Studying The Effect of Window type On Power Spectrum Based On Mat Lab

Soad . T . Abed — **Assistant Lecturer**
Zena . E . Dallalbashi — **Assistant Lecturer**
Faten . A . Taha — **Assistant Lecturer**
Computer Department- Technical Institute of Mosul

Abstract
The representation that describes signal's frequency behavior can be divided into two categories: linear representation such as the Fourier-transform and quadratic representation such as power spectrum. Power spectrum characterizes the signal's energy distribution in the frequency domain, and can answer whether most of the power of the signal resides at low or high frequencies. By performing spectral analysis, some important features of signals can be discovered that are not obvious in the time waveform of the signal. One problem with spectrum analysis is that the duration of the signals is finite, although adjustable. Applying the FFT method to finite duration sequences can produce inadequate results because of "spectral leakage", to reduce the spectral leakage FFT window function is applied. Power spectrum parameters are window size, window type, window over lap and number of FFT. The aim of this work is to demonstrate the effect of varying window type on the power spectrum using Mat Lab software. Five windows have been compared to study their effect on the spectrum of a typical data.

Key word: power spectrum, window type, Matlab software **.**

دراسة تأثير نوع النافذة على قدرة الطيف باستخدام برمجيات Mat Lab

الخلاصة
تمثيل الإشارة التي تصف خواصها من حيث التردد تقسم إلى قسمين القسم الأول تمثيل خطي ويشمل تحليلات فورير والقسم الثاني غير خطي ويشمل قدرة الطيف . قدرة الطيف تصف توزيع الطاقة في حيز التردد. تحليل الطيف يبين وضعية قدرة الإشارة إذا كانت متمركزة في الترددات العالية أو في الترددات الواطئة. بتطبيق تحليل الطيف تظهر بعض الخواص المهمة للإشارات والتي لا يمكن ملاحظتها في حيز الزمن. احد المشاكل المتعلقة بتحليل الطيف فترة الإشارة تكون محددة بالرغم من تنظيمها. بتطبيق FFT على فترة محددة لإشارة معينة تكون النتائج غير دقيقة والسبب في ذلك يعود إلى تسرب الطيف. تستخدم دالة النافذة FFT لتقليل تسرب الطيف. تعتمد قدرة الطيف على نوع النافذة ، حجم النافذة، تداخل النافذة و عدد نقاط FFT. الغاية من هذا العمل دراسة تأثير تغير نوع النافذة على قدرة الطيف باستخدام برمجياتMat Lab. تم استخدام خمسة أنواع من النوافذ ومقارنة تأثير كل نوع على قدرة الطيف لبيانات مختلفة.

الكلمات الدالة: قدرة الطيف، نوع النافذة ، برمجيات Matlab

Introduction

Power spectrum is a representation of the magnitude of the various frequency components of a signal. By looking at the spectrum, one can find how much energy or power is contained in the frequency components of the signal. Power-spectrum analysis is an important tool providing critical information about a signal. The concept and use of power spectrum of a signal is fundamental in engineering, in communication systems, microwave and radars. Recently, it is also being used in diverse applications such as gene identification. There are a couple of techniques for generating the Power spectrum. One is by using the Fourier transform. The other techniques such as the wavelet transform or the maximum entropy method can also be used or by digitizing experimental data and performing a Fast Fourier Transform (FFT).[1]

The aim of this work is to demonstrate the effect of varying window type on the power spectrum using Mat Lab software. Five windows have been compared to study their effect on the spectrum of a typical data. The paper falls into four sections. After this introduction, a basic theory for power spectrum analysis is presented in section two. Results and description of speech and other signals and their representations is presented in section three. Conclusions are introduced in section four).

Theory

A spectrum is a relationship typically represented by a plot of the magnitude or relative value of some parameter against frequency. Every physical phenomenon, whether it is an electromagnetic, thermal, mechanical, hydraulic or any other system, has a unique spectrum associated with it. In electronics, the phenomena are dealt with in terms of signals, represented as fixed or varying electrical quantities of voltage, current and power.

These quantities are typically described in the time domain and for every function of time, f(t), an equivalent frequency domain function F(0) can be found that specifically describes the frequency-component content (frequency spectrum) required to generate f(t). A study of relationships between the time domain and its corresponding frequency domain representation is the subject of Fourier analysis and Fourier transforms. The forward Fourier transform, time to frequency domain, of the function x(t) is defined [2].

$$F[x(t)] = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt = X(\omega) \text{............(1)}$$

Fast Fourier Transform (FFT)

The Fast Fourier transform (FFT) is acomputational tool,which facilitates signal analysis such as power spectrum analysis and filter simulation by mean of digital computer. It is a method for efficiently computing the discrete Fourier transform of series of data samples (refer to as time series). It represents the frequency composition of the time signal. It is commonly used because it requires much less processing power than the Fourier Transform [4]. Like all shortcuts, there are some compromises involved in the FFT. The signal must be periodic in the sample window or leakage will occur. The signal must start and end at the same point in its cycle. Leakage is the smearing of energy from the true frequency of the signal into adjacent frequencies. Leakage also causes the amplitude representation of the signal to be less than the true amplitude of the signal. To help reduce this smearing and preserve the amplitude of a signal, windows are used. Windows work by weighting the start and end of a sample to zero while at the same time increasing the amplitude of the signal at the center as to maintain the average amplitude of the signal [1].

FFT and windowing

Windowing means that the time series to be transferred is multiplied by a window function before the FFT. So instead of x[i], we transform x[i]w[i] for some window function which promises to produce clearer spectral representation of the signal. The function of the window can be thought of as follows: every single frequency bin of the transformed signal is a linear combination of N time samples. If the signal to be transformed is a sine function, then, ideally, all these N samples add up in one bin and cancel out in all other bins, such that the sine will result as a single peak in the spectrum [3].Figure (1) shows how the Hamming window weights the beginning and end of the sample to zero so that it is more periodic during the FFT process.

Computations of Power Spectrum Using the FFT

The power spectrum analysis uses FFT to represent the magnitude of various frequency components of a signal. By observing the spectrum, one can find how much energy or power is contained in the different frequency components of the signal [1]. The power spectrum shows power as the mean squared amplitude at each frequency line but includes no phase information. Because the power spectrum loses phase information, FFT must be used to view both the frequency and the phase information of a signal. The phase information the FFT yields is the phase relative to the start of the time-domain signal. For this reason, trigger must be made from the same point in the signal to obtain consistent phase readings [5]. Figure (2) shows the power spectrum of the cosine wave using blackman window. The power spectrum calculated from the relation shown below:-

$$P_S = \left| FFT\,(x(t)) \right|^2 \quad \text{………………..(2)}$$

$x(t) \rightarrow time\ \ series$

Ps = power spectrum of *x(s)*

Speech signal

The speech signal is normally picked up as an analog electrical representation of the acoustic sound pressure as sensed by a microphone which can be analyzed, amplified, transmitted, or recorded using whatever kind of device is appropriate such as personal or larger computers. This has allowed for an ever growing system complexity that could never realistically be implemented with a nalog systems Digital signal processing (DSP) has expanded tremendously as a field of its own during the last few decades with important contributions from several diverse research disciplines, particularly those of speech There are number of speech analysis methods, spectrum analysis, linear predictive coefficients, and fast Fourier transform (FFT).

Spectrum analysis of speech signal

Spectrum analysis has always been a fundamental tool for description and parameter extraction in speech signal .Two basic representations are predominant, the spectrum section that pertains to a specified time interval and shows level versus frequency. The standard method of spectrograph is to multiply the signal with a time window of suitable length and shape, and finally find the spectral level by the logarithm of the squared magnitude. Figure (3) shows power spectrum of recorded speech using Hanning window.

Window Type:- To understand how a given window affects the frequency spectrum, the frequency characteristics of each window must be known. five kind of window types are discussed below and each window applied to the same signal. [6]

1-Hanning window

The Hanning window achieves a side-lobe reduction by superposition. Three Dirichlet kernels are shifted and added together resulting in partial cancellation of side lobe The amount of shift is 2pi/(N-1) from the center. The resulting characteristics of the Hanning window which is sometimes called the cosine window has a side-lobe level of –32 dB and a main lobe width of 8pi/N where, N is the number of samples.

$$W(n) = 0.5 - 0.5 \cos \frac{2\pi n}{N} \text{ ....}(3)$$

For n=0, 1,2,3,…,N-1

2-Hamming window

The Hamming window is similar to the Hanning window with modifications in weighting the Dirichlet kernels. The time and frequency domain windows are as follows. The main-lobe is 8pi/N with -43dB side-lobes. One characteristic is the non-zero values at both end points and therefore is sometimes referred to as the half-raised cosine window. N is the number of samples.

$$W(n) = .54 - .46 \cos \frac{2\pi n}{N} \text{ ....}(4)$$

For n= 0,1,2,………N-1

3-Blackman window

The Blackman window has a –57dB side- lobe and a main-lobe width of 12pi/N. N is the number of samples.

$$w[n] = \{0.42 - 0.5 \cos(2\pi n/M) + 0.08 \cos(4\pi n/M) \text{..}(5)$$

$For \quad o \le n \le M$

4-FlatTop

This window has the best amplitude accuracy of all the window functions. The increased amplitude accuracy (± 0.02 dB for signals exactly between integral cycles) is at the expense of frequency selectivity. The Flattop window is most useful in accurately measuring the amplitude of single frequency components with little nearby spectral energy in the signal. The Flat top window can be defined as

$$W(n) = a_0 - \left(a_1 \cos \frac{2\pi n}{N} + a_2 \cos \frac{4\pi n}{N} \right) \text{..}(6)$$

Where

$a0 = 0.2810638602$

$a1 = 0.5208971735$

$a2 = 0.1980389663$

5- Kaiser window

Kaiser window is useful in practice zeros-th order modified Bessel function of first kind.

$$w[n] = \begin{cases} I_0[\beta(1-[(n-\alpha)/\alpha]^2)^{1/2}], & 0 \le n \le M \\ 0, & else \end{cases}$$

Where a = M=2, I_0(.) is Bessel function M and b trade off side lobe amplitude and main lobe width.

Results

Choosing a Windowing Function

FFT Windows reduce the effects of leakage but cannot eliminate leakage entirely. In effect, they only change the shape of the spectrum in a slightly different way. Each owns its advantage and disadvantage relative to the others. Some are more effective for specific types of signal such as random or sinusoidal. Some improve the frequency resolution, that is, they make it easier to detect the exact frequency of a peak in the spectrum.

Some improve the amplitude accuracy, that is, they most accurately indicate the level of the peak. Windowing functions are most easily understood in the time domain; however, they are often implemented in the frequency domain instead. Mathematically there is no difference when the windowing is implemented in the frequency or in time domains though the mathematical procedure is somewhat different. When the window is implemented in the frequency domain, the FFT of the window function is computed one time and saved in memory and then it is applied to every FFT frequency value correcting the leakage in the FFT. This gives rise to one measure of the window's characteristics, known as the side lobe. The FFT of a window has a peak at the applied frequency and other peaks, called side lobes, on either side of the applied frequency. The height of the side lobes indicates what affect the windowing function will have on frequencies around the applied frequency. In general, lower side lobes reduce the leakage in the measured FFT but increase the bandwidth of the major lobe. The most common windows and their features are given in table 1and table 2, these tables can be used to choose the best windowing function [6] for each application. A comparison of power spectrum of cosine wave without using window and power spectrum of the same wave using hamming window is shown in Figure 4. It can be seen from the spectrum plots that both plots have their peak amplitude at f=30Hz corresponding to the signal frequency, while the power spectrum plot without using window has a narrower main lobe, the power spectrum using hamming window provides less peak side lobes than the power spectrum plot without using window.

Figure 5 shows a comparison of power spectrum of x(t) using Kaiser window and power spectrum of the same wave using blackman windows. The spectral leakage in the power spectrum is less when using Kaiser window because the side lobe of kaiser window less than the side lobe of blackman window. Figure (6) shows a comparison of power spectrum of x(t) using blackman window, hamming windows and Hanning windows. Figure 7 shows a comparison of power spectrum of x(t) using Hanning window, hamming window and Kaiser window and flattop window. A comparison of power spectrum of recorded speech is made when using flattop window and when using Kaiser window as shown in figure 8.

Conclusions

Each window has its own characteristics; five windows are used for different application. The Hann window is satisfactory in 95% of cases. It has good frequency resolution and reduced spectral leakage. The Flat Top window has good amplitude accuracy, but because it has a wide main lobe, it has poor frequency resolution and more spectral leakage. The Flat Top window has a lower maximum side lobe level than the Hann window, but the Hann window has a faster roll off-rate. If the nature of the signal is not known but window must be applied, start with the Hanning window. If the signal spectrum is rather flat or broadband in frequency content, the Uniform window (no window) must be used. In general, a window with a high side lobe roll-off rate must be chosen. If there are strong interfering signals near the frequency of interest, a window with a low maximum side lobe level must be chosen. If the frequency of interest contains two or more signals very near to each other, spectral resolution is important. In this case, it is best to choose a window with a very narrow main lobe. If the amplitude accuracy of a single frequency component is more important than the exact location of the component in a given frequency bin, choose a window with a wide main lobe.

References

1. Yogindra Abhyankar, Sajish C, Yogesh Agarwal, C.R. Subrahmanya, Peeyush Prasad. "High Performance Power Spectrum Analysis Using a FPGA Based Reconfigurable Computing Platform", Published in the Proceedings of the IEEE International conference on Reconfigurable Computing and FPGAs (ReConFig 2006.
2. Power Spectra Estimation National Semiconductor Application Note 255 November 1980
3. Hanspeter Schmid_ c .How to use the FFT for signal and noise simulations and measurements, c: May 13, 2009
4. William T. Cochran, James W. Cooley, David E. Nelsom Member what FFT G-AE Subcommittee Measurement Concepts IEEE. IEEE TRANSACTIONS on audio and Electro acoustic, Vol. AU-15 NO. 2 June 1967.
5. Michael Cerna and Audrey F. Harvey, "The Fundamentals of FFT-Based Signal Analysis and Measurement Application", Technology paper, February 2003.
6. Prof: J. Bilmes ,TA: Mingzhou Song ,EE518 Digital Signal Processing University of Washington Autumn 2001 Dept. of Electrical Engineering Lecture 17: FIR Design by Windowing, Kaiser Window & Optimal Approximation Nov. 28, 2001

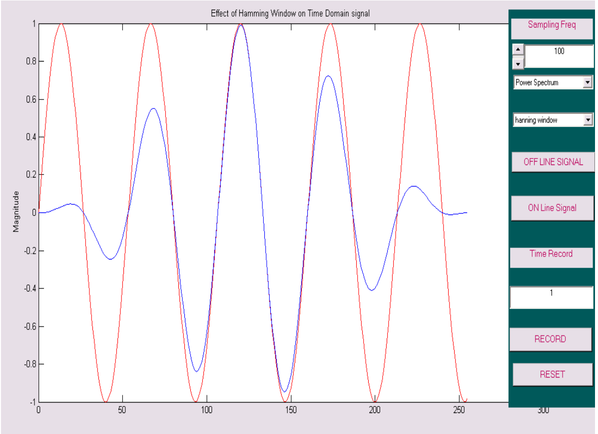

Figure (1) Effect of hamming window on time domain

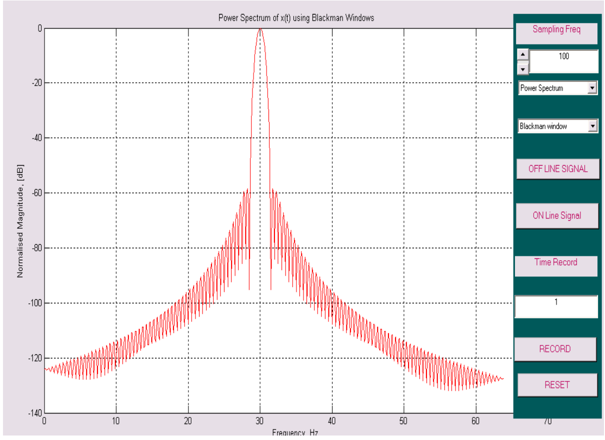

Figure (2) power spectrum of x(t) using blackman window

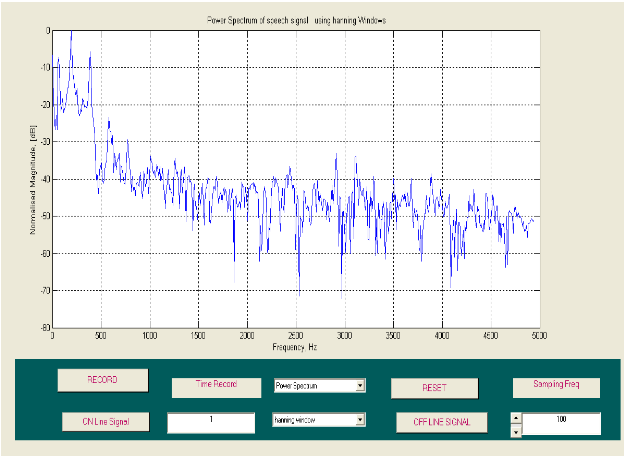

Figure (3) Power spectrum of recorded speech using hanning window

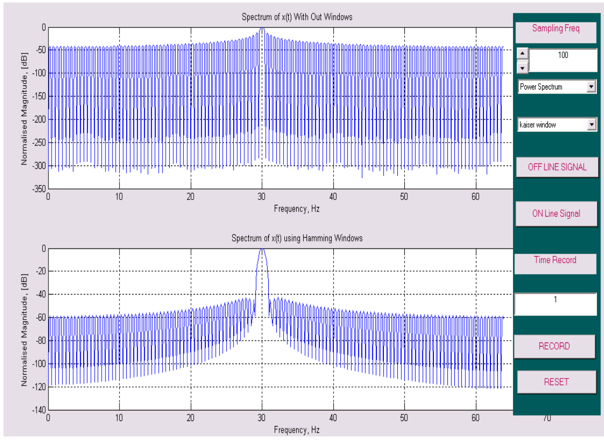

Figure (4) the upper plot power spectrum of cosine wave with out using window , the bottom plot power spectrum of cosine wave using hamming window

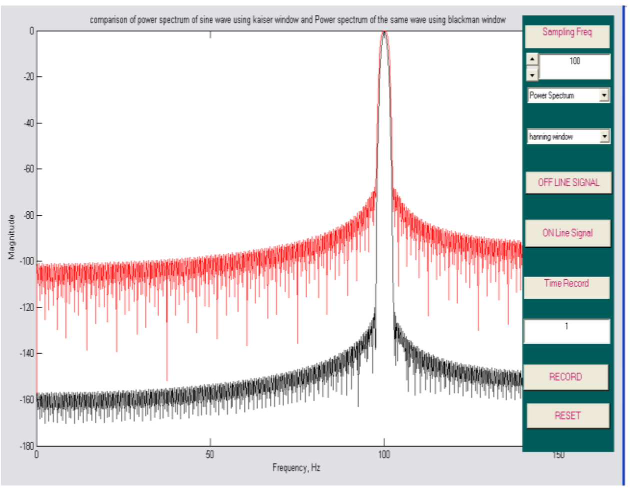

Figure (5) shows a comparison of power spectrum of of x(t) using kaiser window and using blackman windows

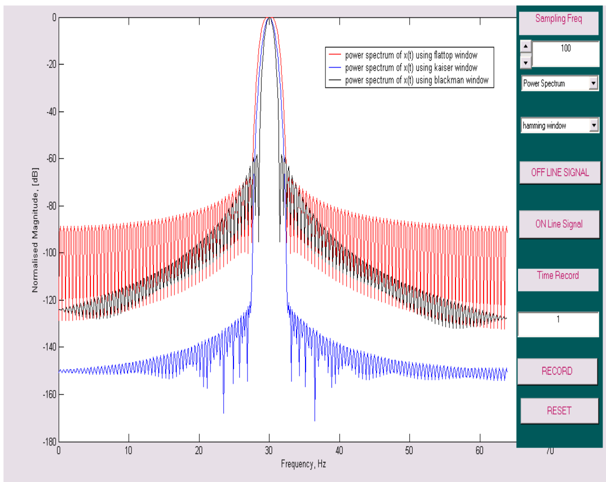

Figure (6) shows a comparison of power spectrum of of x(t) using blackman window, hamming windows and hanning windows.

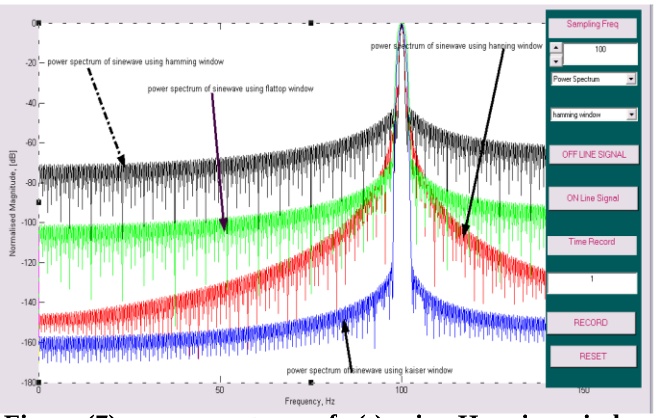

Figure (7) power spectrum of x(t) using Hanning window, hamming windows, kaiser windows and flattop window.

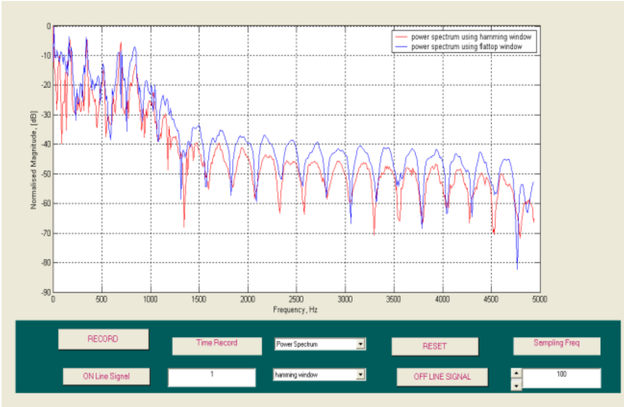

Figure (8) Comparison of power spectrum of recorded speech using flattop window and using Kaiser window

Table (1) Common windows and their features

Window function	Best for these Signal Types	Frequency Resolution	Spectral Leakage	Amplitude Accuracy
Hanning	Random or mixed	Poor	Best	Good
Hamming	Sinusoids	Poor	Good	Best
Blackman	Random	Good	Good	Fair
Flattop	Random	Good	Fair	Fair
Kaiser -Bessel	Random	Fair	Good	Good

Table (2) Window Weighting Characteristics in FFT Analysis

Window function	-3 dB Main Lobe Width	-6 dB Main Lobe Width	Maximum Side Lobe Level (dB)	Side Lobe Rolloff Rate (dB/decade)
Hanning	1.44	2.00	-32	60
Hamming	1.30	1.81	-43	20
Blackman	1.68	2.35	-58	60
Flattop	2.94	3.56	-44	20
Kaiser -Bessel	1.80	2.39	-69	60