

```
clear all
format compact
imatlab_export_fig('print-svg') % Static svg figures.
```

Worksheet 3

To accompany Chapter 2 Elementary Signals

Colophon

This worksheet can be downloaded as a [PDF file](#).

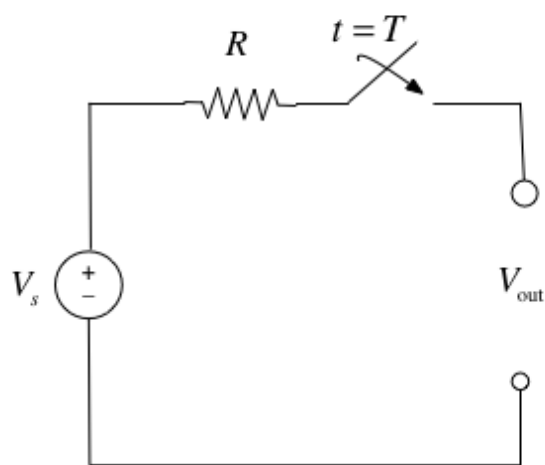
A printout of this worksheet will be distributed before the first class meeting in the **Week 1: Classroom Activities** section of the Canvas site. I will also distribute a copy to your personal **Worksheets** section of the **OneNote Class Notebook** so that you can add your own notes using OneNote.

You are expected to have at least watched the video presentation of [Chapter 2](#) of the [notes](#) before coming to the first class. If you haven't watch it afterwards!

After class, the lecture recording and the annotated version of this worksheet will be made available to you via OneNote and through Canvas.

Elementary Signals

Consider the network shown in below where the switch is closed at time $t = T$ and all components are ideal.



Express the output voltage V_{out} as a function of the unit step function, and sketch the appropriate waveform.

Q1: What happens **before** $t = T$?

1. $v_{out} = \text{undefined}$
2. $v_{out} = 0$
3. $v_{out} = V_s$
4. $v_{out} = V_s/2$
5. $v_{out} = \infty$

-> **Open Poll: 1.2.1**

Q2: What happens **after** $t = T$?

1. $v_{out} = \text{undefined}$
2. $v_{out} = 0$
3. $v_{out} = V_s$
4. $v_{out} = V_s/2$
5. $v_{out} = \infty$

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-> Open Poll: 1.2.2

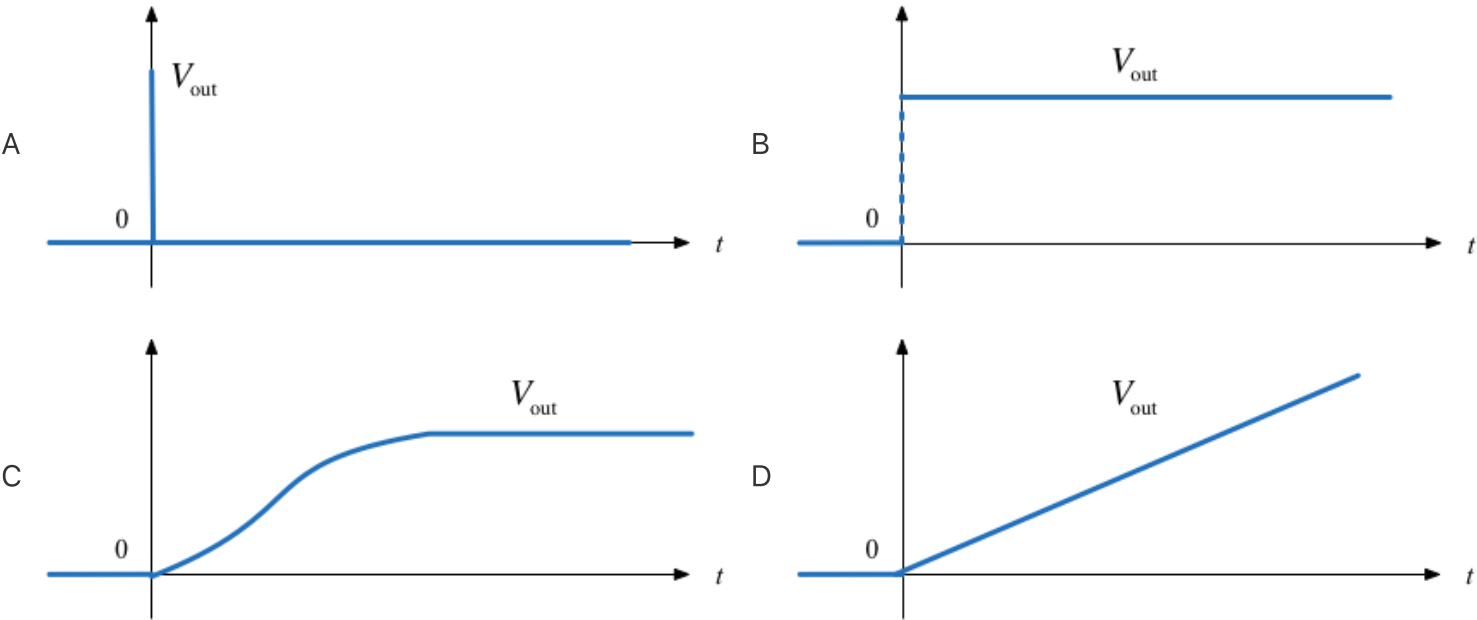
Q3: What happens **at** $t = T$?

- 1. $v_{\text{out}} = \text{undefined}$
- 2. $v_{\text{out}} = 0$
- 3. $v_{\text{out}} = V_s$
- 4. $v_{\text{out}} = V_s/2$
- 5. $v_{\text{out}} = \infty$

-> Open Poll: 1.2.3

Q4: What does the response of V_{out} look like?

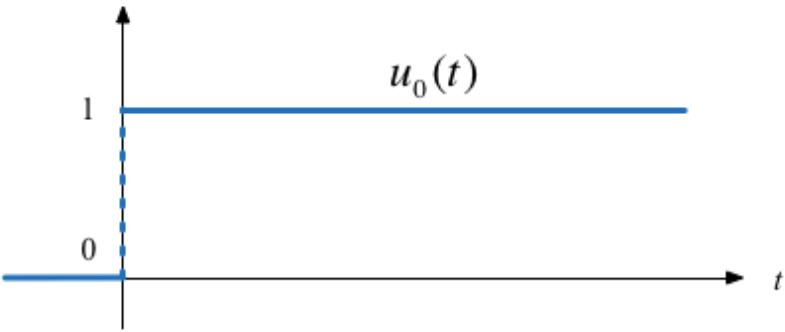
Circle the picture you think is correct on your handout.



-> Open Poll: 1.2.4

The Unit Step Function

$$u_0(t) = \begin{cases} 0 & t < 0 \\ 1 & t > 0 \end{cases}$$



In Matlab

In Matlab, we use the **heaviside** function (Named after [Oliver Heaviside](#)).

```
syms t
ezplot(heaviside(t), [-1,1])
heaviside(0)
```

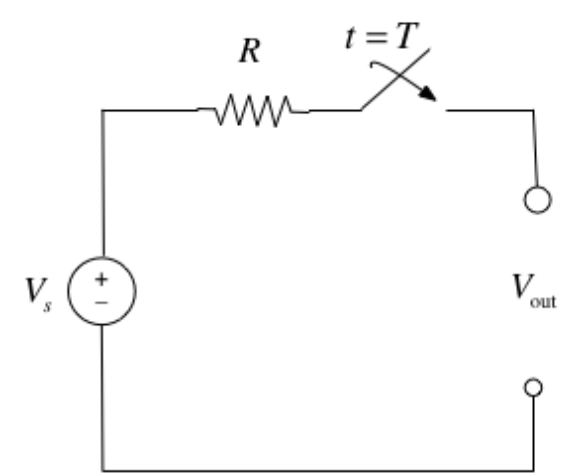
See: [show heaviside.m](#).

Note that, so it can be plotted, Matlab defines the *heaviside function* slightly differently from the mathematically ideal unit step:

$$\text{heaviside}(t) = \begin{cases} 0 & t < 0 \\ 1/2 & t = 0 \\ 1 & t > 0 \end{cases}$$

Circuit Revisited

Consider the network shown below, where the switch is closed at time $t = T$.



Express the output voltage v_{out} as a function of the unit step function, and sketch the appropriate waveform.



Simple Signal Operations

Amplitude Scaling

Sketch $Au_0(t)$ and $-Au_0(t)$



Time Reversal

Sketch $u_0(-t)$

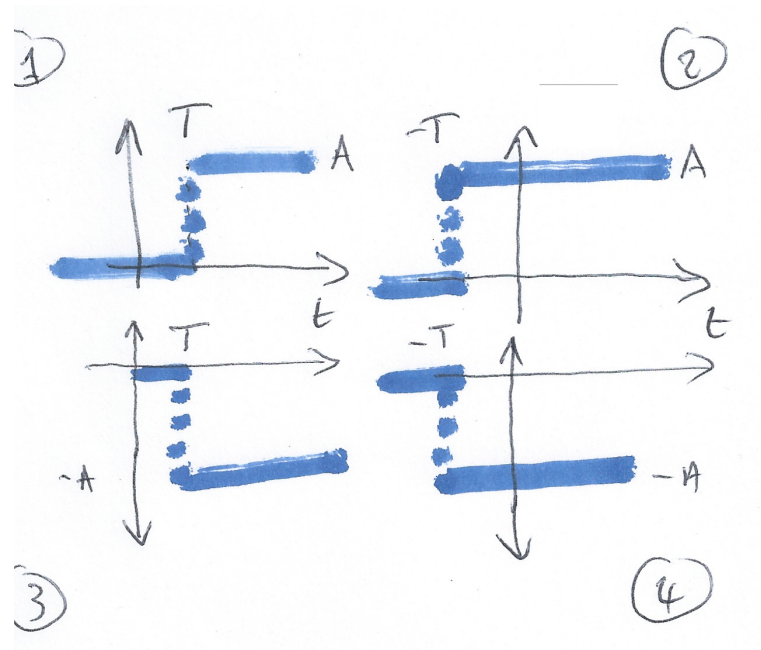
Time Delay and Advance

Sketch $u_0(t - T)$ and $u_0(t + T)$

Examples

Example 1

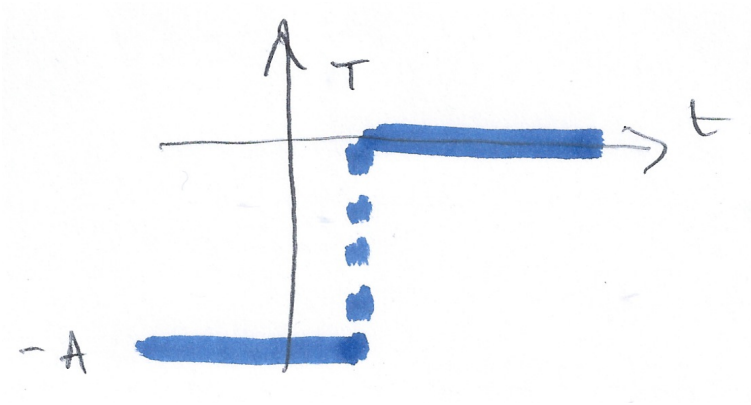
Which of these signals represents $-Au_0(t + T)$?



-> Open Poll: 1.2.5

Example 2

What is represented by



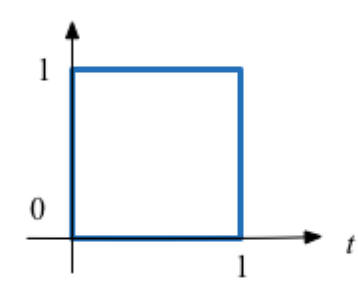
- 1. $-Au_0(t + T)$
- 2. $-Au_0(-t + T)$
- 3. $-Au_0(-t - T)$
- 4. $-Au_0(t - T)$

-> Open Poll: 1.2.6

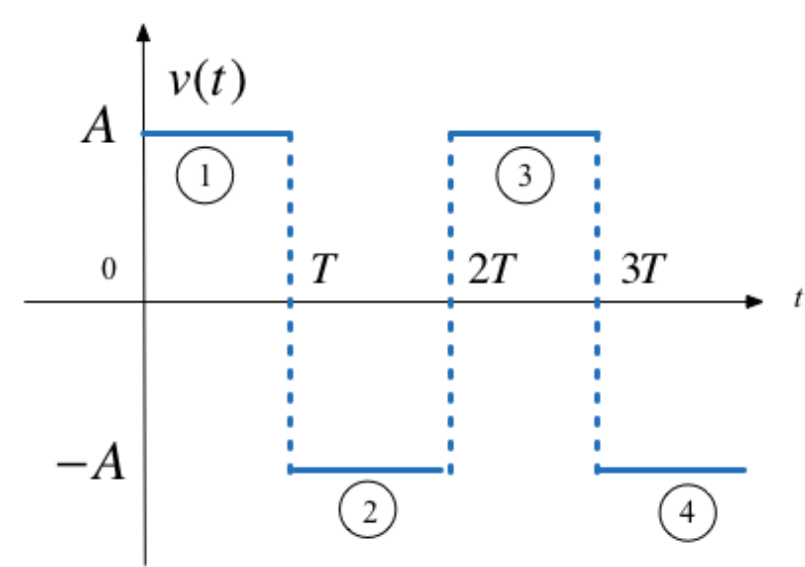
Synthesis of Signals from Unit Step

Unit step functions can be used to represent other time-varying functions such as rectangular pulses, square waves and triangular pulses.

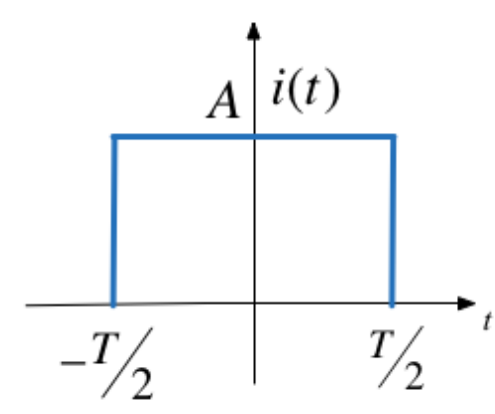
Synthesize Rectangular Pulse



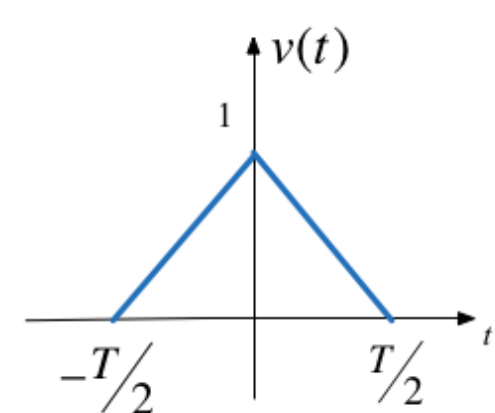
Synthesize Square Wave



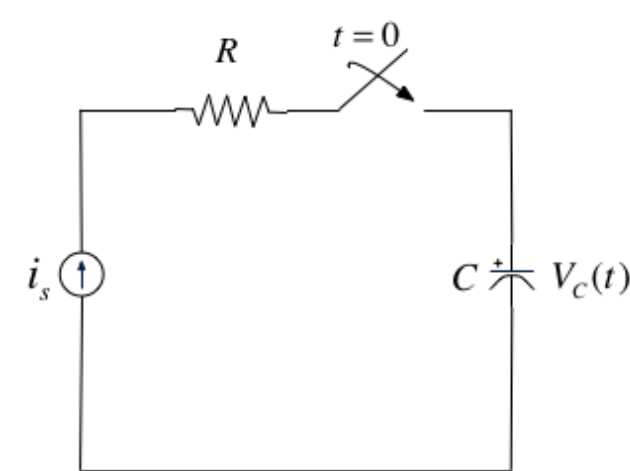
Synthesize Symmetric Rectangular Pulse



Synthesize Symmetric Triangular Pulse



The Ramp Function



In the circuit shown above i_s is a constant current source and the switch is closed at time $t = 0$.

Show that the voltage across the capacitor can be represented as

$$v_C(t) = \frac{i_s}{C} t u_0(t)$$

and sketch the wave form.



The unit ramp function is defined as

$$u_1(t) = \int_{-\infty}^t u_0(\tau) d\tau$$

so

$$u_1(t) = \begin{cases} 0 & t < 0 \\ t & t \geq 0 \end{cases}$$

and

$$u_0(t) = \frac{d}{dt} u_1(t)$$

Note

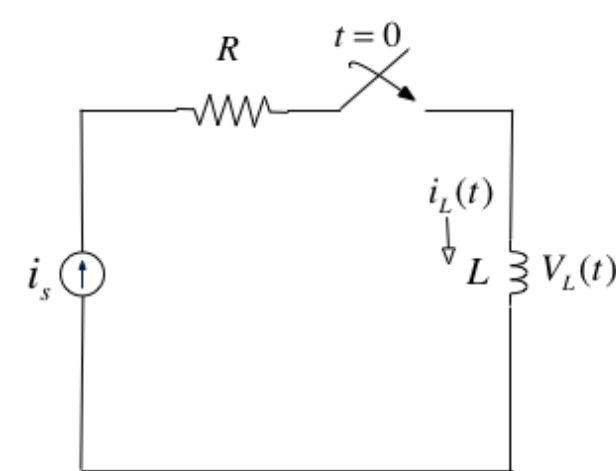
Higher order functions of t can be generated by the repeated integration of the unit step function.

For future reference, you should determine $u_2(t)$, $u_3(t)$ and $u_n(t)$ for yourself and make a note of the general rule:

$$u_{n-1} = \frac{1}{n} \frac{d}{dt} u_n(t)$$

Details are given in equations 1.26—1.29 in the textbook.

The Dirac Delta Function



In the circuit shown above, the switch is closed at time $t = 0$ and $i_L(t) = 0$ for $t < 0$. Express the inductor current $i_L(t)$ in terms of the unit step function and hence derive an expression for $v_L(t)$.

Notes

To solve this problem we need to invent a function that represents the derivative of the unit step function. This function is called $\delta(t)$ or the *dirac delta* function (named after [Paul Dirac](#)).

The delta function

The unit impulse or the delta function, denoted as $\delta(t)$, is the derivative of the unit step.

This function is tricky because $u_0(t)$ is discontinuous at $t = 0$ but it must have the properties

$$\int_{-\infty}^t \delta(\tau) d\tau = u_0(t)$$

and

$\delta(t) = 0$ for all $t \neq 0$.

Sketch of the delta function



Important properties of the delta function

See the accompanying [notes](#).

Examples

Example 3

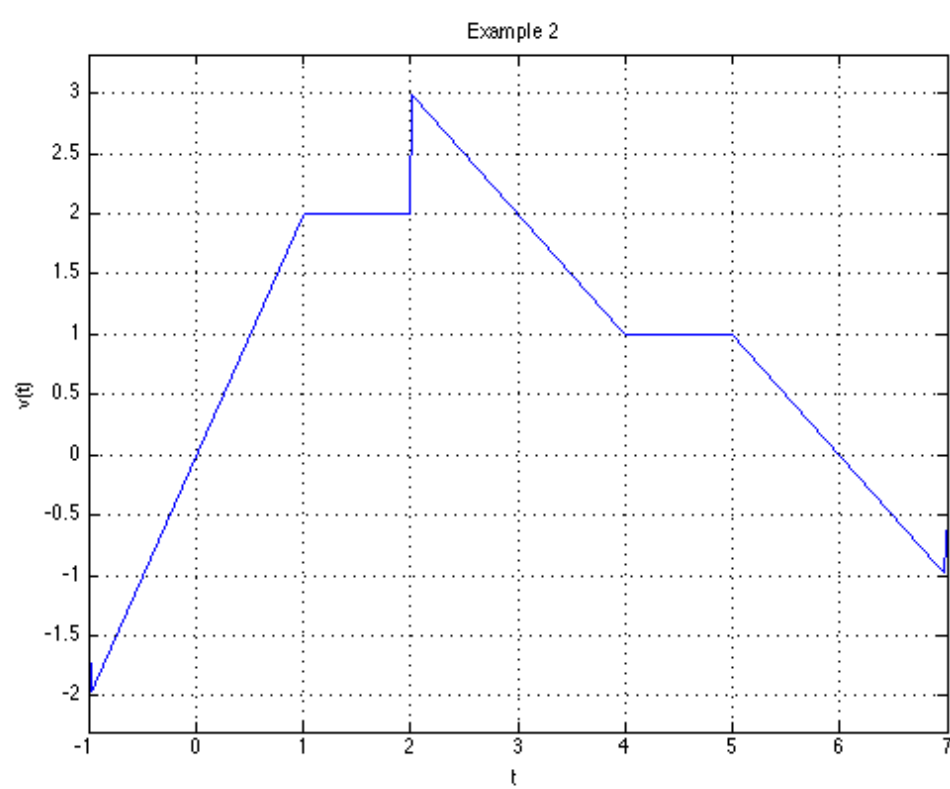
Evaluate the following expressions

$$3t^4 \delta(t - 1)$$

$$\int_{-\infty}^{\infty} t\delta(t-2)dt$$

$$t^2\delta'(t-3)$$

Example 4



(1) Express the voltage waveform $v(t)$ shown above as a sum of unit step functions for the time interval $-1 < t < 7$ s

Using the result of part (1), compute the derivative of $v(t)$ and sketch its waveform.

Lab Work

In the first lab, next Tuesday, we will solve further elementary signals problems using MATLAB and Simulink following the procedure given between pages 1-17 and 1-22 of the Karris. We will also explore the **heaviside** and **dirac** functions.

Answers to in-class questions

Mathematically

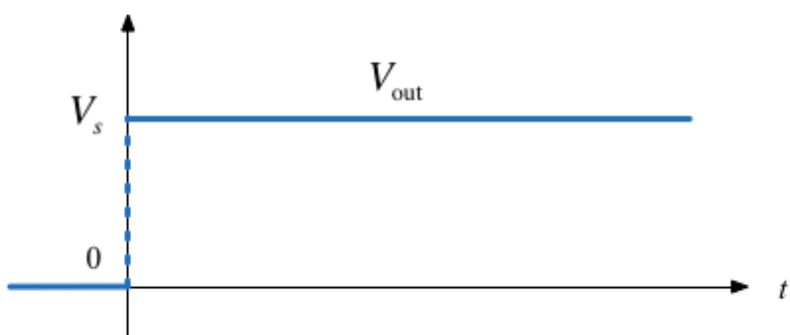
Q1. $v_{\text{out}} = 0$ when $-\infty < t < 0$ (answer 2)

Q2. $v_{\text{out}} = V_s$ when $0 < t < \infty$ (answer 3)

Q3. $v_{\text{out}} = \text{undefined}$ when $t = 0$ (answer 1)

V_{out} jumps from 0 to V_s instantaneously when the switch is closed. We call this a discontinuous signal!

Q4: The correct image is:



Example 1: Answer 3.

Example 2: Answer 2.

By Dr Chris P. Jobling

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