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Generation of IKHZ Square Wave from Multiple Sine Waves

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***Abstract:** This project work shows the synthesis of 1KHz square wave from multiple sign waves using Fourier analysis in the MATLAB environment. Spectrum analyser was used to view the nature of different components (i.e. sine waves) that come together to form the square wave after adding some odd harmonics of 1KHz sine waves and the sine wave together. This scope supports variable-size input, which allows the input frame size to change. This method is a good way of generating high quality audio reproductions which can be used to achieve different sounds like percussive sounds or sounds with fast transients.*
***Keyword:** Fourier analysis, spectrum analyser, harmonics, percussive sound, transient*

I. INTRODUCTION

It has been found that when sine wave signal and cosine-wave(i.e. sine wave with a 90 degree phase shift)or sine-wave harmonicsare combined, periodic function with non-sinusoidal waveforms patterns are generated. This means that a combination of sine and cosine waveforms of certain overtones (i.e. signal frequencies higher than the fundamental frequency) with or without the fundamental frequency produces other waveforms like: square waveform, rectangular waveform, triangular waveform, saw tooth waveform, and some complex waveforms whose shapes are difficult to describe. Superimpositionof sine and cosinewaves to produce other types of periodic waveform is a phenomenon called Fourier Synthesis. The scheme gets its name from a French mathematician and physicist named Jean Baptiste Joseph, Baron de Fourier, who lived in the 18th and 19th century. Joseph Fourier showed that representing a function as a sum of trigonometric functions greatly simplifies the study of heat transfer. (IT KNOWLEDGE EXCHANGE, 2005).

Also, it has been experimentally proved that any repeating signals with non-sinusoidal waveforms can be decomposed to a combination of DC voltage, sine waves, and/or cosine waves (i.e. sine waves with 90 degree phase shift) at various amplitudes and frequencies. No matter how complex the waveform may be, in as much it repeats itself overtime on the regular intervals, it is reducible to a series of sinusoidal waves. When this happens to any waveform, that is, when a series of sine waves with different amplitudes and frequencies are recovered from a periodic non-sinusoidal waveform signal, we call this phenomenon **Fourier Analyses.** (All About Circuits, 2012).

The term spectral analysis is the process that happens to a periodic non-sinusoidal signal when it decomposes to sine waves and/or cosine waves at various amplitudes and frequencies.

In a nutshell, Fourier analysis can be termed as spectral analysis and is the opposite of Fourier synthesis.

Fourier series shown in equation1 below can be used to analyse a given function to its different components:

$$f(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right) \text{....equation1}$$

Note: The above equationis valid if and only if period P = 2L and L = π

(Emmanuel and Barrie, 2002)

In carrying the modelling of this work in the MPLAB IDE, spectrum analyser was used to view the nature of different components (i.e. sine waves) that come together to form the square wave.

Spectral analysis is the analysis of a spectrum which then determines the properties of its source.(Ask Jeeves n.d.).

This literature will be viewed under the following objectives.

A. Objectives

1) To diagrammatically show how square wave is formed from a fundamental frequency and its odd harmonics
2) To show the type of termsof the Fourier seriesthat combine to form a square wave.
3) To show theratio of amplitudes and frequencies of harmonics to the amplitude and frequency of the fundamental frequency respectively.
4) To combine a sinusoidal fundamental frequency with its six subsequent harmonics (i.e. odd sine waves with multiple frequencies) to produce a square wave of 1kHz using MATLAB IDE. This will be modelled in the MATLAB environment, time scope is used to view the generated square wave.
5) To show how a periodic non-sinusoidal frequency decomposes to different frequencies.

B. Theory

1) *Fourier Synthesis:* Since Fourier synthesis is the summing up of sine and cosine ways to form no-sinusoidal functions, we can regard to it as modulation.

Modulation, in electronics, is the addition of information (i.e. signals) to an electronic or optical signal-carrying medium. This is done when a signal (modulating signal) is used to vary the properties of a high frequency periodic waveform, called the carrier signal. (Tech Target, n.d.).

Common analogue modulation methods are:

a) Amplitude modulation (AM): in this case the amplitude(voltage) applied to the carrier is varied over time.
b) Frequency modulation (FM): in this case the frequency of the carrier waveform is made to change in a meaningful amount depending on the frequency of the modulating signal.
c) Phase modulation (PM): in this case the natural flow of the periodic sinusoidal signal is delayed temporarily.

The above analogue modulation can also be called **continuous modulation.**

The common types of digital modulation we have are: phase shift keying(PSK), frequency shift keying(FSK), amplitude shift keying(ASK).

Fourier series is as shown in equation 1 below:

$$f(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right) \quad \text{......equation 1}$$

$$a_o = 1/2L \int_{-L}^{L} f(x)dx \quad \text{.....equation2}$$

$$a_n = 1/L \int_{-L}^{L} f(x)\cos\left(\frac{n\pi x}{L}\right)dx \quad \text{.....equation3}$$

$$b_n = 1/L \int_{-L}^{L} f(x)\sin\left(\frac{n\pi x}{L}\right)dx \quad \text{....equation4}$$

n=1,2,3………………

(Emmanuel, 2002)

Note: All the above equations are valid if and only if period P = 2L and L = π

That means, P = 2π

The graphs (sine, cosine & square waves) given below areto used in the proof of this work, where **L** = π

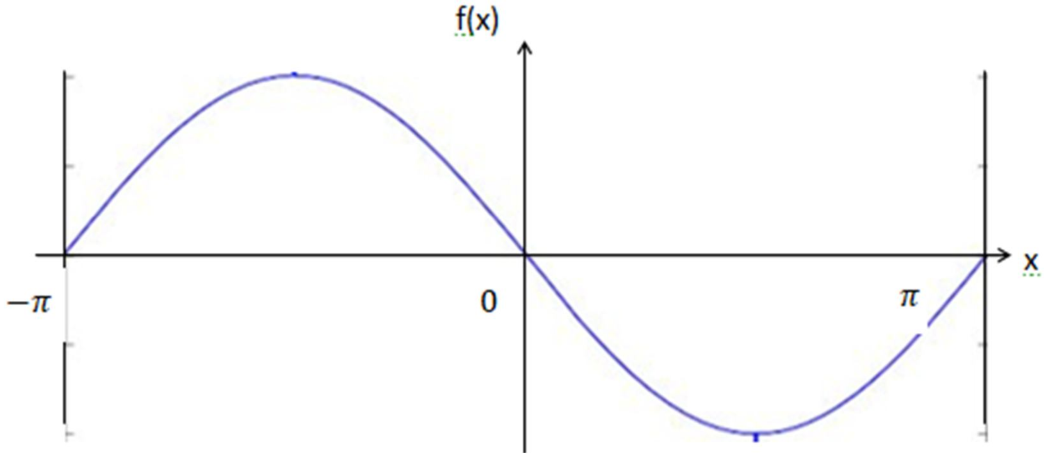

Fig1: Sine wave

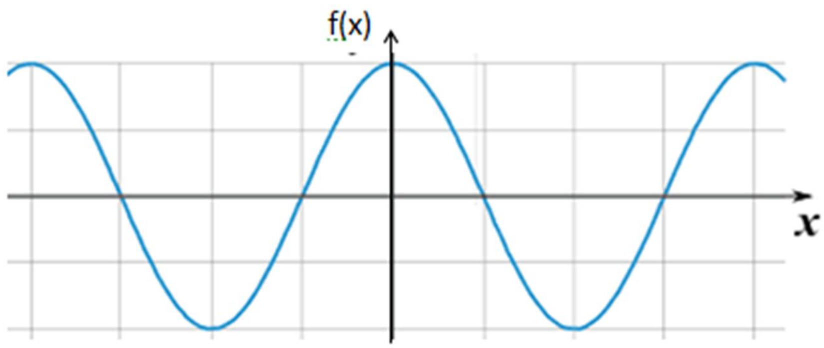

Fig2: Cosine wave (ADEPT SCIENTIFIC, 2011)

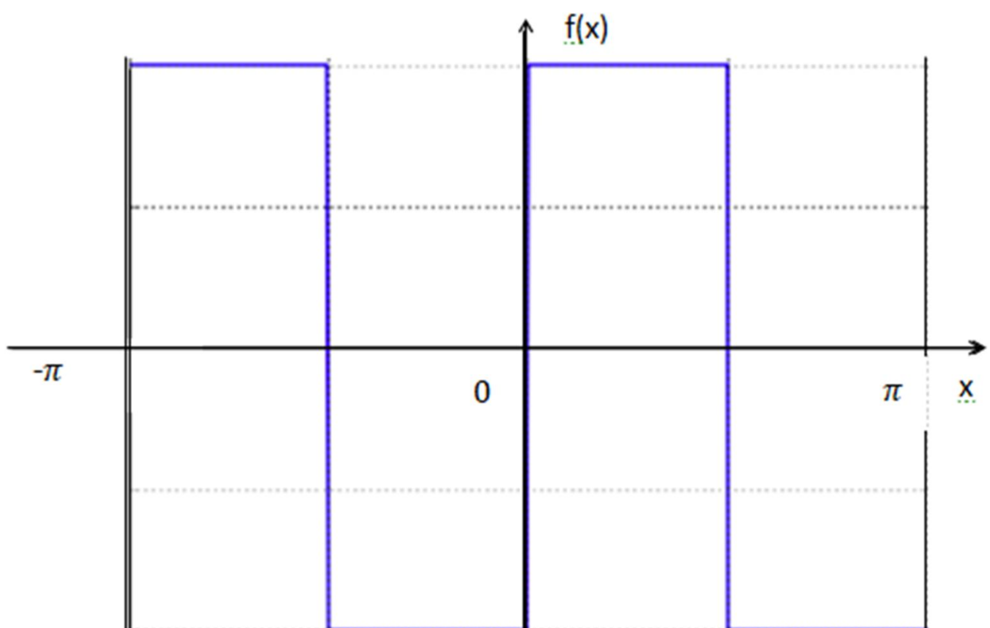

Fig3: Square wave

C. How To Combine Certain Terms Of The Fourier Series To Form A Square Wave

As it was earlier mentioned in this literature, any periodic non-sinusoidal waveform is a composition of a series of sine and cosine(sine waves)waves. To generate a square waveform, a sine wave that is of the same (fundamental) frequency with the square wave to generate is added to its odd harmonics as shown in the figure below.

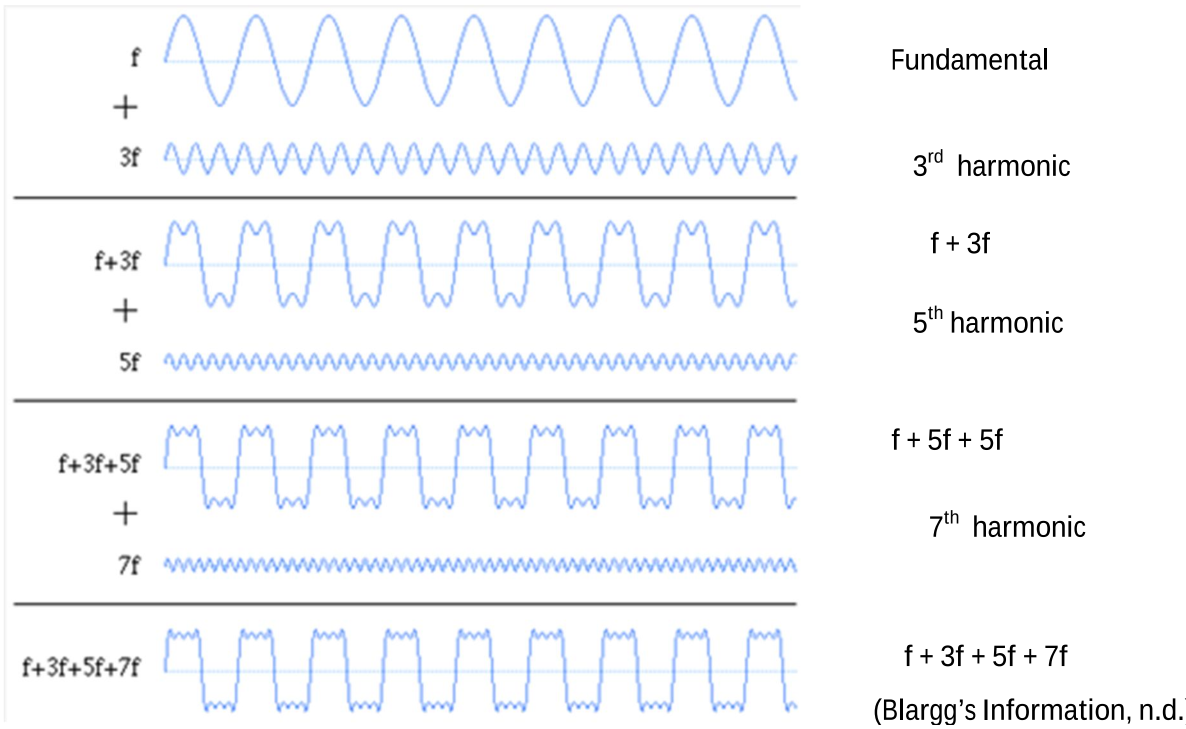

Fig4: Square wave built from sum of sine waves

In the above figure, signal 'f + 3f + 5f + 7f' is the result of the addition of the fundamental frequency with its three odd harmonics. The more the number of harmonics added to fundamental frequency increases, the better the shape of the square wave formed.

In order to get the square wave as required in this assignment, the fundamental frequency with other six odd harmonics of the fundamental frequencymust be summed up as given below:

f + 3f + 5f + 7f + 9f + 11f + 13f.

1) *Conclusion:* From the demonstration shown in figure 4 above, it is evident that a better square wave can be formed by adding more of the odd harmonics to their fundamental frequency.

D. To Show the Type of terms of the Fourier Series that Combine to form a Square Wave

This proof will establish that only odd terms of the Fourier series can be added together to form a square wave

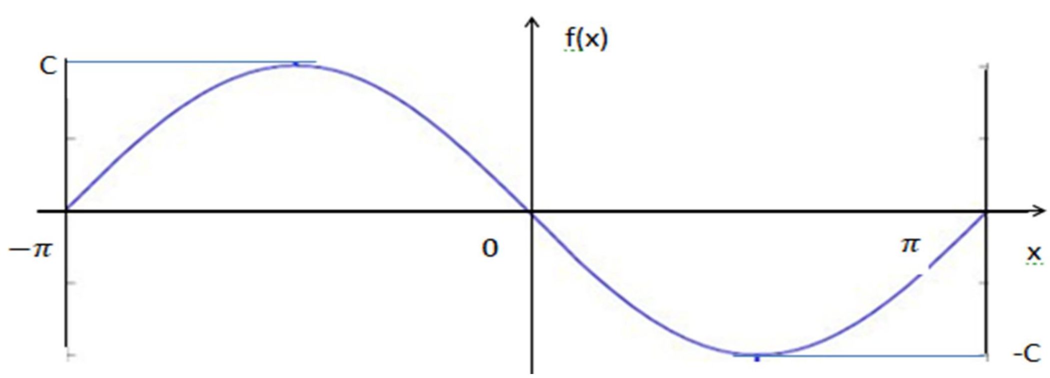

Fig5: Sine wave

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$a_o = 1/2\,\pi \int_{-L}^{L} f(x)dx$

Applying equation2 above to figure 5 above we've:

$a_o = ½\,\pi\,[\int_{0}^{-\pi}(C)dx + \int_{\pi}^{0}(-C)dx]$

$a_o = ½\,\pi[0]$ (sum of integrals of C and –C = 0)

$a_o=0$

From $f(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right)$

We've: $f(x) = 0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right)$ (since a_o=0)

From equation3 given above which is repeated below

$a_n=1/L\int_{-L}^{L} f(x)\cos\left(\frac{n\pi x}{L}\right)dx$

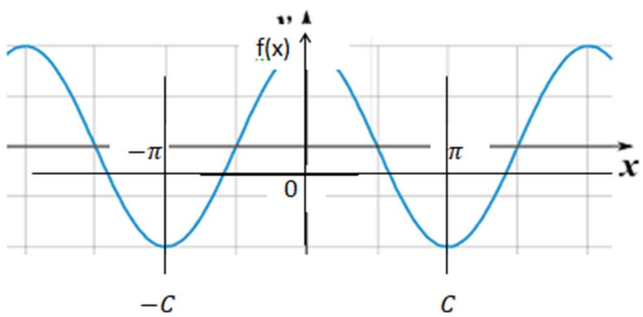


Fig6

$a_1 = 1/L\int_{-L}^{L} f(x)\cos\left(\frac{1\pi x}{L}\right)dx$

$a_1 = 1/\pi\int_{-L}^{L} f(x)\cos\left(\frac{1\pi x}{\pi}\right)dx$

$a_1 = 1/\pi\,[\int_{0}^{-\pi}(-C).\,cosx\,dx + \int_{\pi}^{0}(C).\,cosx\,dx]$

$a_1=1/\pi\,[(0) + (0)]$ ……… (sum of integrals of C and –C = 0)

$a_1=1/\pi\,[(0)]$

$a_1 = 0$

$a_2 = 2/\pi\,.\,[\int_{0}^{-\pi}(C).\,cosx\,dx + \int_{\pi}^{0}(-C).\,cosx\,dx]$

$a_2 = 2/\pi.\,[(0) + (0)]$ ………… (sum of integrals of C and –C = 0)

$a_2 = 2/\pi.[(0)]$

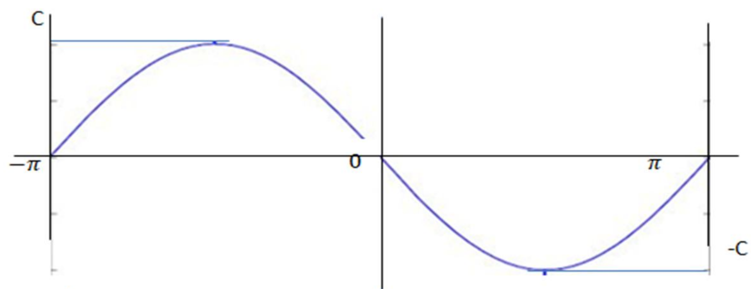
$a_2 = 0$

If the proof continues, it will be discovered that all other coefficients of cosine (i.e. a_n) will continue to be zero.

That means, $a_1= a_2 =a_3=a_4=$ ………………$=a_n=0$

From $f(x) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right) f(x) = a_0 + \sum_{n=1}^{\infty}\left(0 \text{ x } \cos\frac{n\pi x}{L} + b_n \sin\frac{n\pi x}{L}\right)$ (since $a_n=0$)

$f(x) = 0 + 0 + b_1 \sin\frac{1\pi x}{L} + b_3 \sin\frac{3\pi x}{L} + b_5 \sin\frac{5\pi x}{L} +$ ………………..$+ (b_{13} \sin\frac{13\pi x}{L})$



Sine wave

$b_n=1/L \int_{-L}^{L} f(x)\sin\left(\frac{n\pi x}{L}\right)dx$ where n =1,2,3,4…………..

$b_1 =1/\pi \int_{-\pi}^{\pi} f(x)\sin\left(\frac{1\pi x}{\pi}\right)dx$

$-\pi$ $l/\pi \int_{-\pi}^{\pi} f(x)\sin(x)dx$

Following the sine graph in figure above we've:

$b_1= 1/\pi\ [\int_0^{-\pi}(C).\,sinx\ dx + \int_{\pi}^{0}(-C).\,sinx\ dx]$

$b_1=1/\pi\ [(C)(2) + (-C)(-2)]$

$b_1=1/\pi.[4C]$

$b_1 =4C/\pi$

$b_2= 1/\pi\ [\int_0^{-\pi}(C).\,sin2x\ dx + \int_{\pi}^{0}(-C).\,sin2x\ dx]$

$b_2=1/\pi\ [0]$

$b_2 = 0$

$b_3= 1/\pi\ [\int_0^{-\pi}(C).\,sin3x\ dx + \int_{\pi}^{0}(-C).\,sin3x\ dx]$

$b_3 =1/\pi\ [(C)(2/3) + (-C)(-2/3)]$

$b_3 =1/\pi.[4C]$

$b_3 =4C/3\pi$

$b_4 = 1/\pi\ [\int_0^{-\pi}(C).sin4x\ dx + \int_\pi^0(-C).sin4x\ dx]$

$b_4 = 1/\pi\ [0]$

$b_4 = 0$

Thus, $b_2 = b_4 = b_6 = b_8 = 0$

$b_5 = 1/\pi\ [\int_0^{-\pi}(C).sin5x\ dx + \int_\pi^0(-C).sin5x\ dx]$

$b_5 = 1/\pi\ [(C)(2/5) + (-C)(-2/5)]$

$b_5 = 1/5\pi\ .\ [4C]$

$b_5 = 4C/5\pi$

if we continue the proof, it will be established that:

$b_7 = b_1/7$

$b_9 = b_1/9$

$b_{11} = b_1/11$

$b_{13} = b_1/13$

The new Fourier series formed thus is as shown in equation4 below:

$f(x) = 0 + 0 + b_1 \sin\frac{1\pi x}{L} + b_3 \sin\frac{3\pi x}{L} + b_5 \sin\frac{5\pi x}{L} + \ldots\ldots\ldots\ldots\ldots\ldots + (b_{13} \sin\frac{13\pi x}{L})$

$f(x) = 0 + 0 + b_1 \sin\frac{1\pi x}{\pi} + b_3 \sin\frac{3\pi x}{\pi} + b_5 \sin\frac{5\pi x}{\pi} + \ldots\ldots\ldots\ldots\ldots\ldots + (b_{13} \sin\frac{13\pi x}{\pi})$ since $L=\pi$

Thus, we've:

$f(x) = 0 + 0 + b_1 \sin x + b_3 \sin 3x + b_5 \sin 5x + \ldots\ldots\ldots\ldots\ldots\ldots + (b_{13} \sin 13x)$ -----equation4

$f(x) = 0 + 0 + \frac{4C}{\pi} \sin x + \frac{4C}{3\pi} \sin 3x + \frac{4C}{5\pi} \sin 5x + \ldots\ldots\ldots\ldots\ldots\ldots + (\frac{4C}{13\pi} \sin 13x)$ ---equation5

$f(x) = \frac{4C}{\pi} [\sin x + \frac{1}{3} \sin 3x + \frac{1}{5} \sin 5x + \ldots\ldots\ldots\ldots\ldots\ldots + (\frac{1}{13} \sin 13x)\ ]$

Assume $C = \frac{\pi}{4}$

We've: $f(x) = [\sin x + \frac{1}{3} \sin 3x + \frac{1}{5} \sin 5x + \ldots\ldots\ldots\ldots\ldots\ldots + (\frac{1}{13} \sin 13x)\ ]$ ---equation6

From the equation1 given above, x = wt

$x = wt = 2\pi ft = f(2\pi t)$

$3x = 3wt = 3(2\pi ft) = 3f(2\pi t)$

$5x = 5wt = 5(2\pi ft) = 5f(2\pi t)$

$f(x) = [\sin f(2\pi t) + \frac{1}{3} \sin 3f(2\pi t) + \frac{1}{5} \sin 5f(2\pi t) + \ldots\ldots + (\frac{1}{13} \sin 13f(2\pi t))\ ]$ ---eqn7

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1) Conclusion

a) It is evident from equation 6 given above that only the fundamental frequency and its odd harmonics can be added together to form a square wave.

b) From equation7 given above, it was proved that the frequency of each harmonic is the product of its nth position in the Fourier series and the fundamental frequency.

multiplierof fundamental frequency
to get 2nd harmonic frequency

E.g. fundamental frequency = f

2nd harmonic frequency = 3f ………..(i.e. 1st odd harmonic)
3

4th harmonic frequency = 5 f……….(i.e. 2nd odd harmonic)
5

multiplierof fundamental frequency
to get 4th harmonic frequency

E. To Show The Ratio Of Amplitudes And Frequencies Of Harmonics To The Amplitude And Frequency Of Their Fundamental Frequency Respectively

From equation6 given above and repeated below,

That is, $f(x) = [\sin x + \frac{1}{3}\sin 3x + \frac{1}{5}\sin 5x + \ldots\ldots\ldots\ldots + (\frac{1}{13}\sin 13x)]$

From equation1 given above x = wt

$x = wt = 2\pi f t = f(2\pi t)$

$3x = 3wt = 3(2\pi f t) = 3f(2\pi t)$

$5x = 5wt = 5(2\pi f t) = 5f(2\pi t)$

$f(x) = [\sin f(2\pi t) + \frac{1}{3}\sin 3f(2\pi t) + \frac{1}{5}\sin 5f(2\pi t) + \ldots\ldots\ldots\ldots + (\frac{1}{13}\sin 13f(2\pi t))]$

………………..eqn8

1) Conclusion

It is proved that:

a) From equation7 given above, it was proved that the frequency of each harmonic is the product of its nth position in the Fourier series and the fundamental frequency.

multiplierof fundamental frequency
to get 2nd harmonic frequency

E.g. fundamental frequency = f

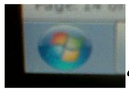
2nd harmonic frequency = 3 f ………..(i.e. 1st odd harmonic)

4th harmonic frequency = 5 f ……….(i.e. 2nd odd harmonic)

Multiplier of fundamental frequency
to get 4th harmonic frequency

- First odd harmonic has its amplitude equal to 1:3 of the amplitude of the fundamental frequency, and its frequency equal to 3:1 of the fundamental frequency.
- From equation7, third odd harmonic has its amplitude equal to1:3 of the amplitude of the fundamental frequency, and from equation8 the frequency of the third harmonic is equal to 3:1 of the fundamental frequency.
- As mathematically proved, each odd harmonic has its amplitude equal to the ratio 1:nof the amplitude of the fundamental frequency, and its frequency equal to the ratio n:1 of the fundamental frequency. Where n is the nth position of the harmonic in the Fourier series.

F. To Combine a Sinusoidal Fundamental Frequency with its Six Subsequent Odd Harmonics (I.E. Odd Sine Waves With Multiple Whole Frequencies) To Produce a Square Wave Of 1khz using MATLAB IDE

1) *Procedure:* Matlab was loaded from the  'start menu' → 'All Programs' → 'MATLAB' → 'Matlab R2013'. When the program started the window below came up:

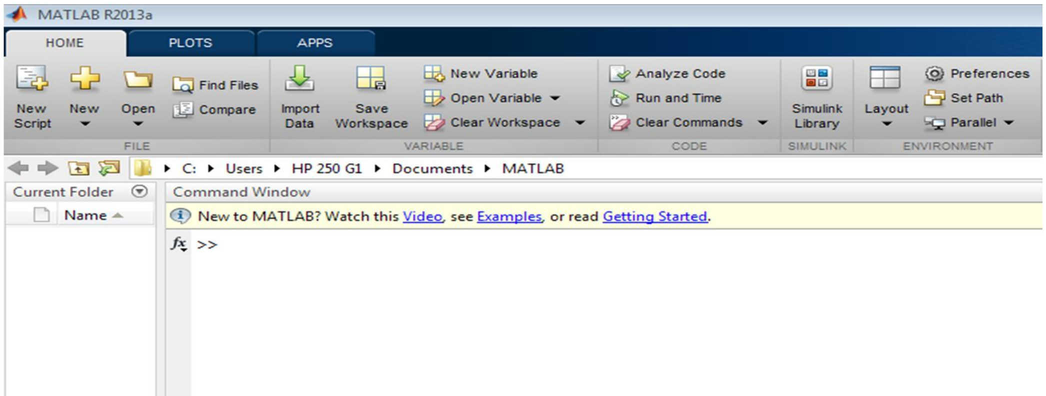


Figure1

Then the Simulink icon was clicked on in MATLAB task bar  and 'Simulink Library Browser' came up as shown below:

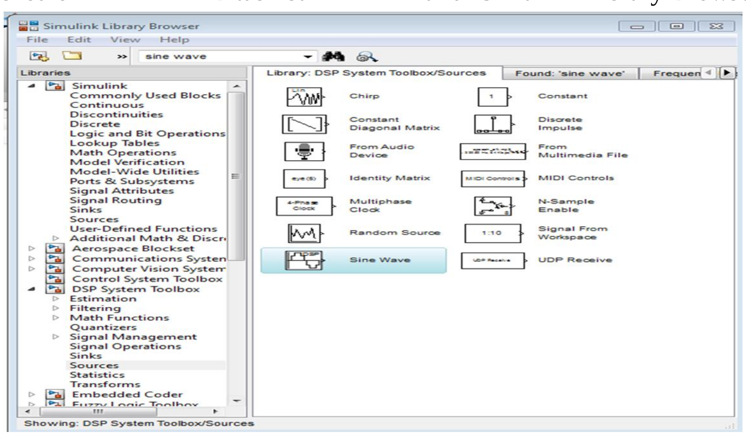


Figure2: Simulink Library Browser

From the Simulink library browser, the following icons: 'File→'New,' and 'Model' one after the other and a GUI work space came up as shown below:

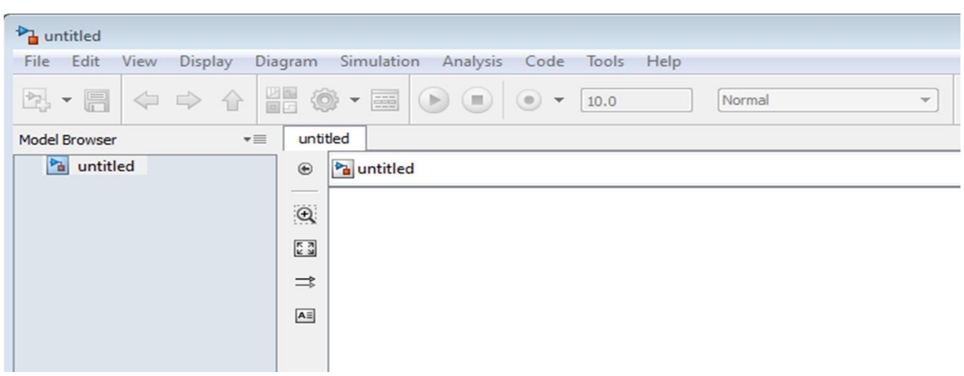


Figure3: Model Window

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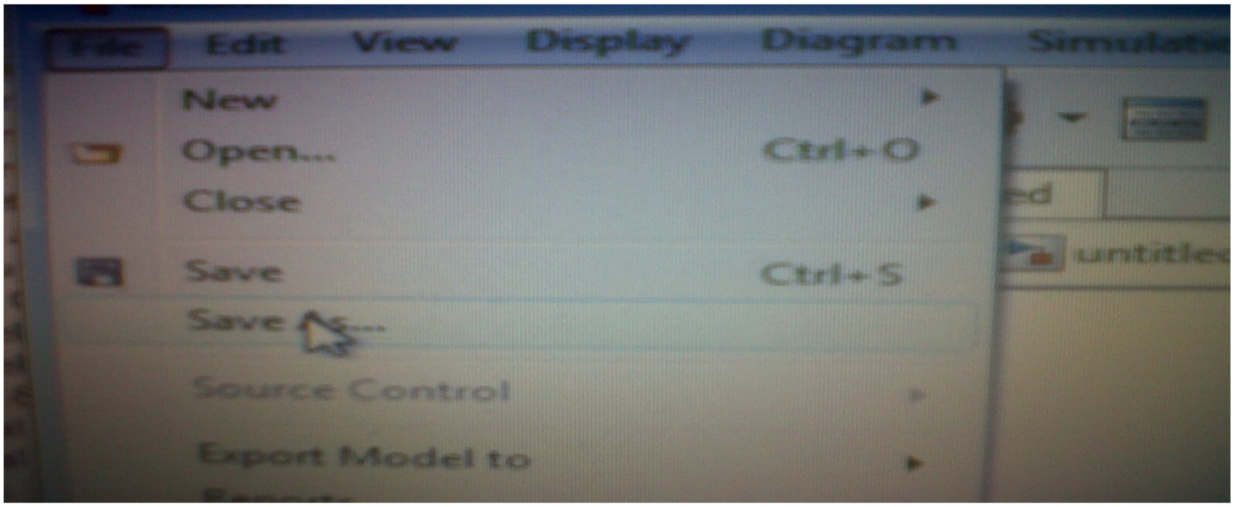

Figure4: Model Window

From the Simulink Model Window, the file was saved as shown in the figure above and saved as 'square_wave.mdl' on the desktop.
From the 'Simulink Library Browser', 'DSP System Tool Box' was clicked upon followed by the icon 'Sources' and seven (7)'sine wave blocks' from the DSP system tool box were dragged to the Model Window.
After then, from the Simulink Library Browser, 'Simulink' was clicked upon followed by 'Math Operations' and 'sum block' was dragged to the Model window and dropped.
Then all the sine waveblocks were connected to the sum block.
From the 'Simulink Library Browser' 'DSP System Tool Box' was clicked upon followed by the 'Sinks' and 'Time Scope' was then dropped in the 'Model Window'. Then the 'sum block' was connected to 'the Time Scope block' as shown in figure5 below. Then time scope was replaced by spectrum analyser. The result is as shown in figure8 below:

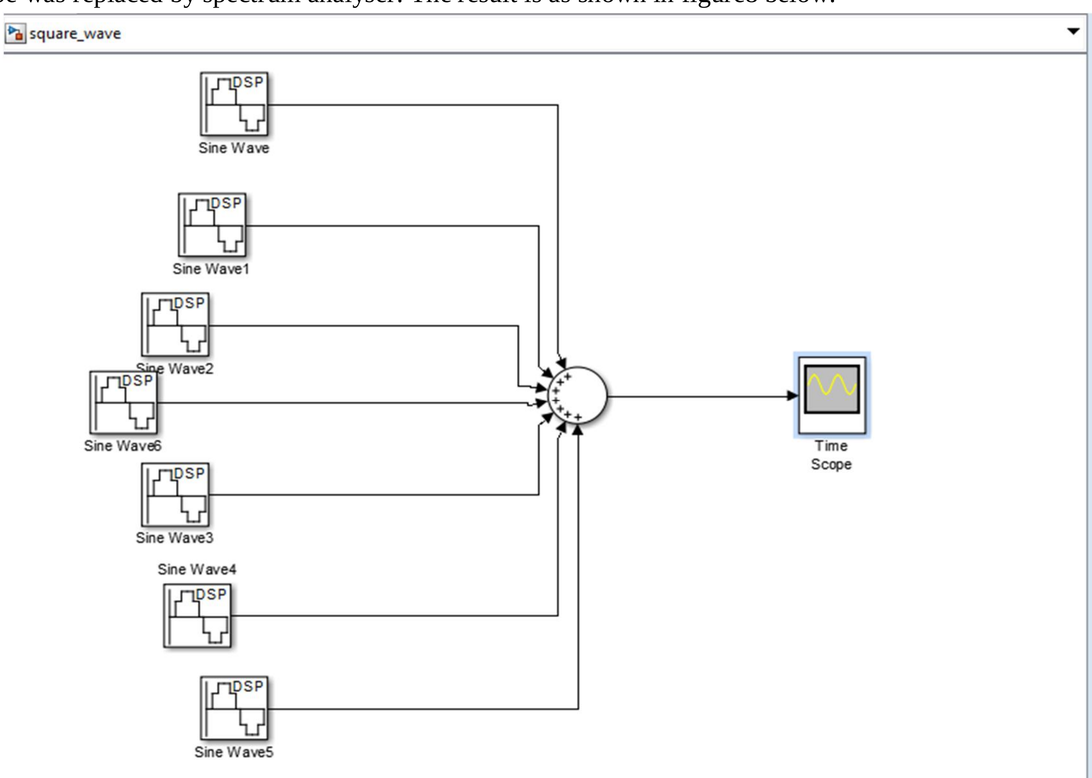

Figure5: Simulation with Time Scope

Each of the 'sine wave block' shown above was double clicked upon and its parameters were set as described below:

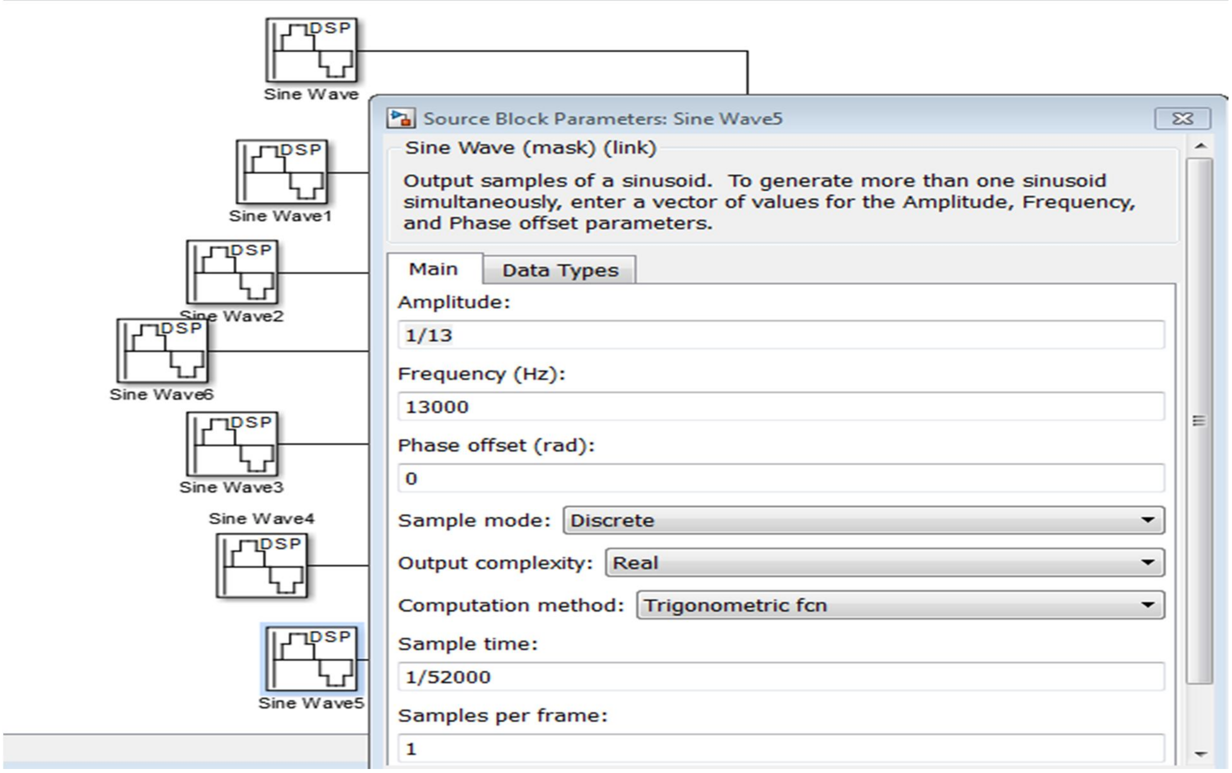

Figure6: setting of sine block parameters

All these parameters were set as proved in equation 6 above.
The amplitude of the first sine wave block was set to one (1), its frequency to 1000Hz and Sample time to 1/52000.
Parameter of each block was set accordingly. The second block which was to give the first harmonic had its amplitude set to one third (i.e. 1/3) of the amplitude of the fundamental frequency while its frequency was multiplied by three (3).
This continued by setting each dividing the amplitude of each sine block by 'n' and multiplied its frequency by 'n'. Where 'n' is the nth position of each harmonic in the Fourier series.
Sample time was set following Nyquist-Shannon sampling theorem which states that:

$2f_b > fs$, where fs= sampling frequency and f_b= frequency bandwidth.

Since the highest harmonic has a frequency is 13000Hz which is equivalent to frequency bandwidth, I chose my Sampling frequency to be 52000Hz.
Frequency (F)= 1/Period (T),
fs= 1/T = 1/52000
fs = 52000Hz.

	Amplitude (m)	Frequency(kHz)
Fundamental frequency	1	1.00
First odd harmonic	1/3 = 0.33	3.00
Second odd harmonic	1/5 = 0.20	5.00
Third odd harmonic	1/7 = 0.142	7.00
Fourth odd harmonic	1/9 = 0.111	9.00
Fifth odd harmonic	1/11 = 0.091	11.00
Sixth odd harmonic	1/13 = 0.077	13.00

Table1: showing amplitudes and frequencies of harmonics and their fundamental frequency

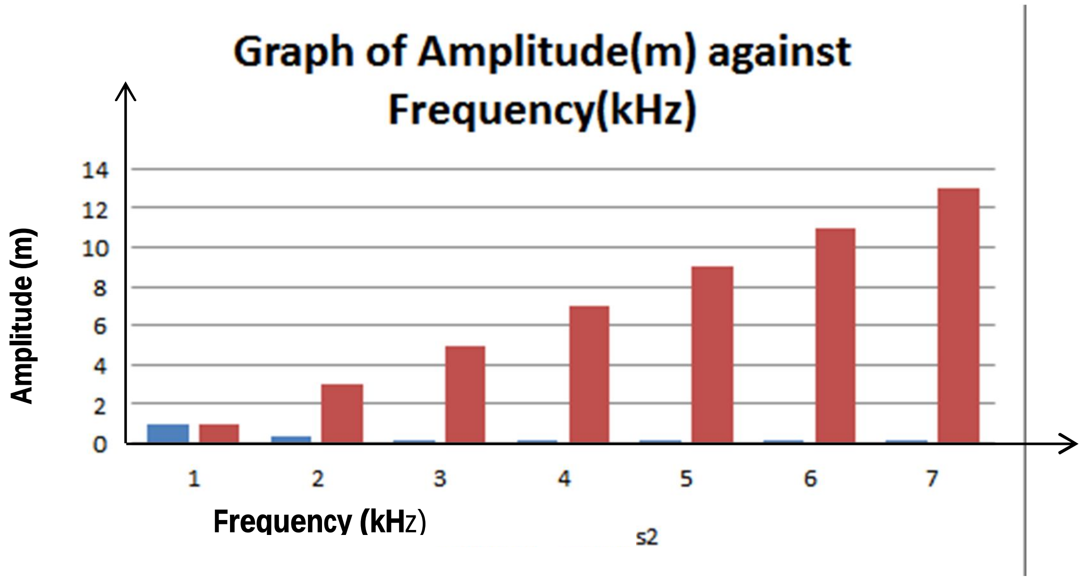

Figure7: Harmonic frequencies in a square wave with a fundamental frequency of 1000Hz(1kHz).

After setting all the necessary parameters, the model was simulated and the given output is as shown in the figure7 below:

Figure7: square wave formed by adding seven(7) sine waves together

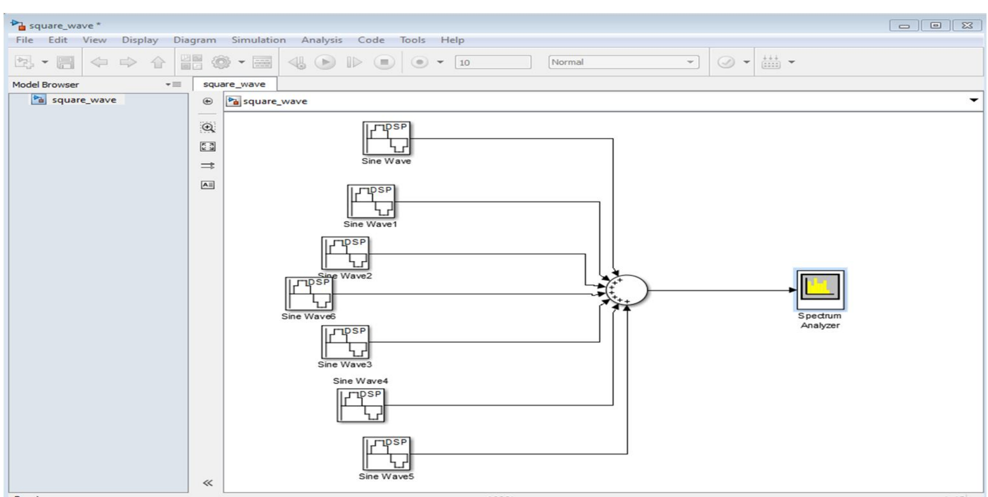

Figure8: simulation with spectrum analyser

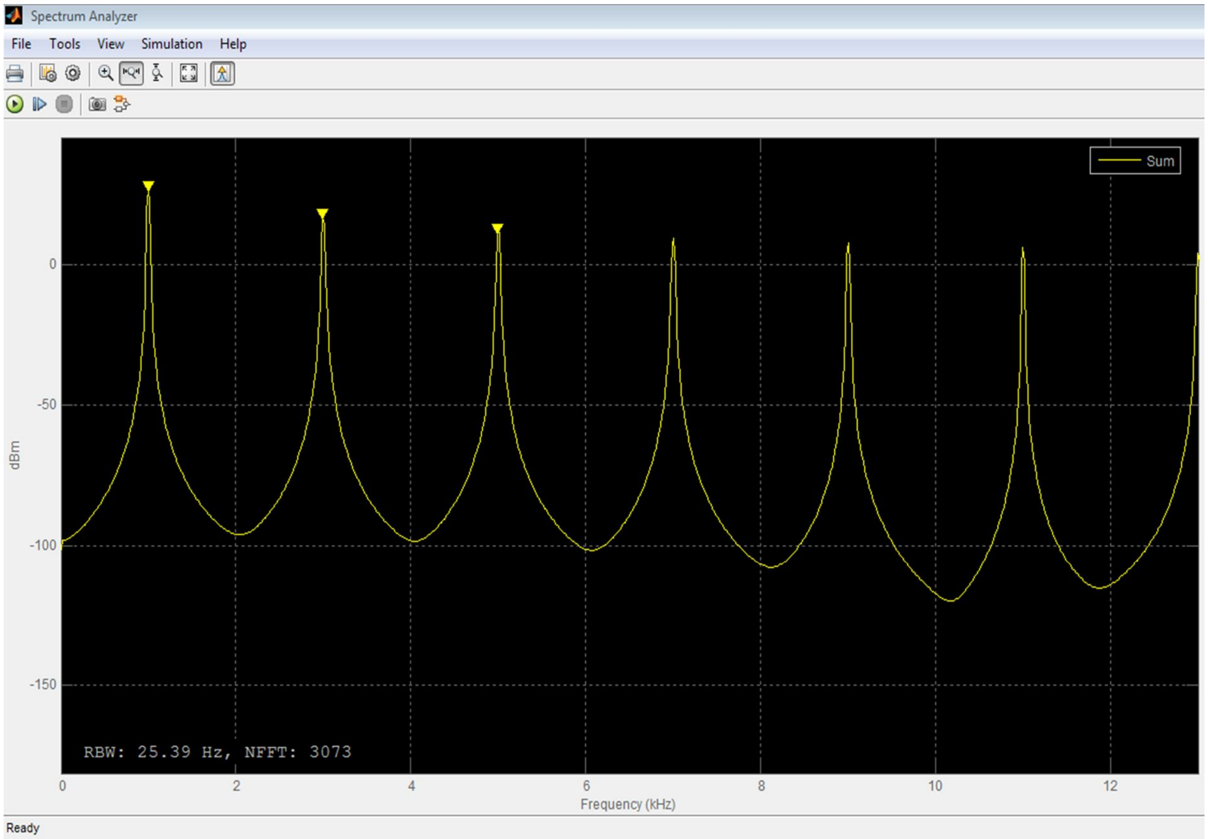

Figure8: output spectrum Analyzer showing fundamental frequency(at 1kHz) and its harmonics

Figure8 above is showing harmonic frequencies in a square wave with a fundamental frequency of 1000Hz(1kHz).

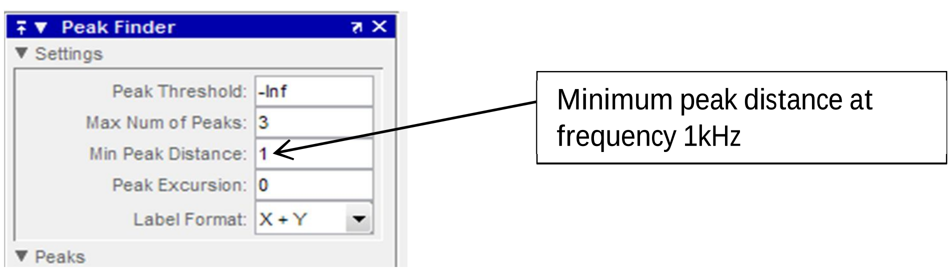

Figure10: Spectrum Analyzer peak finder indicating the peak of the fundamental frequency as 1kHz.

2) Conclusion

a) When odd harmonics and their fundamental frequencies are summed together, a square wave is formed. The more harmonics are added that added together the sharper the shape of the generated square waveform become.

b) The square wave formed is not a

G. To Show how a Periodic non-sinusoidal Frequency Decomposes to Different Sine Signals

The generated square waveform shown in figure7 above was decomposed in the MATLAB IDE environment as described below: From the Simulink Library Browser 'Simulink' was clicked upon followed by ' Math Operations' then 'subtract block' was dragged to the Model window and dropped. Output of the generated square wave was connected to the 'subtract block' and sine waves were subtracted from it in six times and 'Time Scopes' were connected to some of the 'Subtract blocks' to show waveform generated at such stages. This is as shown in figure11 below:

The square waves decomposed to different harmonics and their fundamental frequencies.

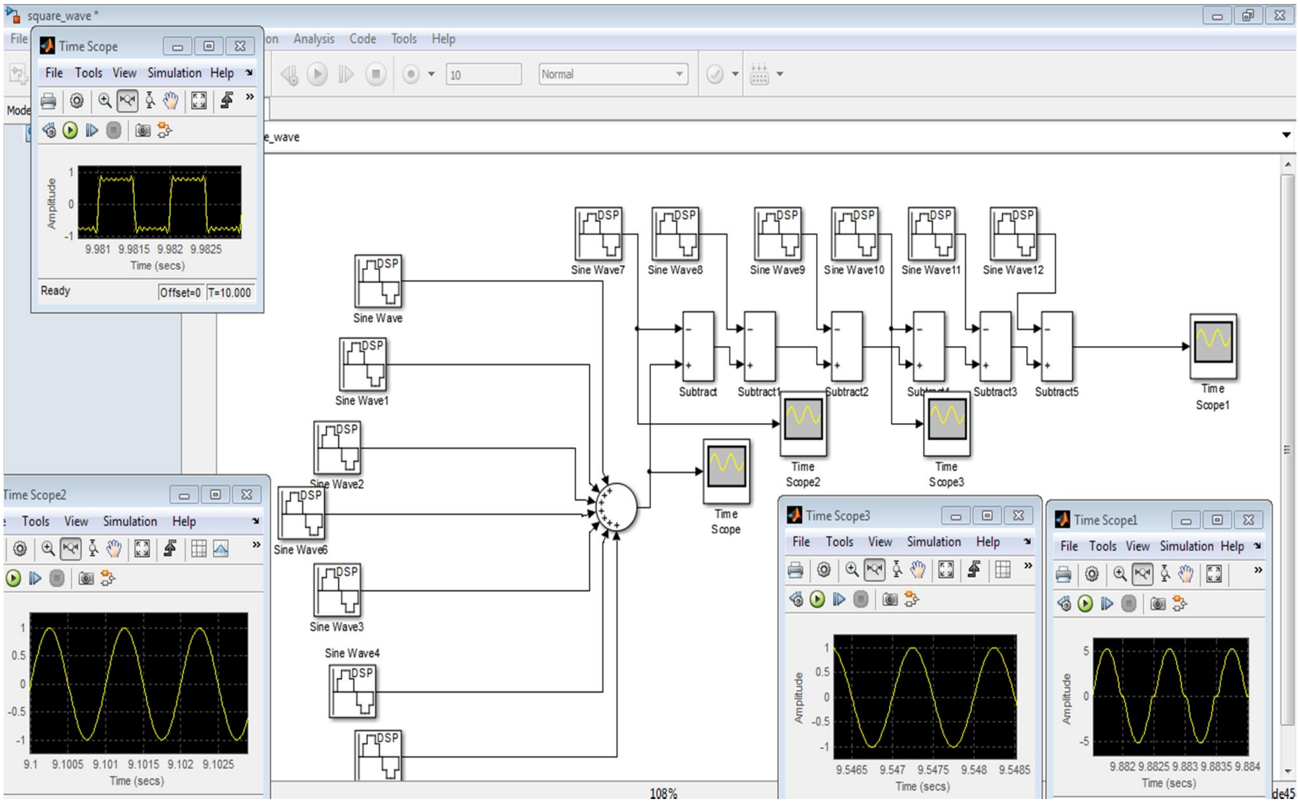

Figure11: showing decomposed square wave

II. CONCLUSION

Any periodic non-sinusoidal waveform can be decomposed to different sine waves.

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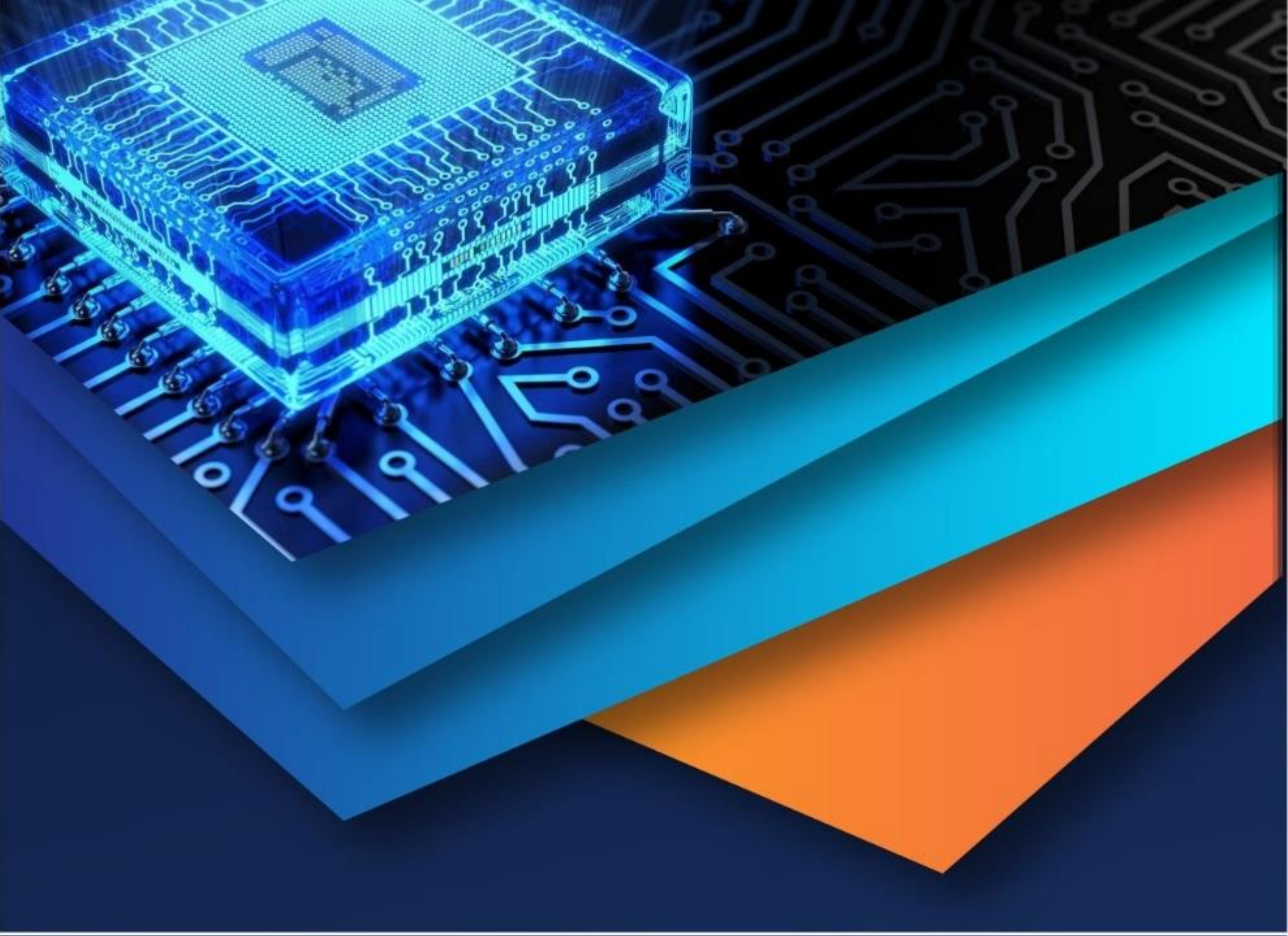

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