Compact Disc Copy Protection

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Abstract

Sometimes, preventative measures can go so far that rather than protect effectively, they inhibit daily life. How effective are today's CD copy protection schemes in this context? In my research I analyze their sensibility not only from a technical aspect, but a social one as well. The paper looks at old schemes, compares them to the new schemes, and details how much of a success each scheme is along these terms.

Keywords: effectiveness, copy protection, usability

1 Introduction

Modern societies tend to take many things for granted. On a basic level, we expect that clean, running water flows to every building; that electricity is a given; that food will always be available. We also tend to make assumptions about some creature comforts as well: the climate of our homes will be well isolated from nature; drugstores will be open twenty-four hours, seven days a week; cellular telephones and the Internet are ubiquitously distributed. While some of these demands stretch the boundaries of what should be required in a functioning society of the 21st century, they illustrate the point that people like to be able to count on things.

And why shouldn't they be able to do so? After all, the point of society is to structure human life into a way that promotes certainties and guaranties. Forms of government protect the rights to property and life. Cultures create typical lifestyles that individuals can choose to take part in, feeling confident that the culture will maintain the expectations they have of it. One aspect that most everyone seems embrace is usability and a form of inter-operability. No matter what, we all have a need to be able to communicate with each other. So we have our translators, to cross the barriers of language. We have the media, to spread news and expand the borders that each culture may reach. We have the Internet, a worldwide network of information exchange. We share our music across nations and continents using recording technology. We rely on these things to exist and function, in some form, no matter where we are. The advent of the digital age has given individuals even more control over the distribution of all forms of information. We have the ability to send exact duplicates of digital information in minuscule amounts of time. This freedom has created controversy in copyright law across the world, and especially in the music world, where peer-to-peer networks have given users access to unlimited, free downloads of digitally compressed music. In response to this growing practice, compact disc (CD) manufacturers and recording labels have taken measures to prevent their CDs from being copied to computers. The hope is that by making copying impossible, they will be able to decrease and eventually extinguish the sharing of copyrighted music. While technologically protecting their content is a reasonable additional layer to the legal protection already ensured by copyright law, there is still a problem with CD copy protection: it has yet to be implemented effectively.

Not that copy protection is an impossible feat to pull off. But in order to make an *effective* copy protection scheme, I vouch that it must meet two basic requirements. The first requirement is that it must actually prevent the music from being stored in a digital format. The second, and possibly even more important requirement, is that it must be compatible with existing hardware. People generally expect their purchased CDs to work in the CD players they already own; they do not suppose there will be problems using disc in a CD-ROM drive; they desire the ability to be able to make at least a legitimate copy for backup uses or playback on their portable audio devices or computer. If those expectations are suddenly thrown out the widow by a copy prevention scheme and lawful users have their use rights taken from them, generally they will become frustrated. I contest that any scheme that creates this frustration is as much of a failure as if it did not provide any copy prevention at all - if not enough users are willing to use the technology, then it cannot be a success. In the music world, integration with standards an unspoken requirement in order to flourish.

2 Technical Background

2.1 CD Technology

The compact disc (CD) is the medium in which most music now is marketed. The CD was a major improvement over vinyl records, because they were smaller, more resilient and able to contain much more data. As opposed to the physically read record, CDs are optical discs, on which music is recorded in digital format and then read by a laser. It is the CD's ability to store and reproduce exact data that makes it susceptible to copying.

To record the digital audio on a master CD, a laser photographically bores pits into the layer that is conventionally considered the "top" of the CD (label side). This process creates bumps in the reflective underside, which are read by another laser during playback. Replicas of the CD are then made using a press. Because the pitted resist layer that is the master CD is so delicate, it cannot be pressed directly to make a mold. Instead, it is sprayed with a fine layer of silver to make it conductive and electroplated: a layer of metal molded to it, and the material is dissolved away, leaving an inverted copy of the master. That metal master is used to create a stamp for an assembly line. Blank CDs are then merely pressed with this stamp, covered in the reflective film and protected, recreating the original over and over again [Wat02].

The bumped side is covered with a clear protective layer through which the laser is focused. Because the diameter of the focused laser is so small (1.7 μm) and the output spread so large (0.7 mm), most scratches or dust on this surface are completely out of focus, not affecting the sound at all [MV01].

2.2 Digital Audio

Analog audio can be defined using an infinite range of numbers; digital audio - and for that matter, all digital information - can only be defined using sets of ones and zeros. Because of this, an audio signal must be run through many steps in order to be transferred accurately to digital format. The basic creation of a digital audio signal follows this general process:

1) Filtering
2) Sampling
3) Quantization
4) Coding [MV01]

2.2.1 Filtering

Filtering is just what it sounds like: taking care of of the pieces of audio data that the encoder doesn't want to deal with. In essence, filtering checks the frequencies of an audio signal and alters them in some way, usually attenuating the frequency to fit inside the desired range [Pro02].

2.2.2 Sampling

To simulate the continuity of an analog signal, digital conversion uses a process known as sampling. Sampling is the process of analyzing the input frequencies only at fixed time intervals to simulate the behavior of an analog input. While this seems as if it might leave imperfections in the sound during the time between samples, the *Nyquist Theorem* proves that it does not. The Nyquist Theorem states that there will be no signal loss if the sampling rate is present in the input signal. However, the signal must actually be sampled at twice that frequency to prevent aliasing and overlap due to harmonics.

In the 20Hz-20kHz range usually expressed in a typical audio signal then, this places the cutoff for a sampling frequency at 40kHz. However, because anti-aliasing process required for this range is very expensive, the sampling rate was chosen higher than necessary, so that only higher, inaudible frequencies are attenuated. The standard sampling rate for an audio CD is 44.1kHz, though studio recording may be sampled at frequencies as high as 48kHz, in order to allow for editing and correct tuning [MV01].

2.2.3 Quantization

Quantization is the process used to convert the completely continuous amplitudes on an analog signal into a finite number of digital representations. Quantization eliminates unnecessary information in the audio signal, leaving only what needs to exist to recreate the sound accurately.

The basic method of quantizing an audio signal is straightforward. First the signal is divided into N quantization intervals. The number N is determined by the number of bits (n) available in the digital recorder:

$$N = 2^n$$

The amplitude at each interval is then associated with a scaled binary representation of its magnitude using some conversion code, turning the continuous wave into a digitized version.

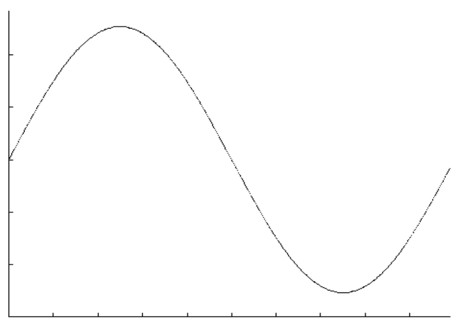

Figure 1: Analog Audio Signal

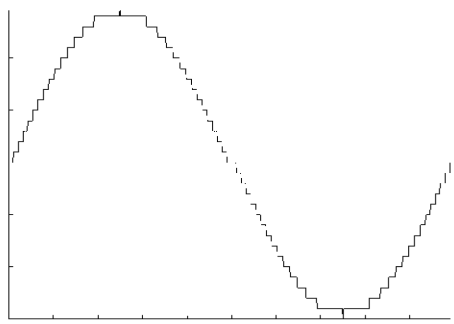

Figure 2: Quantized Signal

There are many different conversion codes that can be used to quantize an analog wave which are broken up into two basic types: unipolar and bipolar. Unipolar codes contains only amplitude information; bipolar codes contain positive or negative sign information as well. Some of the basic audio codes include:

Natural Binary Code

The basic unipolar coding. The most significant bit (MSB) is weighted at 2^{-1}, the second MSB at 2^{-2}, and so forth, until the least significant bit (LSB) is weighted at 2^{-n} [MV01].

Sign Magnitude

Simple bipolar encoding. Magnitude is expressed with the voltage's binary representation, and a leading sign bit is used to define a negative or positive value [MV01].

Offset Binary

The bipolar version of Natural Binary Code. With this type of conversion, the most negative amplitude is offset to be aligned with a zero, and all others stretch upward from there. This method is rarely used, mainly because many of the upper frequencies get cut out when the number of bits is insufficient to handle the offset [Wat02].

Two's Complement Representation

Another bipolar method, very similar to Offset Binary, only it relies on *Two's Complement Representation* of numbers. Two's complement numbers are the way that computers can represent both positive and negative numbers. The first bit in each number will determine the sign of the number: 0 is positive, 1 is negative. The quickest way to determine the negative of a number in two's complement is to represent that number normally in binary, with one less bit than you plan on having. Then, invert all the bits in the number, and finally add one to get the negative [HP98].

$$\begin{aligned}
4_{dec} &= 100_{bin} \\
&= 0100_{bin} \\
&= 1011_{bin} \\
\text{-}4_{dec} &= 1100_{bin} \text{ Two's complement}
\end{aligned}$$

The processing takes the audio signal and finds it's range. That range is divided in half, and the result is added to offset the lowest amplitude level to zero. An Analog-to-Digital Converter (ADC) creates a binary number out of the signal, and its sign bit is inverted to create a two's complement number. This two's complement number can then be manipulated and used just as any regular binary number [Wat02].

2.2.4 Coding

The final step in creating digital audio is to format it into the desired encoding. There are encoding schemes designed to be used for different media, compression and quality standards. The most common problem faced in audio encoding is how to compress losslessly, or at least, perceptually losslessly.

Since digital audio can is recorded in a stream of that consists of either ones or zeros, error correction is very easy: simply reverse the incorrect bit, and it is possible to obtain the correct data. The problem of course occurs when trying to determine *which* bits are in error [Wat02].

There are many different ways to perform error correction. One method of doing so is to add bits to recorded data, creating a *codeword*. The calculated codeword spans a longer time than one bit alone. By creating repetition, it is highly improbable that an entire codeword will get corrupted. Therefore, recognize an erroneous bit, a machine cyclicly checks to see if it contains the codeword. If the representation is not the codeword, then the reader can recognize that segment as faulty. The codeword will be de-constructed and the correct bit restored. These codes are typically called cyclic redundancy check (CRC) codes [Wat02].

The most efficient error correcting code possible (and subsequently, the codes used for compact disc error correction) are *Reed-Solomon (R-S) Codes*. Created by Irving Reed and Gustave Solomon, R-S codes work on burst errors of multiple bits. R-S codes can operate alone or in conjunction with normal error correction codes. The main difference stems from the fact that a CRC checks one division of the codeword, whereas R-S encoded streams get checked twice.

Once a stream is finally written, it needs to be compressed into some format. Some compression schemes essentially leave the data like this, a perfect audio file. Others try to reduce the large file size required but audio files, disregarding quality. The compression format most entrenched in general use is the MP3. Though MP3 may not be the most successful format in terms of both lossiness and file reduction, it is the by far the most wide-spread. This probably derives from it's ease of use and the short amount of time spent compressing files into the MP3 format.

Compression of digital audio into an MP3 undergoes two separate processes. The first relies on psychoacoustics: the differences between the actual existing sounds and what the brain can perceive.

MP3 harnesses this and first algorithmically eliminates sounds that humans cannot process. The next compression is an actual lossless Huffman encoding [Hac00].

3 Copy Prevention

Copy protection has evolved from a system which assumed users were entrenched in the confines of their hardware to one that protects content on a digital, bit-by-bit level. Though the schemes may have drastically changed, the actual successful levels have not.

Track 41 protection was such a scheme based on the physical structure of floppy disks as opposed to software. A floppy disk has gaps in the memory between tracks where data is not naturally read. The idea behind track 41 protection was to instruct the machine to actually write code to these places. If the information was copied, the duplicate disk would in theory not have those additions. The software could then check to see if the correct statements resided in their appropriate locations, and if not, reject the information from the copied disk [Bro87].

Digital watermarking is more recently explored copy detection/prevention method. Watermarking involves the process of embedding bits into the a file that do not interfere with a user's perception, but can be detected by software. As a protection method, detection of a watermark - or a failure thereof - can allow a program different rights based on the files generation (deny playback if the file is a copy, allow copying if it is the original, etc.); alternatively, attempts at removal of a watermark may cause a degradation of the file's quality.

Not only could removing watermarks eliminate the use of files: it can instigate legal proceedings as well under the Digital Millennium Copyright Act (DMCA). The most important tenentes of the DMCA state that 1)circumvention of a security measure is grounds for legal action and B)making circumvention tools available to the public is illegal. These statutes make watermark tampering punishable by the law.

The Secure Digital Music Initiative (SDMI) was a major player in trying to protect digital music. They proposed a challenge that no one could break their watermarking scheme, offering money to anyone who has able to do so. A group of researchers took on the challenge, breaking the four tests that used watermarking. When they attempted to publish their research in their paper, proving that it was possible to break these watermarks, SDMI immediately countered with the DMCA, citing that this would be publication of a circumvention method. Later on, the researchers did go on to publish their research ([Cra01]), but not until after a long fight to find someone willing to do accept a potentiality illegal piece of work [Fel00]. This example shows that copy prevention cannot be instituted flawlessly by technology alone; there must be a social factor for any copy protection to be effective.

4 Analysis of Copy Protection Schemes

This segment analyzes the copy protection schemes used by various companies in terms their effectiveness, which I defined earlier to have social as well as technical aspects.[1]

4.1 EMI

EMI's attempts at copy protection are questionable. In June of 1999, EMI signed with Liquid Audio, a distributor of digital music. Liquid Audio software was supposed to provide security, copy protection and copyright management for the EMI collection [Gro03]. Though EMI's relationship with Liquid Audio remained throughout the years, Liquid Audio never really took off as a major player in the digital music trade. Now, Liquid media integrates with Windows Media Digital Rights Management (DRM) standards [LLC03] and at the beginning of 2003, Liquid dissolved after selling its encoding rights to Microsoft and its distribution system to Geneva Media LLC [Hu02].

EMI's copy protected discs have not fared so well either. They no longer carry the Compact Disc compatibility logo and my research has led to me to experience problems playing their discs on my Magnavox AZ80551701 boombox. On the other hand, they can be easily ripped onto a hard drive using multiple operating systems, as I have researched. As a matter of fact, if I had not been doing research specifically on copy prevention, I would undoubtedly still have no idea that an album that I purchased this summer (Radiohead's *Hail to the Thief*[2]) had copy protection. According to [Mus], copy protected discs are supposed to bear the label, which is the "Worldwide Copy Control Icon":

Figure 3: The Worldwide Copy Control Icon

However, though there is no sign of the Compact Disc logo or name anywhere on the album, case or jacket, the record also does not have the copy control logo on it. Since I had no trouble ripping it into

[1] Due to the nature of the beast that is copy prevention, it was difficult to find detailed technical information on schemes, though I could find information on breaking different protections. I attempted to contact both EMI and Sony Music for more information on their specific implementations. Unfortunately, neither replied.

[2] Radiohead's record label is technically Capitol Records, Inc. in America but Capitol is a subsidiary of the EMI Group

my computer's music library and I mainly listened it through my computer, I never never could have known it was a protected disc; upon playing the disc in my boombox, I most likely would have assumed that the player had gone bad and it was time to purchase a new one.

EMI's copy prevention strategy seems to follow a "The Customer is Always Right" policy. Their main goals are outlined in a presentation given by Executive Vice President John Rose

- `Make available 100% of our repertoire`
- `Allow portability and burning`
- `Make our music available through every legitimate retailer`
- `Enable retailers to use own preferred business model`
- `Ensure fair return for EMI and artists by setting wholesale price`
- `Integrate digital distribution fully into EMI` [Ros03]

Though the company has seemingly good intentions, their protection scheme fails to be very effective: the limited playback is not a major problem, but the sheer simplicity with which the media can be copied gives it no real world effectiveness. The only thing that results is frustration from users when they purchase a disc that is not compatible with their compact disc playing hardware.

4.2 Sony

The DADC division of Sony developed a copy prevention scheme known as key2audio. A Celion Dion album released in Europe during April of 2002 contained this protection.

It also contained a warning not to be used in computer CD-ROM drives [Han02].

Apparently, discs such as Dion's that contained the key2audio features not only didn't allow playback, but crashed computers as well. The discs were so incompatible with current CD standards that Phillips Electronics pushed Sony to not include the CD logo on its protected discs, which Sony eventually decided to agree with. It was the perfect copy protection: the recording device had absolutely no access to the materials ready to be copied.

However, Sony now claims that it's latest version of the scheme - key2audioXS™[3]- is actually compatible for computer playback:

> Along with a sophisticated copy control solution key2audioXS™offers user friendly PC-playback with superior sound quality. key2audioXS™-protected discs play trouble-free on virtually all CD/DVD players and PC devices. When the key2audioXS™disc is inserted into the drive, an authentication process verifies the disc [Son02].

[3]key2audioXS is a trademark of Sony DADC Austria AG

But for the key2audioXS™disc to function in a personal computer, it must meet the following requirements:

- `Windows®98 SE, ME, 2000, XP`
- `Pentium II or higher`
- `64 MB RAM`
- `50 MB free disk space`
- `Internet Explorer 5.0 or higher`
- `DirectX 8.0 or higher` [DAD03]

As far as Macintosh compatibility? Nothing is mentioned.

The basic way a key2audio™disc now works is by creating a multi-session disc: one session contains the audio files to be played on typical CD player and a second session contains computer formatted multimedia [DAD]. The disc installs software to make these files useable on your computer with Sony compliant devices and programs - much like Apple's iPod and iTunes work hand in hand. They are hoping this gesture will quell the rising sentiments against digital media copy protection and offer incentives to return to purchasing physically distributable audio discs [Son02].

I deem past versions of Sony's protection and key2audio a failure in social terms. Though it may not be technically possible to make copies, the cost of non-compatibility is too much; nobody wants to attempt to play their new album and have it crash their computer or not work in their car stereo. However, if the latest technology that incorporates the multi-session disc works as well as Sony claims, it would pass as an acceptable method. Should Sony have developed a way to make their products compatible with the current hardware, their copy preventative measures would be a success.

5 Conclusion

Of the protection schemes I have researched, none of them seem to have achieved an acceptable level of effectiveness, and the reasons are multitudinous. I've seen schemes that do not seem to prevent copying at all (EMI); some that as of yet has not proven to be compatible with current players (Sony/key2audio); some that can be defeated by merely covering the outside track with tape or marker(Cactus Data Shield [Ley02]); software that just doesn't get installed if you hold the shift key (MediaMax CD3 [Hal03]). Though these problems may seem easy to fix from a solely technological standpoint, there is no real forum for them to be installed; right now, the technological cost to the people of copy protection is too high for society to accept. Until a compromise between what the people want, and what the technology can provide can be reached, there will never be a truly effective copy prevention system.

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