How To Share Clocks For Phase Coherency (That suits your Needs)

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Introduction to Phase Coherency

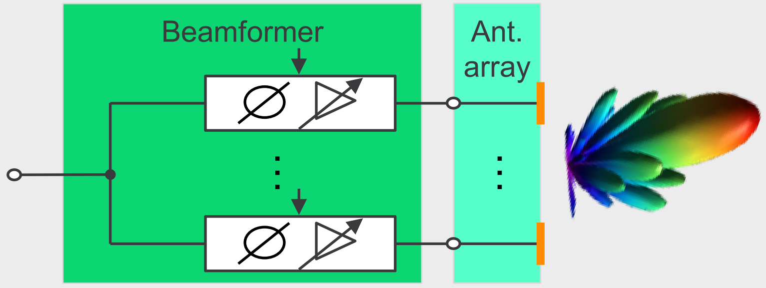
Super Short, Super Brief

Multi-Antenna Systems
– Care about Synchronization

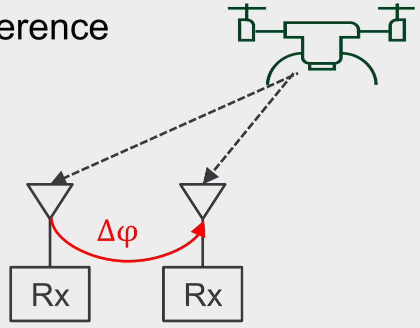
Applications involving multiple antennas require

Systematic phase relations between channels (“Phase Coherence”)

Beamforming –
Tx-Tx / Rx-Rx coherence



Direction Finding –
Tx-Tx / Rx-Rx coherence



Modelling helps with understanding requirements:

- Phase errors
- Time offsets
- Stability
- Repeatability

Many SDRs (like the USRP) are designed with these applications in mind

High End SDRs with LO Sharing (like the USRP X420)

SDRs with Phase Repeatability using Reference Sharing (like the USRP B310)

Based on the needs, SDRs scale in:

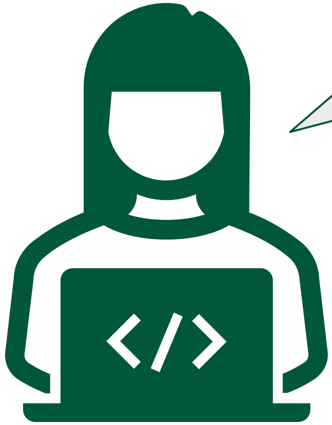
- Frequency range
- Bandwidth
- …
- Method/Level of Synchronization

Application Requirements

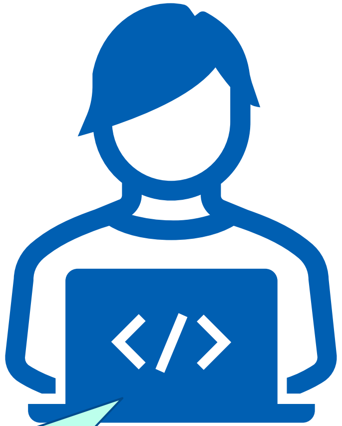
What Level of Coherency will you need?

Phase Coherency Requirements…
Mapping Phase, Time, Stability, Repeatability

Coherency Connoisseur



Synchronization Supplier



I want to do **RF Direction Finding.**
What's the right device for the job?

What do you care about?

- Coverage of new WIFI bands
- Scaling from 2 to 8 antennas
- Signals with medium bandwidth
- Consistency over a longer time

And, I want to rerun the measurement after a reboot with the same phase weights

- **Direction is based on RF Phase accuracy**
- **Wider Bandwidths turn into Time accuracy**
- **For long durations we specify stability**
- **Restarts are captured in repeatabilit**

How accurate does the phase need to be?

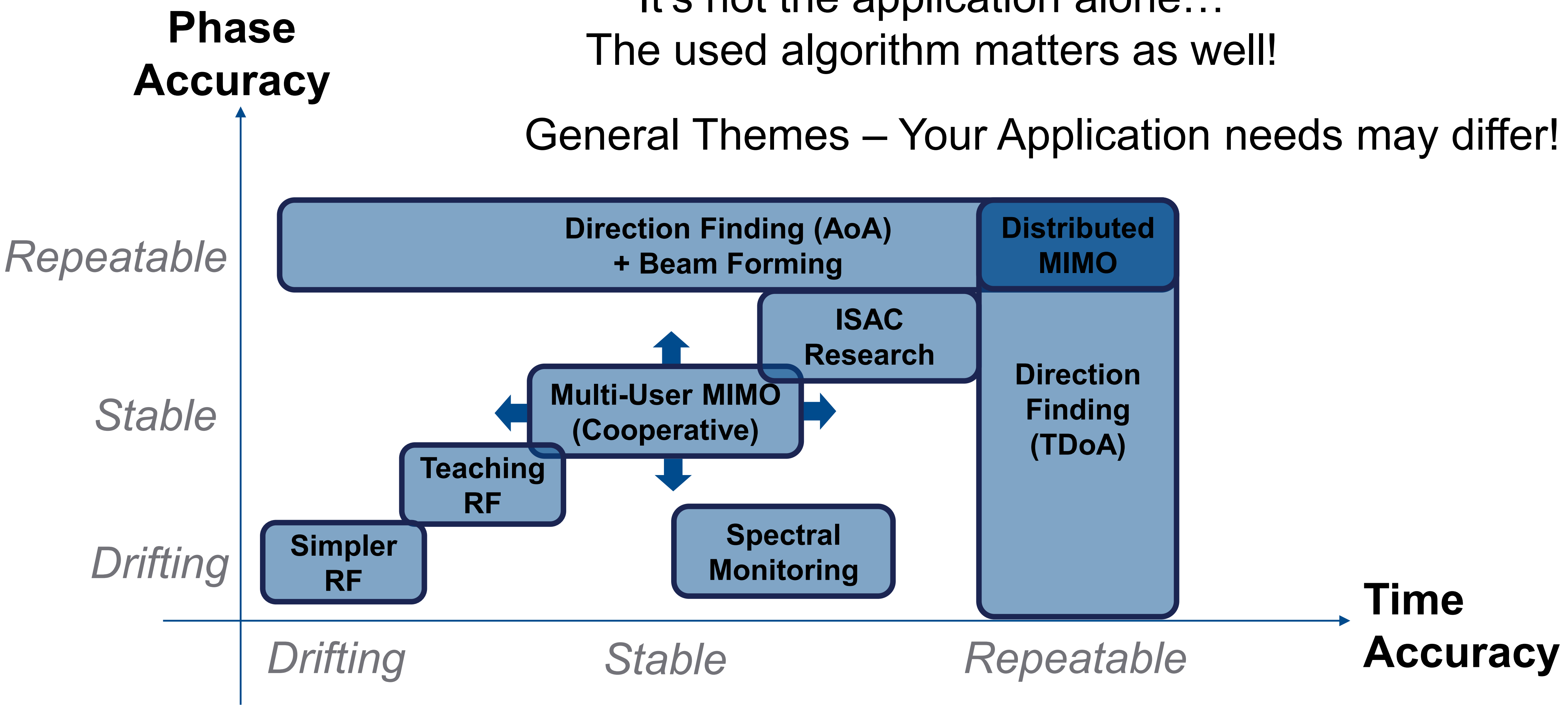
A couple degree – maybe up to 10 degree offsets is usually good enough for

You should consider a device with repeatable phase – e.g. something that scales well to 8 channels using a Multi-Device-Synchronization cable…

Map Applications

It's not the application alone…
The used algorithm matters as well!

General Themes – Your Application needs may differ!



Synchronization Methods

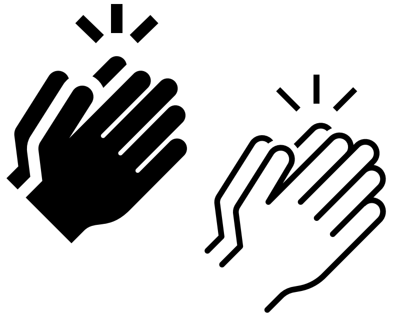
And accuracies…

A little experiment…

Just clap along…

We'll try a song…

What does clapping tell us for synchronization?



- Clapping = Matches your beat to my beat

- Synchronization of Software Defined Radios is similar
  - Your internal reference is pulled by an external reference
  - The reference can be slow / or fast
  - Faster usually has more accuracy (and We Will Rock You is fun to clap along)
    - From 1 PPS, 10 MHz, 125 MHz to Shared LO – things increase accuracies

- Note - following a beat is “over the air synchronization” – with some similarities to GPS ☺

What about Single Device / Within a device?

Device Internal Channels

Time: Repeatable

Phase: Stable, some repeatable

Last Seen: Multi Channel Devices

- Most of this presentation is BETWEEN DEVICES
- What about – WITHIN A DEVICE?
  …The easy choice…
- Time alignment likely repeatable & stable
- Phase Accuracy is Device Specific
  - Usually highly stable phase between channels
    - Separate synthesizers (on different daughterboards) may decrease stability
  - Repeatability depends on the architecture
    - A list of USRPS
      with repeatable phase within the device:
      Specified: B310, X420, X440
      Shared internal LO: B210, E320, TwinRX, N32x
      Seen working: UBX/OBX …

Synchronization: Internal Reference between devices (aka – no synchronization)

Internal Reference

Time: Drifting

Phase: Drifting

Last Seen: Any SDR

Properties between Multiple Devices

- Internal reference – SDR running “on its own”
- (almost) Any SDR has this
- Related specification: Reference/Frequency Accuracy
  - Usually in PPM / PPB (# of 1E-6 or 1E-9)
  - Reference frequency turns into – an RF frequency offset
    +1 ppm (1E-6) reference accuracy turns into 1kHz offset at 1 GHz RF (360 degrees phase in 1 ms!)
- Time and Phase are drifting between devices
  - Both based on reference accuracy
  - Drift can be described with: Allan Variance / Allan deviation or Phase noise

Synchronization: GPS / GNSS

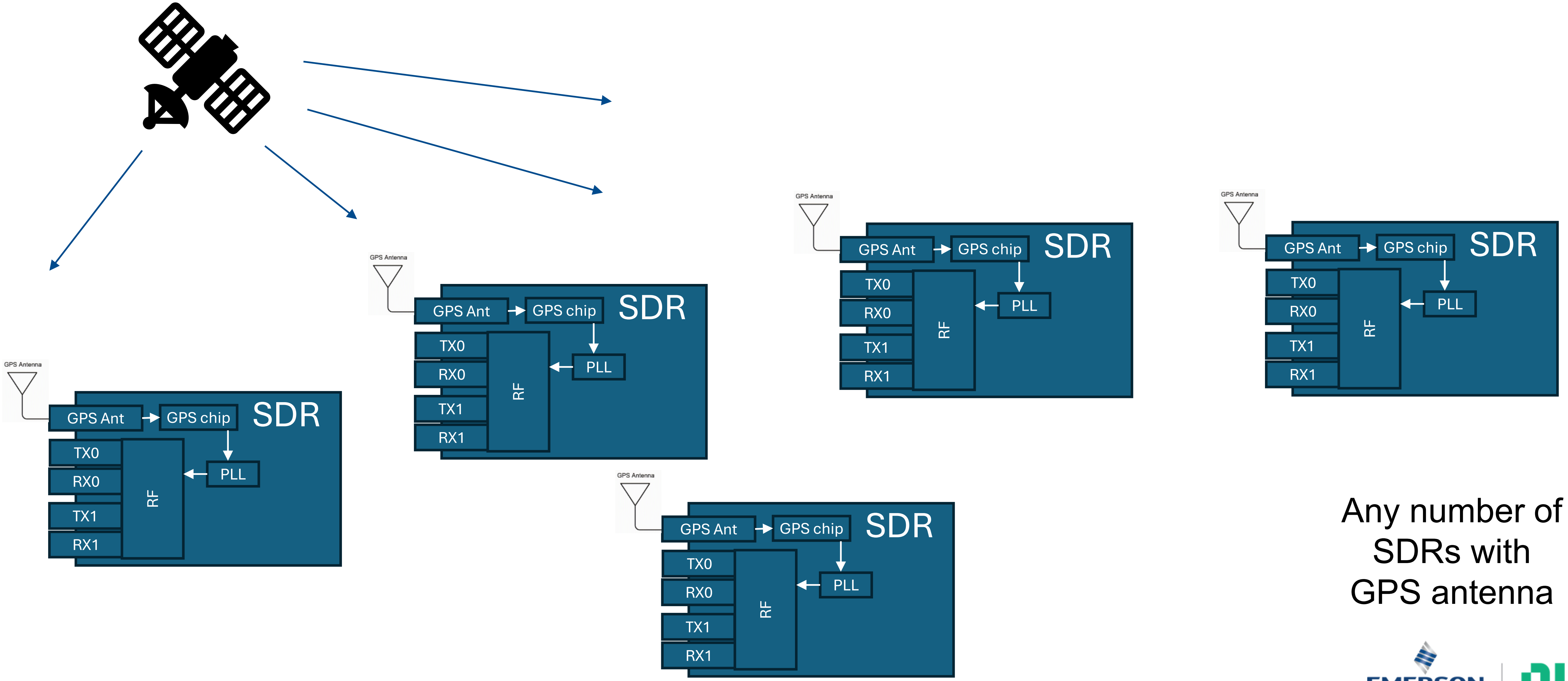
GPS-based Synchronization

Time:	Repeatable
Phase:	Low stability
Last Seen:	Mid/high end

Properties between Multiple Devices

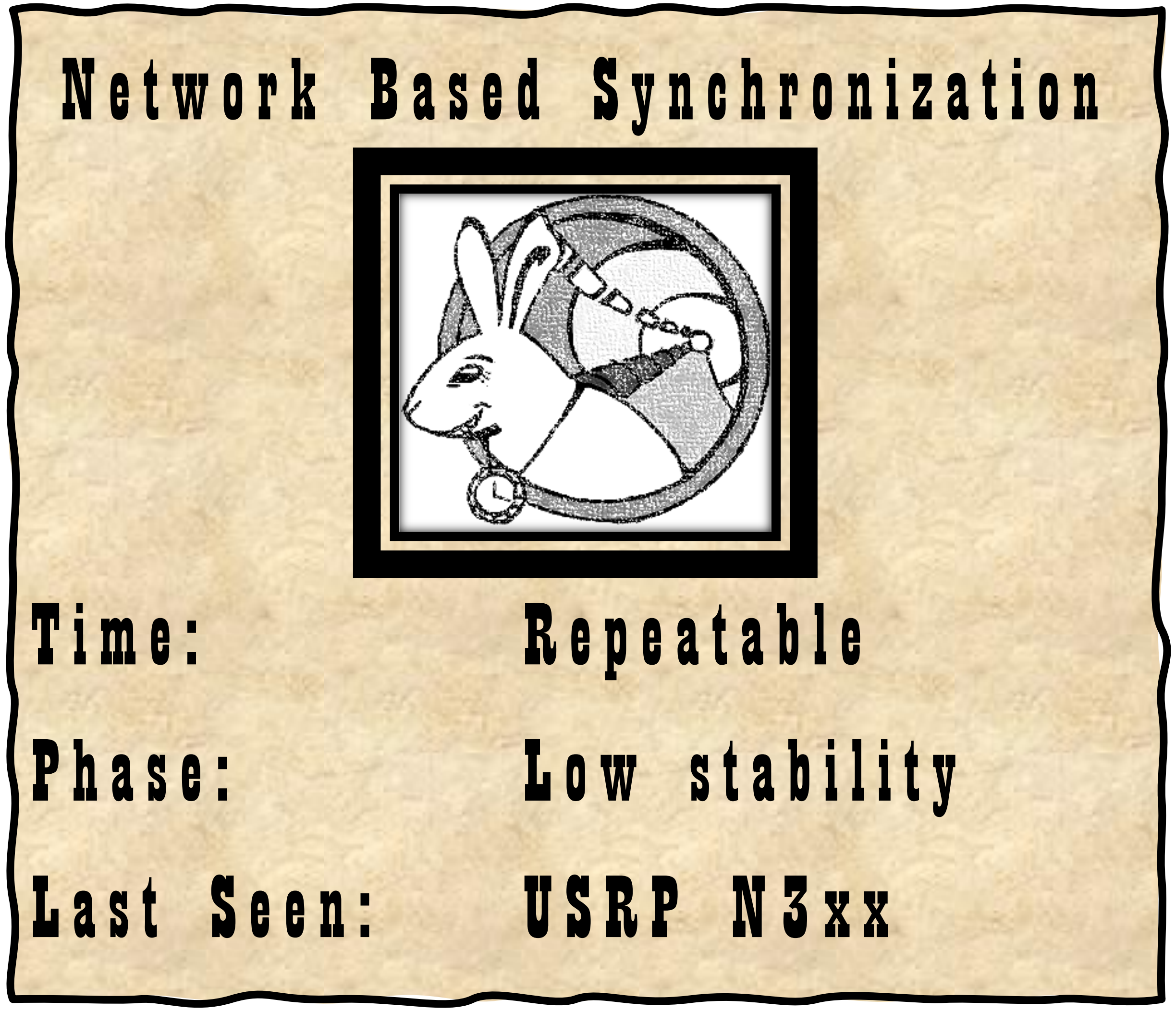
- GPS based synchronization uses an antenna (accessory) hooked up to the SDR … or to a Clock distribution like CDA-2990G
  - Antenna requires direct view of the sky
  - Receives signals from GPS satellites over the air
- GPS data contains position (coordinates) and time/date
- Time information is turned into high Frequency accuracy
  - 1E-9 (1ppb) or better can be achieved
  - Stabilization will take some time (5..10 minutes, sometimes more)
- Time is repeatable over many SDRs across the globe
  - Time accuracy depends on many factors (model, clocking, weather conditions, antenna …) – expect roughly 2-digit nanoseconds
- This is a uni-directional over-the-air synchronization with 20000..26000km distance (77ms worth of propagation time)
  - Don’t expect a repeatable phase

GPS-Based Synchronization



Any number of SDRs with GPS antenna

Network Based Synchronization



Properties between Multiple Devices

- Fewer SDRs out there directly supporting network-based synchronization – e.g. USRP N3xx
- Clock distribution devices available to also create PPS/10 MHz → can be used by many standard SDRs
- 1588 High Accuracy profile / White Rabbit: Time accuracy of << 1ns (down to picoseconds)
  - Requires specific Ethernet infrastructure (White Rabbit Switches)
  - Accuracy and effort/system complexity scale together
- Works over fiber with long distances
- Phase coherency – not repeatable but provides stability

External Reference (10M+PPS)

External Reference

(10 MHz + PPS)

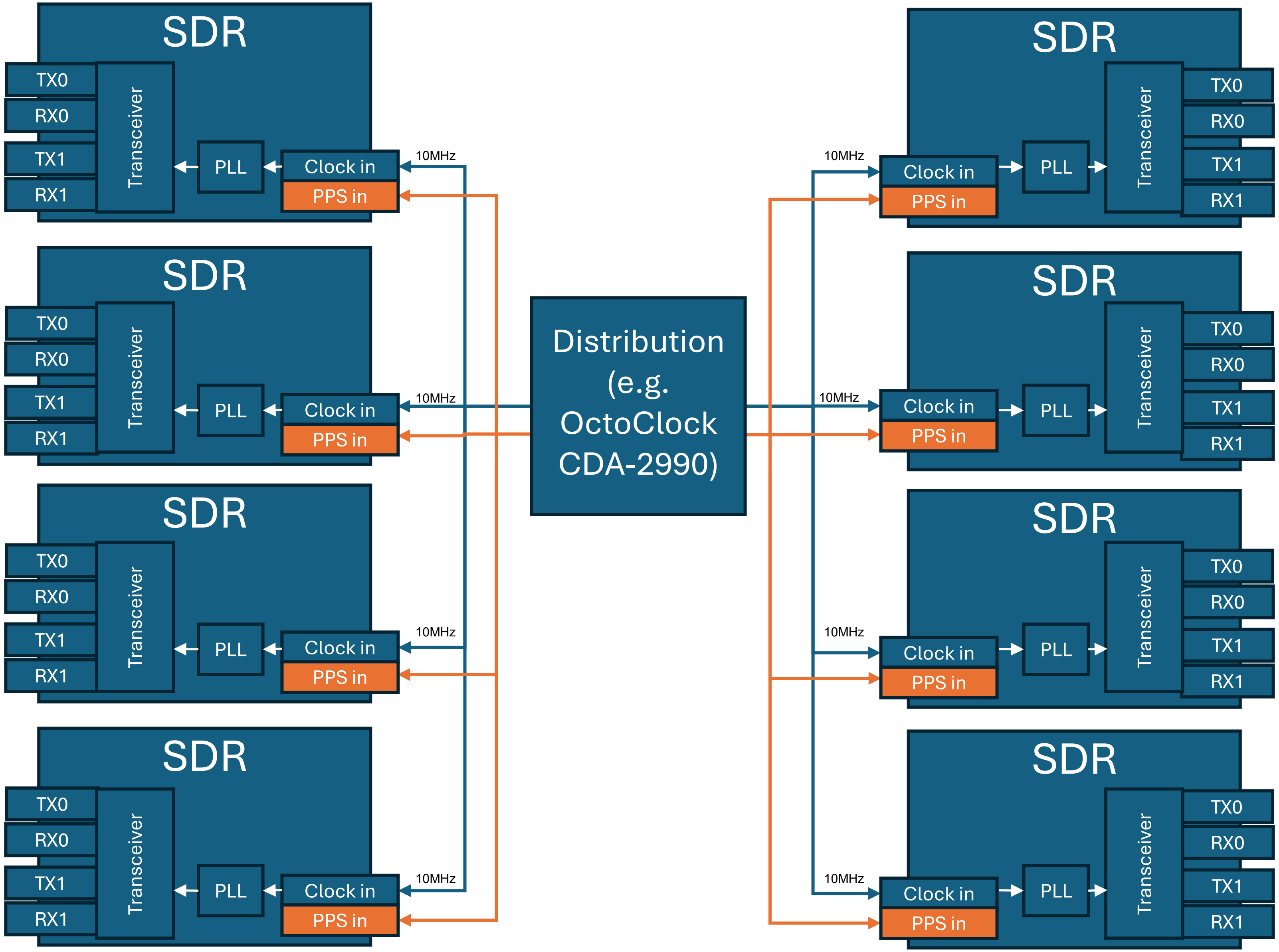
Time: Repeatable

Phase: Some Repeatability

Last Seen: Most SDRs

- Most SDRs and RF instruments support 10 MHz as reference clock
- PPS in addition provides accurate timing
- Distribution devices help to synchronize multiple devices – like Octoclock CDA-2990
- Device-dependent accuracies – but timing repeatability can get to very low levels, e.g. < 10 ps
- Phase repeatability heavily depends on RF clocking – but can get down to 10s of degrees at RF (high temperature dependencies, settling times)

Shared 10 MHz and PPS sync



# of devices based on distribution device (some allow being cascaded)

Multi Device Sync Cable

Multi Device Sync Cable

Time:	Repeatable
Phase:	Good Repeatability
Last Seen:	USRP B310, N210

Properties between Multiple Devices

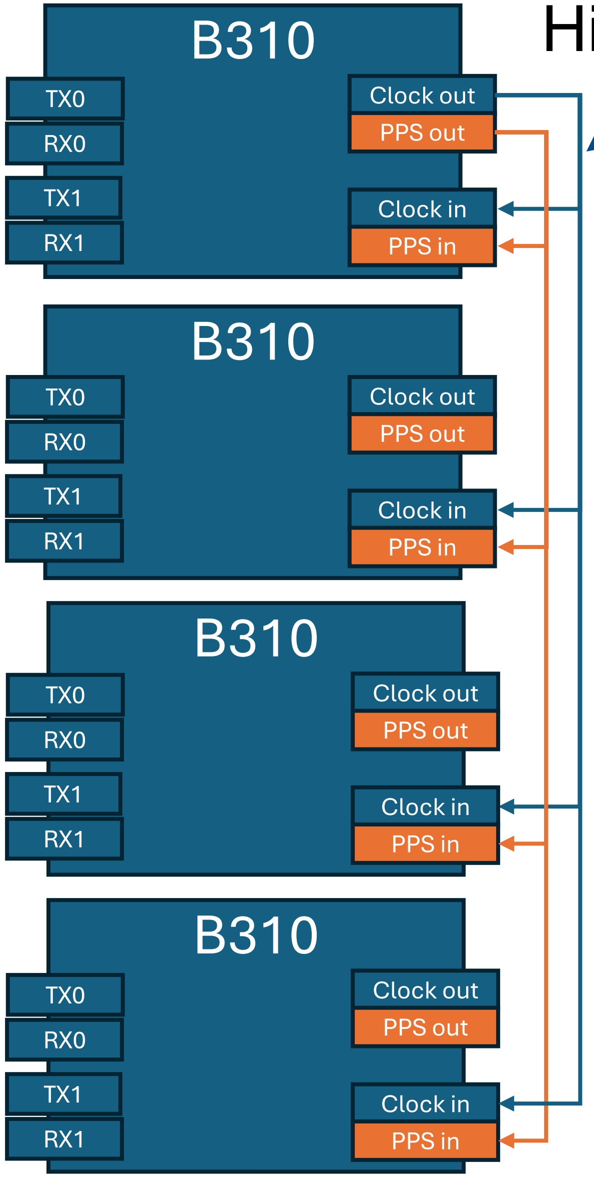
- A couple SDRs are providing multi-device synchronization via extra cabling
  - B310 is the latest USRP with that method
- B310 specifically
  - Shares higher reference frequency ("High Frequency Reference")
  - Still closes timing for 1 PPS
  - Achieves higher accuracies for Time + Phase Repeatability & Stability than 10 MHz
  - Star distribution for high symmetry (1 device shares clocks to 3 more + itself)
- High synchronization accuracy
  - A couple degrees of phase repeatability
  - A couple picoseconds time repeatability

Multi-Device Sync

Specific method for B310

First device shares reference
Wraps back to itself as well

High frequency reference



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LO Sharing

LO Sharing

Time: - (not shared)

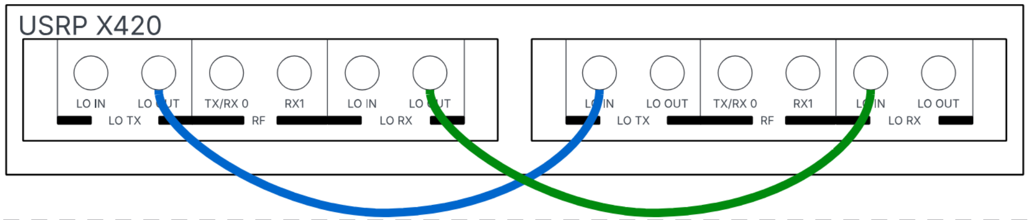
Phase: Best repeatability

Last Seen: USRP X420,
USRP N32x,TwinRX

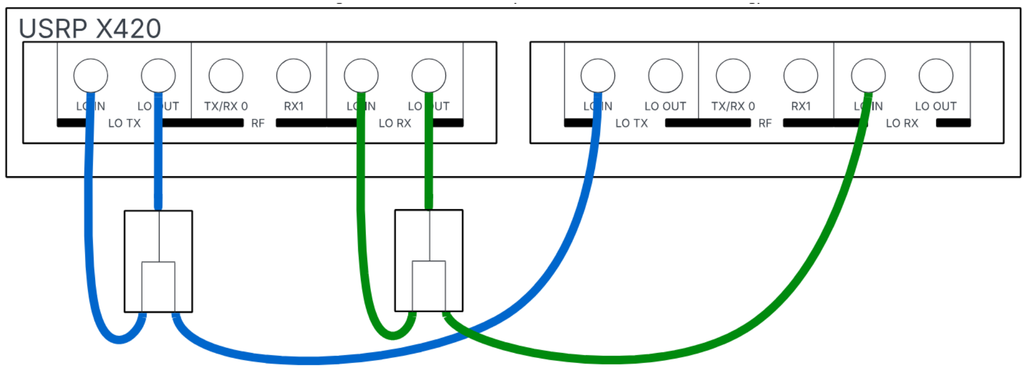
Properties between Multiple Devices

- LO Sharing helps with very accurate phase repeatability / stability between devices
  - E.g. much better than 1 degree RMS at 18 GHz
- Make sure the cabling is suitable
  (phase can be very temperature dependent)
- New LO Sharing accessory for X420
  – SignalCraft SC2510
  - Distributes LO beyond 2 channel configurations
  - Allows Cascading for > 8 channels
- LO Sharing doesn't help with accurate time
  → Still relies on another method like 10MHz+PPS reference for that

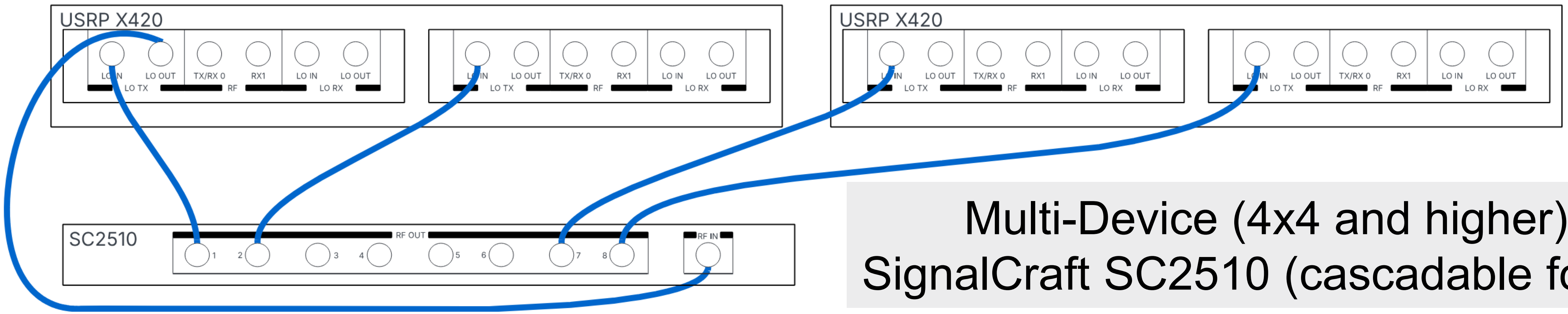
X420 LO Sharing options



Simple 2x2 coherent system



Recommended 2x2 coherent system (symmetric using passive splitter)



Multi-Device (4x4 and higher) via SignalCraft SC2510 (cascadable for > 8x8)

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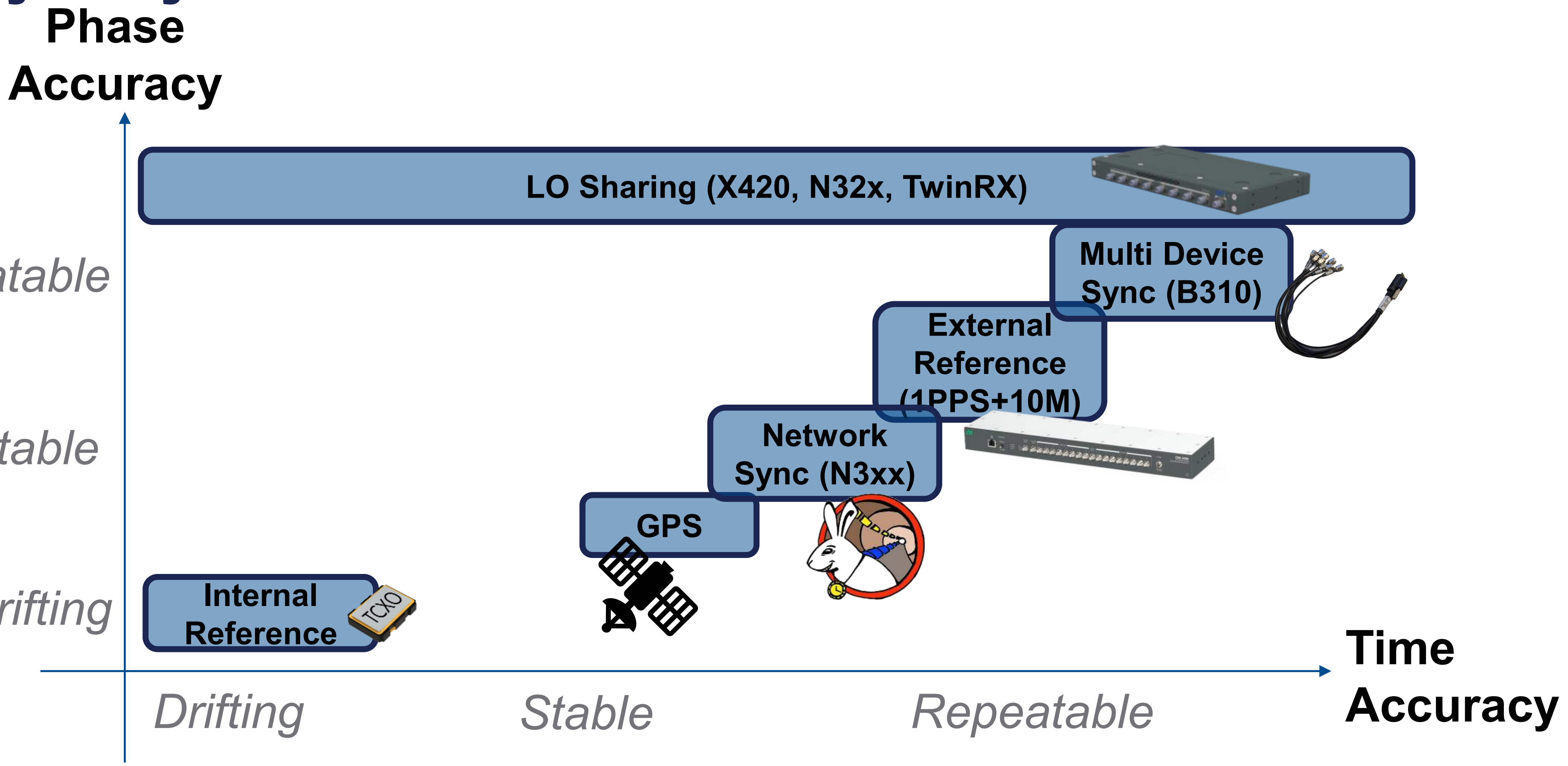
Example Spec – Phase Accuracy

Table 29. Phase Coherency Performance

Configuration	Measurement	Result
Single device (sharing internal LOs)	Phase stability	<0.08° RMS
Single device (sharing internal LOs)	Phase repeatability	<0.3° RMS
Multi-device (USRP Sync Cable)	Phase stability	<1° RMS
Multi-device (USRP Sync Cable)	Phase repeatability (power cycle)	<2° RMS
Multi-device (CDA-2990)	Phase stability	<3° RMS
Multi-device (CDA-2990)	Phase repeatability (power cycle)	<10° RMS

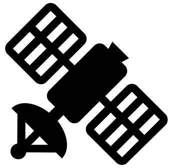
https://www.ni.com/docs/en-US/bundle/usrp-b310-enclosed-specs/page/specs.html

Accuracy of Synchronization Methods between devices



Summary

Summary of synchronization methods – between devices




		Internal	GPS	Network Sync	10M + PPS (Octoclock)	Multi-Device-Sync Cable	LO Sharing
# of Devices		∞	∞	∞	64+	Up to 4	64+
Example Devices		All SDRs	Usually mid/high-end; accessory	USRP N3xx	Most SDRs (10M)	N210 (2 dev) **B310 (4 dev)**	A couple high-end devices TwinRX DB USRP N32x **USRP X420**
Time offset between devices (“group delay”)	Stability	Drifts	Some stability	Stable	Stable	Very stable	[combine with other method]
	Repeatability	Initial SW reset	10s of ns	< 1 ns (White Rabbit) or much more	Repeatable (10ps .. 1 ns)*	Repeatable (< 5ps)	
Phase offset between devices	Stability	Drifts	Low stability	Some stability ~10 degree	Some stability ~ 10 degree**	Stable (1 degree)	Very stable (<< 1 degree)
	Repeatability	None	None	None	Some devices ~10..100 degree**	Repeatable** (< 10 degree)	Very repeatable (<< 1 degree)

* Device dependent
** Device and frequency dependent

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Q&A