IEEE 802.1DG Time Synchronization Required Parameters for Allowable Time Performance Error

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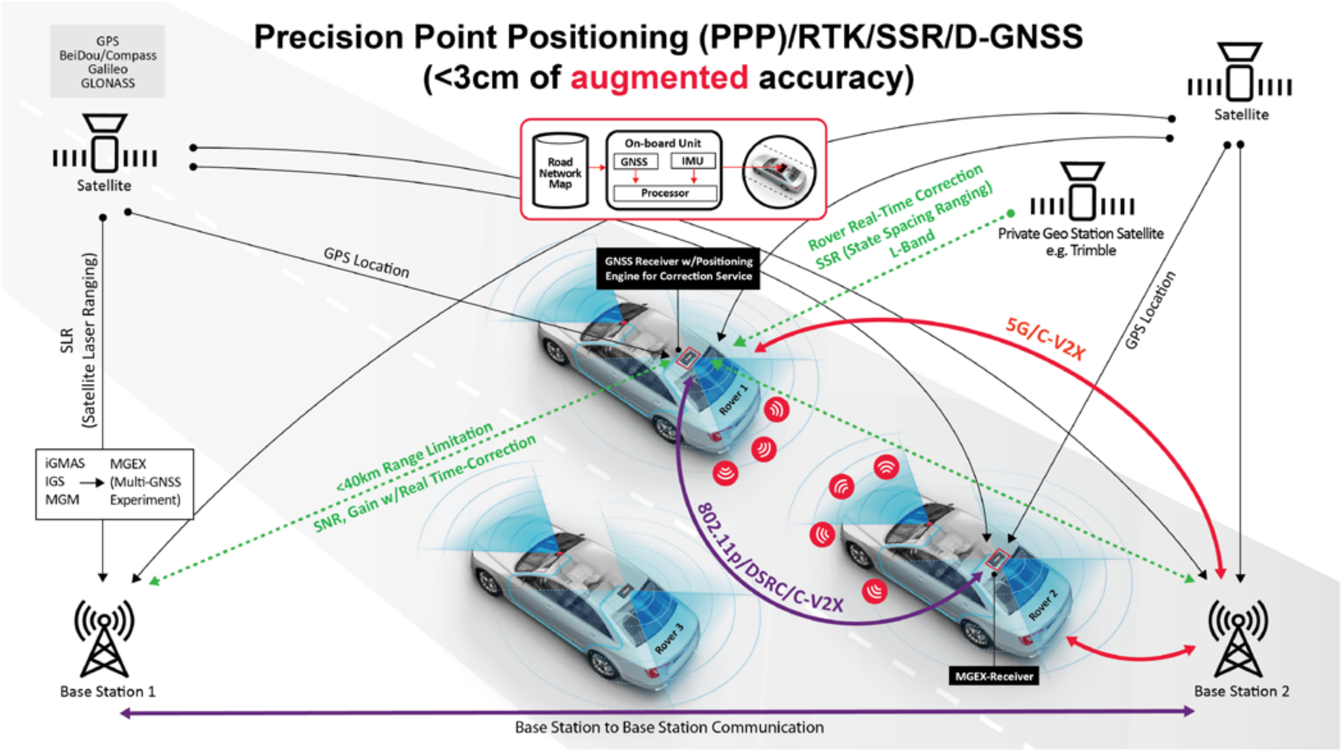
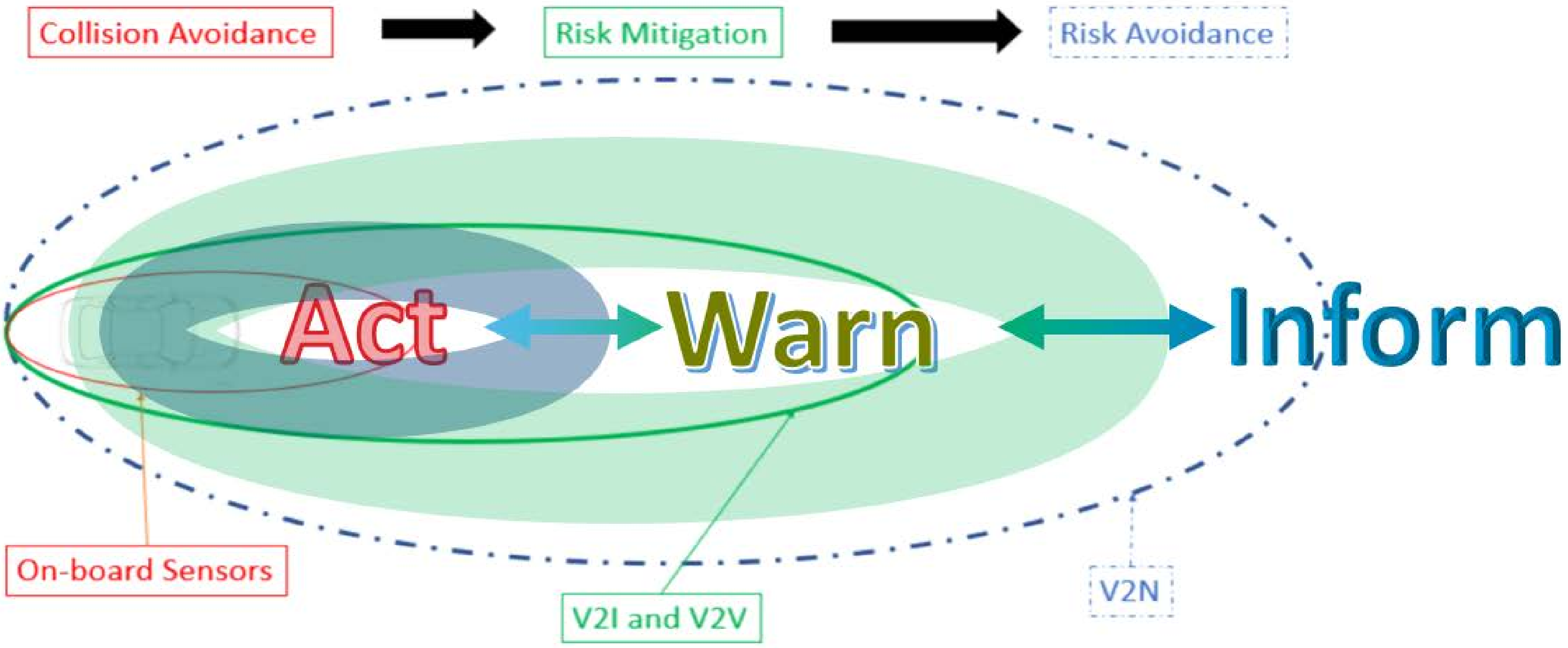
IEEE 802.1DG Time Synchronization – Use Cases for Profile Definitions



Source:

IEEE 802.1DG December 8 Working Group Call
Presented By: Michael Potts

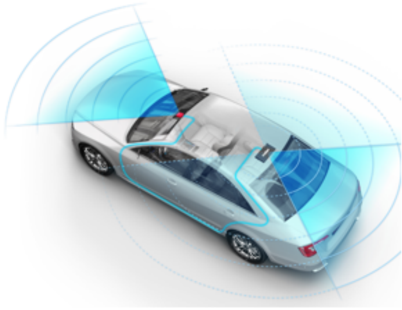
IEEE 802.1DG Time Synchronization – Use Cases for Profile Definitions



Source: https://trimis.ec.europa.eu/project/preventive-and-active-safety-application#tab-docs

IEEE 802.1DG Time Synchronization – Use Cases for Profile Definitions

- **90% information processed is visual**
- **˜ 13ms to process an image (at best)**
- **˜ 552ms to process braking response**
  - 12.3m @ 88.5 kph,
  - 19.9m @ 120.7 kph — at best
- **˜ 1500ms to process braking response**
  - 37m @ 88.5 kph,
  - 50.7m @ 120.7 kph — typical
- **˜ 79.32% braking response is accurate**



˜ 10ms E2E network latency required to avoid collision based on 3 – 27 Mbps application signal rate

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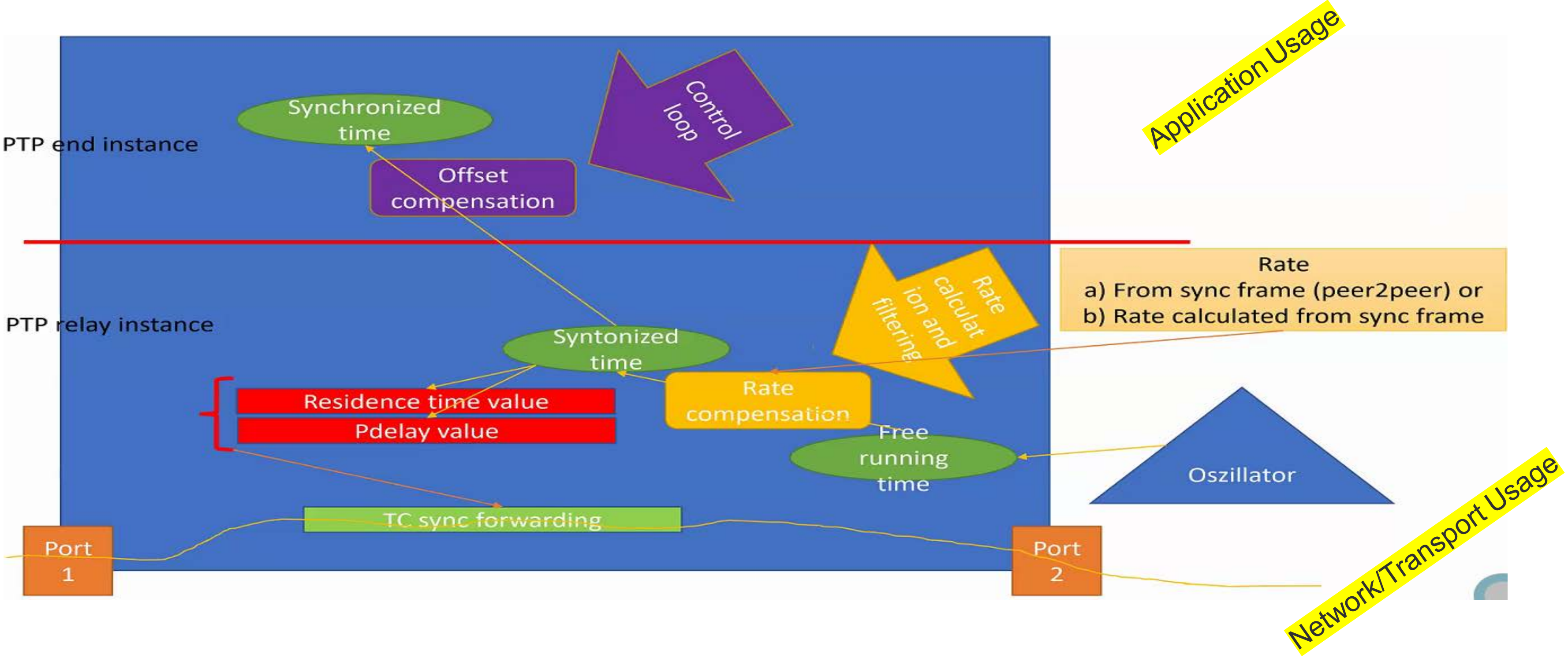
IEEE 802.1DG Time Synchronization Profile Definitions



Source: https://www.ieee802.org/1/files/public/docs2020/60802-Steindl-SynchronizationModels-1120-v1.pdf

IEEE 802.1DG Time Synchronization Profile Definitions

1) Common Definitions:

A. Crystal Oscillator Type[1]: This standard is to make the assumption the oscillator used by the GM will be either a Temperature-Compensated Voltage-Controlled Crystal Oscillator (TCVCXO), Voltage-Controlled Temperature-Compensated Crystal Oscillator (VCTCXO), or a Frequency-Controlled Crystal Oscillator (FCXO)

B. Frequency Tolerance: The initial maximum deviation from the nominal crystal frequency at specified environmental conditions. This tolerance value is required to be specified for ±20 ppm, ±50 ppm, and ±100 ppm

C. Frequency Stability: The maximum deviation from the nominal crystal frequency over a specified environmental range (i.e. for temperature, this deviation is measured with reference to the nominal frequency at 25°C)

D. Oscillator Aging: The cumulative change in frequency of oscillation by the crystal over time. Specified as ppm/year. End-of-Life Vehicle (EOL/ELV) is legislation used to determine the end of a vehicle useful life.

E. Part Per Million (PPM) - represents the output frequency variation and stability tolerance of an oscillator due to environmental conditions (i.e. 1MHz output frequency with a frequency stability of 5 ppm = a frequency variation of 5Hz or 0.0005%):

Parts per Million (ppm): 1 ppm means $1/10^6$ part of a nominal frequency.

$$Variation\ in\ Hz = \frac{f\ *ppm}{10^6}$$

Where, $f = center\ frequency\ (in\ Hz)$

$ppm = frequency\ variation\ in\ ppm$

F. Oscillator total accuracy – the minimum PPM to achieve desired accuracy results. Represented by the sum of frequency tolerance, stability, aging, and component tolerance:

Accuracy = tolerance + stability + aging + component tolerance ≤ +/- #ppm

NOTE:

[1]Micro-Electro-Mechanical Systems (MEMS), High-end silicon oscillators, and PLL clocks used as a frequency source replacement for crystal oscillators will not be considered for a Grand Master (GM) time clock assumption. But a PLL clock is a viable option for application clocking requirements with a 1000 ppm, or 0.1% required frequency deviation or stability tolerance (e.g. Infotainment domain ECU's)

IEEE 802.1DG Time Synchronization Definitions (con't)

2) Measurements and actions that constitute a Time Sync adjustment event that requires a definition:

A. Environmental – Measurable defined IVN conditions that have an affect on the delivery of time sync messaging
   a) Temperature – can have adverse effects on oscillator functionality (see parameters used for oscillator temp assumptions)
   b) Voltage Spikes – assuming OEM has designed voltage stabilizers, Zener diodes or other voltage regulating strategies
   c) EMI/RFI – assuming that OEM has provided proper shielding, filtering and suppression that effects oscillator operations outside the defined oscillator specified ppm stability
   d) Shock & Vibration – assuming OEM has provided a design that deals with vibration as a continuous oscillation that does not affect the defined oscillator specified ppm stability

B. Startup time – Two factors to consider: 1) Initial startup time (e.g. <150ms) and 2) Stabilized operational mode (e.g. >150ms). This is the time it takes an ECU to startup and be synchronized with the ECU's in the entire functional system or time synchronization domain (e.g. GM) in order to provide a specified functional requirement (e.g. diagnostics)

C. Time drift – The maximum, or range, of time synchronization drift of a PTP end-station, from the GM or time source, that will meet the requirements of functional message receipt/transmit within the functional system

D. Time "Jump" – This is the configured maximum, or range, of the time a PTP end-station is allowed to check and correct an unacceptable time drift and to adjust, or correct, back to the "stabilized operational mode". This consideration has an impact on the number and frequency of the time synchronized SYNC. Announce, and pDelay messages that are used to syntonize the system.

E. # of PTP relay instances – Typically in-vehicle networks will have <128 ECU's in total. Based on current architecture designs, Ethernet Time Sync PTP Peer-relay links will be assumed to be <32 hops that require a Master/Slave configuration within a single time sync domain "chain" which is determined by a specific required level of time sync accuracy (i.e. Active Safety=<3ns, Infotainment=<10ms)

F. IVN Time source – The physical location and functionality of an ECU that provides time synchronization with a GNSS system and meets the IVN Safety and ASIL compliance to provide time function at a defined level of accuracy to the vehicles ECU's in the functional system or time synchronization domain(s).

IEEE 802.1DG Time Synchronization Definitions (cont)

3) **Oscillator used to determine frequency stability and tolerance deviations:**

A. Quality of Oscillator considered:

a) PPM: ±20 ppm, ±50 ppm, and ±100 ppm
b) Temperature operating range – AEC-Q100 Grade3 temp -40 to 125°C
c) Frequency tolerance deviation – measured at 25°C
d) Frequency stability deviation – 1.64ppm for ±50 ppm
e) Oscillator startup accuracy: ≤ ±1 ppm
f) Cumulative aging stability deviation: ≤ ±3 ppm / year (estimated vehicle EOL ~ 20 yrs, expected operating life of ECU ~5 yrs)
g) Steady state maximum power supply voltage consumption ~~of: -0.3V to +4.0V~~ Implementation specific?
~~h) Physical location – relative to those PTP link instances that require greater accuracy~~ Implementation specific?
~~i) Cost (?): This is a parameter that we need to consider if OEM's are to follow or be encouraged to use this specification~~ Implementation specific?

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IEEE 802.1DG Time Synchronization Definitions (cont)

Oscillator Crystal Selection Example –

Solve for:
Actual Oscillator Crystal Accuracy required
Selection of Oscillator based (in part) - *Accuracy* = *tolerance* + *stability* + *aging* + *component tolerance* ≤ +/- ?? ppm

Assumptions:

i. Required total time accuracy – ±100 ppm
ii. Temperature operating range – AEC-Q100 Grade3 temp -40 to 125°C
iii. Frequency tolerance deviation – measured at 25°C
iv. Expected operating life of ECU/Oscillator – 5 years
v. Cumulative aging stability deviation - ≤ ±3 ppm / year
vi. Error variance due to component tolerances (determined residence times affect) - ≤ ±8 ppm

Calculations:

Tolerance and stability budget: +/- 77 ppm = 100ppm – 8ppm – (5yrs x 3ppm)

Required Oscillator specification selected:

Tolerance = +/- 20 ppm, and a stability of +/- 50 ppm would be selected
Frequency stability deviation – 1.64ppm for ±50 ppm

IEEE 802.1DG Time Synchronization Assumptions (cont)

4) Distribution of time within the vehicle network profile considerations:

A. Use of accumulating neighborRateRatio vs. successive Sync messages to obtain GrandMaster (GM) rateRatio
B. Use of syncLocked mode for PTP instances downstream from GM
C. Total maximum frequency offset "network" syntonization of ≤ ±100 ppm
D. Initial PTP relay link instance maximum frequency drift rate of ≤ ±1 ppm/s or 0.0001%
E. Consider max|TE| ≤ ±1μs over 64 hops (run through GG simulations for max|TE| over 32 hops[1])
F. Consider number of PTP relay instance hops – (run through GG simulations)
   a) Mandatory: 32
   b) Recommended: 64
   c) Optional: 16, 100
G. Consider ECU residence times – (run through GG simulations)
   a) Mandatory: 10ms
   b) Recommended: 4ms
   c) Optional: 15ms, 1ms
H. Consider Mean Sync message interval – (run through GG simulations)
   a) Mandatory: 125ms
   b) Recommended: ??
   c) Optional: ?? (i.e. 31.25ms)

NOTE:
[1]Simulations based on: https://www.ieee802.org/1/files/public/docs2020/60802-garner-new-simulation-results-dte-updated-assumptions-60802-network-0920-v03.pdf

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IEEE 802.1DG Time Synchronization Assumptions (cont)

4) Distribution of time within the vehicle network profile considerations:

- A. Consider Mean pDelay message interval – (ran through GG simulations)
    - A. Mandatory: 31.25ms (8 messages/s)
    - B. Recommended: ??
    - C. Optional: ?? (i.e. 1000ms)
- B. Consider pDelay turnaround time – (ran through GG simulations – CTE budget needed?)
    - A. Mandatory: 4ms
    - B. Recommended: ??
    - C. Optional: ?? (i.e. 1ms)
- C. Consider max|dTE| based on considered residence times – (ran through GG simulations)
    - A. Mandatory: ≤ 1µs
    - B. Recommended: ≤ 500ns
    - C. Optional: ??

IEEE 802.1DG Time Synchronization Assumptions (cont)

6) Additional vehicle network profile considerations:

A. PTP Link instance port speed – the minimum Ethernet port link speed available for transmission of PTP messages (e.g. 100Mbps

B. Redundancy – Provide method(s) of functional system consistent time synchronization and the process required by the ECU configuration to protect against functional interoperability inconsistencies and the transmitting of unused messages.

C. Functional Compliance – A level of time synchronization functional compliance based on a Safety, ASIL or ECU functional requirement: (e.g. at least ASIL B)

D. Safety
   a. ASIL compliance (e.g. Mandatory –ASIL B, Recommended – ASIL D. This is dependent on vehicle functional classification ADAS Level 0-5)
   b. Reliability (FMEA)
   c. Redundancy (FMEA)

E. Security
   a. GM and failover identification
   b. Messaging
   c. Link (master/slave) relationship

F. Diagnostics

IEEE 802.1DG Time Synchronization Profile Considerations

5) In-Vehicle Network (IVN) Effect:

A. Oscillator accuracy for ECU PTP relay instance: (see previous example)

1. Mandatory -
   i. Total time accuracy required: ≤ ±100 ppm[1]
   ii. Stability: ≤ ±50 ppm
   iii. Startup accuracy: ≤ ±1 ppm
   iv. Frequency stability deviation: <1.64ppm for ±50 ppm
2. Recommended –
   i. Total time accuracy required: ≤ ±50 ppm
   ii. Stability: ≤ ±20 ppm
   iii. Startup accuracy: ≤ ±1 ppm
   iv. Frequency stability deviation: <.65ppm for ±20 ppm
3. Optional – (?)
   i. Total time accuracy required: ≤ ±xx ppm
   ii. Stability: ≤ ±yy ppm (usually the Oscillator advertised accuracy)
   iii. Startup accuracy: ≤ ±xx ppm
   iv. Frequency stability deviation: xx ppm for ±yy ppm

Notes:

[1] Minimum stability and tolerance assumption based in part on ppm referenced in IEEE 802.3-2018 Clauses 96.5.2 and 96.5.4.5 for 100BASE-T1 (@ 66.666MHz) and Clauses 97.5.3.6 for 1000BASE-T1 (@ 750MHz) to support a PHY symbol MASTER transmitter and receiver accuracy rate of ±100 ppm

IEEE 802.1DG Time Synchronization Profile Considerations

2. **In-Vehicle Network (IVN) Effect:**
   - A. # of PTP Relay instances -
     - i. Mandatory: ≤32
     - ii. Recommended: ≤64
     - iii. Optional: ≤100
   - B. ECU Residence time (includes processor(s) type, service prioritization, stack, link delays, etc) -
     - A. Mandatory: ≤10ms
     - B. Recommended: ≤ 5ms (Note: have to run it through Geoff's simulation)
   - C. Messaging frequency intervals -
     - A. Sync
     - B. pDelay
   - D. Safety
     - A. ASIL compliance (e.g. Mandatory –ASIL B, Recommended – ASIL D. This is dependent on vehicle functional classification ADAS Level 0-5)
     - B. Reliability (FMEA)
     - C. Redundancy (FMEA)
   - E. Security
     - A. GM and failover identification
     - B. Messaging
     - C. Link (master/slave) relationship
   - F. Diagnostics

IEEE 802.1DG Time Synchronization Profile Definitions

from Kevin Stanton to everyone: 11:47 AM (December 8)
+q: How is Sync-Tx-time from upstream bridge communicated to the downstream bridge (for the successive-Sync method of computing rateRatio). Explore all the cascaded adjustments of time from the GM that are included in rateRatio.

GM phase correction. Open item

Also, what is the peak-to-peak value of the PPM modulation waveform

- First, the GM phase and frequency variations waveforms are needed; this computation was done in [1], and is copied below

$y(t) = A\sin(2\pi f_0 t)$

$\dot{y}(t) = 2\pi f_0 A\cos(2\pi f_0 t)$

where

$y(t) =$ instantaneous frequency offset in ppm

$A =$ frequency offset amplitude in ppm

Setting A to 50 ppm and the maximum frequency drift rate ($2\pi f_0 A$) to 3 ppm/s produces

$2\pi f_0(50 \text{ ppm}) = 3 \text{ ppm/s}$

$$f_0 = \frac{3}{100\pi} \text{ Hz} = 9.549\times10^{-3} \text{ Hz} = 9.549 \text{ mHz}$$

Note that the maximum time offset of the GM is

$$\frac{50}{2\pi(9.549\times10^{-3} \text{ Hz})} = 8.334\times10^{-4} \text{ s} = 0.8334 \text{ ms}$$

As was seen in previous presentations ([4], [5]), the GM error waveform is of relatively low frequency and large amplitude

Source: https://www.ieee802.org/1/files/public/docs2020/60802-garner-improved-analysis-component-dTER-due-to-GM-time-error-1120-v00.pdf

IEEE 802.1DG Time Synchronization – GG Simulation Results

- Additional factors to be considered to determine time sync accuracy requirement & Max dTER over a given # of hops or PTP relay instances (based on Geoff's plenary presentations):
  1. Understanding of max allowable drift rate that needs to be managed to avoid large "time jumps" and time sync variances
  2. Time sync message (Sync, Announce, pDelay) intervals based on the required allowable variation and required notification of syntonization loss with GM or neighboring PTP link instance
  3. Importance to understand Grand Master (GM) as a source of possible additional ±PPM AND allowable frequency rate variance drift from hop-to-hop based on required variance and tolerance factors (e.g. residence time, oscillator quality, link traffic, etc)
  4. The incremental effect of the max number of hops that constitute a PTP peer relay instance Master/Slave configuration and the desire of an acceptable max range of variance between GM (Node1) to the End station and the application requirements
  5. The effect of all the ECU elements affecting residence time stability variation relative to the transferring of time sync messaging (i.e. sync messages)
  6. Importance of affect of the physical link delay max
  7. Importance of max message egress queuing link delay (i.e. are these message all allowed to be preempted)

IEEE 802.1DG Time Synchronization

Backup and Supporting Slides

IEEE 802.1DG Time Synchronization Parameters

- Proposed values to investigate in Geoff’s models for Automotive: (example for GM below)

Grand Master requirements																	
						Oscillator											
	Supply Voltage (V)			Frequency (MHz)							Processor Residence	Queued Communication Egress Delay		Egress	Egress	Sync Message Interval	
AEC-Q100 (°C)	Min	Max	PPM (±) Stability[1]	Min	Max	Phase Jitter (Calculated - ps)	Max Frequency Offset (calculated)	Max Frequency Drift Rate (calculated)	MTBF (FIT) Reliability/Billion Hrs		Time	Min	Max	Link Type	Link Delay	Min	Max
-40 to +85 (G3)			20														
-40 to +105 (G2)			20														
-40 to +125 (G1)			20														
-55 to +125 (Ext)	-0.3V	+4.0	20	115	137	<1ps											
-40 to +85			25														
-40 to +105			25														
-40 to +125			25														
-55 to +125	-0.3V	+4.0	25	115	137	<1ps											
-40 to +85			30														
-40 to +105			30														
-40 to +125			30														
-55 to +125	-0.3V	+4.0	30	115	137	<1ps											
-40 to +85			50														
-40 to +105			50														
-40 to +125			50														
-55 to +125	-0.3V	+4.0	50	115	137	<1ps											
-40 to +85			100														
-40 to +105			100														
-40 to +125			100														
-55 to +125	-0.3V	+4.0	100	115	137	<1ps											
NOTES:		[1] Do we include vibration and shock sensitivity #'s as a factor or assume this is included as part of PPM Stability?															

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