

**UNIVERSITY OF ELECTRONIC SCIENCE AND TECHNOLOGY OF CHINA**

**SCHOOL OF AUTOMATION ENGINEERING**

**Title: WHY FREQUENCY SPECTRUM IS MEANINGFUL AND TALK ABOUT SOME ENGINEERING APPLICATIONS OF SIGNAL SPECTRUM**

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**Course title: DIGITAL SIGNAL PROCESSING**

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1. **What is spectrum**

A ***spectrum*** is a collection of ***sine waves*** that, when combined properly; produce the time-domain signal under examination. The Fourier theory tells us that any time-domain electrical phenomena is made up of one or more ***sine waves*** of appropriate frequency, amplitude and phase. In other words we can transform a time – domain signal into its frequency domain equivalent. Measurement in the frequency tells us how much energy is present at each particular frequency, without proper filtering a waveform such as the one shown below in figure 1.1 can be decomposed into separate ***sinusoidal*** waves , or ***spectral*** components ,which we can then evaluate independently . Each sine wave is characterized by its amplitude and phase. If the signal we wish to analyze is periodic, Fourier says that the constituent sine waves are separated in the frequency domain by 1/T, where T is the period of the signal.

The figure1.1 below shows the waveform of a complex signal. Suppose that we were hoping to see a sine wave. The waveform certainly shows us that the signal is no a pure sinusoid.



Figure 1.1. Complex time- domain signal

The figure 1.2 below shows the complex signal in both the time domain and frequency domains. The frequency domain display plots the amplitude versus the frequency of each sine wave in the spectrum. As show the spectrum in this case compromises just two sine waves .this implies that both time domain and frequency domain measurements are important in digital signal processing, so that we can get the contained information.

The time domain is better for many measurements and some can be made only in the time domain such as pulse rise and fall times, overshoot and ringing.



Figure 1.2 Relationship between time and frequency domain

1. **Why spectrum analysis is meaningful**

Some measurements require that we preserve complete information about the signal frequency, amplitude and phase. However, another large group of measurements can be made without knowing the phase relation-ship among the sinusoidal components. ***This type of signal analysis is called spectrum analysis***. Because spectrum analysis is simpler to understand, yet is extremely useful.

In the time domain, all frequency components of the signal are summed together and displayed. In the frequency domain, complex signals (that is, signals composed of more than one frequency) are separated into their frequency components, and the level at each frequency is displayed.

Some systems are inherently frequency domain oriented. For example, many telecommunications systems use what is called Frequency Division Multiple Access (FDMA) or Frequency Division Multiplexing (FDM). In these systems, different users are assigned different frequencies for transmitting and receiving, such as with a cellular phone. Radio stations also use FDM, with each station in a given geographical area occupying a particular frequency band. These types of systems must be analyzed in the frequency domain in order to make sure that no one is interfering with users/radio stations on neighboring frequencies.

Also engineers and technicians are very concerned about the distortion of the message modulated onto a carrier. So spectrum monitoring is another important frequency domain measurement activity. Government regulatory agencies allocate different frequencies for various radio services, such as broadcast television and radio, mobile phone systems, police and emergency communications and host of other applications. It is critical that each of these services operate at the assigned frequency and stays within the allocated channel bandwidth. Transmitters and other intentional radiators often must operate at close spaced adjacent frequencies.

1. **Spectrum analysis/measurement**

Many times a transformation is performed to provide a better or clearer understanding of a phenomenon. The time representation of a sine wave may be difficult to interpret. By using a Fourier series representation, the original time signal can be easily transformed and much better understood. Transformations are also performed to represent the same data with significantly less information. Notice that the original time signal was defined by many discrete time points (i.e., 1024, 2048, 4096 …) whereas the equivalent Fourier representation only requires 4Amplitudes and 4 frequencies.



**3.1. Spectrum analyzer**

Traditionally, when you want to look at an electrical signal, you use an oscilloscope to see how the signal varies with time. This is very important information; however, it doesn't give you the full picture. To fully understand the performance of your device/system, you will also want to analyze the signal(s) in the frequency-domain. This is a graphical representation of the signal's amplitude as a function of frequency. The spectrum analyzer is to the frequency domain as the oscilloscope is to the time domain. (It is important to note that spectrum analyzers can also be used in the fixed-tune mode (zero span) to provide time-domain measurement capability much like that of an oscilloscope.)

From this 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 spectrum analyzer. For example the frequency domain analysis is better for determining the harmonic contents of a signal, so people involved in wireless communications are extremely interested in out of band and spurious emissions, so cellular radio systems must be checked for harmonics of carrier signal that might interfere with other systems operating at the same frequencies as the harmonics.

There are basically two ways to make frequency domain measurements (what we call spectrum analysis): Fourier transform and swept-tuned.



The ***Fourier analyzer*** basically takes a time-domain signal, digitizes it using digital sampling, and then performs the mathematics required to convert it to the frequency domain, and display the resulting spectrum. It is as if the analyzer is looking at the entire frequency range at the same time using parallel filters measuring simultaneously. It is actually capturing the time domain information which contains all the frequency information in it. With its real-time signal analysis capability, the Fourier analyzer is able to capture periodic as well as random and transient events. It also can provide significant speed improvement over the more traditional swept analyzer and can measure phase as well as magnitude. However it does have its limitations, particularly in the areas of frequency range, sensitivity, and dynamic range.

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Fourier analyzers are becoming more prevalent, as analog-to-digital converters (ADC) and digital signal processing (DSP) technologies advance. Operations that once required a lot of custom, power-hungry discrete hardware can now be performed with commercial off-the-shelf DSP chips, which get smaller and faster every year. These analyzers can offer significant performance improvements over conventional spectrum analyzers, but often with a price premium.







The most common type of spectrum analyzer is the ***swept-tuned receiver***. It is the most widely accepted, general-purpose tool for frequency-domain measurements. The technique most widely used is super heterodyne. Heterodyne means to mix - that is, to translate frequency - and super refers to super-audio frequencies, or frequencies above the audio range. Very basically, these analyzers "sweep" across the frequency range of interest, displaying all the frequency components present. The swept-tuned analyzer works just like the AM radio in our home except that on our radio, the dial controls the tuning and instead of a display, our radio has a speaker. The swept receiver technique enables frequency domain measurements to be made over a large dynamic range and a wide frequency range, thereby making significant contributions to frequency-domain signal analysis for numerous applications, including the manufacture and maintenance of microwave communications links, radar, telecommunications equipment, cable TV systems, and broadcast equipment; mobile communication systems; EMI diagnostic testing; component testing; and signal surveillance.

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**3.2. Engineering application of spectrum analyzer**

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.

1. **Summary**

Digital signal processing is about theories methods and algorithms how to process signal in digital form. The Fourier theory tells us that any time-domain electrical phenomena is made up of one or more *sine waves* of appropriate frequency, amplitude and phase.so to extract the information contained in the waves , the waves needs to be examined in the domain of interest. So we can transform a time – domain signal into its frequency domain equivalent, so that we can deal with *each spectrum* which used to represent the phenomena in the time domain. Generally there are two types of spectrum analyzers the Fourier and swept analyzer. The *Fourier analyzer* basically takes a time-domain signal, digitizes it using digital sampling, and then performs the mathematics required to convert it to the frequency domain, and display the resulting spectrum.

The *swept - tuned* analyzers "sweep" across the frequency range of interest, displaying all the frequency components present. With the capability to measure measurements of frequency, power, harmonic content, modulation, spurs, and noise, 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 spectrum analyzer. The most common spectrum analyzer measurements are: modulation, distortion, and noise, which have a greater impact on our day to day life, electronic devices and communication industries.

**References**

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