# System Response Using MATLAB Simulink

## 1.1 The notion of system. General properties of systems.

The term system is a notion that covers an extremely wide variety of objects or processes that take an input signal, transform it, and then further transmit the processed signal as an output signal, also called the system's response to the input signal; thus, the system is a functional block that has one (or more) inputs and one (or more) outputs. These signals can be several types of quantities, not necessarily all of the same type, including electrical quantities such as instantaneous voltage, current or power, thermal quantities such as temperature or heat, mechanical quantities such as force or pressure, and information -quantities measured in bits. Next, we consider systems with one input and one output, both electrical quantities, as shown in Fig. 1.

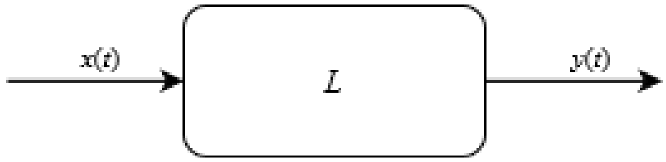



Fig. 1 – General diagram of a system with one input and one output

Systems can be further characterized by certain general properties. Causality refers to the temporal sequence of events; in the case of a causal system, the output signal will only change as a result of a change in the input signal, a behavior described mathematically in Eq. (1). Linearity refers to the linear behavior of the system relative to the input and output signals; if the input signal can be linearly decomposed into multiple elementary signals, then the system's response to the composite signal will be the same linear combination of the responses to the elementary signals, as described in Eq. (2). Time invariance refers to the fact that the initial time at which the application of the signals begins does not affect the behavior of the system, the behavior modeled in Eq. (3). Stability is perhaps one of the most important characteristics of a system for an electronics engineer, referring to the property of the system to produce a response bounded in amplitude for a bounded input signal, as seen in Eq. (4); the lack of this characteristic in a system can lead to nonlinearities, unwanted oscillations, or even destruction of the circuit.

| | | |
|---|---|---|
| Causality | $x(t)=0 \quad \forall t<0 \;\; => \;\; y(t)=0 \quad \forall t<0$ | (1) |
| Linearity | $x(t)=\alpha_1 x_1(t)+\alpha_2 x_2(t) \;\; => \;\; y(t)=\alpha_1 y_1(t)+\alpha_2 y_2(t)$ | (2) |
| Time invariance | $x(t-t_0)\xrightarrow{L} y(t-t_0) \quad \forall t_0 \in \mathbb{R}$ | (3) |
| Stability | $\lvert x(t)\rvert < M_x < \infty \;\; => \;\; \lvert y(t)\rvert < M_y < \infty$ | (4) |

Depending on the type of input and output signals, systems can be further divided into analog and digital systems. Analog systems are generally made up of diports, electronic circuits with an input gate and an output gate that use both passive components such as resistors, capacitors and inductors, and active components such as transistors or operational amplifiers. Digital systems are generally implemented using either digital circuits, in the form of ASIC integrated components or synthesized on FPGAs, or using algorithms running on microcontrollers or digital signal processors, and require an interface consisting of digital-to-analog and analog-to-digital converters to interact with the physical domain.

Examples of systems that satisfy all of the above properties and are common in electronics and telecommunications are filters, amplifiers, audio equalizers, phase shifters, integrators, shifters and delay circuits.

### 1.2 Modeling system response.

In the case of analog, linear, time-invariant systems, the relationship between the input and output signals can be modeled extremely easily by means of a transfer function H(ω), as shown in Eq. (5). In the time domain, the same relationship can be modeled by convolving the input signal with a weight function h(t), which is the Fourier pair of the transfer function; the time relationship between the response of a system and the input signal is given by Eq. (6).

$$Y(\omega) = H(\omega) X(\omega) \qquad (5)$$

$$y(t) = h(t) * x(t) \qquad (6)$$

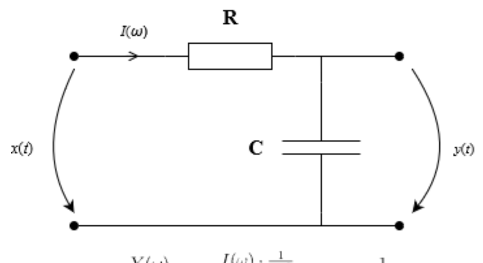
From Eq. (5), bearing in mind that the Fourier transform of a signal is a complex quantity, it can be seen that the amplitude of each spectral component of the input signal will be scaled by the modulus of the transfer function at that frequency, as shown in Eq. (7), and to the phase of each spectral component will be added a phase shift represented by the argument of the transfer function at that frequency, as seen in Eq. (8).

$$|Y(\omega)| = |H(\omega)| \cdot |X(\omega)| \qquad (5)$$

$$\varphi_Y(\omega) = \varphi_X(\omega) + \arg\{H(\omega)\} \qquad (6)$$

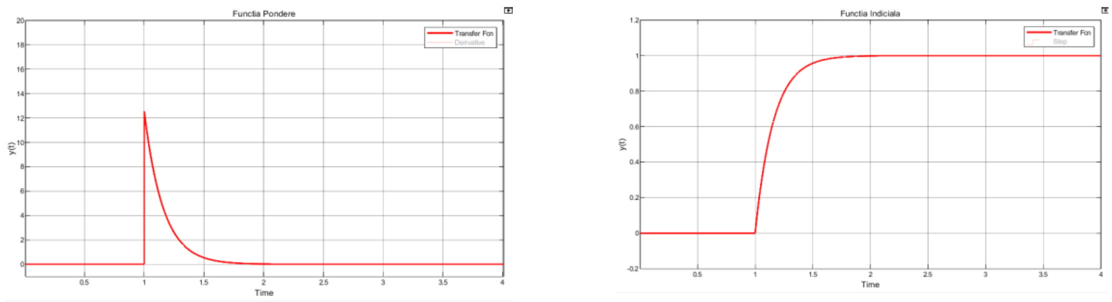
There are also certain input signals whose responses carry special status, since they model very well the transient response of a system. The first of these responses is the weight function h(t) itself, which represents the response of the system to the Dirac impulse x(t) = δ(t), and is useful for modeling short-time perturbations at the input of the system. The second is the index function a(t), which represents the system response to the unit step function $x(t) = \sigma(t) = u(t) = \int_{-\infty}^{t} \delta(\tau) d\tau \approx \begin{cases} 0 & ; \ t < 0 \\ 1 & ; \ t \geq 0 \end{cases}$, being useful for modeling system response to low-frequency rectangular signals, for modeling a spontaneous change in the DC component of a signal, and similar transient phenomena.

For example, in the system represented by the RC circuit in Fig. 2, the weight function and the index function are plotted in Fig. 3.




$$H(\omega) = \frac{Y(\omega)}{X(\omega)} = \frac{I(\omega) \cdot \frac{1}{j\omega C}}{I(\omega) \cdot (R + \frac{1}{j\omega C})} = \frac{1}{1 + j\omega RC}$$

Fig. 2 – RC circuit in gamma topology (1st order low-pass filter)




(a) (b)

Fig. 3 – Weight function (a) and index function (b) for RC circuit in gamma topology (FTJ ord. 1)

A consequence of Eq. (5) and (6) for periodic signals is the so-called **harmonic method**. Since the Fourier transform of any periodic signal can be written according to Eq. (7), the terms akc being the coefficients of the Exponential Fourier Series for the periodic signal under analysis and ω0 being the fundamental pulse of the periodic signal, from the probing property of the Dirac delta Dirac pulses and relation (5) results in relation (8). This being similar to relation (7), from Eq. (8) one can extract the Exponential Fourier Exponential Series terms for the output signal y(t), as seen in Eq. (9). Consequently, the modulus and phase of each harmonic of a periodic signal are found in Eq. (10) and (11).

$$X(\omega) = \sum_{k=-\infty}^{\infty} a_{kc} \cdot 2\pi \cdot \delta(\omega - k\omega_0) \tag{7}$$

$$Y(\omega) = \sum_{k=-\infty}^{\infty} H(k\omega_0) \cdot a_{kc} \cdot 2\pi \cdot \delta(\omega - k\omega_0) \tag{8}$$

$$a_{kc\_y(t)} = H(k\omega_0) \cdot a_{kc\_x(t)} \tag{9}$$

$$A_{k\_y(t)} = |H(k\omega_0)| A_{k\_x(t)} \tag{10}$$

$$\varphi_{k\_y(t)} = \varphi_{k\_x(t)} + \arg\{H(k\omega_0)\} \tag{11}$$

## 1.2 Using MATLAB Simulink.

MATLAB Simulink is a graphical programming interface used for modeling and simulating dynamic systems. Its interface consists of functional blocks that can be added to the workspace and then interconnected using drag and drop.

To carry out the work, MATLAB R2019 will be used, and the Simulink, Signal Processing Toolbox and DSP System Toolbox utilities will be installed by pressing the Add-Ons button as shown in Fig. 4, and then searching for them. In order to find them faster, one can use the filters in the panel on the left side of the window and select Filter By Source > MathWorks and Filter By Type > Toolboxes and Products, as shown in Fig. 5. Checking the installation of the utilities can be done by clicking on the arrow below the Add-Ons button in Fig. 4 and then selecting Manage Add-Ons, where you can see the installed utilities as shown in Fig. 6.

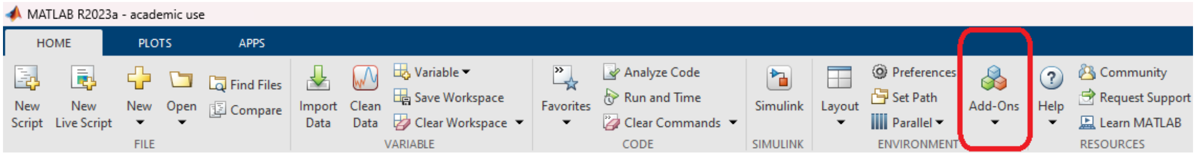
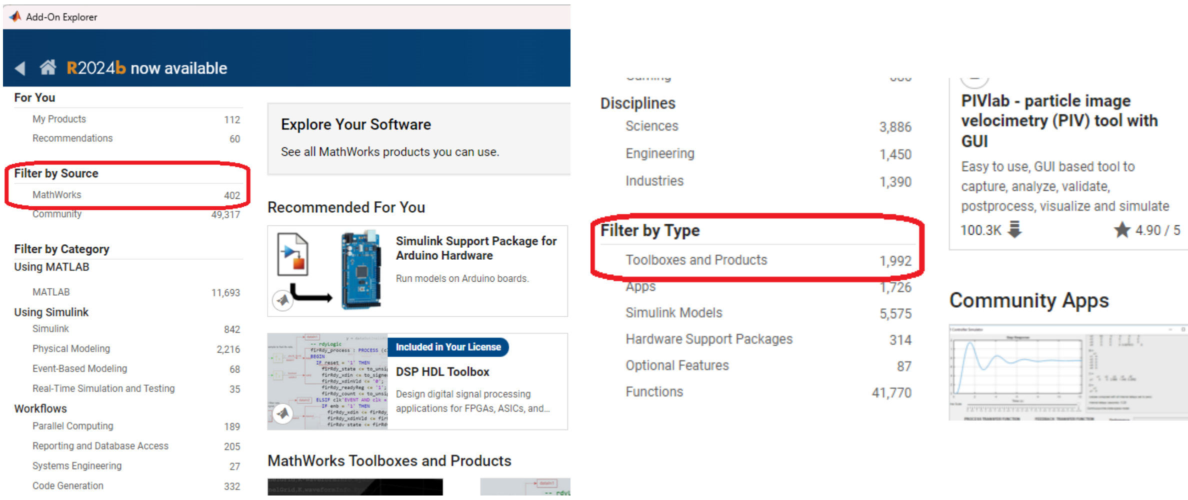



Fig. 4 – Install and manage MATLAB utilities using the Add-Ons button




(a) (b)

Fig. 5 – Selecting filters in Add-On Explorer

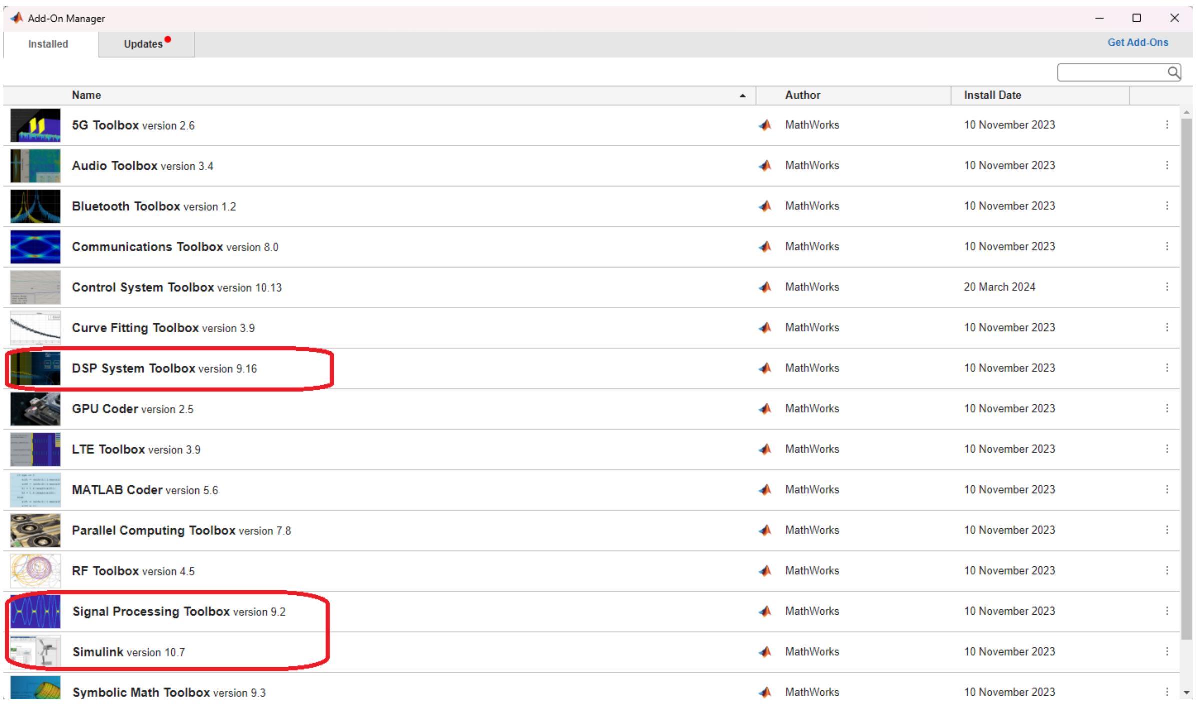



Fig. 6 – View installed utilities in Add-On Manager

To open the Simulink utility, you can click on the button labeled as such in the MATLAB top menu, also shown in Fig. 4, or type the simulink command in the command console. Then create a new model by selecting Simulink > Blank Model in the newly opened window, as shown in Fig. 7.

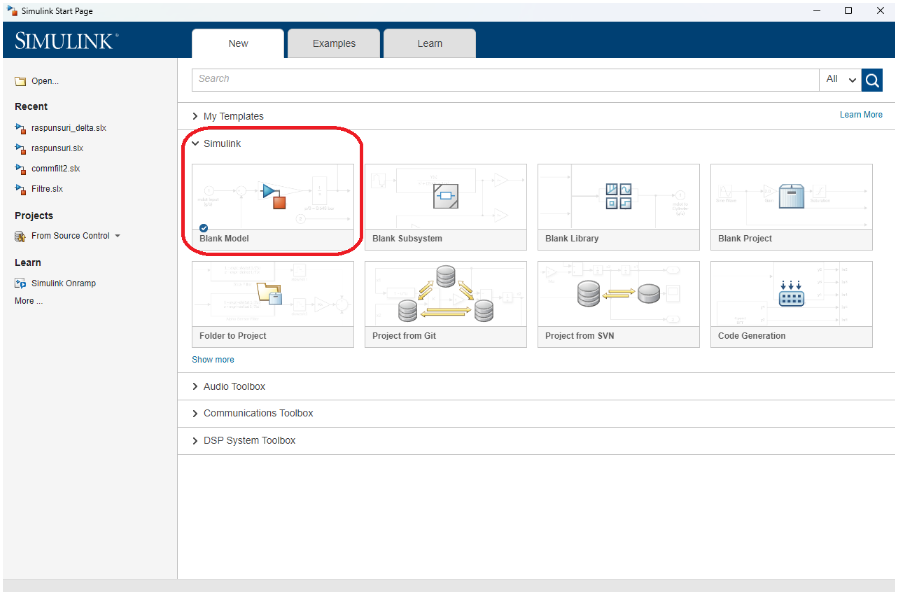



Fig. 7 – Creating a new Simulink model

Before any system can be modeled, Simulink's simulation parameters must be configured so that they have a good enough time resolution to simulate the required system. This can be done from the Model Settings > Solver > Solver Details menu, which can be opened either by using the dedicated button in the Modeling menu, as shown in Fig. 8, or by pressing Ctrl+E. Then, unfolding the Solver Details menu, change the maximum simulation step to 1e-4 (meaning 10-4) and the minimum simulation step to 1e-5 (meaning 10-5), as shown in Fig. 9. The rest of the settings are left unchanged.

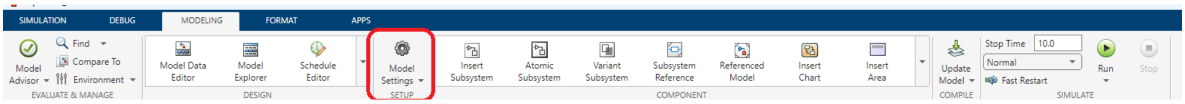



Fig. 8 – Opening the *Model Settings* Menu

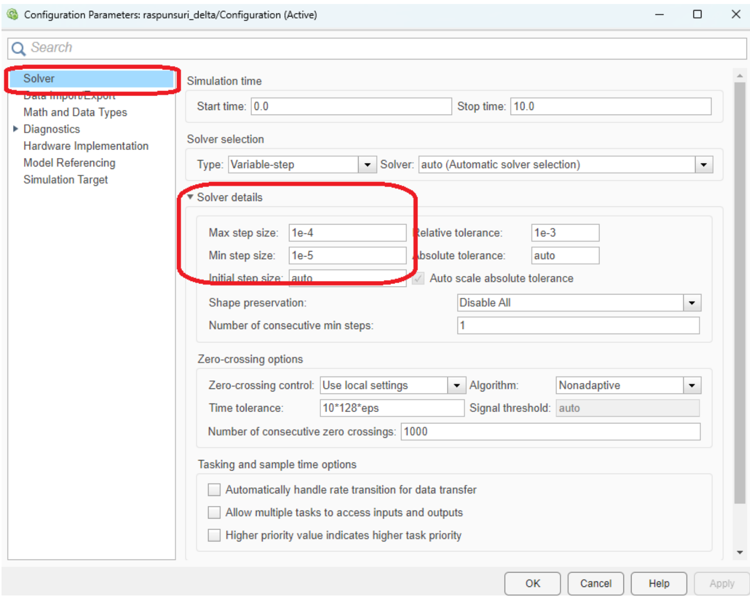



Fig. 9 – Setting the Simulink simulation step

### 1.3 Modeling an RC circuit with FTJ gamma topology in Simulink and evaluating the response for sinusoidal signals.

The RC circuit modeled will be the one represented in Fig. 2. In order to characterize the system, its transfer function must be calculated. From Eq. (5) the relation for the transfer function can be deduced $H(\omega)=\dfrac{Y(\omega)}{X(\omega)}$, and knowing that the two input and output quantities X(ω) and Y(ω) are voltages, they can be rewritten using Ohm's Law as a function of the current I(ω) flowing through both components, resulting in an equation for the transfer function that depends only on the values of the components used in the circuit, as can be seen in Eq. (12).

$$H(\omega)=\frac{Y(\omega)}{X(\omega)}=\frac{I(\omega)\cdot\dfrac{1}{j\omega C}}{I(\omega)\cdot\left(R+\dfrac{1}{j\omega C}\right)}=\frac{1}{1+j\omega RC} \tag{12}$$

Once the transfer function is known, the system can be modeled, as shown in Fig. 10. As a first step, open the component library from the Library Browser menu. Then search in that menu and bring Simulink > Sources > Sine Wave, Simulink > Continuous > Transfer Fcn and two Simulink > Discrete > Zero-Order Holds into the workspace, which will be connected as shown in Fig. 10. To make it easier to find the components, the search menu identified in Fig. 10 by figure 3 can also be used. To connect the components, drag the mouse over the input and output ports of the components, and the arrow that appears is dragged over the port or wire with which the connection is desired.

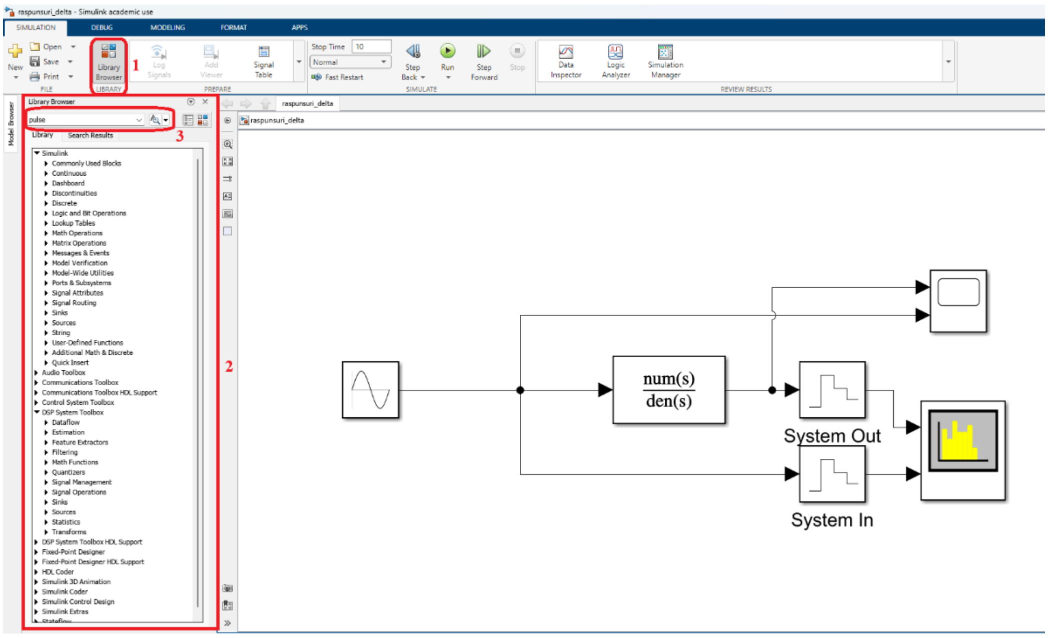



Fig. 10 – Modeling a system in Simulink to evaluate the response to sinusoidal signals

By double-clicking the Sine Wave block, it can be opened, displaying the menu in Fig. 11. Set the input sine input signal pulse as ω = 2π-50 (rad/s) . Double-clicking the Transfer Fcn block will display the menu in Fig. 12, where the transfer function can be set up as a ratio of polynomials, as shown in Eq. (13), using, for convenience, the notation s = jω.

$$H(\omega) = \frac{a_n s^n + a_{n-1} s^{n-1} + \ldots + a_1 s + a_0}{b_n s^n + b_{n-1} s^{n-1} + \ldots + a_1 s + a_0} \tag{13}$$

Consider the value for the constant RC in Eq. (6) as being $\frac{1}{2\pi \cdot 200}$, meaning that in the above expression will be the parameters $a_0 = 1$, $b_1 = \frac{1}{2\pi \cdot 200}$, $b_0 = 1$, values that will be inserted in the configuration menu for Transfer Fcn.

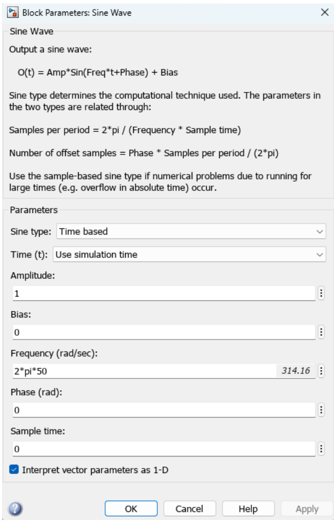



Fig. 11 – *Sine Wave* block configuration

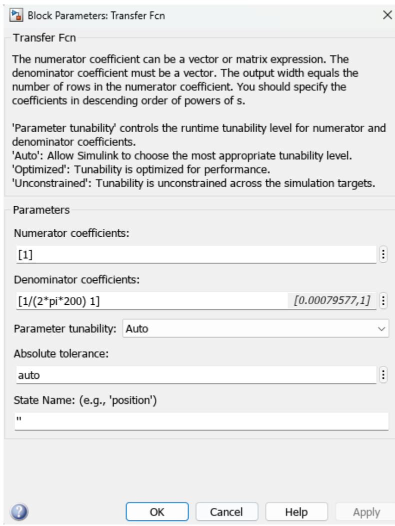



Fig. 12 –*Transfer Fcn* block configuration

To set up the Zero-Order Hold block, open it as in the previous two blocks, and change the only parameter present, the sampling time, to double the maximum sampling step, in our case 2e-4 (or 0.0002). This block represents a sampling circuit found in most digital meters, so we can consider it as a part of the spectrum analyzer to be added. This block is also the way to adjust the frequency band that can be seen with the spectrum analyzer.

To complete the diagram in Fig. 10, the blocks Simulink > Sinks > Scope and DSP System Toolbox > Sinks > Spectrum Analyzer will be added. In order to visualize both the input and output signal, the Scope block must be modified to have 2 inputs. This can be done by opening the block as in the previous blocks, opening a window like the one in Fig. 13, clicking on the cogwheel image labeled 1 in the figure, and in the Main menu changing the Number of input ports from 1 to 2, as shown in Fig. 14.

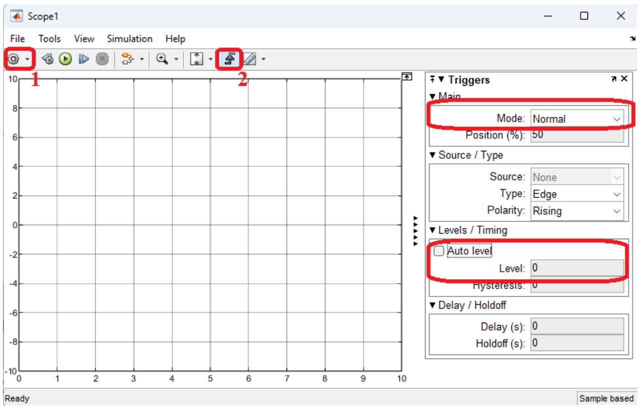



Fig. 13 – *Scope* block interface

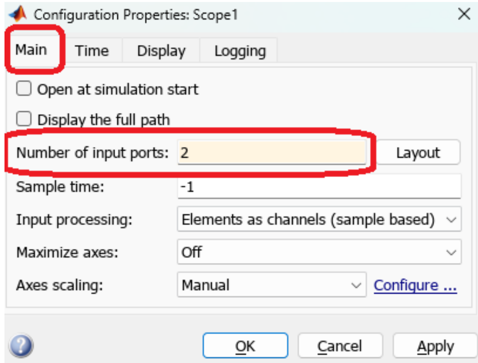
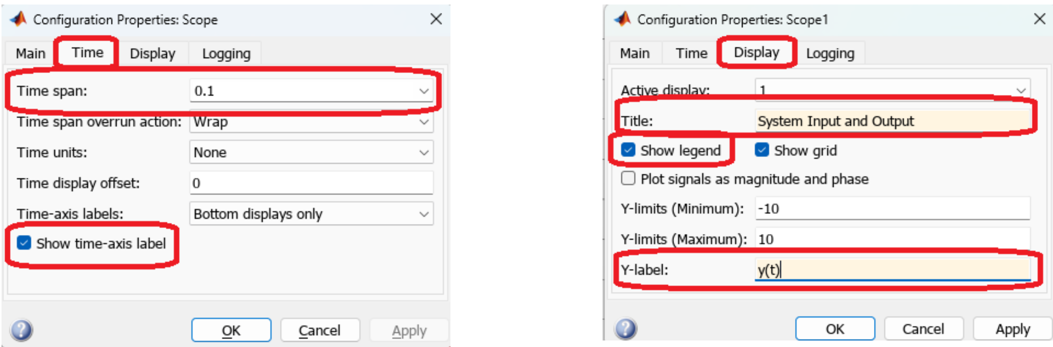



Fig. 14 – Changing the number of Scope block input ports

In the Time menu, change the displayed time interval from Auto to 0.1 and check the Show time-axis label option, as shown in Fig. 15a. In the Display menu, check the Show legend option to display the legend from the virtual oscilloscope; here you can also change both the title of the figure and the name of the vertical axis, as shown in Fig. 15b. Back in the window shown in Fig. 13, click on the trigger button, labeled 2, then change the trigger mode to Normal and set the trigger level to 0, turning off the Auto level function, as shown in the figure.




(a) (b)

Fig. 15 – Setting up the two axes of the Scope block

To configure the Spectrum Analyzer's number of inputs, double-click the Spectrum Analyzer block, then open the block settings from the File > Number of Input Ports menu, as shown in Fig. 16, and change the number of inputs to 2. From the View > Configuration Properties menu, display the legend for the Spectrum Analyzer by selecting the Show legend option.

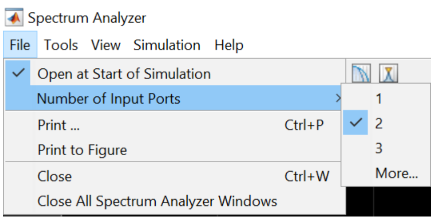



Fig. 16 – Setting the number of inputs for the spectrum analyzer

From this point you can finalize the interconnection of the blocks in Fig. 10, and run the simulation by pressing the Run button. The simulation results can be seen in Fig. 17 and 18. For both the virtual oscilloscope and the virtual spectrum analyzer, you can toggle the display of individual signals on and off from the View > Style menu.

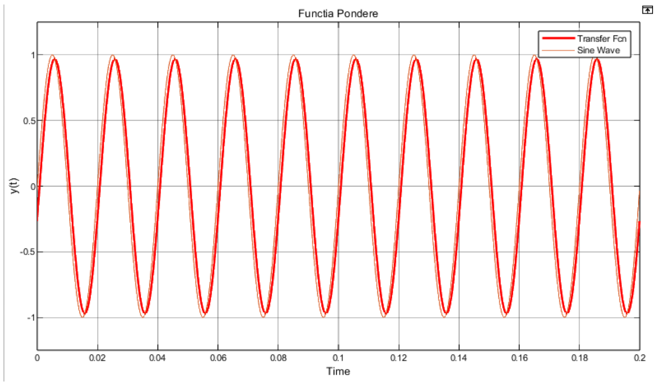



Fig. 17 – Input signal and its time response for a gamma RC circuit

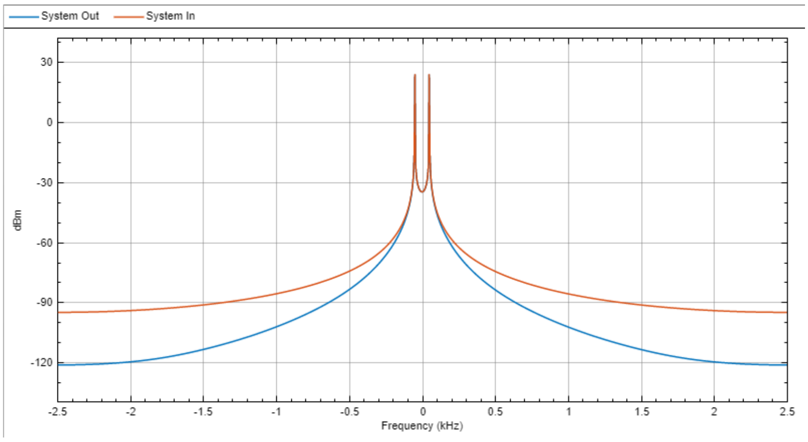



Fig. 18 – Input signal and its frequency response for a gamma RC circuit

## 1.4 Using sliders or the Peak Finder function in the spectrum analyzer to measure attenuations caused by the transfer function.

In the spectrum analyzer interface, you can activate the Peak Finder function by selecting the button circled in red in Fig. 19a. By changing the number of detected peaks to a value of 2, as shown in Fig. 19b, you can measure the amplitude value of the harmonics of the input and output signal in decibels by changing the channel on which the measurement is made via the selector on the left of the display.

**Exercises:**

Fill in the tables below with data from the sliders or the Peak Finder function. Calculate the theoretical value for $|H(\omega)|$ using the formula in Eq. (14). Change the transfer function in the Transfer Fcn block for the second table. Notice how much is the attenuation in the cells that have the thickened contour. What is the relation between the frequencies at which these attenuations occur and the RC constant in Eq. (12)

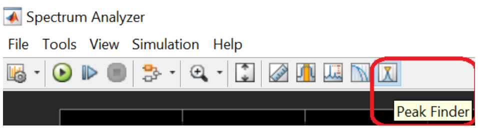
Table 1: $H(\omega)=\dfrac{1}{1+j\omega\cdot\dfrac{1}{2\pi\cdot 200}}$

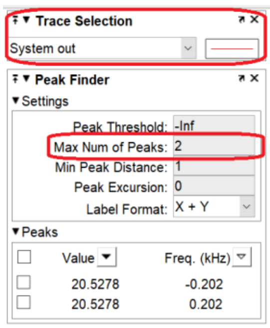
| $\omega$ [rad/s] | $2\pi\cdot 50$ | $2\pi\cdot 150$ | $2\pi\cdot 200$ | $2\pi\cdot 400$ | $2\pi\cdot 800$ | $2\pi\cdot 2000$ |
|---|---|---|---|---|---|---|
| $\lvert Y(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert X(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert H(\omega)\rvert = \lvert Y(\omega)\rvert - \lvert X(\omega)\rvert$ | | | | | | |
| $\lvert H(\omega)\rvert$ (theoretical – Ec (14)) | | | | | | |

Table 2: $H(\omega)=\dfrac{1}{1+j\omega\cdot\dfrac{1}{2\pi\cdot 50}}$

| $\omega$ [rad/s] | $2\pi\cdot 20$ | $2\pi\cdot 50$ | $2\pi\cdot 100$ | $2\pi\cdot 200$ | $2\pi\cdot 500$ | $2\pi\cdot 1000$ |
|---|---|---|---|---|---|---|
| $\lvert Y(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert X(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert H(\omega)\rvert = \lvert Y(\omega)\rvert - \lvert X(\omega)\rvert$ | | | | | | |
| $\lvert H(\omega)\rvert$ (theoretical – Ec (14)) | | | | | | |

$$\left|H(\omega)\right|_{dB}=20\lg\left|H(\omega)\right|=20\lg\left|\frac{1}{1+j\omega RC}\right| \tag{14}$$




(a) (b)

Fig. 19 – Setting up the Peak Finder function of the virtual spectrum analyzer

## 1.5 Modeling an RC circuit with FTJ gamma topology in Simulink and response evaluation for rectangular signals.

Swap the sinusoidal signal source for a rectangular signal source by bringing the Simulink > Sources > Pulse Generator block from the library into the workspace. Then configure the block so that the fill factor is 50% and the period is 1/100 (s), as shown in Fig. 20. Set the transfer function to be $H(\omega)=\dfrac{1}{1+j\omega\cdot\dfrac{1}{2\pi\cdot 400}}$. Notice how the first harmonic is affected compared to the following harmonics. For visualization with the virtual oscilloscope, set the trigger level of the trigger to a positive value between 0 and 1 (e.g., 0.5).

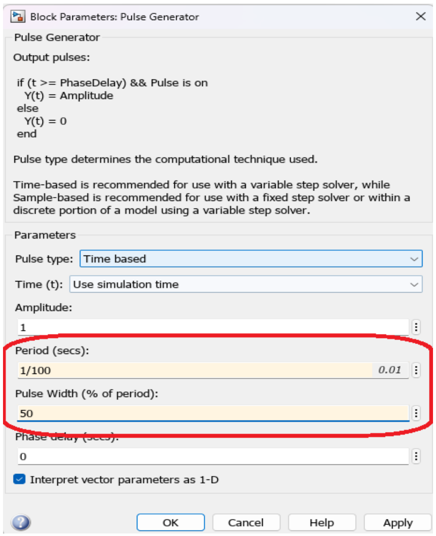



Fig. 20 – Rectangular signal source settings

## 1.6 RC circuit impulse and step response using Simulink. Weight function and index function.

To determine the system response to the step function, replace the previously used signal source with the Simulink > Sources > Step library block, as shown in Fig. 21. Accessing the configuration menu of the block, change the time at which the rising edge occurs, meaning the parameter τ in the expression σ(t-τ), by changing the Step Time field to the value 1. Change the RC constant in the transfer function $H(\omega)=\dfrac{1}{1+j\omega RC}$ to take the values $\dfrac{1}{2\pi\cdot 50}$, $\dfrac{1}{2\pi\cdot 200}$ and $\dfrac{1}{2\pi\cdot 500}$ and observe how the index function a(t) changes.

To measure the rise time (between 0.1 and 0.9), you can use the sliders in the virtual oscilloscope. These can be activated using the button to the right of the trigger button in Fig. 13. Fill in the table below for the 3 measured RC constant values.

Table 3 – Index function of the FTJ type RC circuit

| *RC* | $\dfrac{1}{2\pi\cdot 50}$ | $\dfrac{1}{2\pi\cdot 200}$ | $\dfrac{1}{2\pi\cdot 500}$ |
|---|---|---|---|
| Rise time | | | |

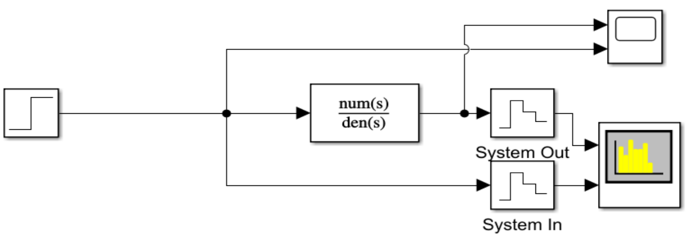



Fig. 21 – Scheme for determining the index function of a system

In order to determine the impulse response of the system, represented by the weight function, a Dirac delta pulse must be provided as input signal. Knowing the relation $\delta(t) = \frac{d}{dt}\sigma(t)$ to be true, the delta pulse can be generated by deriving the previously used step signal by cascading a derivative block, which can be found in the library under Simulink > Continuous > Derivatives, as shown in Fig. 22. Change the RC constant with the same values as for the index function and observe how the weight function h(t) changes, then fill in the table below with the decay time (between the time when h(t) is maximum and the time when h(t) = 0.1) and the maximum value reached. Adjust the time and value range displayed by the virtual oscilloscope as necessary.

Table 3 - FTJ type RC circuit weighting function

| $RC$ | $\frac{1}{2\pi \cdot 50}$ | $\frac{1}{2\pi \cdot 200}$ | $\frac{1}{2\pi \cdot 500}$ |
|---|---|---|---|
| Fall time | | | |
| $\max\{h(t)\}$ | | | |

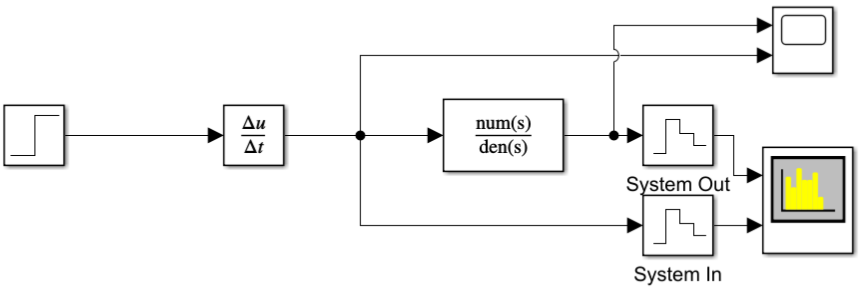



Fig. 21 – Scheme for determining the index function of a system

## 1.7 Modeling an RC circuit with FTS gamma topology in Simulink and evaluation of its transfer function.

Model the RC circuit of Fig. 22, whose transfer function is calculated in Eq. (15). Reconstruct the scheme used in section 1.4 and 1.5 in Simulink, shown in Fig. 10. Modify the Transfer block Fcn so that it models the new transfer function (note that it is necessary to specify both the coefficient a1 = RC and the coefficient a0 = 0 in Eq. (13) to specify to Simulink that it is required to use a polynomial of degree 1 instead of a constant). Simulate the response of the circuit to sinusoidal signals with the pulsations given in the tables below, for RC constant values of $\frac{1}{2\pi \cdot 400}$ and $\frac{1}{2\pi \cdot 800}$. How does this differ from the scenario analyzed in 1.4 and 1.5? Measure the attenuation in a similar way as in 1.5.

Table 4: $H(\omega) = \dfrac{j\omega \cdot \frac{1}{2\pi \cdot 400}}{1 + j\omega \cdot \frac{1}{2\pi \cdot 400}}$

| $\omega$ [rad/s] | $2\pi \cdot 40$ | $2\pi \cdot 80$ | $2\pi \cdot 200$ | $2\pi \cdot 400$ | $2\pi \cdot 800$ | $2\pi \cdot 1000$ |
|---|---|---|---|---|---|---|
| $\lvert Y(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert X(\omega)\rvert$ [dBm] | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| $\lvert H(\omega)\rvert = \lvert Y(\omega)\rvert - \lvert X(\omega)\rvert$ | | | | | | |
| $\lvert H(\omega)\rvert$ (theoretical) [dB] | | | | | | |

Table 5: $H(\omega) = \dfrac{j\omega \cdot \dfrac{1}{2\pi \cdot 800}}{1 + j\omega \cdot \dfrac{1}{2\pi \cdot 800}}$

| $\omega$ [rad/s] | $2\pi \cdot 40$ | $2\pi \cdot 80$ | $2\pi \cdot 200$ | $2\pi \cdot 400$ | $2\pi \cdot 800$ | $2\pi \cdot 1000$ |
|---|---|---|---|---|---|---|
| $\lvert Y(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert X(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert H(\omega)\rvert = \lvert Y(\omega)\rvert - \lvert X(\omega)\rvert$ | | | | | | |
| $\lvert H(\omega)\rvert$ (theoretical) [dB] | | | | | | |

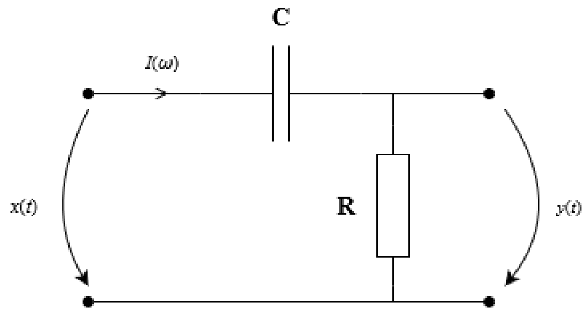



Fig. 22 – RC circuit in gamma topology (1st order high-pass filter)

$$H(\omega) = \frac{Y(\omega)}{X(\omega)} = \frac{I(\omega) \cdot R}{I(\omega) \cdot \left( R + \dfrac{1}{j\omega C} \right)} = \frac{j\omega RC}{1 + j\omega RC} \tag{15}$$

## 1.8 Modeling an RC circuit with FTS gamma topology in Simulink and response evaluation for rectangular signals.

Rebuild the schematic from section 1.6, except that the transfer function used will be the one from the previous section. Reconfigure the Pulse Generator block to set the fill factor to 50% and the period to 1/100. Simulate the circuit response for RC constant values of $\frac{1}{2\pi \cdot 200}$, $\frac{1}{2\pi \cdot 400}$ and $\frac{1}{2\pi \cdot 800}$. What happened to the continuous component of the signal?

## 1.9 Impulse and step response of an FTS RC circuit using Simulink. Weight function and index function.

Proceed similarly as in 1.7 to display the index function and the weight function for the system from the previous section. Simulate the circuit response for the values of the constants RC $\frac{1}{2\pi \cdot 200}$, $\frac{1}{2\pi \cdot 400}$ and $\frac{1}{2\pi \cdot 800}$, and fill in the tables below for the index function with the decrease time (between 0.9 and 0.1) and for the weight function with the increase time (between the time when the minimum h(t) is reached and the time when h(t) = -0.1). Explain in the weight function h(t) what phenomenon occurs at the moment of the momentum δ(t) at the system input.

Table 6 – Index function of FTS type RC circuit

| $RC$ | $\frac{1}{2\pi \cdot 200}$ | $\frac{1}{2\pi \cdot 400}$ | $\frac{1}{2\pi \cdot 800}$ |
|---|---|---|---|
| Fall time | | | |

Tabelul 7 – The weighting function of the FTS type RC circuit

| $RC$ | $\frac{1}{2\pi \cdot 200}$ | $\frac{1}{2\pi \cdot 400}$ | $\frac{1}{2\pi \cdot 800}$ |
|---|---|---|---|
| Rise time | | | |
| $\min\{h(t)\}$ | | | |

### 1.10 Modeling a system with the denominator of the second order transfer function in Simulink.

Recreate the scheme in Fig. 10. Set up the Transfer block Fcn to model the transfer function $H(\omega) = \dfrac{1}{1 + j\omega \dfrac{1}{\pi \cdot 200} - \omega^2 \dfrac{1}{4\pi^2 \cdot 40000}}$ (note, due to the presence of the unit imaginary term j in the notation s = jω, the terms in Eq. (13) will be $a_0 = 1$, $b_2 = \dfrac{+1}{4\pi^2 \cdot 40000}$, $b_1 = \dfrac{1}{\pi \cdot 200}$ and $b_0 = 1$). An example of a circuit that can have this transfer function can be seen in Fig. 23.

Using the Peak Finder function in the virtual spectrum analyzer, measure the attenuation for the pulsations in the table below and fill it in, similar to the way done in 1.5. Do you notice any differences?

Table 8: $H(\omega) = \dfrac{1}{1 + j\omega \dfrac{1}{\pi \cdot 200} - \omega^2 \dfrac{1}{4\pi^2 \cdot 40000}}$

| $\omega$ [rad/s] | 2π·50 | 2π·150 | 2π·200 | 2π·400 | 2π·800 | 2π·2000 |
|---|---|---|---|---|---|---|
| $\lvert Y(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert X(\omega)\rvert$ [dBm] | | | | | | |
| $\lvert H(\omega)\rvert = \lvert Y(\omega)\rvert - \lvert X(\omega)\rvert$ | | | | | | |
| $\lvert H(\omega)\rvert$ (theoretical) [dB] | | | | | | |

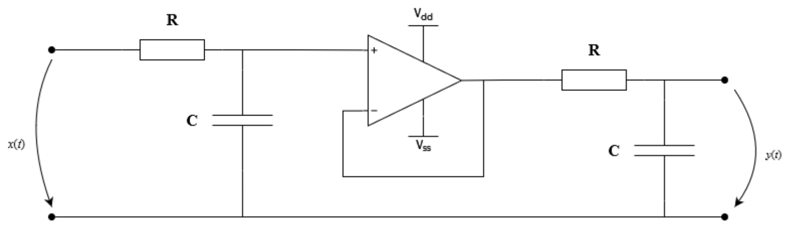



Fig. 23 – Two cascaded RC circuits with intermediate non-inverting repeater

### 1.11 Modeling a phase shifter system in Simulink.

Recreate the scheme in Fig. 10. Set up the Fcn Transfer block to model the transfer function $H(\omega)=\dfrac{j\omega\dfrac{1}{2\pi\cdot 200}-1}{j\omega\dfrac{1}{2\pi\cdot 200}+1}$. Use the virtual oscilloscope to visualize the system's response to sinusoidal signals with pulsations ω = 2π*50, ω = 2π*200, and ω = 2π*800, changing the time interval displayed by the oscilloscope so that between 2 and 5 periods are displayed. What effect does the system have on the amplitude of the signals? What about their phase? Use the sliders and Eq. (16) to determine the delay between the two signals, tx and ty being the times when x(t) and y(t) pass through 0 successively on the rising edge, and then to calculate the phase shift; finally, fill in the table below.

Table 9 – FTT phase shifter system

| $\omega$ [rad/s] | 2π·50 | 2π·200 | 2π·800 |
|---|---|---|---|
| $t_y$ - $t_x$ [$s$] | | | |
| $\varphi(\omega)$ | | | |

$$\varphi(\omega)=-360^o\cdot\left(t_y-t_x\right)\cdot\frac{\omega}{2\pi} \tag{16}$$

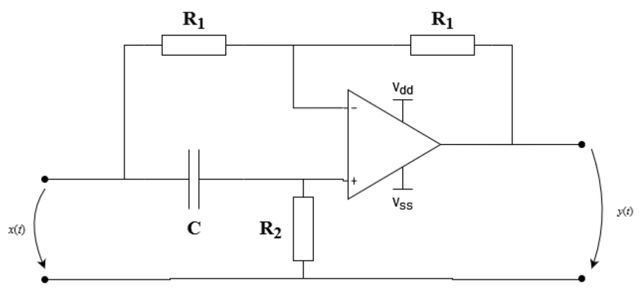



Fig. 24 – Example: Active 1st order FTT phase shifter circuit


**Bibliography:**

1. Petrescu T. „Semnale și Sisteme”. Politehnica Press, București, 2019.
2. Mateescu A., Dumitriu N., Stanciu L. „Semnale și Sisteme. Aplicații în filtrarea semnalelor”. Teora, București, 2001.
3. Petrescu T., Halunga S., Fratu O., Marcu I., Voicu C., Crăciunescu R. „Analiza și sinteza circuitelor – teorie și aplicații”. Politehnica Press, București, 2015.
4. Williams A.B., Taylor F.J. „Electronic Filter Design Handbook”, a 4-a ediție. McGraw-Hill, New York, 2006.
5. www.mathworks.com