Word Clock Explained

Understand word clock, get it right in your studio, and you're guaranteed to hear the difference.

To enable playback of any digital bit stream, a timing reference clock is needed. Thus every digital audio device has within it an internal clock, which is an electronic component made from a piece of quartz crystal. (Because it is a stable and accurate frequency generator, the crystal is used in many electronic devices – such as a wrist watches – to generate a timing reference.) When we connect two digital devices together, it gets a little more complicated. All digital devices need to be referenced to the same clock, otherwise one of two things will happen, depending on the devices in question:

1. The receiving device will see incoming audio data, that is not referenced to its own clock cycles, so the data is reflected. Result? Audio does not pass.

2. The receiving device sees incoming audio data and attempts to pass audio, but due to differing tolerances in the clock timing, pops and clicks are heard in the audio.

To ensure functionality, every digital audio device on the market with a digital input is required to have the ability to accept a clock reference signal. Depending on the digital audio interfaces the device has, it will accept an external clock in one of two ways:

1. By using dedicated word clock connections (Word Clock I/O).

2. By extracting clock signal from an audio stream (Clock Interleaved with Audio Data).

We'll be mainly concentrating on how to get dedicated word clock I/O working in the studio, but have a look at the 'An Overview' box for more on interleaved clock.

What's the Word?

The word clock is a square wave signal that is transmitted via a 75Ω BNC connector. A square wave, of course, alternates between high and low states, which makes it ideal as a timing references. Because many devices can use word clock signals as their master timing reference, it has become a standard type of digital audio system clock.

A word to smaller studios

I have seen some small studios that struggle to get away with not having a master word clock. They use a DAT machine or the PC to clock everything else in a daisy chain. So when they reboot the PC or put a tape in the DAT, everything else goes into a spasm of reclocking – great splats and noise pulses threaten to tear the speakers apart – which does little to impress the client. The other issue with daisy chaining, is timecode syncing. If the DAT is the clock source but the PC is providing the timecode, you can easily end up with the clock from one machine, chasing the timecode from the other. This either means that the machines hunt to synchronise or they just suddenly reclock with a big splat. *Michael Gissing.*

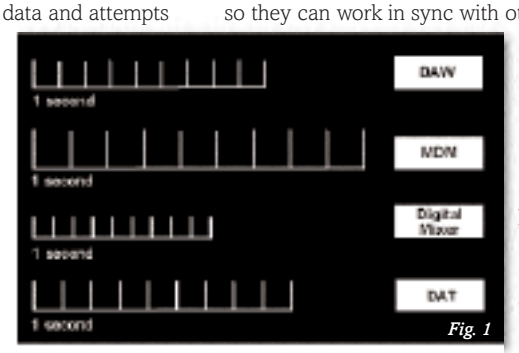


Fig. 1

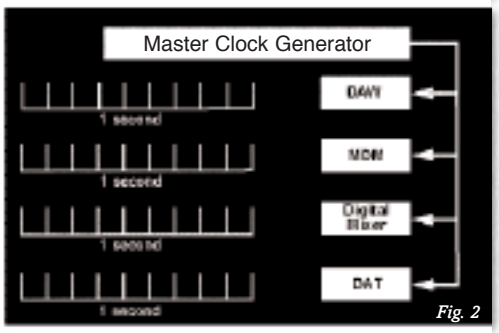


Fig. 2

As you add more digital devices to your studio, you're also adding more digital clocks, which is where most of the problems begin. You record your audio using one device that's using its crystal as a master clock, and then you try to send that signal into another device that's using its own crystal as the master. If you've ever heard a click or a pop in your audio, this is most likely the culprit. Even if both devices are running 44.1k, you're still going to get clicks because two crystals, no matter how accurate, will never be exactly the same. The clicks are audio samples being lost or skipped because there are two different clocks in the system. (See Fig. 1)

Most professional digital audio devices have a word clock input so they can work in sync with other devices in the studio. Some DATs and other gear lack work clock inputs, though, which makes it a whole lot harder to rid your studio of clocking problems. For now, let's assume that all of your digital audio devices that require synchronisation have word clock inputs.

Next, you need to invest in a quality master clock generator to be the master clock for all your digital devices. The ideal way to sync a digital studio is with a low jitter master clock generator that connects a discrete clock output to each digital audio device. This helps tremendously in reducing the jitter in your studio, as well. If each device is getting its own clock from the same low jitter source, then only audio data is being transferred between the two devices, and reclocking jitter does not occur. (See Fig. 2) This completely eliminates any chance of sync problems and also does away with any jitter that might be picked up along the audio cable.

To set up the sync system, simply connect a separate word clock output to the word clock input on each of your devices so all devices are referencing the same clock. Make sure to set each device to slave off of the external word clock – if they're smart, the devices will lock to it automatically.

Video facilities use a house sync generator that generates video black burst sync signals and connects to every room and every video device in the facility. If you already have a video house-sync generator, then you need to get a digital audio master clock generator that will reference video black burst. This guarantees that all your digital audio and video will be locked to one common clock – the most ideal solution.

There are a few rules regarding using word clock that most

engineers do not know. The most important is to watch the cable length of the clock signal. The word clock signal was originally designed to be transferred through a circuit board, not over a long coaxial cable. You shouldn't have a problem as long as you keep your word clock cable length under 15 feet, but anything longer will lead to reflections in the cable, which may cause loss of sync, dropouts, and increased jitter in the digital audio. This jitter can result in cloudiness, a loss of stereo imaging, and lost detail and clarity in the high audio frequencies. You must also use a good quality, 75Ω coax cable; usually a thick video cable works the best.

Spreading the Word

Another important consideration with word clock is the way it's distributed around the studio. It's not good to daisy chain word clock from one device to the next, because of voltage considerations at the input of the word clock. Each word clock input contains a 75Ω resistor that is needed to properly terminate the cable impedance. If one word clock source is connected to several inputs, the word clock signal will be loaded down too much and will not have enough juice to go around.

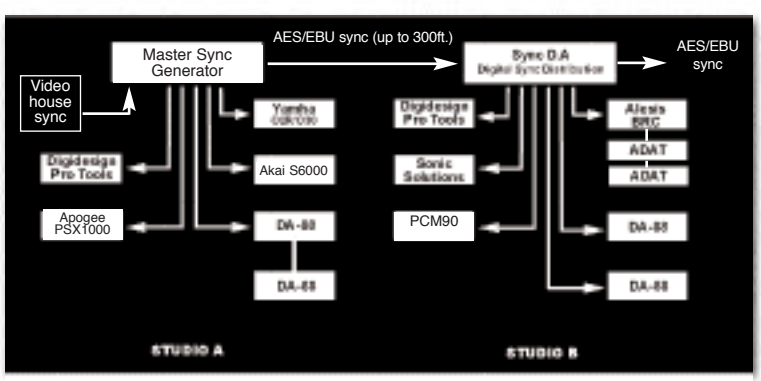
A good word clock distribution amp (DA) solves that problem. But be aware that you cannot use a video distribution amp to distribute word clock. Many people think that because the video signal and the word clock signal have the same BNC connector and cable type, work clock can be distributed by a video distribution amp – it can't. Video DAs are made to work with video signal levels, which are typically 1Vpp, whereas a typical word clock signal runs into the 3 – 5Vpp range. Because of word clock's higher voltage and current requirements, a video DA cannot properly distribute word clock. In addition, the DC restoration circuits used in a video DA can change the word clock polarity from positive to negative. The word clock input circuits are not designed to work with negative voltage levels, and the DC restoration can actually damage your digital audio equipment.

Bring it Together

Let's take a typical setup with ProTools and an 888 I/O, two ADATs with a BRC, Apogee PSX-1000 digital to analogue converters, a Yamaha 02R digital mixer and a unit like Aardvark's Aardsync II low jitter master clock generator. Connect a word clock output from the AardSync to the 02R, another to the Apogee PSX-1000, and one to the BRC (which will sync the ADATs). Make sure your cable lengths are under 15 feet, and set each device to lock to external word clock.

You'll have to place the master clock generator right next to the 888 because you can only take the Superclock a few feet [see An Overview box for more on Superclock]. So connect the Superclock out to the Slave In port on the 888 I/O. Pick a sample rate (commonly 44.1k or 48k) on the master generator, and you should be up and running with a very low jitter, problem-free studio. If you need to use SMPTE timecode, just make sure that the SMPTE source is locked either to video or to word clock. If you're using a MOTU Midi Timepiece, then just take the video black out of the AardSync II and connect it to the video in of the Midi Timepiece. Everything will be in sample-accurate sync.

What if you need to get the same word clock into the next room, where you have to go further than 15 feet? An AES/EBU signal is an excellent source of clock if there's no audio data in it ('digital silence'), and it can go several hundred feet. In fact, the AES-11 standard is just that – transmission of clock data using AES3 I/O



An Overview

Word Clock – Word clock is a timing reference that is specified as a 5Vpp square wave signal, with its frequency matching the sampling frequency of the device. It typically utilises BNC connectors and 75Ω coaxial cable. Word clock requires the 'end of the line' to be terminated using a 75Ω terminating resistor. The terminating resistor 'soaks up' the square wave pulses and stops them being reflected back up the bus.

Superclock – was introduced by Digidesign and designed to be a more accurate version of word clock, by using a 256x sampling rate resolution. This type of clock is more susceptible to interference (due to its higher operating frequency) and therefore Digidesign recommends you use cable runs of less than two feet from the generator to the digital audio workstation. This usually mandates that the master clock generator be placed in the same rack as the ProTools I/O boxes.

Clock Interleaved with Audio Data – Another common way of transmitting clock – as used in S/PDIF, AES/EBU and ADAT optical digital audio interfaces. The receiving device splits the incoming data, sending the clock data to the clocking circuit, while sending the digital audio data to its destination.

So why not just use it as a way to get clocks around the studio? The most obvious reason is that many devices do not have more than one AES/EBU input. More importantly, when the clock is carried along with actual audio data, the clock is a bit more jittery than when all the audio bits are 0 (which is called 'digital silence' or 'AES/EBU black'). The one big advantage of AES/EBU digital audio buses is that they're terminated at both the transmitting and the receiving end. This double termination allows the signal to be transmitted over several hundred feet with minimal jitter problems.

In some broadcast applications, you can see AES-11 inputs, which are simply AES3 inputs with no audio data (just clock data). Further to this, a variant called AES3-ID also exists which uses BNC connectors and 75Ω line impedance, and this is commonly used in applications with existing video cable infrastructure (like broadcast).

Clock Master – Regardless of which clocking method is used, one digital audio device in your studio needs to act as the clock master (conductor of the orchestra) while the rest slave to the clock signal (the musicians in the orchestra). Ideally you should have a dedicated clock master/distribution device which can not only distribute the word clock to all devices, but also resolve incoming sources such as SMPTE timecode into word clock. This is especially important for audio-follow-video applications, where the master timing reference is the timecode track on the video tape. With this setup, if the tape slows down, the word clock stream follows, ensuring audio-video lock. The Aardvark Aardsync II and the MOTU Digital Timepiece are two examples of such a device.

No Word Clock I/O or Digital Input? – Some digital audio devices do not have word clock I/O or a digital input (like many CD players for example). In this case you will need to clock your receiving device to the incoming source (typically S/PDIF for CD players), making the CD player the clock master. (NB: many CD players do not output a clock signal unless a CD is actually playing. In this situation, another device will need to be nominated as the clock master. This is why a lot of people forget about digitally connecting their CD player into the system – sometimes the advantages can be overlooked because of the hassle factor.)

[see An Overview box for more on interleaved clock and AES-11]. You can run the AES/EBU signal into the next room and connect it to a distribution amplifier which will reference the signal's clock and then distribute its to word clock/Superclock outputs.

There are many other problems with keeping the audio and the video locked together, but those are usually much easier to figure out. Digital audio can be complicated issue if you don't know what to look out for. But once you really understand digital audio and know a few common rules about the different kinds of clocks and their idiosyncrasies, many of the common digital audio problems are easily avoided.

Thanks to Erik Lovell and Nick Orsatti for bringing this article together.

Word Clock – Michael Gissing provides a post pro perspective

Word Clock! It's a spectre that strikes fear in the hearts and minds of the modern digital studio owner. Well, only if you let it. In reality it's devilishly simple and yet for some people the concept of getting word clocking right in their studio seems daunting.

I first faced the issue back in the early '90s. I was already aware of video syncronising and timecode. But with the purchase of a digital mixing desk, the issue became paramount. Like many, I wondered why I was ending up with a terrible daisy chain of clock syncronising, none of it in sync with the video machines that I was controlling. I had a Yamaha DMR-8 digital mixer, with two Yamaha digital eight-track machines providing 16 tracks. I also had a Roland S770 sampler with a digital output and a Sony PCM 3402 digital two-track master recorder. I was trying to synchronise them all to timecode at the same time as wordclocking and video syncronising. It just wasn't happening, so I went back to basics.

For starters, everything needs to reference to one source. In my case, the base line was video sync. Visualeyes Productions, a video facility that my studio shares premises with, had a sync pulse generator with a nice clean colour video output that was going begging. Next task was to find someone that made a word clock generator that could lock to a video source. Audio & Design had a box, but they generated video sync from word clock, not the other way around. So I put the hard word on my father to make a box. The brief was for the box to include video in, phase lock and for it to generate a word clock output with eight word clock outputs and eight video outputs. The multiple outs were simple distribution amps, but the word clocking turned into an interesting exercise. PAL video is based on 50Hz sync pulsing. To strip out the 50Hz and multiply it up to 44,100Hz or 48,000Hz would amplify the jitter inherent in the original video sync. For happy digital audio, the aim is to have a low jitter figure for a master word clock. Below 10 nanoseconds is considered good.

My father decided a phase lock loop with a slow slew would 'ignore' a lot of the jitter, but still be able to stay perfectly locked. He multiplied the 50Hz to 4.41GHz to do the phase lock and then divided back to 44.1kHz for the actual clock. This meant the jitter was also divided and, with some experimenting with power supply isolation, we arrived at eight nanoseconds jitter. I was happy and so was all the digital equipment.

The importance of getting a low jitter master clock cannot be overstressed. When digital audio is recorded and re-recorded, as is typical in a sound post facility, the problem of re-recording and adding jitter leads to degradation of the sound. But the joy of word clocking properly extends beyond the jitter/quality issue.

At my facility, Digital City Studios, we have three studios and a digital video on-line which also has a Yamaha digital mixer, plus digital video machines. So by having a master word clock, locked to video, we can safely route digital audio from room to room without concerns about getting those horrible clicks when signals are unclocked. At the heart of the clocking configuration is the mixing desk. The O2Rs are word clocked, as are the CD players, DAT machines and sample rate converters (more about these later). The dSP hard disk recorders take the word clock from the desk directly down the 25-pin multi cables. So three studios are timed to the master clock. Because we mostly work at 48kHz, (although some signal sources are 44.1kHz, like CD and often DAT) these signals are converted to 48kHz by real-time sample rate converters. We use Z-Sys converters and can convert eight channels simultaneously – very handy when dubbing from a Tascam DA88.

One practice that is also made possible by master clocking is to run two or three studios together. A typical example for our studio is when we have a stereo mix of a documentary with narration plus a version for foreign sales with the narration stripped out. Both versions need to be restriped onto a Digital Betacam master. So we open the full mix project in Studio A while the music and effects mix (M&E) project is taken care of in Studio B. Both rooms lock to timecode from the Digital Betacam and the digital signals, timed by the master word clock go straight to the Digital Betacam machine. Everything is locked, video, timecode and word clock, so nothing drifts out of sync and no clicks rear their ugly heads.

Staying in the digital domain at all times is standard practice at Digital City Studios. Having to resort to the analogue domain to get around a sample rate or word clock problem is not necessary in an environment where word clocking is properly addressed. The advantage of this also goes beyond technical considerations. Being able to take a Digital Betacam tape from a job a year ago, load up the project on the dSP DAW and insert a new line of narration in a mix is effortless. Levels, sync timing and identical reproduction means that the changes are insert edited seamlessly.

When I purchase equipment, I always check to see if a separate BNC word clock connector is on the back. Unless the equipment is designed as an insert device, like a reverb unit or signal processor like CEDAR, I expect a word clock connector. In some circles, AES is used to word clock. The disadvantage of this is that AES has some buffering and also the AES signal that you use for clocking may also be a signal that you wish to monitor. A separate signal (used purely for clocking) on a BNC is an advantage. Some purists want to see a separate word clock connector on all equipment. The argument for this is that driving everything from a low jitter clock gives the greatest signal purity in the digital domain. From a practical point of view, I would say the need for a separate word clock BNC connector is most important on a digital mixer, an A/D converter and all digital tape machines. Some A/D converters like the Prism AD02, allow you to reclock a digital signal to a low jitter master word clock. This can improve recorded jitter coming from a DAT tape or poor CD-R, for example.

If you have a word clock generator, or are curious about jitter specs, then it is handy to be three doors down from Rick Dowel at Control Devices (as I happen to be!). Rick is the agent for Prism, which make a wonderful hand held, battery powered digital analyser. This device is invaluable for tracking down digital problems like jitter. Word clock, like video sync, is a fairly simple signal to deal with. Voltages and termination are actually very flexible – most equipment will deal with these variables. What matters is a clean square wave, low jitter, and, if you are syncing to video, it must be referenced to a video sync generator. Don't make the mistake of using a VHS machine or a PC card video black generator as a reference signal. Remember that the more the video jitters, the more your master clock will jitter. And video jitter tends to be amplified, unless clever design of phase lock loops can minimise this effect.

For the distribution of word clock signals, we use standard 75Ω video cable. There is not much variation in cable lengths between the word clock generator and our three studios. Like video, cable length can affect timing. Our studio hasn't encountered any problems with the small variations we have. If you are planning a big install, try and make sure the word clock generator is centrally located, to avoid large variations in cable timing. If you are sending AES signals from room to room, the buffering in the AES signal will give you timing flexibility. The same applies to TDIF which is of course a variation on S/PDIF.

So word clock need not raise the spectre of doom. Just remember to keep the daisy chains for daisies, not word clock.

Michael Gissing