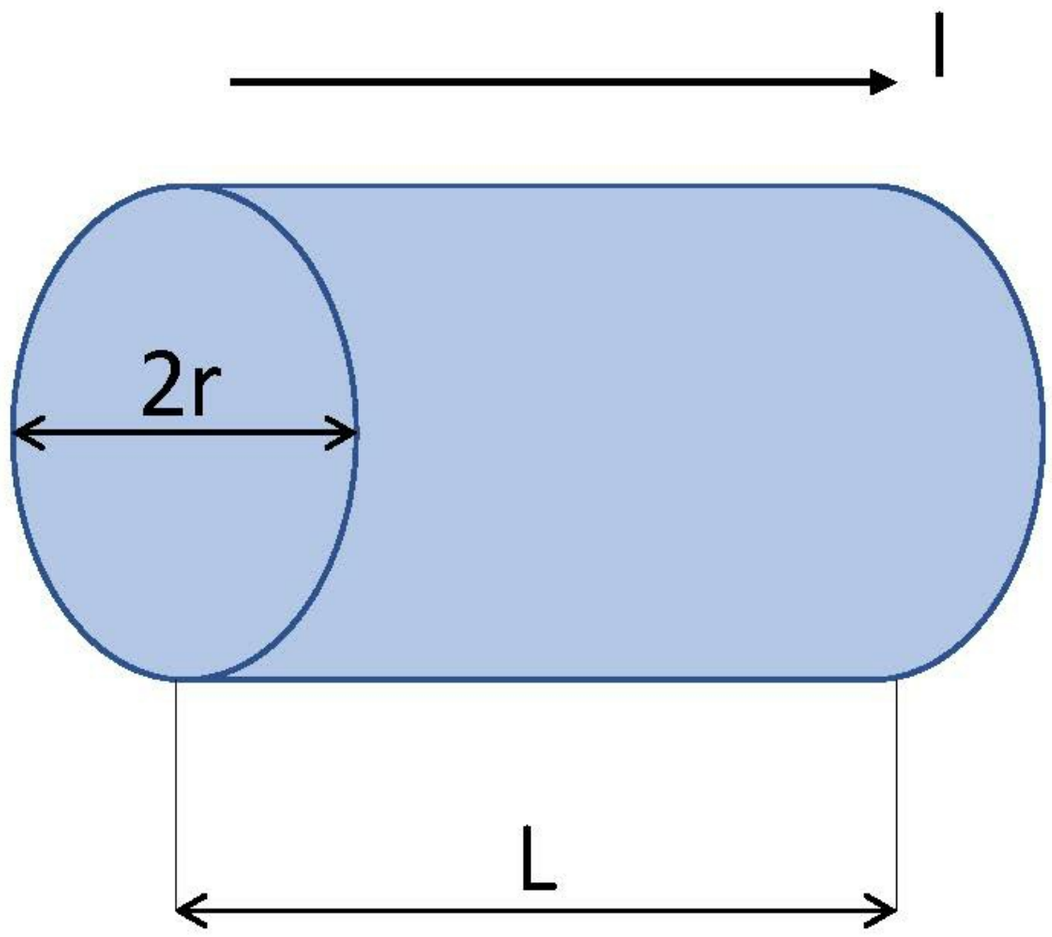
Find the ratio between the thermal and shot noise currents $I_{thermal}/I_{shot}$.

Enter the answer here: .

(2 points for correct answer)

Maximum marks: 2

18 p18v3TFY4190v2021



A current flows through a resistor shaped as a cylinder of resistivity ρ, length **L** and radius **r,** as shown in the figure above.

Use Gauss' law of error propagation to estimate the uncertainty in the dissipated power in the resistor when the relative uncertainties in dimensions are given by $\frac{\Delta r}{r} = 0.02$ and $\frac{\Delta L}{L} = 0.01$. The relative uncertainty in the current measurement is $\frac{\Delta I}{I} = 0.005$.

Enter the answer in % here: .

(2 points for correct answer)

Maximum marks: 2

Solution Exam June 10, 2021

Problem 1

-213 -> -11010101 -> (add one digit) -011010101 -> 100101011 (2comp)

Problem 2

$\frac{I_1}{I_x} = 4$ and $\frac{V_o}{R} = -(I_1 + I_2 + I_3) = -V_i\left(\frac{1}{2R} + \frac{1}{4R} + \frac{1}{8R}\right) = -\frac{7V_i}{8R}$ => $V_o = -\frac{7}{8}V_i = -4.375V$

Problem 3

Hex C2380000 = 1|100 0010 0|011 1000 0000 0000 0000 0000

Sign -, exponent 1000 0100 = 128+4 -bias 127 = 5, fraction = 0.25+0.125+0.0625 = 0.4375

Number = - 2^5 x 1.4375 = 46.00

Problem 4

<x> = 5.070, Precision = 100(1-(5.2-5.060)/5.060) = 97.23%

Problem 5

RMS average = $\sqrt{\frac{1}{T}\int_0^T sin^2\omega t dt} = \sqrt{\frac{\omega}{2\pi}\int_0^{\frac{2\pi}{\omega}} sin^2\omega t dt} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} sin^2 x dx} = \sqrt{\frac{1}{2}} = 0.707$

Rectified average = $\frac{2}{T}\int_0^{\frac{T}{2}} sin\omega t dt = \frac{\omega}{\pi}\frac{1}{\omega}[-cosx]_0^{\pi} = \frac{2}{\pi} = 0.637$

Problem 6

The voltage decreases when moving away from the load (negative imaginary part of load impedance)

$V(d) = Be^{j\beta d}\left(1 + \Gamma_R e^{-j2\beta d}\right) = Be^{j\beta d}\left(1 + |\Gamma_R| e^{j(-|\varphi| - 2\beta d)}\right)$

$\cos(-|\varphi| - 2\beta d)$ decreases as d increases

$VSWR = \left|\frac{V_{max}}{V_{min}}\right| = \frac{1-|\Gamma_R|}{1+|\Gamma_R|} => |\Gamma_R| = \frac{VSWR-1}{VSWR+1}$ = 0.6

Problem 7

$$I = \frac{V - V_N}{\frac{1}{j\omega C_S}} = \frac{V_N(1 + j\omega RC)}{R} => \frac{V_N}{V} \approx \frac{j\omega RC_S}{1 + j\omega RC} => \left|\frac{V_N}{V}\right|^2 = \frac{(\omega RC_S)^2}{1 + \omega^2 R^2 C^2}$$

$$C_s = \left|\frac{V_N}{V}\right| \frac{1}{R}\sqrt{\frac{1}{\omega^2} + R^2C^2} = 1.04pF$$

Problem 8

$$Resolution = \frac{15-(-15)V}{2^{16}-1} = 0.0004578\,V$$

Hex 9DE3 = 1001 1101 1110 0011 -> - 110001000011101 = - $2^{14}+2^{13}+2^9+2^4+2^3+2^2+2^0$ = -25117

Input voltage = -25117 x 0.0004578 V = -11.499 V

Problem 9

Convert 4038.356 to hexadecimal.

4038/16 = 252 + 6/16
252/16 = 15 + 12/16
15/16 = 0 + 15/15

=> FC6

0.356*16 = 0.696 + 5
0.696*16 = 0.136 +11
0.136*16 = 0.176 + 2
0.176*16 = 0.816 + 2
0.816*16 = 0.056 + 13

=> 5,11,2,2,13, = 5B22D…

Problem 10

Nyquist f_s = 48kHz, $f_{cut\text{-}off}$ = 18kHz

Problem 11

$$R(s) = 1\ and\ F(s) = \frac{s}{(s+1)(s+2)}$$

From Laplace table $y(t) = f(t) = 2e^{-2t} - e^{-t} => y(0.5s) = 0.13 = 13\%$

Problem 12

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

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

Problem 13

$$G(s) = \frac{1}{0.01s^3+s+1} \overset{s=j\omega}{\Longrightarrow} G(\omega) = \frac{1}{1+j(\omega-0.01\omega^3)} = \frac{1+j(0.01\omega^3-\omega)}{1+(\omega-0.01\omega^3)^2}$$

$\angle G(\omega) = \tan^{-1}(0.01\omega^3 - \omega)$ since tan(180°) = 0, we get ω(180°) = 10 rad/s

$$\omega T_0 = 2\pi \Rightarrow T_0 = \frac{2\pi}{\omega} = 0.628\,s$$

Problem 14

$$\left(\frac{\Delta V}{\Delta t}\right)_{max} = 5\omega = 10\pi f = \frac{\Delta V_{resolution}}{4\tau} = \frac{\frac{2\cdot 5}{2^{14}-1}}{4\tau}$$

$$\tau = \frac{\frac{1}{2^{14}-1}}{4\pi\cdot 1000}s = 4.86\cdot 10^{-9}\,s = 4.86\,ns$$

Problem 15

$$V_G = \frac{V_B}{Z_G + Z_1} Z_1 \Rightarrow \quad V_B = \frac{Z_G + Z_1}{Z_1} V_G = 12V$$

The reflection coefficient must be -1/3.

$$\Gamma_{12} = \frac{Z_2 - Z_1}{Z_2 + Z_1} = -\frac{1}{3} \Rightarrow 3(Z_2 - Z_1) = -(Z_2 + Z_1) \Rightarrow \quad Z_2 = 0.5Z_1 = 37.5\Omega$$

The load impedance Z_L must be 0 (shorted).

Problem 16

$$u(t) = \sin(\omega t) = \sin(2\pi f t)$$

$$u_n(t) = \sin(2\pi f\, n\tau_s) = \sin(2\pi f\, n\tau_s + m2\pi) = \sin(2\pi[nf + mf_s]\tau_s)$$

There multiples of **f** and $\mathbf{f_s}$ may be present in the sampled signal without using a low-pass filter.

Problem 17

$$I_{thermal} = \sqrt{\frac{4k_B T\, \Delta f}{R}} = 1.287 \cdot 10^{-11}\, A = 12.87\, pA$$

$$I_{shot} = \sqrt{2eI\, \Delta f} = 0.566 \cdot 10^{-13}\, A = 0.566\, pA \Rightarrow \quad \frac{I_{thermal}}{I_{shot}} = 22.75$$

Problem 18

$$P = RI^2 = \frac{\rho L}{\pi r^2} I^2$$

$$\frac{dP}{P} = \frac{dL}{L} - 2\frac{dr}{r} + 2\frac{dI}{I}$$

Gauss => $\frac{\Delta P}{P} = \sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(2\frac{\Delta r}{r}\right)^2 + \left(2\frac{\Delta I}{I}\right)^2} = \sqrt{0.01^2 + 4 \cdot 0.02^2 + 4 \cdot 0.005^2} = 0.042 = 4.2\%$