

Optimizing Digital System Performance

1. Dynamic Range of a Digital Device

Digital devices use integer numbers to represent physical quantities, mostly voltage. Since the smallest positive integer number is 1, the voltage represented by a 1 is the smallest fraction of voltage that can be recognized by the digital device. This voltage is called the SIGNAL RESOLUTION of a digital device. In the digital device, there are a largest and smallest integer numbers which can be used, these numbers represent the largest voltage and smallest voltages. The difference between the largest and smallest integer numbers is the SIGNAL RANGE. Number of binary BITS of a digital device determines its signal range. The ratio of the signal range to the resolution is called the DYNAMIC RANGE of a digital device. Since this ratio is usually a large number, decibel (dB) is used to better represent the dynamic range.

For example, a 16-bit digital device (largest number 32768, smallest -32767) with signal voltage between +/-10V has a signal resolution of 0.3052mV, and its dynamic range is $20000/0.3052=65536$. In decibel, its dynamic range is 96.33dB.

This 96dB is a theoretical limit., Since there are many other factors adding noise to the system, the actual dynamic range of a digital device is always smaller than its theoretical limit.

2. Optimal Use of Dynamic Range

Dynamic range is specified at maximum output voltage. For the digital device in the example above, when signal level is +/-10V, noise level can be as much as 96dB lower than signal level. While when the signal level is +/-0.3052mV, signal is of the same level as the noise.

For example, TDT's D/A converter DA3 is a 16-bit digital device, and its dynamic range limit is 96dB. Due to the noise brought in by other components in the DA3, a conservative 85dB is specified as its S/N ratio. This dynamic range is specified with DA3's full signal range (+/-10V). That means, noise should be at least 85dB lower than +/-10V. This dynamic range should be used correctly in conjunction with the signal range of the application. If a maximum signal level desired is 110dBSPL, the maximum output from DA3 should be calibrated to get this 110dBSPL, and then all the noise should be below 25dBSPL, which is hardly audible. If the maximum output from the DA3 to the headphones is measured 130dBSPL, the noise at the headphones will be 45dBSPL, which becomes clearly audible.

If one says: "the maximum sound level I desire is 130dBSPL, and I still do not want to hear any noise when the signal is very low", a better D/A converter and digital devices with larger dynamic range (at least 110dBV) should be used.

3. Calibration of Digital System

As stated above, to make best use of the dynamic range of a digital device, the desired maximum output signal level should be calibrated against the maximum output from the digital device. This calibration is usually done using a passive attenuator. Following guidelines should also be considered in designing the signal path:

- * Place digital devices before analog devices;
- * Place the calibration (passive) attenuator should be placed last, right before the headphone buffer or speaker amplifier;
- * Avoid using digital attenuation (play small signal) whenever possible;
- * Don't place more than necessary devices in the system.

Example, maximum desired sound level is 110dB SPL. The system consists of a D/A converter (DA), programmable filter (PF), anti-aliasing filter (FT), programmable (passive) attenuator (PA) and headphone buffer (HB). Signal path should be:

DA --> FT --> PF --> PA --> HB --> headphones

To calibrate the system, play a full voltage tone through the DA and adjust the PA to obtain 110dB SPL at the headphones. If the PA will be programmed in the experiment, place another fixed passive attenuator should be used between PA and HB to maintain this attenuation.

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