SIGNALS SPECTRAL ANALYSIS AND DISTORTION MEASUREMENTS USING AN OSCILLOSCOPE, A CAMERA AND A PC

A. A. Azooz

Department of Physics, College of Science, Mosul University Mosul – Iraq

S. K. Talal

Department of Physics, College of Education, Zakho University, Zakho – Iraq

ABSTRACT

This work describes a relatively simple yet effective method for analyzing harmonic distortions and spectral analysis of electronic signals up to the MHz range. The method involves the use a suitable analog or digital oscilloscopes to present the signal, taking a digital picture of the oscilloscope screen, converting the oscilloscope trace to numerical data and performing fast Fourier transform on the data. All MATLAB based software needed for the procedure is given. The results involve the spectrum analysis plot, the overall distortion, and all frequencies up to the tenth harmonic together with their relative amplitudes with respect to that of the fundamental frequency. The program provides for any user's selected frequency band analysis to be presented.

1. INTRODUCTION

The problems related to estimating, measuring and trying to eliminate distortions present in many types of electronic signals are of importance   to electronics and signal processing engineers [1, 2]. Distortion meters, and spectrum analyzers have become essential tools for anyone working in this field. These devices have reached a high level of sophistication. This has come at a material price [3]. Consequently, and although many private enterprises in the fields of power transmission, audio industry and radio communications are able to afford having these measuring equipments, under many circumstances, life may not be that easy else where. Field workers and many undergraduate labs in developing countries are just two examples of such situations. This is particularly true when working with frequencies in the MHz up range. From electronic engineering point of view, most signal analysis and distortion measurements lab experiments are performed in the audio frequency range. This is due to the fact that audio frequency analyzers are much less

expensive. However, distortions and inter-modulation problems associated with high frequency distortion can on many situations be different in causes, nature and consequences from those at audio frequencies. For these reasons, it would be useful to have a cheap, yet effective method to analyze these distortions and harmonics on both teaching and application levels.

All undergraduate physics and electronics engineering labs do indeed have, and use oscilloscopes. Typical analog or digital oscilloscopes now days can handle signals of few MHz at least. A 100 MHz signal will produce a ten wave's trace on a 10 MHz oscilloscope. Many modern digital oscilloscopes have the facility to digitize these traces. However, these again may not be affordable in many developing countries. Computers on the other hand, have become an integral part of most laboratories. Digital camera equipped cell phones have also become an integral part of every student's life. Motivated by these realities of life, one is encouraged to design experiments related to frequency analysis and distortion measurements at both audio and radio frequencies.

2. EXPERIMENTAL PROCEDURE, MEASUREMENTS AND RESULTS

The experimental procedure for this analysis is simple. The signal to be analyzed is connected to the oscilloscope and a stable trace of few full waves is produced. A snapshot with the digital or cell phone camera is taken for each signal to be analyzed. Care should be taken to avoid shadows and reflections on the oscilloscope screen. The camera must be stable and parallel to the screen. An adjustable holder is useful for the purpose. Once the pictures are taken, they can be transferred to a PC which has MATLAB program installed. The use of MATLAB should not be of much concern. This is because most physics and engineering student do indeed take MATLAB courses at some stage or another, and the following analysis and software presented here are made user friendly to a high degree.

The main issue now is to convert the trace in each picture to a reasonable number of experimental data points. Software named "oscilloscope" written by the one of authors can be freely downloaded and used from the MATLAB file exchange library for this purpose [4, 5]. The software is easy to use. The downloaded zip file contains full step by step instructions on how to use the program to convert digital pictures to numerical data with a high degree of accuracy. Figure (1) shows few examples of such conversions for several wave forms. Alternatively, and if one is at the luxury of having a digital data logging oscilloscope, data can be directly saved on the hard drive and the previous steps of acquiring data from screen pictures can be skipped.
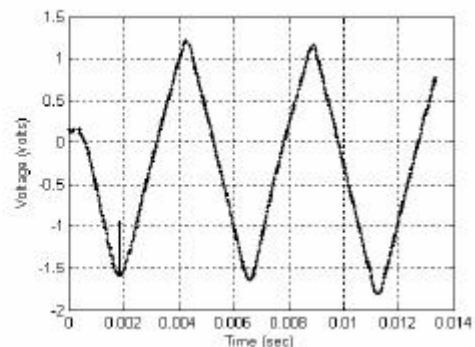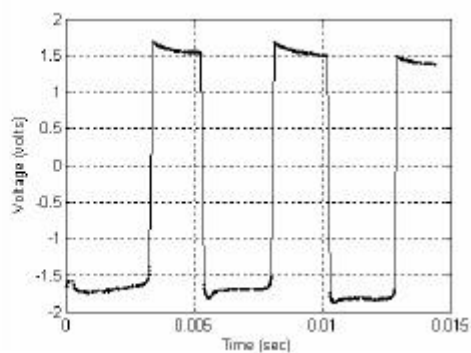
(a)   (b)

(c)   (d)

Figure (1) Two sample results of converting oscilloscope traces to numerical data using the software "oscilloscope"(a) an 800x600 pixel screen photo of a 200 Hz 3.3 Vpp triangular signal (b)- Plot of 999 retrieved data from the trace in a. (c) picture of rectangular signal trace, (d) plot of 512 data points retrieved from (c)

Once numerical data of each wave form are obtained, fast Fourier analysis of the signal can be carried out.

Software named *"Spectrum_Analyser (time, voltage, f1, f2, delta)"* written for this purpose. The software can be freely downloaded from the MATLAB file exchange website [6]. The input arguments to the software are the time t and signal voltage variable v. The accurate scaling of v is not important because the program needs to analyze the signal shape only. The input parameters f1, and f2 are the upper and lower frequency limits defining the bandwidth of the spectrum that will appear. The input parameter delta is a measure of the output data spacing. It can range between 0.001 and 0.1. Using lower values of delta produces more smooth plots but at the expense of CPU time and RAM memory. The Spectrum Analyzer software can be copied, pasted to a new MATLAB M-file and saved in the MATLAB work directory (This is where MATLAB saves all user data and program files by default). The previously mentioned Oscilloscope software should also be saved there together with all digital pictures.

Once the program is activated by entering the statement, "Spectrum Analyzer (t, v, 0, 10^7, 0.001) for example, the program will automatically produce the following outputs:

1- A spectrum analysis plot with bandwidth between f1 and f2 showing all

   relative amplitudes of all frequency contents in the original signal.

2- Numerical output of frequencies and relative amplitudes of first ten most

   prominent peaks in the spectrum.

3- The over all percentage distortion of the signal.

   The overall distortion D is calculated using the equation

$$D = \left[\frac{\sum\limits_{n=2} A_n^2}{\sum\limits_{n=1} A_n^2} \right]^{1/2} \qquad (1)$$

The software structure and the function of each step are described in the non executable comments statements (These are in green fonts) within the program. These are intended for interested MATLAB programmer or developer and to skip reading them and treating the software as a black box will not in any away affect the ordinary user.

In order to test the robustness of the software's ability to analyze signals, few known simulated signals were generated mathematically, and then analyzed by the program.

The first test involved the computer generation of 10 MHz pure sinusoidal signal, $v = \sin(2\pi \times 10^7 t)$. This test is used to asses the accuracy of automatic fundamental frequency estimation facility contained in the program and the effect of the number of complete wave cycles involved on the sharpness of the spectral lines. The numbers of cycles considered are 2, 10, 25, and 50. The results are shown in figure (2-a)

Figure (2) (a) Spectrum of a 10 MHz signal using different number of complete cycles. (b) Variation of FWHM derived from (a) with number of complete cycles analyzed.

It is clear from this figure that the software is successful in fully estimating the correct frequency in all cases. The value of the distortion obtained is practically zero. However, using small number of cycles is obviously associated with larger lines bandwidths. Even so, the bandwidth seems to drop almost exponentially as the number of cycles is increased. A value of

FWHM $= \Delta f / f \approx 5 - 10\%$ can be achieved using between 10 and 25 cycles. This range of

cycle numbers is easily distinguishable on an oscilloscope screen. Narrower lines can be obtained when numerical data logging is used instead of analyzing oscilloscope pictures.
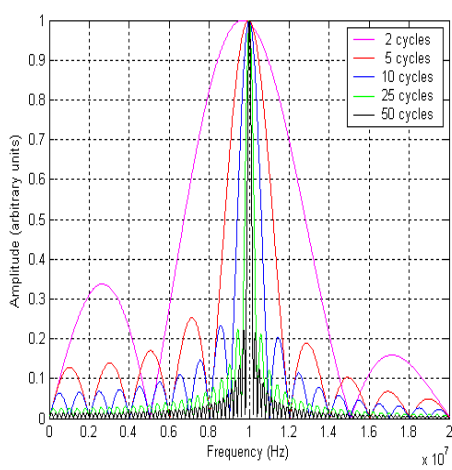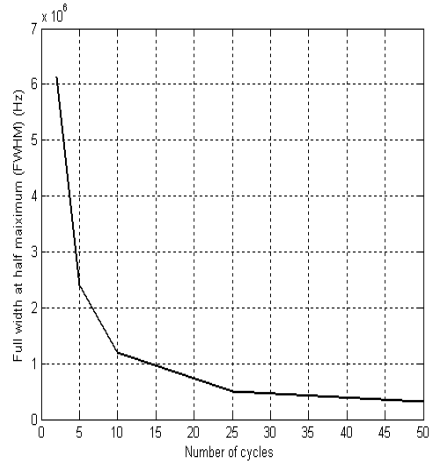
(a)   (b)

With the above point in mind, a computer generated 10 MHz saw-tooth signal is analyzed. This is carried out for the purpose of testing the software's ability to find the correct harmonic structure of this signal. The number of cycles used in the analysis is twenty five. It is known from analytical Fourier theory that a saw-tooth signal of angular frequency ω can be represented as

$$F(t) = \frac{2\alpha}{\pi}(\cos\omega t + \frac{1}{2}\cos 2\omega t + \frac{1}{3}\cos 3\omega t + \frac{1}{4}\cos(4\omega t) + \frac{1}{5}\cos(5\omega t) + ...)$$

(2)

α is the slope of the rising part of the signal. Figure(3) shows the frequency spectrum obtained.
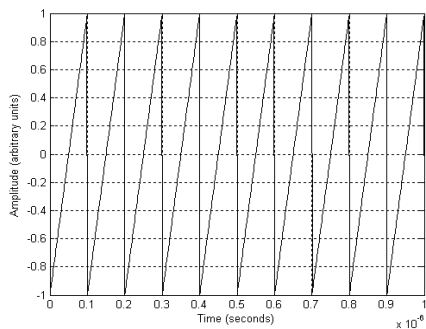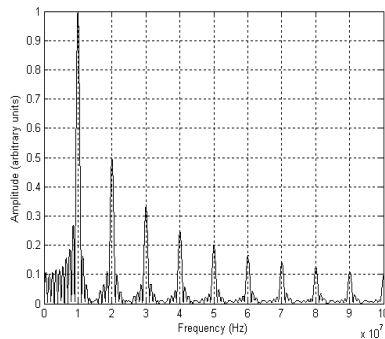
(a)   (b)
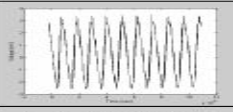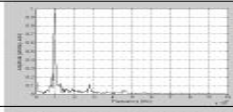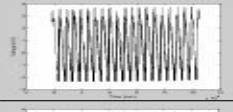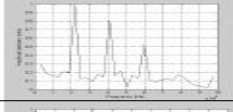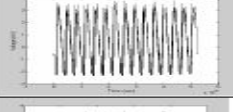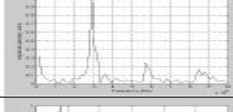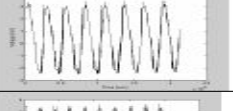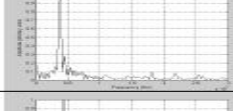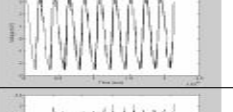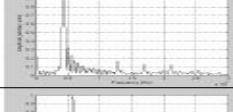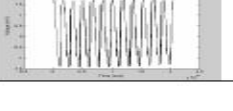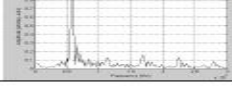
Figure (3) (a) simulated 10 MHz saw-tooth signal. (b) Frequency analysis spectrum obtained using the software showing only the first ten harmonics.
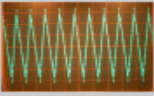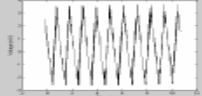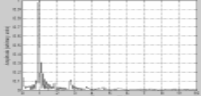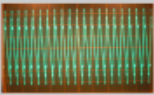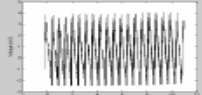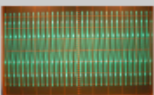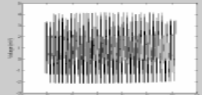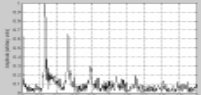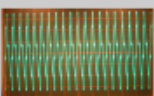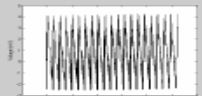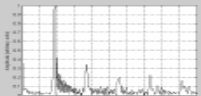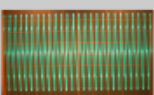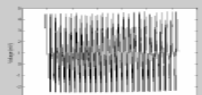
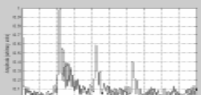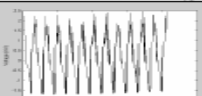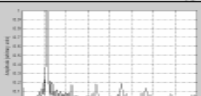It is clear from figure (3-b) that the program is very much successful in obtaining all the harmonics at the correct positions and with the correct amplitudes. The value of the distortion obtained is 59.6%. This is in good agreement with the theoretical value of 62% if one considers the first 100 terms of equation (2).
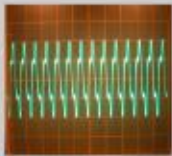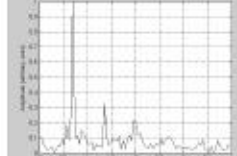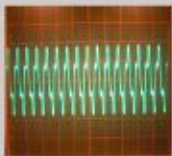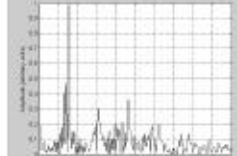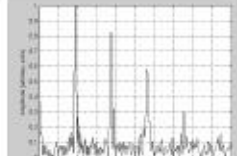
From the above simulation one may conclude that correct signal spectral analysis of data extracted from oscilloscope pictures similar to that of figure (3-a) can be performed if one can obtain relatively clear digital pictures from the oscilloscope screen of any signal at any frequency provided that the picture represents over twenty five full cycles of the fundamental frequency.

Several experimental test signals have been studied using this method. Signals are obtained from a 10 MHz Hung Chang model G305 sweep function generator connected to a Hung Chang 100 MHz model 5510 oscilloscope. Tests have shown that the generator is usually capable of producing up to 1 MHz sinusoidal, triangular or rectangular signals with only relatively small distortions. However and as one tries to gets into the higher frequency range, the generator tend to produce significantly more distorted signals. Signals in the 1-10 MHz frequency range are used as test signals. Two types of signals are analyzed. These are the sinusoidal and the triangular signals. Results of analysis are presented in tables (1) and (2) respectively.

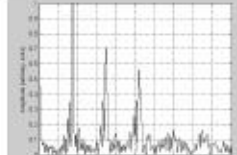**Table- 1.** Results of analysis of sinusoidal signals between 1 and 10 MHz

signal frequency & time base setting	CRO picture	Extracted data	Spectrum analysis	Over all distortion
1 MHz 1 μs/cm				21%
2 MHz 1 μs/cm				69%
3 MHz 0.5 μs/cm				29%
4 MHz 0.2 μs/cm				17%
5 MHz 0.2 μs/cm				28.5%
6 MHz 0.2 μs/cm				30%

signal frequency & time base setting	CRO picture	Extracted data	Spectrum analysis	Over all distortion
1 MHz 1 μs/cm				17%
2 MHz 1 μs/cm				30%
3 MHz 1 μs/cm				73%
4 MHz 0.5 μs/cm				52%
5 MHz 0.5 μs/cm				67%
6 MHz 0.2 μs/cm				38%
7 MHz 0.2 μs/cm				42%
8 MHz 0.2 μs/cm				60%
9 MHz 0.2 μs/cm				72%
10 MHz 0.2 μs/cm				76%

3. DISCUSSION

As it may appear from tables (1) and (2), the sweep generator produces distorted signals even at 1 MHz. However, and although the overall distortion is frequency dependent, this dependence tend to assume changing values as the frequency is increased. One point worth noticing is that the over all distortion of a triangular wave at 1 MHz is about 17% which is not much higher that the theoretical value of 12%. This indicates that the generator has a better performance at 1 MHz triangular wave than with sinusoidal. The approximately 1/10 third harmonic amplitude is another indication to the system reliability.

Tables also indicate that the results of analysis and the number of harmonics produced are directly related to the visual distortion of waves noted on the oscilloscope screen.

4. CONCLUSIONS

From above one may conclude that the system suggested can perform well in spite of the fact that it is a simple one. The MHz frequency range used here is not binding by any mean. These frequency values are selected for the simple reason that they are the highest available to us. The same analysis can be performed at any frequency provided that the oscilloscope can handle these frequencies.

REFERENCES

[1]   M. S. Sarma, *Introduction to electrical engineering*: Oxford University Press, 2001.

[2]   National Instruments, "Harmonic distortion measurement, tutorial document Sep 6," 2005.

[3]   http://www.testequipmentdepot.com/usedequipment/spectrumanalyzers.htm.

[4]   A. Azooz, *Instruments and Experimental Techniques,* vol. 54, pp. 364–368, 2011.

[5]   http://www.mathworks.com/matlabcentral/fileexchange/25007-oscilloscope.

[6]   http://www.mathworks.com/matlabcentral/fileexchange/28688-fully-automatic-signal-spectrum-analyser.