# Physical Media for Music Release

## The Vinyl Record

The original physical medium was the phonograph record. Invented in the 19th century, this medium was entirely mechanical at first. A horn was attached to a vibrating stylus, or needle, that etched grooves into a foil cylinder. Operated in the reverse direction, sound could be reproduced. Many optimizations were required before high fidelity music was possible. The first such optimization was the spinning disc and later electroacoustic cutting and playback greatly improved the sound reproduced. The early records used 78 rpm rotation and rather large grooves but eventually the system was refined to use 33 1/3 rpm and smaller and smaller grooves. Finally, a system to reproduce stereo recordings was developed and the medium achieved its pinnacle in the mid 20th century.

To allow stereo reproduction, two channels of audio are fed to a cutting head that has two solenoids mounted at a 90º angle relative to each other. This allowed the walls of the groove to be cut so that one represented the right channel signal and the other the left. One disadvantage is that out-of-phase information would cause the stylus to move up and down, potentially pushing the stylus out of the groove when playing the final disc. Since there is a limit to the number of grooves that can be carved onto the disc surface, the playing time is limited. There is a trade-off between the amount of low frequency content, requiring wide groove swings, and the distance between adjacent grooves to allow full motion of the stylus. And there is always the issue of noise generated by the process of playing the disc due to imperfections in the vinyl and dirt that invariably accumulates in the playback system.

## The Compact Disc

Although downloadable digital files and streaming have largely replaced physical media in the marketplace, the compact disc (CD) is still a common medium for music distribution. The compact disc was the first digital medium designed for the consumer market and was the most popular medium for commercial releases for a decade. It was envisioned as a replacement for the phonograph record, but with several important enhancements: not the least of which are the longer play time, increased dynamic range and resistance to wear-induced noise. The technical details of the system include special data encoding procedures necessary to correct errors and a physical tracking system to allow reading of the data on any CD player. While arguments persist about the sampling rate and quantization level chosen for the CD, few would deny the overall advantages presented by the digital storage of musical data. Most professionals eventually agreed that the sound quality of the 44.1kHz/16-bit format was sufficient for general use as a finished playback format provided no further digital processing was applied. On a disc of slightly less than 5 inches in diameter, up to 650 megabytes of data may be written, allowing for up to 72 minutes of stereo music. The storage of additional data allows fairly precise cueing of the selections in a rapid, random access manner. The specifications for the audio CD were developed by Philips and Sony and are documented in the so-called Red Book. The CD was a remarkable development, particularly as it involved cooperation between competitive manufacturers who agreed to share their expertise.

### CD Tracking

Because the data are stored as binary optical information, some way of aligning the laser beam that reads the disc is necessary. On a phonograph record, the stylus (needle) simply rides in the groove that contains the data using gravity and a sophisticated mechanical balancing system. Obviously, this cannot be employed to track the data on the CD. The CD is tracked using the same optical information that contains the data. The data are encoded as pits that are created by a high-power laser beam, the intensity of which is modulated by the data to be written. Once the entire disc is written, the surface is plated with a thin metal coating. The coating is read from the bottom of the disc by scanning with a focused laser beam that reflects into a photosensitive element. The pit depth is 1/4 of the wavelength of the laser light used to read the data (780 nm), so the beam reflected from the pit bottom cancels the incident beam while that reflected from the land reinforces the beam, creating an interference pattern. By using two additional pickup beams, one to the left and behind the data pickup beam and one to the right and ahead of the data pickup beam, the relative beam intensities are used to tell the mechanism when the beams stray from the data track. The rotation rate is varied to maintain a constant linear velocity, which may be adjusted to allow more data to be recorded.

### Data encoding

The raw audio samples are encoded along with synchronization and error detection/correction (CIRC) information and are interleaved before being written to the CD itself. Sub-code data (like the copy-protect bit) are also used on the CD, allowing many different types of data in addition to audio data to be read and identified, as in CD-ROM and the other variants of the CD. Unlike the DAT (Digital, which uses eight-to-ten modulation, the CD uses EFM (eight-to-fourteen modulation). This adds a lot of "extra" bits, but it has the advantage of lowering the bandwidth necessary to handle the output data. Data are coded as edges of pits, so several 0 bits in succession are coded by a single pit. EFM greatly reduces the number of short pits and the overall number of pits, as well, making manufacturing easier.

In the process of encoding, sub-code information is added to the CD data. One sub-code byte is added to every 32-bit symbol as output from the CIRC encoder. Each bit in the sub-code byte is assigned a designation P,Q,R,...,W. Only the P and Q bits are defined in the Red Book. (The remaining bits can carry user information, but are usually 0's on audio CDs.) The P bit is zero during music tracks and 1 between tracks. The P bit alternates between 0 and 1 at 2 Hz at the end of the disc (lead-out).

The Q bits from 98 frames form a sub-code word 98 bits long. This word conveys information about track number, time, address and error correction. The first two bits provide synchronization. The address bits determine the mode for the following data (the lead-in area gets a different mode from the actual audio data region.) The actual Q sub-code bits describe timings, copy permission, number of channels, and pre-emphasis. There is also CRCC error detection provided for the sub-code data.

## Mastering for Specific Media

Mastering is the process by which recordings are delivered to manufacturing plants for duplication and distribution. Before the CD, we were given only two formats: vinyl LP or cassette. In the first half of 2016, the CD still sold 50 million units, while vinyl managed about 6 million in sales. (In the same period, there were almost 210 billion songs streamed - equivalent to 140 million albums.) Vinyl sales are growing still but represent a small portion of music sales. Surprisingly, even cassettes are growing in popularity as a physical medium for music release. (In 2014, more than 10 million tapes were produced by one of several remaining tape duplicators.) The form in which the final recording is to be distributed determines the format in which the master recording must be delivered. Optimally, we would like the final medium to sound just like the master recording. Unfortunately, each medium has sonic characteristics that may require the mastering engineer to take into account these characteristics and alter the recording in a way so as to make the final recording more faithfully represent the original sound. An experienced mastering engineer will be able to find any problems with the program material that would create undesirable effects in the finished product. These problems vary from one format to another.

## The Compact Cassette

The least expensive commonly used distribution medium was once the analog cassette. It was the first medium that could be produced by anyone without specialized equipment. These tapes may be duplicated on any cassette recorder in small quantities or may be commercially duplicated in larger quantities. Small quantity duplications are often done at real-time speeds: that is, the original tape is played regular speed and the recording is done at regular speed on a blank cassette. Some machines allow 2x real- time duplication, whereby both machines run at twice the normal speed while commercial duplicators run at up to 16x. In commercial duplication facilities, banks of record-only machines are controlled from a master playback machine, which may be a cassette, reel-to-reel tape, or CD. Depending on the system, duplication can be done to pre-loaded cassettes or to large reels or blank tape that are then cut and loaded into cassette shells. Duplication can be done from real-time up to 64:1 but lower speeds produce better copies.

High-speed duplication is generally not favored for music duplication. So-called audiophile duplicators will run real-time duplication and some even duplicate both sides of the cassette at the same time, with playback from a four-channel digital system. It is possible to keep the recording digital up to the actual duplication to analog cassette. Noise reduction encoding is done at the time of recording, so a decision about what, if any, type of noise reduction is to be used must be made.

When mastering for cassette distribution, the main limitation will be the dynamic range of the analog cassette. Often, multi-band limiting or compression will be required to help the final tape reproduce the wider dynamic range of the original recording. Also, the type of tape (Type I, Type II, Type IV) may be selected to best fit the original material. Dolby HX-Pro processing during duplication will preserve more of the high frequency response on the product, regardless of the deck on which it is played, by varying the record bias current as the signal spectral content changes. In addition to the duplication of the music, graphics such as cassette labels and J-card inserts for the tape case are required. With full color printing, the graphics costs often surpass the cost of actual tape duplication. Not including mastering, graphics, and set-up charges, cassette duplications ran around $2.00/ tape.

Mastering media for cassettes include reel-to-reel tape and CD-R. The factory will need to make a copy of the master tape from which to duplicate the actual cassettes. For bin-loop high-speed duplication, a reel-to-reel copy (duplication master) is made and used as an endless-loop source to duplicate the many copies. Since several generations of copies are involved, the final quality may not be perfect. Test tapes are usually provided to customers in order to approve the sound before the entire run is made.

## Vinyl Records

Prior to the invention of the CD, vinyl long-playing (LP) records were the final product delivered to the consumer. Some listeners still prefer the sound of vinyl, although their options are limited since major manufacturers adopted the CD as the standard medium of product delivery. In recent years, there has been a resurgence of interest in the LP and new pressing plants have been opened. The process of manufacturing LPs involves many physical processes that potentially alter the frequency content of the program. The mastering engineer must account for these alterations in order to end up with an acceptable recording. Like cassettes, LPs have some limitations to the dynamic range possible, especially at lower frequencies. The low-frequency content will determine how closely spaced the grooves may be cut; thereby determining how much music may be recorded on the disc. Also, since the frequency response of the pickup is non-linear, the RIAA equalization curve is required on playback to make the final output sound correct (much like the equalization curve used with analog magnetic tape recorders). Finally, since the groove pitch (grooves/inch) limits the amplitude of the signal, the pitch is determined by the amplitude of the program material; quiet passages have more grooves/inch and loud passages have fewer grooves/inch. Out-of-phase signal content between the left and right channels causes the stylus to move up and down, potentially ejecting it from the grooves during playback. This will need to be considered when delivering recordings for record production as no such limitations exist for tape or CD.

The actual process of cutting a record involves playing the master tape or file through an equalizer and limiter into the cutting lathe. The lathe actually cuts grooves into the lacquer disc master. A digital delay or tape deck with a special preview head is used to delay the signal to the lathe, allowing some quick EQ or level changes as the tape is played back for cutting. Since the groove must be continuous, the cutting process must also be continuous.

## Compact Discs

For many years, the compact disc (CD) was the dominant medium of music delivery, although downloading has recently cut significantly into its share of the music market. It has advantages of nearly random access, self-contained cueing information, non-degrading reproduction, flat frequency response and near-archival lifetime. Although originally difficult to master, replicated CDs are now possible from CD-R copies and digital image files, greatly simplifying the process of preparing for CD replication.

The usual method of pre-mastering for CD release involves the use of a digital editor to assemble the program material into a continuous digital data stream. The songs are assembled with silent spaces of 2 to 4 seconds between cuts and with the final EQ and other settings to produce the exact sound desired at the output of the system. Programs such as Toast/Jam, Nero, and several others including iTunes may be used to assemble the sound files for the CD and burn them to CD-R in the proper order with the desired spacing between cuts, even making adjustments in the track amplitude. Often, replicated CDs are made from CD-R masters, but any errors on the CD-R are then replicated as well. To avoid this, a process known as DDP (Disc Description Protocol) may be used. In this protocol, information about track spacing, crossfades and other disc information is included with the audio data in an error correction protected file.

Unlike tape and vinyl media, the CD reproduces the original signal exactly, with no equalizing or coloration. While this is strictly true, there is some confusion about the sound of CDs, partially due to the many re-issues of older recordings that were prepared for vinyl release. When originally recorded, the master tapes were often equalized to account for the shortcomings of the vinyl medium, boosting the high frequencies to compensate for the eventual losses and lowering the bass to prevent skips for example. When played back on a CD, the high frequencies sound overly emphasized and the bass is reduced. Even in some digitally mastered CDs, there can be an apparent emphasis of high frequencies. Care must be taken to guarantee, even with CDs, that the sound delivered to the customer is exactly what the engineer wanted. By using a mastering house with an experienced engineer, the master can be digitally equalized to deliver the desired sound at the output of the CD player.

One consideration is the possibility of CD amplitude causing distortion on some CD players. If the CD is mastered to full 0 dBFS, some analog output stages may overload due to D/A converter overshoot feeding into analog amplifiers with limited amplitude capability. The current trend in making louder and louder CDs contributes to this problem. Although everyone wants their CD to play louder than (or at least as loud as) all the other CDs, we should remember that playback systems DO have volume controls.

## CD-Rs

Single unit CD printing machines have been developed and are cheap and readily available. Since the blank CDs cost about $.30, this method of production is now cost-effective for more than a few copies, even though replication costs under $1 per unit. The CD-R (CD recordable) allows inexpensive creation of individual CDs playable in standard CD players from most computer-based recording systems and from stand-alone recorders. The CDs created by this system are not as robust as replicated CDs, since they rely on a dye layer rather than the metalized film used in standard CDs.

## Some general practices

When preparing any project for release, it is recommended that you listen to the “final” mixes on different speaker/stereo systems and at different volume levels. The idea is to get the finished project to sound the best you can on the widest array of systems. While we are tempted to make the program sound great on the studio monitors, we must also make it sound good on the average home stereo and even on a “boom-box” at the beach. This might require some equalization or compression that would not be optimal for studio listening. Remember that the finished product is designed for the consumer environment. A good mix should sound good on any system.