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THE PROBLEM OF COMPATIBILITY AND INTEROPERABILITY OF SATELLITE NAVIGATION SYSTEMS IN COMPUTATION OF USER'S POSITION

PLAN OF PRESENTATION

- Introduction
- Political acknowledgment
- Signal in space
- Time reference frame
  - GPS time (GPST)
  - GLONASS system time (GLONASSST)
  - Galileo system time (GST)
  - other systems and translations
- Geodetic coordinate reference frame
- Conclusions

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INTRODUCTION (1)

➢ Satellite Navigation System (SNS)

- **at present**
  - **GPS – fully operational**
  - **GLONASS – operational**
- **under construction**
  - **Galileo – Europe**
  - **COMPASS – China**

➢ Regional SNS under construction

- **IRNSS – India**
- **QZSS – Japan**

INTRODUCTION (2)

- **Satellite Based Augmentation System (SBAS)**
  - **at present fully operational**
    - **EGNOS – Europe**
    - **WASS – USA**
    - **MSAS – Japan**
  - **under construction**
    - **GAGAN – India**
    - **SDCM – Russia**
- **SNS and SBAS ⇨ GNSS**

INTRODUCTION (3)

- today more than 60 operational SNS and SBAS satellites are in orbit transmitting a variety of signals on multiple frequencies

- within 5 years 90 or more satellites with new signals, new frequencies

- All these changes, new signals, new frequencies ⇨ good news, but sometimes not such good news for GNSS product designers, service providers, and finally users

- All these systems, signals, services must be **compatible**

and

all open signals and services should also be **interoperable** to the maximum extent possible

INTRODUCTION (4)

- **compatibility** of GNSS ⇨ ability of each system to be used separately or together without interfering with each individual system and without adversely affecting navigation warfare

- **interoperability** of GNSS ⇨ ability of each system having independent control loop to operate jointly with other systems without interfering each other on condition that signal frequency ranges, coordinate reference frames and time reference frames coincides as much possible

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POLITICAL ACKNOWLEDGEMENT (1)

- the U.S. Government, EU, Australia, China, India, Japan, Russia, ICAO, IMO, ITU, NATO ⇨ cooperatives activities related to space-based PNT systems:
  - Japan, 1998, Joint Statement on GPS Cooperation
  - European Union, 2004, GPS – Galileo Cooperation Agreement
  - Russia, 2004, Joint Statement, GPS – GLONASS cooperation
  - India, 2007, Joint Statement on GNSS cooperation
  - China, 2007, operator-to-operator coordination under ITU auspices
  - Australia, 2007, Joint Delegation Statement on Cooperation in the Civil Use

POLITICAL ACKNOWLEDGEMENT (2)

Country	Compatibility and interoperability
China	Compass & Galileo
India	IRNSS & Galileo and GAGAN & EGNOS
Japan	QZSS &Galileo, good prospect for on E6CS/QZSSLex interoperable signal
Russian Federation	GLONASS & Galileo and SDCM & EGNOS
United States	GPS & Galileo, common MBOC civil signal On GPS L1C – Galileo E1 Open Service

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SIGNAL IN SPACE

System	Frequency carrier [MHz]			
	1176.45	1207.14	1227.60	1575.42
GPS	L5 (satellites IIF)	–	L2	L1 all satellites
Galileo	E5a	E5b	–	E2-L1-E1
GLONASS K1 and later	–	L3	–	–
GLONASS K2 and later	L5	L3	–	–
Compass	B2a	B2b	–	B1C
SBAS	L5 (WAAS in the future)	–	–	L1
QZSS	L5	–	L2	L1

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TIME REFERENCE FRAME
GPS time (GPST)

- own, continuous time scale
- referenced to UTC (US Naval Observatory – USNO)
- differs from UTC by a nearly integer number of seconds

$$GPST - UTC = n \cdot s - C_t$$

- not corrected to match the rotation of the Earth ⇨ without leap second
- paper time scale
- GPST and UTC were coincident at 0h January 6, 1980

$$TAI - GPST = 19 \text{ seconds}$$

- today difference between GPST and UTC is 15 seconds

TIME REFERENCE FRAME
GLONASS system time (GLONASSST)

- based on a atomic time scale
- controlled by the GLONASS Control Synchronizer, based on a set of hydrogen masers

$$UTC = GLONASSST + \zeta_c - 3h$$

ζ_c – discrepancy, communicated in navigation message (frame 5)

3h – difference Moscow time to Greenwich time

- implementation of leap second

TIME REFERENCE FRAME
Galileo system time (GST)

- continuous atomic time scale
- nominal constant offset (integer number of seconds) with respect to TAI
- will be maintained by an ensemble of atomic frequency standards
- implementation of leap second
- the data concerning the offset of GST with respect to TAI and UTC will be included in navigation message

TIME REFERENCE FRAME
other system and translations

- **Compass system ⇨ BeiDou time (BDT), Chinese UTC maintained by atomic clocks**
- **QZSS system ⇨ time scale is aligned to TAI, the same integer offset to TAI as GPS system**
- **UTC can be obtained from GPS receiver, in the future from Galileo receiver also, information in the navigation data**

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GEODETIC COORDINATE REFERENCE FRAME (1)

- GPS system ⇨ WGS–84 frame, almost identical with the latest version ITRF
- GLONASS system ⇨ PZ–90.02 frame, coordinated to ITRF
- Galileo system ⇨ GTRF (Galileo Terrestrial Reference Frame)
- Compass system ⇨ CGCS2000 (China Geodetic CoSystem 2000), consistent with ITRF
- problem of compatibility of SNS and SBAS in the case of reference frame for majority users does not exist

GEODETIC COORDINATE REFERENCE FRAME (2)

- on the ship one GPS receiver at least, sometimes even four
- on the bridge navigation several hundred chart at least, often several thousand
- majority of the charts are referred to local or regional geodetic datum
- datum used by GPS receiver and datum on which the chart is published must be the same
- since 1982 the shift „Satellite Derived positions" is published on many chart

The number of United Kingdom Hydrographic office charts referred to different geodetic datums

Geodetic datum	Year			
	2004	2006	2008	2010
Australian Geodetic	142	127	118	69
European (1950)	817	686	547	481
ETRS 89	636	724	1107	1467
North American Datum (1983)	312	319	348	356
Pulkovo 1942	60	61	69	77
Undetermined	**1993**	1997	1773	1667
WGS72	39	33	34	33
WGS84	1488	2081	2339	**2892**
Total (all charts)	**6786**	**7144**	**7359**	**8014**

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CONCLUSIONS (1)

- increasing number of agreements between GNSS providers guarantees the interoperability of all systems and their signals
- each GNSS ⇨ the main goal of the international cooperation ⇨ better compatibility and interoperability with existing and future SNS and SBAS for user benefit
- **L1C** signal transmitted by the first QZSS satellite (Michibiki) is the **first truly interoperable signal**
- for all users **one official reference frame** (time and datum) of all SNS and SBAS **would be very desirable**, but actually this demand cannot be realized
- GPS positions referred to different datums can differ by several hundred metres

CONCLUSIONS (2)

- the time offset between the difference reference time SNS will be emitted in the navigation message of these systems

- each GNSS uses own geodetic coordinate reference frame, but for navigation purposes and most user requirements, the recent agreement between ITRF, GTRF and WGS-84 is sufficient

level of GNSS integration	kind of utilization
compatibility	regulation
interoperability	coordination
interchangeability	cooperation

THANK YOU VERY MUCH

FOR

YOUR ATTENTION