Chapter 1

The converter as a black box

1.1 Introduction

A/D and D/A converters are the link between the analog world of transducers and the digital world of signal processing and data handling. In an analog system bandwidth is limited by device and element performance and by the parasitics introduced. Thermal noise generated in active and passive components limits the dynamic range of an analog system. The ratio between the maximum allowable analog signal and the noise determines the dynamic range of the system. The signal-to-noise (S/N) ratio is a measure of the maximum dynamic range.

In a digital system the amplitude is quantized into discrete steps, and at the same time the signal is sampled at discrete time intervals. When the sampling time moments at quantization differ from the sampling time moments at the time the signal is reconstructed into an analog signal again, a signal distortion is introduced. This phenomenon is very important in discrete-time systems and finds its origin in "time jitter" or time uncertainty of the sampling clock. In particular, input signals at the high-frequency end of the signal band show a great sensitivity to a sampling time uncertainty. Furthermore, the sampling operation of analog signals introduces a repetition of input signal spectra at the sampling frequency and multiples of the sampling frequency. If the input signal bandwidth is larger than half the sampling frequency, aliasing of spectra occurs. In that case frequencies around the sampling frequencies and its multiples are folded back into the baseband of the system. Usually this is an unwanted phenomenon. To avoid
CHAPTER 1. THE CONVERTER AS A BLACK BOX

aliasing of the signal, the input bandwidth must be limited to not more than half the sampling frequency (Nyquist criterion see [7]). This filtering must be performed by continuous-time filters.

The quantization of analog signals into a number of amplitude-discrete levels places limitations on the accuracy with which signals can be reproduced. This quantization error is often called “quantization noise” to indicate that the errors have a random amplitude distribution and in this way have a noise-like frequency spectrum. This random character, however, implies that under no circumstances should the analog input signal and the sampling clock have any correlation [8]. If a correlation exists then the quantization errors appear at well-defined points in the frequency spectrum which are generally multiples of the signal frequency. The ratio between the frequency of the input signal and the sampling frequency should preferably be an irrational number to avoid this correlation. The dynamic range of a digital system is determined by the number of quantization levels as will be shown in this chapter. By definition the noise is measured over a bandwidth equal to half the sampling frequency of the system.

In this chapter the different criteria mentioned will be described in more detail. The converter will be treated as an ideal black box. Specifications for input and output circuitry connected to the ideal converter will be derived under the condition that the overall system performance must be close to the ideal converter performance.

1.2 Basic D/A and A/D converter function

In Figure 1.1 a block diagram of a D/A converter is shown. Digital signals are applied to the converter as parallel signals. Suppose we have a binary-weighted converter, then the digital input value is converted into an analog value using the following equation:

$$V_{out} = \sum_{m=0}^{n-1} B_m 2^m R_{ref}. \quad (1.1)$$

In this equation $V_{out}$ represents the analog output value and $R_{ref}$ is a reference value. ($R_{ref}$ may be a reference voltage, current or charge).