FINAL REPORT

Frequency Spectrum and Applications of Signal Spectrum

COURSE TITTLE: -	DIGITAL SIGNAL PROCESSING
NAME: -	JADOON AHMER KHAN
STUDENT ID: -	201414020106
DEPARTMENT: -	ELECTRONICS ENGINEERING
COUNTRY: -	PAKISTAN
SUBMMITED TO: -	Assoc. Prof. JING RAN LIN
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Q# Why the frequency spectrum is meaningful, talk about some engineering applications of signal spectrum.

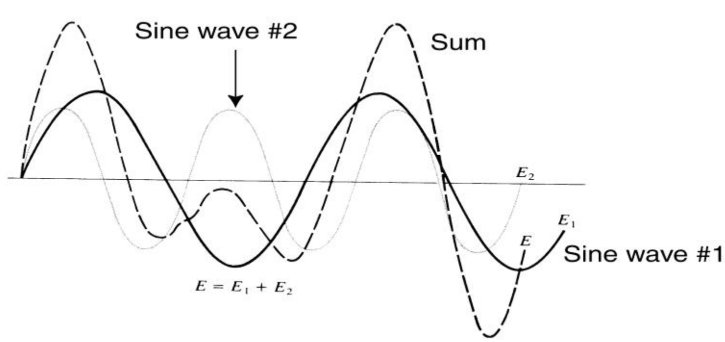
INTRODUCTION

With the frequency domain analyses, signals are decomposed to the sum of fundamental sinωt and its harmonics, and the system response for sinωt could be attracted attention only.

The **frequency spectrum** of a time-domain signal is a representation of that signal in the frequency domain. The frequency spectrum can be generated via a Fourier transform of the signal, and the resulting values are usually presented as amplitude and phase, both plotted versus frequency. Why would we do the exchange between time domain and frequency domain? Because we can do all kinds of useful analytical tricks in the frequency domain that are just too hard to do computationally with the original time series in the time domain. Over 80% of all DSP applications require some form of frequency domain processing. Time-domain graph shows how a signal changes over time, whereas a frequency-domain graph shows how much of the signal lies within each given frequency band over a range of frequencies. A frequency-domain representation can also include information on the phase shift that must be applied to each sinusoid in order to be able to recombine the frequency components to recover the original time signal.

A given function or signal can be converted between the time and frequency domains with a pair of mathematical operators called a transform. An example is the Fourier transform, which decomposes a function into the sum of a (potentially infinite) number of sine wave frequency components. The 'spectrum' of frequency components is the frequency domain representation of the signal. The Inverse converts the frequency domain function back to a time function.

Frequency domain measurements have several distinct advantages. For example, let's say you are looking at a signal on an oscilloscope that appears to be a pure sine wave. A pure sine wave has no harmonic distortion. If you look at the signal on a spectrum analyzer, you may find that your signal is actually made up of several frequencies. What was not discernible on the oscilloscope becomes very apparent on the spectrum analyzer.

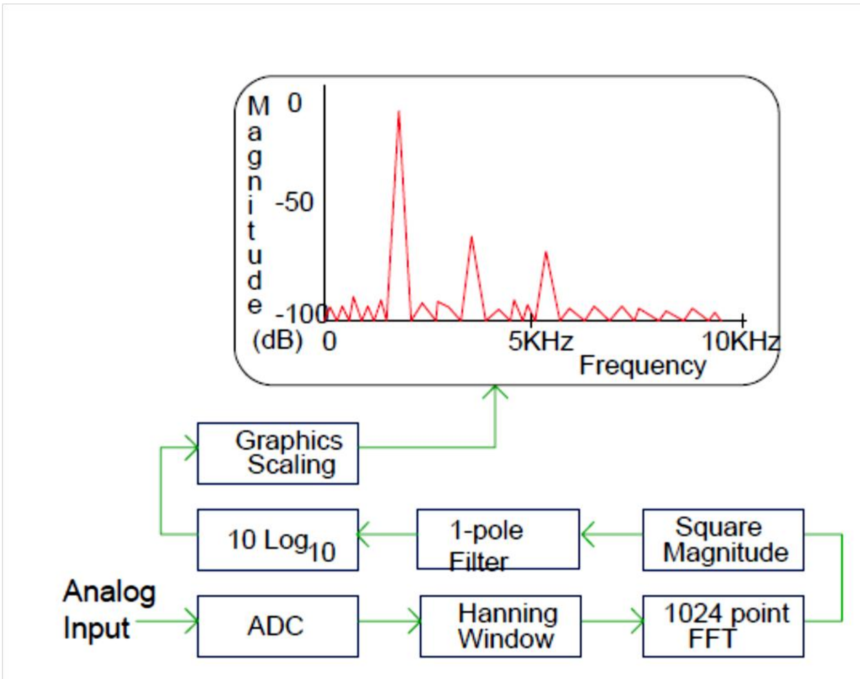


SPECTRUM ANALIZER

If you are designing, manufacturing, or doing field service/repair of electrical devices or systems, you need a tool that will help you analyze the electrical signals that are passing through or being transmitted by your system or device. By analyzing the characteristics of the signal once its gone through the device/system, you can determine the performance, find problems, troubleshoot, etc. How do we measure these electrical signals in order to see what happens to them as they pass through our device/system and therefore verify the performance? We need a passive receiver, meaning it doesn't do anything to the signal - it just displays it in a way that makes it easy to analyze the signal. This is called a spectrum analyzer. Spectrum analyzers usually display raw, unprocessed signal information such as voltage, power, period, wave shape, sidebands, and frequency. They can provide you with a clear and precise window into the frequency spectrum. Depending upon the application, a signal could have several different characteristics. For example, in communications, in order to send information such as your voice or data, it must be modulated onto a higher frequency carrier. A modulated signal will have specific characteristics depending on the type of modulation used. When testing non-linear devices such as amplifiers or mixers, it is important to understand how these create distortion products and what these distortion products look like. Understanding the characteristics of noise and how a noise signal looks compared to other types of signals can also help you in analyzing your device/system. Understanding the important aspects of a spectrum analyzer for measuring all of these types of signals will help you make more accurate measurements and give you confidence that you are interpreting the results correctly.

The most common spectrum analyzer measurements are: modulation, distortion, and noise. Measuring the quality of the modulation is important for making sure your system is working properly and that the information is being transmitted correctly. Understanding the spectral content is important, especially in communications where there is very limited bandwidth. The amount of power being transmitted (for example, to overcome the channel impairments in wireless systems) is another key measurement in communications. Tests such as modulation degree, sideband amplitude, modulation quality, occupied bandwidth are examples of common modulation measurements. In communications, measuring distortion is critical for both the receiver and transmitter. Excessive harmonic distortion at the output of a transmitter can interfere with other communication bands. The pre-amplification stages in a receiver must be free of intermodulation distortion to prevent signal crosstalk. An example is the intermodulation of cable TV carriers that moves down the trunk of the distribution system and distorts other channels on the same cable. Common distortion measurements include intermodulation, harmonics, and spurious emissions. Noise is often the signal you want to measure. Any active circuit or device will generate noise. Tests such as noise figure and signal-to-noise ratio (SNR) are important for characterizing the performance of a device and/or its contribution to overall system noise.

For all of these spectrum analyzer measurements, it is important to understand the operation of the spectrum analyzer and the spectrum analyzer performance required for your specific measurement and test specifications. This will help you choose the right analyzer for your application as well as get the most out of it.



APPLICATIONS OF FREQUENCY SPECTRUM ANALYSIS:

From the view of the spectrum, measurements of frequency, power, harmonic content, modulation, spurs, and noise can easily be made. Given the capability to measure these quantities, we can determine total harmonic distortion, occupied bandwidth, signal stability, output power, intermodulation distortion, power bandwidth, carrier-to-noise ratio, and a host of other measurements, using just a Frequency domain analysis. The meaning of the analytical results can be quite different, of course, but as long as we understand the transform relation clearly and capture that in the application design, then the time-domain and frequency-domain procedures are remarkably similar. In some applications, the results of this analysis convey the signal content. For other tasks, an inverse transformation back to the time domain is required. In any case, the principal tools are the Fourier transform and its inverse, in both their analog and discrete formulations.

APPLICATIONS IN SIGNAL PROCESSING

When processing signals, such as audio, radio waves, light waves, seismic waves, and even images, Fourier analysis can isolate individual components of a compound waveform, concentrating them for easier detection and/or removal. A large family of signal processing techniques consist of Fourier-transforming a signal, manipulating the Fourier-transformed data in a simple way, and reversing the transformation.

Some examples include:

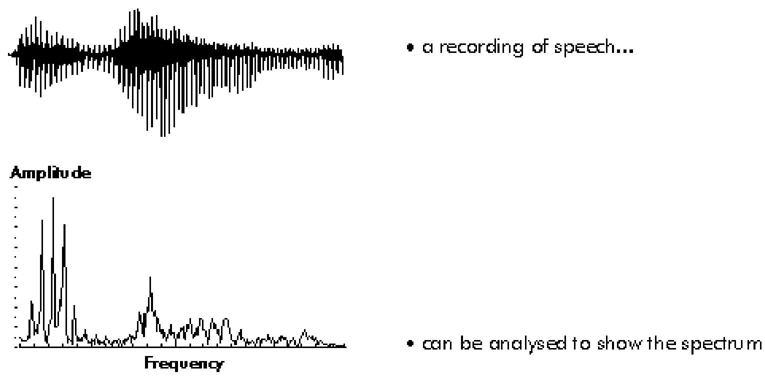
- Equalization of audio recordings with a series of bandpass filters;
- Digital radio reception with no superheterodyne circuit, as in a modern cell phone or radio scanner;
- Image processing to remove periodic or anisotropic artifacts such as jaggies from interlaced video, stripe artifacts from strip aerial photography, or wave patterns from radio frequency interference in a digital camera;
- Cross correlation of similar images for co-alignment;
- X-ray crystallography to reconstruct a crystal structure from its diffraction pattern;
- Fourier transform ion cyclotron resonance mass spectrometry to determine the mass of ions from the frequency of cyclotron motion in a magnetic field.
- Many other forms of spectroscopy also rely upon Fourier Transforms to determine the three-dimensional structure and/or identity of the sample being analyzed, including Infrared and Nuclear Magnetic Resonance spectroscopies.
- Generation of sound spectrograms used to analyze sounds.
- Passive sonar used to classify targets based on machinery noise.

APPLICATION IN FREQUENCY SELECT FILTRING:

The concepts of phase and group delay arose in frequency-domain signal analysis applications where discrete filters were necessary. Applications that filter incoming signals for noise removal, frequency selection, or signal shaping and then analyze the output must take into account the delay characteristics of the filter. We observed the phase delay of sinusoidal tones in the DTMF filter bank application, for example. Other applications involve group delay, such as speech analysis and edge detection. Many applications require that the filters provide linear, or nearly linear, phase. In communication systems, for example, the information is carried on the envelope and the carrier has a constant frequency. Thus, nonlinear phase delay could well stretch and compress the frequencies in the signal so that the distortions render the signal unintelligible. Important aspects of seismic signal processing are to properly measure the time delays between different signal components. Thus, linear phase is crucial when filtering; and for this reason, finite impulse response (FIR) filters, which we proved to have linear phase, are preferred.

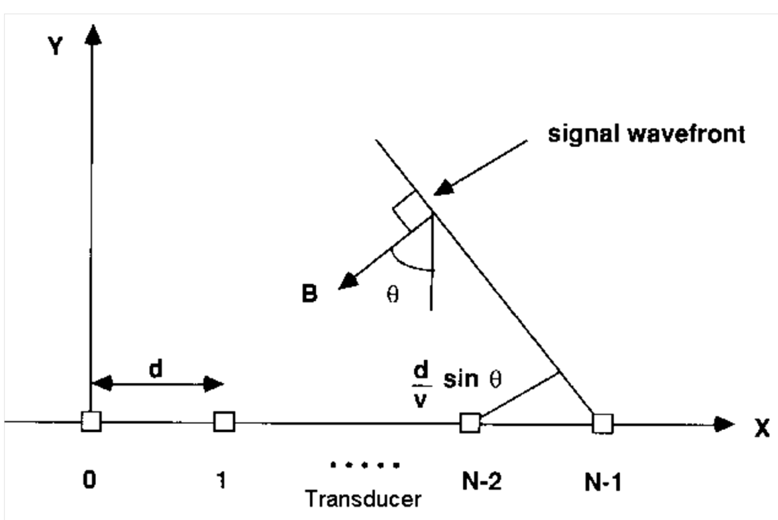
APPLICATION IN DIGITAL AUDIO SYSTEMS:

For some years, real-time general-purpose digital audio systems, based around specialized hardware, have been used by composers and researchers in the field of electronic music, and by professionals in various audio related fields. During the past decade, these systems have gradually replaced many of the audio-processing devices used in amateur and professional configurations. Today, with the significant increase in computing power available on the desktop, the audio community is witnessing an important shift away from these systems, which required specialized hardware, towards general purpose desktop computing systems featuring high-level digital signal processing (DSP) software programming environments. Frequency-domain processing primitives allow the development of sophisticated frequency-domain signal processing applications.



Frequency Domain Beamforming

Beamforming is the acquisition of a signal using an array of transducers and then applying a delay (at its most simplest), to "steer" the direction of the "beam" in a particular direction. Essentially the direction of the beam is relative to the sampling phase of the transducers, In the time domain, the beams are steered in a single direction One of the limitations of time domain beamsteering is that one bank of delays can only steer the beam in one single direction. The solution is to use the fact that time delays in the time domain are equivalent to complex exponential multiplication in the frequency domain. The benefit of performing this operation in the frequency domain is that we can effectively steer the beam in all directions at the same time.



FREQUENCY-DOMAIN SIGNAL PROCESSING OPERATIONS:

The standard operations which are used when processing audio signals in the frequency domain typically include:

- Windowing of the time-domain input signal,
- Transformation of the input signal into a frequency domain signal (spectrum) using the Fourier Transform (FT),
- Various frequency-domain operations such as complex multiplication for convolution,
- Transformation of the frequency-domain signals back into the time domain using the Inverse Fourier Transform(IFT),
- Windowing of the time-domain output signal.

FORIER TRANSFORM

According to the Fourier Transform, all waves can be viewed equally-accurately in the time or frequency domain, we have a new way of viewing the world. And this view is sometimes much more intuitive and simple to understand than the initial domain view. as an engineer, the ultimate goal is to apply knowledge to the real world and should have a knowledge about all waveforms that arise in real-life. Not only does the Fourier Transform give us a special insight into how the world works, it shows up in real-world applications such as MRI (magnetic resonance imaging), signal processing, electromagnetics, quantum physics, and theoretical mathematics. Whether F(t) is periodic or not, a complete description of F(t) can be given using sines and cosines. If F(t) is not periodic it requires all frequencies to be present if it is to be synthesized. A non-periodic function may be thought of as a limiting case of a periodic one, where the period tends to infinity, and consequently the fundamental frequency tends to zero. The harmonics are more and more closely spaced and in the limit there is a continuum of harmonics.

when a time-domain function is sampled to facilitate storage or computer-processing, it is still possible to recreate a version of the original Fourier transform according to the discrete-time Fourier transform.

The Fourier transform of a periodic signal only has energy at a base frequency and its harmonics. Another way of saying this is that a periodic signal can be analyzed using a discrete frequency domain. Dually, a discrete-time signal gives rise to a periodic frequency spectrum. Combining these two, if we start with a time signal which is both discrete and periodic, we get a frequency spectrum which is both periodic and discrete. This is the usual context for a discrete Fourier transform. An important conclusion: DTFT is equivalent to Fourier series but applied to the "opposite" domain. In Fourier series, a periodic continuous signal is represented as a sum of exponentials weighted by discrete Fourier (spectral) coefficients. In DTFT, a periodic continuous spectrum is represented as a sum of exponentials, weighted by discrete signal values.

$$F(j\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}\,dt$$

And

$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n]e^{-j\omega n}$$

INVERSE FOURIER TRANSFORM

As

$$x(t) \overset{F}{\leftrightarrow} X(j\omega)$$

$$x(t) = \tfrac{1}{2\pi}\int_{-\infty}^{\infty} X(j\omega)e^{j\omega t}d\omega$$

FOURIER TRANSFORM OF GATE SIGNALS:

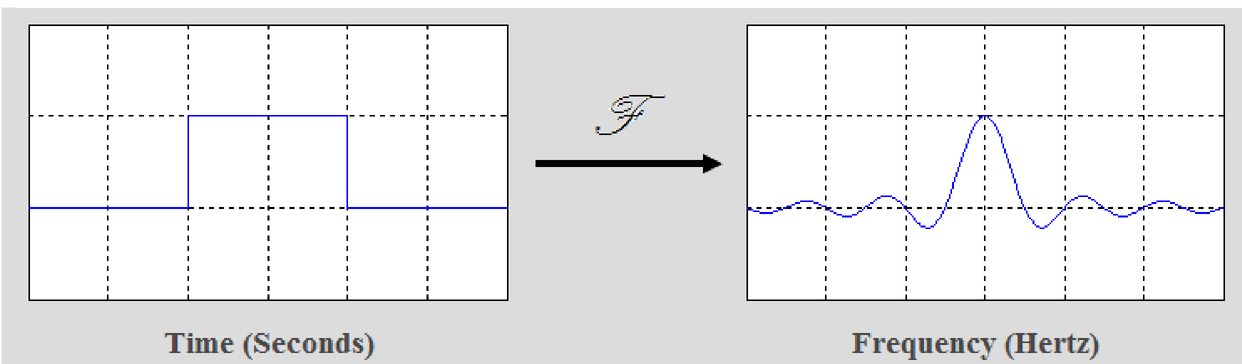
$$F(j\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$$

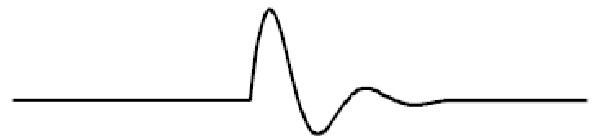
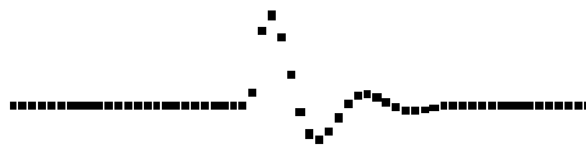
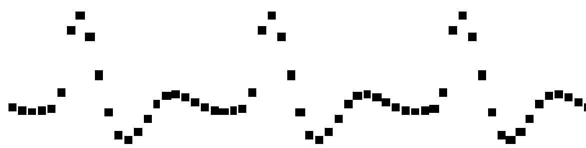
$$= 2\int_{0}^{\infty} p_{\tau}(t)\cos\omega t dt$$

$$= 2\int_{0}^{\tau/2} \cos\omega t dt$$

$$= \frac{2}{\omega}\sin\frac{\omega\tau}{2}$$

$$= \tau Sa(\frac{\omega\tau}{2})$$ **Where** Sa(x) = sinx/x



Type of Transform	Example Signal
Fourier Transform *signals that are continious and aperiodic*	
Fourier Series *signals that are continious and periodic*	
Discrete Time Fourier Transform *signals that are discrete and aperiodic*	
Discrete Fourier Transform *signals that are discrete and periodic*	

Time domain **Frequency domain**

Continue aperiodical ← FT → Continue aperiodical

Periodical ← FST → discrete spectrum

Discrete ← DTFT → periodical spectrum

Discrete periodical ← DFT → periodical discrete

PROPERTIES OF FORIER TRANSFORM:

LINEARITY:
The Fourier transform is a linear operation so that the Fourier transform of the sum of two functions is given by the sum of the individual Fourier transforms.

Therefore

$$af_1(t) + bf_2(t) \longleftrightarrow aF_1(j\omega) + bF_2(j\omega)$$

where $F_1(j\boldsymbol{\omega})$ and $F_2(j\boldsymbol{\omega})$ are the Fourier transforms of f1(t) and f2(t) and a and b are constants.This property is central to the use of Fourier transforms when describing linear systems.

TIME SHIFT:
Signal's shift in time domain equals phase shift in frequency domain

$$f(t - t_0) \longleftrightarrow F(j\omega)e^{-j\omega t0}$$

POWER SPECTRUM:
The Power Spectrum of a signal is dened by the modulus square of the Fourier transform, being $F|(u)|^2$. This can be interpreted as the power of the frequency components. Any function and its Fourier transform obey the condition that

$$W = \int_{-\infty}^{\infty} | f(t) |^2 \, dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} | F(j\omega) |^2 \, d\omega$$

It is called Parseval's theorum.W is energy of signal, $|F(j\omega)|^2$ named signal energy spectrum is signal energy in unit frequency band that has similar shape with $|F(j\omega)|$, but no phase information.

CONVOLUTION THEOREM
Convolution property of Fourier transform is the most important application of Frequency domain analysis because it make our work much easy and converts long calculations into small and simple arithmetic calculations. The **convolution theorem** states that under suitable conditions the Fourier transform of a convolution is the pointwise product of Fourier transforms. In other words, convolution in one domain equals point-wise multiplication in the other domain Versions of the convolution theorem are true for various Fourier-related transforms.

$$f_1(t)*f_2(t) \longleftrightarrow F_1(j\omega)\, F_2(j\omega)$$

and

$$f_1(t)\, f_2(t) \longleftrightarrow 1/(2\pi)[F_1(j\omega) * F_2(j\omega)]$$

CONCLUSION

Any signal that can be represented as amplitude that varies with time has a corresponding frequency spectrum. When the physical phenomena are represented in the form of a frequency spectrum, certain physical descriptions of their internal processes become much simpler. Often, the frequency spectrum clearly shows harmonics, visible as distinct spikes or lines that provide insight into the mechanisms that generate the entire signal. In engineering, the **frequency domain** is the domain for analysis of mathematical functions or signals with respect to frequency, rather than time and it has many useful applications regarding the engineering point of view.

The scope of the field of Frequency Spectrum is very large, with several useful textbooks available, so I only focus on some very basic principles and structures that allow us to trace the development of some interesting results, ideas, and techniques, which may also have value in various other applications. However, in doing so, I fully realize that many very interesting applications have been touched upon only very lightly, or even not at all for example Sound filtering, convolution theorem , Data compression, Partial differential equations, Multiplication of large integers, Antenna Design, Image processing etc. Hence translating signals from the time to the frequency domain can allow a whole new and powerful area of signal processing.

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