NBE-E4310 - Biomedical Ultrasonics
Exercise 1
Model Answers

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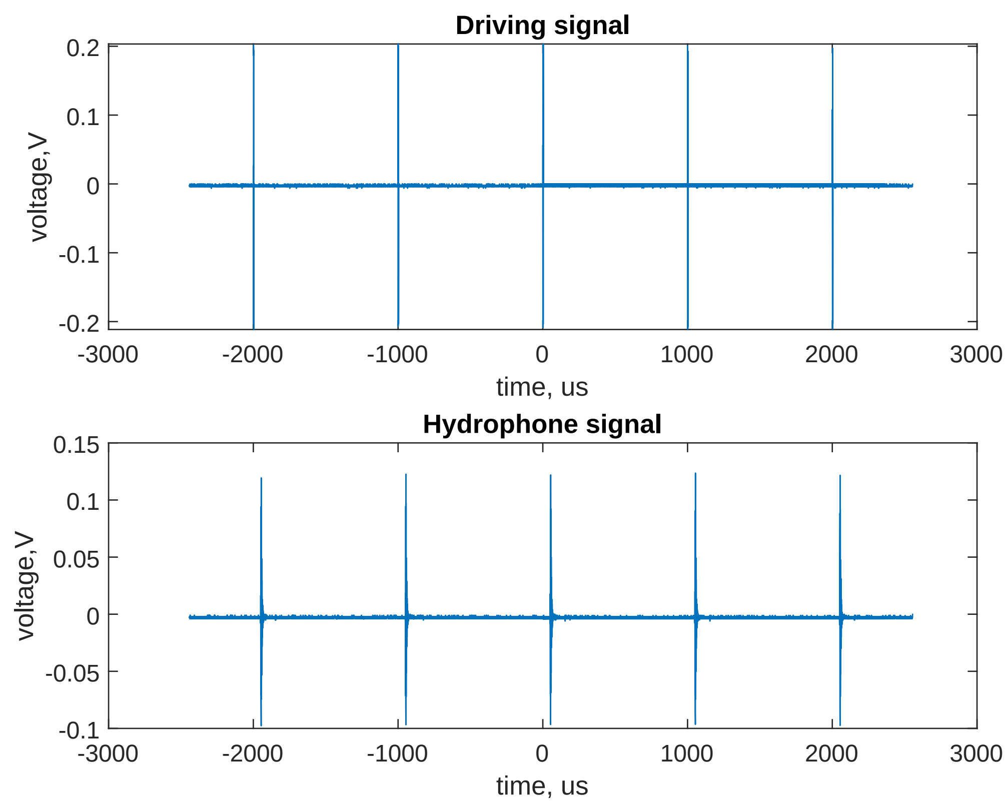
1. Measures of an ultrasound burst (10p)

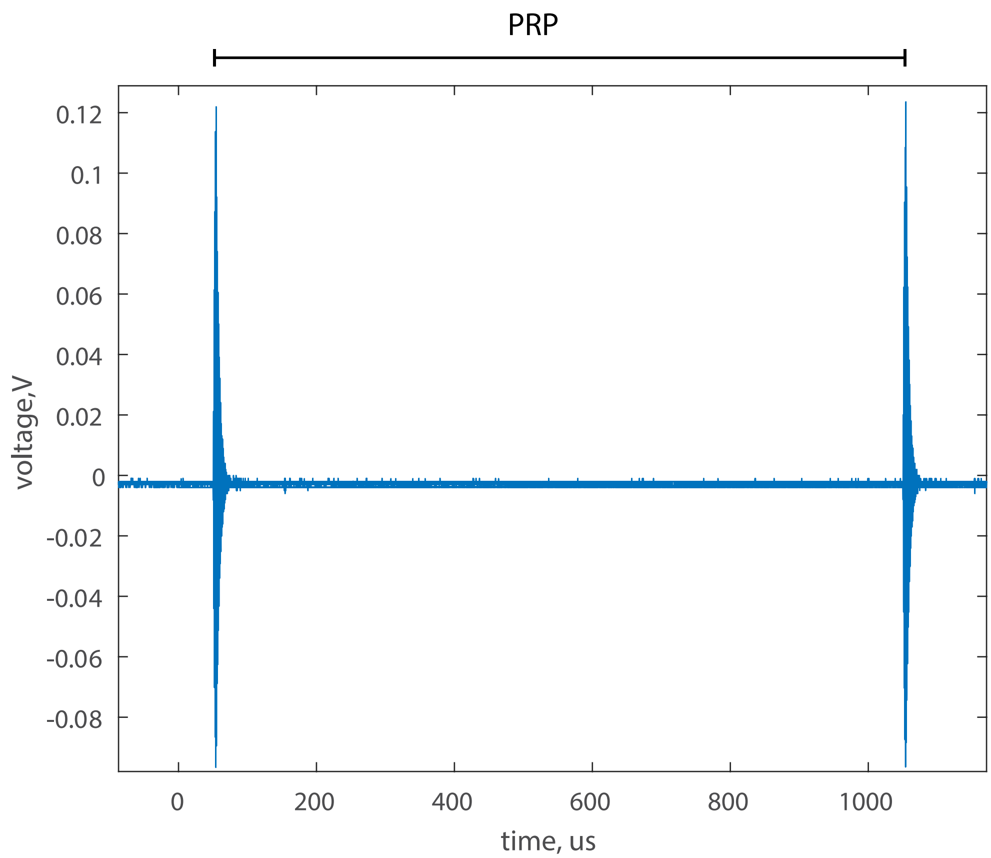
(a) **Plot the hydrophone signal (V) and the driving signal (V) as a function of time (μs). Label clearly parameters and units. 1p**



(b) **What is the PRP? 1p**

(c) **What is the PRF? 1p**

The PRP is the time between the bursts, while the PRF is the inverse of the PRP.




```
load demo1.mat

data(isnan(data)) = 0; % replace NAN values with 0

t = data(:,1);
p = data(:,2);
v = data(:,3);

PRP = (1050 - 50)*1e-6; % s
PRF = 1/PRP ; % Hz
```

Reading the time interval manually from the plot one obtains:

$PRP = 1\,\text{ms}$
$PRF = \frac{1}{PRP} = 1\,\text{kHz}$

(d) **Plot the amplitude spectrum of the pressure signal in decibels. Choose the refence value to be the maximum value of the spectrum. 2p**

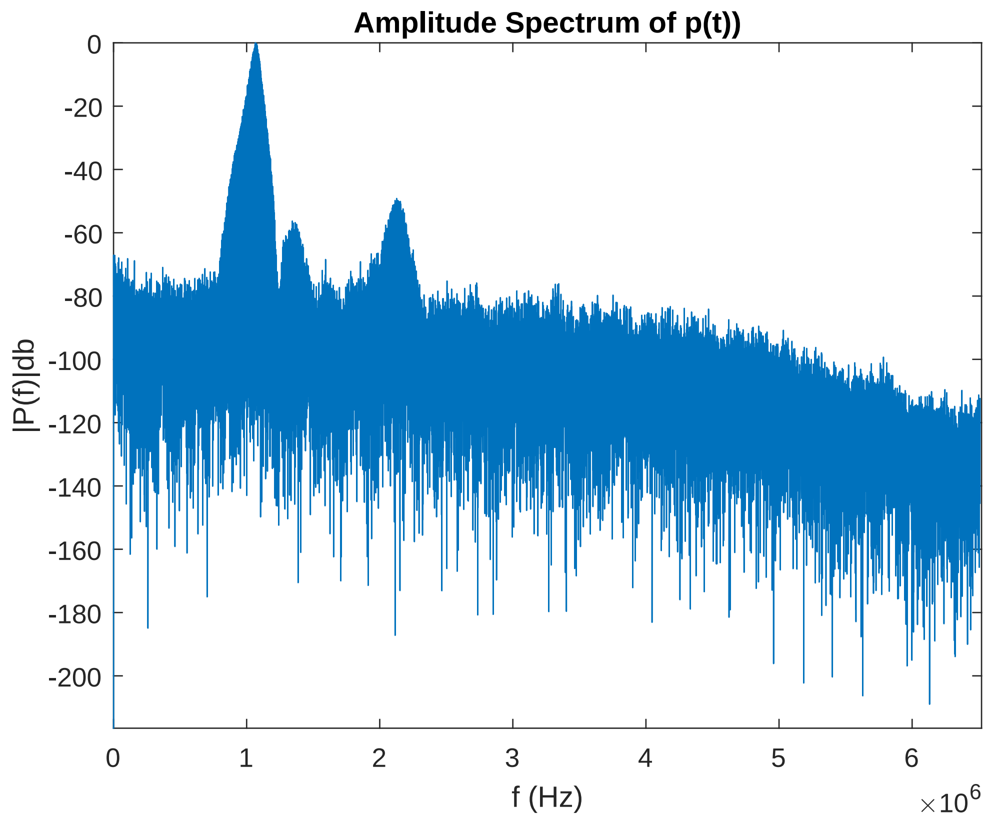
Given $p(t)$ the hydrophone signal as function of time, its amplitude spectrum in decibels is obtained by:

$P(f)_{dB} = 20 \cdot log(|FFT(p(t))|)$

where FFT is the Fast Fourier Transform of the signal. In Matlab:

```
dt = t(2)-t(1);     % time step
fs = 1/dt;      % sampling frequency
L = length(p);     % length of the signal
```

```
P = abs(fft(p-mean(p)));  % fft of the signal
P = P(1:L/2+1);     % we only take the first half of the fft.
f = [1:L]*fs/L;     % frequency vector
f = f(1:L/2+1);
P  = 20*log10(P/max(P));  % amplitude spectrum normalized by its maximum

figure
plot(f,P)
title('Amplitude Spectrum of p(t))')
xlabel('f (Hz)')
ylabel('|P(f)|dB')
```



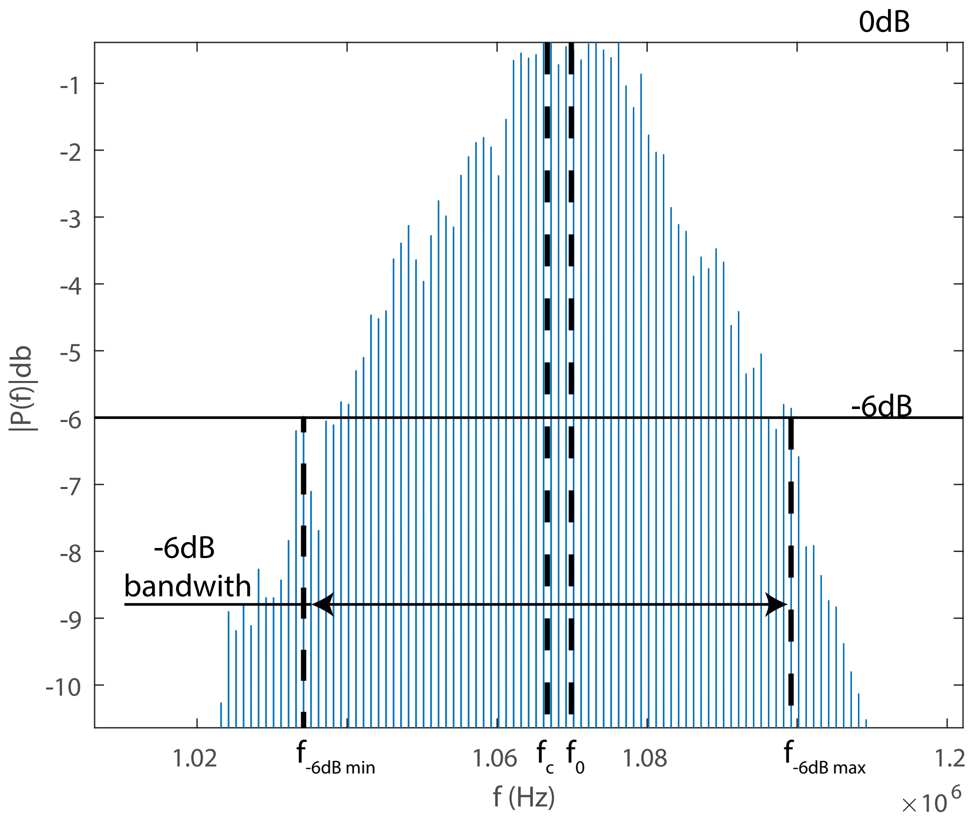
(e) **What is the -6dB bandwidth of the burst? 2p**

(f) **What is the peak frequency of the amplitude spectrum? 1p**

(g) **What is the center frequency of the amplitude spectrum? 1p**

(h) **What is the approx. maximum frequency of the amplitude spectrum? 1p**

The **-6dB bandwith** is the frequency range in which the amplitude spectrum of the signal is greater than -6dB. The **peak frequency** f_0 is the **frequency** at which the maximum of the amplitude spectrum occurs. The **center frequency** is given by: $f_c = (f_{-6dBmin} + f_{-6dBmax})/2$. The **maximum frequency** is the highest frequency above which there is only noise.



In Matlab:

```
figure
plot(f,P)
title('Amplitude Spectrum of p(t))')
xlabel('f (Hz)')
ylabel('|P(f)|dB')

% e)
b_6dB = f(find(P>-6));
b_6dB = [b_6dB(1), b_6dB(end)];

%f)
peak_f = f(find(P==max(P)));

%g)
center_f = sum(b_6dB)/2;

%h) max_freq = 3MHz;
```

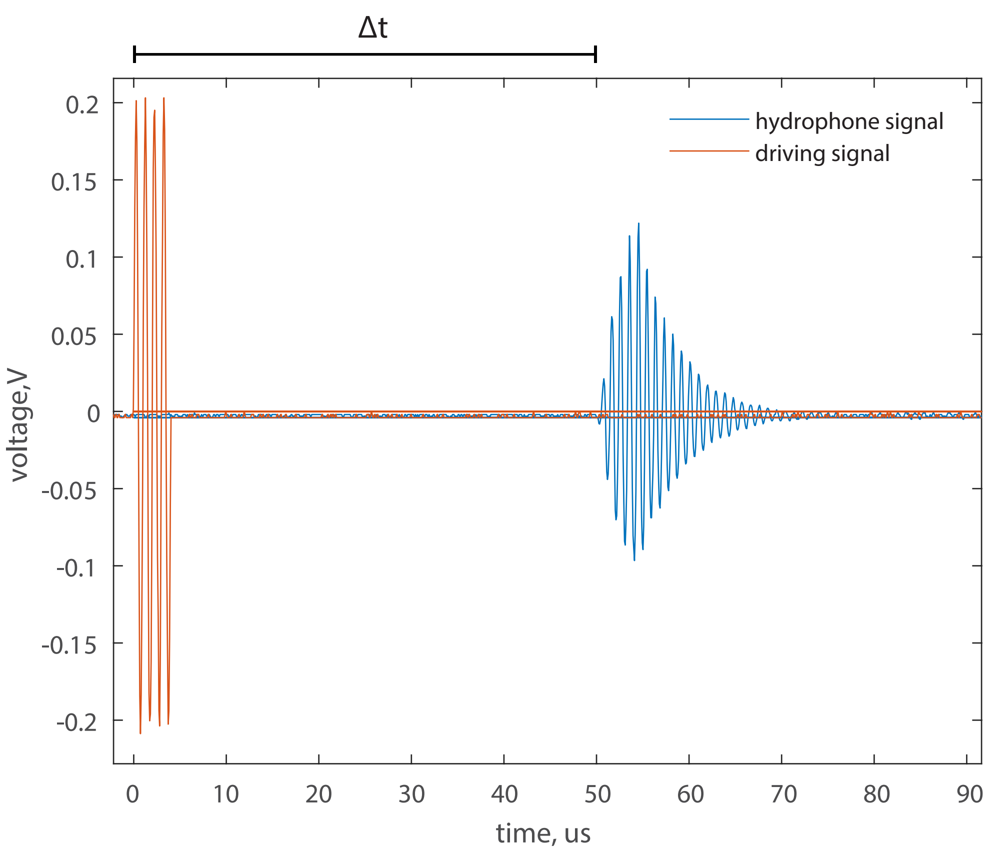
$f_{-6dBmin} = 1.0062\,\text{MHz}$
$f_{-6dBmax} = 1.1182\,\text{MHz}$
$f_0 = 1.0662\,\text{MHz}$
$f_c = 1.0622\,\text{MHz}$
$f_{max} \approx 3\,\text{MHz}$

2. Speed of sound in water (5p)

(a) **What is the time that takes for the pulse to travel from the transducer to hydrophone? 1p**

(b) **b) Considering the hydrophone is at the geometric focus of a spherical bowl transducer (aperture = 60 mm, R = 75 mm), what is the speed of sound in water? 2p**

The time travel can be measured from the graph, by taking the time interval between the beginning of the two signals.



Considering $\Delta t = 50.26\,\mu s$, the speed of sound in water is measured as:

$c = \frac{R}{\Delta t} = 1492.2\,\mathrm{m\,s^{-1}}$

(c) **What must be the temperature of the water considering it is distilled water? 2p**

To answer this question we would need to know what is the relationship between the of speed of sound in distilled water and the temperature, $c_w = f(T_w)$.

Temperature, in °C	Speed, in m/sec	Temperature, in °C	Speed, in m/sec
14.277	1463.75	39.889	1529.27
15.900	1469.57	40.457	1530.13
17.234	1473.98	47.515	1540.32
19.184	1480.27	49.112	1542.00
20.619	1484.65	60.552	1551.94
23.935	1493.19	66.226	1554.49
26.935	1502.10	74.585	1555.78
35.941	1522.17	95.044	1547.80

From the experimental values in the table above, that can be found in literature, we can obtain the temperature by interpolating the missing data.

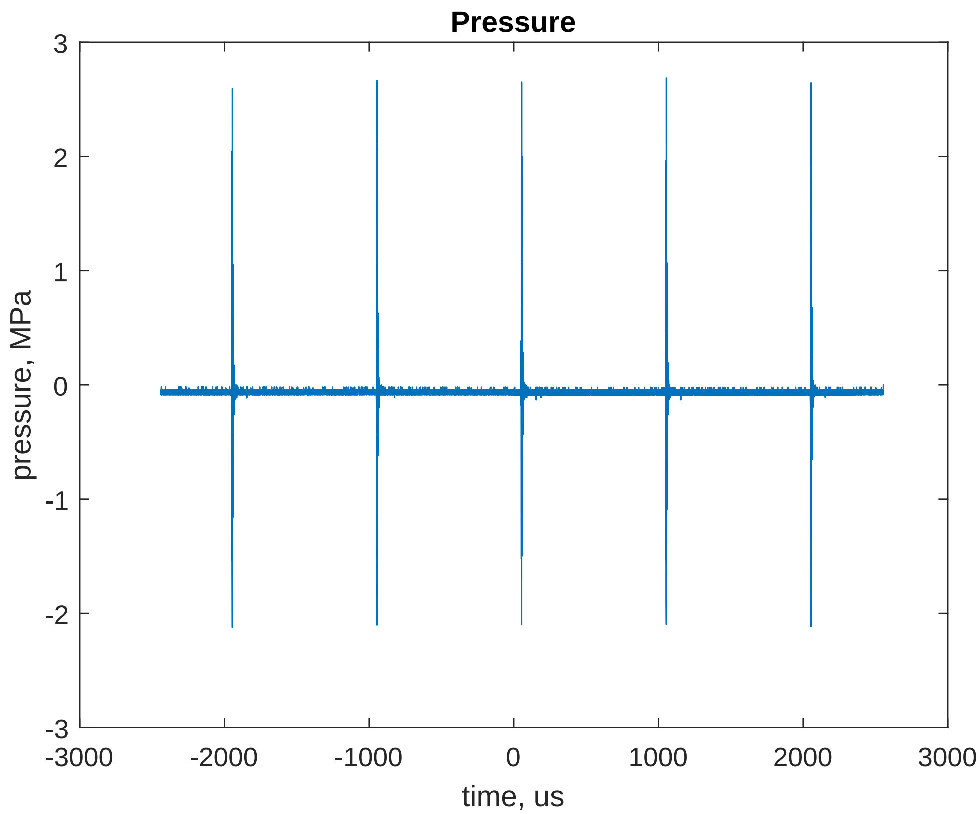
```
%% Speed of sound in water (5p)
figure
plot(t,p,t,v)
xlabel('time, us')
ylabel('voltage,V')
legend('hydrophone signal','driving signal')
%a)
t_travel = 50.26*1e-6;

%b)
R = 75*1e-3 ; %m
c = R/t_travel; %m/s

%c) %from 'Measuring the speed of sound in distilled water, S. S. Sekoyan'

T1 = 20.619;  %celsius
T2 = 23.935 ;

v1 = 1484.65 ; %m/s
v2 = 1493.19 ; %m/s

% y = m*x+q
m = (T2-T1)/(v2-v1);
q = T1-m*v1;
T_w = m*c + q;
```

$T_w = 23.57\,°\mathrm{C}$

Pressure and intensity measures of an ultrasound burst (15p)

(a) **Convert the pressure signal to MPa and present it as a function of time (μs). Use the frequency information presented in task 1 and table below. 2p**

The hydrophone signal can be easily converted to Mpa by dividing it by the sensitivity. The peak frequency of the signal is $\approx 1\,\mathrm{MHz}$, so a sensitivity of $46\,\mathrm{mV/MPa}$ can be chosen.



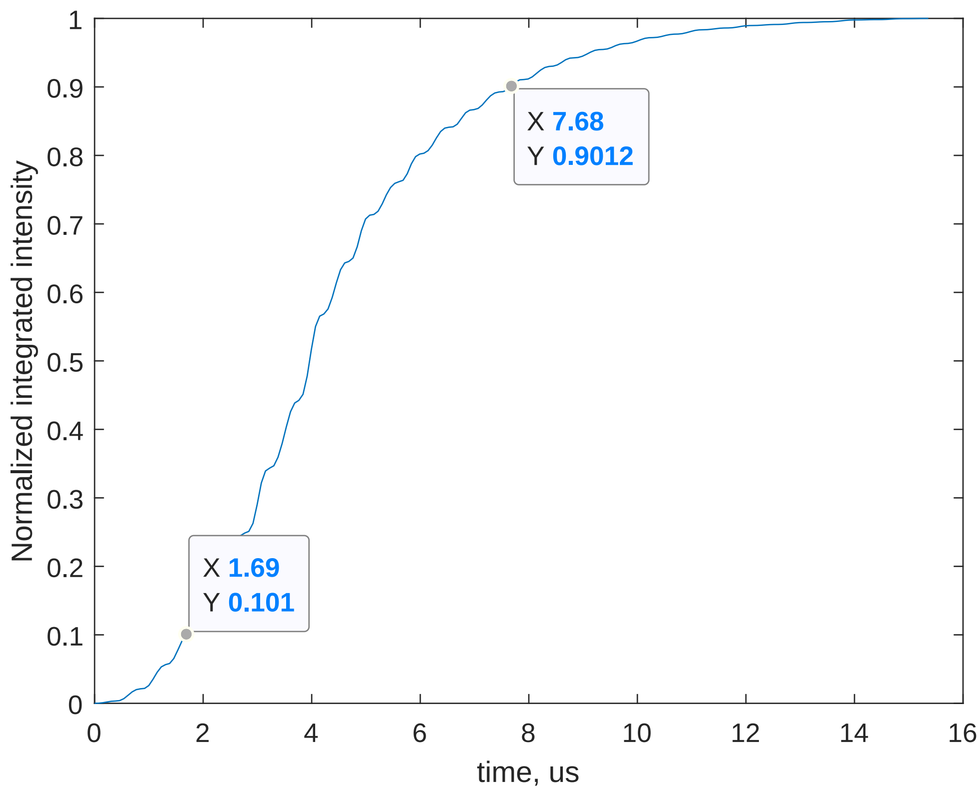
(b) **What is the PPP? 1p**

(c) **What is the PNP? 1p**

PPP and **PNP** are respectively the golbal maximum and global minimum of the signal.

$PPP = 2.69\,\mathrm{MPa}$
$PNP = 2.12\,\mathrm{MPa}$

Pulse duration **PD** is calculated as 1.25x the interval between 10% and 90% points in the intensity integral.




```
%d)
pulse_start_indx  = 32450; %from the graph
pulse_end_indx  = 32650;

I_int = cumtrapz(t(pulse_start_indx:pulse_end_indx),p2(pulse_start_indx:
    pulse_end_indx).^2); %intensity integral over the pulse duration

figure
plot(t(pulse_start_indx:pulse_end_indx)*1e6-t(pulse_start_indx)*1e6,I_int/
    max(I_int))
xlabel('time, us')
ylabel('Normalized integrated intensity')

t1 = find(I_int>0.1*I_int(end),1);
t2 = find(I_int>0.9*I_int(end),1);

PD = (t2-t1)*dt*1.25;
```

$PD = 7.49\,\mu s$

(d) **What is the instantaneous intensity at PPP? 1p**

(e) **What is the instantaneous intensity at PNP? 1p** The istantaneous intensity at PPP, also called I_{SPTP} (spatial peak temporal peak intensity), is calculated as $I_{PPP} = \frac{PPP^2}{\rho c}$. In an analogous way the istantaneous intensity at PNP can be also calculated.

$I_{PPP} = 484.3\,\mathrm{W\,cm^{-2}}$
$I_{PNP} = 302.6\,\mathrm{W\,cm^{-2}}$

(f) **What is the ISPPA (Spatial Peak, Pulse Average) of the signal? 3p**

(g) **What is the ISPTA (Spatial Peak, Time Average) of the signal? 3p**

(h) **What is the duty cycle of your pressure signal? 1p**

I_{SPPA} is is the average intensity during the pulse: $I_{SPPA} = \frac{1}{PD}\int_{t_1}^{t_2} \frac{p(t)^2}{\rho c} dt$. You can get the I_{SPTA} by multiplying the pulse average by duty cycle: $I_{SPTA} = I_{SPPA} \cdot DC = I_{SPPA} \cdot \frac{PD}{PRP}$.

```
%e)
I_PPP =  (PPP)^2/( rho *c )/1e4;  %W/cm2

%f)
I_PNP =  (PNP)^2/( rho *c )/1e4;  %W/cm2

%g)
I_sppa = I_int(end)/( rho *c )/PD/1e4;  %W/cm2

%h)
I_spta = I_int(end)/( rho *c )/PRP/1e4;  %W/cm2
```

$I_{SPPA} = 115.6\,\mathrm{W\,cm^{-2}}$
$I_{SPPA} = 0.9\,\mathrm{W\,cm^{-2}}$
$DC = 0.75\%$

(i) **What is the duty cycle of the driving signal? 1p**

In the same way we first measure the **PRP** and the **PD** fro the driving signal graphs, then the ducty cycle can be measured as $DC = \frac{PD}{PRP} \cdot 100$

$DC_{drivingsignal} = 0.40\%$