Primary
Reference
Time Clock
Class B

Global
Navigation
Satellite
System

PRTC-B USING MULTI-BAND GNSS IN ITU-T STANDARDS WITH INITIAL RESULTS

ITSF2020 Keynote talk, Helmut Imlau, 4.11.2020

Multi-band GNSS: PRTC-B in synchronization networks
Agenda

(1) Introduction

  Primary reference time clocks in telecommunication networks

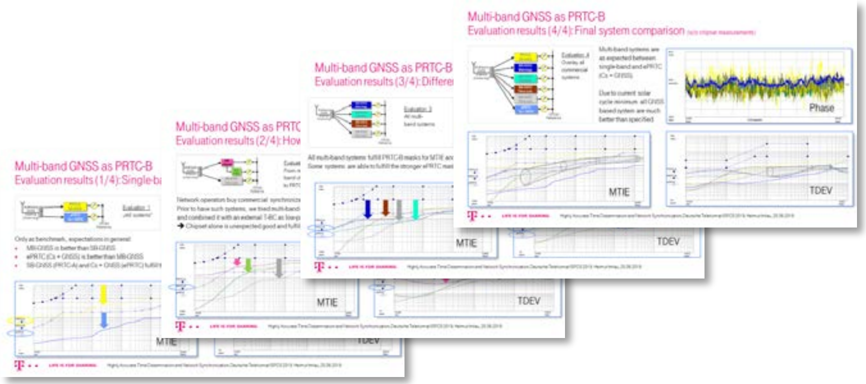
  Earth, ionosphere, sun activity … and related GNSS time error

(2) The multi-band GNSS solution

(3) Measurements & results

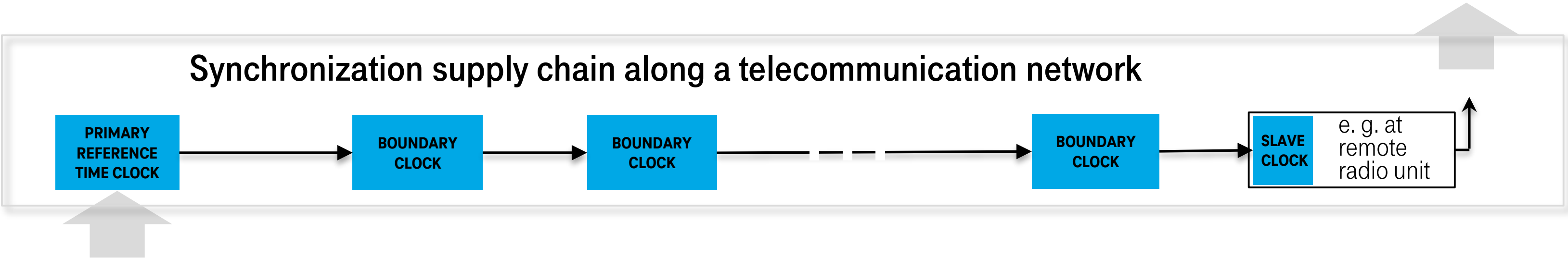
(4) Lessons learned & summary

+ Backup slides
with details:
measurement
und result evaluation



Multi-band GNSS: PRTC-B in synchronization networks
Introduction: Primary Reference Time Clocks

Synchronization is for mobile air interface
e. g. for Time Division Duplex
or co-operation features
max. Time Error: 1500 ns - 130 ns

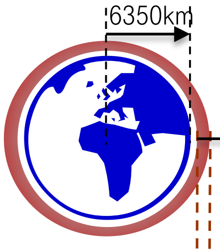


Primary Reference Time Clocks: Must have the needed accuracy depending on requirements of end-application, length of supply chain and quality of used secondary clocks

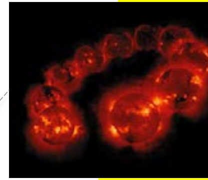
Time clock name		ITU-T	Used sources
Primary Reference Time Clock	PRTC	G.8272	GNSS, PRTC-A (single-band GNSS), PRTC-B (multi-band GNSS)
enhanced PRTC	ePRTC	G.8272.1	Clock Combiner with Cesium atomic clock(s) and GNSS
coherent network PRTC	cnPRTC	G.8275	Architecture concept: Mashed ePRTC (Cs + GNSS) at the network

Multi-band GNSS: PRTC-B in synchronization networks

Earth, ionosphere, sun activity ...



147.000.000km - 152.000.000km

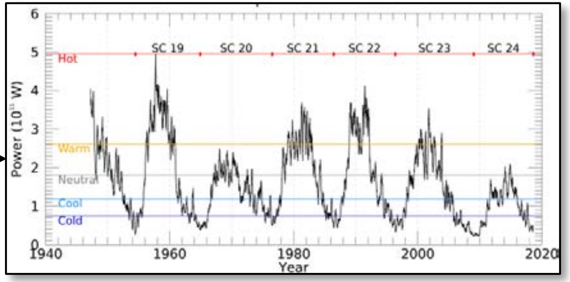


A solar cycle: a montage of ten years' worth of Yohkoh SXT images, demonstrating the variation in solar activity during a sunspot cycle, from after August 30, 1991, to September 6, 2001. Credit: the Yohkoh mission of ISAS (Japan) and NASA (US).

Ionosphere: (≈85 km... ≈700 km)

- Ionosphere consists of gas molecules
  ... are ionized by cosmic and mainly solar radiation ➔ The name ionosphere comes from
- Solar radiation depends on sun activity:
  ➔ on regularly basis: 24h cycle due to earth rotation, summer-winter variation, sun has a 11year activity cycle
  ➔ spontaneous: sun storms and space weather in general

ESA: https://www.youtube.com/watch?v=uRH9DuTRyCw



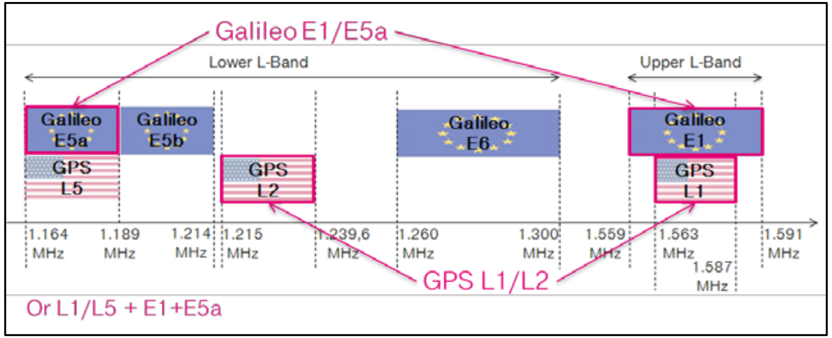
Source: https://solarscience.msfc.nasa.gov/predict.shtml

Result of ionization:

positive ions and electrons => impacts electro-magnetic field around earth, which influences radio propagation ➔ **leads to delay variation for satellite signals e. g. GNSS**

Multi-band GNSS: PRTC-B in synchronization networks
Earth, ionosphere, sun … and GNSS receiver time error

- Delay variation of GNSS signals for the receiver has a huge impact at time error. The maximum diurnal wander shows the impact. Deutsche Telekom has measured up the 48 ns with a single-band GNSS receiver 6 years ago.
- Delay variation depends on radio frequency.
- Relationship between frequency and delay is known.



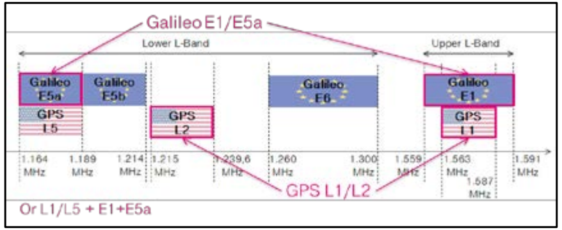
Delay at 1.5 GHz GNSS band (GPS L1 / Galileo E1)
differs from
delay at 1.2 GHz GNSS band (GPS L2 / Galileo E5

Multi-band GNSS as PRTC-B
The Multi-band GNSS solution

- Phase shift between two GNSS carrier frequencies (1.2 and 1.5 GHz) can be measured and used for estimation of absolute ionosphere delay …. to compensation for lower time error.
- Multi-band GNSS receivers
  ➔ can use measurement results of two frequencies from satellites at the same time.
  ➔ have the 'known' factor for equations to eliminate the ionosphere delay variation.

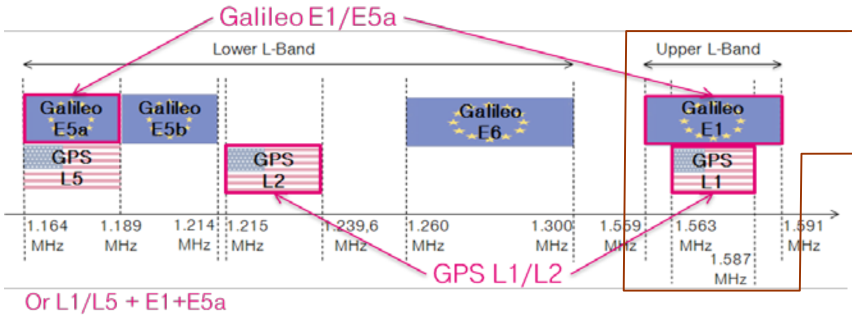
This technology:

- is well known at metrology community,
  e. g. by national UTC(k) time labs,
  Multi-band GNSS receivers are used for BIPM UTC process.
  Metrology receiver are produced in a very low quantity & expensive.



- For telecommunication, it is brand new, specified by ITU-T, needed for a much higher quantity than single-band, with lower costs compared to metrology receivers.
- Deutsche Telekom was one of the main contributors for related PRTC-B specification.

Multi-band GNSS as PRTC-B
Single- and multi-band GNSS as PRTC Class A and B



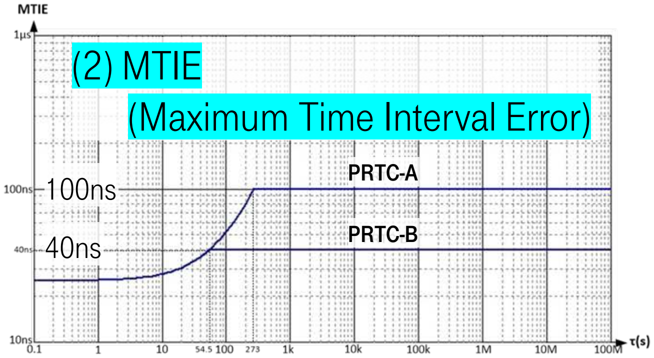
- Single-band GNSS, related to PRTC Class A uses upper L-Band only: 1.5 GHz
- Multi-band-band GNSS, related to PRTC-B uses upper & lower L-Band: 1.5 GHz and 1.2 GHz

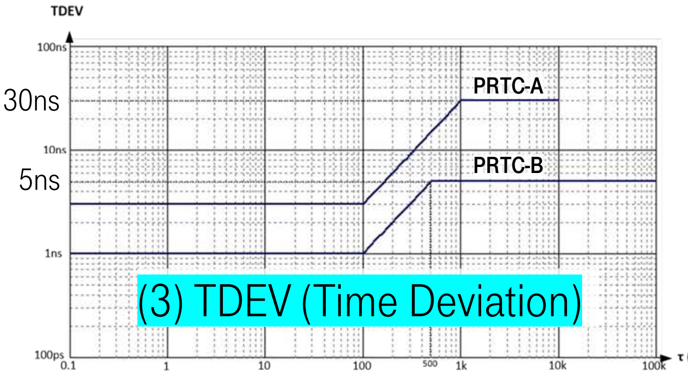
ITU-T PRTC specification acc. to G.8272

(1) maxITEI:

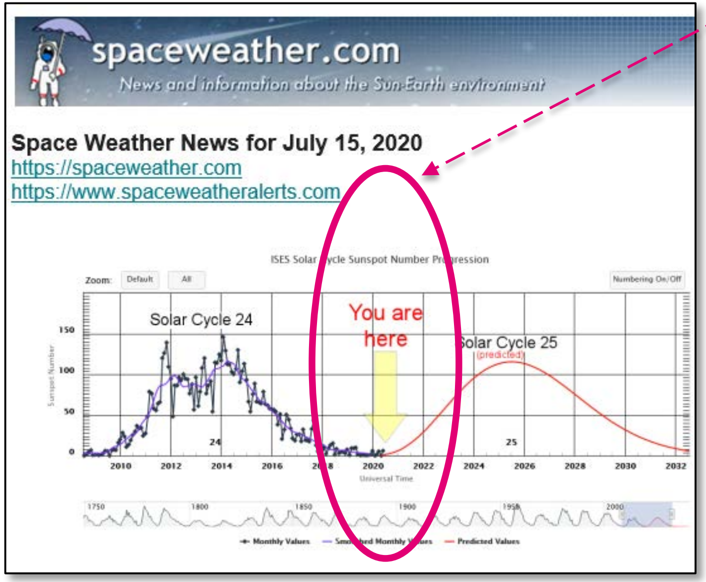
Class A: maxITEI=100 ns

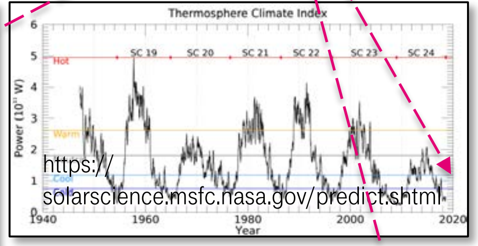
Class B: maxITEI=40 ns

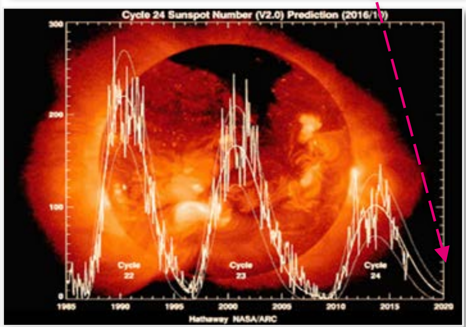




Multi-band GNSS as PRTC-B
Measurement result evaluation: 11years cycle. Where are we now?







Several sources,
all telling the same truth:

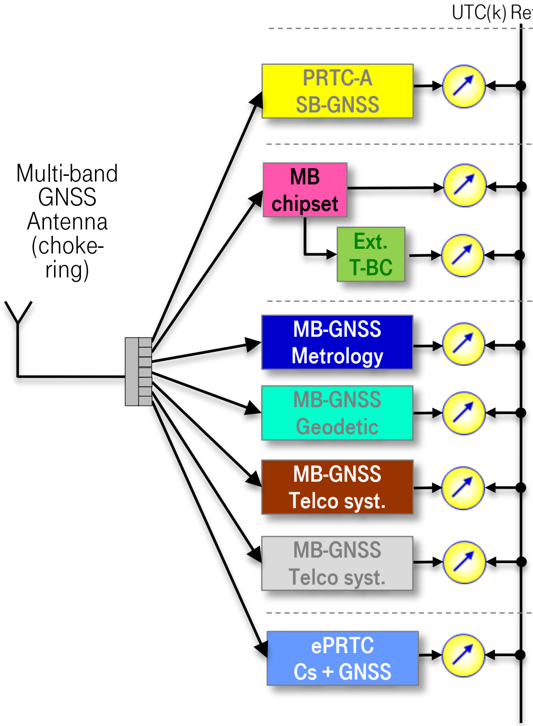
We are in a
solar cycle minimum phase

All GNSS receiver
performance measurement
results look much better now.

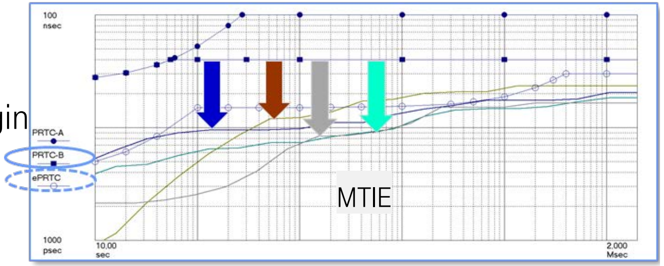
2020 was bad for
worst-case testing
to evaluate GNSS
receiver system performance

Multi-band GNSS as PRTC-B
Measurements: Overview and high-level results (8 measurements / 20 days)

Details @ Backup

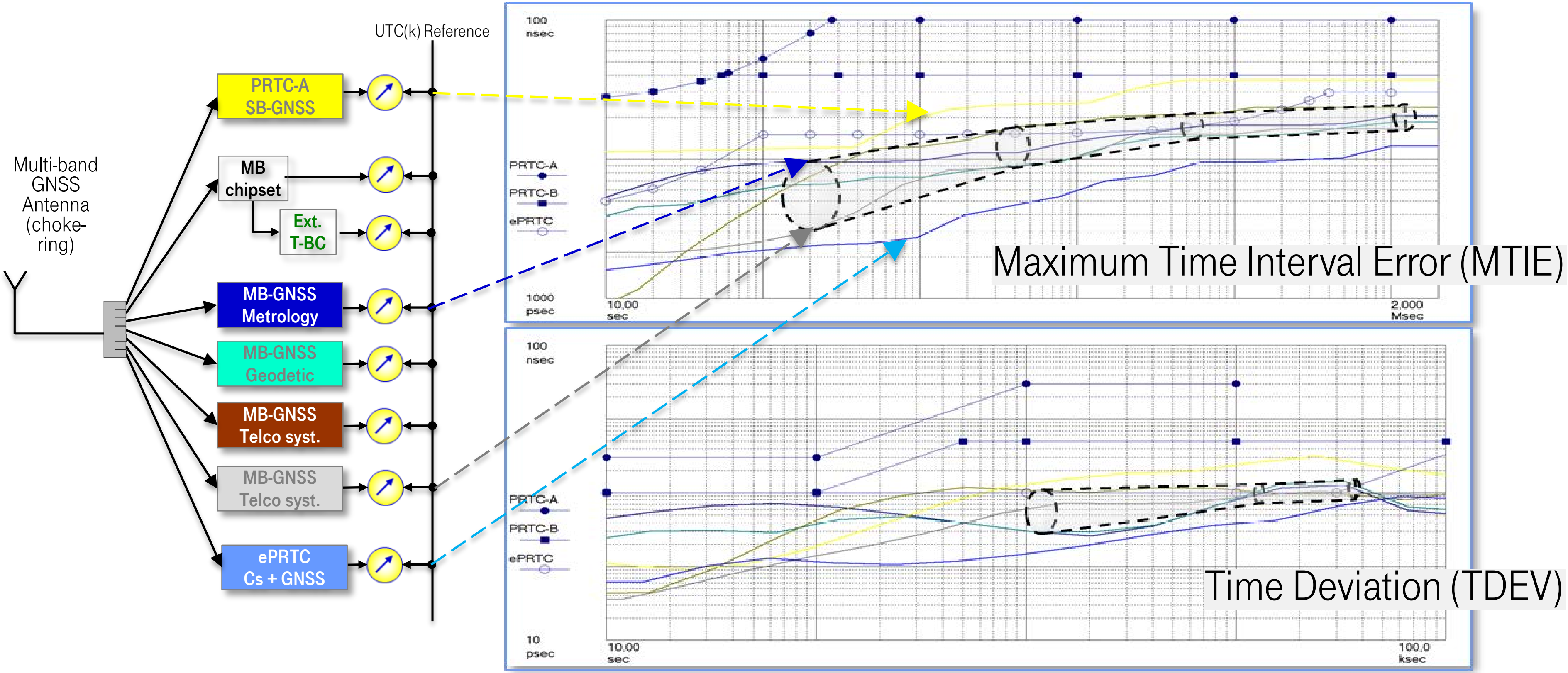


System Under Test (SUT)	Result at solar cycle low 07-2020
▪ Single-band GNSS, PRTC-A system for comparison only	➢ Was able to fulfill much stronger PRTC-B maska (based on multi-band technology)
▪ GNSS chipset only ▪ Chipset combined with T-BC (low-pass)	➢ Chipset alone was able to fulfill PRTC-B masks (chipset only, w/o a strong oscillator / low-pass)
▪ Different multi-band GNSS SUT: for metrology, geodetic and telco	➢ All been able to fulfill PRTC-B masks with margin ➢ Some do fulfill stronger ePRTC masks
▪ Enhanced PRTC: Cesium atomic clock with GNSS	➢ Gives the very best performance (and long holdover) ePRTC masks where fulfilled with margin



Evaluations: Phase=20days, MTIE:=2Ms, TDEV=100ks, please refer backup slides for more details

Multi-band GNSS as PRTC-B
Measurements: 6 GNSS systems: MTIE and TDEV



Multi-band GNSS: PRTC-B in synchronization networks
Lessons learned 1/2

Testing:

1) Due to current solar activity minimum: This year is a bad for worst-case GNSS receiver testing:

   ➔ Single-band system was able to fulfill the stronger PRTC-B masks and

   ➔ Multi-band systems where able to fulfill the stronger ePRTC masks.

   But, installed systems at networks ➔ must fulfill related recommendations during entire 11y cycle.

2) GNSS simulator ?

   .. .. so far, we have not seen adequate simulator test setups for sun activity cycle and sun eruptions.

   Deutsche Telekom as network operator sees simulator testing more under responsibility of system vendors.

3) A proper reference signal is needed for performance evaluation, there are two options

   (a) To measure at UTC(k) lab.

   (b) To have high-accuracy time transfer from UTC(k) lab to your test lab,

   e. g. via Optical Time Transfer (ELSTAB) or IEEE1588-2019 (v2.1) high-accuracy profile.

Multi-band GNSS: PRTC-B in synchronization networks
Lessons learned 2/2

Other aspects:

1) Due to broader bandwidth, multi-band systems have higher probability of interference by intentional or unintentional jamming.

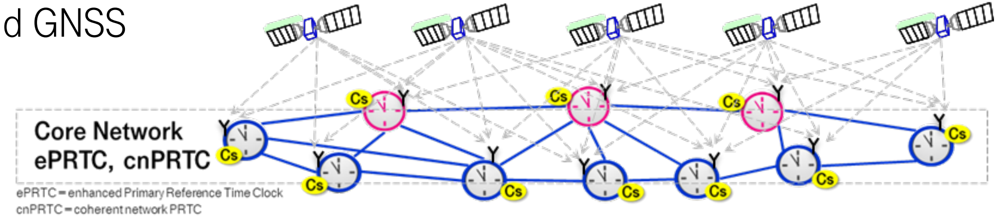
2) The components are more sensitive to any high-frequency issues like reflection loss
   ➔ HF components must be better (than for single-band), e. g. lower return loss.

3) All components used (chipset, antenna, amplifier and signal distributor) for GNSS frequency must support multi-band and are still more expensive than single-band components.

4) To take advantage of the new technology:
   Installation and calibration (like delay compensation for specific antenna, cable, amplifier and signal distributor) is more important than for single-band systems to reach better quality.

Multi-band GNSS: PRTC-B in synchronization networks with initial results
Summary for Deutsche Telekom

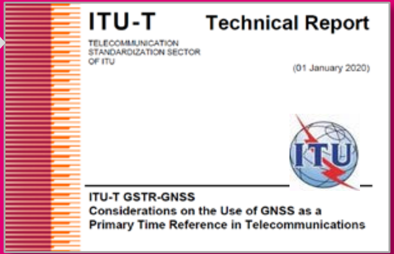
- With specification by ITU-T, multi-band GNSS technology is available for telecommunication market now.
- More effort is needed to make sure, that multi-band technology will fulfill related masks for the entire 11year sun activity cycle.
- Using Multi-band GNSS improves the performance, but is still more effort and is more sensitive to any high-frequency problems including radio interference.
- So, network operators must carefully decide where to use multi-band GNSS at the network.
- For Deutsche Telekom, currently, multi-band GNSS is for synchronization core, the highest level of the layered synchronization network
  … and for synchronization measurement systems.



PRTC-B USING MULTI-BAND GNSS IN ITU-T STANDARDS WITH INITIAL RESULTS

Recommended Links:

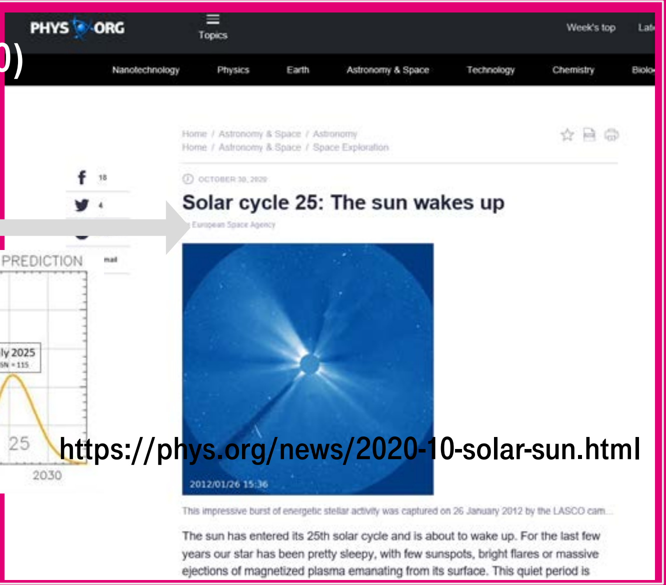
ITU-T	Report GNSS for Primary Clocks	http://handle.itu.int/11.1002/pub/815052de-en
ITU-T	PRTC specification:	https://www.itu.int/itu-t/recommendations/rec.aspx?rec=13769
ESA	Space Weather:	https://www.youtube.com/watch?v=uRH9DuTRyCw
Wikipedia	Carrington-Event:	https://en.wikipedia.org/wiki/September_1859_geomagnetic_storm



Thank you very much.

Latest news (30.10.2020)

The sun wakes up ☺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Topics
Week's top
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OCTOBER 30, 2020

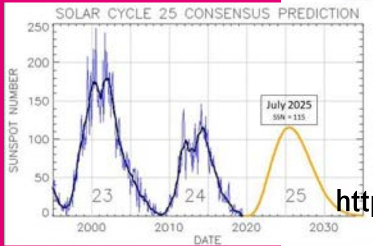
Solar cycle 25: The sun wakes up

European Space Agency

2012/01/26 15:36

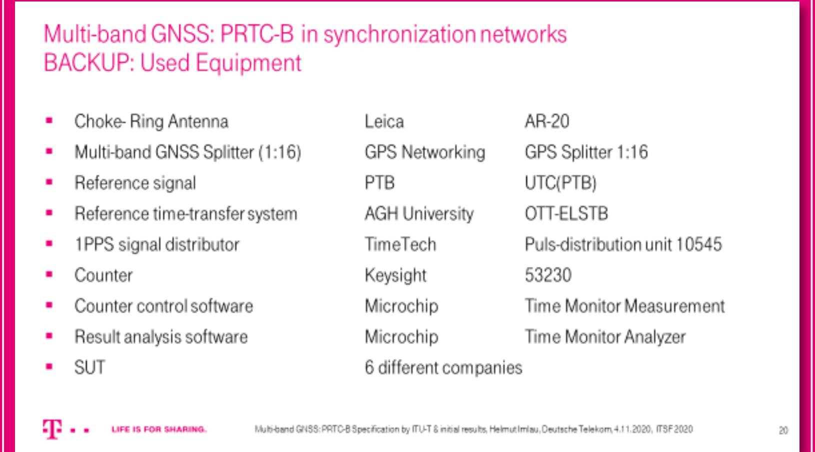
This impressive burst of energetic stellar activity was captured on 26 January 2012 by the LASCO cam...

The sun has entered its 25th solar cycle and is about to wake up. For the last few years our star has been pretty sleepy, with few sunspots, bright flares or massive ejections of magnetized plasma emanating from its surface. This quiet period is



https://phys.org/news/2020-10-solar-sun.html

For more details ... ... see Backup slides


Multi-band GNSS: PRTC-B in synchronization networks
BACKUP: Used Equipment

Choke- Ring Antenna	Leica	AR-20
Multi-band GNSS Splitter (1:16)	GPS Networking	GPS Splitter 1:16
Reference signal	PTB	UTC(PTB)
Reference time-transfer system	AGH University	OTT-ELSTB
1PPS signal distributor	TimeTech	Puls-distribution unit 10545
Counter	Keysight	53230
Counter control software	Microchip	Time Monitor Measurement
Result analysis software	Microchip	Time Monitor Analyzer
SUT	6 different companies	

LIFE IS FOR SHARING.
Multi-band GNSS: PRTC-B Specification by ITU-T & initial results, Helmut Imlau, Deutsche Telekom, 4.11.2020, ITSF 2020
20

Backup slides.

Multi-band GNSS: PRTC-B in synchronization networks
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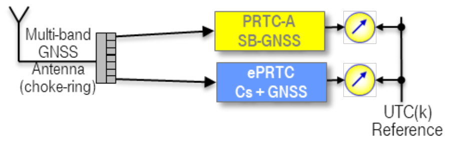
Multi-band GNSS as PRTC-B
Measurement setup ➔ 4 separate evaluations

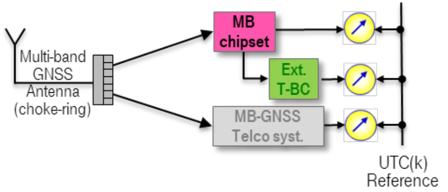
For information only, not shown during talk, see additional slides ...



Evaluation 1

Other systems

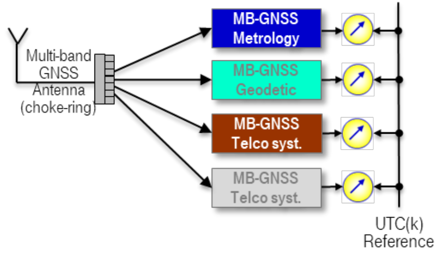
Purpose:
Only as benchmark



Evaluation 2

From multi-band chipset to PRTC-B

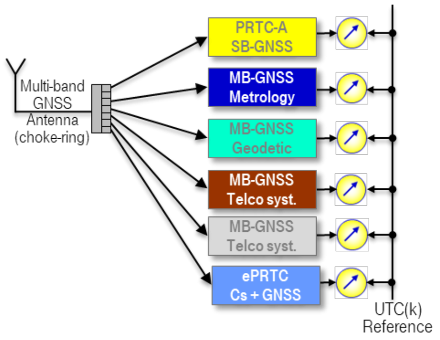
Purpose:
To follow latest chipset developments,
To have early feasibility results for ITU-T specification



Evaluation 3

All multi-band systems

Purpose:
To compare different commercial system solutions from different system vendor



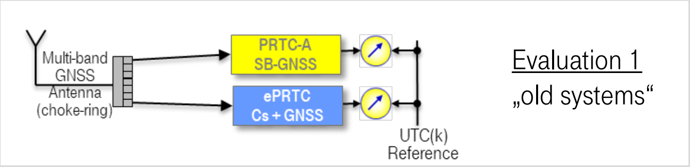
Evaluation 4

Overlay all commercial systems

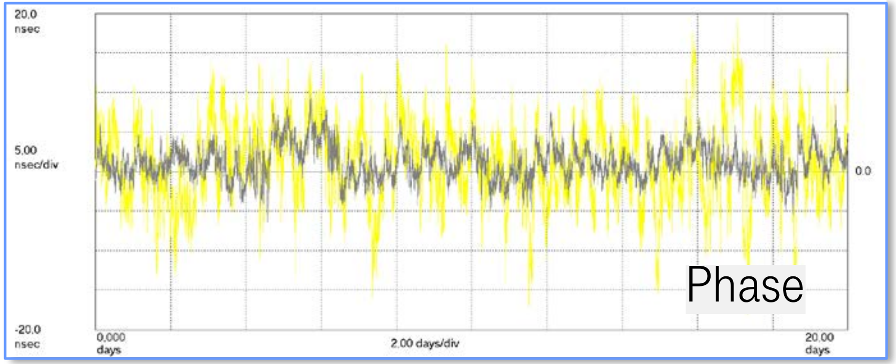
Purpose:
To compare different commercial systems with different technology,
as PRTC-A, PRTC-B and ePRTC

Multi-band GNSS as PRTC-B

Evaluation results (1/4): Single-band GNSS (PRTC-A) and ePRTC (Cs+GNSS)

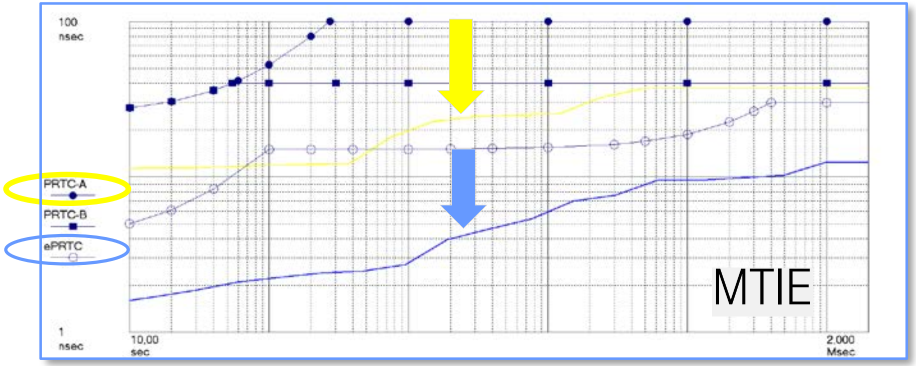


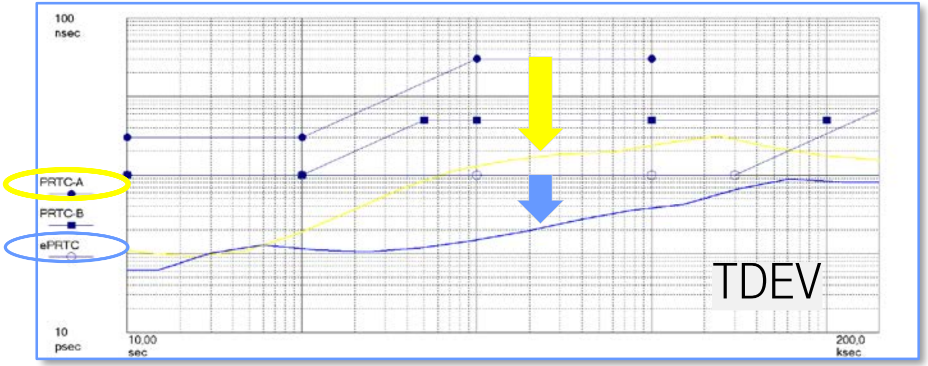
Evaluation 1
„old systems“



Only as benchmark, expectations in general:

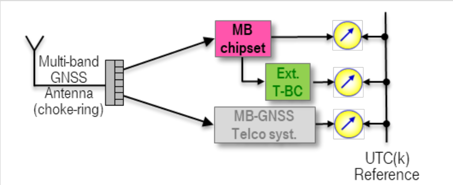
- MB-GNSS is better than SB-GNSS
- ePRTC (Cs + GNSS) is better than MB-GNSS
- SB-GNSS (PRTC-A) and Cs + GNSS (ePRTC) fulfill their masks ✓





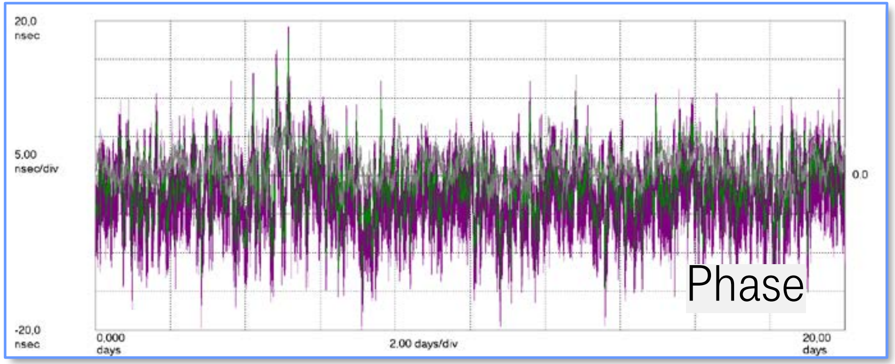
Multi-band GNSS as PRTC-B

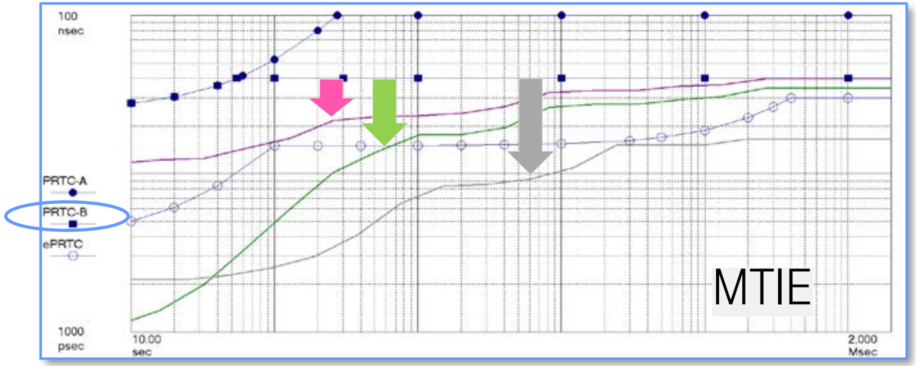
Evaluation results (2/4): How to build a MB-GNSS system?

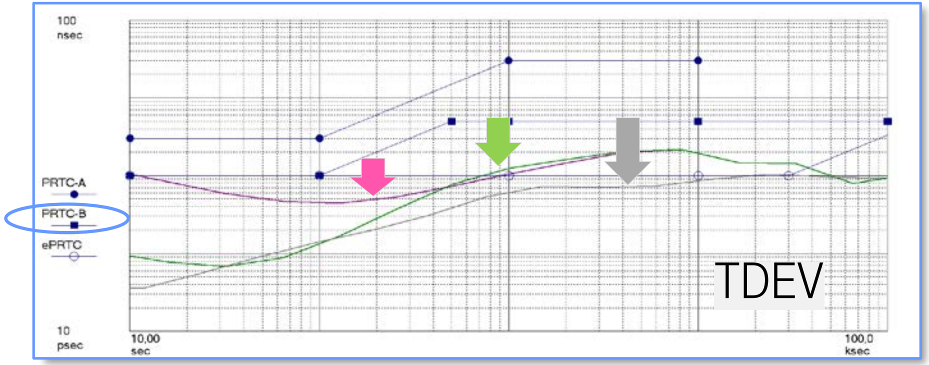


Evaluation 2
From multi-band chipset to PRTC-B

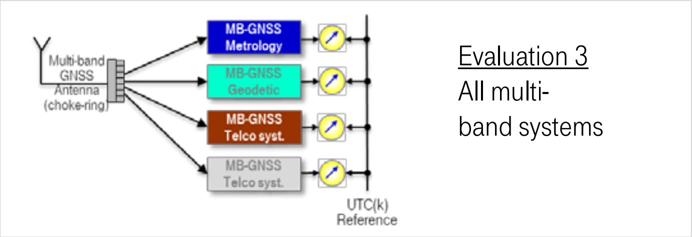
Network operators buy commercial synchronization systems.
Prior to have such systems, we tried multi-band chipset only and combined it with an external T-BC as low-pass
➔ Chipset alone is unexpected good and fulfills PRTC-B mask ✓





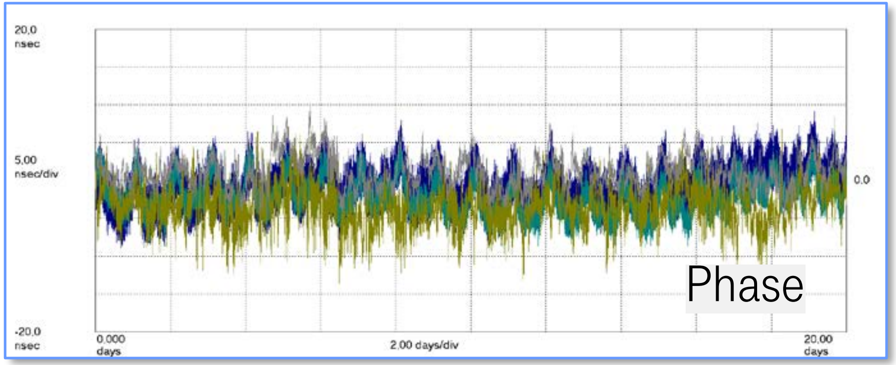


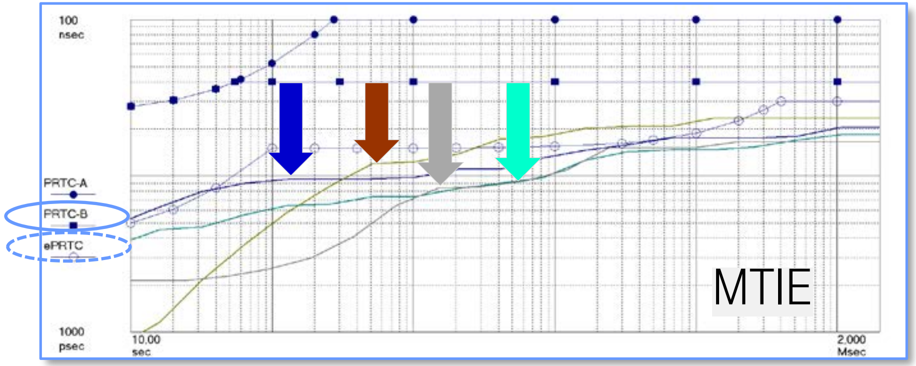
Multi-band GNSS as PRTC-B
Evaluation results (3/4): Different multi-band systems

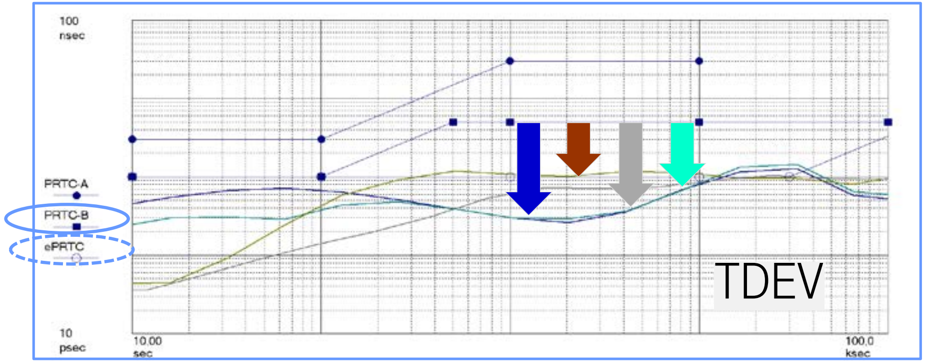


<u>Evaluation 3</u>
All multi-band systems

All multi-band systems fulfill PRTC-B masks for MTIE and TDEV ✓
Some systems are able to fulfill the stronger ePRTC mask

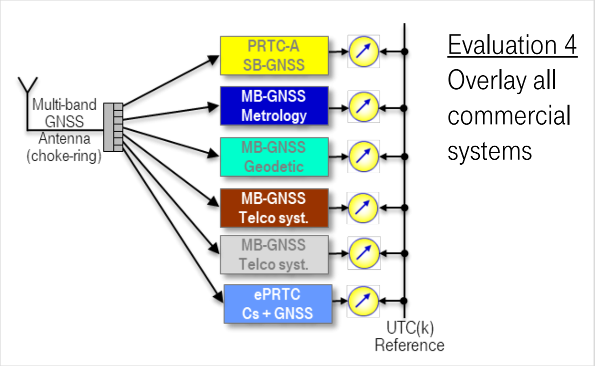






Multi-band GNSS as PRTC-B

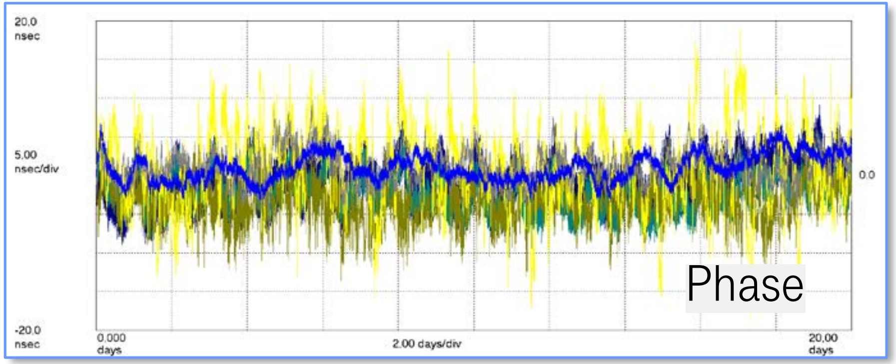
Evaluation results (4/4): Final system comparison (w/o chipset measurements)

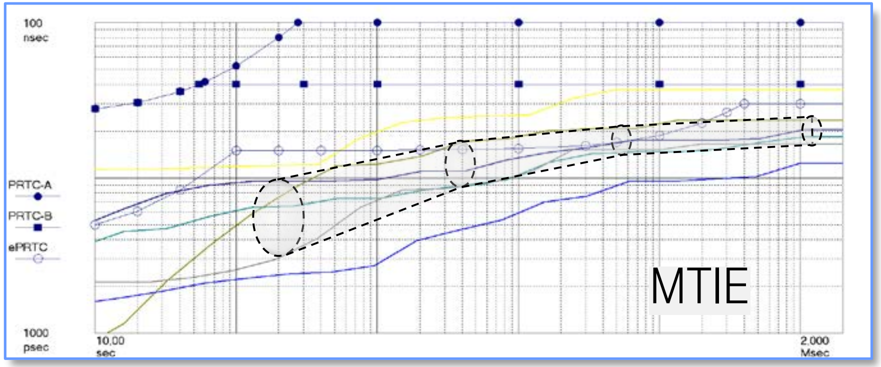


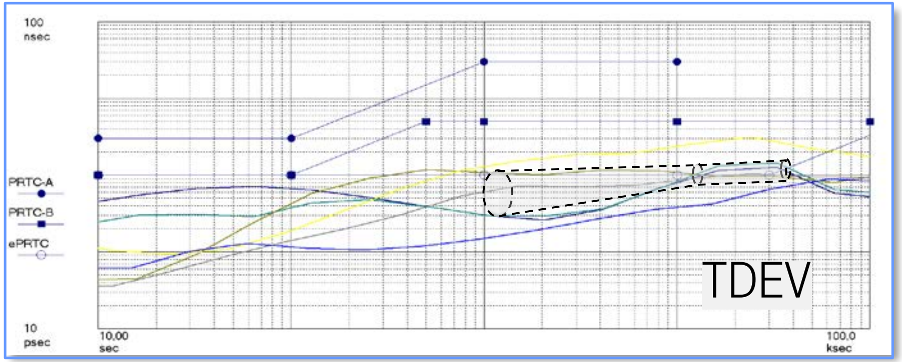
Evaluation 4
Overlay all commercial systems

Multi-band systems are as expected between single-band and ePRTC (Cs + GNSS).

Due to current solar cycle minimum all GNSS based system are much better than specified







Last slide.

Abbreviations:

cnPRTC	- coherent network PRTC
Cs	- Cesium atomic clock
ePRTC	- enhanced PRTC
HRM	- Hypothetic Reference Model
GNSS	- Global Navigation Satellite Systems
MB	- Multi-band GNSS
MTIE	- Maximum Time Interval Error
OCXO	- Oven Controlled Crystal Oscillator
PLL	- Phase Locked Loop
PRTC	- Primary Reference Time Clock
SB	- Single-band GNSS
TE	- Time Error
TDEV	- Time Deviation