Optically Pumped Cesium enabling ePRC and ePRTC ClassB

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Frequency time requirements in Telecom
Driven by Mobile Backhaul LTE-A

Application	Radio Interface		Backhaul	
	Frequency	Phase	Frequency	Phase
CDMA 2000	±50ppb	±3 to 10μs	GPS	GPS
GSM/WCDMA	±50ppb	n/a	±16ppb	n/a
LTE (FDD)	±50ppb	n/a	±16ppb	n/a
LTE (TDD) (large cell)	±50ppb	±5μs	±16ppb	±1.1μs
LTE (TDD) (small cell)	±50ppb	±1.5μs	±16ppb	±1.1μs
LTE-A MBSFN	±50ppb	±1 to 5μs	±16ppb	±1.1μs
LTE-A CoMP*	±50ppb	±500nsec to 5μs	±16ppb	500ns - ±1.1μs
LTE-A eICIC*	±50ppb	±1 to 5μs	±16ppb	±1.1μs

The 500ns at Backhaul level translates into 30ns at core level (ePRTC)

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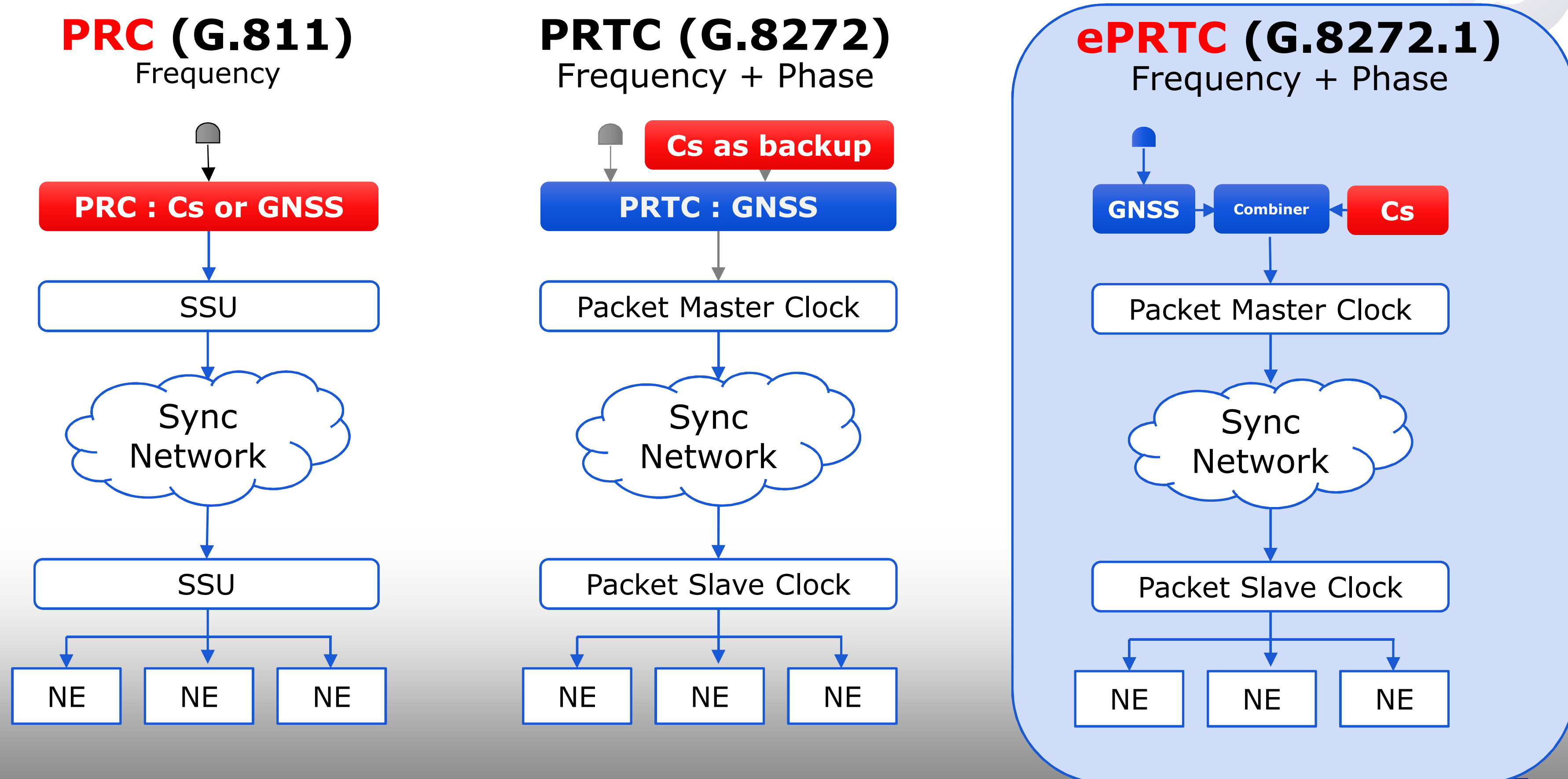
Standards for primary reference sources

Frequency source		Time source	
Name	**ITU-T Rec.**	**Name**	**ITU-T Rec.**
PRC	G.811	PRTC	G.8272
ePRC	G811.1	ePRTC-A	G.8272.1
		ePRTC-B (project)	

Cesium Clock as Time source



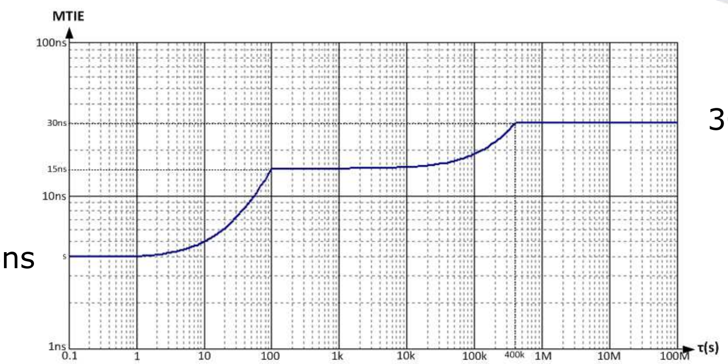
ePRTC: enhanced PRTC (ITU-T G.8272.1)

What is enhanced?

Cesium Clock to filters GNSS instabilities:

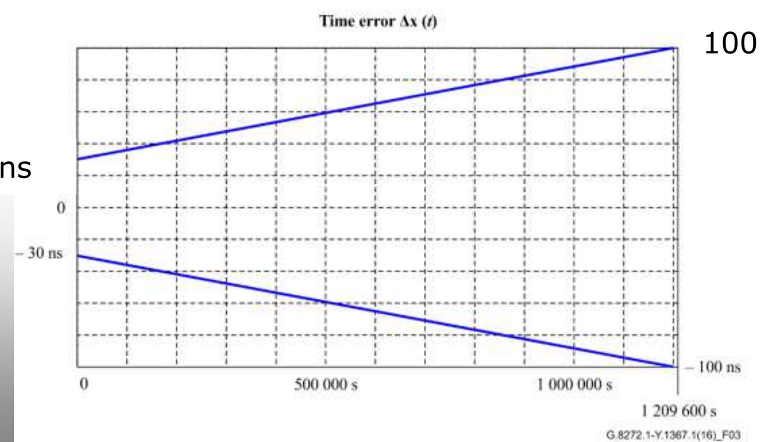
- atmospheric interference
- solar storms
- Equatorial diurnal Ionospheric variation

→ **30 ns MTIE in GNSS locked mode**

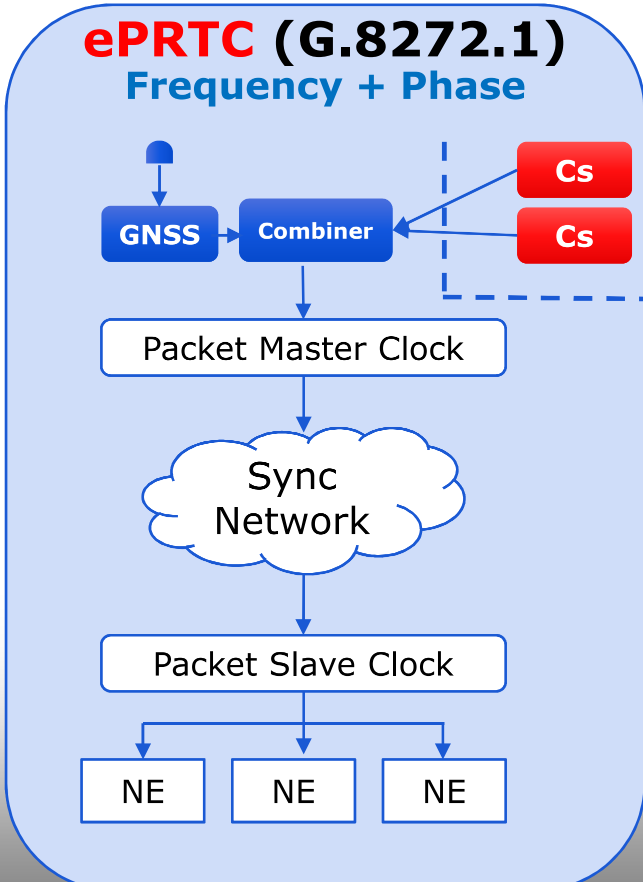


Cesium Clock: Resiliency against GNSS outage

→ **100 ns MTIE over 14 days in Holdover mode**



Where is ePRC hiding?

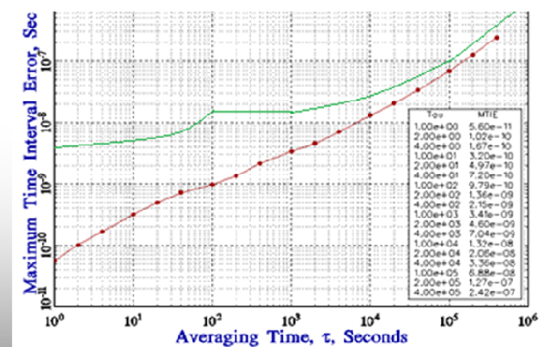


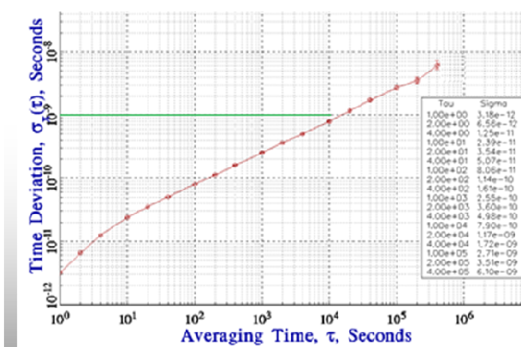
ePRC (G.811.1)

Frequency domain

Requires E-12 frequency accuracy

(Achieved with Magnetic cesium clocks)





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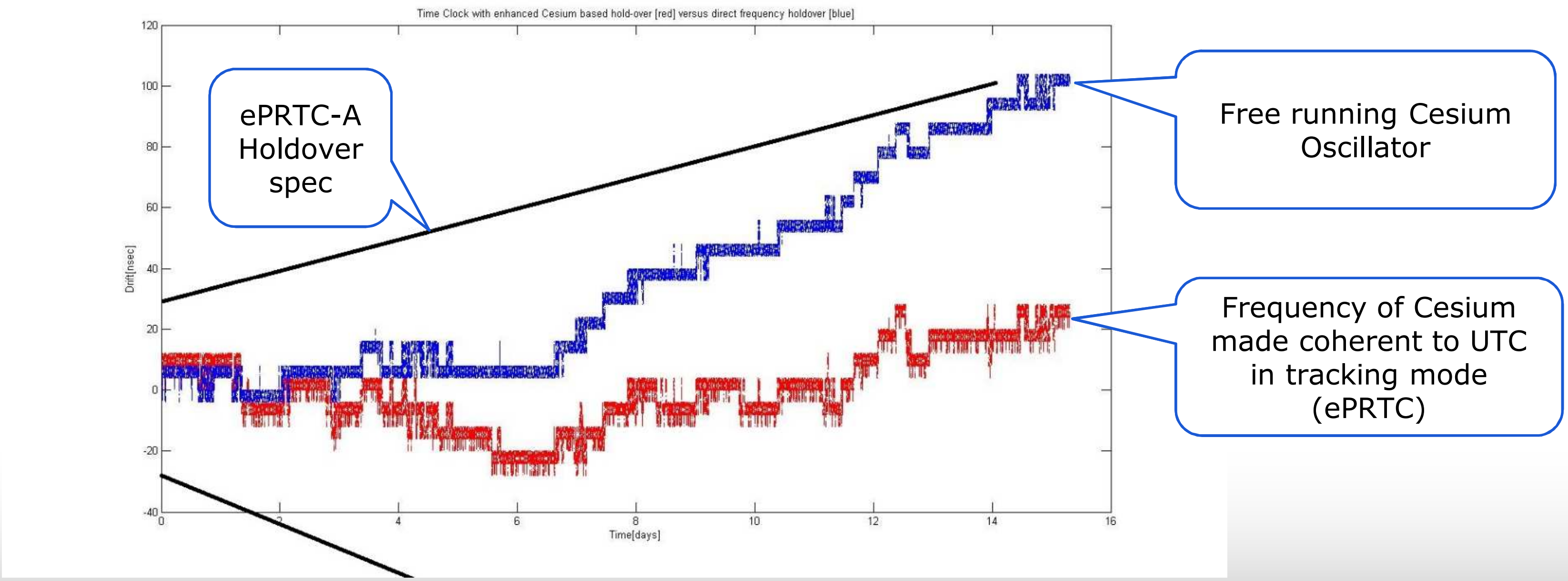
ePRTC Class A Holdover requirement



ePRTC class A phase/time holdover measurement

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ePRTC G8272.1 – Phase error in holdover

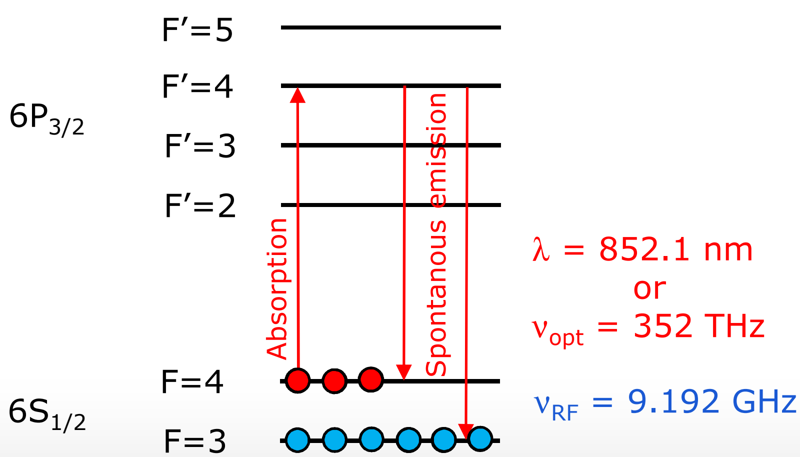
Evolution toward a class-B Holdover

ePRTC Class	Holdover performance
ePRTC-A	100 ns over a 14 day
ePRTC-B	100 ns over a 80 day (Project) Could also be a tighter error budget over a shorter period.

Class B: *will require a frequency accuracy as tight as 1 x E^{-14} and better !*
(How to?)

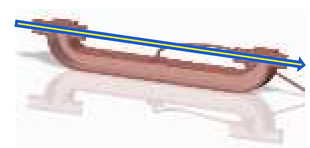
Improving frequency stability with Optical pumping (Versus magnetic deflection)

^{133}Cs atomic energy levels



- Atomic energy states
  - **Ground states** (F=3,4) equally populated
  - **Excited states** (F′=2,3,4,5) empty

- Switching between ground states F by **RF interaction 9.192 GHz** without atomic selection (no useful differential signal)



- ~~Atomic preparation by **magnetic deflection** (loss of atoms)~~

- Atomic preparation by **optical pumping** with laser tuned to F=4 →F′=4 transition (gain of atoms)

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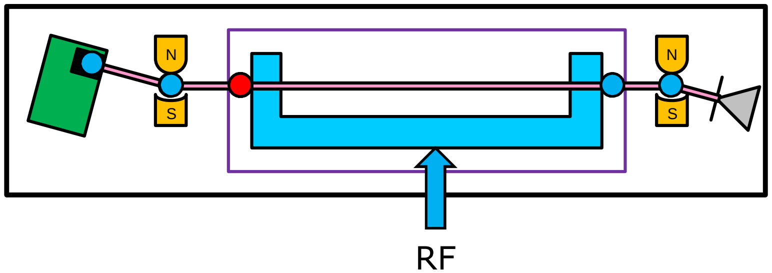
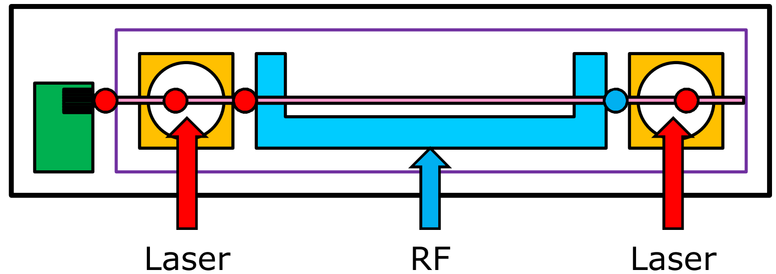
Improving frequency stability with Optical pumping (Versus magnetic deflection)





- Weak flux
  - Strong **velocity selection** (bent)
  - Magnetic deflection (**atoms kicked off**)
- Typical performances: ADEV
  - **2.7 x E^{-11} x $\tau^{-1/2}$**

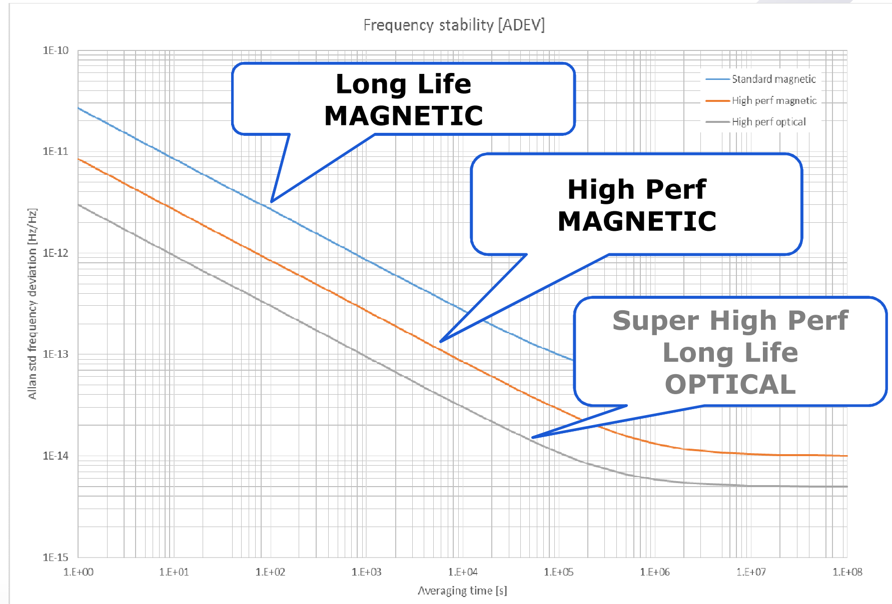
- High flux (x100)
  - **No velocity selection** (straight)
  - Optical pumping (**atoms reused**)
- Typical performances:ADEV
  - **3 x E^{-12} x $\tau^{-1/2}$**

Available commercial Cs clock products

- **Long life magnetic** Cs clock
  - Stability : **$2.7 \times E^{-11}$** $\times \tau^{-1/2}$
  - Floor : $5 \times E^{-14}$
  - Lifetime : 10 years

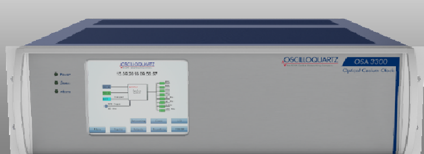
- **High performance magnetic** Cs clock
  - Stability : **$8.5 \times E^{-12}$** $\times \tau^{-1/2}$
  - floor : $1 \times E^{-14}$
  - Lifetime : 5 years

- **High performance and long life optical** clock
  - Stability : **$3.0 \times E^{-12}$** $\times \tau^{-1/2}$
  - floor : $5 \times E^{-15}$
  - Lifetime : 10 years



ADEV: Allan Deviation

3 generation commercial clocks



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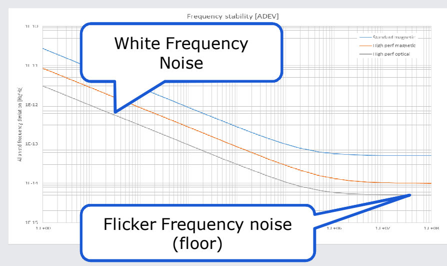
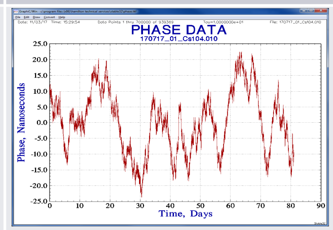
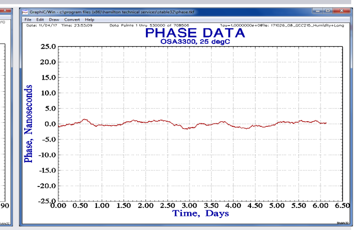
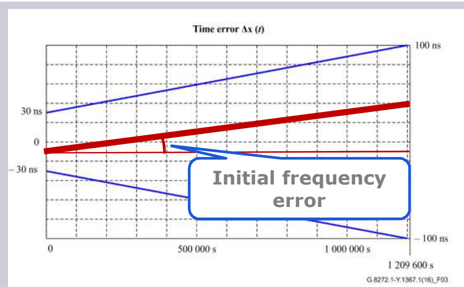
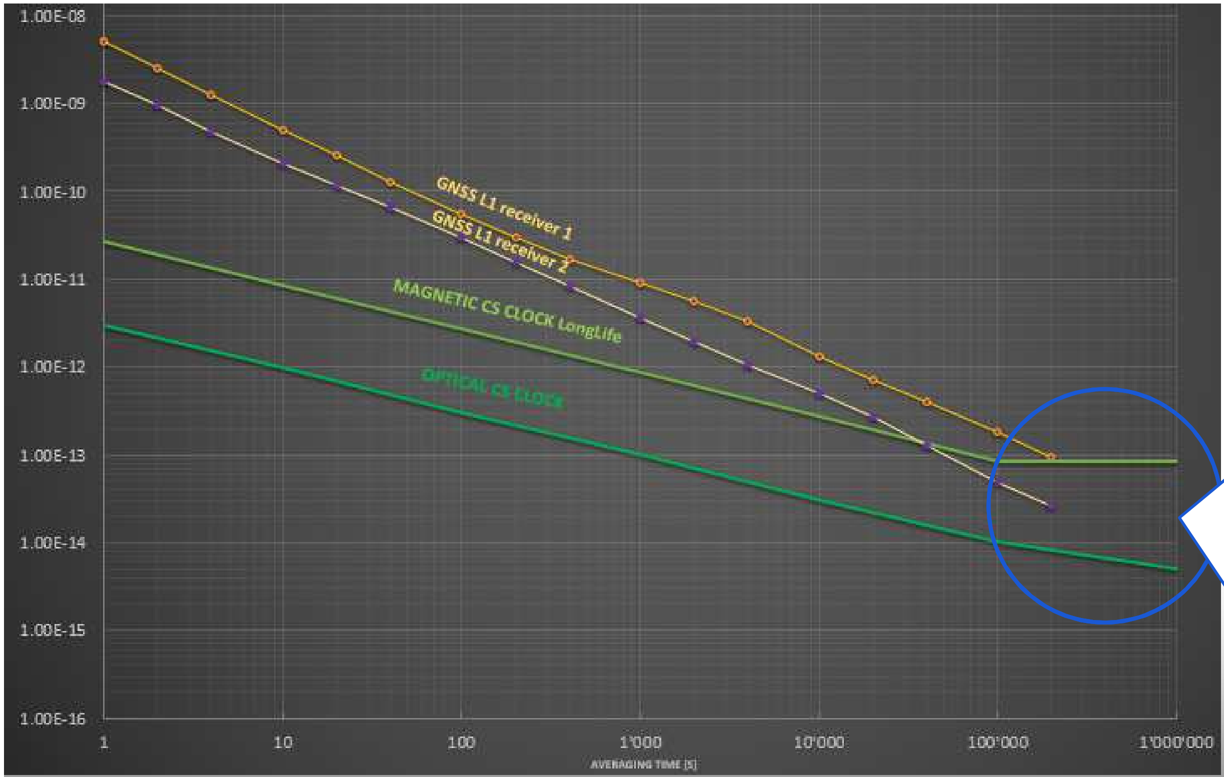
Decomposition of ePRTC Holdover phase error budget

Origin of Phase error	Note	Required for ePRTC-B
initial phase error *GNSS instabilities + Clock stability* +	*+/- 30 ns as per ePRTC G.8272.1* How to use only ±10ns ?	High stab. GNSS+ High stability clock
Random Phase excursions (Holdover) *White frequency noise +* *Flicker Frequency noise* *cesium clock* +	Higher Stability clocks  	  Typ. Φ excursion Magnetic (±20ns) Typ. Φexcursion Optical (±5 ns)
***Phase drift** due to initial clock freq. offset.* *Which is a function of :* - *Clock stability @Tau> 1 d* - *GNSS stability @Tau>1 d*	 	Higher stability GNSS + higher stability clock (long term). Required: Freq. error << 5x E^{-14} ePRTC-A Freq. error << 1x E^{-14} ePRTC-B

As well, faster GNSS technics needed



ADEV (frequency stability)

Area of interest: Tau=1-10d.

GNSS sets clock accuracy

= 5 x E^{-14} requires 1-2 d.
< 1 x E^{-14} requires > 10 d.

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Thank You