

United Nations/Nepal Workshop on Applications of Global Navigation Satellite Systems

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Software-defined GNSS receiver as a framework for GNSS-related research and education

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GNSS SDR receiver as a framework for research and education

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▪ **Content of the presentation**

- Introduction: Software-Defined Radio (SDR) concept
- GNSS SDR: a signal perspective
- GNSS SDR: practical implementation
- GNSS SDR: prospects for research
- GNSS SDR: prospects for (academic) education
- GNSS SDR MSc course at University of Rijeka, Croatia
- Conclusion: Proposal for recommendations

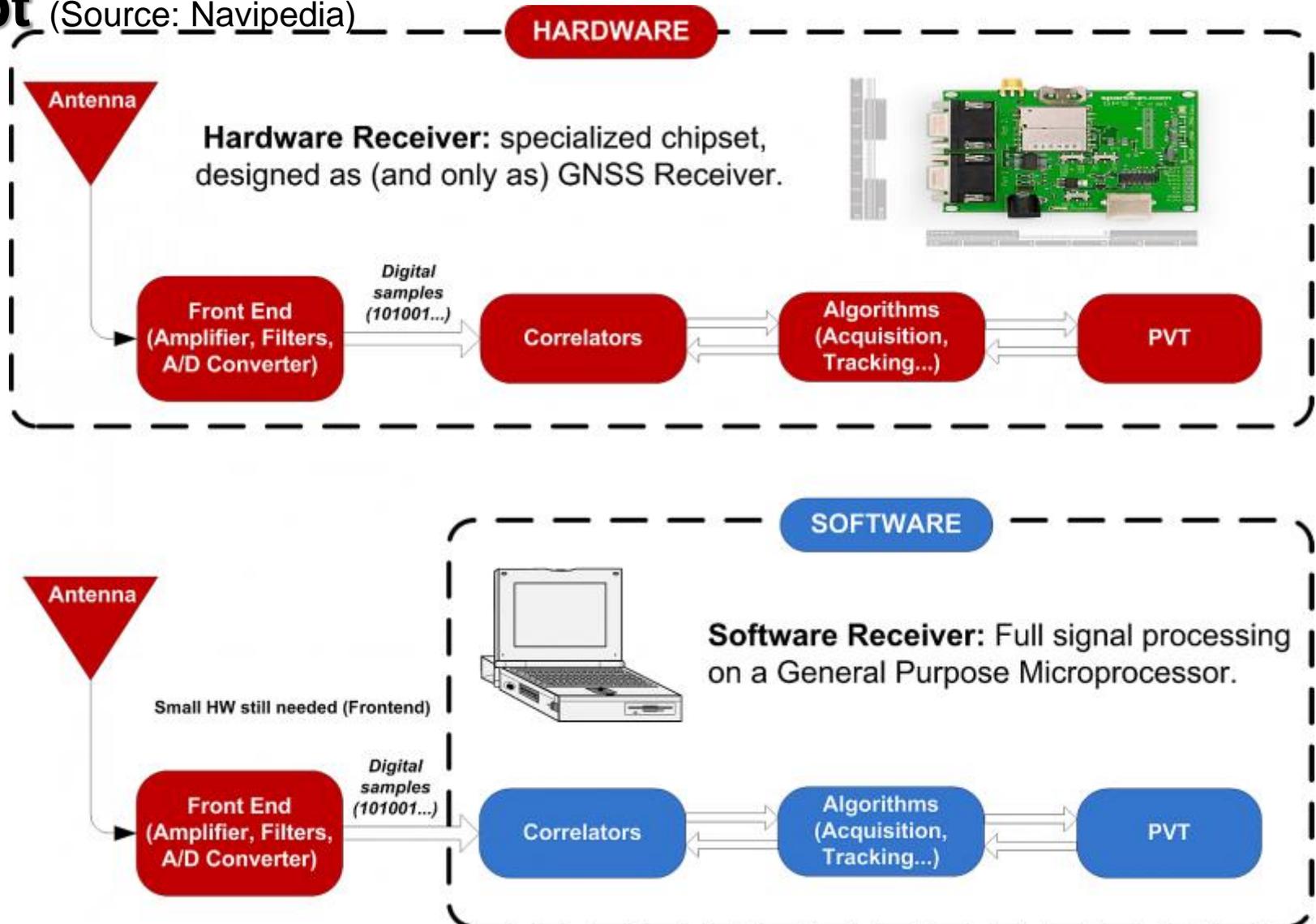
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Introduction: Software-Defined Radio (SDR)

concept (Source: Navipedia)



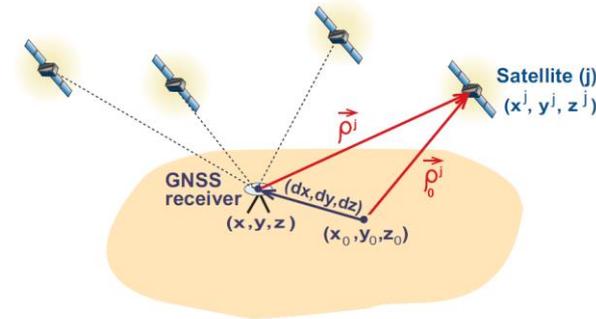
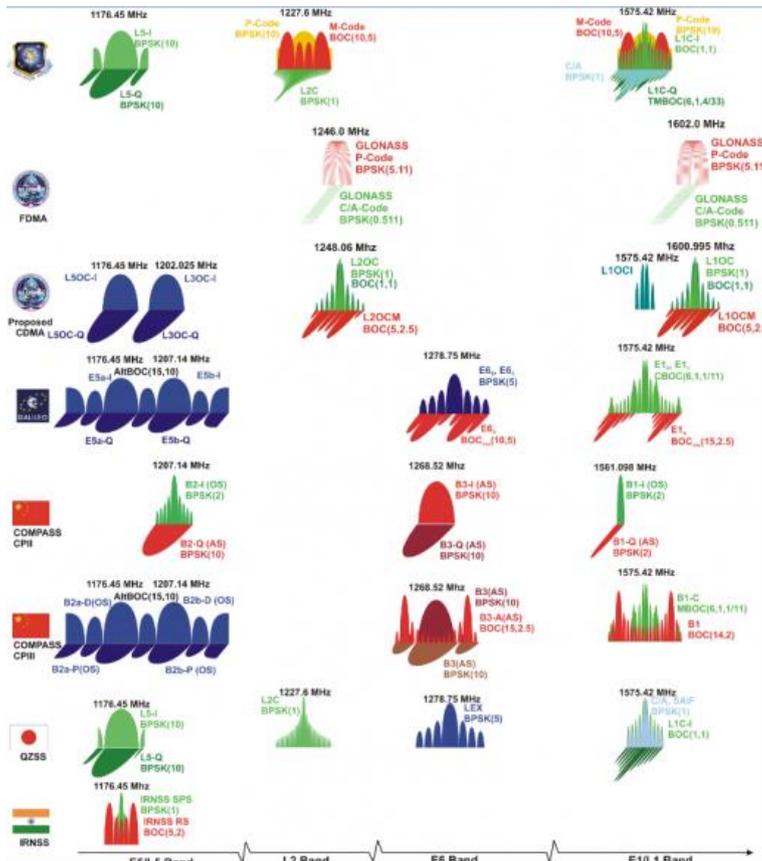
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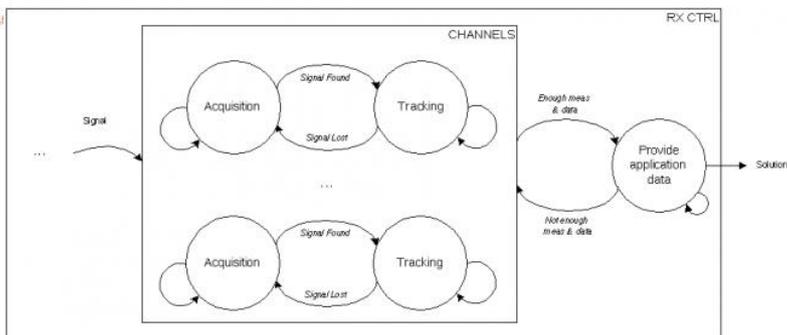
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■ GNSS SDR: a signal perspective

(Source: Navipedia)



$$\rho^j(x, y, z) = \sqrt{(x^j - x)^2 + (y^j - y)^2 + (z^j - z)^2}$$



$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} + \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix}$$

$$\begin{bmatrix} R^1 - \rho_0^1 - D^1 \\ \vdots \\ R^n - \rho_0^n - D^n \end{bmatrix} = \begin{pmatrix} \frac{x_0 - x^1}{\rho_0^1} & \frac{y_0 - y^1}{\rho_0^1} & \frac{z_0 - z^1}{\rho_0^1} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{x_0 - x^n}{\rho_0^n} & \frac{y_0 - y^n}{\rho_0^n} & \frac{z_0 - z^n}{\rho_0^n} & 1 \end{pmatrix} \begin{bmatrix} dx \\ dy \\ dz \\ c \delta t \end{bmatrix}$$



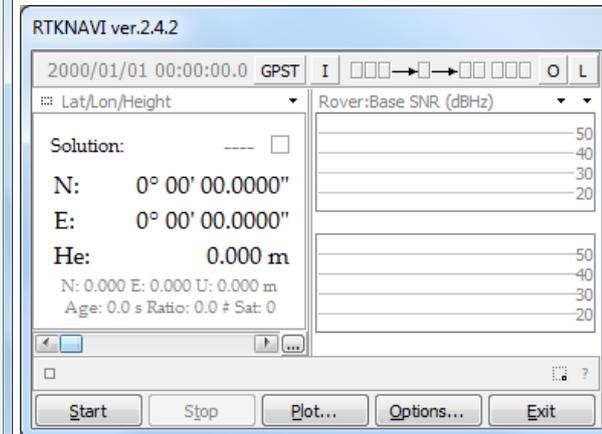
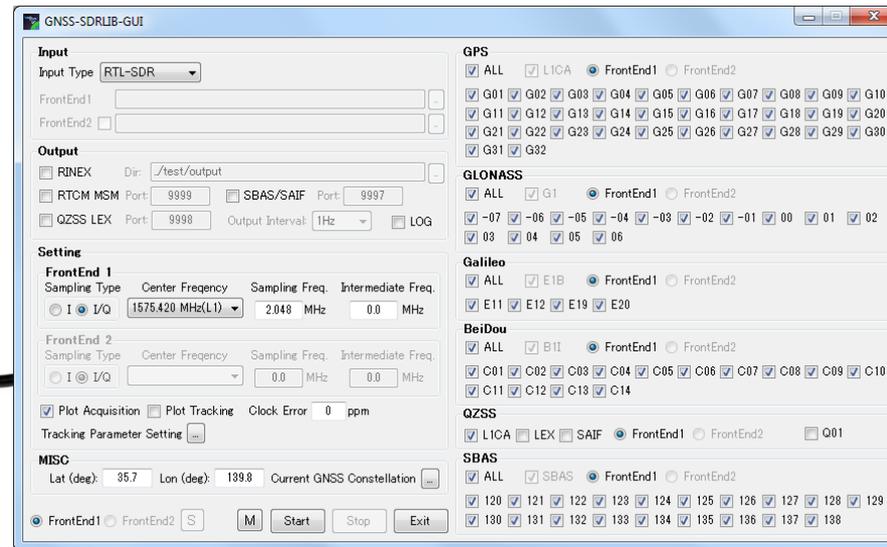
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■ GNSS SDR: practical implementation

(Source: Navipedia, Amazon)



RF processing

Baseband processing

Navigation (application) processing

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■ GNSS SDR: prospects for research

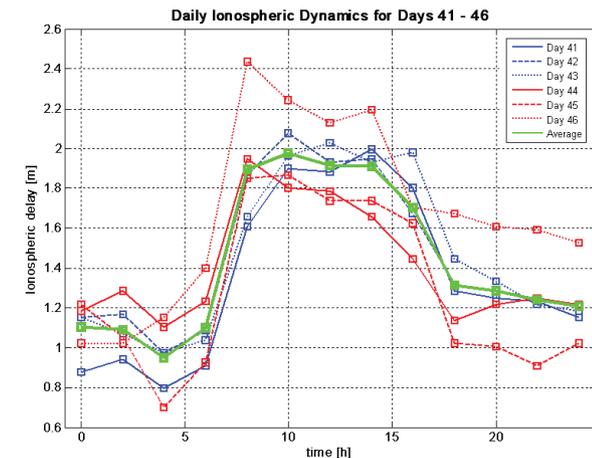
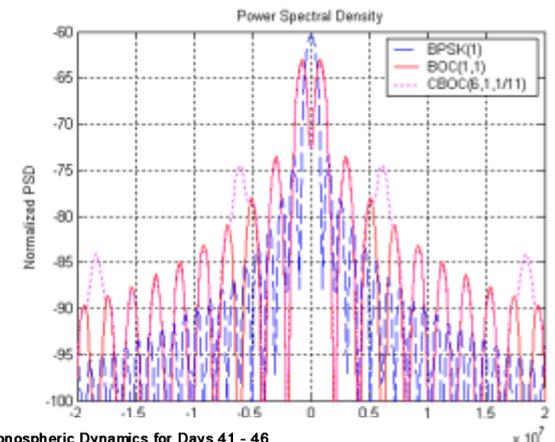
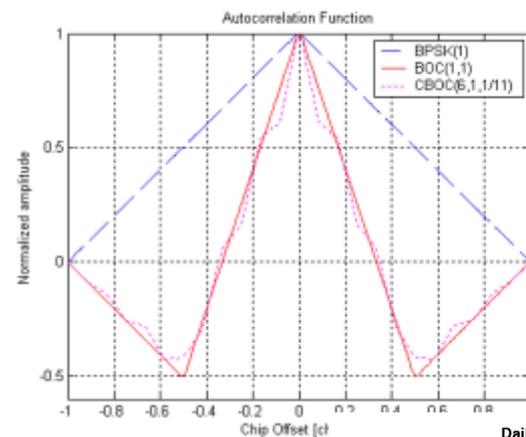
■ General: development of your own GNSS SDR receiver with bespoke processing and estimation algorithms; GNSS vulnerabilities assessment and resilient GNSS development

■ Baseband processing:

- signal waveform
- signal attenuation
- spectrum
- correlation
- signal anomaly detection

■ Navigation processing:

- error corrections
- position estimation
- velocity estimation
- positioning error assessment
- performance anomaly detection



(Source: Navipedia, R Filjar)

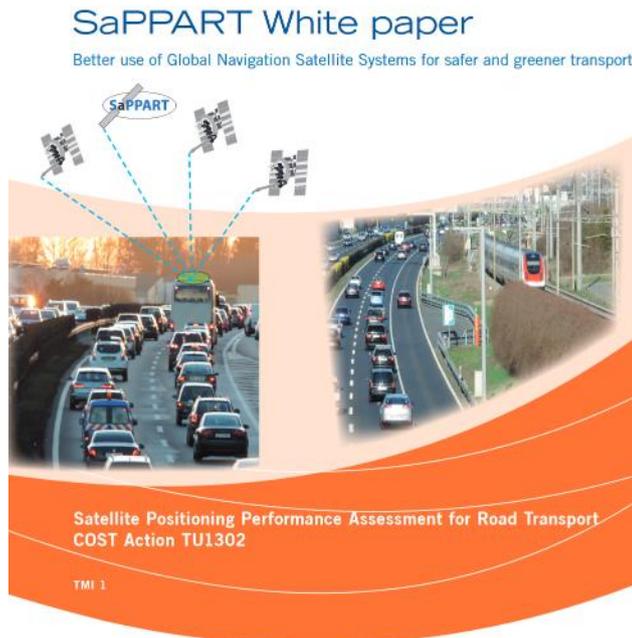
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- **GNSS SDR: prospects for research**
- GNSS positioning performance assessment – methodology described in the recent *EU COST Action TU1302 Satellite Positioning Performance Assessment for Road Transport* white paper - available at: <http://bit.ly/1N3wO5L>

TECHNIQUES ET MÉTHODES



(Source: COST Action SaPPART)

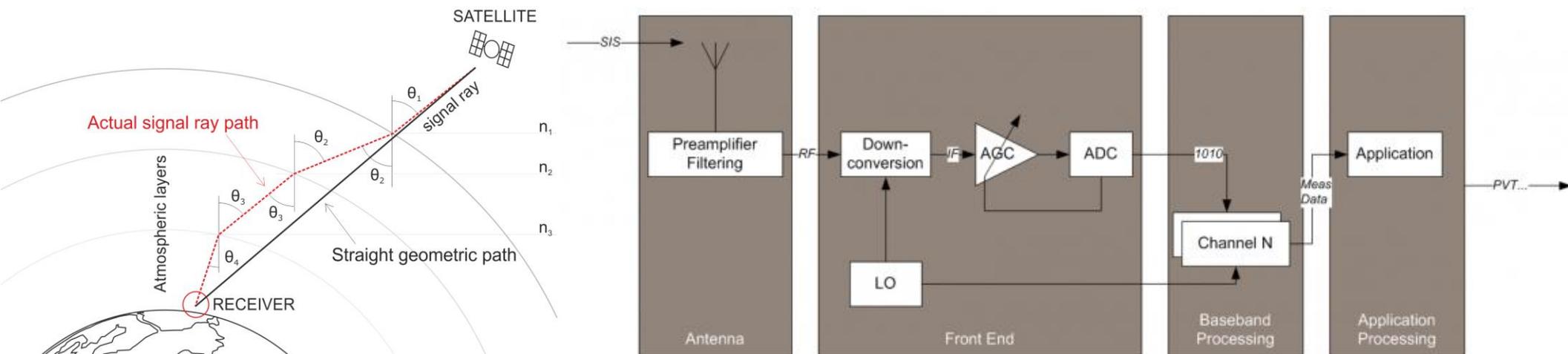
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■ GNSS SDR: prospects for (academic) education

- General: understanding of GNSS SDR receiver, and its processing and estimation algorithms; understanding GNSS shortcomings and vulnerabilities
- Baseband processing: statistical signal processing, filters and correlators, pseudorange estimation
- Navigation processing: position estimation; ionospheric, satellite ephemeris and DGNSS corrections deployment for GNSS positioning estimation improvement (Source: Navipedia, Sanz Subirana *et al*, 2013))



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▪ **GNSS SDR MSc course at University of Rijeka, Croatia**

- A one-semester course for MSc students of computer science, navigation, electrical engineering, mathematics, physics and the other STEM-oriented subjects
- Content: general concept of Software-Defined Radio presented from navigation algorithm, signal processing and spectrum management perspectives; detailed assessment of the SDR concept application on GNSS SDR receiver development; algorithms and models; advanced design using modern computing technologies (distributed and parallel computing, cloud), GNSS positioning performance assessment and improvement
- Lectures and laboratory work based on open-source software every student can freely install on his/her computer
- Lectures in Croatian and in English

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▪ **Conclusion: Proposal for recommendations**

1. Considering the flexibility and transparency of signal and information processing, the inclusion of GNSS SDR concept in the UN IGC GNSS curriculum is recommended as the good practice.
2. The broadband and navigation processing and algorithms are recommended to enhance the UN ICG GNSS curriculum with, as fundamental subjects.
3. The introduction of the practical laboratory work with the open-source GNSS SDR receiver is recommended as the good practice for students, scientists and engineers of various disciplines that utilise GNSS in scientific and engineering activities.

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■ Reference

- Takasu, T. (2016). RTKLIB open-source software package. Available at: <http://bit.ly/2gXSd42>, accessed on: 5 December, 2016.
- Suzuki, T. (2016). GNSS SDRLIB: An Open Source GNSS Software Defined Radio Library. Available at: <http://bit.ly/2h9NCi5>, accessed on: 5 December, 2016.
- ESA, in partnership with United Nations Office for Outer Space Affairs. (2016). Navipedia. Available at: <http://www.navipedia.net>, accessed on: 5 December, 2016.
- Stewart, B *et al.* (2015). Software-Defined Radio Using MatLab & Simulink and the RTL-SDR. University of Strathclyde. Glasgow, UK. Available at: <http://www.desktopsdr.com>, accessed on: 5 December, 2016.
- Sanz Subirana, J *et al.* (2013). GNSS Data Processing – Volume I: Fundamentals and Algorithms. ESA. Noordwijk, The Netherlands. Available at: <http://bit.ly/1tDzJIQ>, accessed on: 5 December, 2016.
- Filić, M, Filjar, R and Ruotsalainen, L. (2016). An SDR-based Study of Multi-GNSS Positioning Performance During Fast-developing Space Weather Storm. *TRANSNAV*, **10**(3), 395 – 400. DOI: 10.12716/1001.10.03.03. Available at: <http://bit.ly/2fxAvph>, accessed on: 5 December, 2016.

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▪ **Traceability**

This lecture is partially based on manuscripts presented and discussed at the Annual Baska GNSS Conference (Baska, Krk Island, Croatia) series, a meeting point for scientists, engineers, strategists, advisors, policy-makers, technology- and business-developers, regulators, end-users and the other interesting parties.

The Annual Baska GNSS Conference addresses the latest developments in:

- GNSS core and advanced PNT,
- development of resilient GNSS (especially against space weather, ionospheric and jamming effects),
- (statistical) signal processing and navigation algorithms for software-defined radio (SDR) GNSS receiver design,
- GNSS alternatives, and
- GNSS PNT navigation and non-navigation applications (incl. navigation of autonomous rovers, intelligent transport systems, location-based services, space weather and ionospheric monitoring, timing and synchronisation applications, forestry, and agriculture).

**Invitation to 11th Annual Baska GNSS Conference to be held in
Baska, Krk Island, Croatia on 7 - 9 May, 2017**

Latest news and Call for Papers at: <http://bit.ly/2hndJ11>

**THANK YOU FOR YOUR
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