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WHY THE FREQUENCY SPECTRUM IS MEANINGFUL, TALK ABOUT SOME ENGINEERING APPLICATIONS OF SIGNAL SPECTRUM.

*by*

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DIGITAL SIGNAL PROCESSING

COMMUNICATION AND INFORMATION ENGINEERING

**INTRODUCTION**

The distribution of a characteristic of a physical system or phenomenon, especially: the distribution of energy (electrons) emitted by a radiant source, as by an incandescent body, arranged in order of wavelengths or the whole range of electromagnetic radiation with respect to its wavelength or frequency. This phenomenon was first predicted to exist by James Maxwell in 1865 and was first fashioned and observed by Heinrich Hertz in 1887. In most modern communication systems, they depend on manipulating and controlling signals within the electromagnetic spectrum. The frequency spectrum ranges from 30Hz which are radio frequencies to high cosmic rays of more than 10 million trillion Hz. Thus a spectrum can be defined as a range of values of a quantity or set of related quantities or a broad sequence or range of related qualities, ideas, or activities or simply the whole range of electromagnetic radiation with respect to its wavelength or frequency.

Communication involves implicitly the transmission of information from one point to another through a succession of processes and irrespective of the communication process in which the system goes through.

**Frequency Spectrum**

Frequency is defined as the number of complete electromagnetic energy wave cycles that occur each second. The international unit of measurement used to describe one cycle is 1 hertz (Hz). Since each portion of the electromagnetic spectrum has a telltale frequency signature, it can be identified by means of a frequency spectrum analyzer that is capable of accurately measuring the wave cycles per second of the particular electromagnetic phenomenon under observation.

The energy created by electromagnetic radiation is generated from the forces exerted by the variable fluctuations of magnetic and electrical force fields emanating at right angles to each other traveling at the speed of light. These electromagnetic disturbances create waves which can be measured and which occur or pulse at different rates or frequencies each second thus frequency spectrum is a method of classifying, by their commonly understood names, the discrete and unique elements of all electromagnetic occurrences in terms of the frequency of the radiated energy induced each second. And also 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.

Radio waves, television broadcasts, X-rays, microwaves, and infrared transmissions are all electromagnetic radiations whose essential attributes can be defined and identified by the frequency or amount of radiation each type produces.

**Importance of Frequency Spectrum**

1. Noise is a limitation factor in communication thus frequency spectrum is used in the design of filters to allow the required frequencies to pass, hence reducing the noise level in the system.
2. Bandwidth of the signal is the range of frequencies over which most of the signal energy of a signal is contained or is the difference between the upper and lower frequencies in a continuous set of frequencies. The bandwidth determines the portion or band of frequencies required to transmit a particular signal over the electrometric spectrum. Thus the frequency spectrum enables the estimation of the signal bandwidth hence makes it important in engineering especially in the field of communication.
3. The performance of a communication system depends on the bandwidth which is also called the frequency spectrum and the transmitted power. But it largely depends on the bandwidth which varies linearly to the signal to noise ratio (SNR). But these are being improved by the frequency spectrum thus the performance is being improved.

**APPLICATION OF SIGNAL SPECTRUM IN ENGINEERING**

The knowledge of signal spectrum is of great importance to the field of engineering and thus is the main brain behind most discoveries made in this field of study. There are so many applications such as Radar, Tele communication, Satellite Communication, Military Communication, Intelligence, Surveillance, and Reconnaissance and Software Defined Radio, of which the following are just but a few applications:

**Electrocardiogram (ECG)**

The objective of ECG signal processing is manifold and comprises the improvement of measurement accuracy and reproducibility (when compared with manual measurements) and the extraction of information not readily available from the signal through visual assessment. In many situations, the ECG is recorded during ambulatory or strenuous conditions such that the signal is corrupted by different types of noise, sometimes originating from another physiological process of the body. Hence, noise reduction represents another important objective of ECG signal processing; in fact, the waveforms of interest are sometimes so heavily masked by noise that their presence can only be revealed once appropriate signal processing has first been applied. The filtering techniques are primarily used for preprocessing of the signal and have as such been implemented in a wide variety of systems by the knowledge of signal spectrum.

Considerable attention has been paid to the design of filters for the purpose of removing baseline wander and powerline interference; both types of disturbance imply the design of a narrowband filter. Removal of noise because of muscle activity represents another important filtering problem being much more difficult to handle because of the substantial spectral overlap between the ECG and muscle noise.

In order to minimize changes in beat morphology that do not have cardiac origin, which is especially important when subtle changes in the ‘‘low-frequency’’ ST segment are analyzed for the diagnosis of ischemia, which may be observed, for example, during the course of a stress test. The frequency content of baseline wander is usually in the range below 0.5 Hz; however, increased movement of the body during the latter stages of a stress test further increases the frequency content of baseline wander. The design of a linear, time-invariant, highpass filter for removal of baseline wander involves several considerations, of which the most crucial are the choice of filter cutoff frequency and phase response characteristic. The cutoff frequency should obviously be chosen so that the clinical information in the ECG signals remains undistorted while as much as possible of the baseline wander is removed.

**Radar Communication**

The active radar illuminates the sensing area, sending pulse or continuous microwave emissions with known Modulation. Matched filtering is applied to the received signal to increase range resolution. In the case of relative motion between the target and radar, additional cross-range compression (SAR or ISAR processing) is applied to increase spatial resolution, which is well beyond the true (physical) antenna resolution, which in many cases is in the order of a few degrees.

Passive radar does not emit any radiation but collects the radiation available in the surveillance area. It should be equipped with a multi-beam antenna system. One of the available beams should be directed towards a selected transmitter, while the other to the observed scene. The beam directed towards the transmitter receives a copy of the illumination signal, while the surveillance beams directed towards the scene receive the echo signals. Fig. below presents a typical scenario of remote sensing using a single transmitter of opportunity.

Also the power delivered to the receiver to the power for the transmitter of the antenna all depends on the signal spectrum and the radar cross section or echo area.



**Hyperspectral Image Classification**

Hyperspectral sensors have hundreds of contiguous bands for spectral analysis, which provide more detailed spectral information of ground objects relative to multispectral sensors. the widely used metric-based methods in hyperspectral image classification can measure the spectral similarity between target and reference spectral signatures. More importantly, these methods are not influenced by the Hughes phenomenon.

A novel spectral similarity measure approach, which is named *spectral frequency spectrum difference* (SFSD), is proposed for hyperspectral image classification based on the frequency spectrum of spectral signature using the Fourier transform.

Many important characteristics of spectral signature can be clearly reflected in the frequency spectrum. Therefore, the spectral similarity is defined as the frequency spectrum’s difference between the target and reference signatures. The frequency spectrum analysis in this study suggests that the magnitude values of the first few low-frequency components for spectral signature can effectively represent the spectral similarity. To balance the difference between the low- and high-frequency components, the frequency spectrum of the target spectral signature is taken as the normalized factor in the SFSD method.

**Frequency Reuse Concept**

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a cell. Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. The base station antennas are designed to achieve the desired coverage within the particular cell. By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits. The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning. This concept has not only improved the spectrum utilization efficiency but has also offered an opportunity for designers to extend services to more mobile users.



**Cellular frequency reuse pattern**

**Ultrasonic Imaging**

Imaging using optical waves on optical coherence tomography allows achieving sub-micrometer resolution and is widely used in medicine or industry. Radio waves imaging is gaining in medicine and engineering. For decades, application area of the ultrasonic systems is expanding: non-destructive testing and evaluation, robotic vision and navigation, measurements in production automation, medicine diagnostics and treatment, imaging in solid and liquid environments, food industry and agriculture. Here due to the high energy content produced by the spread spectrum signal, spectroscopy can be carried out well beyond the specified transducer bandwidth.

**Multiplexing and Multiple Access Techniques**

It is of importance to point out that spectrum is a limited resource. Effective general design objective is to use two primary resources as efficiently as possible. Multiplexing or Multiple access technique is the knowledge of signal spectrum allowing several transmitters or user to share common resource such as spectrum whether collocated or not.