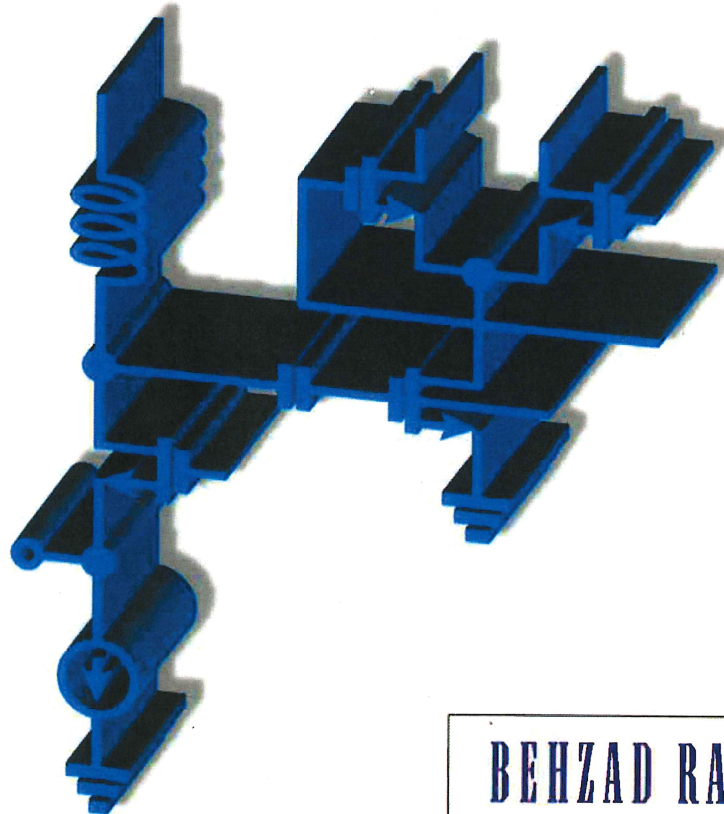
RF

MICROELECTRONICS



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RF MICROELECTRONICS

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It is useful to remember that for a Gaussian distribution approximately 68% of the sampled values fall between $m - \sigma$ and $m + \sigma$ and 99% between $m - 3\sigma$ and $m + 3\sigma$.

Power Spectral Density Since our knowledge of random signals in the time domain is usually quite limited, it is often necessary to characterize such signals in the frequency domain as well. In fact, as we will see throughout this book, the frequency-domain behavior of random signals and noise proves much more useful in RF design than do their time-domain characteristics.

For a deterministic signal $x(t)$, the frequency information is embodied in the Fourier transform:

$$X(f) = \int_{-\infty}^{+\infty} x(t)\exp(-j2\pi f t)dt. \tag{2.63}$$

While it may seem natural to use the same definition for random signals, we must note that the Fourier transform exists only for signals with finite energy,[3]

$$E_x = \int_{-\infty}^{+\infty} |x(t)|^2 dt < \infty, \tag{2.64}$$

i.e., only if $|x(t)|^2$ drops rapidly enough as $t \rightarrow \infty$. As shown in Fig. 2.21, this condition is violated by two classes of signals: periodic waveforms and random signals. In most cases, however, these waveforms have a finite power:

$$P = \lim_{T\rightarrow\infty} \frac{1}{T} \int_{-T/2}^{+T/2} |x(t)|^2 dt < \infty. \tag{2.65}$$

For periodic signals with $P < \infty$, the Fourier transform can still be defined by representing each component of the Fourier series with an impulse in the frequency domain. For random signals, on the other hand, this is generally not possible because a frequency impulse indicates the existence of a deterministic sinusoidal component. Another practical problem is that even if we somehow define a Fourier transform for a random (stationary or nonstationary) process, the result itself is also a random process [5].

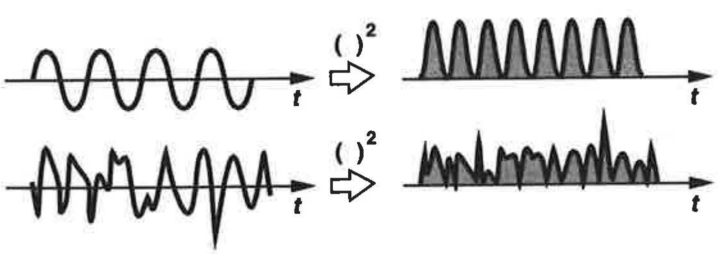

Figure 2.21 Signals with infinite energy.

[3] The definition of energy can be visualized if $x(t)$ is a voltage applied across a 1-Ω resistor.

From the above discussion we infer that frequency-domain characteristics of random signals are embodied in a function different from a direct Fourier transform. The power spectral density (PSD) (also called the "spectral density" or simply the "spectrum") is such a function. Before giving a formal definition of PSD, we describe its meaning from an intuitive point of view [6]. The spectral density, $S_x(f)$, of a random signal $x(t)$ shows how much power the signal carries in a unit bandwidth around frequency f. As illustrated in Fig. 2.22, if we apply the signal to a bandpass filter with a 1-Hz bandwidth centered at f and measure the average output power over a sufficiently long time (on the order of 1 s), we obtain an estimate of $S_x(f)$. If this measurement is performed for each value of f, the overall spectrum of the signal is obtained. This is in fact the principle of operation of spectrum analyzers.[4]

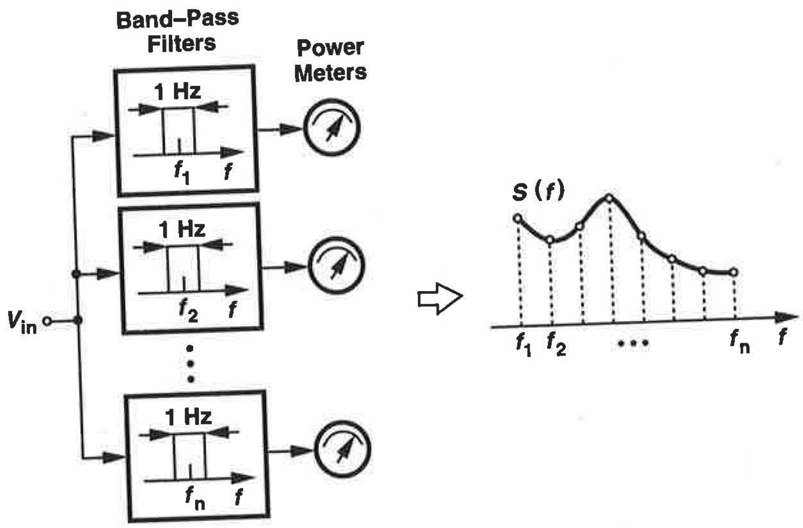

Figure 2.22 Measurement of spectrum.

The formal definition of the PSD is as follows [3]:

$$S_x(f) = \lim_{T\to\infty} \frac{\overline{|X_T(f)|^2}}{T}, \tag{2.66}$$

where

$$X_T(f) = \int_0^T x(t)\exp(-j2\pi f t)dt. \tag{2.67}$$

[4] Building a low-loss BPF with 1-Hz bandwidth and a center frequency of, say, 1 GHz is impractical. Thus, actual spectrum analyzers both translate the spectrum to a lower center frequency and measure the power in a band wider than 1 Hz.