EE-100 Lab: Nonlinear Circuit Synchronization Phenomenon and Design of Frequency Dividers - Theory

1. Objective
In this laboratory measurement you will learn the *nonlinear phenomenon of synchronization* and the physical mechanism responsible for this phenomenon.

2. Introduction: Synchronization
Synchronization is a very natural phenomenon observed in our daily life (including for example fireflies flashing and crickets chirping in synchrony, heart cells beating in rhythm). It plays crucial role in many technical applications (quartz watch, atomic clock, oscilloscope, radio, wireless communication, GPS positioning system, etc.) In science, the study of the synchronization mechanism has started with the historical observation by Huygens in pendulum clocks. Theory of synchronization implies periodicity of oscillators and nonlinear dynamics. This phenomenon is unique in that it can occur only in nonlinear systems. In this lab, we investigate the basic synchronization mechanism using a simple electronic circuit.

Consider the circuit shown in Figure 1. This is our well known (from the previous lab measurement) negative resistance converter with a capacitor connected across the input port.

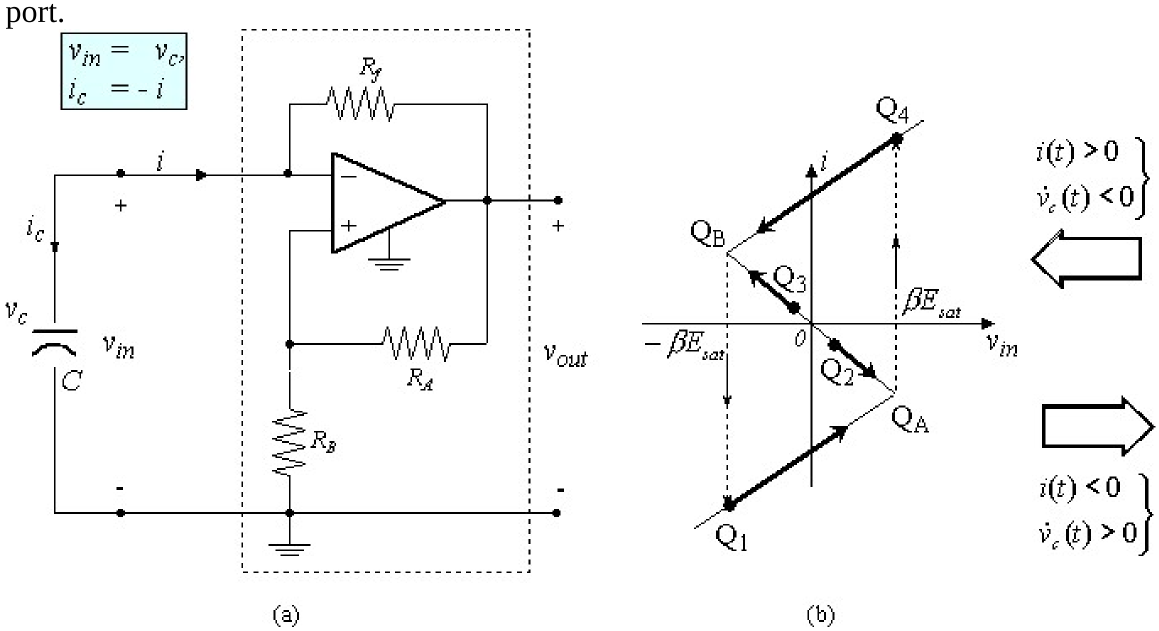

Figure 1 (a) An oscillating RC op-amp circuit and (b) its driving-point characteristic

This circuit oscillates at its natural frequency (f_y) determined by its component parameters (R_A, R_B, R_f, C, and the saturation voltage of the op-amp). This frequency will vary depending on such parameters as the supply voltage, changes in temperature, noise, etc. There are various methods that can be used to force the oscillator frequency f_y to "synchronize" with an input signal with a frequency f_x. Since the basic principles are the same in all cases, we shall consider only one method, the *pulse synchronization method*.

In the pulse synchronization method the oscillator is synchronized with a voltage pulse $v_s(t)$ having the same frequency f_x as the input signal. This synchronization signal can be derived from the input signal by some standard waveform operation in order to ensure that the frequency is exactly f_x. Let us connect a synchronization voltage source $v_s(t)$ in series with the capacitor as shown in Figure 2(a). Suppose the $v_s(t)$ has a sharp positive pulse with amplitude E_S.

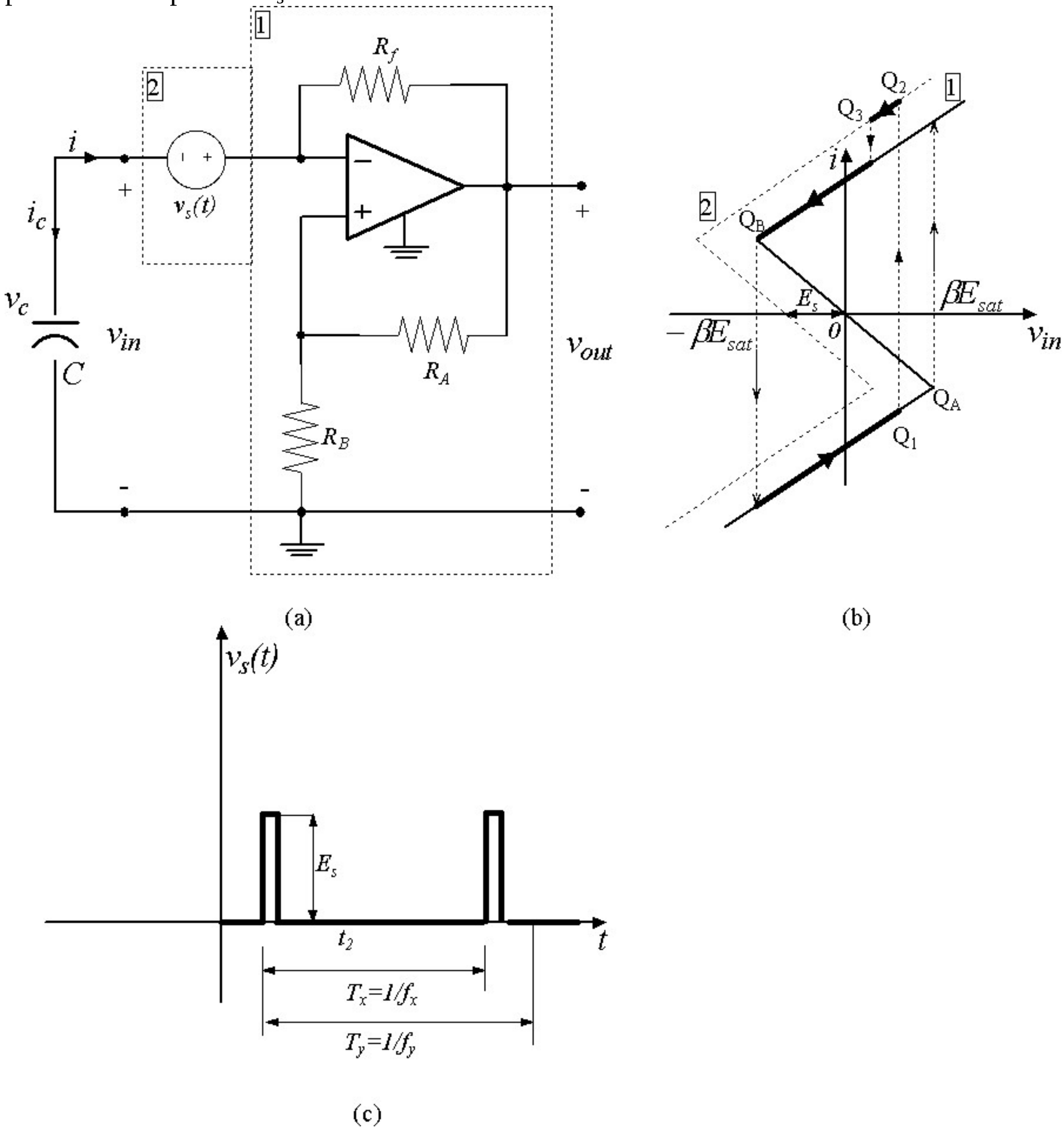

Figure 2 Oscillator circuit with a triggering signal connected in series with the capacitor, (b) shifted dynamic route of the oscillator corresponding to a square pulse triggering signal, (c) triggering square pulse

If $v_s(t)$ is as shown in Figure 2(c), then the DP plot will be shifted to the left by an amount equal to the pulse height E_s. Whenever a pulse appears, the capacitor will see a different dynamic route as shown in Figure 2(b). Observe that if the pulse appears (e.g. at Q_1) before the dynamic route reaches the impasse point Q_A then a sudden instantaneous transition will occur (i.e. jump) to the new DP route at Q_2. Note that the capacitor voltage cannot change suddenly therefore the jump should be vertical. After the pulse (Q_3) the dynamic route changes to its original position. We can see that a minimum pulse height (E_s) and a minimum pulse frequency (f_x) (relative to the unsynchronized frequency f_y) is required to ensure synchronization. It is easy to see that the frequency of the triggering signal (f_x) should be greater then the natural frequency of the oscillator (f_y). Then this jump will occur always closely to Q_A and even a small amplitude of the pulse (E_s) will be enough to cause switching. The oscillator will be precisely switch at the frequency of the trigger signal i.e. synchronized to the input frequency. Synchronization can occur not only when the triggering signal has a slightly greater frequency than the oscillator but also when the oscillator frequency is subharmonic of the input triggering signal frequency, namely,

$$f_y = \frac{1}{n} f_x$$

This property is the basic operating principle of most frequency dividers that exist today. By connecting an appropriate number of these dividers in cascade, it is possible to divide accurately an extremely high-frequency pulse train down to any desired output frequency. This property has been used in design e.g. of an atomic clock.

EE-100 Lab: Nonlinear Circuit Synchronization Phenomenon and Design of Frequency Dividers – Experiment Guide

Exp 1 – Oscillation and triggering

Build an astable RC op-amp circuit (oscillator) shown in Figure 1. This is composed of a negative resistance converter and a capacitor connected across its input port. You will be provided a box specially designed for this measurement (Figure 3). *This is the same box which was used for oscillation laboratory measurement.* Let R_A, R_B, and R_f be 1k, 10k, and 10k, respectively. Connect a 22nF capacitor across the inverting terminal of the op-amp and the ground. This circuit will serve as a time-base generator.
(Hint: the AD823 op-amp is more robust for this measurement than other type of op amps.) Use V_{DD}=12V and V_{SS}= -12V (on the datasheet these are called $+V_S$ and $–V_S$). Refer to the basic lab experiment on how the power supply should be connected!

1-a) Oscillator measurement: Switch on the circuit. Measure the parameters of the output square wave signal (frequency, amplitude, duty cycle). Observe the waveform of the capacitor voltage. What is the maximum amplitude level? The measured capacitor voltage will be our "*time-base generator signal*" with its natural frequency f_y. This oscillator will be synchronized by a small amplitude trigger signal.

1-b) Set up a triggering signal: Now, we will imitate a triggering signal using either the *HP33120A* function generator or a simple oscillator designed specifically for this lab to be provided by your TA. Set the signal of the triggering circuit to a 250 mV V_{pp}, 125mV DC offset, 20% duty cycle square wave with a frequency of approximately 600Hz (to produce positive "spikes" only). *(Remark: the specific triggering circuit designed for this lab is capable to generate not only a square wave, but sharp spikes as well.)* This will serve as a "*triggering input signal*" with frequency f_x. Note down what the amplitude ratio is between the oscillator and the triggering signal.

1-c) Unsynchronized case: Switch on both circuits but do not connect them together yet. They will work separately. Observe both the time-base generator signal (capacitor voltage of our oscillator) and the triggering input signal (output of the function generator or the simple oscillator designed for this lab). Connect the time-base generator signal to the first channel (*A1*) and the triggering input signal to the second channel (*A2*) of the scope. Set the scope trigger to channel *A2*. Try to display the waveform of the oscillator (channel *A1*) to remain stationary on the oscilloscope screen by changing the frequency of the triggering input signal (channel *A2*). Of course, because these two circuits work independently, you will not be able to display signal *A1* stationary on the screen. It will drift slowly to the left or to the right of the oscilloscope screen. The direction of the drift depends on whether the output frequency of the triggering circuit is slightly above or below than the frequency of the time-base generator.

Exp 2 – Synchronization

2-a) Synchronization

Now, let us synchronize the time-base generator signal to the triggering input signal. Switch off both circuits and connect the output of the triggering circuit in series with the capacitor of the time-base generator (*the input ort of the box*).

IMPORTANT NOTE ABOUT EARTH GROUND: *The following caution applies to both the HP33120A function generator and the oscilloscope. The building earth ground is connected to the ground wire of the instruments (outside ring of each of the BNC probe connectors is connected to this ground). If you put the ground clips of probe A1 and probe A2 of the oscilloscope at two different nodes, the ground will short both nodes together. If you put the ground of the function generator at a different node then this will also be connected to the earth ground. So always take care on how you set up your measurement and avoid connecting nodes together that are considered to be separate.*

Select the instruments ground (earth ground) to be the common point of the capacitor and the triggering source. Switch on both circuits and observe both signals (start with a frequency of approximately 600Hz for the triggering source). Which signal is drifting and which one is stationary? Increase the frequency of the triggering signal with an increment step of 10Hz (later 1Hz) and observe the changes. What is the frequency region when synchronization occurs? Observe that our oscillator no longer oscillates at its natural frequency but rather at the frequency of the triggering circuit. Change the amplitude of the triggering signal and determine the minimum pulse height required to ensure synchronization.

2-b) Frequency division

Now, we will use synchronization phenomenon for frequency division. Set the frequency of the triggering signal to approximately two times higher than the natural frequency of the oscillator. By increasing its frequency find and record the frequency range when synchronization occurs. In this case, since the oscillator frequency is equal to 1/2 of the triggering signal, the oscillator circuit is used to divide the frequency of the input (triggering signal) by 2. Such circuits are basic building blocks in the design of quartz watches and atomic clocks.

Similarly, find the frequency ranges for dividing the frequency by 3, 4, … etc.

Appendix: You will use a special box designed for this laboratory measurement (Figure 3).

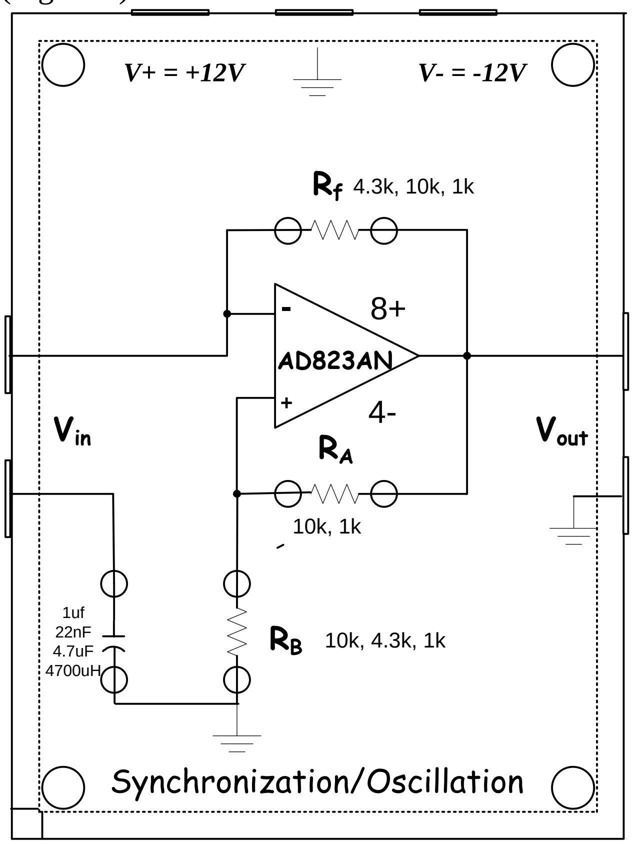

Figure 3 **Box designed for synchronization measurement.**

The arrangement of the components of box matches the corresponding schematic. The box requires power supply refer to the basic lab guide what the proper connection is. You can see labels showing which banana socket belongs to the positive power supply (*V+= +12V*, and red color), the common terminal (always in the middle), and the negative power supply (*V- = -12V*). Do not mix them. If you fill unsure ask your TA to help you. Passive components (resistors, capacitors, etc) are prepared in advance you need only to put them to the proper small banana sockets. Large banana sockets on the left side of the box are used for input, while sockets on the right for the output. If you need to set DC input voltage you can use the 6V output of the power supply. To set periodic input voltage using the function generator you can use BNC-banana converters. Also, there are prepared banana plugs with small pins so you can connect the alligator clips of the scope probe and measure any desired signal.