UNIVERSITY OF TEHRAN
School of Electrical and Computer Engineering
Digital Logic Laboratory, ECE 045, Fall 1392

Final Experiment (Sessions 11, 12, 13)

Digital Oscilloscope

The purpose of this lab is to:

- Design a rather complex digital circuit.
- Learn to design a digital system from scratch.
- Learn to design digital system by partitioning it into smaller units.
- Implement the circuit on Altera DE0-nano board and verify its performance experimentally.

1. Background

1.1. What does an oscilloscope do?

An oscilloscope is the most useful instrument available for testing circuits because it allows you to see the signals at different points in the circuit. Figure 1 shows the front Panel of an analog oscilloscope.

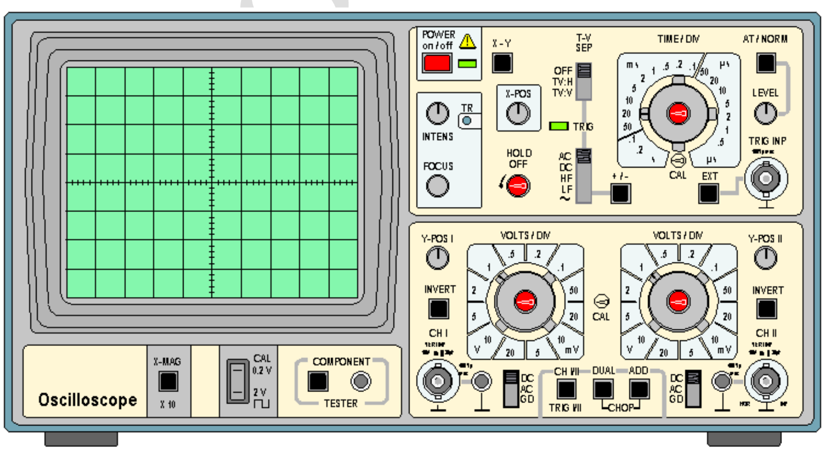

Figure1. Front panel of an analog oscilloscope.

The oscilloscope is basically a graph-displaying device. It draws a graph of an electrical signal. In most applications the graph shows how signals change over time: the vertical (Y) axis represents voltage and the horizontal (X) axis represents time. The intensity or

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brightness of the display is sometimes called the Z axis. This simple graph can tell you many things about a signal.

- You can determine the time and voltage values of a signal.
- You can calculate the frequency of an oscillating signal.
- You can see the "moving parts" of a circuit represented by the signal.
- You can tell if a malfunctioning component is distorting the signal.
- You can find out how much of a signal is direct current (DC) or alternating current (AC). You can tell how much of the signal is noise and whether the noise is changing with time.

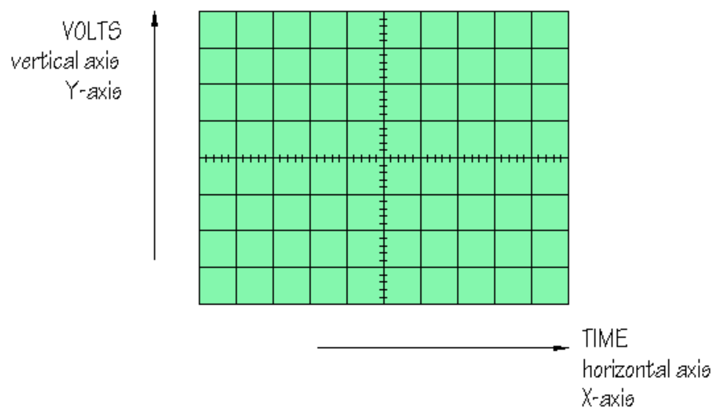

Figure 2. X, and Y components of a displayed waveform.

1.2.How Does an Analog Oscilloscope Work?

1.2.1. Analog Oscilloscope

When you connect an oscilloscope probe to a circuit, the voltage signal travels through the probe to the vertical system of the oscilloscope. Figure 3 is a simple block diagram that shows how an analog oscilloscope displays a measured signal.

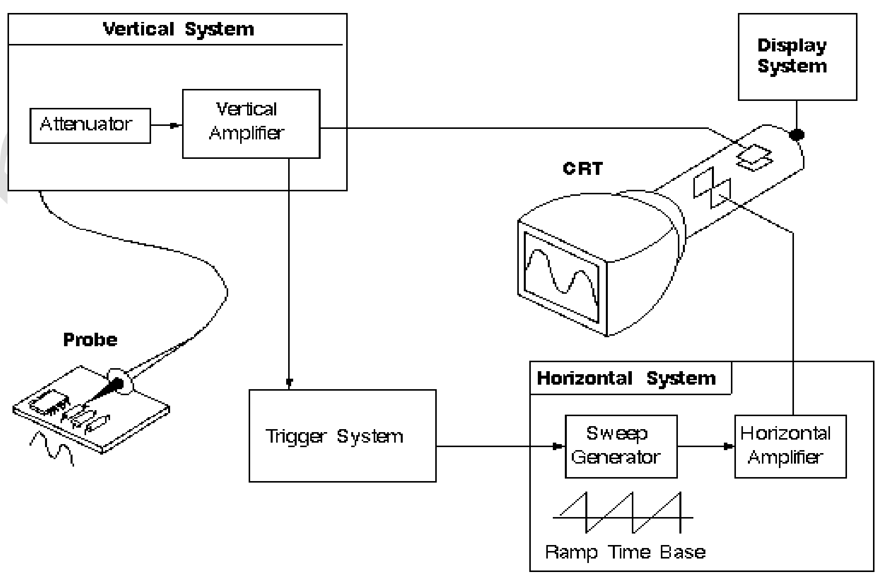

Figure 3. Block diagram of a digital oscilloscope

Depending on how you set the vertical scale (volts/div control), an attenuator reduces the signal voltage or an amplifier increases the signal voltage.
Next, the signal travels directly to the vertical deflection plates of the cathode ray tube (CRT). Voltage applied to these deflection plates causes a glowing dot to move. (An electron beam hitting phosphor inside the CRT creates the glowing dot.) A positive voltage causes the dot to move up while a negative voltage causes the dot to move down.
The signal also travels to the trigger system to start or trigger a "horizontal sweep." Horizontal sweep is a term referring to the action of the horizontal system causing the glowing dot to move across the screen. Triggering the horizontal system causes the horizontal time base to move the glowing dot across the screen from left to right within a specific time interval. Many sweeps in rapid sequence cause the movement of the glowing dot to blend into a solid line. At higher speeds, the dot may sweep across the screen up to 500,000 times each second.
Together, the horizontal sweeping action and the vertical deflection action trace a graph of the signal on the screen. The trigger is necessary to stabilize a repeating signal. It ensures that the sweep begins at the same point of a repeating signal, resulting in a clear picture as shown in Figure 4.

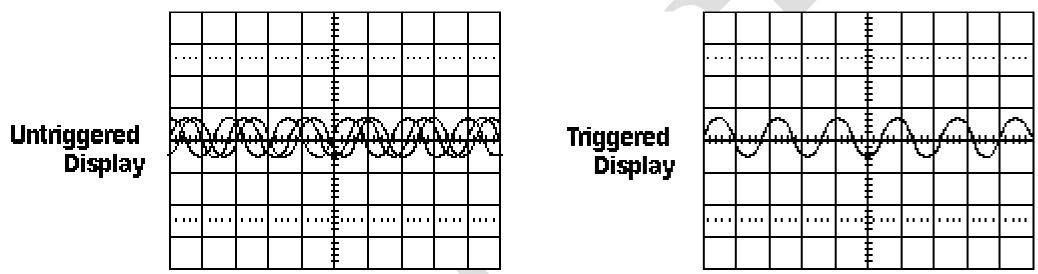

Figure 4. Triggering stabilizes a repeating waveform

Also, adjusting the focus and intensity controls enables you to create a sharp, visible display. In addition, DC or AC coupling on an oscilloscope enables the user to choose the portion of the signal to observe. DC allows the entire signal to be shown on the screen, including the steady plus or minus voltages. AC mode blocks the steady voltage to allow the small variations to be shown on the display. In fact, in a real oscilloscope, in the AC mode a capacitor is placed in the signal path that blocks DC signals but allows AC signals to pass.

In conclusion, to use an analog oscilloscope, you need to adjust three basic settings to accommodate an incoming signal:

- The attenuation or amplification of the signal. Use the volts/div control to adjust the amplitude of the signal before it is applied to the vertical deflection plates.
- The time base. Use the sec/div control to set the amount of time per division represented horizontally across the screen.
- The triggering of the oscilloscope. Use the trigger level to stabilize a repeating signal, as well as triggering on a single event.

1.2.2. Digital Oscilloscope

Some of the systems that make up digital oscilloscopes are the same as those in analog oscilloscopes; however, digital oscilloscopes contain additional data processing systems. (See Figure 5) With the added systems, the digital oscilloscope collects data for the entire waveform and then displays it.

When you attach a digital oscilloscope probe to a circuit, the vertical system adjusts the amplitude of the signal, just as in the analog oscilloscope. Next, the analog-to-digital converter (ADC) in the acquisition system samples the signal at discrete points in time and converts the signal's voltage at these points to digital values called *sample points*. The horizontal system's sample clock determines how often the ADC takes a sample. The rate at which the clock "ticks" is called the sample rate and is measured in samples per second. The sample points from the ADC are stored in memory as *waveform points*. More than one sample point may make up one waveform point.

Together, the waveform points make up one waveform *record*. The number of waveform points used to make a waveform record is called the *record length*. The trigger system determines the start and stop points of the record. The display receives these record points after being stored in memory. Depending on the capabilities of your oscilloscope, additional processing of the sample points may take place, enhancing the display. Pretrigger may be available, allowing you to see events before the trigger point.

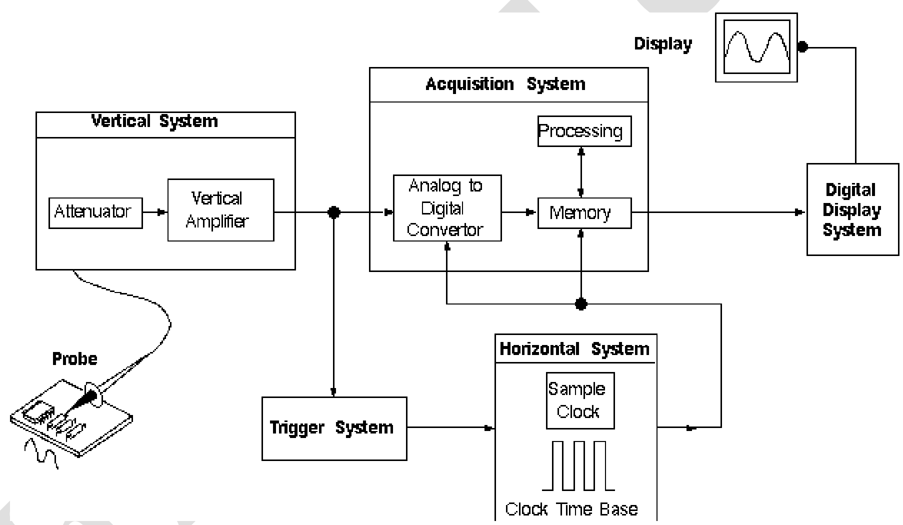

Figure 5. Block diagram of a digital oscilloscope

1.3. Trigger Controls

The trigger controls let you stabilize repeating waveforms and capture single-shot waveforms. Figure 6 shows a typical front panel and on-screen menus for the trigger controls.

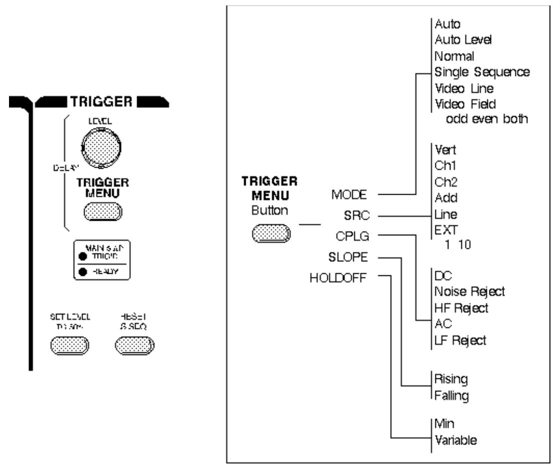

Figure 6. Trigger Controls

1.3.1. Trigger Level and Slope

Your oscilloscope may have several different types of triggers, such as edge, video, pulse, or logic. Edge triggering is the basic and most common type and is the only type discussed in this book. For edge triggering, the trigger level and slope controls provide the basic trigger point definition. The trigger circuit acts as a comparator. You select the slope and voltage level of one side of the comparator. When the trigger signal matches your settings, the oscilloscope generates a trigger.

- The slope control determines whether the trigger point is on the rising or the falling edge of a signal. A rising edge is a positive slope and a falling edge is a negative slope.
- The level control determines where on the edge the trigger point occurs.

Figure 7 shows you how the trigger slope and level settings determine how a waveform is displayed.

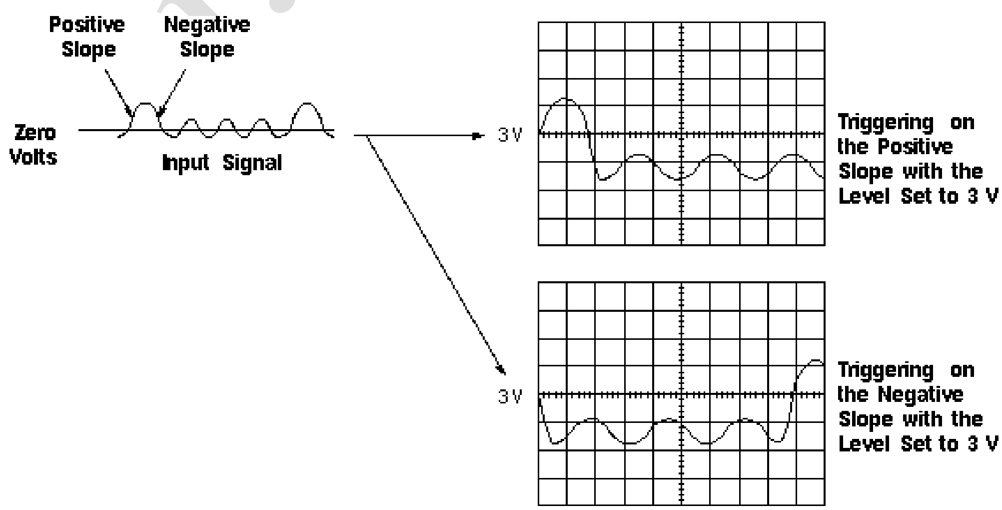

Figure 7. Positive and Negative Slope Triggering

1.3.2. Trigger Sources

The oscilloscope does not necessarily have to trigger on the signal being measured. Several sources can trigger the sweep:

- Any input channel
- An external source, other than the signal applied to an input channel
- The power source signal
- A signal internally generated by the oscilloscope

Most of the time you can leave the oscilloscope set to trigger on the channel displayed.
Note that the oscilloscope can use an alternate trigger source whether displayed or not. So you have to be careful not to unwittingly trigger on, for example, channel 1 while displaying channel 2.

1.3.3. Trigger Modes

The trigger mode determines whether or not the oscilloscope draws a waveform if it does not detect a trigger. Common trigger modes include *normal* and *auto*.
In normal mode the oscilloscope only sweeps if the input signal reaches the set trigger point; otherwise (on an analog oscilloscope) the screen is blank or (on a digital oscilloscope) frozen on the last acquired waveform. Normal mode can be disorienting since you may not see the signal at first if the level control is not adjusted correctly.
Auto mode causes the oscilloscope to sweep, even without a trigger. If no signal is present, a timer in the oscilloscope triggers the sweep. This ensures that the display will not disappear if the signal drops to small voltages. It is also the best mode to use if you are looking at many signals and do not want to bother setting the trigger each time.
In practice, you will probably use both modes: normal mode because it is more versatile and auto mode because it requires less adjustment.
Some oscilloscopes also include special modes for single sweeps, triggering on video s ignals, or automatically setting the trigger level.

1.3.4. Trigger Coupling

Just as you can select either AC or DC coupling for the vertical system, you can choose the kind of coupling for the trigger signal.
Besides AC and DC coupling, your oscilloscope may also have high frequency rejection, low frequency rejection, and noise rejection trigger coupling. These special settings are useful for eliminating noise from the trigger signal to prevent false triggering.

1.3.5. Trigger Holdoff

Sometimes getting an oscilloscope to trigger on the correct part of a signal requires great skill. Many oscilloscopes have special features to make this task easier.
Trigger *holdoff* is an adjustable period of time during which the oscilloscope cannot trigger. This feature is useful when you are triggering on complex waveform shapes, so that the oscilloscope only triggers on the first eligible trigger point. Figure 8 shows how using trigger holdoff helps create a usable display.

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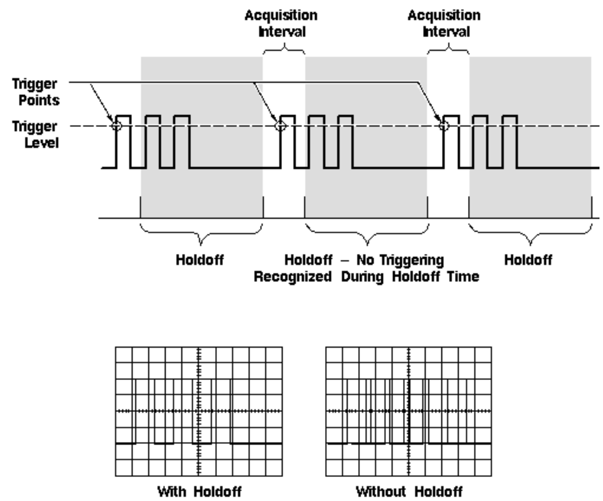

Figure 8. Trigger Holdoff

2. Problem Statement:

In this experiment, you are to design a digital oscilloscope using FPGA. To do so, you should use from the learned concepts in previous experiments such as ADC and VGA controller. Your digital oscilloscope acquires a waveform by converting the input signal to a digital representation with an analog-to-digital converter (ADC), sampling the digital signal, storing the sampled digital data in the memory, and then reconstructing the waveform for viewing on the display. Digital oscilloscopes sample the input signals at a frequency called the sample rate.

Your oscilloscope should have four parts:

- horizontal control
- trigger control
- vertical control
- the display

The horizontal part controls the time base or sweep of the instrument. The control of this part is the Time-per-Division (Time/Div) selector switch. This selector is a 2-bit input that changes the frequency of sampling. A 2-bit Time/Div selector chooses the frequency value according to Table 1.

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Table 1. Time/Div Selection

Time/Div	Frequency
2'00	1 KHz
2'01	512 Hz
2'10	256 Hz
2'11	128 Hz

As mentioned the trigger part controls the start event of the sweep. It is used when a signal is acquired and stored in memory. The level control determines where on the edge the trigger point occurs. In this project, you should consider an 8-bit trigger level and a 1-bit slope.

The vertical section controls the amplitude of the displayed signal. This section carries a Volts-per-Division (Volts/Div) selector and an AC/DC selector switch. The vertical scale control (Volts/Div) adjusts the height of the waveform on the display. For this part, you have a 2-bit Volts/Div input that changes the input amplitude according to Table 2.

Table 2. Volts/Div Selection

Volts/Div	Amplitude
2'00	1
2'01	$1/2$
2'10	$1/4$
2'11	$1/8$

The screen has reference grid. It should be noted that you need to read and show samples of the input signal from the memory with proper clock rate. In addition to the grid and waveform, you should write the value of Time/Div and Volts/Div on the top of the screen. Moreover, you should display "DLD Lab" plus your group code below the screen. This text should move horizontally from left to right.

3. How to Design

You can use a dual port RAM to store samples and read the data for display. The dual port RAM is a type of Random Access Memory that allows read and write operations to occur at the same time and at different addresses. Using the dual port RAM you can partition your system into two sub-system. Left sub-system does the triggering and stores samples in the RAM. Time/Div switch can be placed in this partition. The right sub-system reads the samples from the RAM and shows the appropriate image on the VGA. Volt/Div switch can be placed in this part. You must assign some switches for triggering such as slope, auto, normal and trigger level.

Optional: You can assign a switch on the board for selecting between AC and DC modes. This feature is optional. If you implement this feature, you are given a positive point.

Figure 9 shows top view of what you must design.

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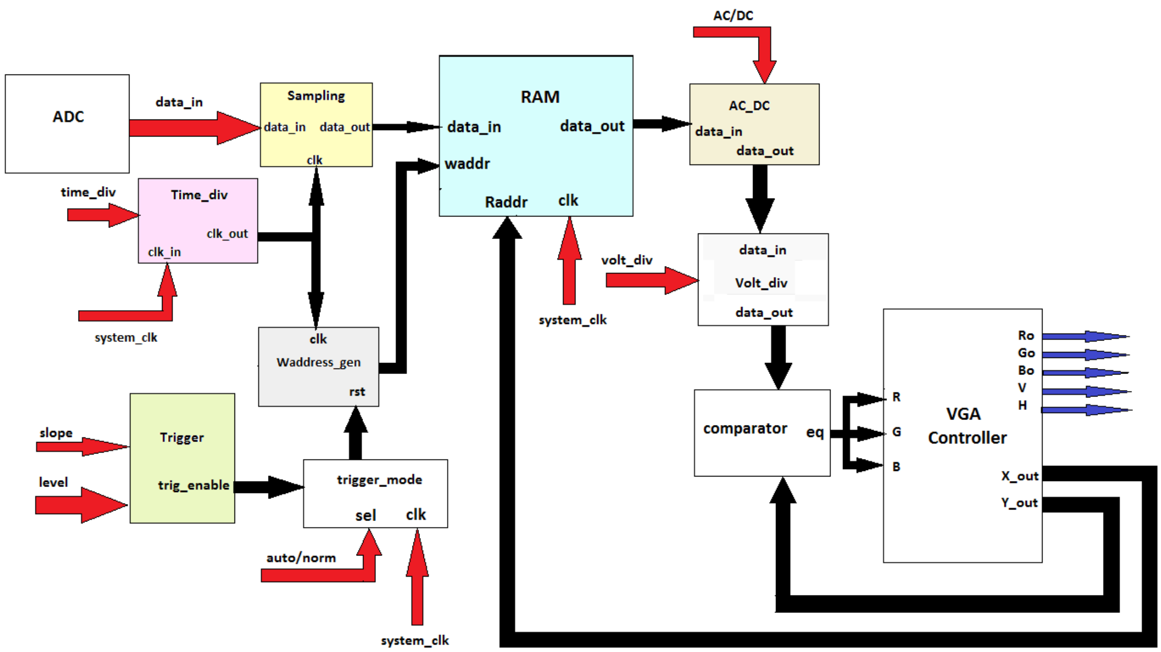

Figure 9 Top view of the final design.

NOTE: Your goal is to design and implement the oscilloscope on an FGPA. The lab is more complex than the previous ones. It will be very important that you work systematically and give yourself enough time to design and debug the system. Debugging is a normal part of any design task. You must partition the system in smaller modules. After designing each module, simulate it thoroughly and make sure that it works as expected. ***Do not skip this step*** since finding an error later on will be much more difficult. Once you have designed and simulated a module, add it to the top circuit schematic and do a simulation of the partial schematic, so that you make sure that the blocks work together. Simulating and testing your design progressively will make it easier to find errors. Errors may be not only the result of the wrong circuit design but also due to timing or synchronization errors that may show up only when you link blocks together.

Pre-lab assignments

- Draw schematic of your proposed design using building blocks (like VGA Controller, 2-Port memory, …) For each new block in this experiment explain its behavior (1 or 2 sentence(s)) then draw the schematic of its datapath (in Register Transfer Level) as well as the State Diagram of the control unit (If there is any).
- Review State Machines and their Verilog implementation before coming to lab.

In-lab assignments

You must deliver the implemented and tested design to your TA part by part.

Hand in:

At the end of the 1st session: hand in the structure of datapath (its components and their connections). Do not worry if your design details changes later on. They will serve as a starting point for the project.

For the final report: You must hand in a final lab report in the correct format. The lab report is an important part of the laboratory. It must be clear and well- organized. It is the only way to convey that you did a great job in the lab. The reports will be evaluated on their technical accuracy as well as on the quality of writing. This includes overall organization, presentation of figures, tables, and overall clarity of writing.

Reference:

[1] Oscilloscope Tutorial [Online]. available: http://.ece.rochester.edu/courses/ECE112/

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