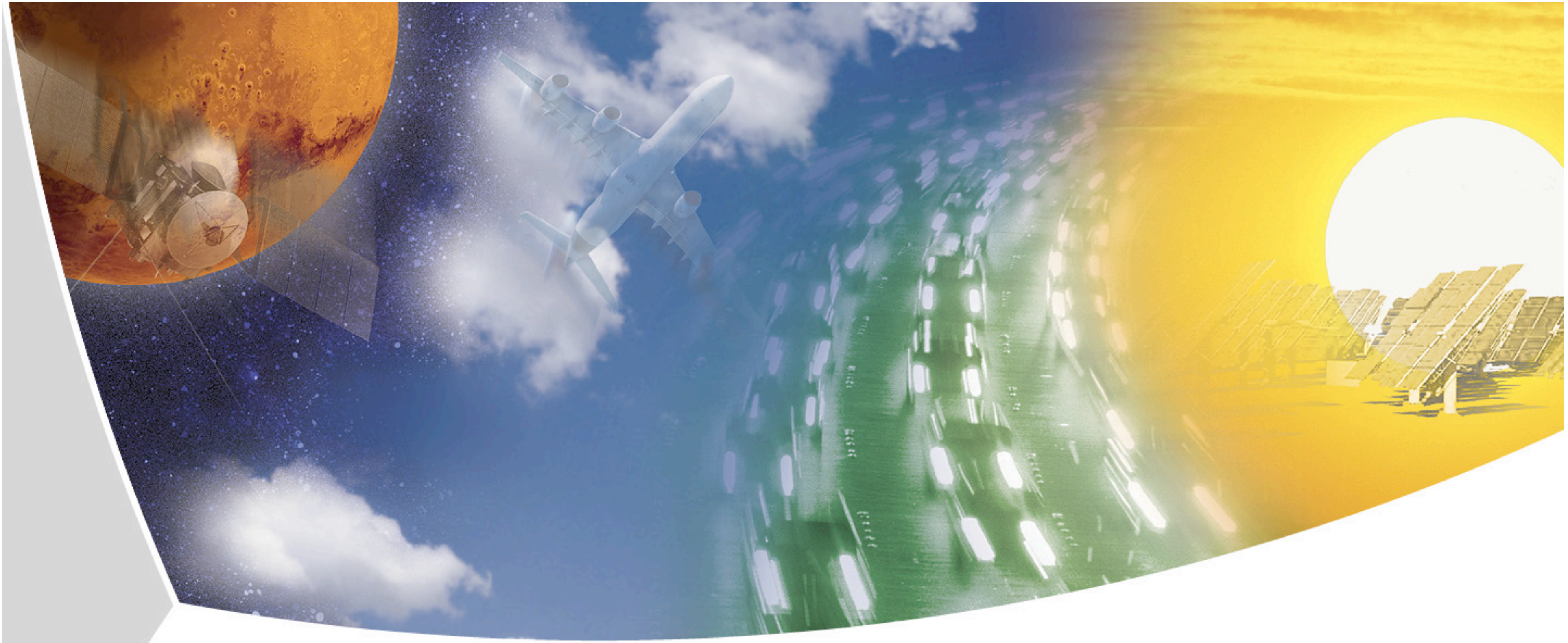
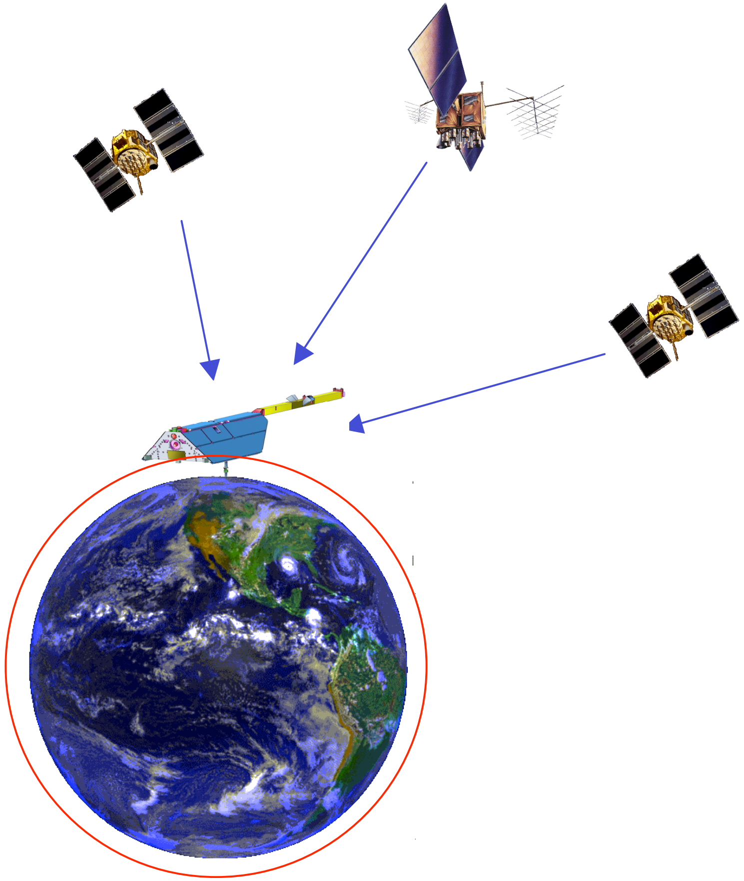


Dual-Frequency GNSS Receivers for Space Applications

O. Montenbruck. M. Garcia-Fernandez

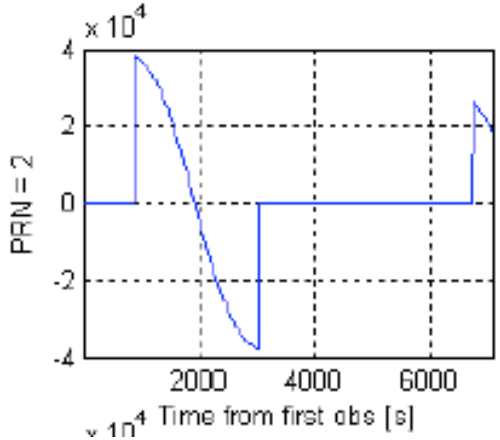
Dual-Frequency GNSS Receivers for Space Applications

- Space – a different world!?
- SGPS receiver overview
- Performance comparison
- Galileo – the next step
- Conclusions



SGPS – What's Special?

- Signal Dynamics
  - High Doppler shift and line-of-sight acceleration
  - Rapid constellation change
  - Pronounced code-carrier divergence

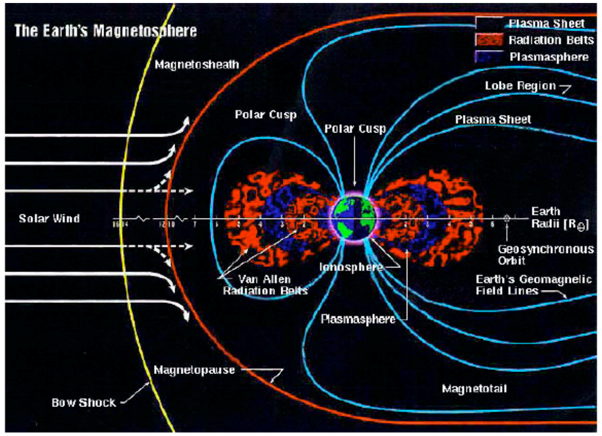


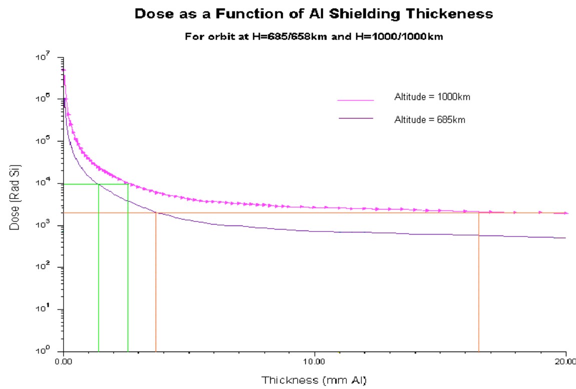
- Legal Issues
  - International Traffic in Arms Regulations (ITAR)
  - European and national export laws

```
if (altitude>60000ft ||
    speed   >1000knots  )
{
  exit();
};
```

Space – A Different World?

- Temperature
  - E.g. –20°C ... +60°C *inside* a representative satellite
  - Compatible with consumer electronics
- Vacuum
  - Outgassing, leakage
- Vibration
  - Only a few minutes at launch (unlike a car on a bumby road)
  - But: risk of resonances
- Radiation
  - Total Ionization Dose (aging, current increase, death)
  - Single Event Effects (bit errors, hick-up, desctructive latch-up)



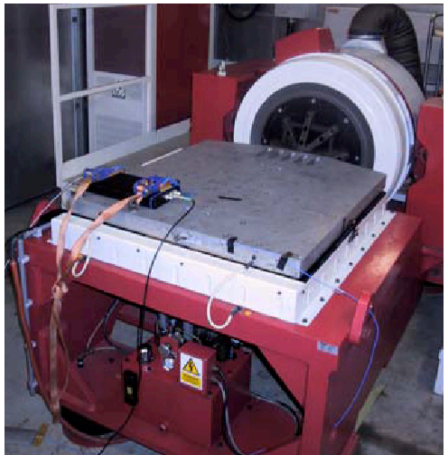


Testing of Space Hardware

Signal Simulator

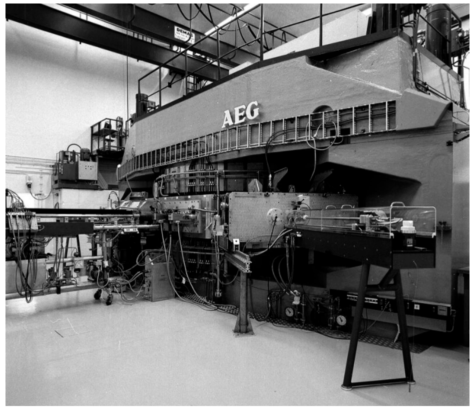
Thermal Vacuum Chamber

Co-60 Source



Shaker

€€€€



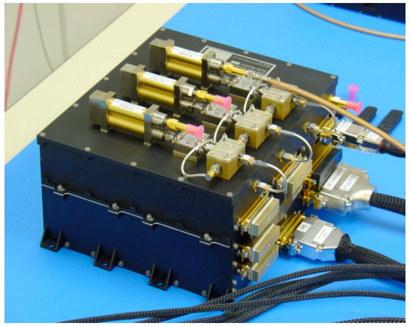
Proton Cyclotron

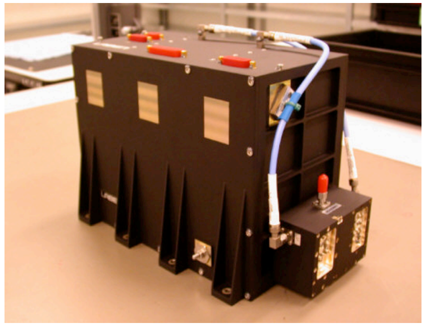
Spaceborne Dual-Frequency GPS Receivers

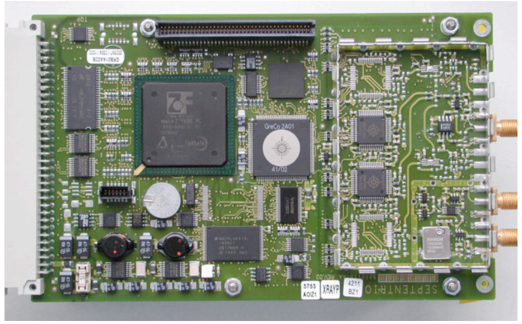
Receiver	Chan	Ant	Data	Nav. Acc.	Power Mass	TID	Temp. Range	ROM Cost	Missions
Monarch (General Dyn)	6-24	1-4	C1,P1,P2 LA,L2	3 m SPP	25 W 4 kg	100 krad	-34°C / +71°C		
BlackJack (JPL)	16 x 3	4	C1,P1,P2 LA,L1,L2	17 m SPP	10 W 3.2 kg	20 krad?	-10°C / +55°C		SAC-C, CHAMP GRACE, Jason-1
IGOR (BRE)	16 x 3				16 W 4.6 kg	>12 krad	-10°C / +55°C	500 k€	TanDEM-X (2006) COSMIC (2006)
GRAS/GPSOS (Saab)	n/a	3 (?)		<100 m	50 W 10-30 kg			2 M€	METOP (2006)
Lagrange (Laben)	16 x 3 (?)	1 (?)	C1,P1,P2 LA,L2	20mSPP 8m KF	30 W 5.2 kg	20 krad	-25°C / +60°C	700 k€	ENEIDE, Radarsat-2 (2006), GOCE (2007)
DFSG (NEC/Toshiba)	6 x 2	1			30 W 4.1 kg	20 krad	-15°C / +55°C	1 M€	
TopStar 3000G2(Alcatel)	6 x 2	1 (?)	C1,L2C LA,L2						Under development
Innov. GNSS Nav. Rcv. (AAE)	Up to 36	2	C1,P1,P2 L2C,LA,L2	<5m		>20 krad	-25°C / +60°C		Under development
OEM4-G2L (NovAtel)	12 x 2	1	C1,P2 LA,L2	14 m SPP	1.5 W 50 g	6 krad	-35°C / +50°C	10 k€	CanX-2 (2006) CASSIOPE (2007)
PolaRx2 (Septentrio)	16 x 3	1 (4)	C1,P1,P2L A,L2	1m	5 W 120 g	9 krad	-30°C / +70°C	10 k€	TET108 (2008)

Disclaimer: Despite adequate care in compiling this table neither the authors nor DLR assume any responsibility for the validity and comparability of individual data. Rough-order-of-magnitude cost figures are given for orientation only and have not officially been endorsed by the respective manufacturers.

Spaceborne Dual-Frequency GPS Receivers



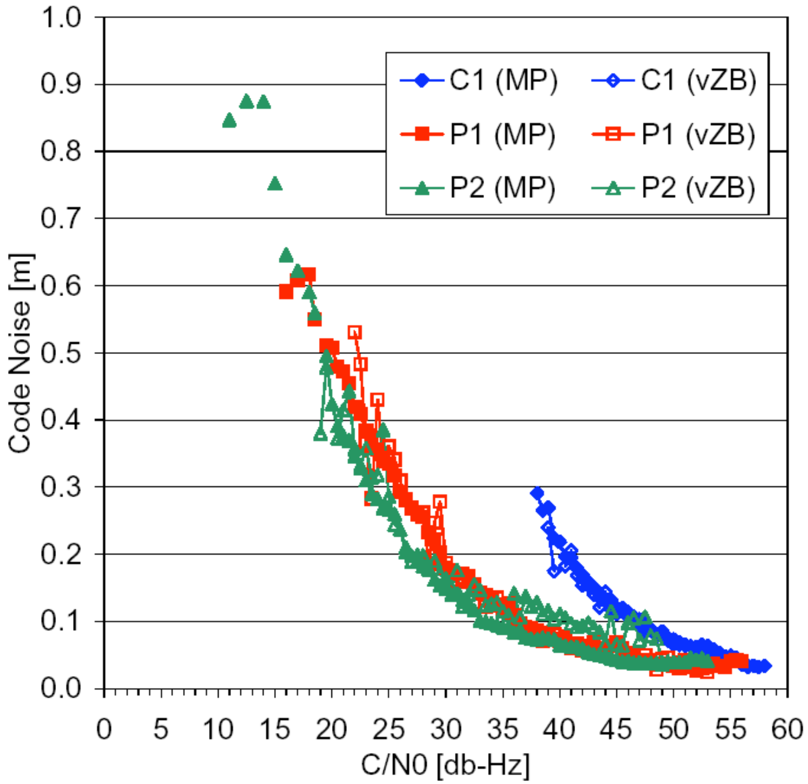




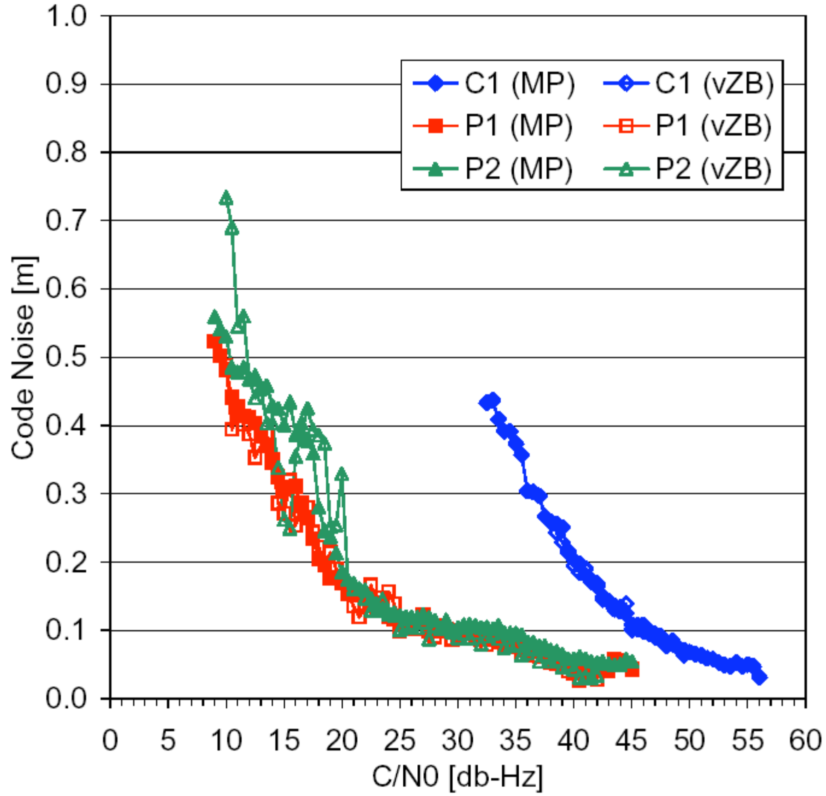
	IGOR (Broadreach/JPL)	Lagrange (Laben)	PolarRx2 (Septentrio)
Type	16 x 3 channels L1/L2	16 x 3 channels L1/L2	16 x 3 channels L1/L2
Raw data accuracy	C/A, P(Y) 0.1 m LA,L1,L2 0.5 mm	C/A, P(Y) 0.2 / 0.1 m LA, L2 2 mm	C/A, P(Y) 0.1 m LA, L2 1 mm
Nav	15 m	20 m	1 m
TTFF	3-16 min	???	1-3 min
Power, Mass	16 W, 5kg	30 W, 5 kg	5 W, 120 g
Radiation tolerance	12 krad SEE hard	20 krad SEE hard	9 krad ???
Cost (ROM)	500 k€	700 k€	(10 k€)

Code Noise

IGOR



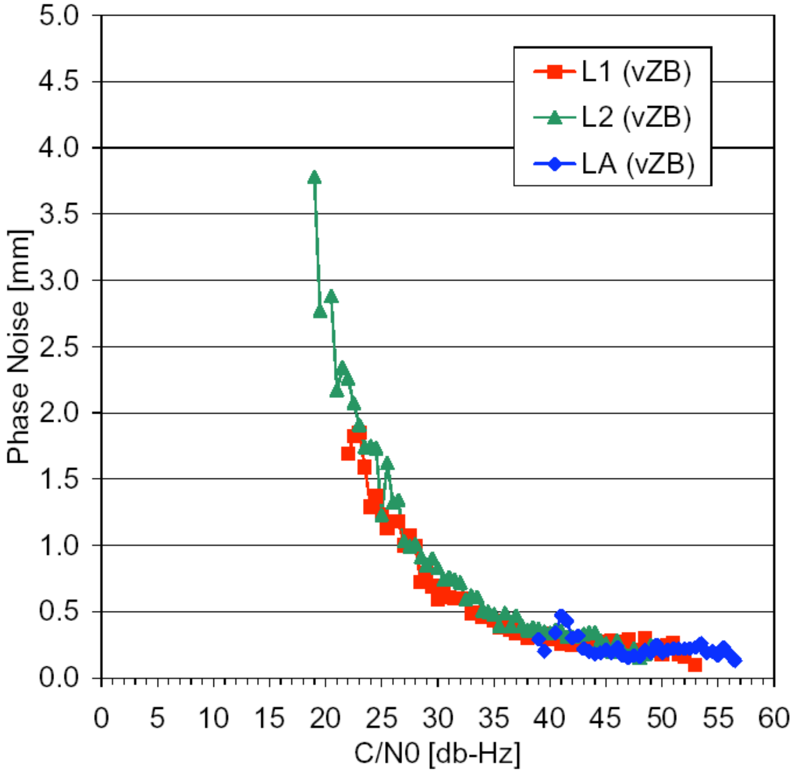
PolaRx2



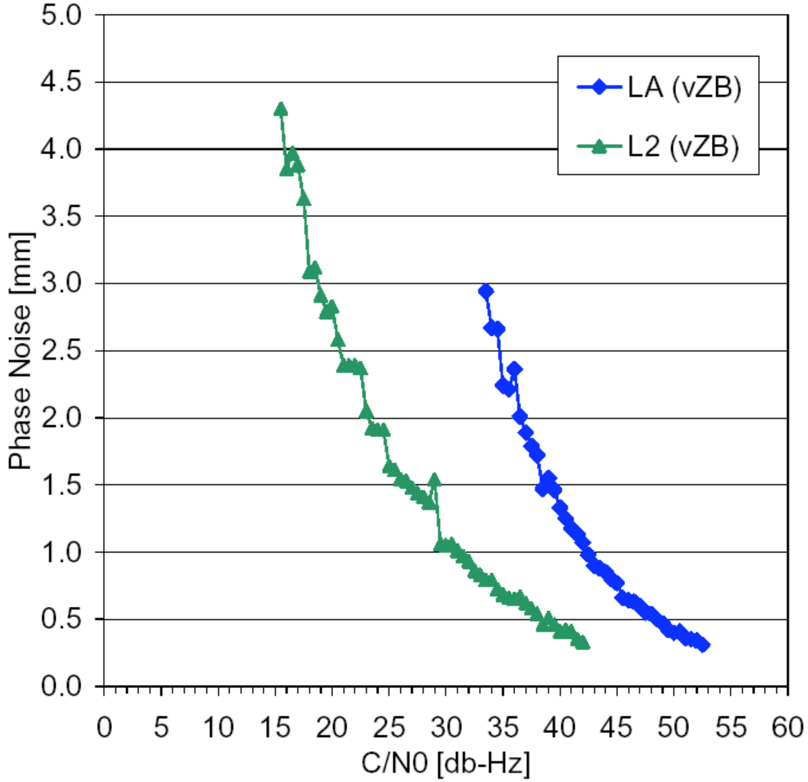
Source: DOI 10.1007/s10291-006-0025-9

Phase Noise

IGOR



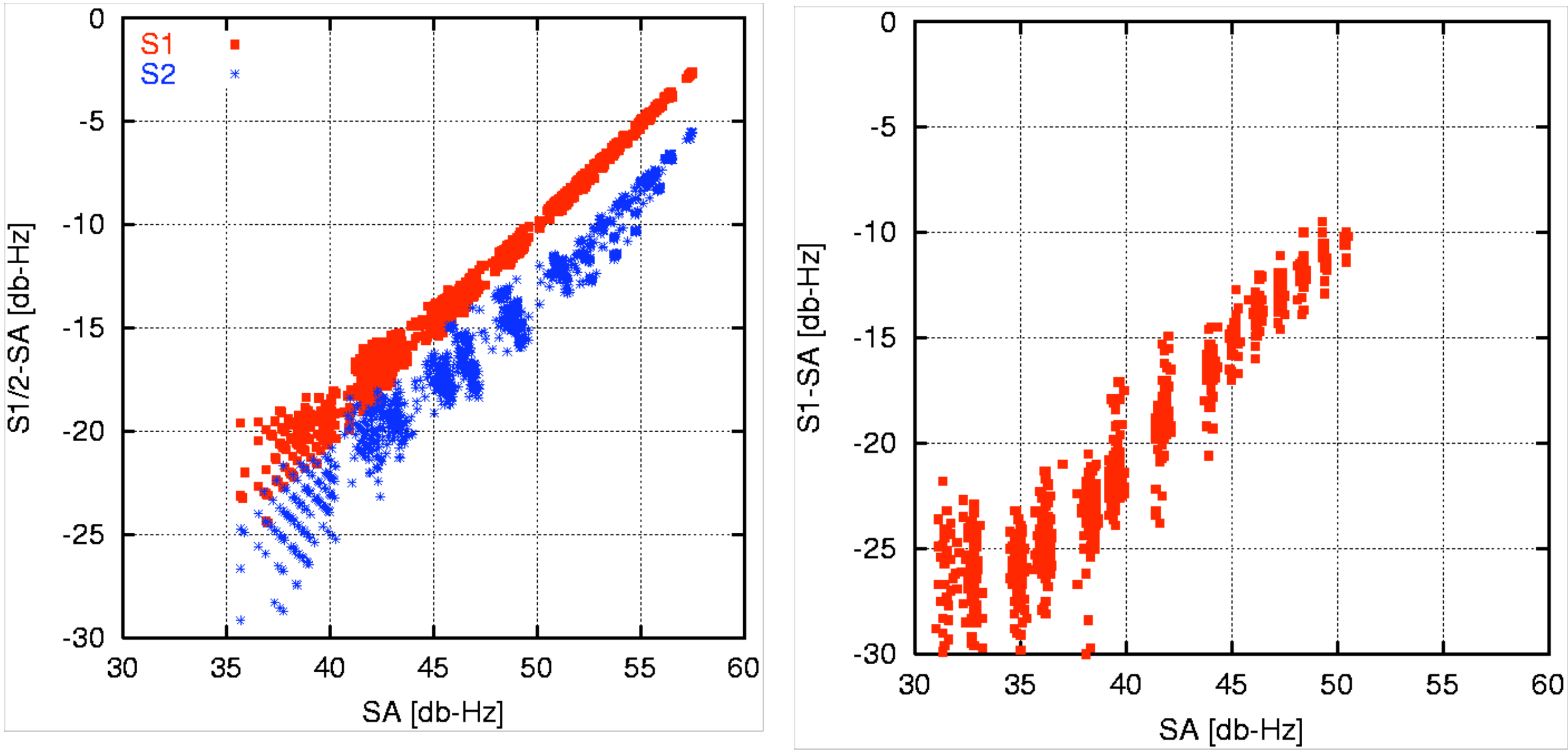
PolaRx2



Source: DOI 10.1007/s10291-006-0025-9

Semi-Codeless Tracking Losses

IGOR PolaRx2



Source: DOI 10.1007/s10291-006-0025-9

Differential Code Biases

Receiver	Unit	P1-C1	P2-C1	P2-P1
IGOR	a	+0.3 m	+4.7 m	+4.4 m
PolaRx2	a	-0.3 m	0.0 m	+0.3 m
	b	-0.5 m	+0.1 m	+0.6 m
	c	-0.4 m	+0.1 m	+0.5 m

- DCBs determined from pseudorange differences in signal simulator test without ionospheric path delays

Source: DOI 10.1007/s10291-006-0025-9

Carrier Phase Timing Offsets

Receiver	LA/L1	L2
IGOR	-0.45±0.05 μs	-0.45±0.05 μs
OEM4-G2	-1.00±0.10 μs	-3.10±0.10 μs
PolaRx2	-0.60±0.05 μs	-0.60±0.05 μs

- Carrier phase time offset relative to the code based clock solution. The specified values need to be added to the time stamp given by the receiver to obtain the true measurement epoch.
- 1μs time offset maps into 7 mm along-track error
- Internal offsets of signal simulator may be suspected, but inter-receiver bias remains.

Source: DOI 10.1007/s10291-006-0025-9

Galileo - The Next Step

- Prospects
  - More satellites (joint GPS-Galileo receiver, e.g. L1/E5a or L1/L2/E5)
  - Link to GPS *and* Galileo time
  - Reduced code/phase noise through direct signal tracking
  - Better code multipath supression (ISS environment!)
  - Correction of 2nd order ionopsheric effects (3 frequencies)
- No spacequalified Galileo receivers available yet
  - Signal specification pending
  - AGGA-3 and frontend development substantially delayed
- Terrestrial receivers „in the pipeline“
  - Septentrio (GeNeRx1)
  - NovAtel (L1/E5a card)
  - Javad/Topcon (GeNiuSS / Paradigm G3)

Conclusions

- Commercial-off-the-shelf (COTS) receivers
  - can cope with high signal dynamics of LEO spacecraft
  - can provide adequate tracking, navigation and timing accuracy in LEO
  - provides access to latest receiver technology
  - require dedicated qualification testing
  - are potentially sensitive to single-event effects (SEE)
- ACES specific considerations
  - benign environmental conditions *inside* the ISS (benefits COTS use)
  - potenial cost savings; but dependent on requirements specification!
  - use of Galileo signal highly desirable (noise, multipath); feasibility??
  - ensure extensive and transparent pre-flight testing with signal-simulator
- Multipath
  - assess ISS multipath environment (ray tracing, Monte Carlo simulation)
  - assess need for choke rings
  - consider use of twin antennas to identify code multipath

Further Reading

- Langley R. B., Montenbruck O., Markgraf M., Kang C.S., Kim D.; *Qualification of a commercial dual-frequency GPS receiver for the e-POP platform onboard the Canadian CASSIOPE spacecraft*; 2nd ESA Workshop on Satellite Navigation User Equipment Technologies, NAVITEC'2004, 8-10 Dec. 2004, Noordwijk, The Netherlands (2004).
- Garcia-Fernandez M., Montenbruck O., Markgraf M., Leyssens J.; *Affordable Dual-Frequency GPS in Space*; 16th International ESA Conference on Guidance, Navigation and Control; 17-21 Oct. 2005, Loutraki, Greece (2005).
- Montenbruck O., Garcia-Fernandez M., Williams J.; *Performance Comparison of Semi-Codeless GPS Receivers for LEO Satellites*; GPS Solutions (2006). DOI 10.1007/s10291-006-0025-9