Pro Tools® and Time Division Multiplexing (TDM)

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May 23, 2007

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Abstract

Pro Tools®, made by Digidesign®, is a Digital Audio Workstation (DAW) which integrates hardware and software. It is widely used by professionals in music production, post production, TV and film scoring.

As one of the first programs to provide CD-quality (16 bit and 44.1 kHz) multitrack digital audio editing on a personal computer, Pro Tools has quickly grown in the sound recording field. It originally became popular because of its simple, streamlined interface for non-linear, non-destructive editing. This appealed to analog producers making the switch to computer-based digital audio production.

The professional-level Pro Tools|HD® system uses Peripheral Component Interconnect (PCI), developed by Intel Corporation, or PCI Express cards to perform audio processing on digital signal processing (DSP) chips to reduce computing burden on the Central Processing Unit (CPU). Similarly, it utilizes Time Division Multiplexing (TDM) to communicate with external input/output (I/O) devices and other DSP cards to reduce burden on the computer’s PCI bus, for example.

This paper will provide an introduction to Digidesign’s line of DAW’s with special emphasis on Pro Tools|HD®. The general concept of multiplexing will be explained with focus on time division multiplexing (TDM) and how it is integrated into the Pro Tools|HD® system. Lastly, sections covering control surfaces, wiring of a TDM system, and typical hardware prices will be reviewed.

1 Introduction to DAW’s and Pro Tools®

With the advent of computers and digital media comes the ability to, not only record but edit ones recorded performance, digitally. Systems that perform such tasks are called digital audio workstations (DAW). Today, these systems typically reside on computers (PC or Macintosh) in the form of software along with some type of hardware audio interface which performs the actual manipulation of audio, both digital to analog (D/A) and analog to digital (A/D) conversions. Systems have a variety of inputs (which record an audio signal) and outputs (typically used for monitoring). Once a series of inputs has been recorded, the user has the option of recording more input signals or can simply mix (i.e., balance the relative levels or frequency) any existing audio track(s).

Today, digital audio workstations are typically computer based. These systems include digital audio editing software and, the previously mentioned, D/A and A/D hardware converters. One such system that has gained enormous popularity as a DAW is manufactured by the company Digidesign® and is called Pro Tools®.

Pro Tools® has its origins in the early 90’s where original releases were used in both the music and television industry. Since that time, Pro Tools® has becomes an industry standard for not only music and television, but for film and radio broadcasts as well, both pre and post production. Today Degidesign’s® Pro Tools® comes in three
flavors, Pro Tools LE™, Pro Tools M-Powered™, and Pro Tools|HD®, the later of which is the subject of this report.

The Pro Tools LE™ system is targeted for home users who have personal or project studios. This package includes the audio editing software (Pro Tools LE™) and hardware such as Digidesign’s® 003 family of firewire-based audio interfaces. Additionally, one can select from their more affordable line of interfaces such as the Mbox 2™. The M-Powered™ system is the Pro Tools® application designed to work with select M-Audio® hardware peripherals. This was made possible by the acquisition of M-Audio® by Avid® (Digidesign’s® parent company) in 2004 [International, 2004]. Lastly, Digidesign’s® flagship product is Pro Tools|HD® which requires a proprietary interconnect based on time division multiplexing (TDM) to communicate with external input/output (I/O) devices.

In this report, the general concept of multiplexing, including TDM, will be discussed (see Sec. 2). This is followed by a discussion of the Pro Tools|HD® system in Sec. 3 which utilizes the concept of time division multiplexing.

## 2 Multiplexing

In this section we introduce the concept of multiplexing in addition to some common multiplexing techniques. Multiplexing is simply a process for sending (and receiving) multiple information signals (or packets) down a single communication path. The signals can be analog or, more commonly, digital. Furthermore, the communication path can be a transmission channel or electrical circuit. Familiar examples include, but are not limited to, telephone and cable television networks where hundreds of channels of information (e.g., voice and video) are transferred back and forth through a few transmission lines. For example, with multiplexing one has the ability to combine as few as 24 channels onto one T1 transmission link or as many as 129,024 channels onto one fiber optic strand [Rosengrant, 2002].

### 2.1 Frequency-Division Multiplexing (FDM)

One of the earliest forms of electrical multiplexing has its roots in the telephone system. In the 1930’s the telephone companies began to use the concept of frequency division multiplexing (FDM) to combine multiple voice signals over one line to maximize efficiency of their long distance trunks [Answers, n.d.]. Note that the signal can be just about anything; data, text, voice, video, etc. (see Figure 1). This combining of multiple voice signals is achieve through a technique called frequency division multiplexing which we will now explain. Following our voice-signal example, we first assign a different frequency to each of the individual voice-signals (conversations, for example). More specifically, each voice-signal (a sub channel) is given its own frequency, or carrier, with
in the overall transmission bandwidth of a larger or main channel. The various carriers are then modulated (e.g., frequency modulated (FM), amplitude modulated (AM) or phase modulated (PM)) and combined to be, ultimately, transmitted as a single signal. At the receiving end (e.g., your radio, phone, TV, etc.), the signals are separated out using a process called de-multiplexing where they are finally routed to the end user or location for interpretation.

2.2 Wavelength-Division Multiplexing (WDM)

In wavelength division multiplexing (WDM), we simply assign each message a wavelength (i.e., wavelength = 1/frequency) instead of a frequency, as previously illustrated in Sec. 2.1. This is a popular method of multiplexing in optical communications and is easy to do with fiber optics and optical sources. Each unique message wavelength is generated using different infrared red (IR) wavelength LASERS. These messages or data streams are then multiplexed onto a single fiber optic line as illustrated in Figure 2. At the receiving end, wavelength sensitive filters are used to de-multiplex the signals.

2.3 Time-Division Multiplexing (TDM)

With the advent of digital electronics in the 1950’s and 60’s came the introduction of digital communication techniques. It is here that we see a new method of multiplexing that would soon replace FDM in many applications. This digital counterpart to FDM is based on time division and is thus called time division multiplexing (TDM). It is by far the most common method of multiplexing used today and can ride on all types of media – copper, radio frequencies, and fiber [Rosengrant, 2002].
2 MULTIPLEXING

In TDM, sharing of the signal is accomplished by dividing available transmission time (unlike frequency or wavelength previously explained) on a medium. That is, a digital time slot is reserved for each data stream. Here digital signaling is used exclusively where the bits and bytes are interleaved one after the other. For example, we could have four incoming 1000 bps signals (a, b, c, d) interleaved into one outgoing 4000 bps signal, as seen in Figure 3. In order to generate the ‘stream’ of data traveling down the single line in Figure 3, a scanning switch selects data from each of the input sources in sequence to form a composite signal consisting of the interleaved data signals. It is this method, as we will see in Sec. 3.3, that Digidesign® implements in their high end audio workstations as a means to communicate with external I/O devices and other digital signal processing (DSP) cards.

Fundamentally, there are two types of time division multiplexing, synchronous and asynchronous (or statistical). These are discussed in the following sections.

2.3.1 Synchronous TMD (STDM)

The original method of time division multiplexing is called synchronous TDM (STDM). In STDM, the time (slot) allocated to an input device is fixed. Device 1 transmits for a fixed time, then device 2, etc. through device N and then back to device 1, regardless if a device has anything to transmit or not. If a device has nothing to transmit, the multiplexer must still insert a piece of data from that device into the multiplexed stream. This can be in the form of 1s and 0s so that the receiver may stay synchronized with the incoming data stream. Furthermore, the receiver must be perfectly synchronized to the slot period, hence the name STDM. The time it takes to complete one full cycle of
all the devices is called a *frame*. For example, in our previous example shown in Figure 3, we would have four frames in the data stream, each composed of the bit pattern $|a|b|c|d|$. 

### 2.3.2 Asynchronous TDM (ATDM) \ Statistical TDM

The problem with STDM is that it becomes inefficient when traffic is intermittent because the time slot is still allocated for each device even when the channel from the device has no data to transmit [Howe, 2001]. What is needed here is a method that does not rely on synchronized time slots but rather asynchronous time slots. This approach to multiplexing is called, expectedly, *asynchronous time division multiplexing* ATDM or more commonly referred to as *statistical time division multiplexing*.

In ATDM, if a device has nothing to transmit, it doesn’t get a time slot, unlike what we saw with STDM. That is, only data from active devices gets transmitted through the multiplexer. In this way, space is not wasted on the multiplexed data stream which ends up being a much more efficient use of the overall bandwidth. Furthermore, unlike STDM, the number of time slots in a frame (e.g., $|a|b|c|d|$) does not have to equal the number of input devices nor does each device have to transmit at the same time. To keep this asynchronous information in check such that the receiver can de-multiplex the data stream, additional information, stored in a *header*, is included with each frame. This can include the address of the originating device and/or information about the length of the data. The aggregate of header information and frame data is collectively called a *packet*. 
3 Pro Tools|HD®

In previous sections, we provided an overview of some of the Pro Tools systems (Sec. 1) with some details on the concept of multiplexing (Sec. 2). In this section, and subsequent sections, we will address the Pro Tools|HD® software/hardware environment with some insight into its integration of TDM technology.

In 2002, Digidesign® released its current professional level DAW called Pro Tools High Definition or simply Pro Tools|HD® [Wikipedia, n.d.]. This system is an upgrade to the previous generation of TDM systems which included Pro Tools|24, Pro Tools|MIX and Pro Tools|MIXplus. The new HD system offers resolution of 16 to 24-bits at a sample rate up to 192 kHz, in addition to a total of 256 possible audio tracks. This is a significant improvement over older systems such as the Pro Tools-MIX series, which could only record or play up to 64 audio tracks at 24-bits with a sampling rate of up to 48 kHz [Sound on Sound, 2001].

3.1 Digital Signal Processing (DSP) Cards

Unlike Pro Tools LE™ or other similar DAWs which strictly use the computers CPU for processing, Pro Tools|HD® utilizes dedicated digital signal processing (DSP) hardware (in the form of expansion cards) to handle all of the audio processing (i.e., signal routing, mixing, effects, etc.). These 64-bit cards are simply inserted in a computer (into the mother board) via an available peripheral component interconnect (PCI) or PCI express (PCIe) slot. The PCI bus is most common to PC’s, however, it will eventually be succeeded by the faster PCIe bus, (found in Mac’s and some PC’s) which is the standard on most new computers [Wikipedia, n.d.].

All Pro Tools|HD® systems require at least one expansion card called a Core card which, at its heart, contains nine Motorola 56k DSP chips (see Figure 4) for audio processing. Previous generation cards, from the Pro Tools Mix series, only offered six Motorola Onyx DSP chips on each card [Sound on Sound, 2001]. Furthermore, the new DSP chips are 25% more powerful than DSP chips from the older Mix series cards [Mix, 2002].

If one wishes to increase overall compute power, additional cards called Accel (formally known as Process) cards can be added to available PCI or PCIe expansion slots. The Accel card is physically identical to the Core card but is used only for plug-in processing. Up to six additional Accel cards can be added to a system bringing a total card count to seven (includes one Core card) with a total of 63 available DSP chips where each card adds an additional 32 channels of audio input and output to the HD system. The DSP cards are not only plugged into PCI or PCIe expansion slots, they are additionally connected to one another using a TDM FlexCable (see Figure 5). This is so the multiplex data bus can be seen by all DSPs on all cards. This is further
Pro Tools HD® systems come in three configurations. These packages are called HD1, HD2, and HD3, where the number denotes the number of DSP expansion cards included in the package. For example, an HD3 system would include one Core card and two Accel cards.

While the consumer version of Pro Tools (i.e., LE) has a limited track count of 32, the HD system has the ability (depending on which configuration) for one to mix up to 192 separate tracks (see Table 1). Adding a second Accel card (e.g., HD3 configuration) only increases DSP power and not track count.

### 3.2 The Audio Interface

The HD system is not complete without an audio interface. Digidesign offers a variety of interfaces that couple with the DSP cards through use of a DigiLink cable. The
audio interfaces simply differ in their sampling rates and input configurations. Systems include the 192 I/O, 192 Digital I/O, 96 I/O, and 96i I/O (see Figure 6). The first number in the naming scheme denotes the maximum sampling rate (i.e., 196 versus 96 kHz) the unit can handle. Each interface has 24-bit A/D and D/A converters and can handle a variety of input sources. For example, the 192 I/O includes 8 channels of analog I/O, 8 channels of AES/EBU, 8 channels of TDIF, 16 channels of ADAT, and 2 additional channels of AES/EBU or S/PDIF digital I/O. Summary specifications for these interfaces can be seen in Table 2 and Table 3.

### Table 2: Summary for the 192-series audio interfaces. [Pro Tools Manual, 2007].

<table>
<thead>
<tr>
<th>Sampling Rate (kHz)</th>
<th>192 I/O</th>
<th>192 Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Input</td>
<td>8 (DB25)</td>
<td>–</td>
</tr>
<tr>
<td>Analog Out</td>
<td>8 (DB25)</td>
<td>–</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>8 AES/EBU (DB25)</td>
<td>16 AES/EBU (DB25)</td>
</tr>
<tr>
<td></td>
<td>8 TDIF</td>
<td>16 TDIF</td>
</tr>
<tr>
<td></td>
<td>16 ADAT (Toslink)</td>
<td>16 ADAT (Toslink)</td>
</tr>
<tr>
<td>Digital (Enclosure)</td>
<td>2 AES/EBU (XLR)</td>
<td>2 AES/EBU (XLR)</td>
</tr>
<tr>
<td></td>
<td>2 S/PDIF (RCA)</td>
<td>2 S/PDIF (RCA)</td>
</tr>
<tr>
<td>ADAT Optical</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

3.3 Integration of TDM in Pro Tools|HD®

#### 3.3.1 Short History of Pro Tools and TDM

Previous versions of Pro Tools, prior to Pro Tools|HD® circa 1991, could only process a small number of tracks simultaneously (i.e., 4 tracks) due to the hardware design of the Macintosh computer and Digidesign’s own NuBus audio cards [Create Digital Music, 2005].
Table 3: Summary for the 96-series audio interfaces. [Pro Tools Manual, 2007].

<table>
<thead>
<tr>
<th></th>
<th>96 I/O</th>
<th>96i I/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Rate (kHz)</td>
<td>96 max</td>
<td>96 max</td>
</tr>
<tr>
<td>Analog Input</td>
<td>8 (TRS)</td>
<td>16 (TRS)</td>
</tr>
<tr>
<td>Analog Out</td>
<td>8 (TRS)</td>
<td>2 (TRS)</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Digital (Enclosure)</td>
<td>2 AES/EBU (XLR)</td>
<td>–</td>
</tr>
<tr>
<td>ADAT Optical</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
To increase this capacity effectively, would mean one would have to figure out a better way to compete for bus time in accessing the CPU, memory, etc. However, rather than compete for bus time a solution was to build another communication bus that was specifically dedicated for digital audio signals. This would mean that one would have to create a dedicated bus to each of the devices, which in itself was a formidable process. Rather than build dedicated buses, an elegant solution was to use a single bus which would simply take advantage of time division multiplexing (TDM) so as to rout data from various sources to others in a much more efficient manner. In this way, audio signal could also be broadcast to many destinations (e.g., DSP chips) simultaneously. This would take the audio traffic burden off the then, NuBus, which has since been replaced by the faster PCI and PCIe buses. (Note: this is why the DSP cards stated in Sec. 3.1 are connected via the TDM FlexCable.) Hence the Pro Tools TDM systems were born. One of the first systems to use this technology was Pro Tools III, back in 1994. This was followed by Pro Tool|24 (24 bit A/D), Pro Tools|MIX (expanded DSP capabilities for mixing audio), Digi 001 with Pro Tools LE, Pro Tools|HD®, and finally Pro Tools|HD® Accel systems.

Technically, the actual interconnect which communicates with today’s Pro Tools DSP’s is proprietary to Digidesign, however, we can still shed light on how it might function. To their credit, Digidesign was the first company to pioneer the use of TDM technology in digital audio and mixing applications.

### 3.3.2 DSP and the TDM Bus

The use of time division multiplexing (TDM) in Pro Tools is analogous to that explained in Sec. 2.3 except now we are talking about multiplexing sources like audio tracks and sends onto a single bus. This multiplexed information or bus, is visible to the DSP hardware (i.e., expansion cards) on the receiving end where cards have the capacity to extract, from the bus, whatever data is needed for processing.

An early version of this concept, called TDM I, allocated a total of 256 time slots to make up a single frame (as explained in Sec. 2.3.1) on the bus. This architecture appear in Pro Tools|24 MIX systems [Pro Tools Manual, 2007]. Here, all 256 time slots were shared across the available DSP’s. The limitation to this approach was the fact that whenever you had a plug-in assigned to a track (i.e., an insert), for example, it would utilize a full time slot as a means of communication with other DSP’s, thus making ‘that time slot’ unavailable for use by the rest of the system. See example in Figure 7.

Since the original implementation of TDM as a means of communication amongst the DSP cards, Digidesign has improved upon the technology by introducing the TDM II architecture. In this scheme the TDM bus is now between each DSP. That is, each DSP, connected serially, can talk to each other through use of the TDM bus. As each
DSP card is added to the system through use of the TDM FlexCable, the string of serially connected DSP’s simply gets longer (see Figure 8).

New to this architecture is a wider 512-time slot bus that is also bi-directional. This is a significant improvement over the TDM I technique in that a time slot is only used to talk between DSP’s locally. Furthermore, the same time slot maybe available for other DSP’s to use through out the serial DSP chain. For example, we can see from Figure 9, using our previous TDM I example, that we have now freed up two time slots after DSP 3, for the rest of the system to use. The worst case scenario would be if DSP 1 needed to talk to the last DSP in the serial chain, say DSP 18 (assuming 2 cards each with nine chips). This would globally render the allocated time slot as unavailable.

4 Control Surfaces

Even though one can control audio mixes via a computer monitor or LCD screen using a mouse, there are those that favor a physical mixing console or control surface complete with hardware faders, inputs, EQ’s, inserts, etc. In a digital console design, input signals are converted from analog into digital data or are directly inserted into the console’s signal chain as digital data. Once done, these signals are thereafter distributed, routed, and processed entirely in the digital domain [Huber, 2005]. This is exactly analogous to...
Figure 8: Concept of TDM II architecture showing DSP chips serially connected from card to card.

Figure 9: Concept of TDM II architecture showing the engine DSP talking to both the mixer and reverb assigned DSP’s, \textit{locally}. 
a traditional analog console except now the sound engineer works in the digital domain.

Digidesign’s flagship surface, which integrates with the TDM II HD system, is the D-Control™ worksurface (see Figure 10). This surface is part of what Digidesign calls their ICON series of consoles. It can be expanded, via optional 16-channel fader modules, to have a total of up to 80 physical faders/channel strips. Its sister console in the ICON series, called the D-Command™ surface, is a medium format board expandable up to 24 faders/channel strips, though in its base configuration it comes with 8 faders (see Figure 11).

Another, very popular surface is Digidesign’s Control|24™ worksurface (see Figure 12). Not only does this console include 24 faders/channel strips (though it is not expandable), but it boasts 16 Focusrite mic/line preamps, unlike the D-Control™ or D-Command™ surfaces in which one must supply preamps via outboard gear. Furthermore, this surface is compatible with both the Pro Tools|HD® and LE systems.

Lastly, there are those that have small project studios that are comfortable with using their mouse and are not looking to purchase a control surface. As an alternative, one can use custom keyboards (see Figure 13) that are labeled in such a way so as to have direct access to primary transport and editing functions.
Figure 11: Digidesign’s D-Command™ digital worksurface. (Image from Digidesign.com).

Figure 12: Digidesign’s Control|24™ digital worksurface. (Image from Digidesign.com).
Typical Studio Wiring

The following section provides an overview of how one might setup and utilize a Pro Tool|HD® system. This example layout can be seen in Figure 14. The first thing to note is the insertion of DSP cards into PCI or PCIe slots, which ever your computer contains. As previously noted, Digidesign does produce Core and Accel cards for both architectures. The cards are then connected together via the TDM FlexCable, as shown. A DigiLink cable connects the DSP cards to one of the audio interfaces described in Sec. 3.2. Furthermore, only one card (the Core card) needs to be connected to the audio interface through the Core DigiLink port. The other end of the DigiLink cable is connected to the Primary Port on the audio interface (this port is common in all types of interfaces). At this point one can route audio signals in through a patchbay or preamp. This connection is made to the audio interfaces Analog Input card via a DB25 connector (for the 192 I/O and 192 Digital I/O interfaces), as seen in Figure 14. Output signals are obtained from the audio interfaces Analog Output card via TRS connectors (as in the 96 I/O and 96i I/O units) or a DigiSnake break out cable (as in the 192 I/O and 192 Digital I/O units). These breakout cables convert the DB25 connector to an XLR or TRS-type connector. Lastly, effects can be routed through the system (via patchbay, for example) as actual hardware (as seen in Figure 14) or as software plugs-ins through use of the Pro Tools DAW.
Figure 14: Diagram of possible studio layout utilizing the Pro Tools|HD system which includes an audio interface and DSP cards.
### Table 4: Typical pricing of common products required for a Pro Tools|HD® system.

<table>
<thead>
<tr>
<th>Digidesign® Product</th>
<th>Price†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pro Tools</td>
<td>HD 3†</td>
</tr>
<tr>
<td>Pro Tools</td>
<td>HD 2†</td>
</tr>
<tr>
<td>Pro Tools</td>
<td>HD 1†</td>
</tr>
<tr>
<td>HD Accel Card (PCI or PCIe)</td>
<td>$4,995</td>
</tr>
<tr>
<td>192 I/O</td>
<td>$3,995</td>
</tr>
<tr>
<td>192 Digital I/O</td>
<td>$2,495</td>
</tr>
<tr>
<td>96 I/O</td>
<td>$1,995</td>
</tr>
<tr>
<td>96i I/O</td>
<td>$2,195</td>
</tr>
<tr>
<td>PRE</td>
<td>$2,495</td>
</tr>
<tr>
<td>D-Control Surface</td>
<td>$60k to $125k</td>
</tr>
<tr>
<td>D-Command Surface</td>
<td>$20k to $50k</td>
</tr>
<tr>
<td>Control</td>
<td>24 Surface</td>
</tr>
<tr>
<td>Control</td>
<td>8 Surface</td>
</tr>
<tr>
<td>Custom Keyboard – Windows</td>
<td>$105</td>
</tr>
<tr>
<td>Custom Keyboard – Mac</td>
<td>$119</td>
</tr>
<tr>
<td>DigiSnake (DB25 to XLR)</td>
<td>$95</td>
</tr>
</tbody>
</table>

†Includes Pro Tools® HD 7 software and DigiLink cable.
‡As of May, 2007.

### 6 Typical Pricing

This last section gives examples of typical prices associated with components used in a Pro Tools|HD® setup. This price information can be seen in Table 4. Prices were obtained from Digidesign’s website as well as third party vendor websites.

### References


