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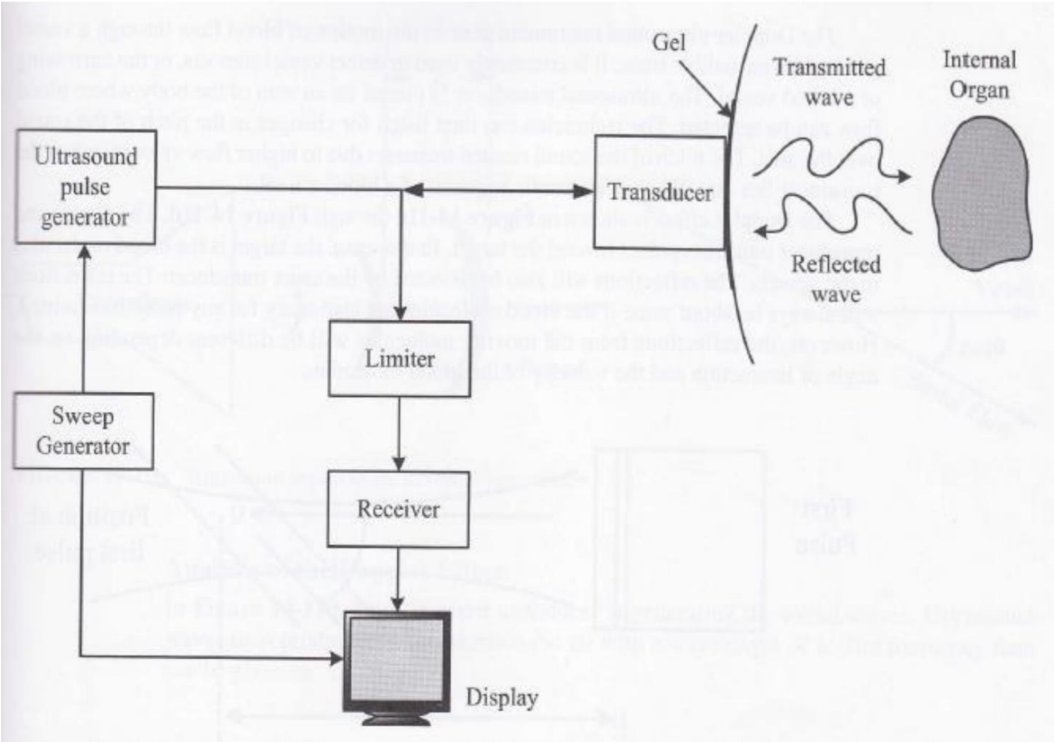
1. (a)



Block diagram of Ultrasound System

(b)

Firstly we have to find the range of V_{ab} to design suitable signal conditioning circuit to get desired V_{out}.
As the range of V_{ab} depends on the value of RTD at different temperatures, we have to find the value of RTD at 125°C and 250°C.
RTD at 125°C = 100 [1+0.005 (125-100)] =112.5
RTD at 250°C = 100 [1+0.005 (250-100)] =175
We find that the given circuit is Wheatstone bridge, hence
V_{ab} = (RTD×150 – 150×150)/ ((150+RTD) (150+150))

V_{ab} at 125°C = -0.07

V_{ab} at 250°C =0.038

From the question we understand that -0.07 and 0.038 has to be amplified and shifted to get V_{out} as 0.1 and 10

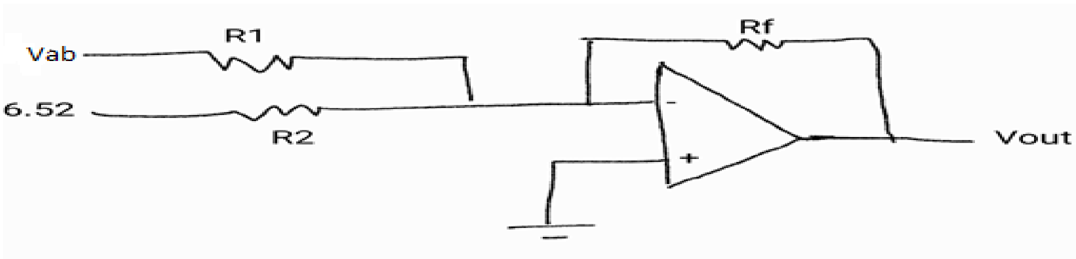
Let us assume that the equation is in form of
y=mx+c where y is output voltage, x is input voltage of signal conditioning circuit.

0.1=m (-0.07) +c
10=m (0.038) +c

Solving the equations, we get signal conditioning equation as:

y= (-91.65)x+(- 6.52) => y= -(91.67(x) + 6.52) -------------------------- eq.(1)

Summation amplifier can be used to obtain the desired signal conditioning circuit as below:
Vout = - (Rf/R1 (Vab) + Rf/R2 (6.52)) --------------------------------------eq.(2)



Hence the resistors can be chosen such that Rf/R1= 91.67 and Rf/R2=1 by comparing eq.(1) and eq.(2), therefore we can get many combinations of them. For e.g.: choose Rf = R2 = 100ohm then R1= 1.09ohm.

2.

a) Slew Rate = 0.6V/µs
Vin = 0.2 sin(10^3t) volt

Vout = |(120k/R1)| Vin
= (120k/R1) (0.2 sin (10^3t))
Here K = (120k/R1)0.2
$\omega = 10^3$
The minimum value of R1 required for the op-amp to avoid distortion due to slew rate limitation can be found using the condition:

ω<= SR/k
10^3 <= (0.6 x R1)/(10^{-6} x 120k x 0.2)
R1>= 40
Hence minimum value of R1 is 40 Ω.

b) Another equation that has to be satisfied for the output to be not distorted is :

-15V<= Vout <=15V

Max value of Vout =(120k/R1)0.2
Putting min value of R1 we get
Vout = (120k/40)0.2 =600V which is not less than 15V, hence output distortion will occur for the minimum value of R1 computed in part (a).
To avoid output distortion we should have
(120k/R1)0.2<=15
Hence minimum value of R1 that will avoid distortion is 1.6k Ω.

c) The first half of the given circuit acts like low pass filter

$f_H = 1/(2\pi R C)$
$= 1/(2 \times 3.14 \times 1.2k \times 0.01\mu)$
$= 10^3/(2 \times 3.14 \times 1.2 \times 0.01)$
$= 13.269k$ Hz

All the frequencies less than 13.629k Hz will be passed by this first half of the circuit.
The second half of the given circuit acts like high pass filter

$f_L = 1/(2\pi R C)$
$= 1/(2 \times 3.14 \times 1k \times 0.1\mu)$
$= 10^3/(2 \times 3.14 \times 0.1)$
$= 1.592k$ Hz

All the frequencies greater than 1.592k Hz will be passed by this second half of the circuit.
Hence the circuit shown in the question acts like Band Pass Filter with pass band 1.592k<=f<=13.269k.

d) • Signal bandwidth = 0 to 3k Hz
• Noise from 20kHz ⇒ Stopband should begin at 20kHz
• So (fSIG= 3kHz) < fC < (f1 =20kHz)
- select fC to be 3.2kHz (to begin with)
Signal: 200mV; Noise = 10 mV(from 20kHz)
SNR of input signal = 20 log 200/10 = 26dB
Additional SNR needed = 80 dB – 26 dB = 54 dB (i.e. Noise needs to be attenuated by 54 dB)
3.2kHz to 20kHz = log10(20k/3.2k) = 0.795 Decade
N = (54dB/0.795)/(20dB) = 3.39 ⇒ 4th order
Minimum order of filter needed is four.

3. a)
i)
Assume that y is z-transformable and the z-transform of y (k) is Y (z) and set the sampling interval to 1.
u (k) is a unit step function that shifted to the right by 1. The Z-transform of unit step function is z/ (z-1), so Z [u (k)] = 1/ (1-z)
Let us find out y(1) using the difference equation and we know that u(k)<0 =0 as it is z-transformable and u(0)=1, u(1)=0.5142, u(2)=-0.5142, and u(k)=0, k=3,4,5,……

Let us substitute -1 in place of k in difference equation, then we get:
y (1)-1.5241y(0)+0.5241y(-1)= 0.5241u(0)+0.2642u(-1)
Hence y (1) =0.5241
Apply shifting theorem to find the z-transform of difference equation
$Z[y(k+2)] = z^2 * [Y(z)-y(0)-z^{-1}y(1)] = z^2 * Y(z) - z(0.5241)$
$Z[y(k+1)] = z * [Y(z)-y(0)] = z * Y(z)$
$Z[u(k+1)] = z* [U(z)-u(0)]=(z/1-z) -z$
So the difference equation can be written as:

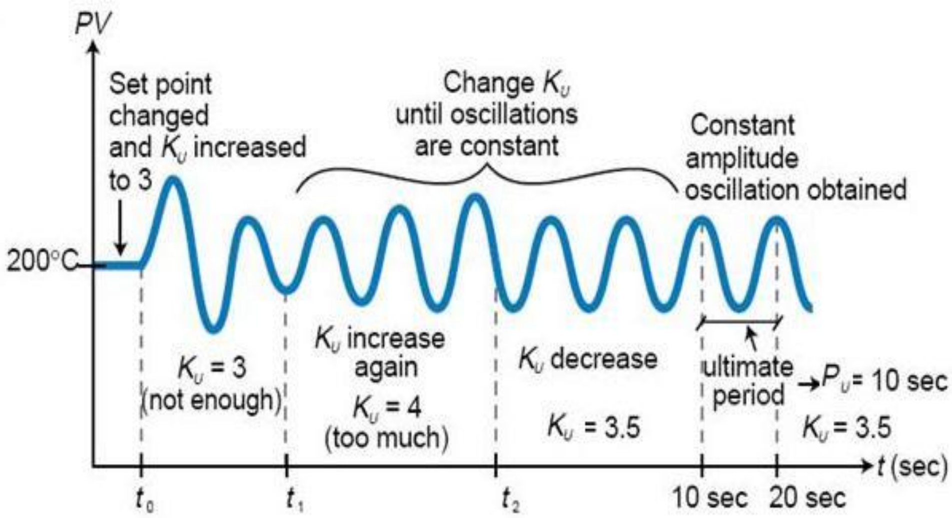
$z^2 * Y(z) - z(0.5241) - 1.5241z\, Y(z) + 0.5241\, Y(z) = 0.5241((z/1-z)-z)+0.2642(1/1-z)$
$Y(z) = (0.5241z+0.2642)/(- z^3 + z^2 +z -1)$ is the Z transform.

ii)
We know y(0)=0, y(1)= 0.5241
when k=0 the difference equation becomes
y(2)-1.5241y(1)=0.5241*0.5142+0.2642
y(2)=1.33

b)
Given Ku=10 and Pu=0.1sec
P=0.6Ku =6
I=0.5Pu = 0.05
D=0.125Pu =0.0125

Ziegler-Nichols Tuning Method

- Switch off the integral and derivative control .
- Increase the proportional gain until the response oscillates with constant amplitude, then the period is ultimate period and gain is ultimate gain at that point.



4.

a) Open loop stability:
The poles of the equation lies in the equation:

G(z)=(z-0.5141)(z-1) => z= 0.5141 or 1.
We find that one pole is less than one and another is equal to 1. Hence single pole lies on unit circle which makes the system critically stable.

b) P(z)= 1+K G(z)
=1+ K(0.5142z+0.2642)/((z-0.5142)(z-1))

P(z)=0 is the characteristic equ then:
z^2+(0.5142K- 1.5142)z+0.2642K+0.5142=0
According to Jury Stability Test when a system is stable following conditions apply:
A0=1, A1=(0.5142K-1.5142), A2=0.2642K+0.5142

i. A0<0 True
ii. |A2|<A0 |0.2642K+0.5142|<1
-5.73<K<1.839
iii. At z=1 the equation>0
1+0.5142K-1.5142+0.2642K+0.5142>0 => K>0
iv. At z=-1 the equation>0 (even)
1-0.5142K+1.5142+0.2642K+0.5142>0 => K<12.11

0<K<1.839

Either iii. or iv. equation should be 0 for the system to be critically stable. Hence for K=0, 1.839 it is possible.

c) T= 0.01s
The characteristic equation when K=1 will become :
z^2+ (0.5142- 1.5142)z+0.2642+0.5142=0
z^2-z+0.2642+0.5142=0
z^2-z+5.4062=0

$$2\cos(w_n T\sqrt{1-\varsigma^2})e^{-\varsigma\omega_n T} = 1$$

$$e^{-2\varsigma\omega_n T} = 5.4062$$

$$\varsigma\omega_n = \frac{\ln 5.4062}{2*0.01}$$

Settling time = $T_s = \dfrac{4}{\varsigma w_n} = 0.0474\text{s}$

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Thank you and all the best for your exams! ☺