WXYC 89.3 FM Stereo
The University of North Carolina at Chapel Hill

Howard Hoyt
Chief Engineer
hhoyt@mebtel.net

Audio CD Copying Issues

In an ideal world, performing a disc-to-disc copy of a CD-DA (Compact Disc-Digital Audio) would be a trivial act, with a guarantee that the copied disc is identical in all respects to the original. Many disc-copying programs perform as if this is always the case, when in reality it is not. In the real world, the situation is complicated by two factors: *Opto-Electrical Performance* and *Audio CD player interpolation*. Let us look at how these two factors interact to inhibit accurate Audio CD Copying.

Opto-Electrical Performance

The information on a Compact Disc is carried in a track of differing length pits starting from the center of the disc and spiraling outwards. These pits are scanned with a laser and turned into electrical signals in the player. This is why the playability of a disc is expressed as its opto-electrical performance. Scratches, fingerprints, poor quality blank discs, or bad recorders create problems with the opto-electrical performance. In other words, any defect in the recorded pits, or a defect on the disc that interferes with the player accurately seeing the pits will cause errors. In the process of creating a CD-DA, the data representing the audio is sent to the recorder drive, where it is encoded with and mixed together with error correction data. All of this resulting data is then stored on the disc. On playback, the error correction data retrieved from the disc is used to correct any errors induced by the disc storage, then stripped off of the digital music data. The digital music data is then sent to the player to be reconverted to analog.

Being able to play back a CD-DA on the recorder that made it, or any other single CD-Audio or CD-ROM drive does not mean the original disc contains a good quality recording. A CD-DA can have poor opto-electrical performance, yet problems may only occur as a compatibility issue only with certain drives or players. The error correction embedded in the CD-DA system has the following characteristic: When opto-electrical performance is good, as is the case with a new properly molded disc, there are small amounts of raw errors being sent to the error correction circuitry. Even the best quality new disc may have as many as 10 to 20 fully correctable errors per second, and thousands per disc. In this situation, the error correction circuitry in the CD player can easily recover the original data completely free of errors. If the amount of raw errors from the disc is somewhat higher due to scratches, fingerprints, or other flaws, the error correction will still perform in a predictable way to correct these errors and deliver error free data. If the rate of errors being sent to the error correction circuitry exceeds its capabilities, the error correction will fail to correct the errors, and the original data on the CD will not be recovered. This is called an uncorrectable error. This means that one

cannot assess the opto-electrical performance of a CD-DA by merely playing it on a player. The disc may be extremely poor quality, and have a very high raw error rate, yet somehow escape generating an uncorrectable error on a very good player, or some specific player.

Audio CD Player Interpolation

The audio format was designed at the outset to carry audio and as such, was designed to optimize storage capacity/play time. Compared to a Data CD-ROM, the two data attributes that were discarded in an effort to free up space on the disc and increase playing time were sector numbering and a third layer of error correction.

A CD-DA has two layers of error correction, followed by an error-concealment facility. What this means is that if an error occurs on the disc that is too severe for the error-correction circuit to recover the original data, the corrupt data is then passed to an error-concealment circuit. This circuit performs interpolation between the previous known good data, and the next known good data. It literally makes a calculated "guess" as to what the missing bit of data was supposed to be.

Most audio professionals consider the application of this type of interpolation as unacceptable in a professional application, where no degradation or change to the original audio is permitted. This is why audio professionals discourage the transfer of recordings using a CD-DA. Once upon a time in the 1980's and early 1990's, the ¾" UMatic tape with Sony 1630 PCM digital audio was the preferred method of transferring digital audio, due to it's extensive error detection facilities. These days, creating a DDP (Disc Description Protocol) image of the CD-DA disc and then transferring it on a CD-ROM is far more robust.

For the purposes of a consumer playing a CD-DA it is a totally different situation. Most consumers do not take sufficient care with the disc and let it get scratched and smudged, which results in data that is not recoverable. If consumer CD-Audio players had no interpolation, playback of many discs would be marred by gaps, clicks and bursts of noise. Interpolation is an absolute necessity in this application.

CD-DA Copying

As described in the previous section, a CD-DA contains no sector numbering, which makes it almost impossible to find an exact bit of data on the disc. This means that after copying the CD-DA to a CD-R, it is extremely difficult to find the same chunk of data on each disc for the purpose of comparing them. Therefore, most CD-DA copying programs perform what is called a "RAW" copy; that is, they merely perform a read, and then write whatever is read to the target disc. Lack of sector numbering means that an audio CD player cannot actually find a specific sector in an audio track more accurately than the low resolution time code embedded in the disc, or 1/75th of a second. While this is totally sufficient for casual use, it disallows a player to find an exact digital sample of music, of which there are 44,100 every second.

Beginning in the late 1980's, programs for PCs such as CDDA and others attempted to perform bit-for-bit comparisons of digital audio by a method known as bit-pattern matching. This technique effectively makes a serial bit pattern in memory for each of two bit streams, then slides the two past each other in time to see if any patterns match up. If and when they do, the two bit streams can be synchronized. Of course, any errors or differences between the two will cause this technique to fail.

If there were uncorrectable errors on the read, most players or copying programs will not abort, since they figure that the missing data will be inaudible. The end result of this is that a copy operation can finish without error, and yet the target disc will have different data than the source disc. Since error correction is removed inside of the CD-ROM drive during play, and new error correction bits added back in the CD-Recorder during the CDR burn, you can and often will get a copied CD-DA that has incorrect data, but with no disc errors where the original source CD-DA had an uncorrectable error.

There are bit-accurate CD copying programs of two different types: Rip to disc with full error checking, performed by programs for a PC such as Exact Audio Copy, which then necessitates reconstructing the audio CD as a project and re-burning it from tracks on the HDD; and fully professional CD copying programs which do full error checking during and after copying, such as Eclipse ImageCopy or GEAR Mastering Pro.