Ellisys Expert Note | EEN_BT11 Rev. B

Measuring Audio Latencies

Using the Ellisys Audio Grabber

Overview

In this Expert Note, we will discuss latencies typically present in Bluetooth audio systems and how to use the Ellisys **Audio Grabber** (Figure 1) in conjunction with integrated audio-related features available in the Ellisys Bluetooth analyzer software and hardware to characterize these latencies.

The Audio Grabber is a small accessory for use with all Ellisys Bluetooth analyzer models. It enables precise, time-synchronized capture and measurement of audio latencies involving analog audio signals and I2S (Inter-IC Sound) digital audio inputs, all synchronized to any other traffic streams captured by the analyzer, such as Bluetooth, Host Controller Interface (HCI) traffic (UART, SPI, and USB), Wi-Fi, I2C, SPMI, UART, WCI-2, I2C, CAN, GPIO/logic, and others.

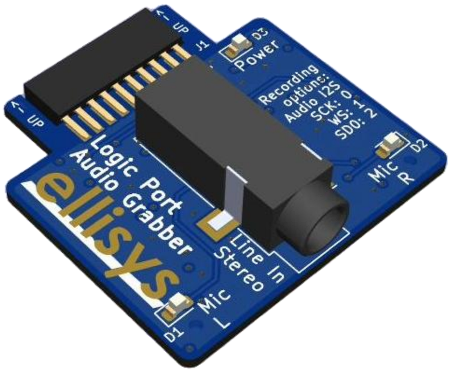

Figure 1 - Audio Grabber Accessory

The Audio Grabber connects to the analyzer's Logic port, either directly or through an adapter (which provides access to additional logic / GPIO lines by connecting a Flying Leads probe, described later in this document). It can fit Bluetooth Tracker and Bluetooth Vanguard models directly, but a provided adapter must be used to connect to the Logic port on the Bluetooth Explorer.

The Audio Grabber accepts two mono analog inputs / one stereo input (L and R). These can be either Line IN (3.5 mm TRS), the two integrated microphones (L and R), or a mix of one Line and one MIC. It converts the analog audio channels to I2S digital audio for time-synchronized display in the analyzer's Audio and Timing views. This two-channel audio input (now in digital form) is hardwired onto Logic inputs 0, 1, and 2 (signals SCK, WS, and SD0, respectively). These inputs must be configured in the Recording Options dialog (Wired tab) of the analyzer application. For convenience, these inputs are printed on the Audio Grabber's PCB.

The two MIC inputs (L and R) are typically for use when capturing audio from earbuds, which can be placed atop the MICs.

Three LEDs are also present, one each for activity at the L and R MICs and another to indicate the Audio Grabber is powered from the analyzer Logic connector to which it is attached (either directly or through the adapter).

Using the Adapter and the Flying Leads Probe

The adapter (Figure 2) is used to facilitate concurrent and time-synchronized capture of other signals, when needed, such as I2S digital audio, UART, commonly used audio control protocols like I2C and SPI, logic signals, and other traffic types, by use of a Flying Leads probe (Figure 4), supplied with Ellisys analyzers. See the section titled

Flying Leads Probe for more information on connecting the Flying Leads probe.

Note: The adapter *must* be used with Bluetooth Explorer analyzers, as the Logic connector on Bluetooth Explorer is of a larger size than is used on the Audio Grabber; it is optional for Bluetooth Tracker and Vanguard.

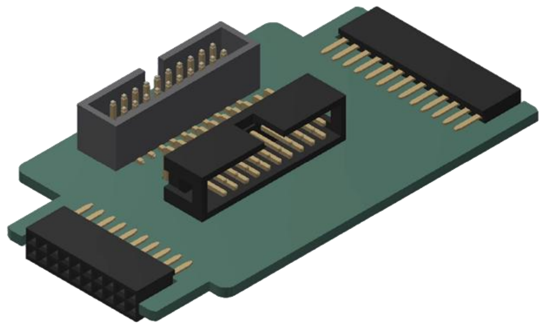

Figure 2 - Adapter for Audio Grabber

Looking at Figure 2 (above), the connector at left will attach to the Logic port on Bluetooth Tracker or Vanguard. The connector on the right attaches to Bluetooth Explorer's Logic port. There are two center-mounted connectors – the perpendicular connector at back allows for insertion of the Flying Leads probe – the size / type normally provided with Tracker and Vanguard; the other accommodates the connection of the Audio Grabber (see Figure 3, below).

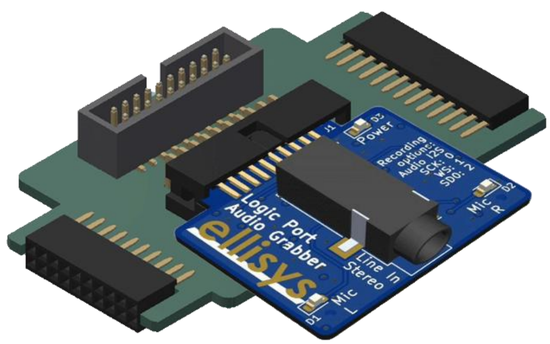

Figure 3 - Audio Grabber Inserted into Adapter

The Flying Leads probe is shown in Figure 4 (below). The probe is purely passive and uses color-coded, socket-tipped wires which can be assigned in the analyzer's Recording Options dialog (Wired tab). In addition to I2S, the probe facilitates concurrent, time-synchronized capture of UART (HCI and Generic), SPI (HCI and Generic), logic signals, I2C, SPMI, SWD, and other supported protocols.

Figure 4 - Flying Leads Probe

Audio Latencies

Audio systems must ideally deliver audio streams to users with near-perfect synchronizations, as even small variances in the rendering of audio streams, for example, L and R stereo streams, can result in poor user experiences.

Audio latency can be defined as the time it takes for an audio signal to traverse a system from input to output. Audio systems might be large, such as a theater or outdoor concert venue, where the speed of sound can play a role, or small, such as an electronic device, component, or module, where latencies are present from a variety of processing and transport requirements.

For our purposes here, we are more concerned with smaller-scale implementations, like component- or modular-level signal processing or implementations involving two communicating devices, where digital and analog representations of audio will be subject to various delays (see Figure 5, below). Delays realized through digital-to-analog converters (DACs) and analog-to-digital converters (ADCs) are often the focus of latency analyses in audio systems, while data buffering, digital signal processing tasks, other software processes, and even wireless transport can contribute to latency.

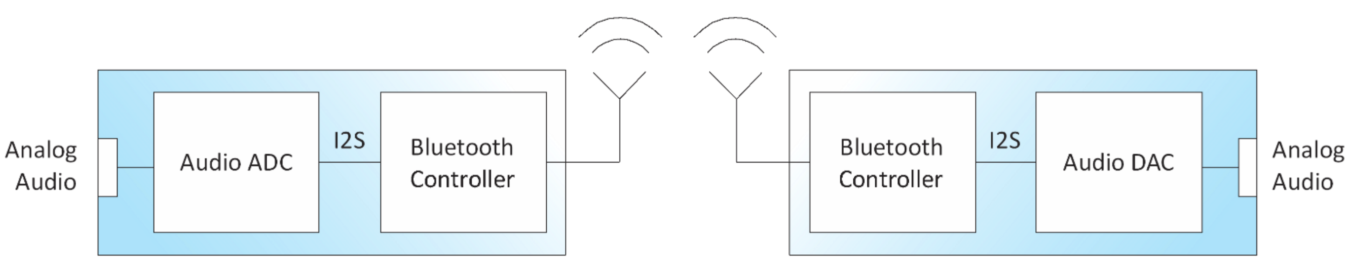

Figure 5 - Simplified Audio System Block Diagram

Bluetooth Audio

Bluetooth presents a wide variety of applications for audio, ranging from BR/EDR (Classic Bluetooth) for telephony and music to newer approaches using Bluetooth Low Energy LE Audio and its solitary companion codec LC3, which supports both broadcast and unicast (connection-oriented) topologies.

These applications can address many use cases, such as a single user listening to multiple synchronized streams, multiple users sharing the same broadcast, multiple users sharing different synchronized broadcasts (such as language-specific cases), bi-directional audio, and much more.

Figure 6 shows an Ellisys analyzer capture of many LE Audio streams. In this case, the LE Protocol Overview (filtered to show only Isochronous traffic) and the Spectrum view are also shown. The audio streams are indicated by blue lines in the Audio view. This capture includes primarily broadcast isochronous streams (BIS) although there may be unicast streams or Classic Bluetooth audio included as well. In this case, these streams are captured over the air, but there can also be concurrent captures of time-synchronized analog and I2S digital streams input via the Audio Grabber or I2S digital streams captured directly via the analyzer's Logic port (these would also be represented in the Audio view). In addition, one or more audio streams carried over the HCI can be captured. Quite the systemic view!

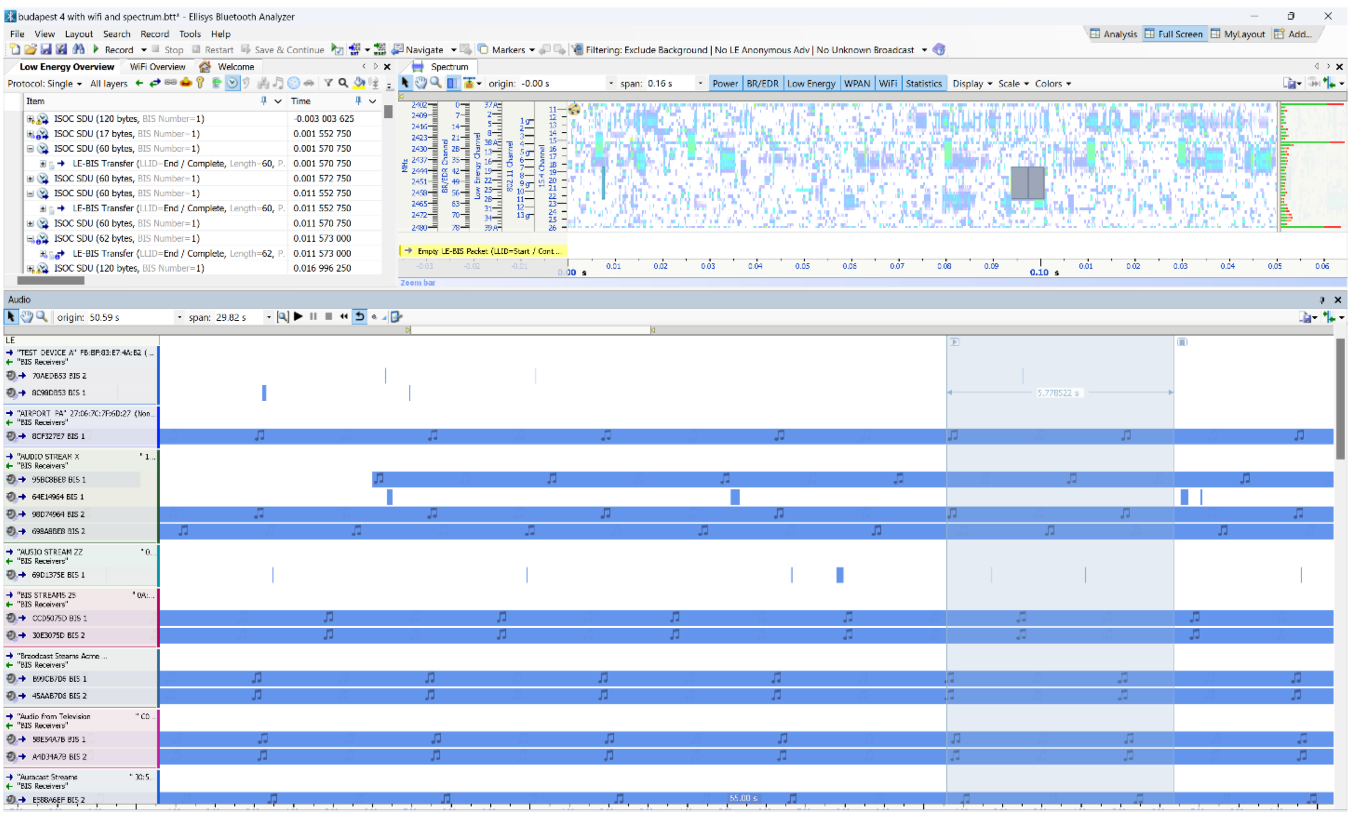

Figure 6 - Capture of Many Broadcast and Connected Audio Streams

What is Inter-IC Sound?

I2S (Inter-IC Sound) is a straightforward communication bus designed for transmitting digital audio (PCM) between integrated circuits such as DACs, ADCs, DSPs, and buffers. While I2S can be used to connect two audio devices externally, this is uncommon, and there is no standardized cable designed for such use.

The I2S bus consists of a serial clock (SCK), a Word Select line (WS), sometimes called Frame Sync, where a LOW enables the left channel's data and a HIGH enables the right channel's data, and typically one multiplexed (stereo) serial data line (SD). The clock rate will be dependent on the sample rate, the number of bits used per channel, and the number of channels.

Use of Ellisys Bluetooth Analyzers by Audio Engineers

Ellisys Bluetooth analyzers are heavily used by audio engineers worldwide for a variety of functions, including characterizing audio quality, optimizing transmission characteristics, latency measurements, protocol debug of stack issues, retransmission characterizations, power and battery optimizations, wireless coexistence studies, and more.

Users can concurrently capture audio in many forms, including digital format (PCM I2S), over-the-air via Bluetooth and Wi-Fi, over the host controller interface (HCI), and with the Audio Grabber, via analog source(s). These various captures are all perfectly timed and presented to the user in various logical, textual, and graphical formats. Audio can be exported for further analysis in third-party applications as well, e.g., Audacity (free open-source audio editor, see https://www.audacityteam.org).

To get a sense of what a typical audio capture contains, look at Figure 7 below. This includes capture of Bluetooth over-the-air traffic, with concurrent capture of HCI traffic (USB in this case). Capturing audio on both sides of the controller can be quite useful. A device-based filter is applied to focus just on the two communicating devices, and protocol filters are enacted on both traffic streams to further focus on audio. Command and audio streams are shown in the Audio view, which allows for playing the audio live during recording or on a saved capture, looping sections of the audio, timing measurements, time correlation to other views, and export to WAV files.

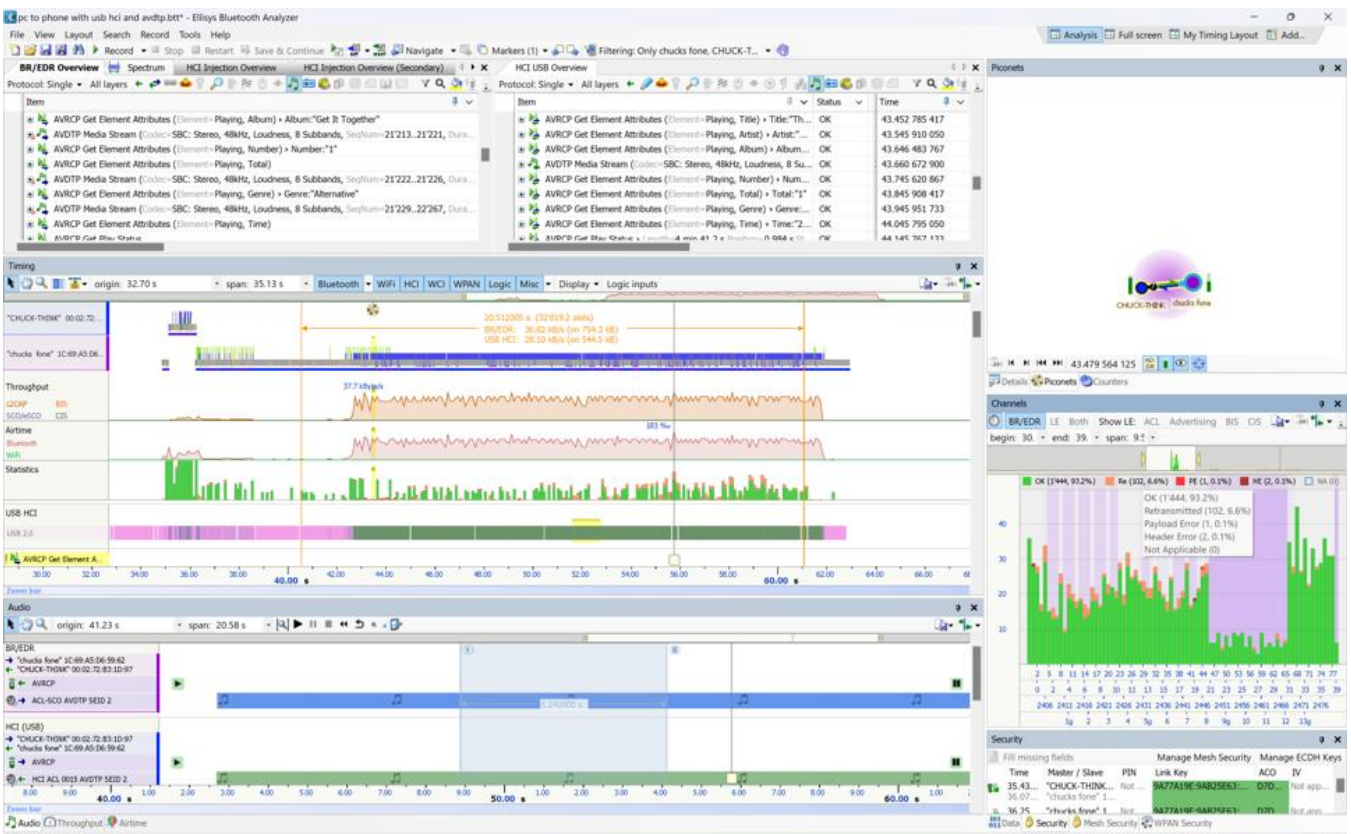

Figure 7 - Ellisys Comprehensive Bluetooth Audio Capture

The Channels view (middle-right of Figure 7, above) indicates the per-channel quality of the capture, including retransmissions, dynamic avoidance of interferences (magenta lines), encrypted traffic, packet errors, etc. All captured streams, wired and wireless, are shown perfectly synchronized in the Timing view, along with throughput information, airtime utilization, and various statistics.

Ellisys analyzers include advanced, unique audio features, such as LC3 AutoDetect (standard feature) which involves an implementation of a test-equipment-grade LC3 codec for improving LE audio capture quality, and tZERO™ Tracking (standard on Bluetooth Vanguard), a proprietary, high performance processing technology that allows for capture of the earliest instances isochronous traffic following encryption and capture of encrypted LE audio without having to pre-enter an LTK.

In Figure 8, we see a typical capture of multiple I2S digital streams, including the clock (SCLK), word select (WS), and serial data lines. Note that the I2S clock (SCLK) is not required for capture as it is recovered from the bit stream (this nicely reduces capture size). Two synchronized views are shown: the Timing view and the Audio view. These streams may be natively digital (as captured using the Flying Leads probe), or they may be digital representations of captured analog audio from the Audio Grabber's 3.5 mm jack or its MIC inputs.

Note the correlated time scales at the bottom of each view and the timing cursors, also populated into each view. Markers are also set, which are included with exported audio (see the section on Exporting Audio).

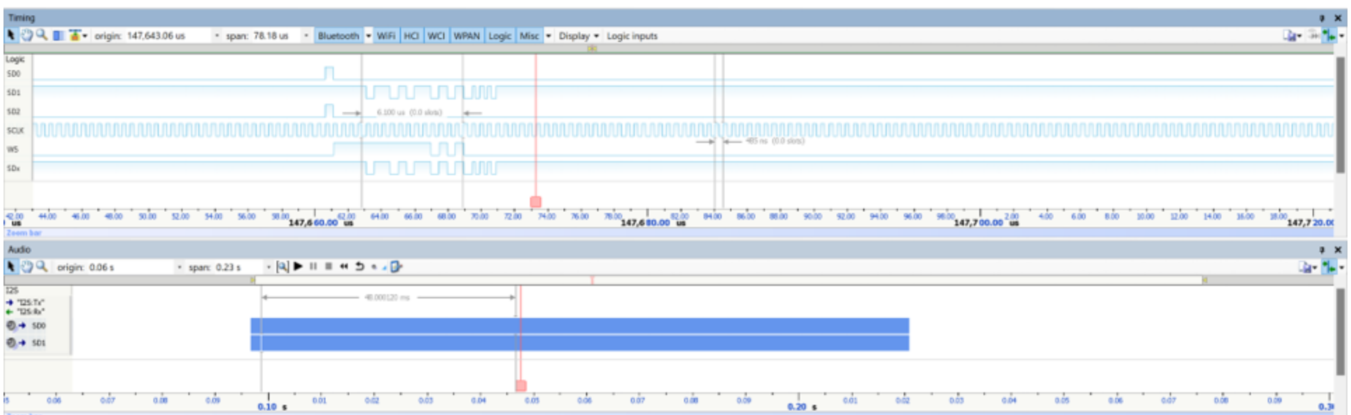

Figure 8 - Timing and Audio Views Showing Capture of Digital Audio Streams

Setting Up to Use the Audio Grabber

To set up the Audio Grabber, perform the following:

1. If the Audio Grabber is to be attached through the adapter (Figure 2), connect the Flying Leads probe (Figure 4), if needed, to the adapter, otherwise proceed to Step 2.

Note: For Bluetooth Explorer units, the adapter must be used due to the mismatching size of the Logic connector connector on Explorer. For Bluetooth Tracker and Vanguard, it is optional. The adapter also allows for attachment of the Flying Leads probe, used for capture of additional I2S buses, other communications standards (e.g., UART, SPI, I2C, SWD, SPMI), and logic signals. See the section titled

Flying Leads Probe for more information.

2. If using the Audio Grabber without the adapter, connect it to the Logic connector on the analyzer. If using the adapter, connect the Audio Grabber to the adapter (Figure 3), then attach the adapter to the Logic connector.

3. If the Flying Leads probe is used, attach the probe's lead(s) to the desired input(s), except for inputs 0, 1 and 2 which are dedicated to the Audio Grabber.

4. In Recording Options, assign primary Audio I2S inputs as shown in Figure 9. The analog inputs to the Audio Grabber are converted to I2S and are hardwired to I/O's 0 (SCK), 1 (WS), and 2 (SD0) as shown on the Audio Grabber PCB and as shown below in Figure 9.

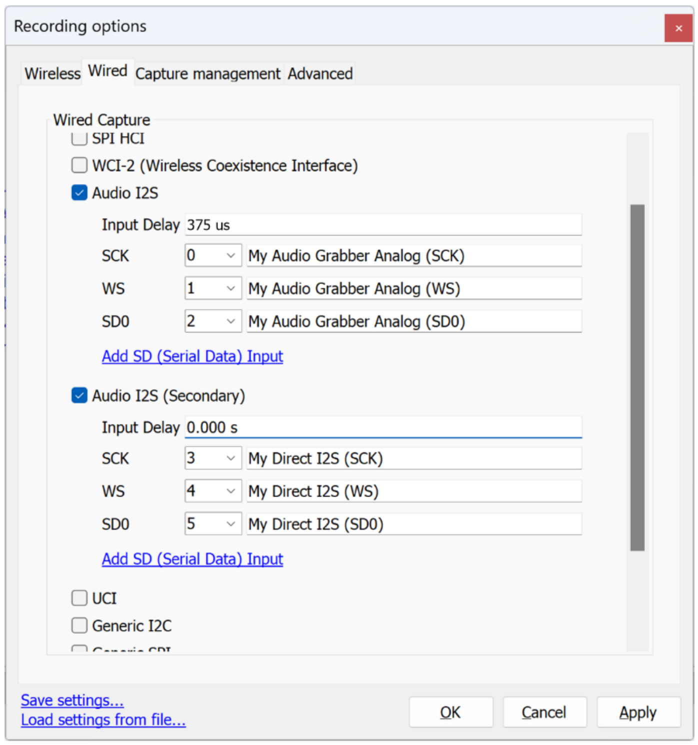

Figure 9 - Recording Options Setup for Audio I2S Inputs and Input Delay

Conveniently, an Input Delay is available in the Recording Options setup for Audio I2S. This setting is used to compensate for expected ADC latencies on the Audio Grabber. The ADC will have an expected latency when converting the analog inputs to the digital I2S format used by the analyzer. As users want the time of the analog audio, not the time of the digital audio, the Input Delay setting compensates for this ADC latency, so that the timestamping displayed by the analyzer software will match the actual time of the analog audio. The Audio Grabber latency has been precisely characterized at 375 us.

The Audio Grabber configuration can be reviewed and edited from the analyzer tab of the About box accessible from the Help menu, by clicking the blue Configure link, as shown in Figure 10.

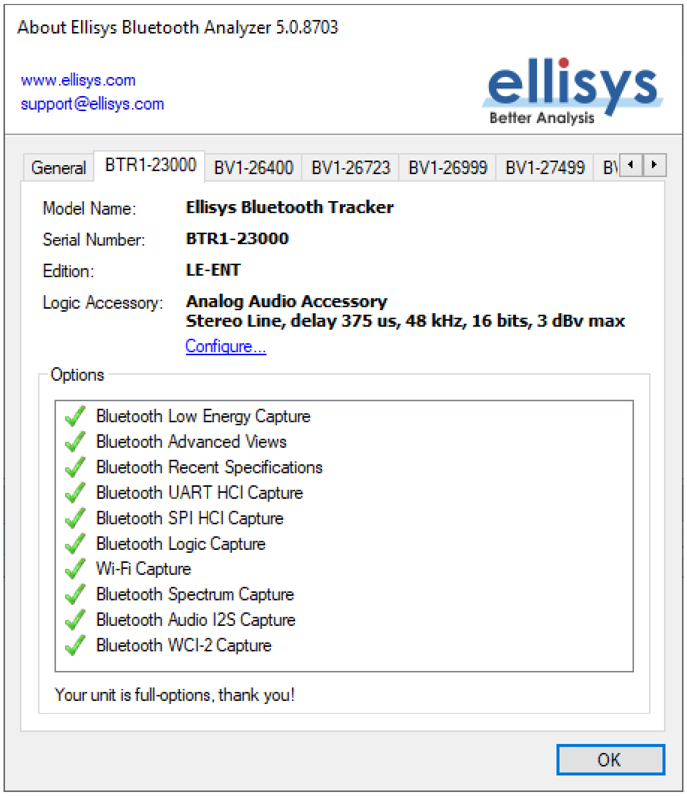

Figure 10 - Audio Grabber Configuration Menu in Help | About

There are currently four configurations from which to choose, shown in Figure 11, below. Select the desired configuration. This can be both Line IN inputs, both MIC inputs, and one of each.

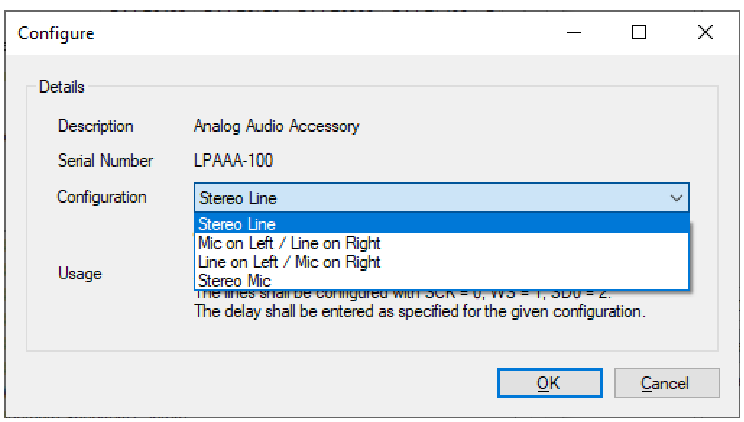

Figure 11 - Audio Grabber Configuration Dialog

Typical Latency Measurements

Without the Audio Grabber, the analyzer can still provide capture of digital audio streams (up to eight I2S streams). This is depicted in Figure 12.

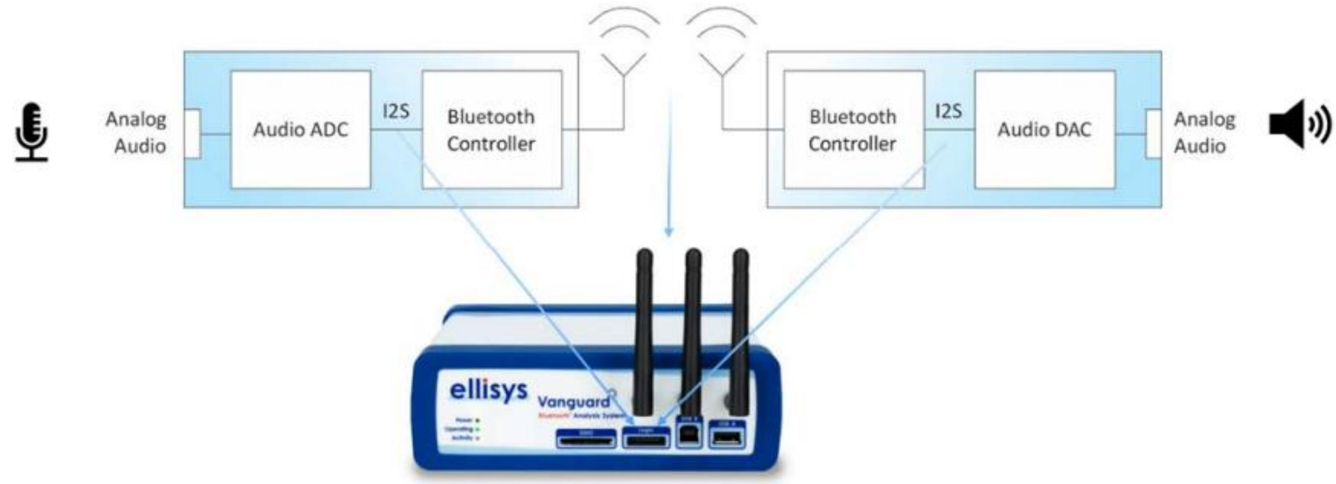

Figure 12 - Analyzer Setup to Capture Two Digital Audio Streams and Over-the-Air Traffic

With the Audio Grabber, *analog* audio can effectively be added to the analysis, providing precise latency measurements, including through ADC and DAC components. See Figure 13, below.

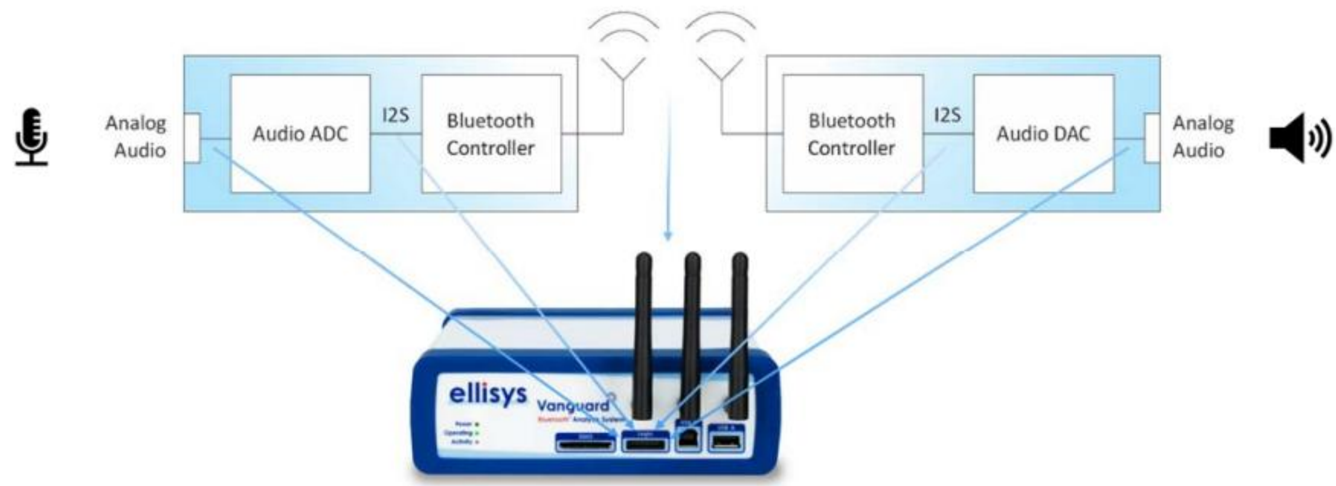

Figure 13 - Analyzer Setup to Capture Two Digital and Two Analog Audio Streams, and Over-the-Air Traffic

Exporting Audio

All audio streams captured by the analyzer can be exported from the File | Export menu as shown in Figure 14 below.

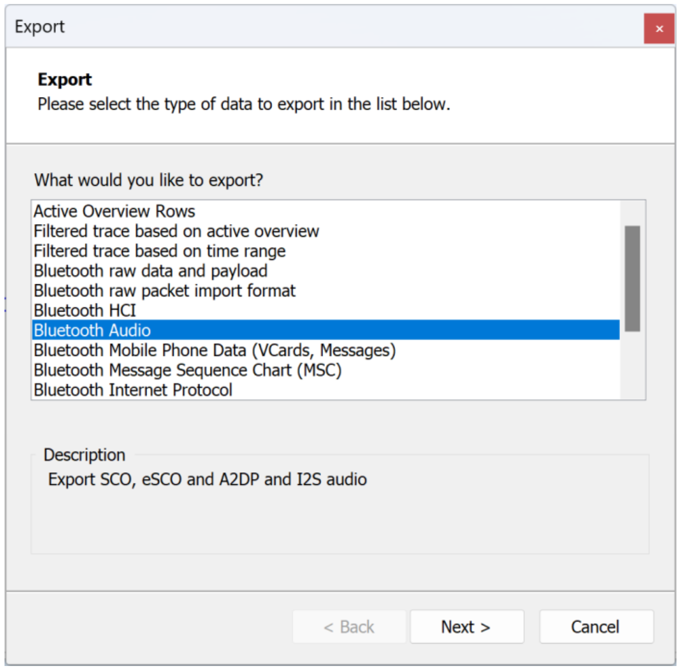

Figure 14 - Export Menu (Bluetooth Audio Selected)

Streams exported will include WAV files for each stream, RAW payload files, a TOF file (used for opening all files in Audacity at once, time-aligned), and a TXT file (Labels) that can be imported to Audacity to add bookmarks created by the user in the Ellisys software.

Below is an example of an LOF file opened in Audacity, including over-the-air audio (AVDTP), analog audio from the Audio Grabber input, which was converted by the Audio Grabber to digital audio (SD0), and a Labels file, imported with the bookmarks that had been added in the trace. Bookmarks can simplify latency analyses between streams.

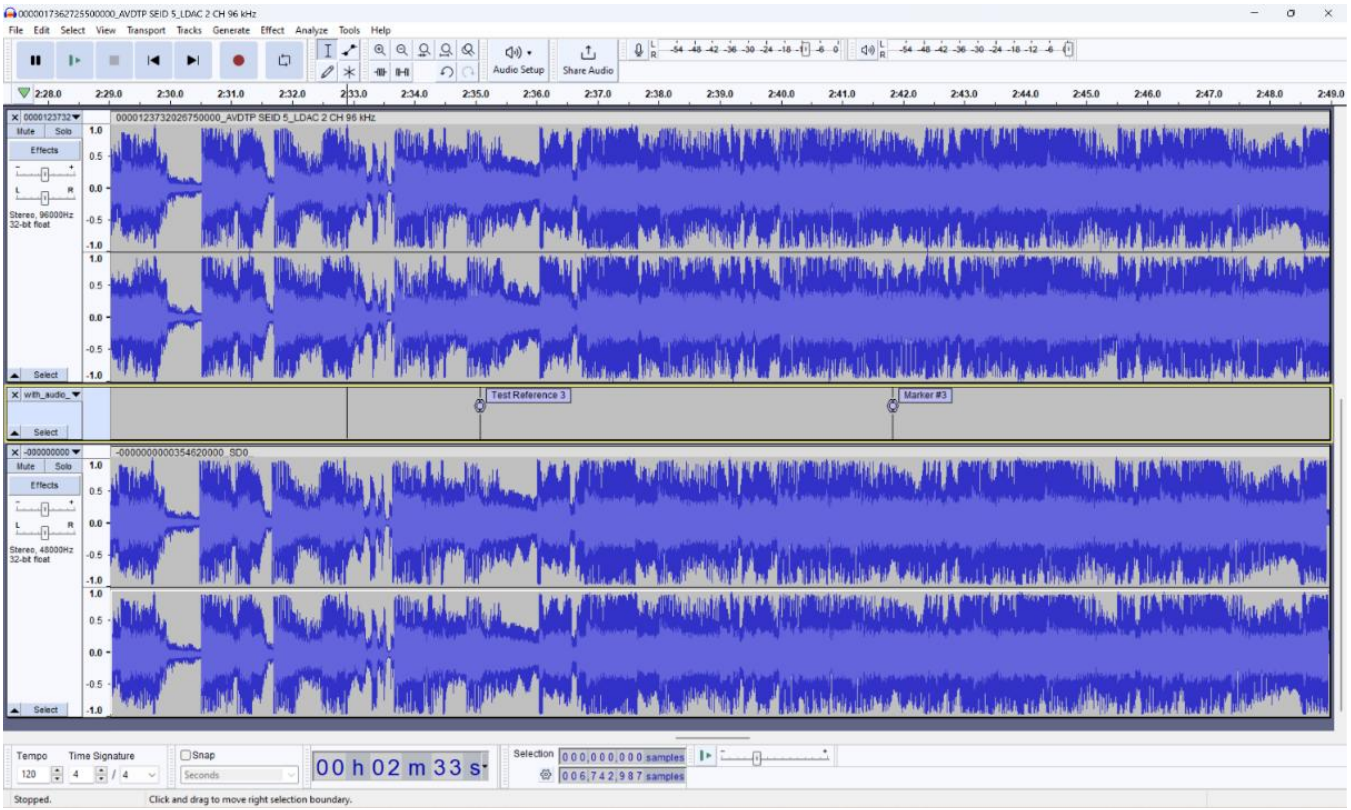

Figure 15 Exported OTA and I2S Streams

Below, the user has zoomed in to get a precise characterization of latency between two streams.

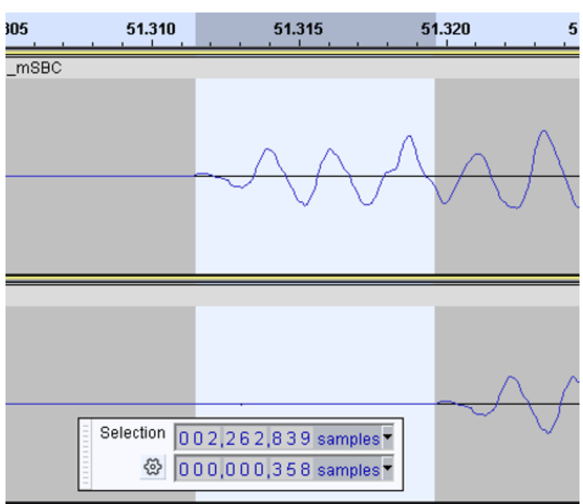

Figure 16 Zoomed-In View of Audio Streams

Flying Leads Probe

The Logic connection on the Bluetooth Tracker and Vanguard analyzers contains 20 pins (two rows of 10 pins), which mate with sockets on the mating connector of the Flying Leads probe that is supplied with these analyzers. This probe is the same probe (and the only probe) that can be used with the Audio Grabber. The probe supplied with the Bluetooth Explorer will not fit the receptacle on the Audio Grabber. Contact Ellisys if the correct Flying Leads probe (the type supplied with Tracker and Vanguard) is needed.

There are two versions of the Flying Leads probe supplied with Bluetooth Tracker and Bluetooth Vanguard, shown below. These two probes are electrically and mechanically identical but use differing wire color schemes.

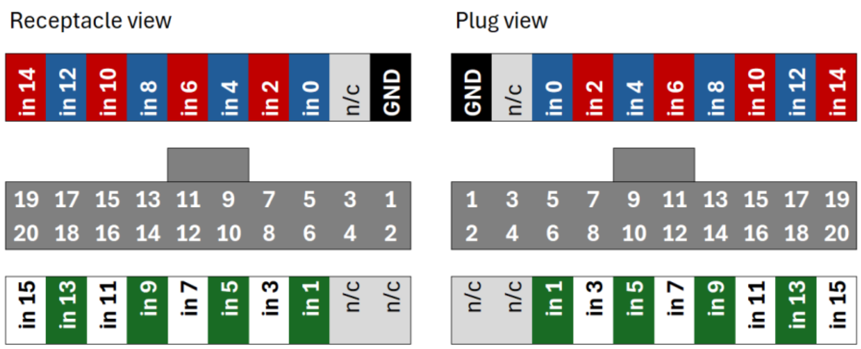

Figure 17 - Latest color-code (from July 2025)

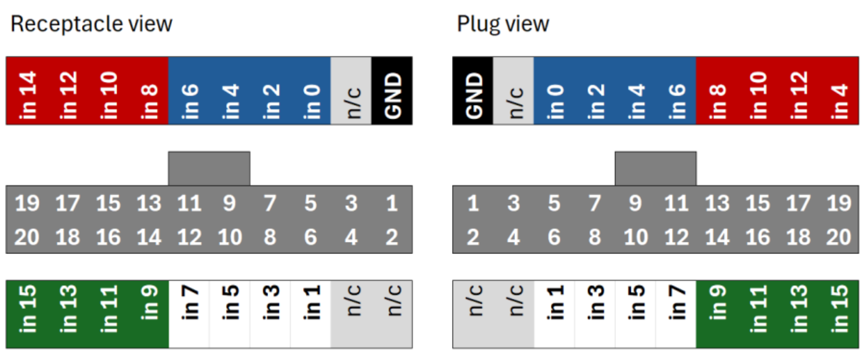

Figure 18 - Previous color-code (before July 2025)

The 26-pin plug and receptacle pair for Bluetooth Explorer is shown below, just for reference. Note that the Flying Leads probe supplied with Bluetooth Explorer is <u>not used</u> with the Audio Grabber adapter. Contact Ellisys if the correct Flying Leads probe (the type supplied with Tracker and Vanguard) is needed.

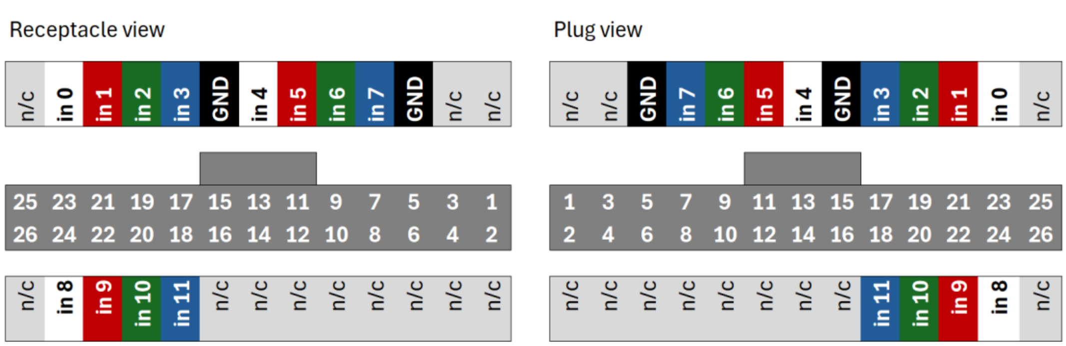

Figure 19 - Bluetooth Explorer 26-pin plug and receptacle

Practical Examples

This section outlines several practical methods for measurement. Diagrams are simplified. [Contact Ellisys](#) for more information as needed.

Note: In working through these examples or your own projects, it can be useful to export audio streams from the analyzer software (available in File | Export) to a third-party audio application, such as Audacity, briefly described in the Exporting Audio section earlier in this document.

Example 1 - Mobile Phone Streaming to Earbuds

Each earbud is a Bluetooth device playing either Left or Right audio channels. Each earbud contains a Bluetooth controller and a speaker. In this setup, the user might want to compare the delay between the Left and Right audio speakers. In this case, the Audio Grabber can be used to capture both speakers. The Analyzer box at the right shows the L-R speaker streams (received as an I2S digital audio stream from the Audio Grabber) in the Audio view as well as I2S inputs in logical form.

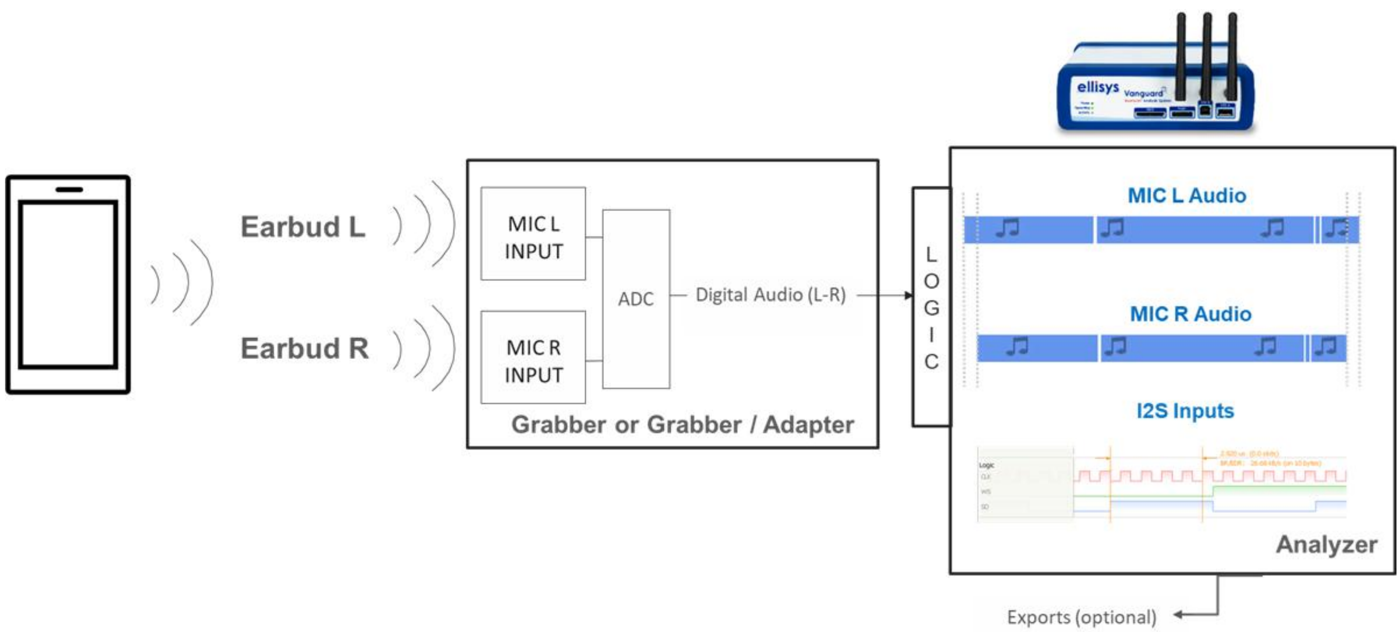

Figure 20 L to R Measurements on Mobile Phone Steaming to Earbuds

Example 2 - Measuring Delay from Bluetooth Audio to Analog Audio

In this example, in addition to capturing analog audio from the earbud speakers, the user also captures Bluetooth audio over the air and can then compare the delay between the Bluetooth audio stream and the analog audio stream. This comparison is done by exporting the audio waveforms from the Ellisys application software (File | Export) and using specialized audio software (like Audacity) to do the measurements.

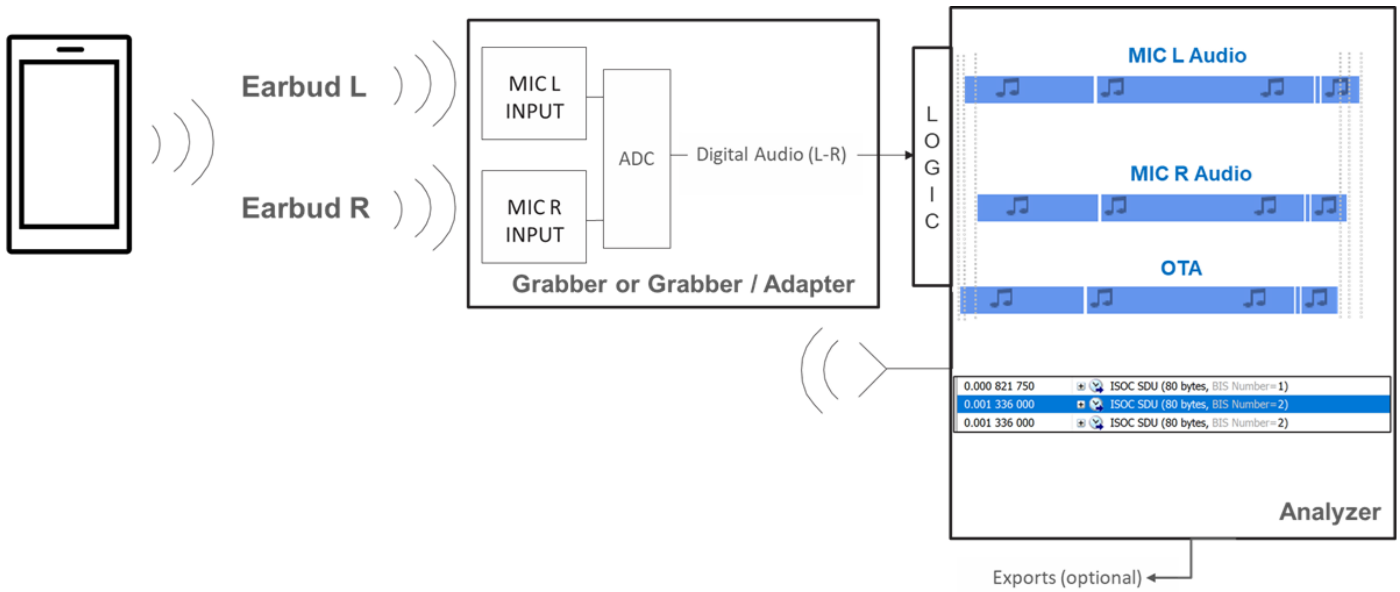

Figure 21 Measuring Delays between OTA Audio and Analog Audio

Example 3 - Characterizing a Bluetooth Audio Receiver Containing an integrated Audio DAC

In this example, the audio receiver has a Bluetooth controller, an I2S interface going to an Audio DAC, and an analog audio output from the DAC (see Figure 13 above for reference). In this setup, the analyzer can capture the wireless Bluetooth audio, the I2S digital audio from the Bluetooth controller (directly into the Flying Leads probe on the adapter, not shown here), and the L-R analog audio from the DAC by using the Audio Grabber. The user can then characterize the audio delay introduced by each block.

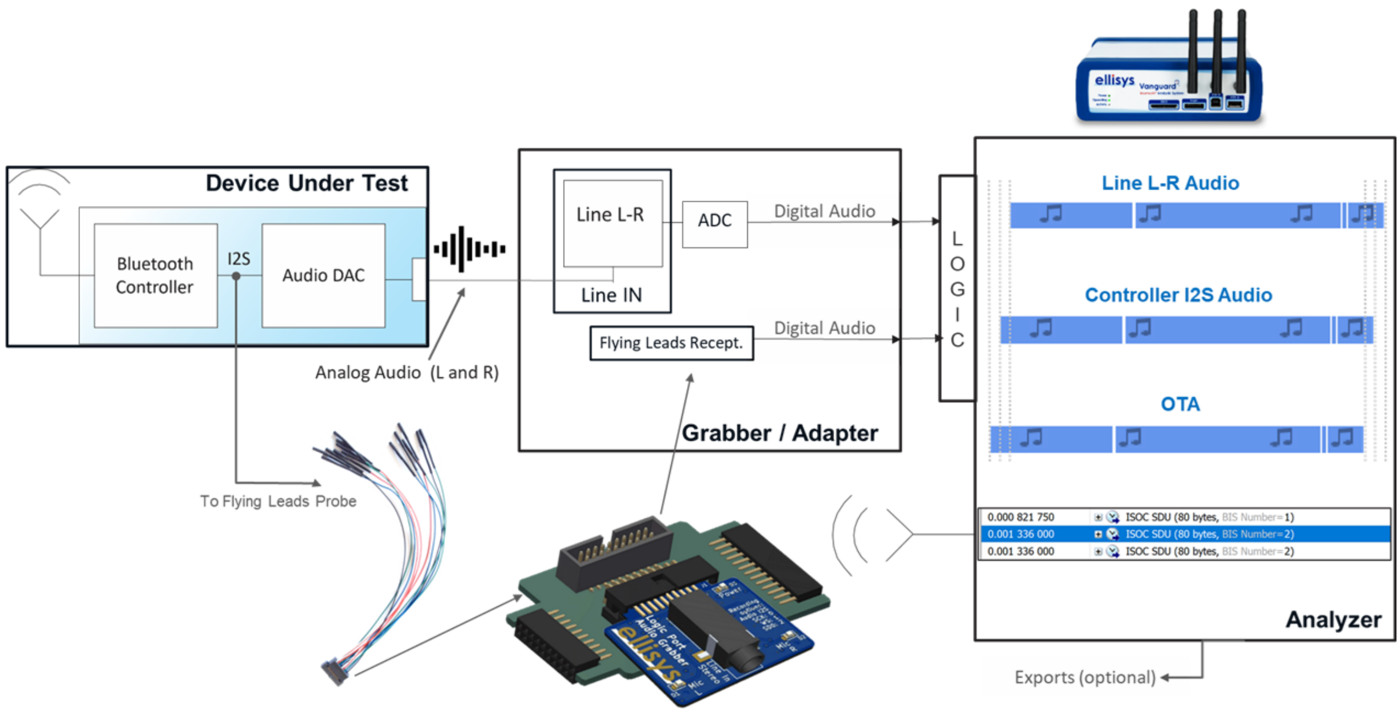

Figure 22 Audio Receiver with Integrated DAC

Example 4 - Synchronizing the Audio with other Information

In this example, the audio needs to be synchronized with other information, like in a case involving a TV, where the audio needs to be synchronized with video. Here, the analyzer can be quite useful. Let's say a TV is showing a video and is streaming audio to earbuds. In this example, the analyzer will capture the (digitized) audio from the earbud speakers as well as the Bluetooth OTA audio traffic.

To verify the audio's synchronization with the video, a typical approach is to use a photo-sensor that can create a logic signal based on a certain portion of the screen. This logic signal can be provided to the analyzer's Logic port using the Flying Leads probe, through the adapter and the Audio Grabber. The user would then use a specific video and audio pattern to test the synchronization between the audio and the video. The analyzer will have all information needed to compare the video / audio synchronization, using the logic signal from the photo-sensor, the analog audio processed through the Audio Grabber, and as needed, the Bluetooth audio captured at the analyzer's antenna.

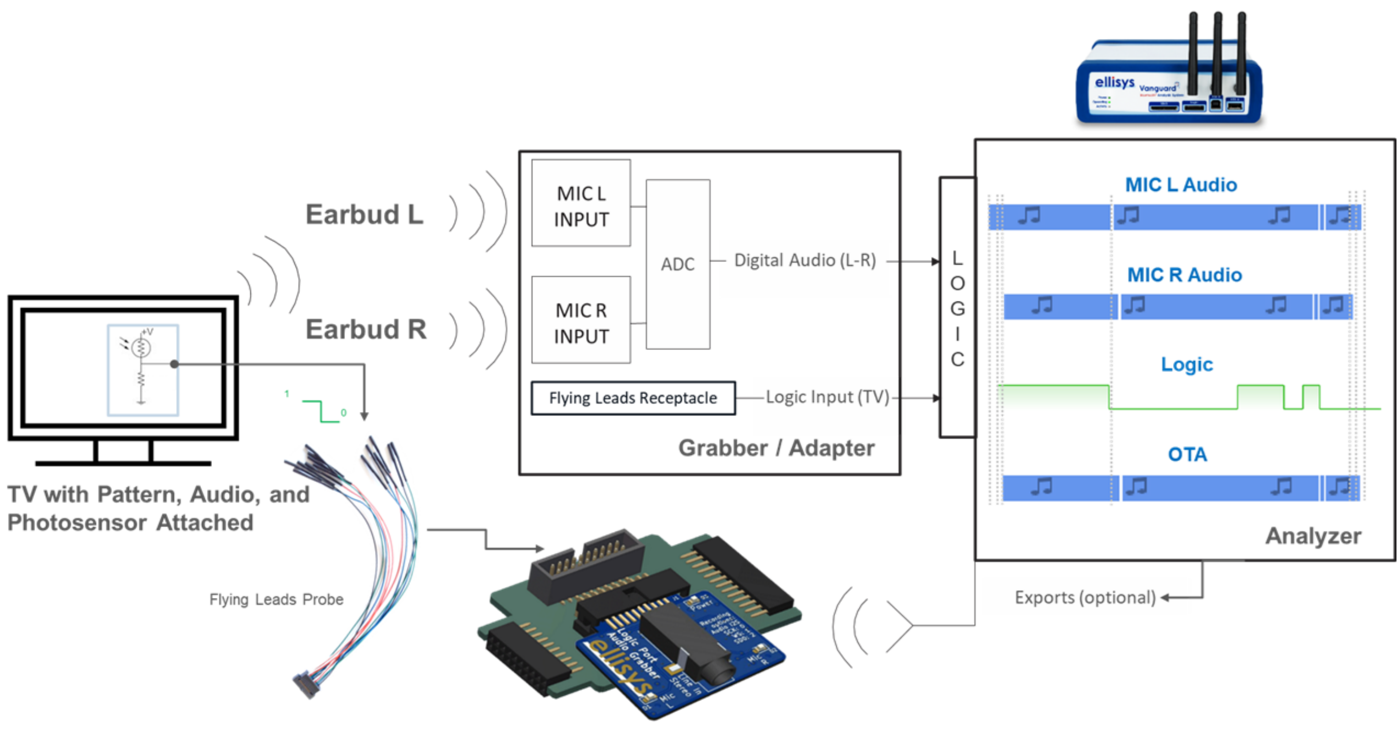

Figure 23 Synchronizing Audio with Other Information

Conclusion

Managing Bluetooth audio-related timing characterizations is often predicated on accessibility to the analog and digital formats in use. The Audio Grabber provides a simple and convenient adaptation to any of the Ellisys Bluetooth analyzer platforms, and when paired with the Ellisys Bluetooth software application and its array of audio features, it can help to enable a comprehensive understanding of your system's audio performance.

Other Interesting Reading

- EEN_BT02 - Analyzer Features Tour
- EEN_BT04 - Optimal Placement of Your Analyzer
- EEN_BT05 - Understanding Antenna Radiation Patterns

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