RF System Synchronization – LO’s

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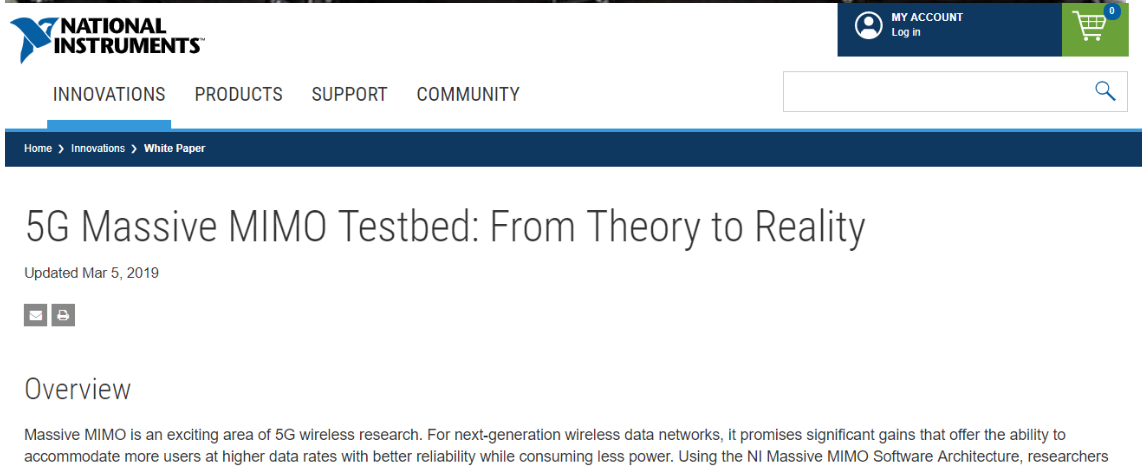
RF Systems

Massive MIMO Prototyping System Example

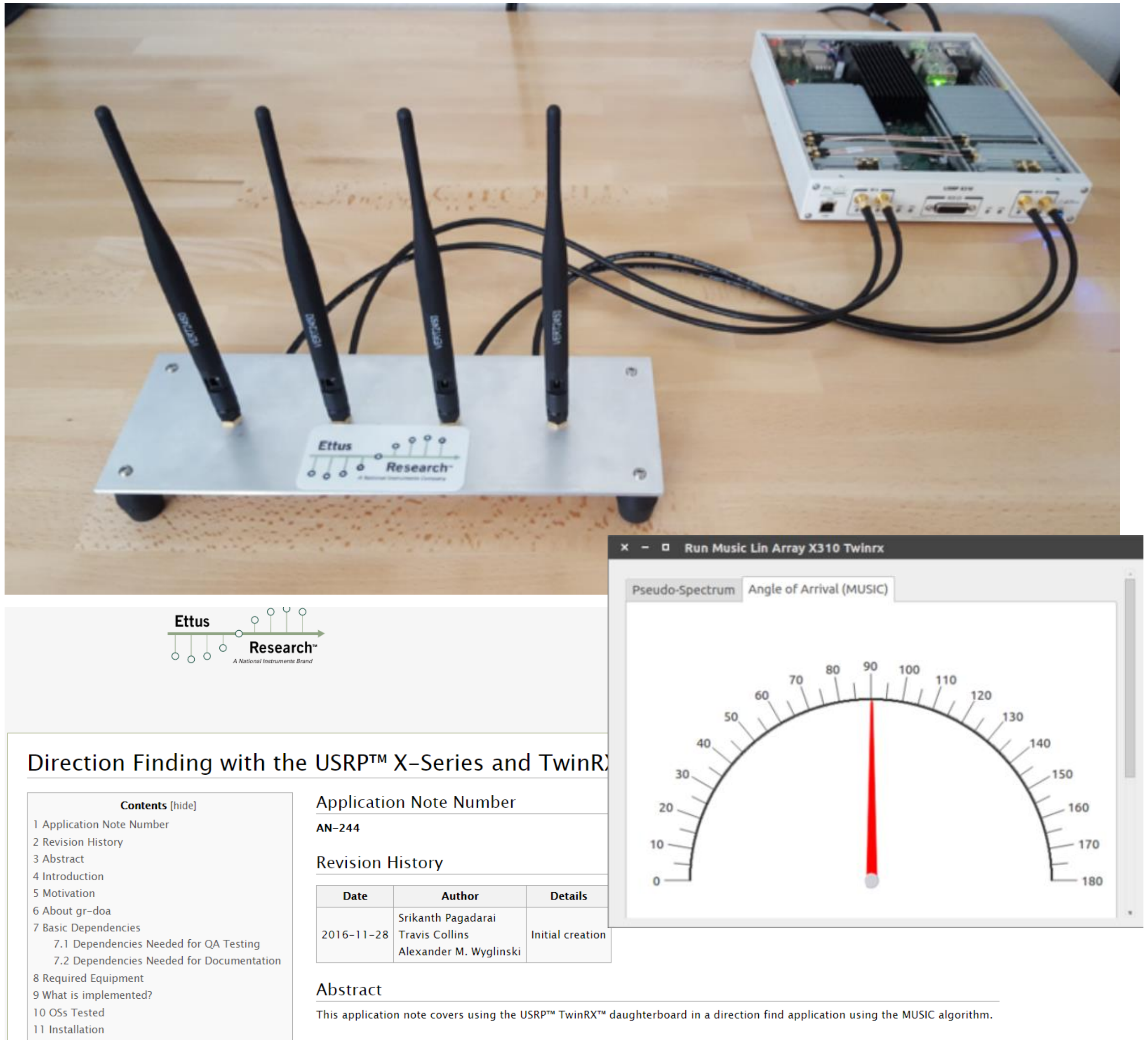
- Many RF Channels
- What level of signal alignment is required?
- Uses LO Reference Clock Sharing
  - Can do measurement step at startup and adjust



http://www.ni.com/en-us/innovations/white-papers/14/5g-massive-mimo-testbed--from-theory-to-reality--.html

Direction Finding Example

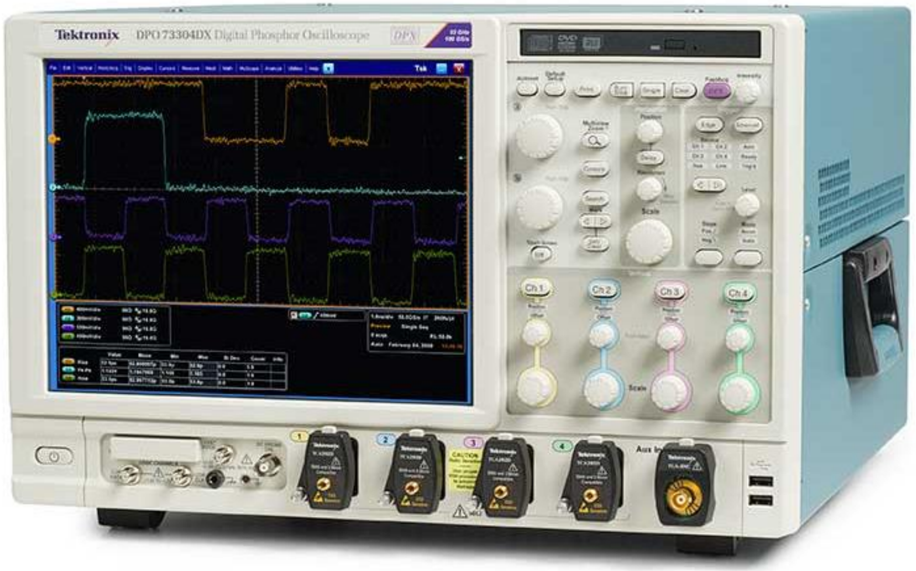
- Few to moderation number of RF channels
- What level of signal alignment is required?
- Out of the box full alignment would be useful…but in reality
  - Need to perform a “system tuning” step to calibrate the signal alignment (RF channels, cables, fixtures, etc)
- LO sharing is critical for location precision

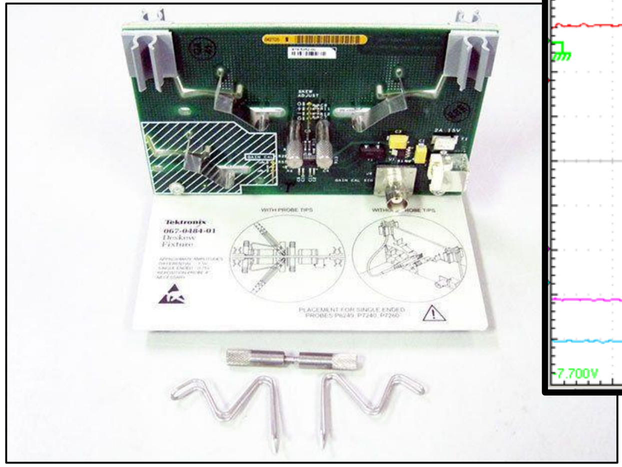


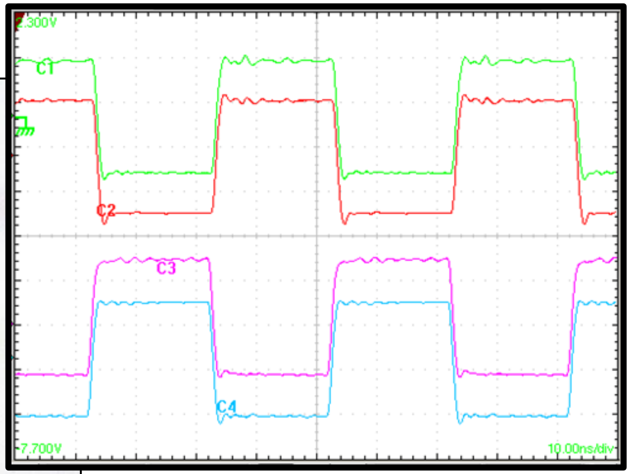
https://kb.ettus.com/Direction_Finding_with_the_USRP%E2%84%A2_X-Series_and_TwinRX%E2%84%A2

Oscilloscope Example

- Ok this isn’t traditional RF, but it’s a useful analogy
- What level of signal alignment is required?
- Out of the box “alignment” is expected
- Can purchase a probe deskew kit for ps level alignment







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What does it mean to be synchronized?

What does it mean to be synchronized?

- The way it used to be – every city had its own time based on when the sun was overhead
- The introduction of trains in the 19th century created a need for synchronized time
  - Greenwich Mean Time introduced in 1840
- Synchronization = all cities along the route having aligned time, to within a few minutes

https://qz.com/1272446/the-order-of-time-by-physicist-carlo-rovelli-show-that-time-as-we-know-it-is-a-fiction/

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What does it mean to be synchronized?

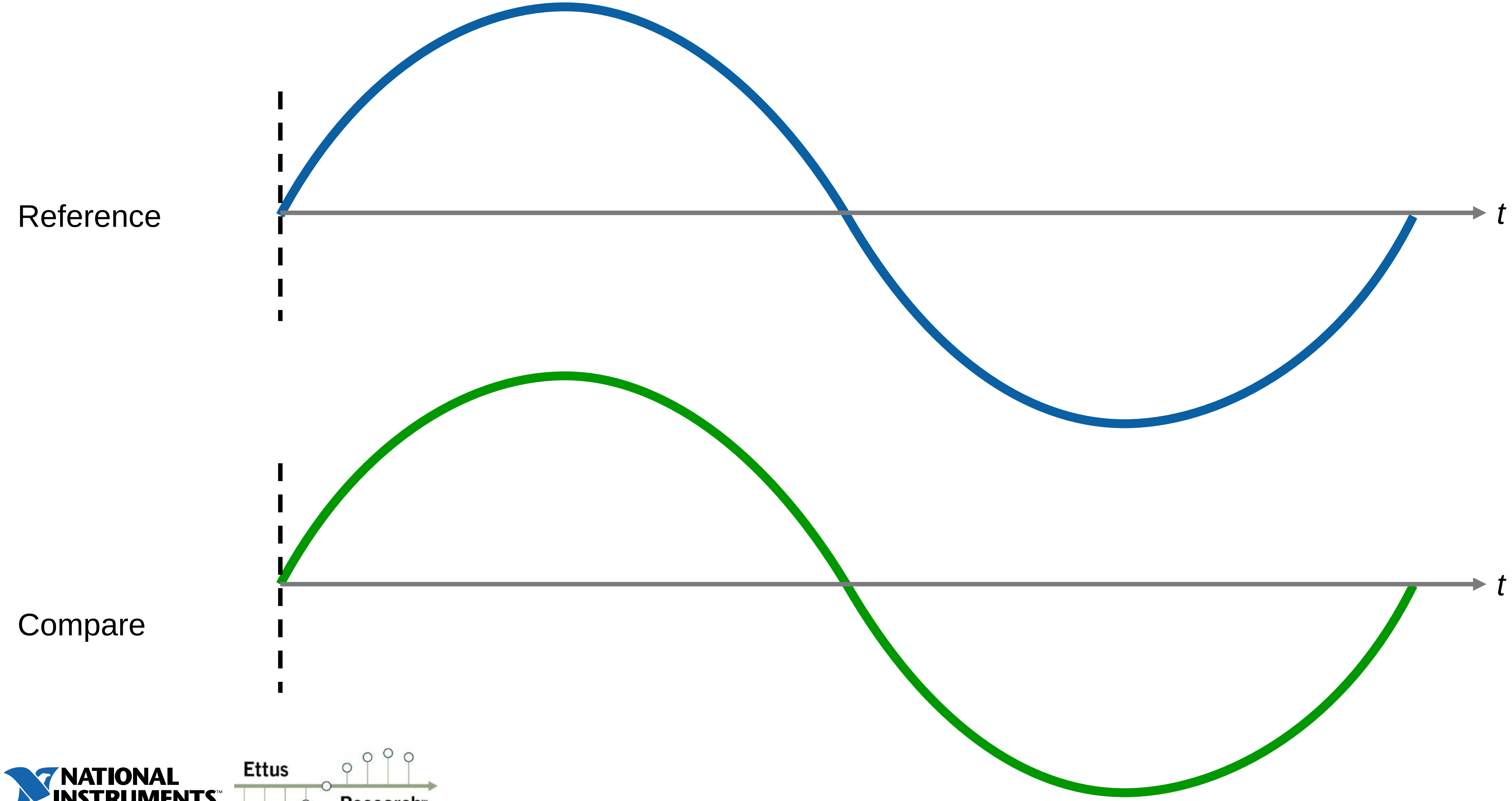
- 1 minute
  - Cities along a train route
- 1 second
  - Checking in for my Southwest flight

Understand the needs of your RF system, what is possible, and the best solution to meet your needs

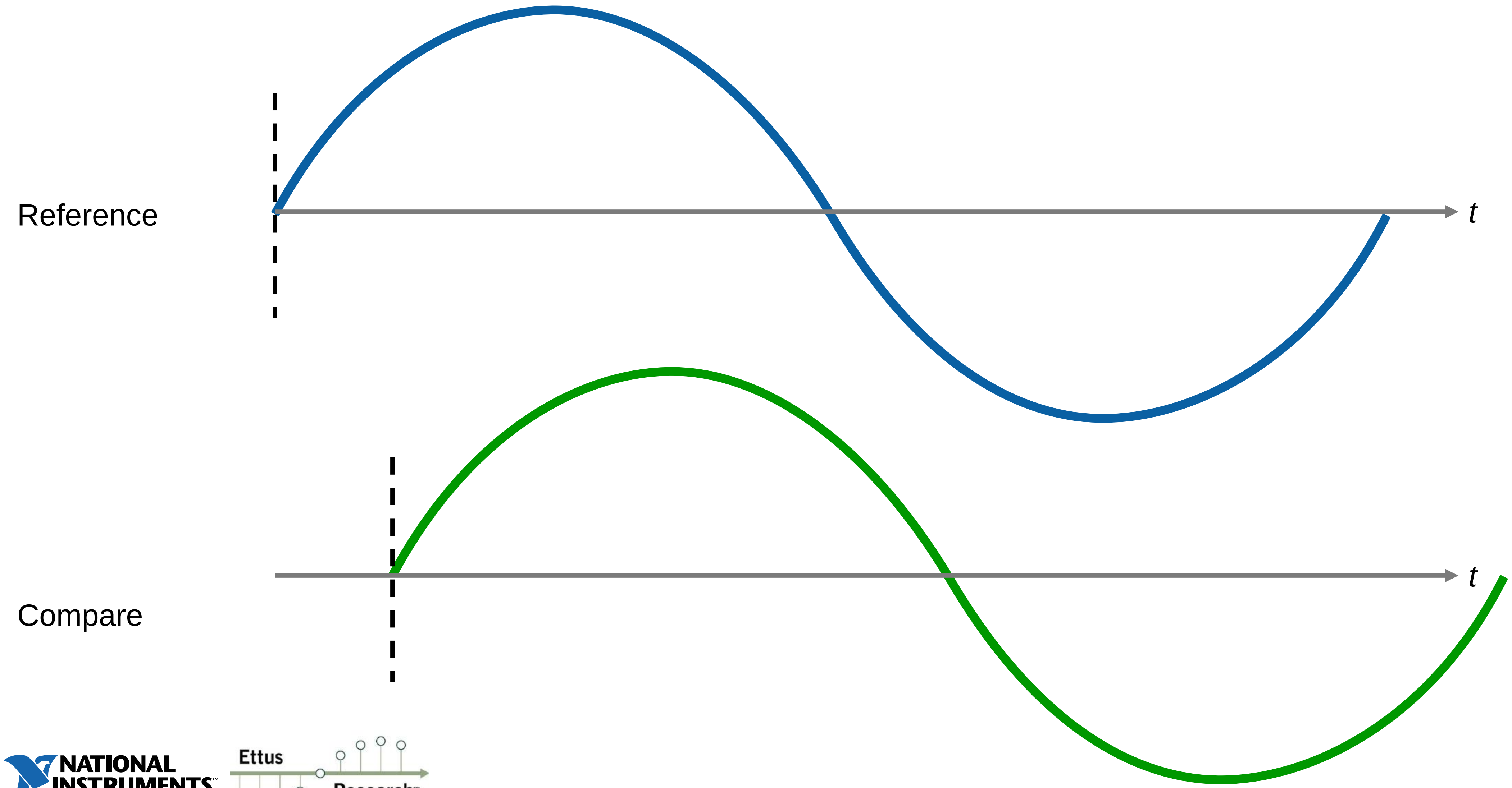
- 1 ns
  - Multi-channel RF systems: baseband

- 1 ps
  - Multi-channel RF systems: local oscillators

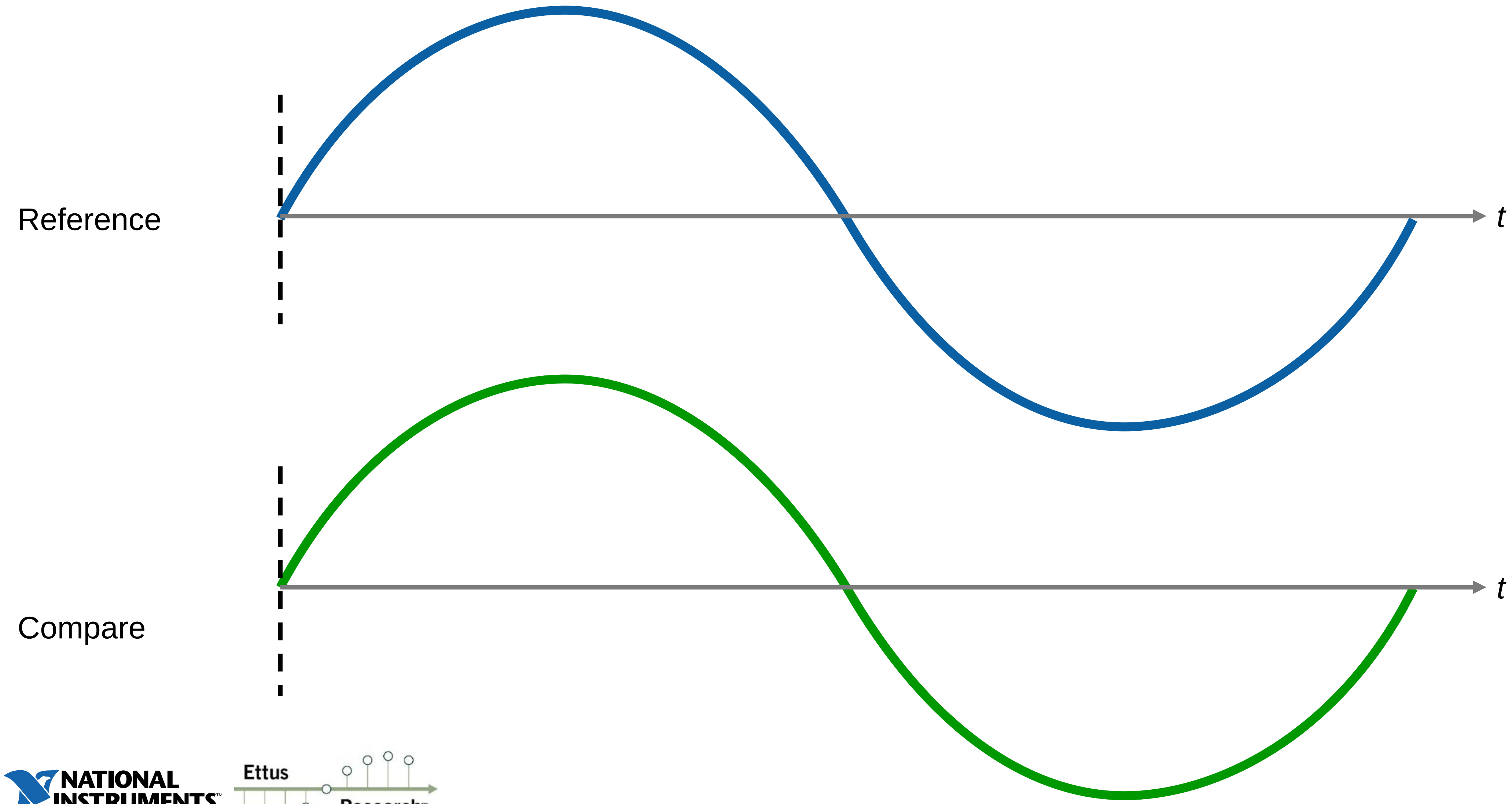
Fully aligned



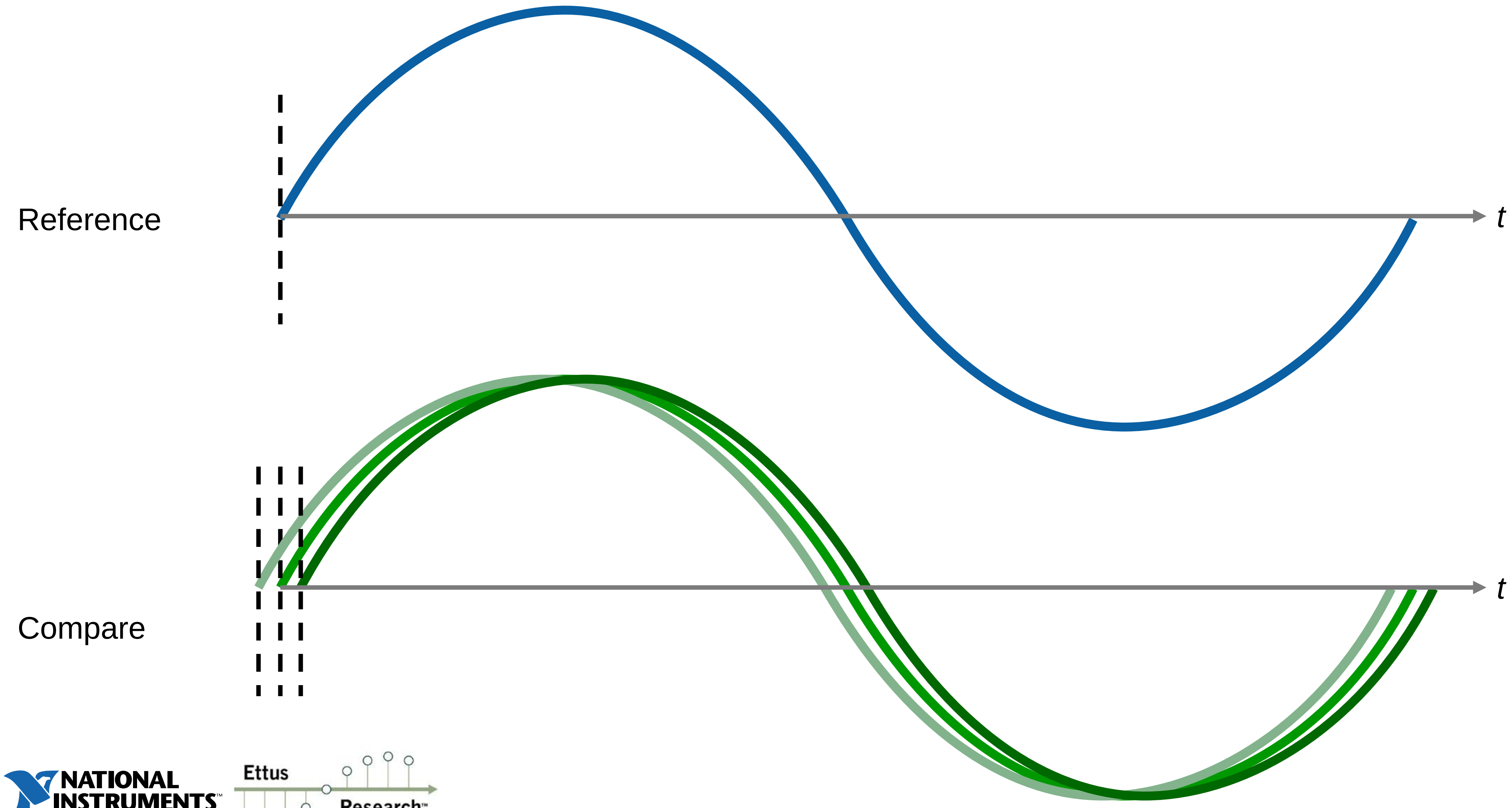
Fixed offset



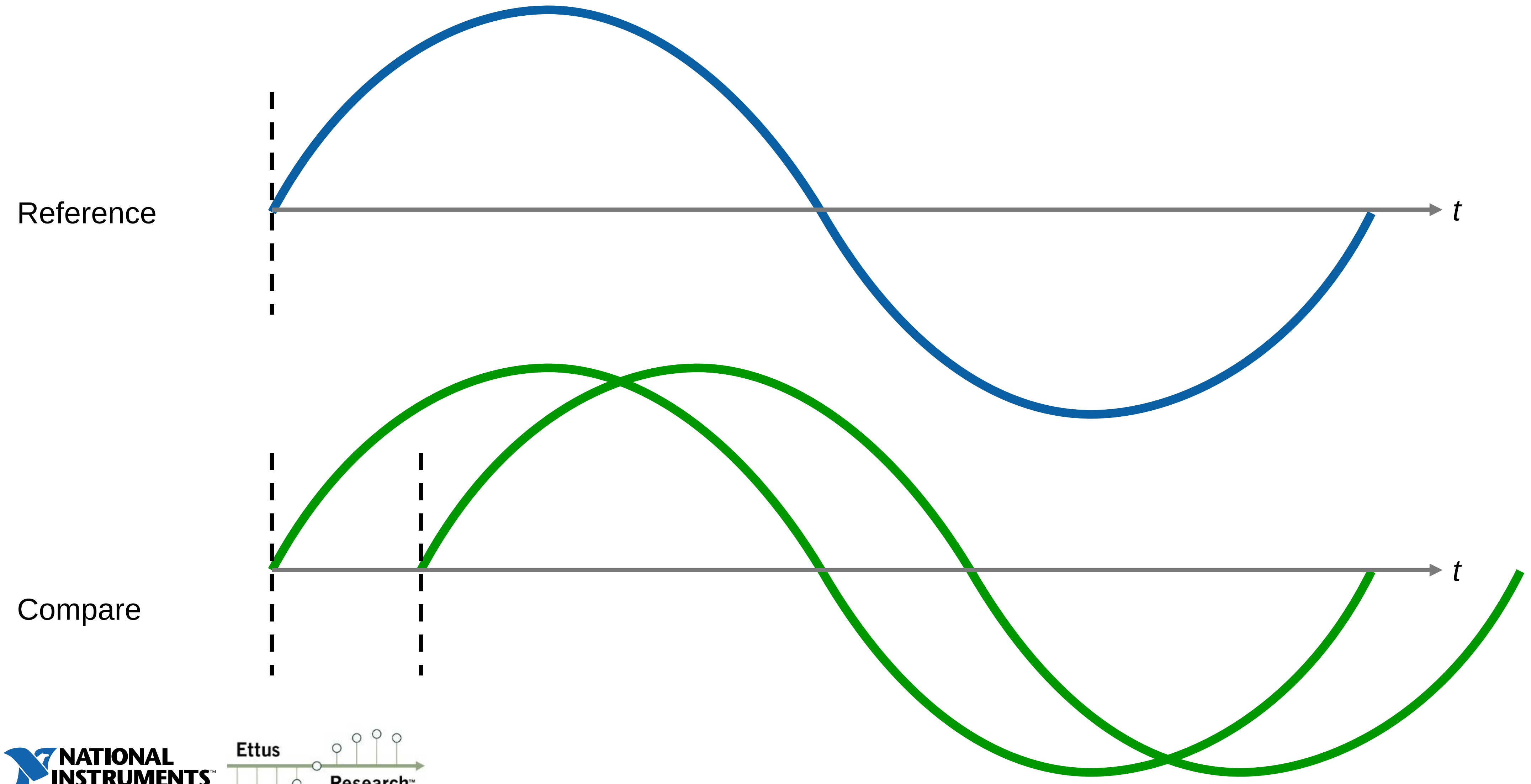
Long term drift over time/temp



Short term phase incoherency (jitter)



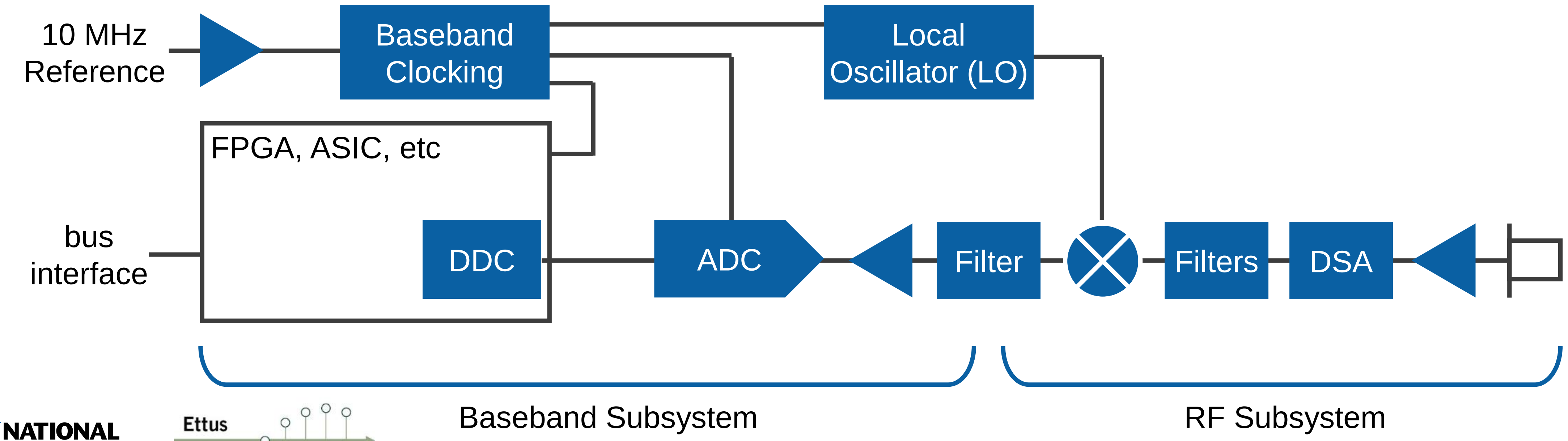
Run-to-run misalignment



Where do the problems come from?

Where do the problems come from?

- Everywhere!
  - Ref clk distribution (fanout mismatch, drift)
  - Reference input (skew, drift, jitter)
  - Clock distribution and converter synchronization (skew, run-to-run misalignment)
  - DSP reset misalignment (NCO, interp/dec filters, clock dividers)
  - Local oscillators, signal chain components



What can we do about it?

What can we do about it?

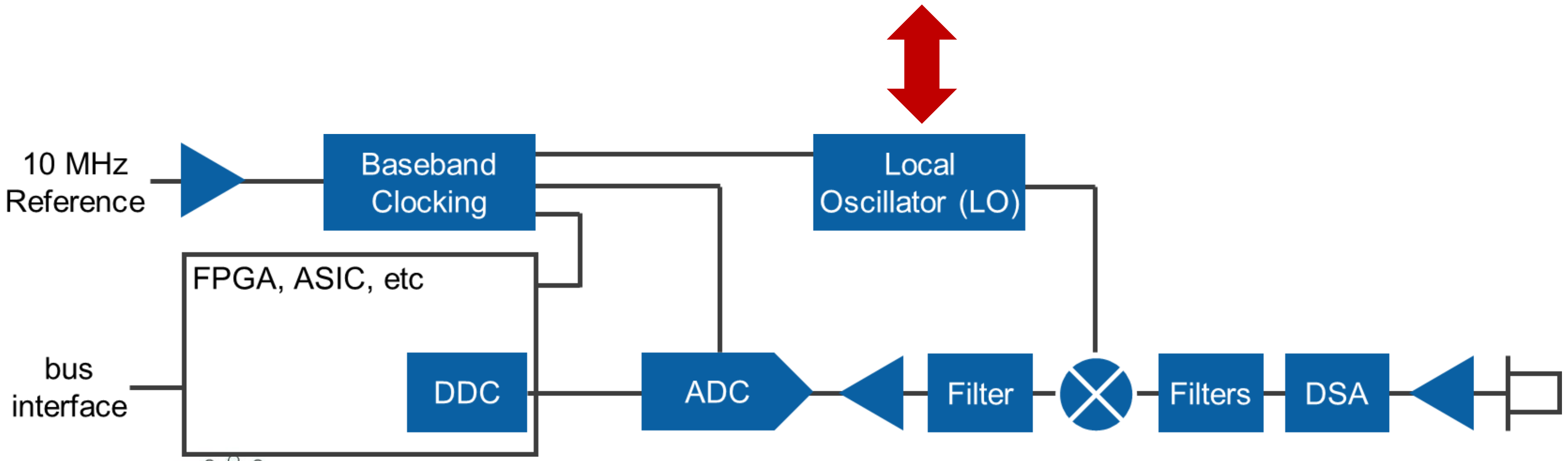
- Clock distribution
  - Use low skew components, with tight variation over temperature
- Converting clocking and sync
  - See the next presentation
- Local Oscillators
  - The majority of this presentation
- Digital compensation
  - Likely not enough time today

- *These are techniques that NI incorporates as we design USRP devices. But they also need to be considered at the system level when creating large multi-channel RF systems.*

Local Oscillators

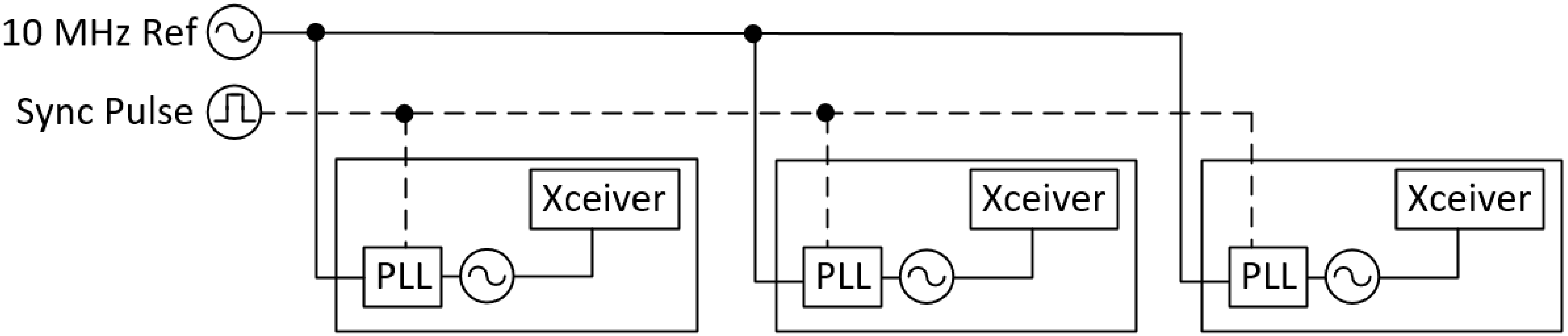
Local Oscillator Alignment

- There are three common methods for aligning LOs between multiple RF devices
  1. Reference Clock Sharing
  2. Daisy Chaining
  3. Star Distribution



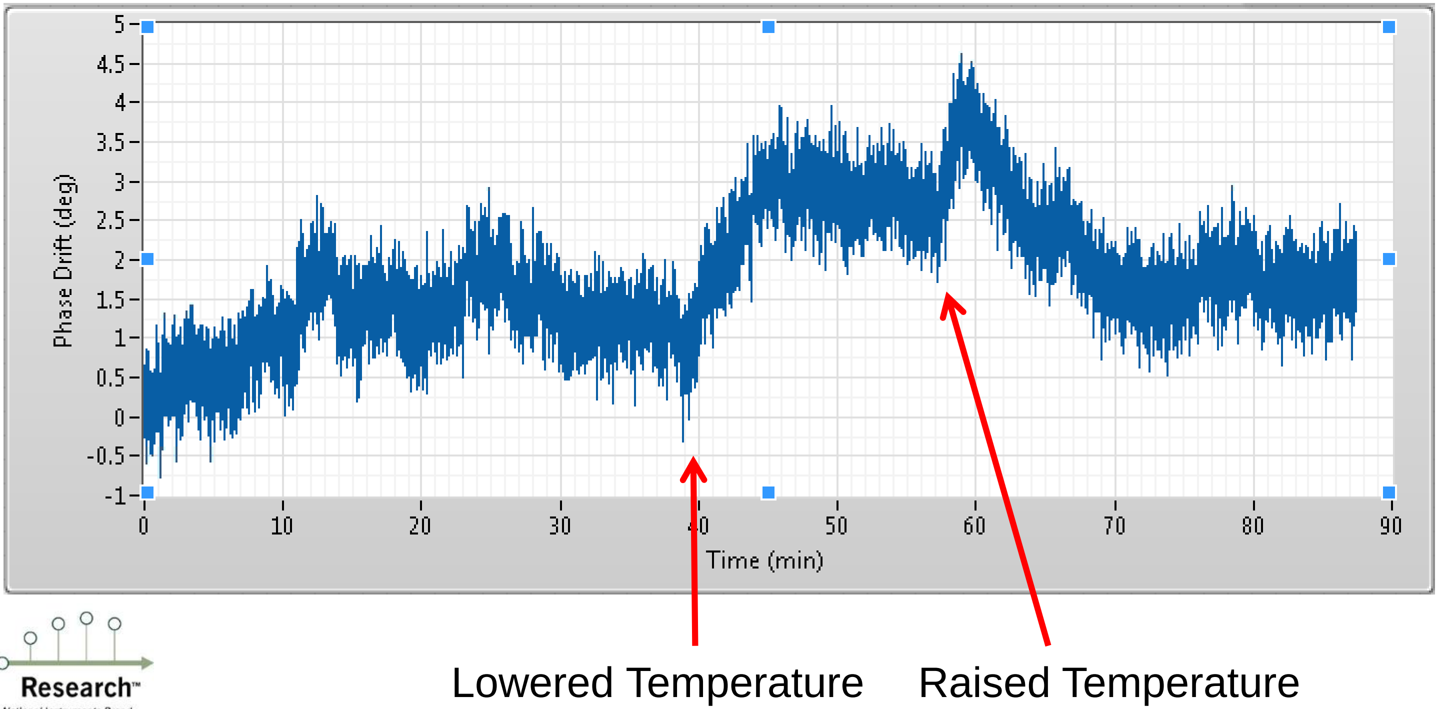
1. Reference Clock Sharing

- All LO PLLs locked to a common time base
  - 10 MHz Reference
  - GPSDO (GPS Disciplined Oscillator)
  - IEEE 1588 (Ethernet) / White Rabbit
- PLLs must have divider and phase accumulator registers that can be reset deterministically
- PPS sync pulse is required to start all PLL at common time



1. Reference Clock Sharing

- Expect ~10’s of degrees of drift due to ref clock sharing
- Expect ~1’s of degrees of “noise” (short term phase incoherency)
  - Drift due to buffer in PLL circuit, ref clk distribution buffer, RF front end
  - Two NI 5644R’s measured 5.5 degrees (@ 3.6 GHz) drift over time/temp



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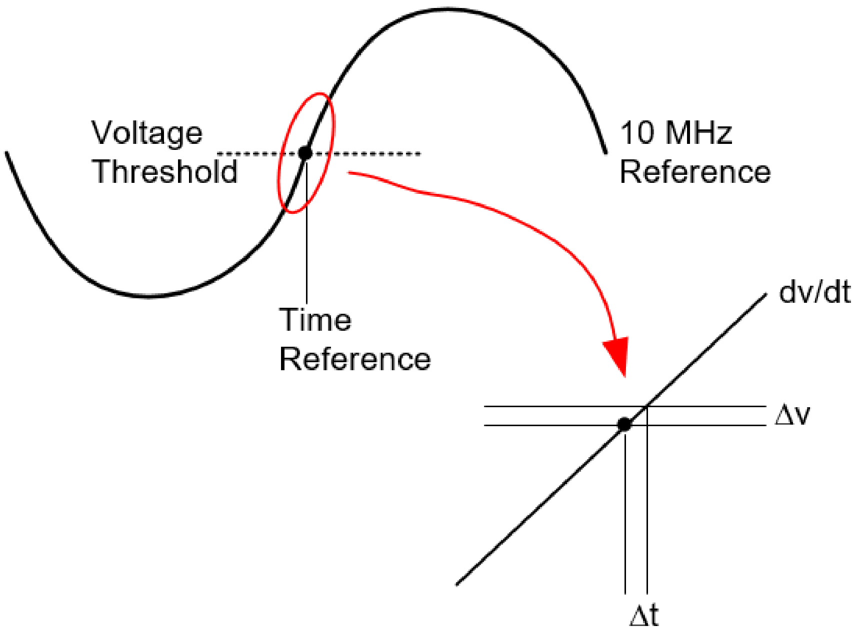
Theoretical Derivation of Phase Drift

- 10 MHz signal can be distributed as a sinusoid
- A voltage threshold in the PLL (or input buffer) will determine a time reference
- *Some calculus . . .*

$$\frac{dv}{dt} = 2\pi f V_p \quad \text{where Vp is the peak of the sinusoid}$$

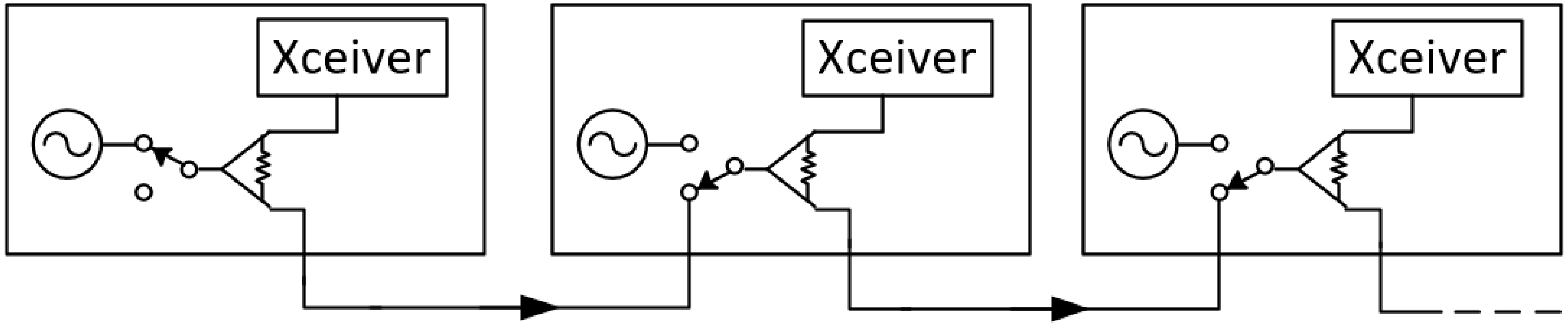
$$\Delta t \approx \frac{\Delta v}{2\pi f V_p}$$

- Any change in the threshold voltage translates to a change in the time reference
- Higher frequency and higher peak voltage lessen the change in the time reference
- *Math & assumptions…*
- = 10's of degrees of drift at 6 GHz



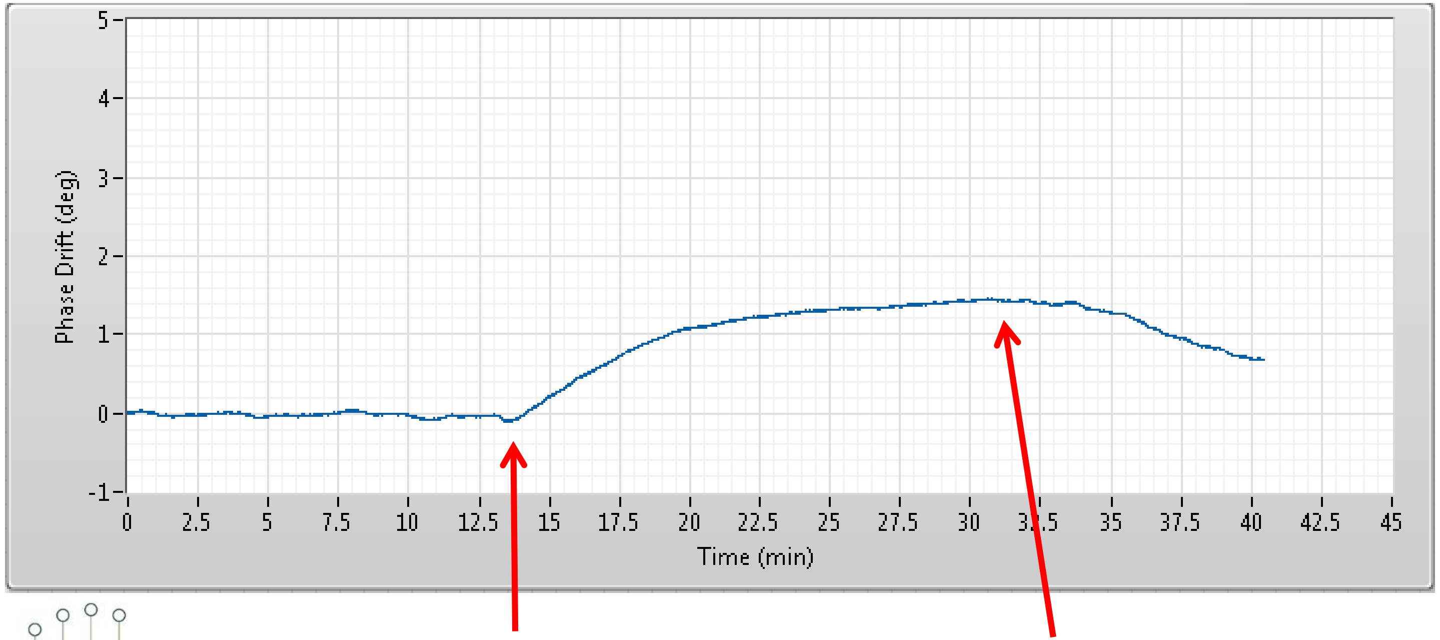
2. Daisy Chaining

- The first device in the chain exports its LO
- Each subsequent device imports the LO, and then re-exports it to the next device
- Unknown but (fairly) stable phase relationship between each device in the chain
- Drift and jitter increase as you go further down the chain
- Typical for high end instrumentation



2. Daisy Chaining

- Expect ~1's of degrees of drift per daisy chain stage
- Expect ~0.1's of degrees of "noise" (short term incoherency)
- Drift due to LO Out & LO In circuits (per stage) + RF front end
- Two NI 5644R's measured 1.6 degrees (@ 3.6 GHz) drift over time/temp



Lowered Temperature

Raised Temperature

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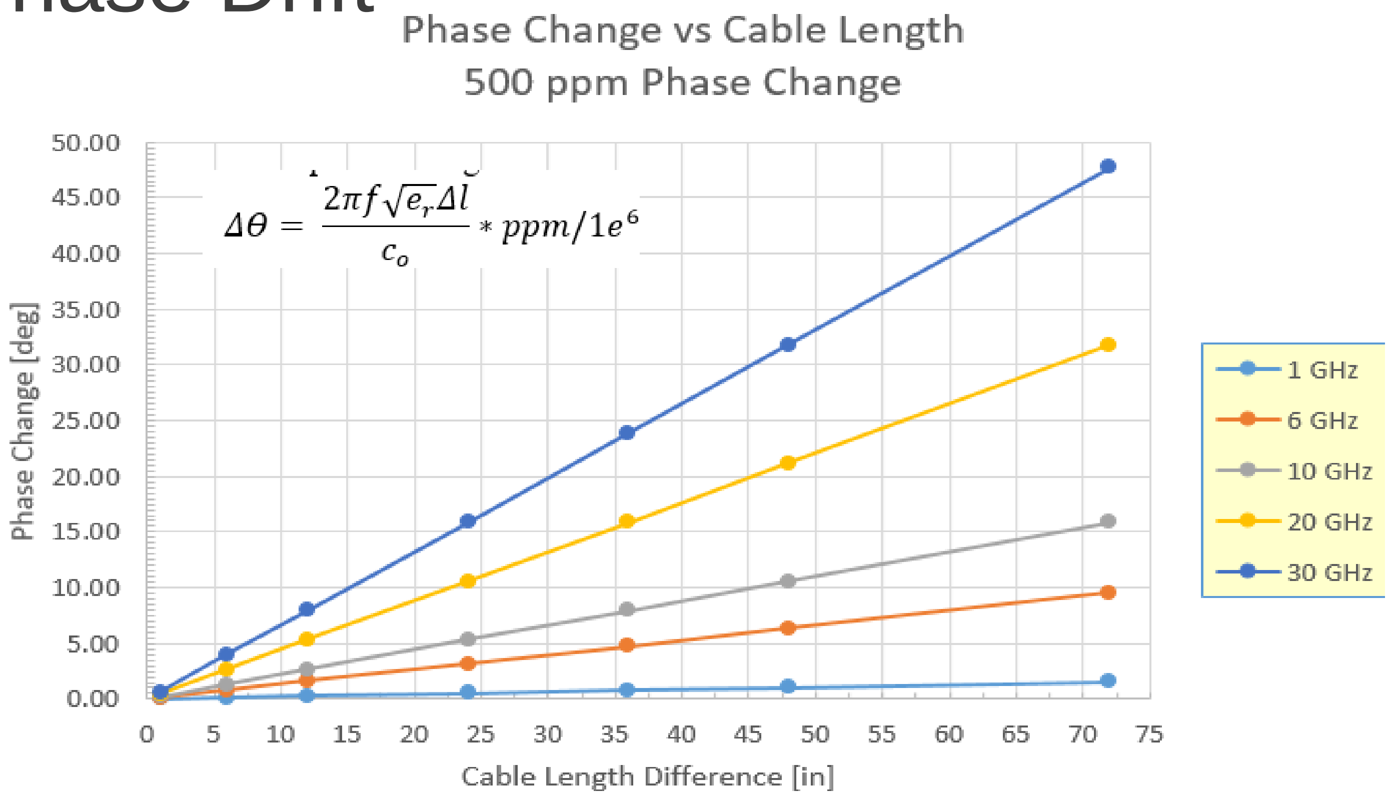
Theoretical Daisy Chain Phase Drift



- Cable length difference between LO source and each transceiver varies along the chain
- Phase drift is a function of cable length and frequency
    - Drift due to the Teflon knee
- Need to take into account LO frequency and cable length between transceivers

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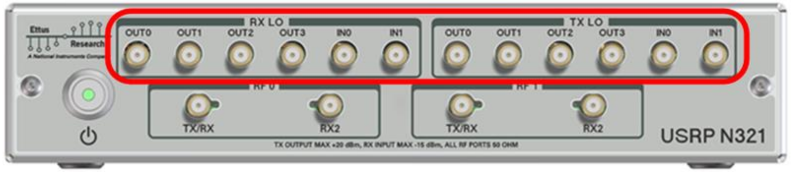
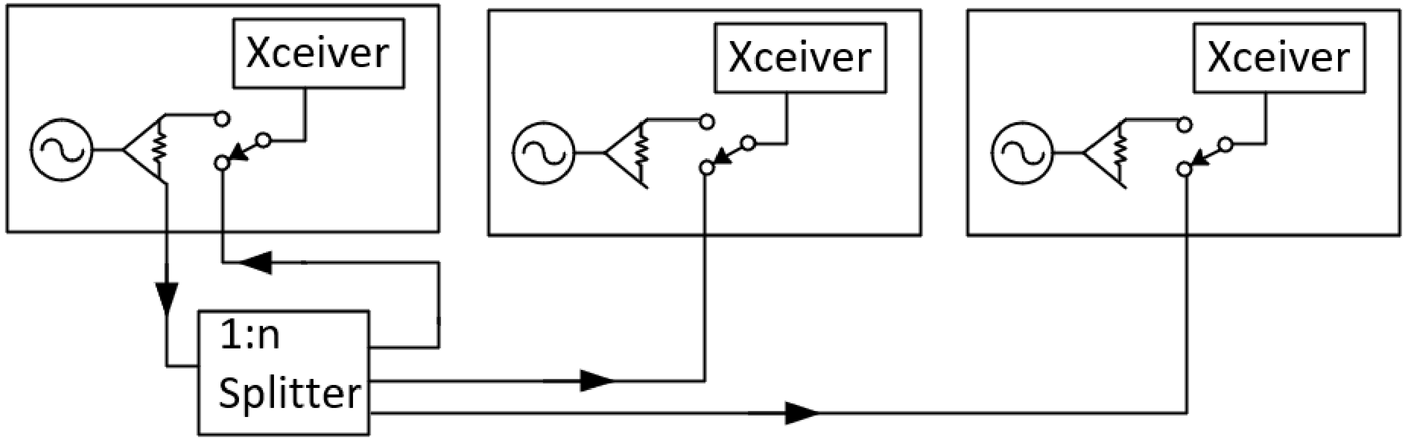
3. Star Distribution



- The first device in the chain exports its LO
- A power splitter is used to send copies to subsequent devices
- Stable phase relationship between each device in the chain
- Often utilized for large or phase sensitive systems



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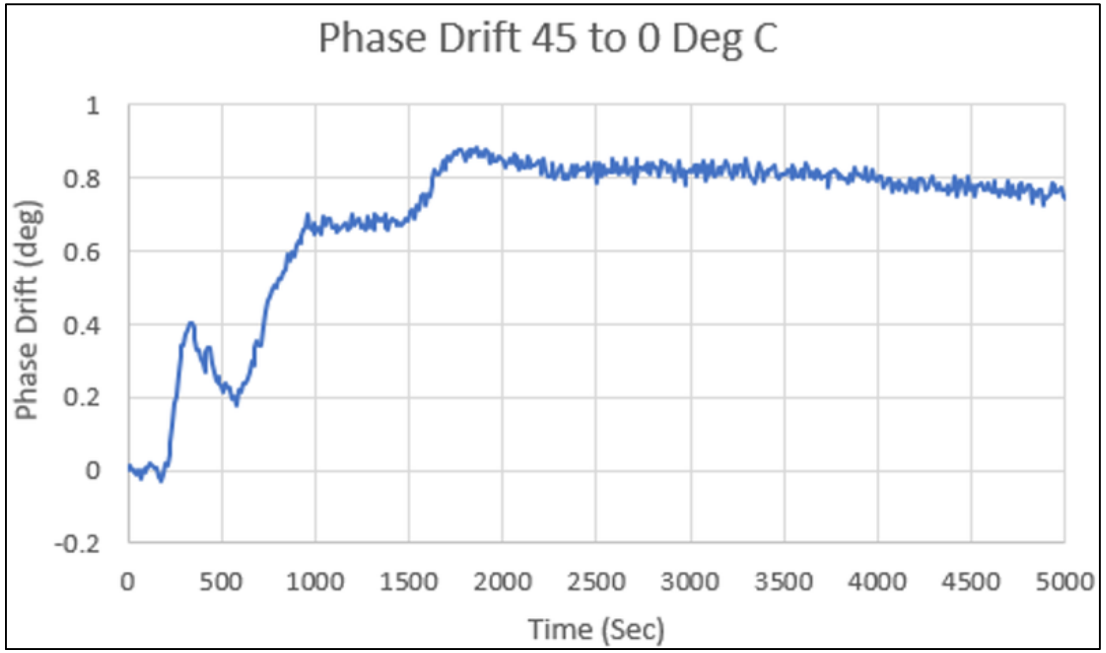
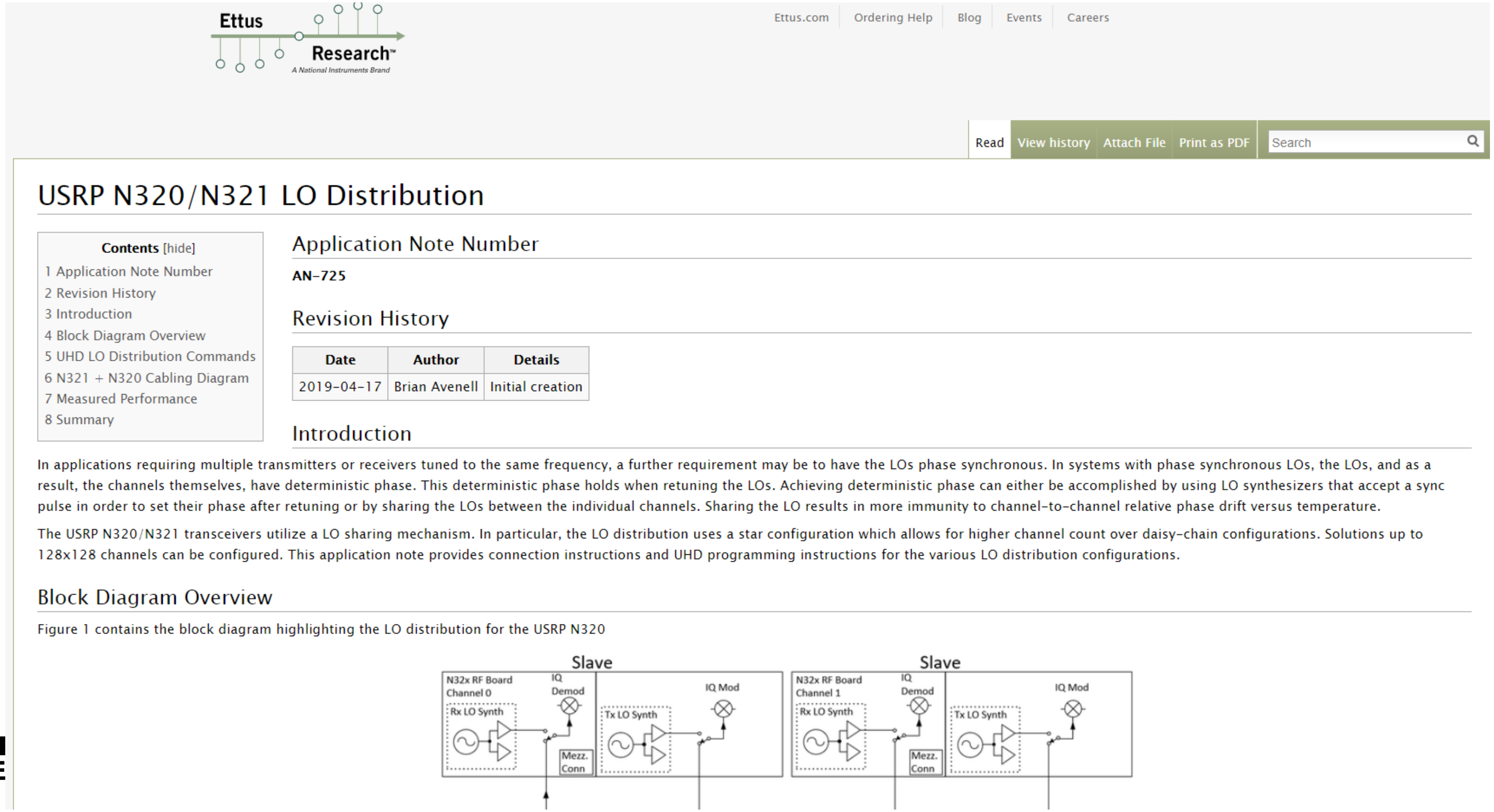
3. Star Distribution

- Expect ~1’s of degrees of drift total
- Expect ~0.1’s of degrees of “noise” (short term incoherency)
- Drift due to LO distribution + RF front end
- Two USRP N320/321 channels measured <1 degrees (@ 6 GHz) drift over time/temp



USRP N320/N321 LO Distribution

- https://kb.ettus.com/USRP_N320/N321_LO_Distribution
- The USRP N320 / N321 were designed for this purpose



USRP N320/N321 LO Distribution

Application Note Number

AN-725

Revision History

Date	Author	Details
2019-04-17	Brian Avenell	Initial creation

Introduction

In applications requiring multiple transmitters or receivers tuned to the same frequency, a further requirement may be to have the LOs phase synchronous. In systems with phase synchronous LOs, the LOs, and as a result, the channels themselves, have deterministic phase. This deterministic phase holds when retuning the LOs. Achieving deterministic phase can either be accomplished by using LO synthesizers that accept a sync pulse in order to set their phase after retuning or by sharing the LOs between the individual channels. Sharing the LO results in more immunity to channel-to-channel relative phase drift versus temperature.

The USRP N320/N321 transceivers utilize a LO sharing mechanism. In particular, the LO distribution uses a star configuration which allows for higher channel count over daisy-chain configurations. Solutions up to 128x128 channels can be configured. This application note provides connection instructions and UHD programming instructions for the various LO distribution configurations.

Block Diagram Overview

Figure 1 contains the block diagram highlighting the LO distribution for the USRP N320

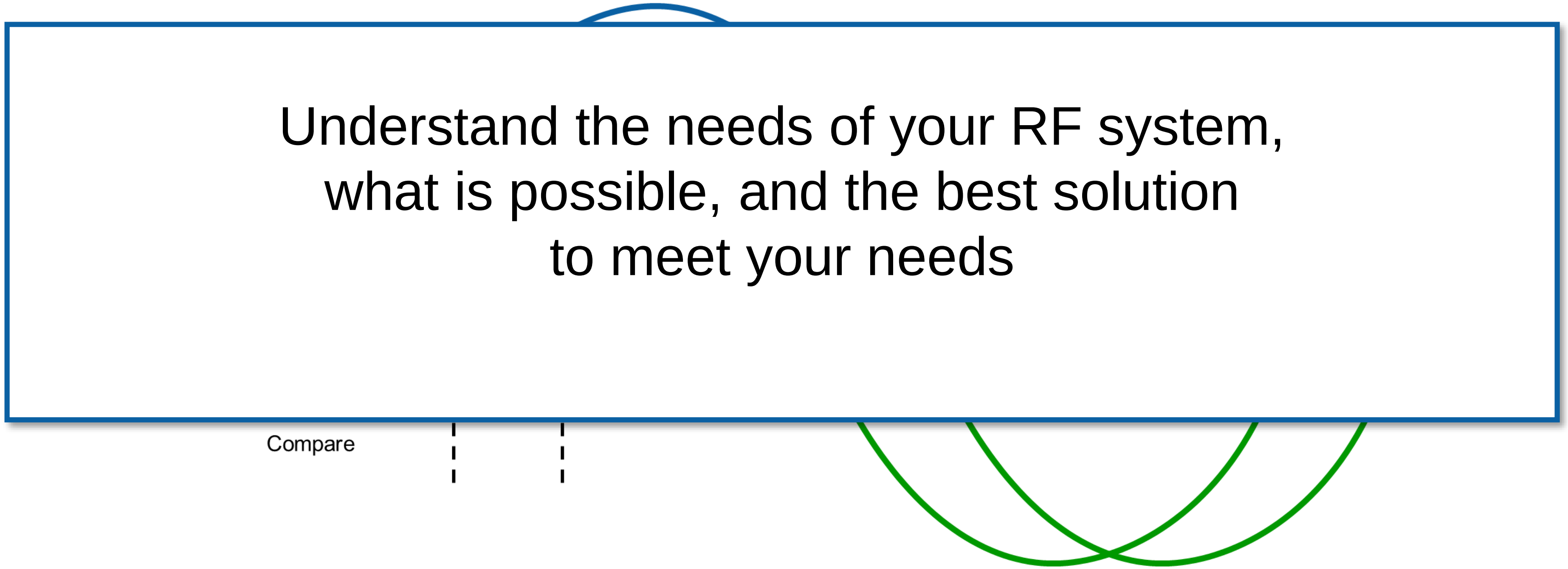
Digital Compensation

Digital Compensation

- How to digitally compensate?
  - Adjust phase using NCO / DDC / DUC / IQ complex Mult
  - Adjust time delay using converter clock delays (single CLK steps)
  - Adjust time delay using fractional delay FIR (sub-CLK steps)

However….

- None of this matters if your baseband synchronization doesn’t work
- See the next session by Daniel Jepson



Understand the needs of your RF system,
what is possible, and the best solution
to meet your needs

Thank you! Questions?