Application Note

10MHz Exporter to Exciter Synchronization for the HD Radio™ System

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1. Exporter to Exciter (E2X) Synchronization

The transfer of HD Radio audio frames between the Exporter and Exciter is done asynchronously. There is no request/response exchange in the E2X protocol. PDUs are merely sent from the Exporter to the Exciter at predetermined rate of precisely .673 Hz or one frame rate PDU every 1.486 seconds. In turn, the Exciter expects a complete frame every 1.486 seconds to form the next HD radio message to be passed to the modulator. Independent crystal referenced clocks in the Exporter and the Exciter are responsible for these actions. Some form of synchronization between these clocks is required to maintain lock-step between these functions. Without synchronization, even the slightest variation between the clock's frequencies and phases will result in analog-to-digital blending artifacts and buffer underflow or overflow in the Exgine buffers. As the buffer levels change, so to will the apparent of diversity delay between the analog and digital signals.

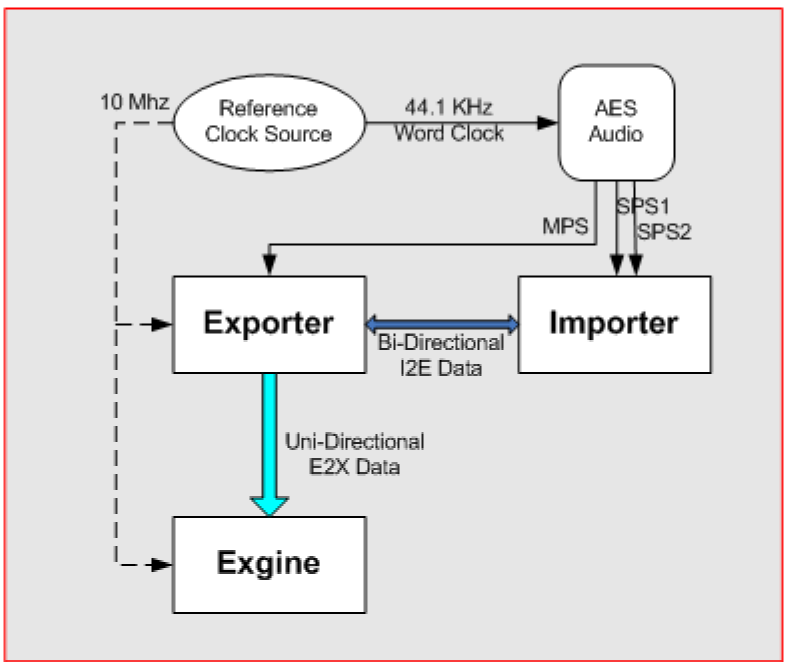

Figure 1 - Necessary HD Radio Synchronization

1.1. Synchronization Methods

There are three methods that may be used to assure synchronization between the Exporter and Exciter.

- Local Synchronization
- GPS Referenced Remote Synchronization
- Sync 10MHz Remote Clock Phase Locked Loop Synchronization

1.1.1. Local Direct Synchronization

Figure 2 illustrates the simplest method is to connect data through a simple network or even crossover cable, and provide a direct connection between the Exporter's 10MHz output and the Exciter's 10MHz external reference input. This method of course, is only practical when the Exporter and Exciter are co-located. To use this method, select *External* Synchronization on the Flexstar.

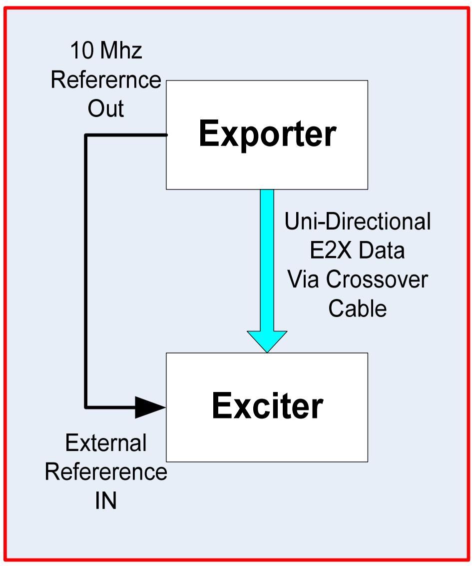

Figure 2 - Local Synchronization

1.1.2. GPS Referenced Remote Synchronization

Most implementations would prefer to have the Exporter at the studio connected to the exciter at the transmitter site via an STL system. Figure 3 illustrates the preferred method of synchronization. The most reliable remote method is to provide GPS locked a reference word clock source at the Exporter at the studio and separate GPS locked 10MHz reference to the Exciter located at the transmitter site. To use this method, select *External* Synchronization on the Flexstar.

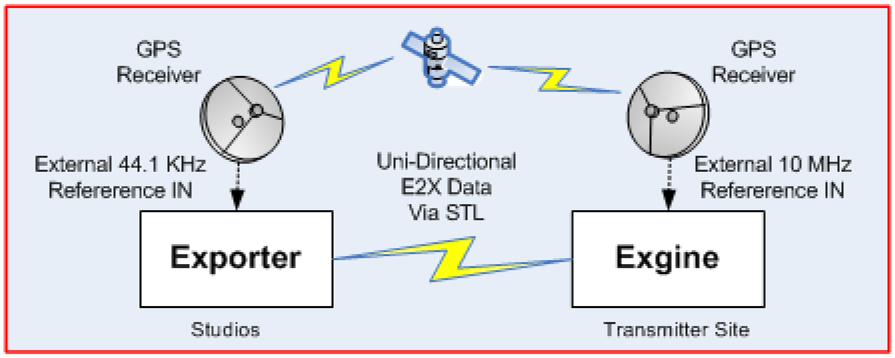

Figure 3 - GPS Referenced Synchronization

1.1.3. Sync 10MHz Remote Clock Synchronizer

The third method employs a 10MHz Remote Clock Synchronizer in a Phase Locked Loop. The Sync10MHz system receives a pulse every time the Exgine receives an E2X Modem Frame Boundary Clock Message from the Exporter. The Sync10MHz system continuously outputs a 10 MHz clock to the Digital Up-Converter. This clock is phase-locked to the Exporter's 10 MHz clock. The PLL circuit is very slow to respond to changes and attempts to average the frequency of the incoming pulses over several hours to train the 10MHz oscillator. To use this method, select *Exporter* Synchronization on the Flexstar.

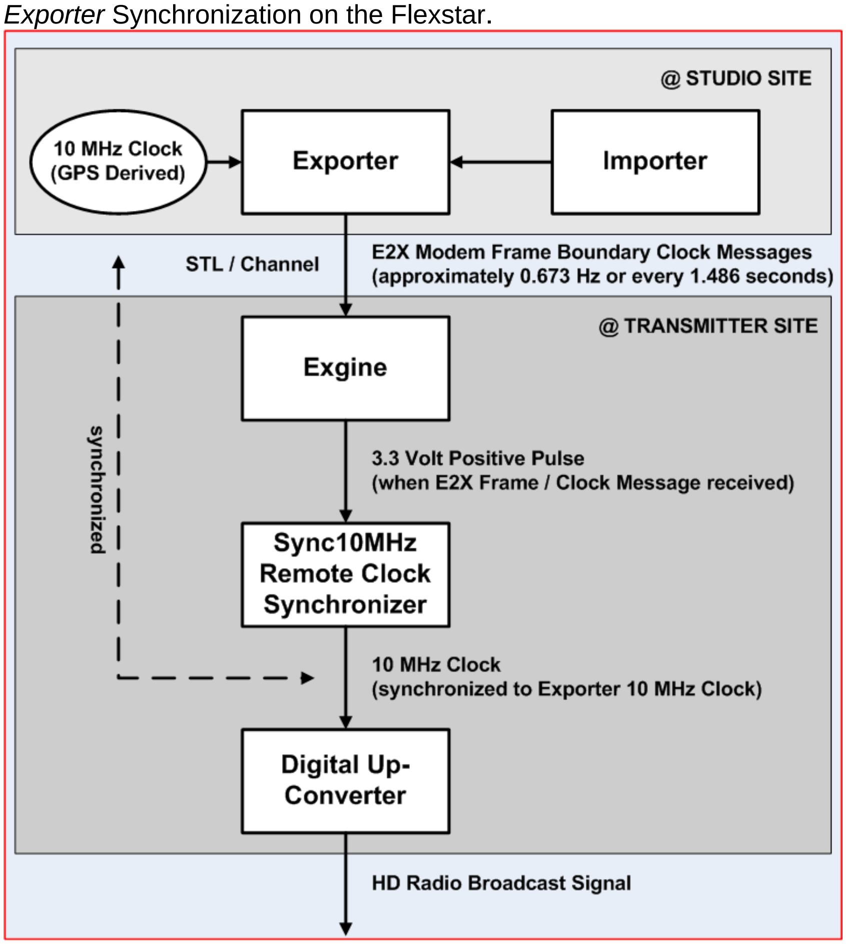

Figure 4 - Remote Clock PLL Synchronization

This method may be deployed successfully when GPS synchronization is not possible at the transmitter site but it must be understood that it has significant limitations. Because the synchronization is now derived by a precision cadence over the network/STL link, any dropouts or jitter in the transport system will result in a skewing of the 10MHz reference frequency. The Sync10MHz Remote Clock Synchronizer requires a relatively low jitter network/STL combination to work reliably. Although “system jitter” is difficult to measure and quantify on a long term basis, HD radio installations that intend to make use of the Sync10MHz Remote Clock Synchronizer system should aim to keep their end-to-end E2X clock message jitter below +/- 10 milliseconds (or preferably below +/- 5 milliseconds) for reliable operation

Unbalanced jitter can produce frequency deviations of the PLL away from its ideal frequency. Although the phase-locked loop will usually remain “locked” during an unbalanced jitter event and the Exporter and Exgine data buffers are large enough to keep the entire HD radio system operating reliably for a time, the sample alignment between the analog and digital audio streams may be effected and left unresolved, may eventually result in a buffer underflow or overflow causing the HD stream to stop until the buffers can be stabilized.

As an example, if the PLL is pulled off its ideal frequency by 1 Hz (.1 ppm @ 10 MHz) the Exporter and Exgine clocks will drift away from each other at a rate of 0.36 milliseconds per hour. This is equivalent to skewing the audio alignment at a rate of 15.876 audio samples per hour.

Because of the very long settling time inherent in the PLL circuit, if the jitter is frequent and excessive, the PLL’s 10MHz output will continue to wander resulting in continuously varying apparent diversity delay. A variation of +/- thousands of samples is not uncommon.

2. Real World Clock Message Jitter Issues

It is impossible to test the Sync10MHz Remote Clock Synchronizer system in all the real world combinations of network architectures and STL equipment that will be found at radio station studio and transmitter sites deploying HD Radio systems. That said, several configurations were characterized utilizing different makes and models of STL equipment (as well as configurations without any STL equipment).

In doing these characterizations, several sources and types of “jitter” on the E2X modem frame boundary clock messages were noted. Two types of jitter were observed. The first is classic “balanced jitter” where a clock edge (or in this case a clock message pulse edge) is equally likely to occur before or after the expected time. The second type of jitter is referred to as “unbalanced jitter”. This type of jitter can only occur after (and never before) the expected time. It seems to be produced by certain system events (i.e. – a temporarily heavily loaded Ethernet router or even GUI interactions on the Exciter or Exporter) that can only delay the processing or transmission of the clock message (and conversely can never speed it up or make it occur earlier). Another name that could be used to describe this type of jitter might be “temporary latency” (although we will continue to use the term “unbalanced jitter”).

This unbalanced jitter is somewhat problematic for the Sync10MHz system to deal with. The phase-locked loop filter within the Sync10MHz system will tend to correct for any unbalanced jitter that affects the clock messages for a significant period of time. And when that unbalanced jitter resolves itself (i.e. – the Ethernet router becomes lightly loaded after a period of heavy loading), the phase-locked loop filter will once again try to correct in the opposite direction. The effect of this situation on the Sync10MHz system is that the 10 MHz VCXO may be unnecessarily pulled off of its ideal frequency from time to time.

After much experimentation, the following sources of jitter have been identified:

1. Exporter clock message transmission uncertainty. (balanced jitter, less than +/- 3 msec)
2. Exporter clock message transmission temporary latency caused by occasional user interface or operating system activity. (unbalanced jitter, on the order of a millisecond, depends on activity)

3. Channel effects. (balanced and unbalanced jitter, varies widely with STL equipment and network environment)
4. Exgine clock message handling uncertainty (balanced and unbalanced jitter, seems negligible with iBiquity reference design, other manufacturers Exgine implementations may vary)

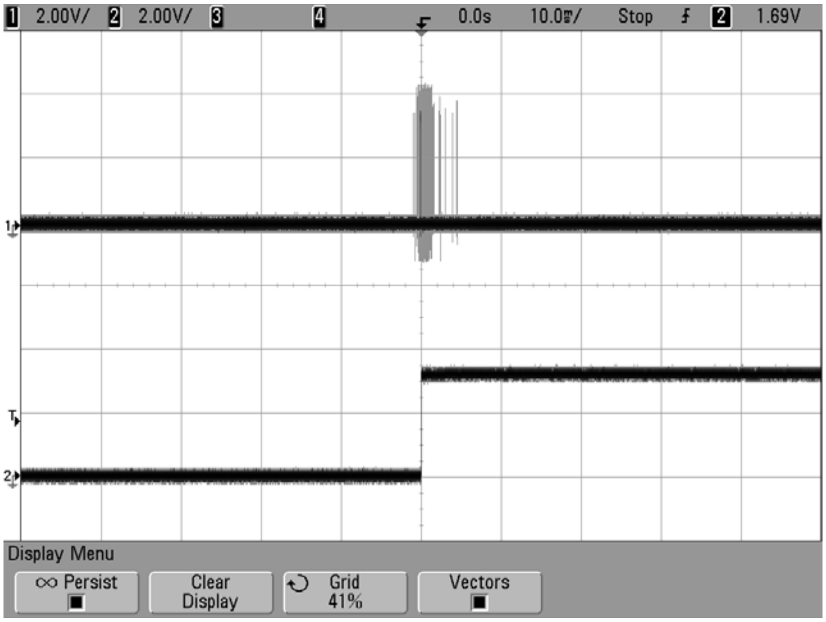

Figure 5 - Jitter - Crossover Cable - 15 minutes of operation, 10 msec/div

Figure 5 shows an example of the simplest configuration for measuring end-to-end system clock message jitter. In this configuration the Exporter and Exgine are connected by a simple Ethernet crossover cable. As can be seen in the diagram, the overall system jitter for 15 minutes of operation spans about 6 msec (which could be described as +/- 3 msec around a center point). Since there is no channel per se in this system configuration, the jitter must be coming directly from either the Exporter or the Exgine.

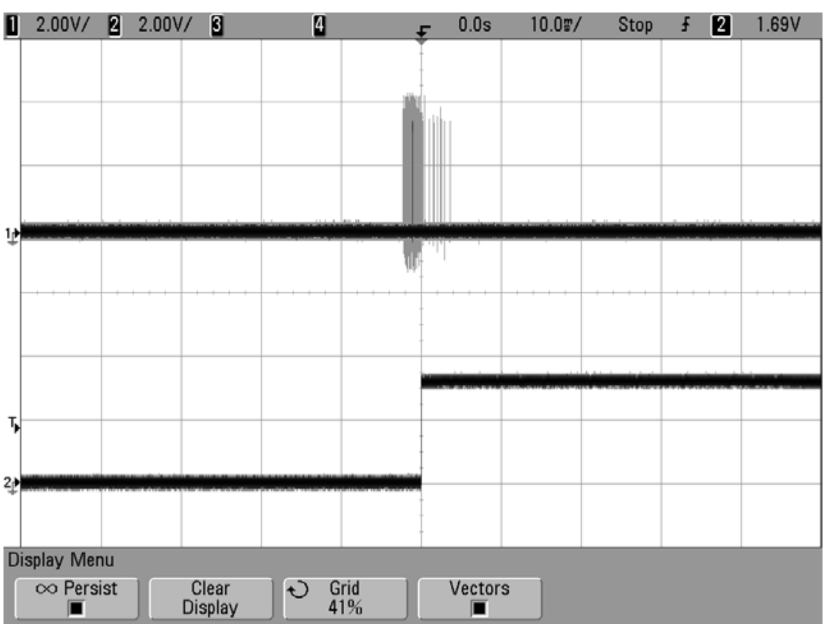

Figure 6   Jitter - Harris Intraplex STL (384 kbps) - 15 minutes of operation, 10 msec/div

Figure 6 shows the end-to-end system clock message jitter for a configuration where the Exporter and Exgine are connected directly via a Harris Intraplex STL (provisioned for 384 kbps of E2X data). As can be seen in the diagram, the overall system jitter for 15 minutes of operation still spans only about 6 milliseconds. This seems to indicate that a channel consisting of just the Harris STL adds very little clock message jitter to the overall system.

Figure 7 shows the end-to-end system clock message jitter for a configuration where the channel consists of another popular data link system (operating at a 512 kbps data rate). Note that the oscilloscope time scale is set to 100 milliseconds/division for this diagram (all the other diagrams are set to 10 milliseconds/division). The amount of system jitter spans about 500 milliseconds. This is at least an order of magnitude more jitter than the current Sync10MHz clock synchronizing method can handle.

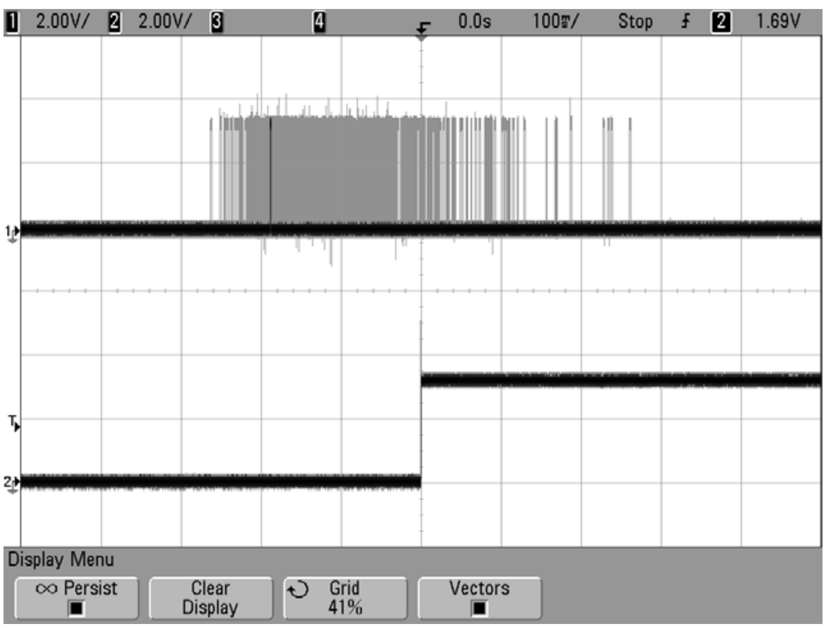

Figure 7   Jitter – Popular data STL (512 kbps) w/ Network - 15 minutes of operation, 100 msec/div

3. Summary

Clock synchronization between the Exporter and Exciter is critical to the proper operation of the HD Radio system. In order to maintain buffer depth, apparent diversity delay and proper analog to digital blend alignment the 44.1 KHz AES word clock to both the Importer and the Exporter must be referenced to the Exciter by synchronizing the 10MHz clock in the Exciter directly from the Exporter or from the same reference source as the Exporter. Operation of the Harris Flexstar Exporter/Exciter system in any configuration without positive synchronization is not recommended.

Direct connection using a crossover cable and direct local 10MHz synchronization from the Exporter to the Exciter is by far the simplest and most reliable configuration. It is not however the configuration that most stations will want to implement as the Exporter was designed to operate from the studio environment over a data link.

When operating E2X over an IP data link and STL system, it is imperative that some method of remote synchronization be implemented. The use of separate GPS receivers at the studio and transmitter sites to provide synchronized reference clocks is how the system was designed to operate and is the Harris recommended practice.

In order to provide a method of remote synchronization in situations where GPS reception is not practical, the Sync10MHz Remote Clock Synchronizer system has been developed. This is still somewhat of a work in progress. It requires a relatively high quality, low jitter network/STL combination to work reliably but is a viable solution where direct connection with the Exporter or GPS reception is not an option.

4. Acknowledgements

Sync10MHz Remote Clock Synchronizer Reference Design Application Note – TX_TN_5089, Brian Kroger, Allan Black, iBiquity Digital Corporation - 31 October 2006

HD Radio Networking Requirements,- TX_TN_2040
Tim Anderson et. al., iBiquity Digital Corporation – 26 October 2006