Frequency Domain Waveforms

Acknowledgements: Developed by Roger Harlow, Faculty of Mesa Community College, Mesa, Arizona. Special thanks to Electronic Workbench for providing this simulation as a stand-alone activity.

Special Notes: This simulation should be completed before starting the Frequency Domain Waveforms Lab.

Approximate Time Required: 1 hour

Simulation Summary: The purpose of this interactive simulation is to prepare you for the hands-on laboratory. The purpose of this laboratory experience is to introduce the Fourier mathematical equations for non-sinusoidal waveforms in the frequency domain view. Calculated peak values of the first nine harmonics of a square wave will be determined. A circuit will be built and voltages will be measured using an oscilloscope and a function generator. Directions for completing the lab are provided. The data collected will be compared to the calculated values and used to answer pertinent questions.

Simulation Goal: Observe a circuit and determine the differences between the calculated and measured output voltages of a square wave in the frequency domain view.

Learning Objectives

1. Use the Fourier mathematical expressions to calculate harmonic frequencies when given the voltage, frequency, and time.
2. Use a function generator to produce and fine-tune the output voltages at different harmonics.
3. Measure the peak values at different harmonics and record the values.

Grading Criteria: Your lab grade is determined by your performance on the simulation and the lab questions.

Simulation Preparation

1. Print this entire procedure to use as a reference, schematic, and workbook while completing the simulation.
2. Read the Introduction (below).
3. Review the Simulation Procedures (below).

Software Alert: When performing circuit simulations, failing to read and follow directions exactly can result in incorrect circuit operation and data measurements. For instance, if you fail to stop or pause the circuit at the appropriate times and leave circuits running, functions within Multisim 7 may become inoperative.

Introduction

The Fourier theory is an infinite mathematical series that Fourier used in his analysis and design of heat and thermodynamic systems. It was later discovered that it could be used in almost any engineering analysis including mechanical and electrical/electronic systems. The Fourier theory shows the relationship between the time and frequency domains. It provides a way to represent complex non-sinusoidal signals as the sum of harmonically related sine and/or cosine waves. In electronics, the Fourier theory can be used to explain how signals are filtered and processed. The Fourier series can be used to show how sine waves are used to make up the far more complex waves, such as the square, triangle, pulse, sawtooth, and other waves.

The Fourier theory states:
Any complex repetitive, non-sinusoidal waveform may be expressed mathematically as a fundamental sine wave at the signal frequency plus an infinite number of harmonic signals of varying amplitudes and phases.

A general expression of the Fourier theory is:

$$y = A_o + \sum [A_n \sin 2\pi(nf)t + B_n \cos 2\pi(nf)t]$$

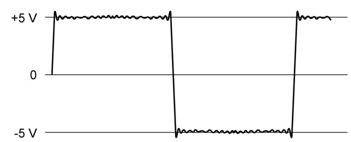
The term y is some signal that is a function of time or f (t). A_o is the DC component of the wave if it has one. The summation sign ($\sum$) indicates that a whole series of sine and cosine terms are to be added together. A is the sine amplitude, B is the cosine amplitude. The first term where n = 1 is the fundamental, the second term where n = 2 is the 2nd harmonic, etc. The term n designates the higher integer values of the harmonics.

The non-sinusoidal waveform most used to illustrate the Fourier theory is the square wave. If put through a rigorous Fourier analysis, the square wave is shown to be made up of a fundamental sine wave and an infinite number of odd harmonics (3rd, 5th, etc.).

The Fourier expression for a square wave is:

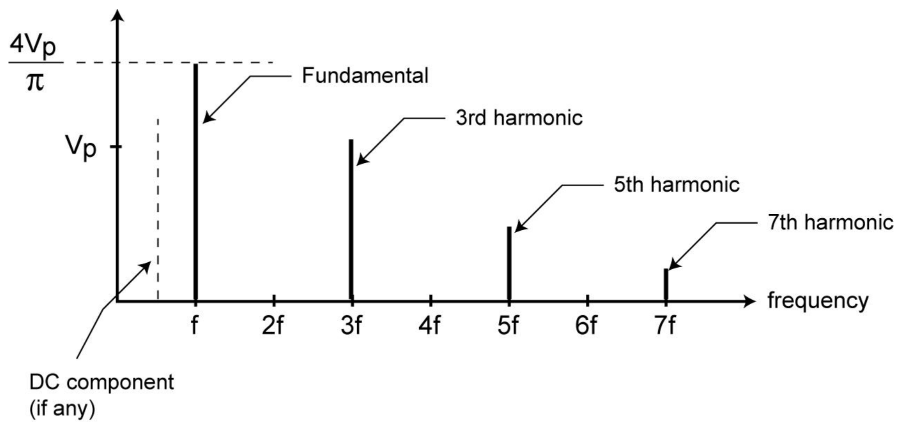
$$y = V_p + 4V_p/\pi\ [\sin\omega t + (\sin 3\omega t)/3 + (\sin 5\omega t)/5 + (\sin 7\omega t)/7 + \ldots.]$$

A computer generated plot of a square wave made up of the fundamental plus the first 20 odd harmonics shows the resulting wave is nearly a perfect square wave.



It can be shown that as the lower frequency harmonics are added it produces the flat top of the square wave and that the higher frequency harmonics shape the straight sides of the square wave.

In the frequency domain plot of the square wave, the amplitudes of the harmonics decrease in proportion to their frequency. The DC component is shown dashed.

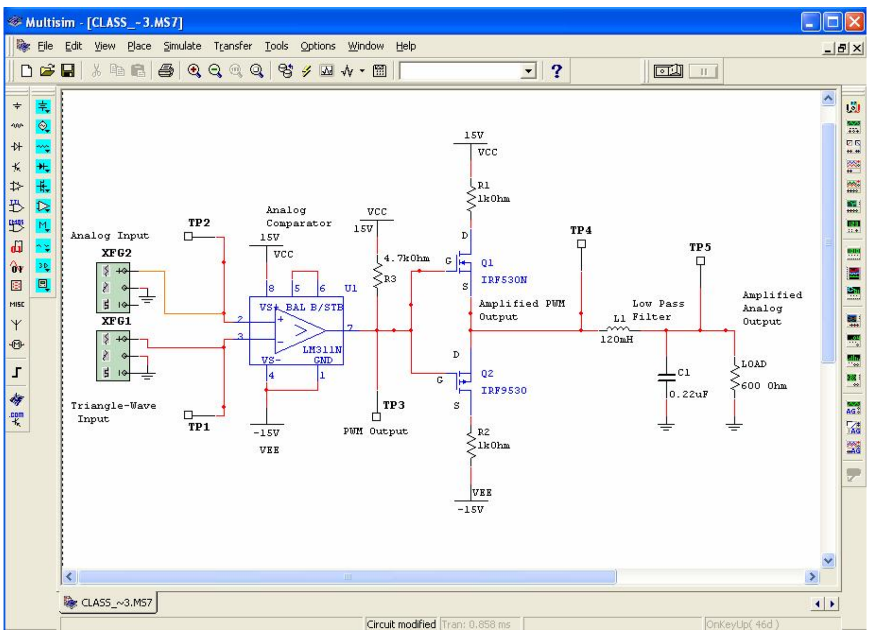


Simulation Procedures

NOTE: The schematic and lab questions are at end of this document.

Using Multisim

1. Download the Multisim demo from the WRE Module Learning Resource tab.
2. Open the file called Fourier3.
3. If you have not used Multisim before, please review the following section.

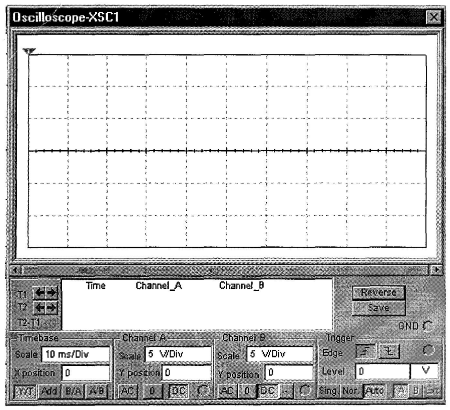


a. A simulation circuit is in the center of the screen.

NOTE: This is an example only. The circuit you are using is at the end of this procedure.

b. The Run/Stop and Pause/Resume simulation buttons are on the tool bar near the Help (?) button. Run/Stop is on the left and Pause/Resume is on the right.

c. To use an instrument, place your mouse over the instrument and double click. This will open the view like the oscilloscope shown.



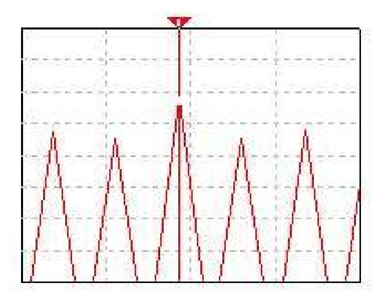
d. The slide bar below the oscilloscope screen can be used to move and adjust the wave image in the screen when the simulation is paused.

e. To set or change values, positions, or other parameters, place your mouse over the entry you want to change. When the hand appears, click once and up/down arrows will appear to allow you to scroll through preset values. Be sure to note the measurement units.

f. To get the most accurate reading, adjust the scale so the wave is as large as it can be without clipping.

Fourier Simulation

4. Determine the calculated peak values of the first nine odd harmonics of a square wave when $V_p = 10$ V, f = 465 kHz, and t = 580 nSec. The time (580 nSec) is chosen to represent some point in time other than the peak value of the first harmonic. If you perform the calculations at the half wave time point, the voltage values would calculate to zero.
5. Record the calculated values in Table 1 following this procedure.
6. Activate circuit simulation by pressing the Run/Stop switch found in the top portion of Multisim.
7. Double click on the oscilloscope (XSC1) and spectrum analyzer (XSA1) and observe the input and output signals.
8. Press the Pause/Resume button to pause the simulation.
9. Click on the red bar marked 1 on the spectrum analyzer. Drag the line to the tallest peak as shown in the example below.



10. Double click on the function generator (XFG1). Confirm the input frequency is set to 465 kHz.
11. Measure the peak values of V_{out} and V_{in} using the oscilloscope XSC1.

12. Use the following formula to determine dBV and complete Table 2. $dBV = 20 \log (V_{out}/V_{in})$
13. Enter your values on the graph provided.
14. Double click on the Bode plotter (XBP1). Compare your graph with Multisim.
15. Measure the largest peak value of V_{out}. Record the value in the table below.
16. Determine the peak value of the third harmonic by setting the function generator at 1/3 of the 465 kHz value observed in step 9.
17. Press Run/Stop to start the simulation.
18. Press Pause/Resume to pause the simulation.
19. Use the center peak frequency and measure the voltage and frequency for V_{out}. Record the values.
20. Repeat for the 5^{th}, 7^{th}, and 9^{th} harmonics by setting the function generator to one-fifth, one-seventh, and one-ninth of the fundamental frequency measured in step 5. Record the values.
21. Repeat for the even harmonics. Since a square wave is made up of a fundamental sine wave and odd harmonics, you can determine how “perfect” the function generator square wave is.

Simulation Questions:

Table 1: Peak Values of Harmonics

Formula: $y = V_p + 4V_p/\pi\ [\sin\omega t + (\sin 3\omega t)/3 + (\sin 5\omega t)/5 + (\sin 7\omega t)/7 + \ldots.]$

Square Wave Harmonic	Calculated Value	Actual Value	Frequency
First			
Second			
Third			
Fourth			
Fifth			
Sixth			
Seventh			
Eighth			
Ninth			

Table 2

Frequency	dBV
350	
375	
400	
425	
450	
475	
500	
525	

Bode Plot Graph

dBv

f

Circuit Schematic