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CS2105 Computer Networks I
Laboratory Experiment 7

Understanding Fourier Analysis with a Digital Storage Oscilloscope

Objectives:

(1) To study the functions and operations of a Digital Storage Oscilloscope (DSO).

(2) To construct approximately periodic waveforms based on Fourier analysis using the DSO.

1. Introduction

The oscilloscope is an electronic measuring instrument which displays electrical signals in graphic form. It can be used to observe waveforms as well as measure voltage, time, frequency, and phase angle.

A digital storage oscilloscope (DSO) performs waveform acquisition using high-speed sampling and digitizing rates. This allows the waveform to be digitized into a complete set of points from a single triggered acquisition.

The Fluke Autoranging CombiScope oscilloscope is a combination of an analog real-time oscilloscope and a fully featured DSO. The analog mode of operation is for complex data streams, modulated waveforms, and video signals. The digital mode of operation is more suited for single events, signals with low repetition frequencies, and when automatic measurements need to be performed. The oscilloscope has a bandwidth of 100 MHz with a sampling rate of 100 or 200 MS/s. It also has a standard memory of 8 Kbytes.

Periodic waveforms, such as sine waves and square waves, are waveforms that repeat over regular intervals or periods of time. According to the theory of Fourier analysis, all periodic waveforms are made up exclusively of specific sinusoids. The base sinusoid is referred to as the fundamental. Its frequency is the same as the waveform's frequency. The fundamental is the dominant frequency component of the waveform and determines the period of waveform repetition. Along with the fundamental component, non-sinusoidal periodic waveforms also have harmonic components. A harmonic is a sinusoid with a frequency that is an integer multiple of the fundamental. In addition to having specific frequencies, a periodic waveform's fundamental and harmonics also have specific amplitude and phase relationships. These relationships allow the fundamental and harmonics to add up to the specific waveform. This is illustrated further in Figure 1, where the first five non-zero frequency components of a square wave are summed.

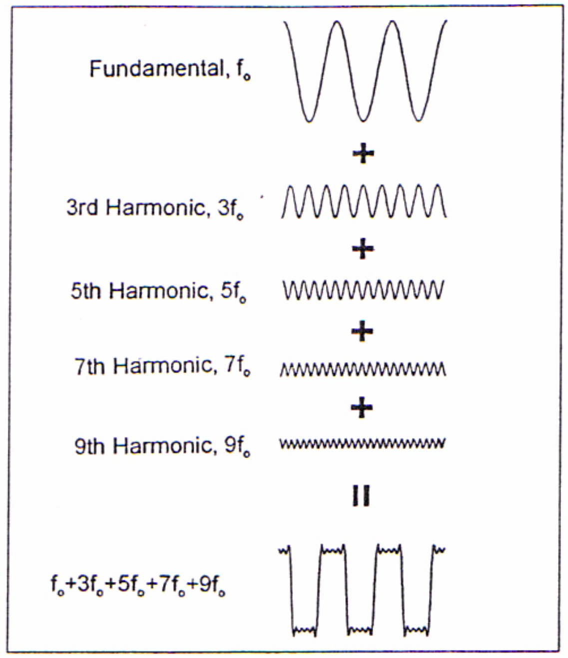

Figure 1. The fundamental frequency, 3rd, 5th, 7th, and 9th harmonics are added in an attempt to obtain a square wave.

In theory, all harmonics out to infinity are necessary for an ideal square wave or any other non-sinusoidal wave shape. In reality, all waveforms are bandwidth limited, which means that the energy of a waveform is contained within a finite frequency range. Usually, a waveform's significant frequency components are illustrated with spectral lines. This is shown in Figure 2, which depicts the frequency spectrum of a square wave. The frequency components are represented by vertical lines with each component placed at its frequency on a frequency axis. The length of each spectral line indicates the frequency component's amplitude relative to other components.

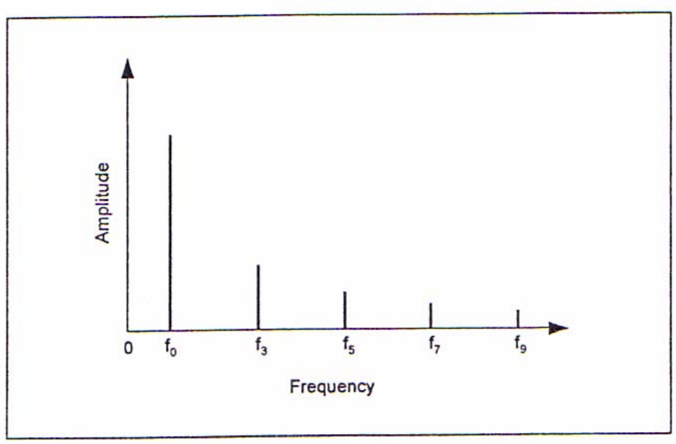

Figure 2. The spectrum of a square wave.

For more details, refer to the recommended textbook ("Data and Computer Communications", by W. Stallings, 7th Edition, Pearson Prentice-Hall, 2004, Chapter 3, p.56 – 68) and your lecture notes.

2. Equipment Provided

(1) A function generator with connector
(2) The Fluke Autoranging CombiScope oscilloscope

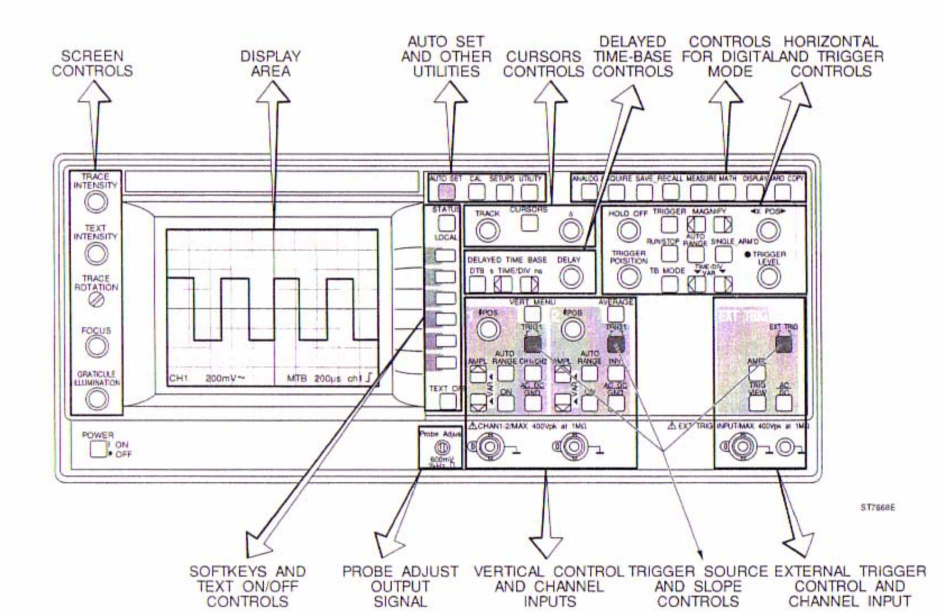

Figure 3. The front panel layout of the Fluke Autoranging CombiScope oscilloscope.

3. Procedure

Do the following:

(1) Connect the function generator to the oscilloscope with a probe to the CH1 input. Power on the scope and apply a sine wave signal to input CH1. Learn to use the following functions/softkeys on the scope:

Screen controls - use the **TRACE INTENSITY**, **TEXT INTENSITY**, **FOCUS**, and **GRATICULE ILLUMINATION** controls to the left of the screen to adjust the screen controls for optimum trace.

Auto setup - use the **AUTOSETUP** key to find and scale automatically all relevant parameters on all channels.

Operating modes - use the **ANALOG** key to switch from the analog mode to the digital mode and back at any time.

VERT (vertical) menu - use the following functions to control the vertical deflection of input waveforms: **POS** (position), **AMPL** (amplitude), and **AUTO RANGE** (an amplitude display of 2 to 6 divisions).

TB (timebase) menu - use the following functions to set the instrument to a predefined state to create a correct start situation for the horizontal deflection of input waveforms: **TIME/DIV** (the number of displayed periods or cycles),

AUTO RANGE (a display of 2 to 6 waveform periods), **MAGNIFY**, and **X POS**.

CURSORS menu - use the second blue softkey from the top to select one of the three cursor modes: '**=**' (amplitude cursor measurements), '**||**' (time cursor measurements), and '**#**' (amplitude and time measurements).

SAVE/RECALL menu - use the following memory functions (softkeys) to deal with storing and recalling waveforms in memory (eight memory locations '**m1**' to '**m8**') for later use: **Save**, **Clear**, **Copy**, **Clear & Protect**, **Display**, and **Clear Display**.

MATH (mathematics) menu - press the softkey next to **MATH 1** to enter the MATH 1 submenu and select the **ADD** function to perform a point-to-point addition of two waveforms. The result of the ADD function is a new waveform in a different register. This new waveform can be scaled and positioned.

(2) Given the time-domain function S(t) of a square waveform with period T and amplitude A,

$$S(t) = \begin{cases} A, & \text{for } 0 < t \leq T/2, \\ -A, & \text{for } T/2 < t \leq T. \end{cases}$$

It can be shown that the trigonometric Fourier series for the waveform is given by

$$S(t) = \frac{2A}{\pi} \sum_{n=1}^{\infty} \frac{(1 - \cos n\pi)}{n} \sin(2\pi n f_0 t)$$

where f_0 is the fundamental frequency.

Apply a sine wave signal to input CH1 with f_0 in the frequency range 1 kHz to 1 MHz. Based on the above equation, adjust the generator output amplitude for the fundamental component. Store the waveform in a register memory (from only **'m2'** to **'m8'**).

(3) Now apply the 3rd harmonic component to input CH1 and set its amplitude according to the equation. Check very carefully the parameter settings, such as frequency, MATH 1 scale, TIME/DIV. Use the ADD function to perform an addition of the fundamental and the 3rd harmonic components. If necessary, adjust the frequency and amplitude settings until you get the correct resultant signal. Store the resulting waveform in a different register memory.

(4) Repeat step (3) by adding the 5th, 7th, 9th harmonics, respectively, to the preceding resulting waveform to construct approximately a square waveform.

Answer the following questions:

Q1. When you are ready, demonstrate to your tutor the steps how you would obtain the resulting waveform constructed from the fundamental frequency, 3rd, 5th, 7th, and 9th harmonics.

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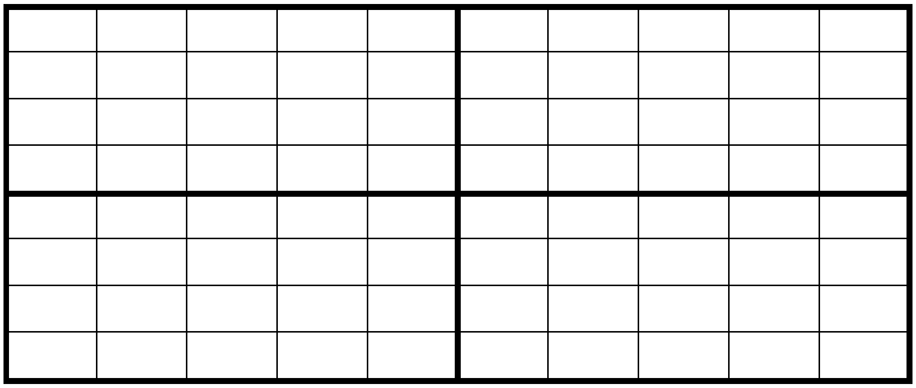
Q2. Sketch the resulting waveform in the “screen” below:



Q3. Record in the table below the measured values for your resulting waveform:

Frequency component	Amplitude (Volts)	Frequency (Hz.)
1st harmonic		
2nd harmonic		
3rd harmonic		
4th harmonic		
5th harmonic		
6th harmonic		
7th harmonic		
8th harmonic		
9th harmonic		

Q4. What is the effective bandwidth of the constructed square waveform?

Q5. If a dc (direct current) component of magnitude A is added to the waveform obtained in step (4), what would the resulting waveform look like? What is its effective bandwidth?

Q6. If you send the original square waveform through a noiseless telephone cable, why can’t the receiver obtain a waveform which is exactly identical to the original transmitted waveform?

Q7. So far, you have learned how to construct a square waveform by eliminating higher harmonic components and retaining only a few lower harmonic components. What would the signal waveform look like if you retain all higher harmonics and eliminate a few lower harmonics?

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