Dynamic range and human perception

The human sense of hearing has a very high dynamic range. A human is capable of hearing (and usefully discerning) anything from a quiet murmur in a soundproofed room to the sound of the loudest rock concert. Such a difference can exceed 100 dB which represents a factor of 10,000,000,000 in power. But a human cannot perform these feats of perception at both extremes of the scale at the same time: the instantaneous dynamic range of human audio perception is similarly subject to masking, so that, for example, a whisper cannot be heard in loud surroundings. Nevertheless, a good quality audio reproduction system should be able to reproduce accurately both the quiet sounds and the loud.

In practice, it is difficult to achieve the full dynamic range perceived by human beings using electronic equipment. Electronically captured and reproduced audio often uses some trickery to fit original material with a wide dynamic range into a narrower recorded dynamic range that can more easily be stored and reproduced: these techniques are called dynamic range compression and employ the use of a compressor device or algorhythm.

The 16-bit Compact Disc has a theoretical dynamic range of 96 dB. 20-bit digital audio is theoretically capable of 120 dB dynamic range; similarly, 24-bit digital audio calculates to 144 dB dynamic range. All digital audio recording and playback chains include input and output converters and associated analog circuitry, significantly limiting practical dynamic range. Observed 16-bit digital audio dynamic range is about 90 dB.

Dynamic range in analog audio is the difference between low-level noise in the electronic circuitry and high-level signal saturation resulting in increased distortion and, if pushed higher, clipping. Noise can be picked up from microphone self-noise, preamp noise, wiring and interconnection noise, media noise, etc. Early 78 rpm phonograph discs had a dynamic range of up to 40 dB, soon reduced to 30 dB and worse due to wear from repeated play. German magnetic tape in 1941 was reported to have had a dynamic range of 60 dB, though modern day restoration experts of such tapes note 45-50 dB as the observed dynamic range. Ampex tape recorders in the 1950s achieved 60 dB in practical usage, though tape formulations such as Scotch 111 boasted 68 dB dynamic range. In the 1960s, improvements in tape formulation processes resulted in 7 dB greater range, and Ray Dolby developed the Dolby A-Type noise reduction system that increased low- and mid-frequency dynamic range on magnetic tape by 10 dB, and high-frequency by 15 dB. The peak of professional analog magnetic recording tape technology reached 90 dB dynamic range in the midband frequencies at 3% distortion, or about 80 dB in practical broadband applications. The Dolby SR noise reduction system gave a 20 dB further increased range resulting in 110 dB in the midband frequencies at 3% distortion. Compact Cassette tape performance ranges from 50 to 56 dB depending on tape formulation, with Metal Type IV tapes giving the greatest dynamic range, and systems such as XDR, dbx and Dolby HX noise reduction circuitry increasing it further. Specialized bias and record head improvements by Nakamichi and Tandberg combined with Dolby C noise reduction yielded 72 dB dynamic range for the cassette. Vinyl microgroove phonograph records typically yield 55-65 dB, though the first play of the higher-fidelity outer rings can achieve a dynamic range of 70 dB. The rugged elements of moving-coil microphones can have a dynamic range of up to 140 dB (at increased distortion), while condenser microphones are limited by the overloading of their associated electronic circuitry.