HOMEBREW LONG-BASELINE INTERFEROMETRY (LBI) FOR EDUCATION AND RESEARCH

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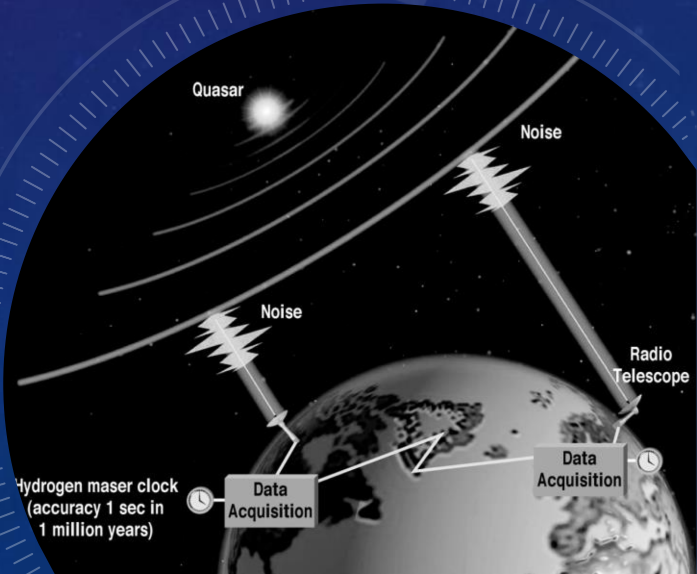
WHAT IS LBI OR VLBI

- LBI (Long Baseline Interferometry) or VLBI (Very Long Baseline Interferometry) is a radio (e.g., microwave-based) space geodetic technique that measures the time difference of arrivals (TDOAs) of signals from a radio source through cross correlation.
- Recently radio telescopes in the European VLBI Network (EVN) have observed a repeating fast radio burst (FRB) in a spiral galaxy similar to the Milky Way.
    - This FRB is the closest to Earth ever localized and was found in a radically different environment to previous studies.
    - The discovery changes researchers' assumptions on the origins of these mysterious extragalactic events.

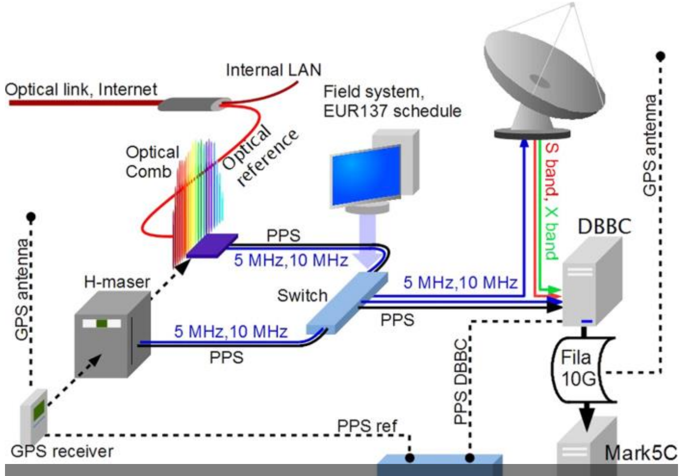
G. Xu (ed.), Sciences of Geodesy - II, DOI: 10.1007/978-3-642-28000-9_7, © Springer-Verlag Berlin Heidelberg 2013, by Harald Schuh and Johannes Böhm



VLBI NETWORK IS MASSIVE AND EXPENSIVE

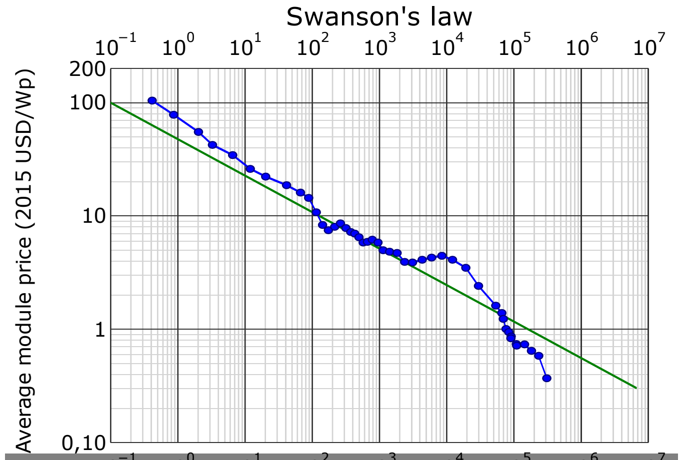
Approximate Cost for Current VLBI Technology	
Component	Cost
Digital BBC units (500 Hz)	$20,000 each
Data Storage units (1 Gb/s)	$16,000 each
Network Unit(10 sec)	$175,000
Power Supplies + Backplane + GPS clock	$20,000
Total	$270,000

Doeleman, Shep. “mmVLBI in the Future technical/experimental”. Haystack Observatory

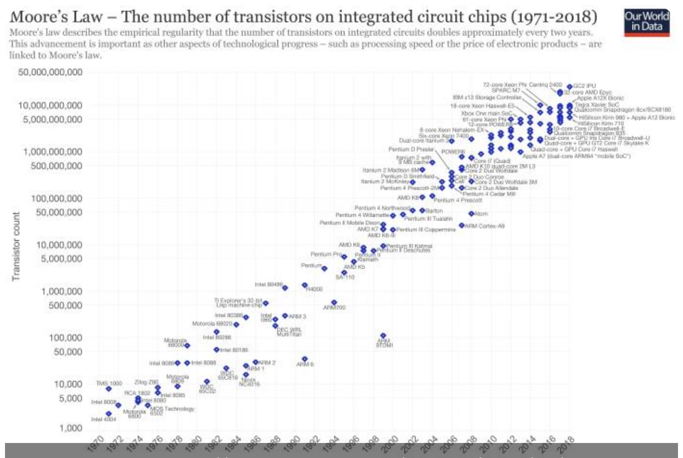


Clivati, C., Ambrosini, R., Artz, T. *et al.* A VLBI experiment using a remote atomic clock via a coherent fibre link. *Sci Rep* 7, 40992 (2017).

CAN WE MAKE ULTRA-LOW COST LBI FOR MOST OF US?



https://en.wikipedia.org/wiki/Swanson%27s_law

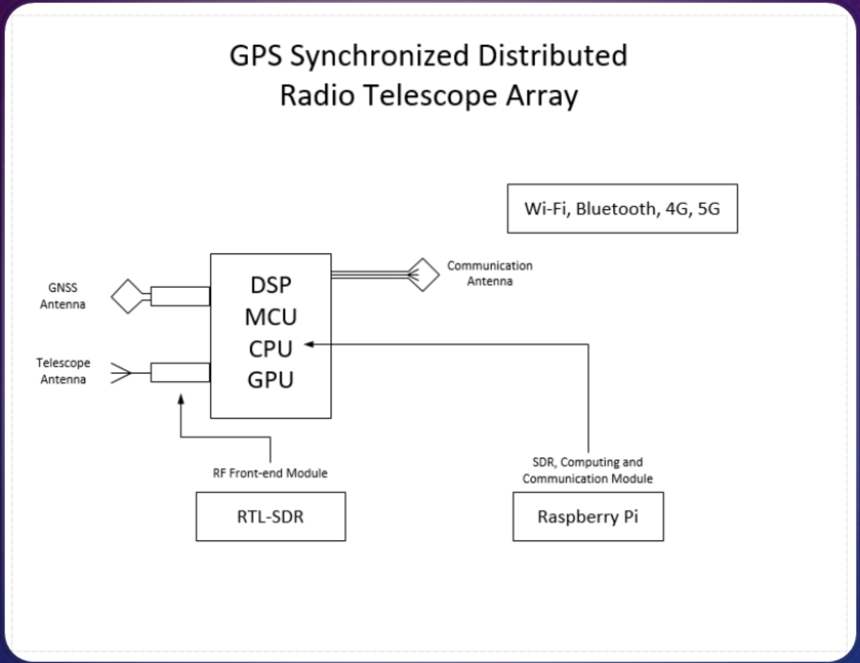


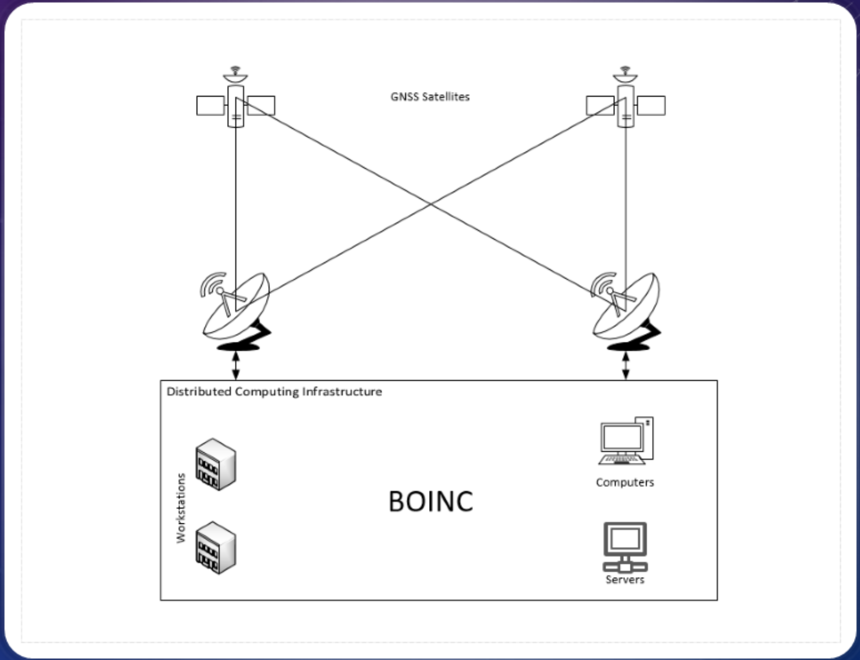
By Max Roser - https://ourworldindata.org/uploads/2019/05/Transistor-Count-over-time-to-2018.png, CC BY-SA 4.0

- Current very long-baseline interferometry (VLBI) technology is highly customized and extremely expensive for researchers. However, they are good.
- Is there any thing similar for students and amateurs?
  - Are Swanson's law and Moore's law also applicable to VLBI and LBI?

Approximate Cost for Proposed Homebrew LBI As An Example	
Component	Cost
2x Software Defined Radio + Dipole Antennas	$60.00
Raspberry Pi	$46.07
Micro SD Memory Card	$8.90
Software-Defined Radio (e.g, RTL-SDR)	$24.00
Total	$139.97

OUR HOMEBREW LBI SYSTEM





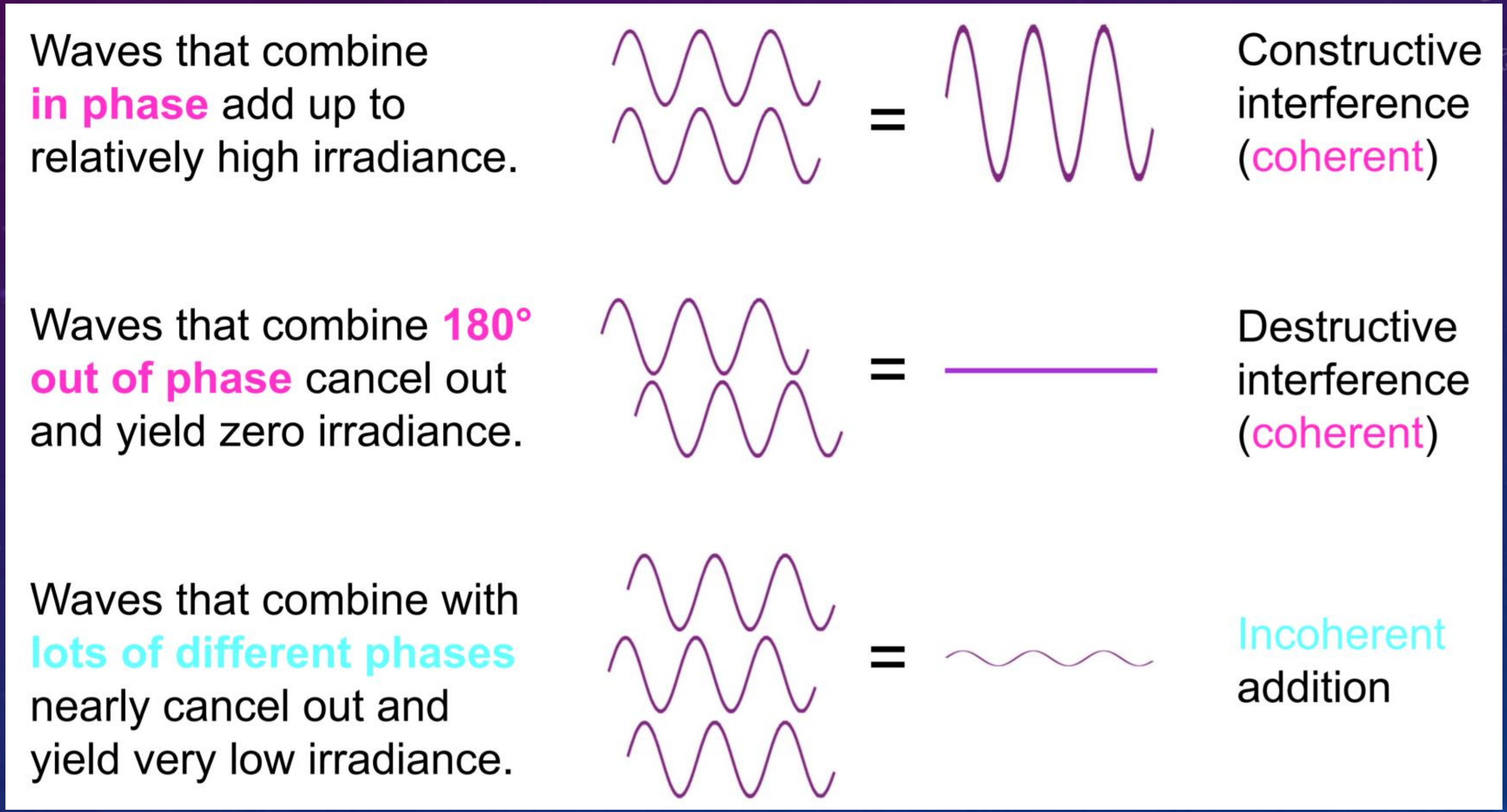
WHAT STARGAZINGTECH.ORG WANTS TO ACHIEVE IS

- During the past summer, we started Stargazing Technologies, a non-profit organization, for developing ultra-low cost and portable LBI devices for students and amateur astronomy researchers from and with:
  - Off the shelf hardware. It will be made from SDR hardware, Raspberry Pi computer, portable battery and computers.
  - Open Source software. GNU radio, RTL-SDR
  - Open Computing Infrastructure. BONIC (Berkeley Open Infrastructure for Network Computing)
- We will demonstrate the capability of imaging distant cosmic radio sources, satellites and spacecraft tracking.
- We want to help promote the education and research cooperation between worldwide students and amateur astrophysicists.

SOLVING THE SAME HARD ENGINEERING PROBLEMS, BUT AT MUCH MUCH LOWER COSTS

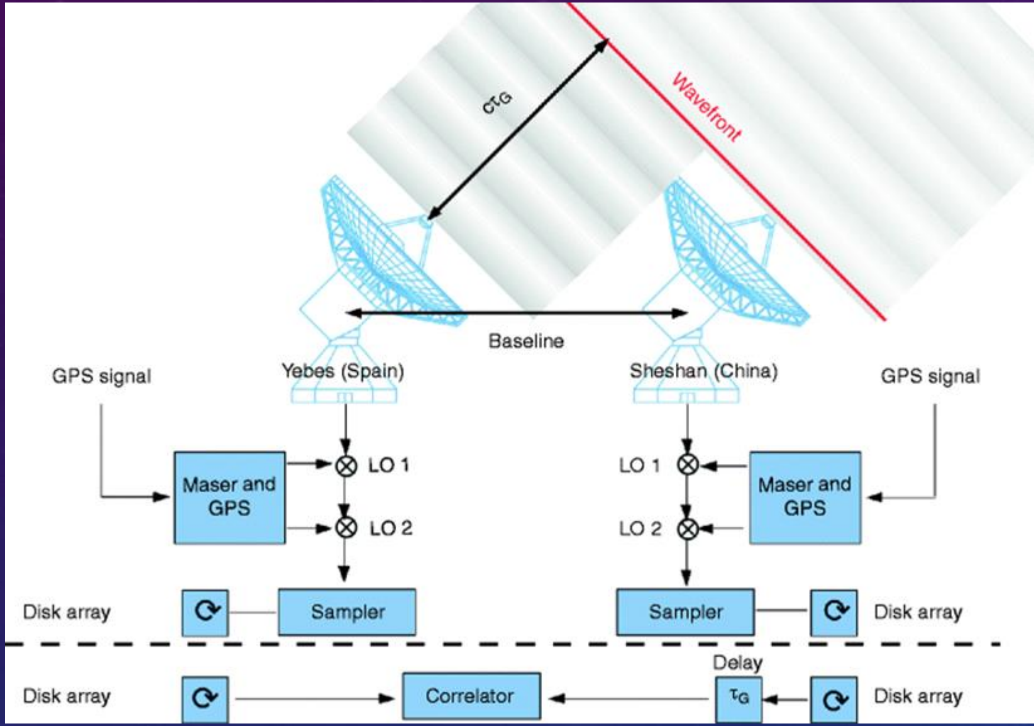
- The main problem is, how to receive weak radio signals?
  - The reception of weak radio signals is improved through interference, "coherent combining" the signals received by a distributed network of LBI station.
- How to coherently combine the independently and individually received radio signals?
  - Because LBI stations are spatially distributed and each equipped with their own local clock references (LO).
  - In order to successfully coherently combining the signals, we have to estimate the relative timing offset or the composite phase difference between the signal samples generated by the LBI stations.
  - The relative timing offset(s) are estimated from the observed time difference of arrival (OTDOA) of common GPS signals
  - Besides GPS signals, other common reference signals will be also considered in the future

INTERFERENCE – COHERENT SUPERPOSITION



Rick Trebino, Interference, http://www.physics.gatech.edu/frog/lectures, Georgia Tech

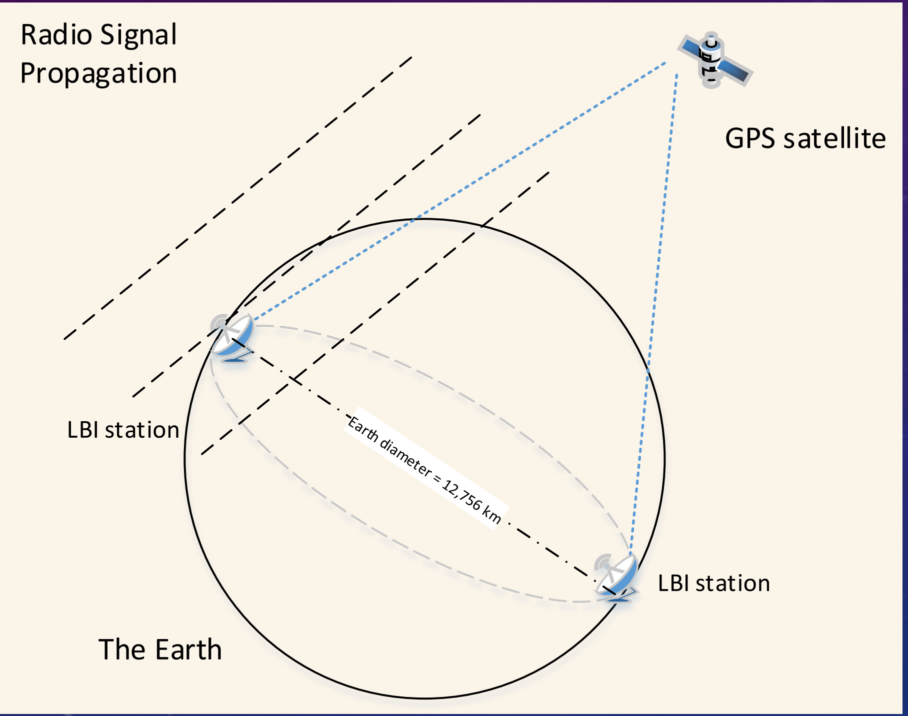
HOW TO COMBINE THE SIGNALS GEOGRAPHICALLY DISTRIBUTED?



Helmut Wiesemeyer and Axel Nothnagel, Very Long Baseline Interferometry, https://doi.org/10.1007/978-90-481-8702-7

The geographical distance between Yebes, Spain and Sheshan, China is more than 10,000 kilometers.

THE KEY IS THE TIMING SYNCHRONIZATION BETWEEN STATIONS THROUGH GPS

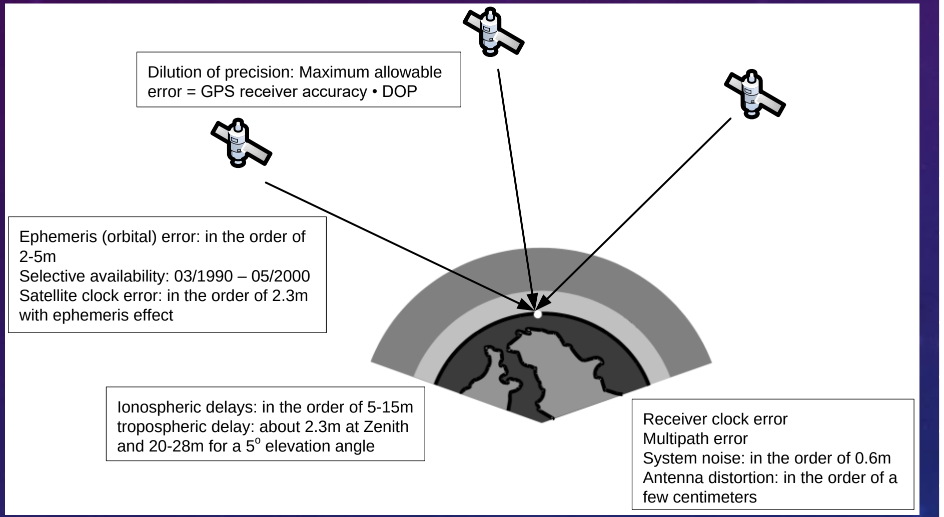


- In our design, we are using an independent radio reference signal source (e.g., GPS) for the timing synchronization between spatially distributed stations.
- As such, there are two major timing error sources:
  - <u>System Error</u>, due to the uncorrelation between reference signals and the target signals.
  - <u>Synchronization Error</u>, e.g., the GPS synchronization error
- These two error sources will be analyzed and further compensate during interference and coherent combining stage.

MAJOR TIMING ERRORS(1/2): SYSTEM ERROR

- In our current Phase I prototyping, our design doesn't consider the radio signal propagation distamce difference between two LBI stations
  - This limits the spatial distribution distance between two LBI stations.
- On earth, the earth diameter is ~12,765 km. As such, the maximum propagation delay between two LBI station is 12,765 km / 300,000 kmps = ~42550 us.
- In our initial prototyping, we are using low cost RTL-SDR receiver, which can operate at 3.0MHz sampling clock, which generates one sample every 0.33 us.
- As such, the recommended maximum LBI station distance of our initial prototyping is several 100 meters.
- In our next generation prototyping, the propagation delay will be taken accounted into design.

MAJOR TIMING ERRORS(2/2): SYNCHRONIZATION ERROR



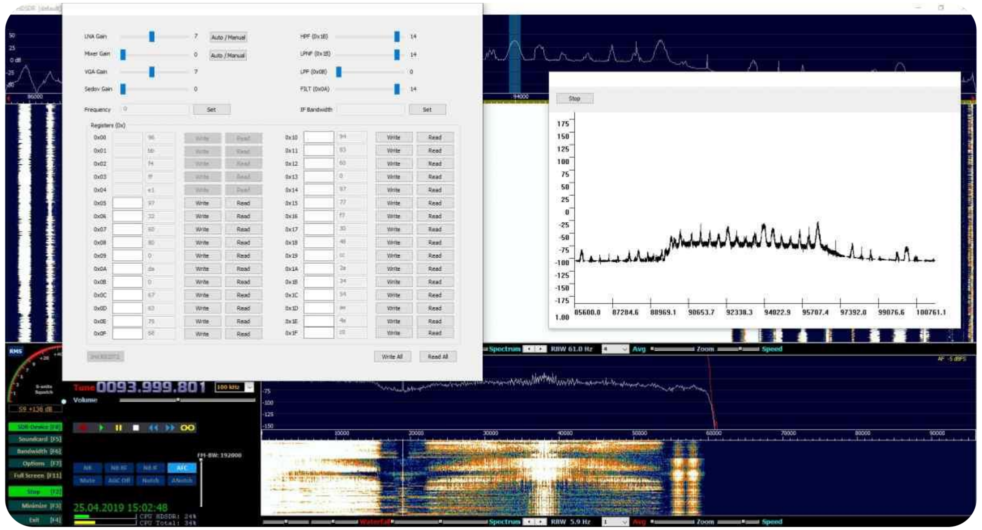
Error Sources	Absolute GPS		Differential GPS	
	P Code	L1 C/A Code	P Code	C/A Code
Satellite Clock & Ephemeris Errors	0.013 us	0.013 us	0	0
Ionospheric Delay	0.01033 us	0.03 us	0	0
Tropospheric Delay	0.006667 us	0.006667 us	0.0005 us	0.0005 us
Receiver Noise and Resolution	0.003667 us	0.037 us	0.003667 us	0.037 us
Multipath	0.004 us	0.04 us	0.004 us	0.04 us
Other			0	0
***Selective Availability**		0.1 us	0	0
Total System Error 1σ	0.01867 us	0.1187 us	0.004333 us	0.05333 us
Position Error PDOP = 2.92	**16.3 m**	**104 m**	**3.8 m**	**48 m**

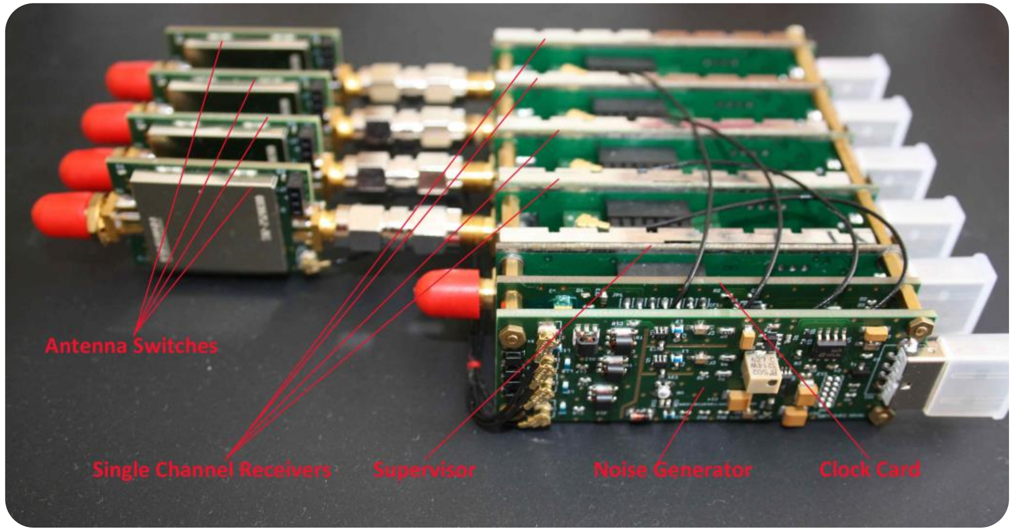
Shu Wang, et al., "Location Based Services for Mobiles: Technologies and Standards," IEEE ICC 2008, Beijing, China, 2008
R. M. Kalafus, et al., "Differential operation of Navstar GPS", Navigation Vol. 30, No. 3, 1983

LOW-COST RTL-SDR BASED COHERENT-RECEIVER

•Single-board multi-tuner receivers

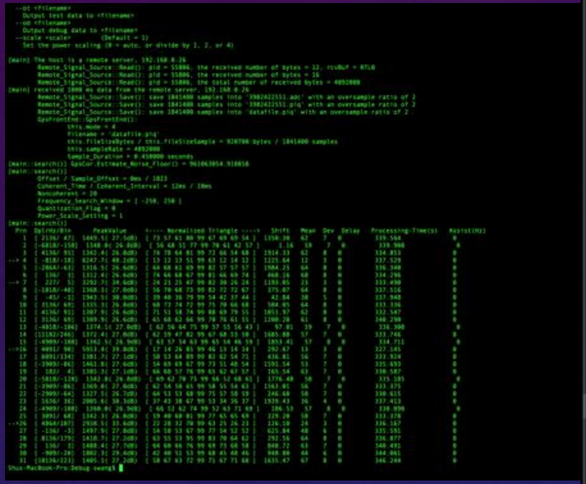
- Frequency Range: 24 MHz – 1.7 GHz
- ADC Sample Rate: 25 MSPS
- up to 8 MHz spectrum (10 MHz on request with an alternative tuner) per tuner
- Bit Depth: 8 bits – 4 Tuners on board; 12 bits-16bits – 2 Tuners on board
- All channels on the board are sampled synchronously and have common clock (2 or 4 synchronous channels). External synchronization is necessary only for the phase calibration. Multiple boards can be chained together with a common clock and an additional I/Q-synchronization

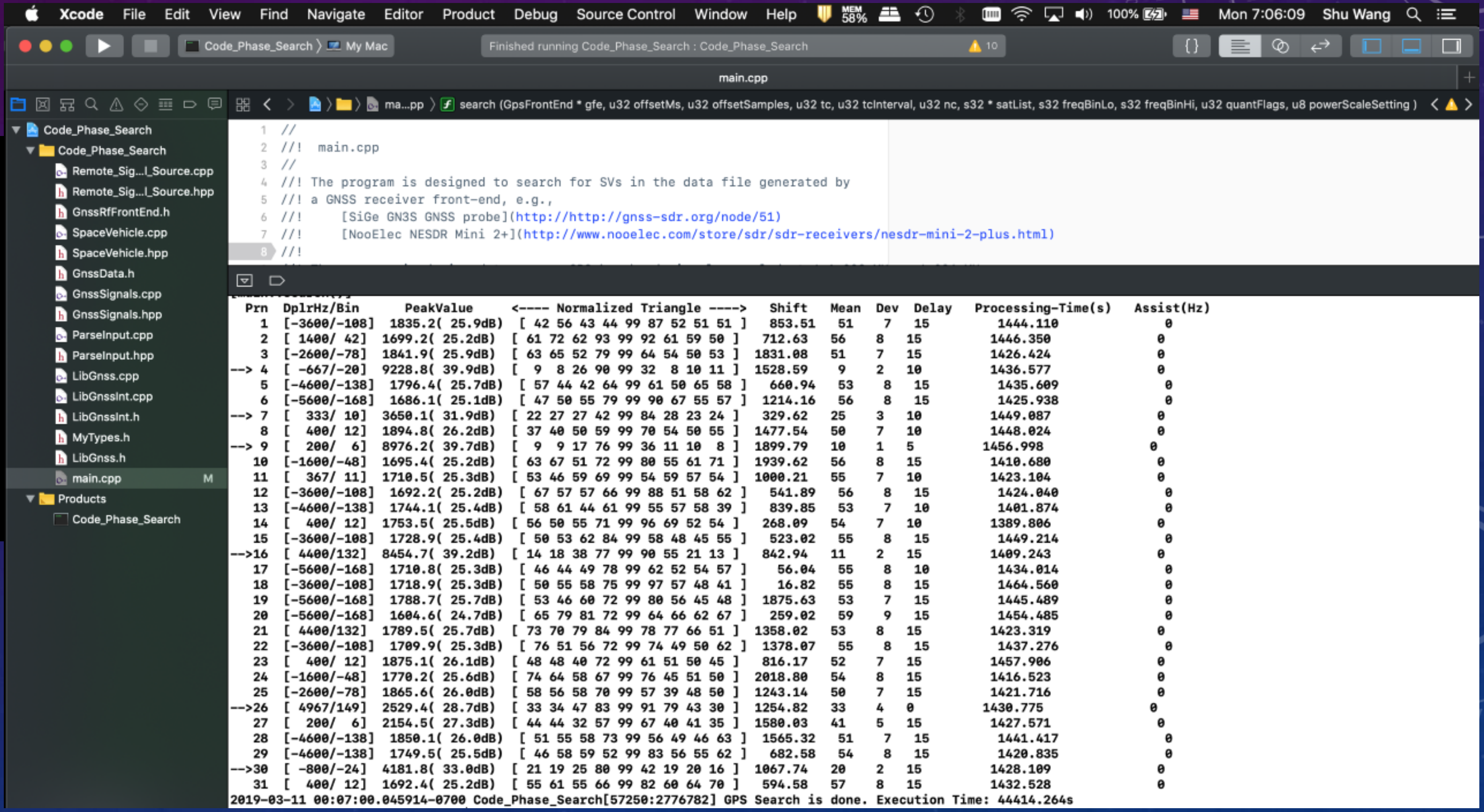




https://coherent-receiver.com/products/coherent-receivers/1-supervisory-and-4-coherent-channels

SOME PRELIMINARY RESULTS





PHASED DEVELOPMENT PLAN

	Phase I	Phase II	Phase III
Radio Frequency up to 1.7GHz	✓	✓	✓
GPS-Base Synchronization	✓	✓	✓
Distributed Signal Processing in BOINC	✓	✓	✓
Battery Power Supply	✓	✓	✓
Radio Frequency up to 6GHz		✓	✓
Distributed File Synchronization		✓	✓
Wi-Fi Mesh Network		✓	✓
Solar Panel Power Supply			✓
Data Integrity Guard			✓
GPGPU Processing Acceleration			✓
Airborne Deployment Capable			✓

	UHF Antenna $12~$90	GNSS Antenna $8~$160	RTL-SDR $22~$30	Raspberry Pi 4 $60~$100	MicroSD Card $20	Lithium PolymerBattery $27
Telescope Antenna	✓					
GNSS Antenna		✓				
Communication Antenna				✓		
Radio Telescope RF Front End			✓			
GNSS RF Front-End			✓			
Signal Processing, Control and Communication Module				✓		
Data Storage					✓	
Power Supply						✓

THANK YOU SO MUCH FOR YOUR TIME!