TUTORIAL 1 … part 2

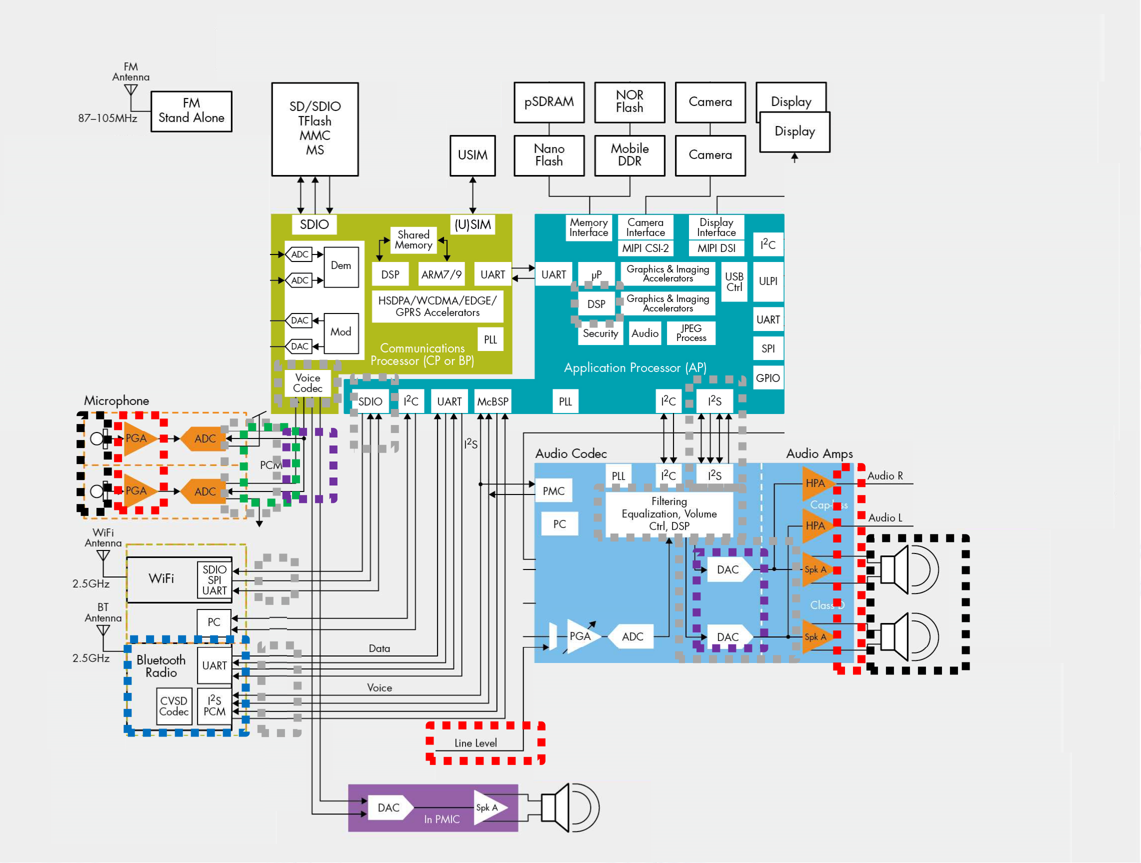
Not your Father’s AM Car Radio

Characterizing the Audio Performance of Today’s Multi-layered Infotainment Systems

Jayant Datta and **Dan Foley**

08 Sep 2017

Today's Head Unit Signal Path



Acoustic

Analog

Bluetooth

PDM

I2S/TDM

A2B

> ap.com

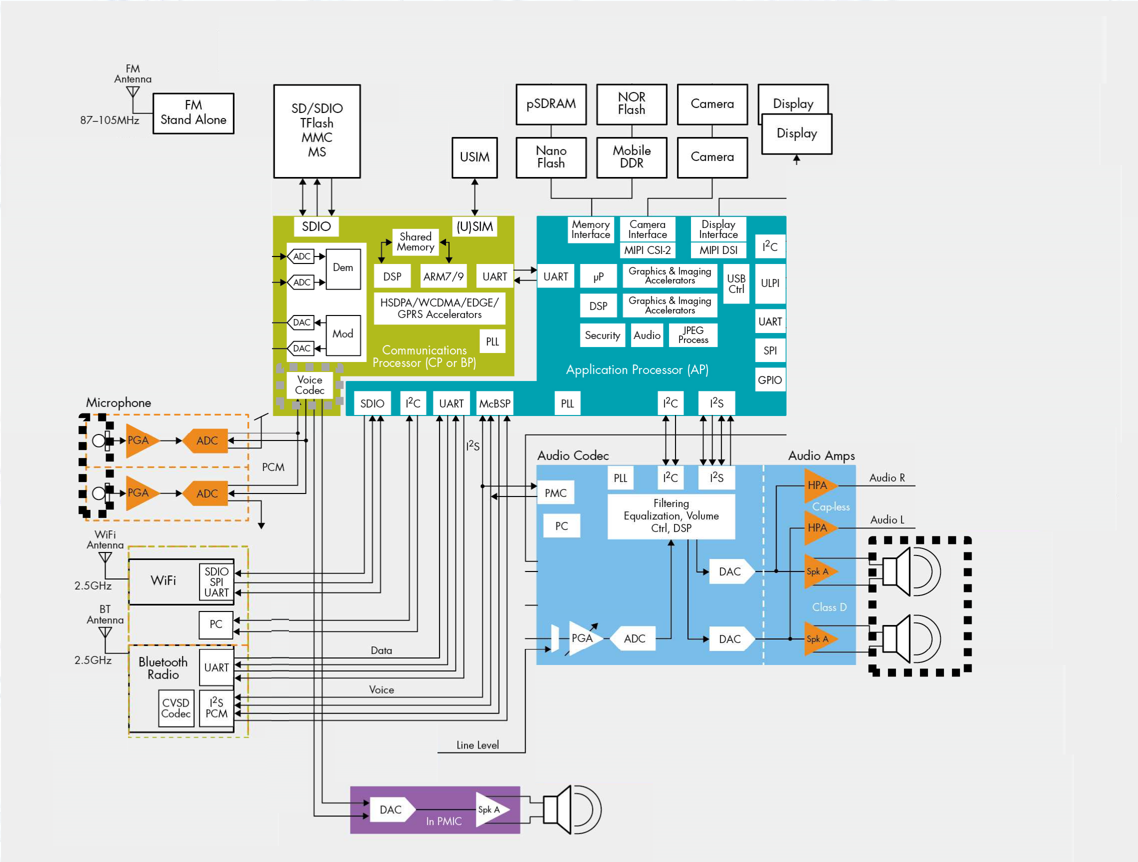
Gotchas – Eval Boards

- Purpose is to evaluate a part (e.g. PDM mic, DSP chip, Class D chip, etc.)
- This board is NOT YOUR FINAL DESIGN!
  - ⇨ Substrate much larger than final implementation (e.g. PDM mic element)
  - ⇨ Converters on eval board may not be of same quality as used in final design
  - ⇨ Grounding, EMI susceptibility, etc. may be worse than your design
  - ⇨ Power supply typically a “wall wart”
    - Additional IM products if a switching power supply
    - Additional noise that may not be present in final design which is powered by car battery

Gotchas – Eval Boards

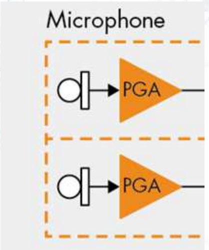
- TDM/I²S headers often not configured for easy connection to audio analyzers.
- Support/setup software for board can make or break your success. Check it out before you buy.
- Eval board design
  - ⇨ Break up audio signal paths with straps that:
    - Allow signal injection
    - Pick off between major blocks (e.g. after an input buffer amplifier before ADC input pin, or between a power amp output and the on-board resistive load).

Acoustic Signal Path

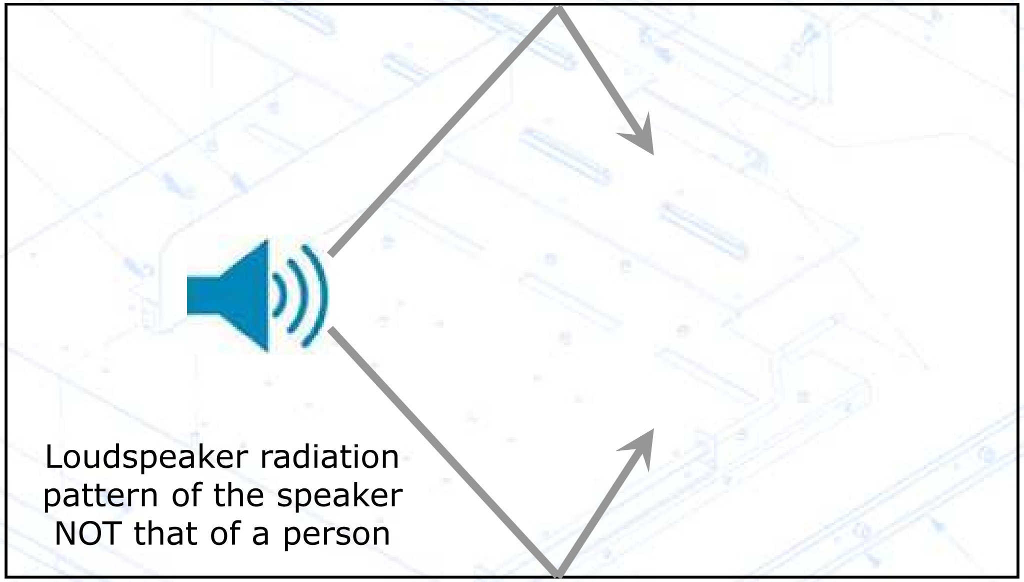


Acoustic - Microphone

- Voice or ANC (or both)?
  - ⇨ Voice – Need Head and Torso Simulator (HATS)
  - ⇨ ANC – Need source with adequate low frequency response and SPL
- “Gotchas”
  - ⇨ Acoustic source distortion
  - ⇨ Power amp rolls off at 20 Hz
    - 2 Hz or lower needed for “door slam” test
  - ⇨ MEMS eval board
    - Large flat surface causing reflections
    - Final design most likely a completely different form factor

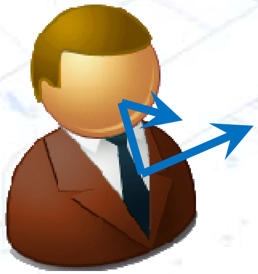


Why the need for a HATS?



Vehicle Interior

Why the need for a HATS?

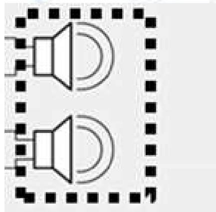


Manikin includes mouth
radiation pattern and body
reflection/diffraction

Vehicle Interior

Acoustic – Loudspeaker(s)

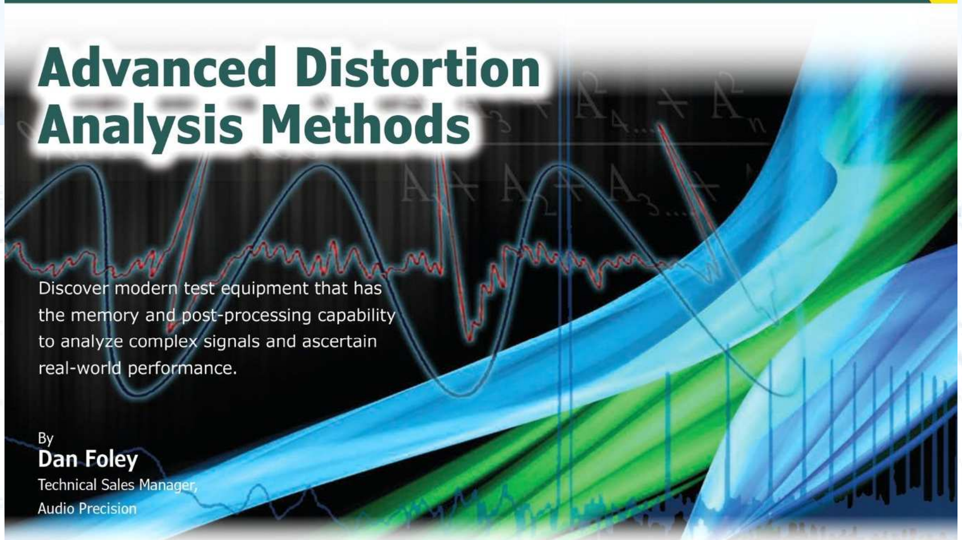
- Test signal
  - Sine-based
    - Log chirp
    - Stepped Frequency
    - Stationary tone
    - Two-tone/Multitone



- Noise (pink and/or music-weighted)
- Impedance
- "Gotchas"
  - Low-Z spkr requires lower-Z amp output
  - Too fast of a chirp (wrong bass FR)
  - "Weird" FR due to chosen measurement not being able to use time window
  - Don't forget H10-Hxxx!

A Shameless "Plug"….

INDUSTRY FEATURES



Advanced Distortion Analysis Methods

Discover modern test equipment that has the memory and post-processing capability to analyze complex signals and ascertain real-world performance.

By
Dan Foley
Technical Sales Manager,
Audio Precision

Since the advent of the sine wave oscillator until present, sinusoids and sinusoid-based excitation signals (e.g. two-tone and multi-tone) have been the primary stimuli used to characterize distortion. With single-tone excitation, the primary distortion measurement is either total harmonic distortion (THD) or total harmonic distortion plus noise (THD+N). The latter is almost exclusively used for characterizing electronic devices. THD and THD+N are often times the only distortion measurement presented in product datasheets and associated marketing material. In addition, engineering decisions are often made based solely on these measurements.

Determining THD

THD is determined via two methods. The THD value generated from **Equation 1** only has the energy of the Fundamental (A_1) in the denominator.

$$\%THD = 100\frac{\sqrt{A_2^2 + A_3^2 + A_{4\ldots}^2 + A_n^2}}{A_1} \quad [1]$$

In **Equation 2**, the THD value can be slightly lower compared to the THD calculated using **Equation 1**, because the denominator includes the energy of the fundamental plus the harmonics.

$$\%THD = 100\frac{\sqrt{A_2^2 + A_3^2 + A_{4\ldots}^2 + A_n^2}}{A_1 + A_2 + A_{3\ldots} + A_n} \quad [2]$$

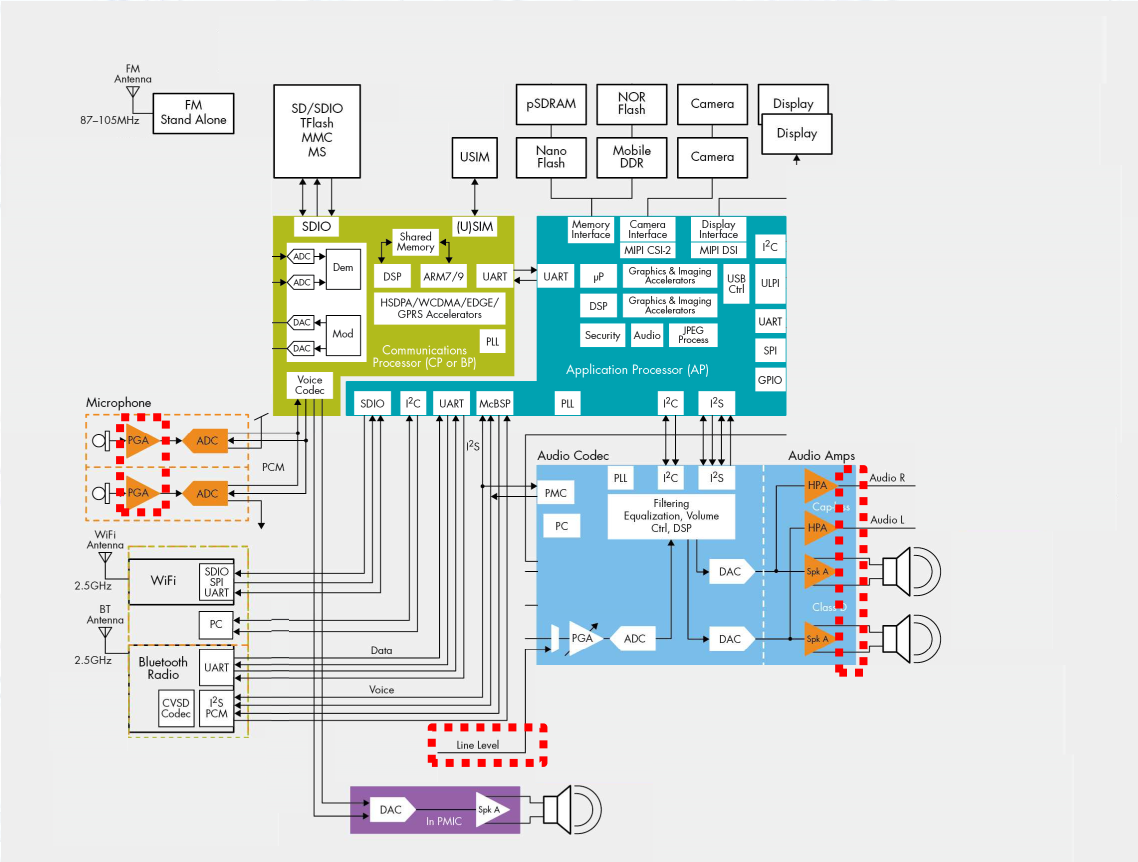
While these measurements indicate how accurately the device under test (DUT) reproduces a sine wave from a signal generator, these metrics have two major drawbacks:

1. THD and THD+N do not indicate the level of high-order harmonics, which are more audible than lower-order harmonics.
2. A sine wave has a crest factor of only 3 dB, which is at last 10 dB lower than speech and/or music. Such a low crest factor may not excite non-linear behavior that otherwise would be present using a signal that has a much larger crest factor.

In regards to THD+N, the measurement is comprised of harmonic energy and noise energy. A THD+N value does not give any indication as to whether or not the distortion is dominated by harmonics or noise or if both are equivalent in total energy.

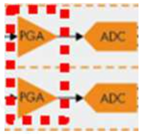
Since the THD value is typically dominated by the second and third harmonics, these low-order harmonics are often masked psychoacoustically by the fundamental. Thus, a THD value can be in the

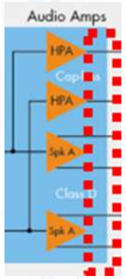
Analog (Electrical)



Analog (Electrical)

- *ALWAYS* view live FFT
  - ⇨ Will show noise and ground problems
  - ⇨ Monitor sweeps to see details of THD/THD+N

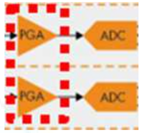


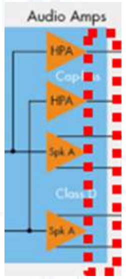


- Stepped FR vs. Log Chirp
  - ⇨ Stepped FR MUCH longer than Log Chirp
    - Better for measuring very low THD and/or THD+N
  - ⇨ Log Chirp - many thousands of frequencies
  - ⇨ Provides impulse response for DUT delay/polarity
- Ground analyzer to DUT
- Use a good quality bench power supply when testing subassembly boards

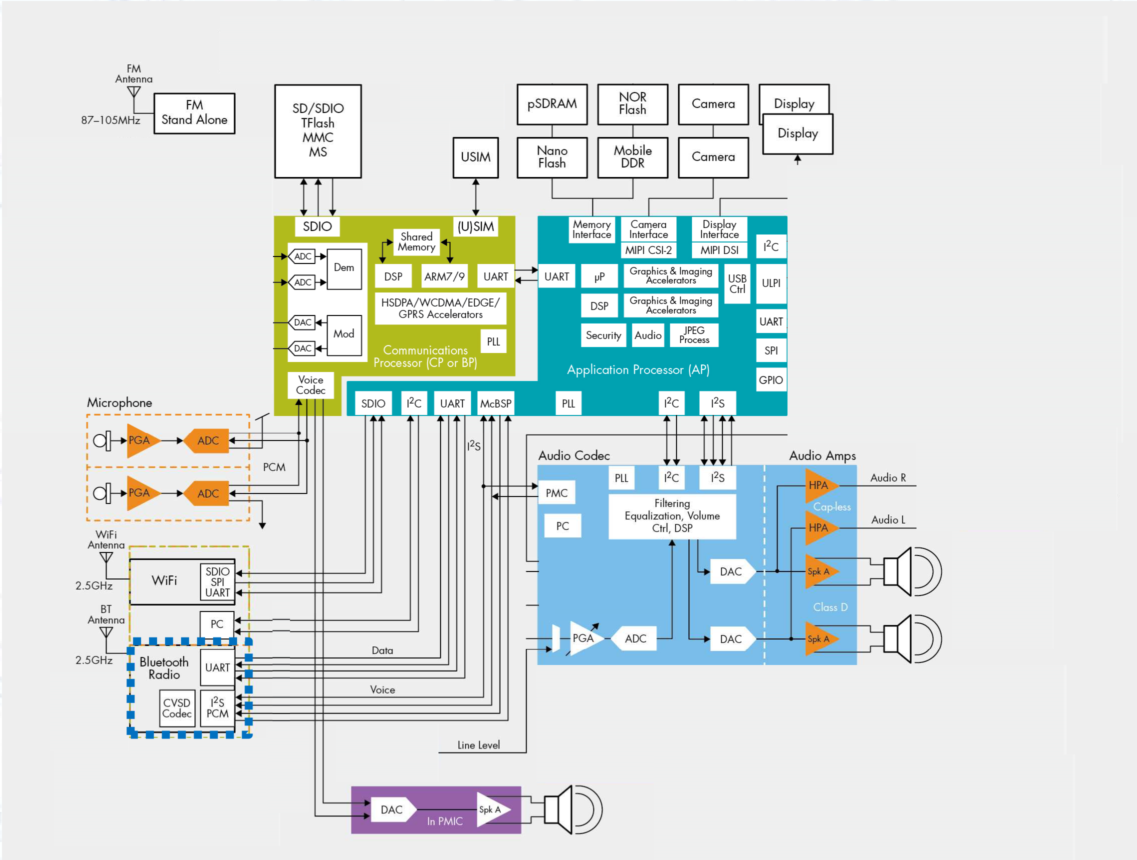
Analog (Electrical)

- "Gotchas"
  - ⇨ Too fast of a log-chirp sweep
    - Unstable FR and/or distortion curves
    - THD only – **NO** THD+N
  - ⇨ Be aware of output Z of analyzer (models/brands)
  - ⇨ Be aware that analog generator output that can drive 90 mA at 13 V: avoid damaging a prototype part or circuit
  - ⇨ Class D amp - use AES17 filter *before* analyzer analog input op amps even if your Class D amp has output filtering
  - ⇨ NEVER use this adapter to float (+) & (-)





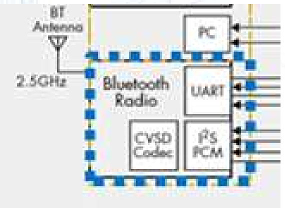
Bluetooth® Signal Path



Bluetooth

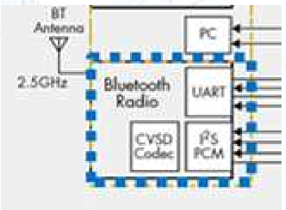
Bluetooth® Signal Path

- Voice or Music Streaming or Both?
  - Voice – use perceptual measurements & real speech
  - Music – need appropriate codecs
- Unpair all devices except the DUT.
- Have ability to change RF power to replicate smartphone in purse/back seat use case
- Use sniffer in conjunction with audio analyzer
- Rely on analyzer measurement meter settling to reject the measurements that otherwise would be affected by interference from other devices (rejects short audio dropouts and glitches)

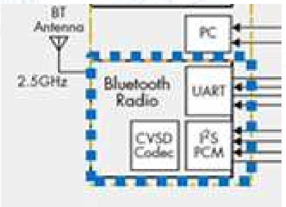


Bluetooth® Signal Path

- Gotchas
  - DUT delay set to 0 msec (or lower value than actual delay)
  - Using sine for voice codecs (CVSD in particular)
  - External RF interference
  - Turn off all event tones in the DUT that may mix with audio, such as chimes, warnings, etc. These unexpected signals in the DUT will pollute your audio measurements

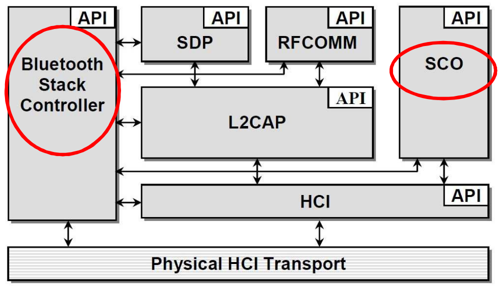


Guilty Until Proven Innocent



Bluetooth RF & Stack

- Aspects of RF Design
  - Antenna location in Head Unit
  - Adequate RF Power on Tx & Rx sides
- Bluetooth Stack
  - Stack issues can impact SCO
  - SCO used to connect HFP/HSP
  - Case Study #1– PAB download



SCO

Synchronous Connection Oriented link

The Synchronous Connection Oriented link is one of the two possible Bluetooth data link types defined. The SCO link is a symmetric, point-to-point link between the master device and a specific slave device. The SCO lin reserves slots between the master and the slave and can therefore be considered to provide a circuit switched connection. The SCO link is usually used to support time critical information, e.g. voice, since time critical SCO packets are never retransmitted. The master device can support up to three SCO links, this might be to the same slave or to different slaves. A slave can support up to a maximum of three SCO links, assuming they are from the same master. If the slave has links from different masters, a maximum of two SCO links are available.

http://www.technology-training.co.uk/sco.php

Case Study #1 – PAB Download

- Unreleased Head Unit tested at Bluetooth SIG Unplugfest event
- PAB (public address book) could be downloaded to Head Unit while streaming music from smart phone via Bluetooth connection
- HORRENDOUS pops and clicks would occur making music listening impossible
- Head Unit Bluetooth Design Team unware this problem existed
- Follow-on Unplugfest six months later
  - Eng Team discovered audio problem due to Bluetooth programming NOT prioritizing music packets over PAB data packets
  - Reprioritization of music data solved this pop-and-click problem

Bluetooth Voice Codecs

- CVSD
  - Continuously Variable Slope Delta Modulation
  - One of the early BT voice codecs
  - 8 kHz sampling rate (at best 4 kHz bandwidth)
- mSBC – better quality voice codec
  - Implemented in HFP 1.6
  - Sampling rate of 16 kHz (8 kHz bandwidth)
- Case Studies 2,3 & 4

Case Study #2 – Handsfree audio issue

- Head Unit with newly-released mSBC voice codec tested at Bluetooth SIG Unplugfest event
- mSBC codec has 16 kHz sampling rate (wideband speech codec) to make speech during hands-free conversation sound more natural
- Legacy voice codec (CVSD) has only 8 kHz sampling rate
- Frequency response tests using AP analyzer showed that frequencies above 4 kHz rolled off dramatically
- DSP engineer "forgot" to implement the anti-aliasing filter for mSBC codec (8 kHz cut-off freq) and thus original filter still in place (4 kHz cut-off) filtering out upper octave of speech

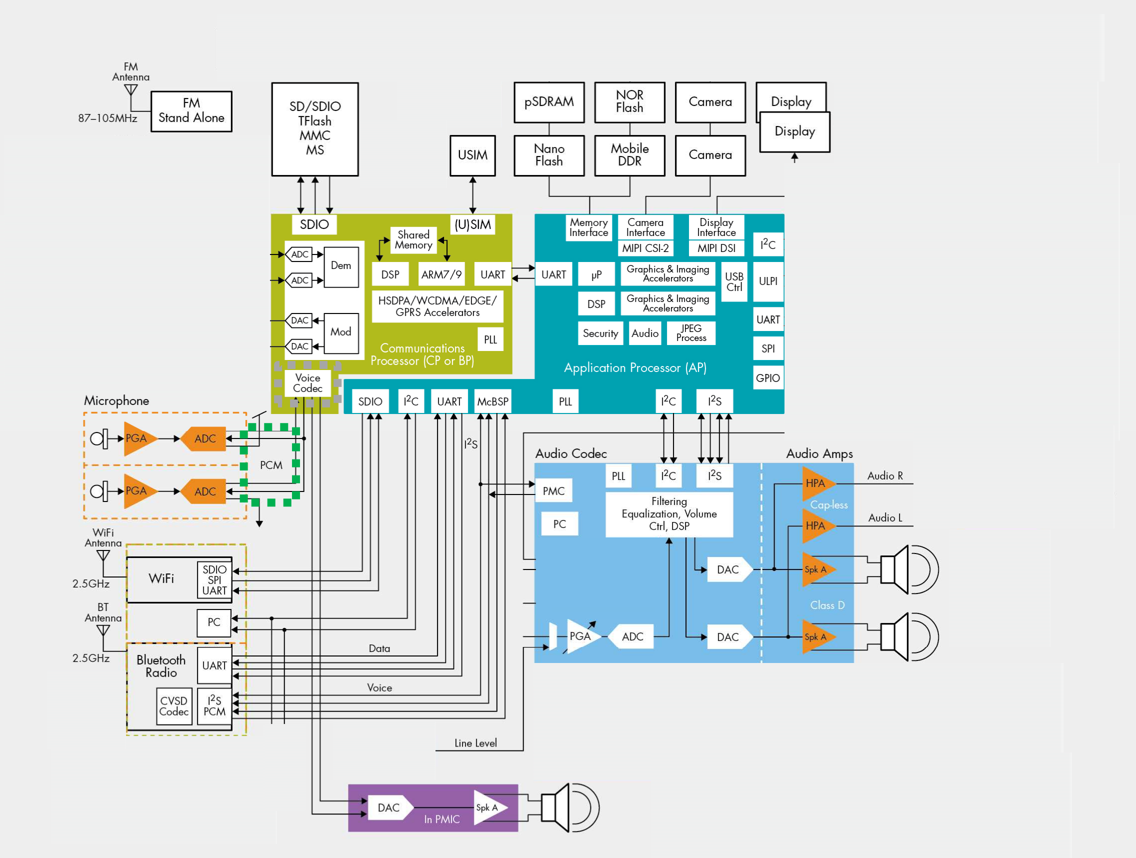
Case Study #3 – Pitch-shifting of music while streaming to Head Unit

- Audio file with a 1 kHz test tone sampled at 48 kHz loaded onto a smart phone
- Head Unit supposedly supported sample-rate conversion (down-sample a 48 kHz music file to 44.1 kHz)
- 1 kHz tone streamed to head Unit via Bluetooth
- AP analyzer showed that frequency was 918.75 Hz and NOT 1 kHz
- 44.1/48 = 0.91875
- Sample rate conversion had not been properly implemented

Case Study #4 – Bluetooth Stack

- Tier Two being blamed by Tier One for "bad" hands-free voice quality as well as pops and clicks while streaming music via Bluetooth
- Tier One supplies Head Unit to OEM
- Tier Two supplies PC board with on-board DSP that contains Tier Two's actual product - algorithms for voice enhancement, noise control, etc.
- When music streamed from smart phone in Tier Two lab to head unit, in-vehicle problem accurately reproduced
- Tier Two used AP analyzer with ability to inject audio directly into DSP chip in order to bypass Bluetooth chip
- When BT chip bypassed, audio issues went away
- Root-cause – BT stack issue in BT chip.

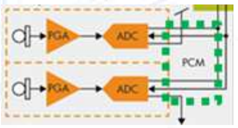
PDM Signal Path



PDM

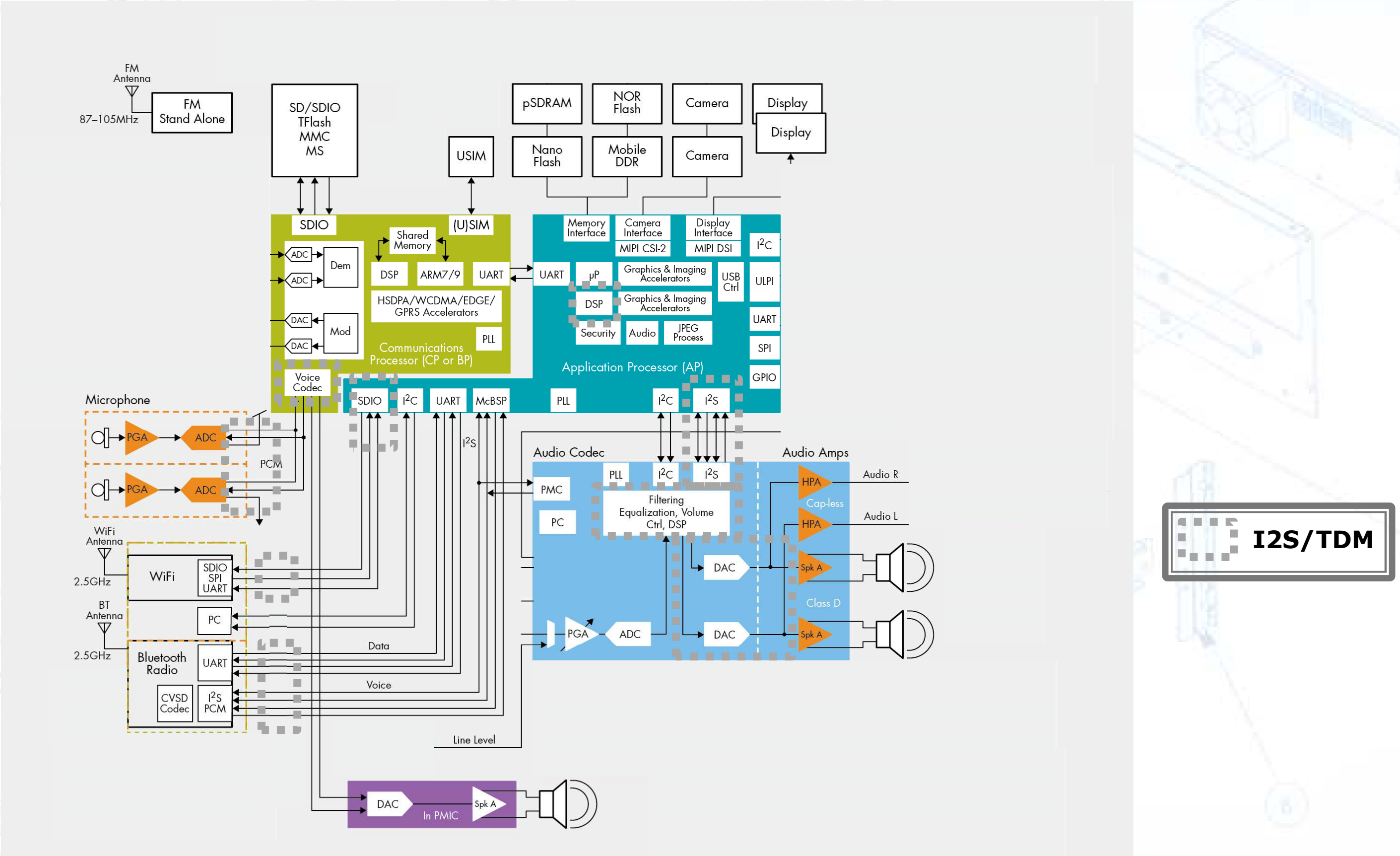
PDM Signal Path

- Typically used for Microphones (MEMS)
- Anyone else know of any other PDM implementations (e.g. air bag accel, etc.)?



- Gotchas
  - Appropriate decimation rates
  - Long cables can cause clocking problems due to additional capacitance
    - Sol’n – PDM Line Driver

I²S/TDM Signal Path



I^{2}S/TDM Signal Path

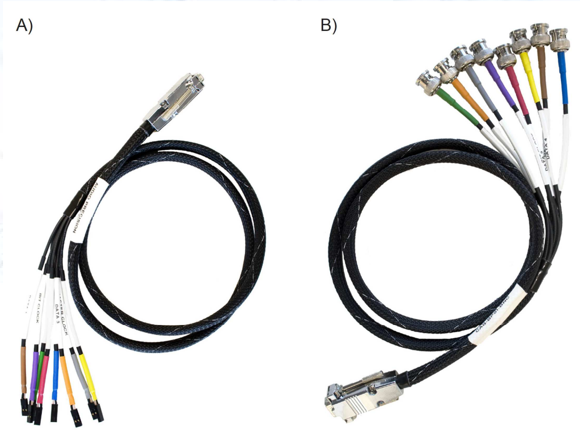
- I^{2}S/TDM – Inter IC Sound/Time Div MUX
  - How ICs send/receive PCM audio data
- Classic I^{2}S – two audio channels per data line
- TDM – up to 16 audio channels per data line
- Sample rates up to 216 kHz (but not 16 channels)
- Max sample rate based on highest Master Clock Rate
- Use high-speed scope in conjunction with analyzer

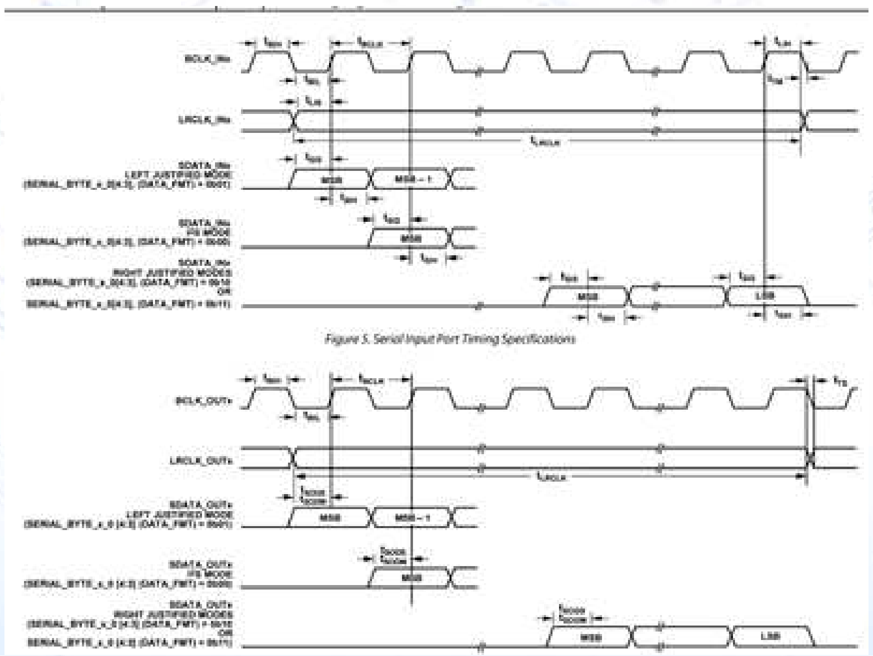
I^{2}S/TDM Signal Path

- Gotchas
  - Cable length – excess capacitance degrades rise/fall time and increases jitter susceptibility (30 MHz and higher Master Clock rate
  - Cable terminations - Incorrect impedance terminations result in reflections that distort pulse edges resulting in edge time errors
  - Timing diagram of part being measured is incorrect

I^{2}S/TDM Signal Path

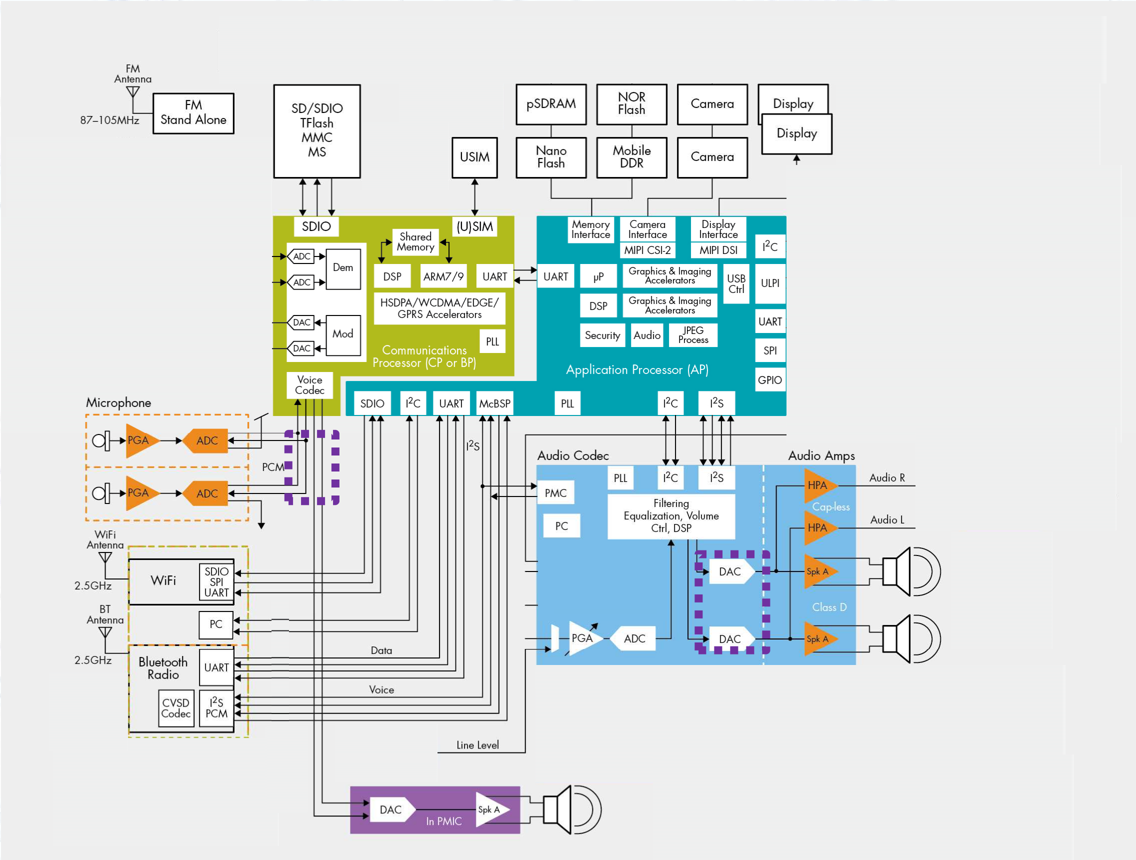
- Gotchas





Automotive Audio Bus

Signal Path



A2B

A2B Signal Path

- New digital audio transport from ADI
  - Can move up to 32 channels of 24-bit audio at 48 kHz over a twisted pair
  - Audio data AND power on twisted pair
- Can provide OEMs reduction in weight and cost regarding wiring of all audio

- Gotchas
  - Connecting to network via TDM can be tricky
    - Access to TDM header (unless using eval board)
    - Register settings
  - Elegant solution – Mentor A2B Analyzer with ASIO driver
  - ASIO does NOT allow jitter measurements
    - Still need to connect via TDM
    - Analyzer requires ability to generate clock jitter

QUESTIONS?