

Space and Missile Systems Center



ISM for ARAIM (MT-38/39/40)

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25 Sep 19



Up-Front Remarks

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- This has been a long-term effort
 - Much work done at US-EU Bi-Lat Working Group C
 - Multiple Global Navigation Satellite Systems (MGNSS)
 - GPS+Galileo together to support civil aviation operations
 - Advanced Receiver Autonomous Integrity Monitoring (ARAIM)
 - Integrity Support Message (ISM)
- Not much has changed technically since the last PICWG
 - Same MT-38 as briefed on 12 Sep 18
 - Galileo event in Jul 19 proved the need for 2-bit status flags
 - MT-39/-40 are still here for the time being
 - Progress being made elsewhere on ‘civil key management’
 - May be able to take advantage of other people’s work



Context

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- Previously briefed at the PICWG in 2018 & 2016
 - Earlier draft versions of this ISM proposal
- Reviewed and refined within US-EU Working Group C
 - Few substantial changes
 - Operational concept harmonization
 - Competing ISM concepts found lacking
- This is one of the final socialization steps
 - Overview for PICWG questions & feedback
 - From 'big picture' to 'bit particulars'
 - Expect final PIRNs for review at next year's PICWG



- **Integrity Support Message (ISM)**
- **GPS MT-38/39/40 Proposal**
 - MT-38 – ARAIM Parameters
 - MT-39 – ISM Management
 - MT-40 – ISM Signature Key
- **MT-38/39/40 Details**
 - L2CM signal, IS-GPS-200
 - L5I5 signal, IS-GPS-705
 - L1C_D signal, IS-GPS-800
- **Concluding Remarks**

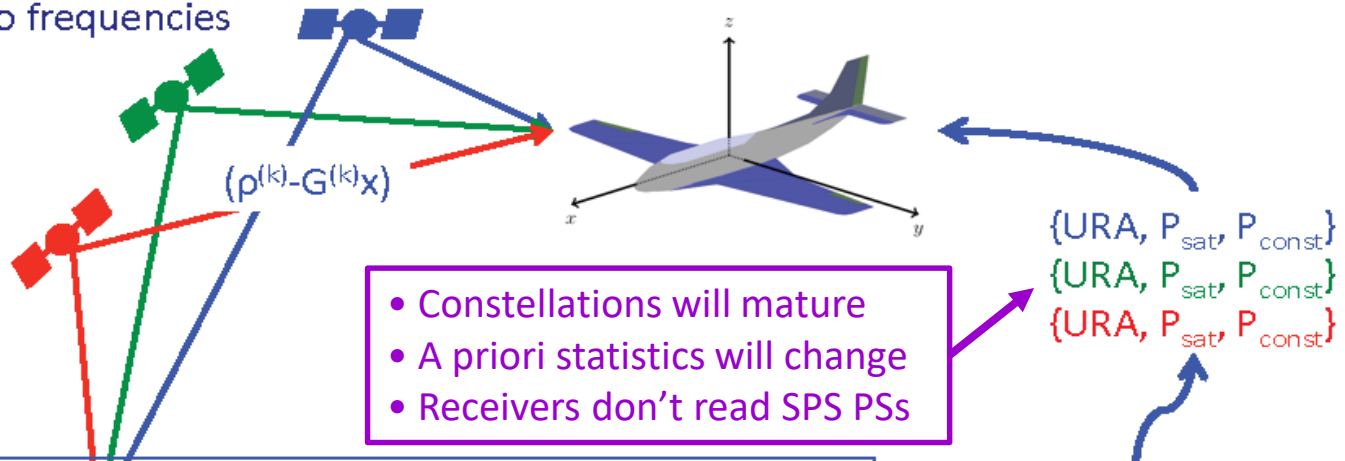


ISM Principles

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Advanced RAIM to Support Lateral + Vertical Navigation Worldwide

Multi-constellation
Two frequencies



Independent of GNSS Ground Segments

Reference Stations

- global network
- e.g. SBAS reuse or
- e.g. NASA's GDGPS

Offline monitors check GNSS commitments on P_{sat} & P_{const}

Integrity support message (ISM)

- new constellations
- $\{URA, P_{sat} \& P_{const}\}$
- broadcast using databases or GNSS

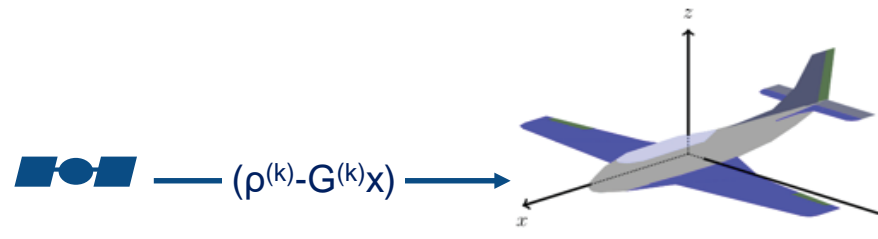


RAIM Reminders

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Baseline RAIM has been Supporting Horizontal Navigation Since 1993

GPS constellation
Single frequency
Possibly with SA



- RAIM runs at same rate as PVT solution (e.g., 1 Hz typical)
- RAIM is basically a statistical consistency test
 - 4 measurements will always be consistent = no RAIM
 - 5 measurements may be inconsistent = “Fault Detection” (FD)
 - Each subset of 4 will always be consistent = no more info
 - 6 measurements may be inconsistent = FD
 - 5 of the 6 subsets of 5 may be inconsistent = “Fault Exclusion” (FE)
 - 7 measurements may be inconsistent = FD+FE = “FDE”
 - 6 of the 7 subsets of 6 may be inconsistent = FE
- RAIM works provided ≤ 1 faulty measurement at a time
 - 2 faulty measurements might – or might not – be detected

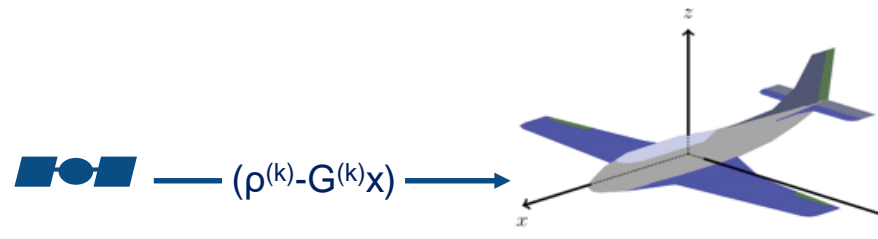


RAIM Can Be Helped

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Baseline RAIM has been Supporting Horizontal Navigation Since 1993

GPS constellation
Single frequency
Possibly with SA



- RAIM is inescapably a statistical consistency test
 - If a priori statistics too tight
 - Too many false detections / false exclusions
 - Poor usability (users hate this)
 - If a priori statistics too loose
 - Can only detect/exclude huge faults
 - Poor availability (users hate this)

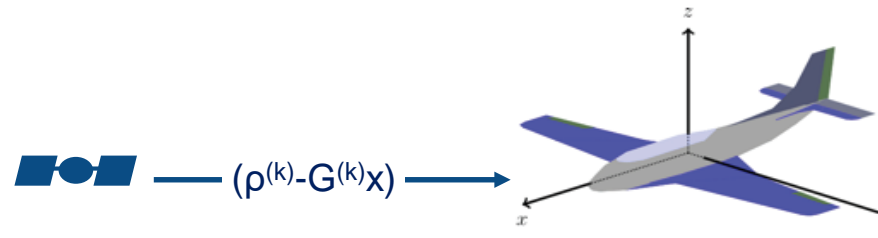


ISM is to Help RAIM

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Advanced RAIM to Support Lateral and Vertical Navigation

GPS constellation+
Dual frequency+
SA gone forever



- ISM provides the proper a priori statistics
 - Not too tight
 - Not too loose
 - Just right for current conditions
- Optimum RAIM performance!



- **Integrity Support Message (ISM)**

- **GPS MT-38/39/40 Proposal**

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- MT-40 – ISM Signature Key

- **MT-38/39/40 Details**

- L2CM signal, IS-GPS-200
- L5I5 signal, IS-GPS-705
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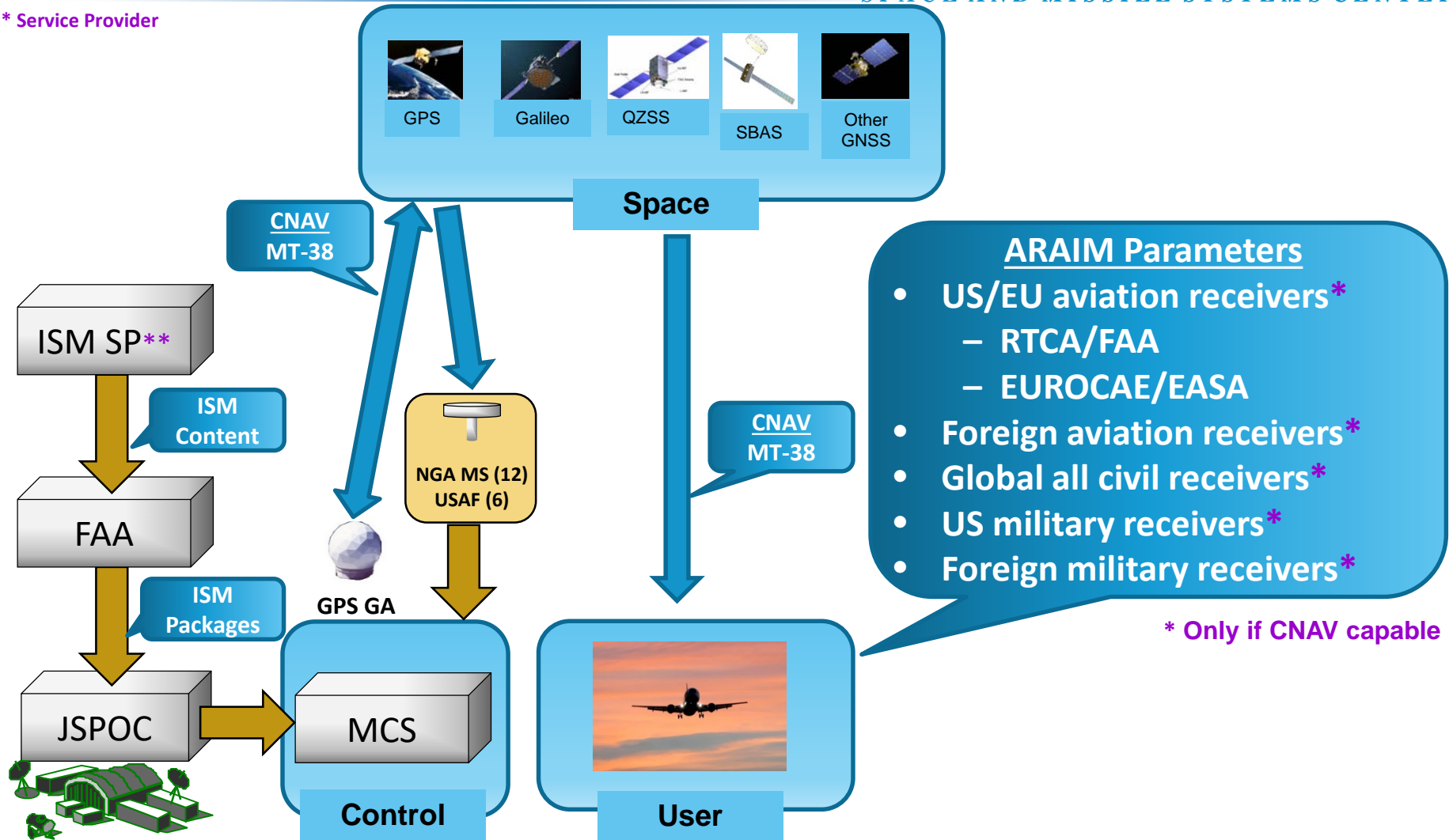
- **Concluding Remarks**



GPS MT-38 "Big Picture"

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** Service Provider

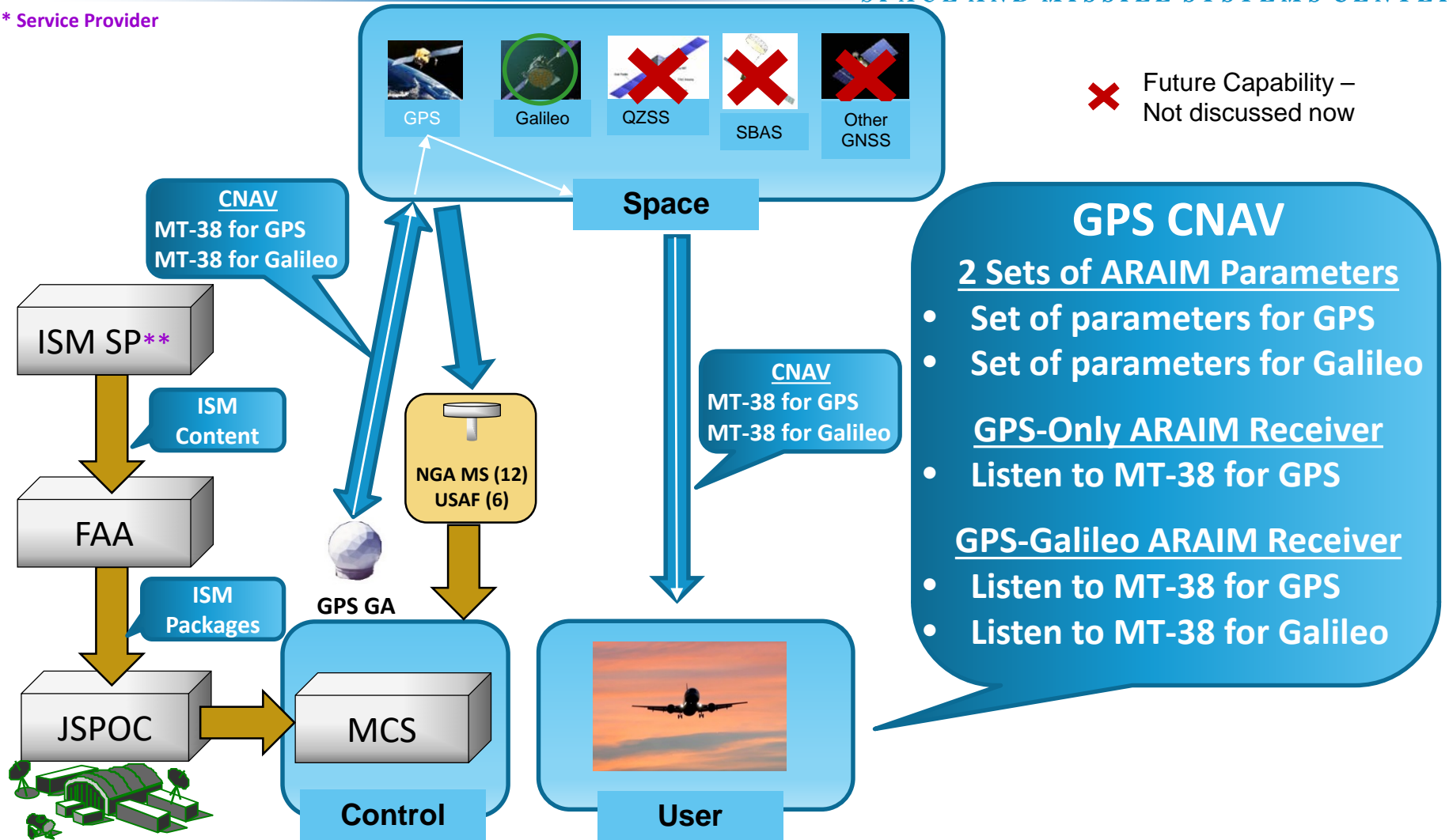




GPS MT-38 “Simple First Case”

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** Service Provider





International Politics However...

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- **National Space Policy of the U.S.A (POTUS, 28 Jun 10)**

- The United States shall:

“Engage with foreign GNSS providers to encourage compatibility and interoperability, promote transparency in civil service provision, and enable market access for U.S. industry”

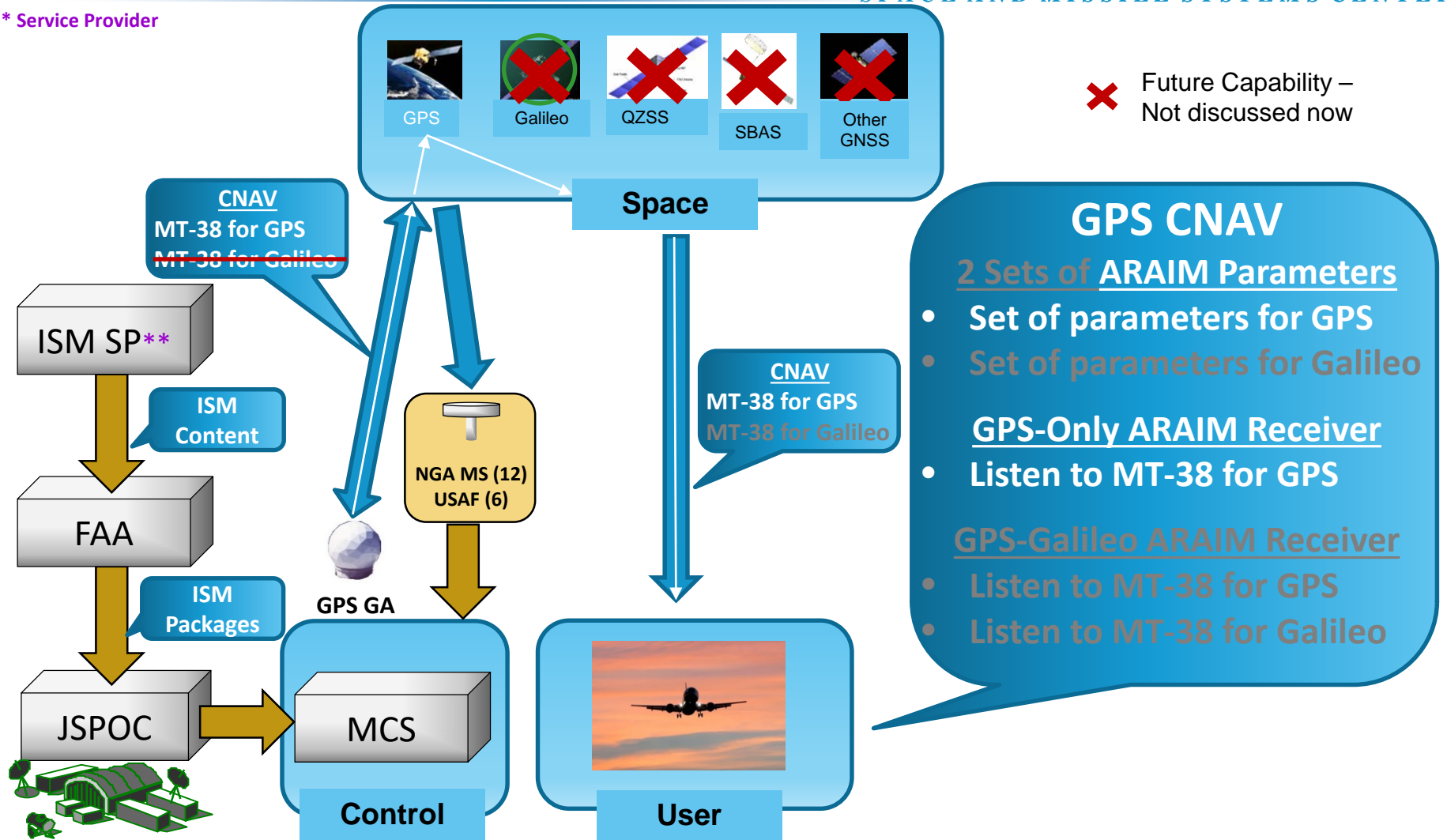
- **The MT-38/-39/-40 design can accommodate GPS only, GPS and Galileo, GPS and GNSS_x and SBAS_y etc.**
- **The EU may NOT be ready for so much cooperation**
 - GPS might not broadcast an ISM for Galileo (yet)
- **Just broadcasting ISM for GPS still very worthwhile**
 - International civil aviation almost exclusively based on GPS



GPS MT-38 “**Very** Simple First Case”

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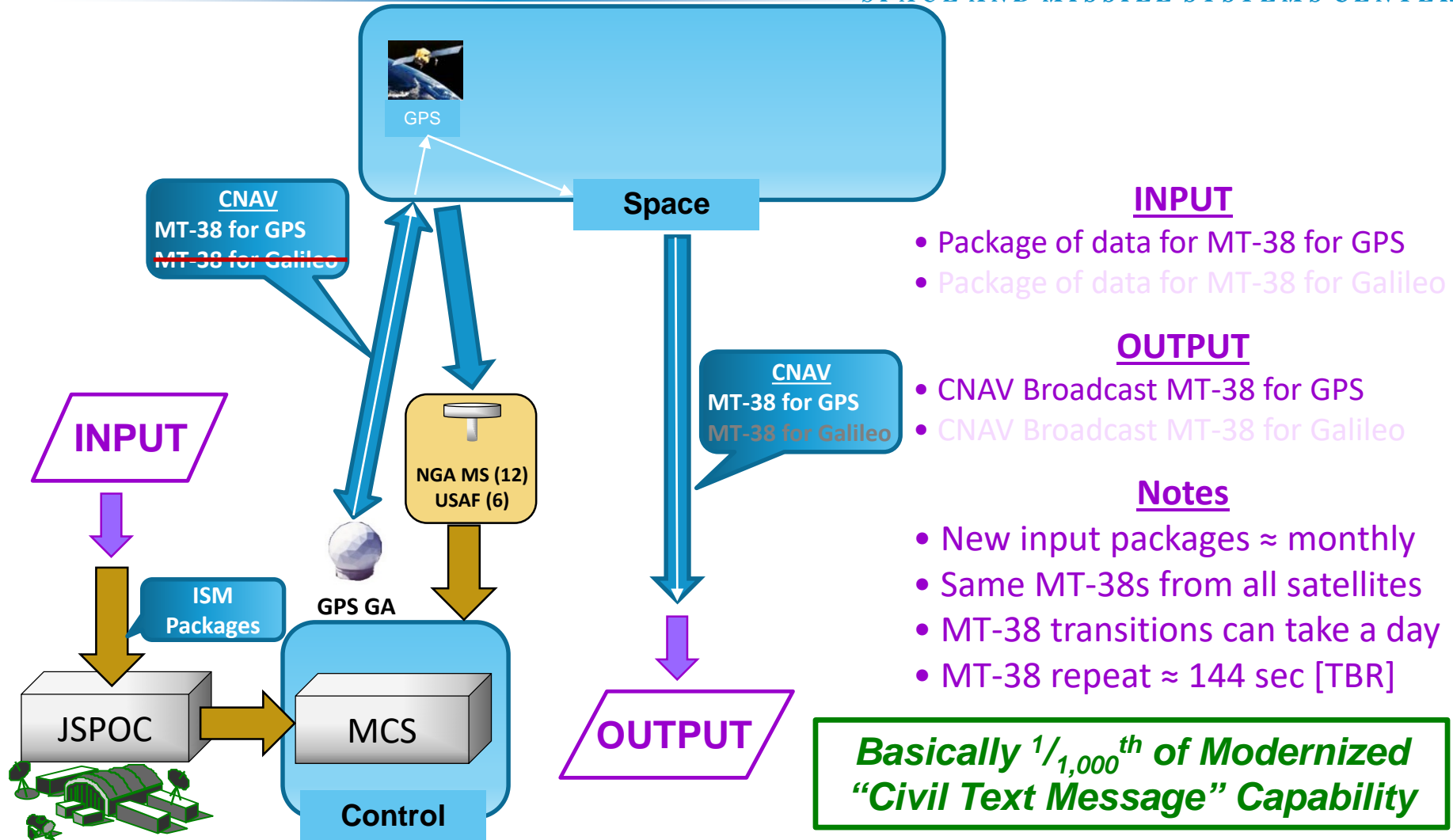
** Service Provider





GPS MT-38 “Enterprise Perspective”

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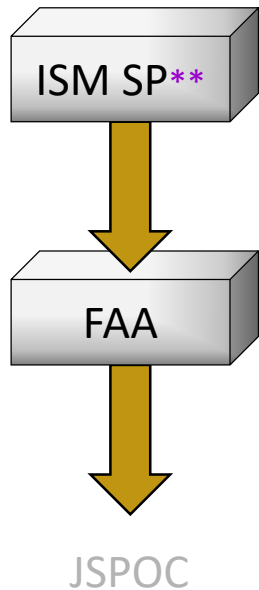


GPS MT-38 “Source Perspective”

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** Service Provider

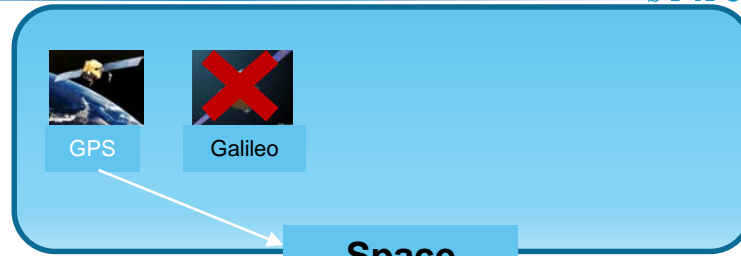
- FAA will be “source” of the ISM data packages
 - Direct service provider of ISM data for GPS
 - Pay heed to DoD’s *SPS PS* commitments
 - Possible refinement using the WAAS network
 - Possible refinement using outside contractor
 - Responsible for the ISM data for GPS
 - Indirect provider of ISM data for Galileo
 - Make arrangement with European authorities
 - Suitable European “service provider” (e.g., GSA)
 - Pay heed to EU’s *OS SDD* commitments
 - Possible refinement using the EGNOS network
 - Possible refinement using outside contractor
 - Responsible for the ISM data for Galileo





GPS MT-38 "User Perspective"

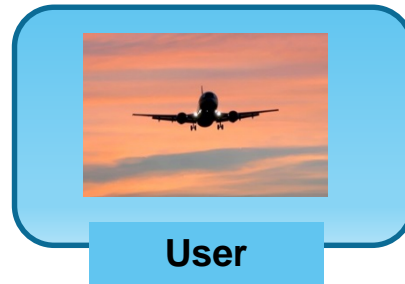
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Future Capability –
Not discussed now

- User receiver processes GNSS
 - GPS-only or GPS+Galileo
- User receiver processes MT-38s
 - GPS-only or GPS+Galileo
- User receiver performs FD/FDE
 - Better than standard RAIM
- User navigates safely
 - Life is good

CNAV
MT-38 for GPS
~~MT-38 for Galileo~~



GPS CNAV

~~2 Sets of ARAIM Parameters~~

- Set of parameters for GPS
- ~~• Set of parameters for Galileo~~

GPS-Only ARAIM Receiver

- Listen to MT-38 for GPS

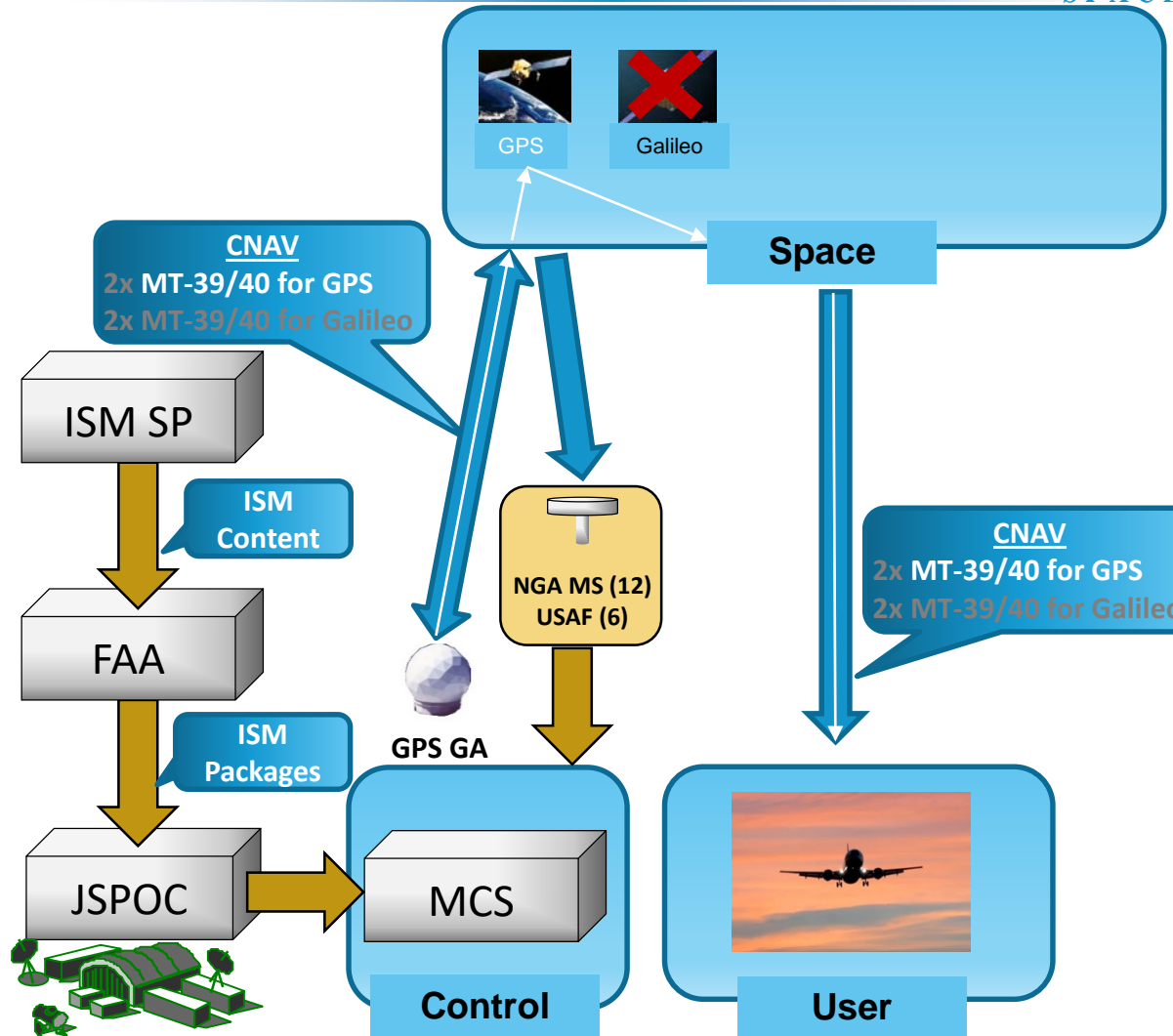
~~GPS-Galileo ARAIM Receiver~~

- ~~• Listen to MT-38 for GPS~~
- ~~• Listen to MT-38 for Galileo~~



GPS MT-39/40 Special Features

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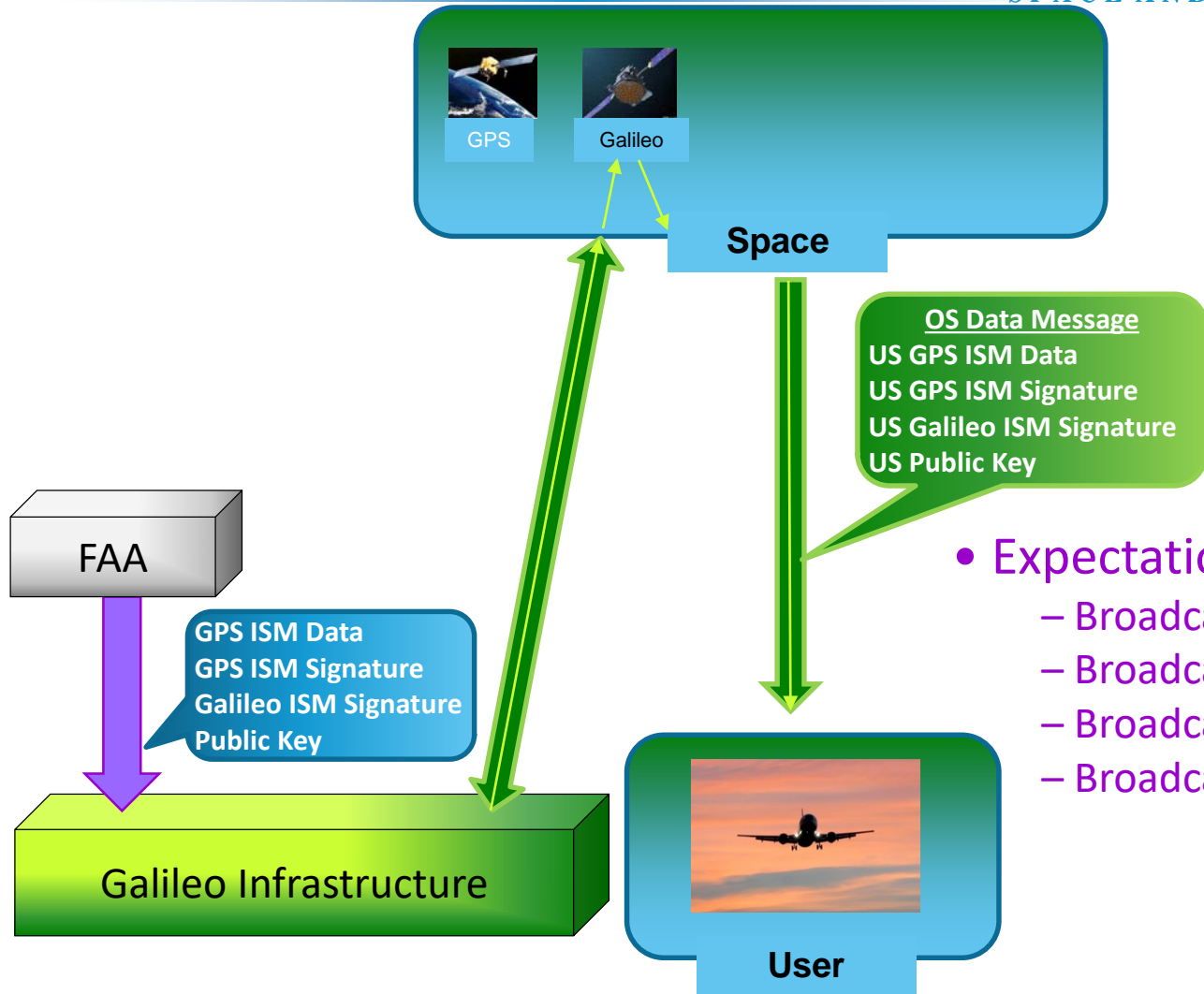
- Digital Signatures*
 - Not technically required
 - Addresses other concerns
- FAA to digitally sign MT-38s
 - MT-38 for GPS
 - MT-38 for Galileo
- EU to digitally sign MT-38s
 - MT-38 for GPS
 - MT-38 for Galileo
- MT-39 is digital signature
- MT-40 is public key

* See FIPS PUBs 180-4 & 186-4



End State: MT-38/39/40 *Quid Pro Quo*

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- Expectations from Galileo
 - Broadcast US GPS ISM data
 - Broadcast US GPS ISM signature
 - Broadcast US Galileo ISM signature
 - Broadcast US public key



Outline

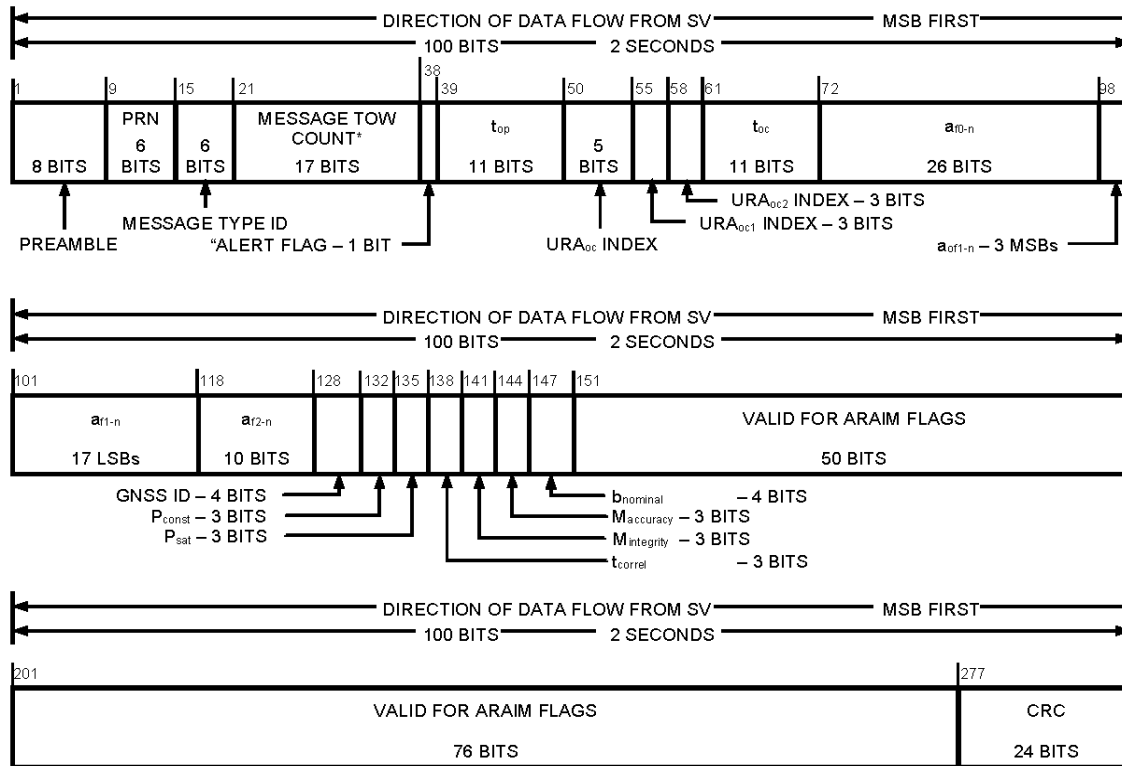
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GPS MT-38 Details – 1

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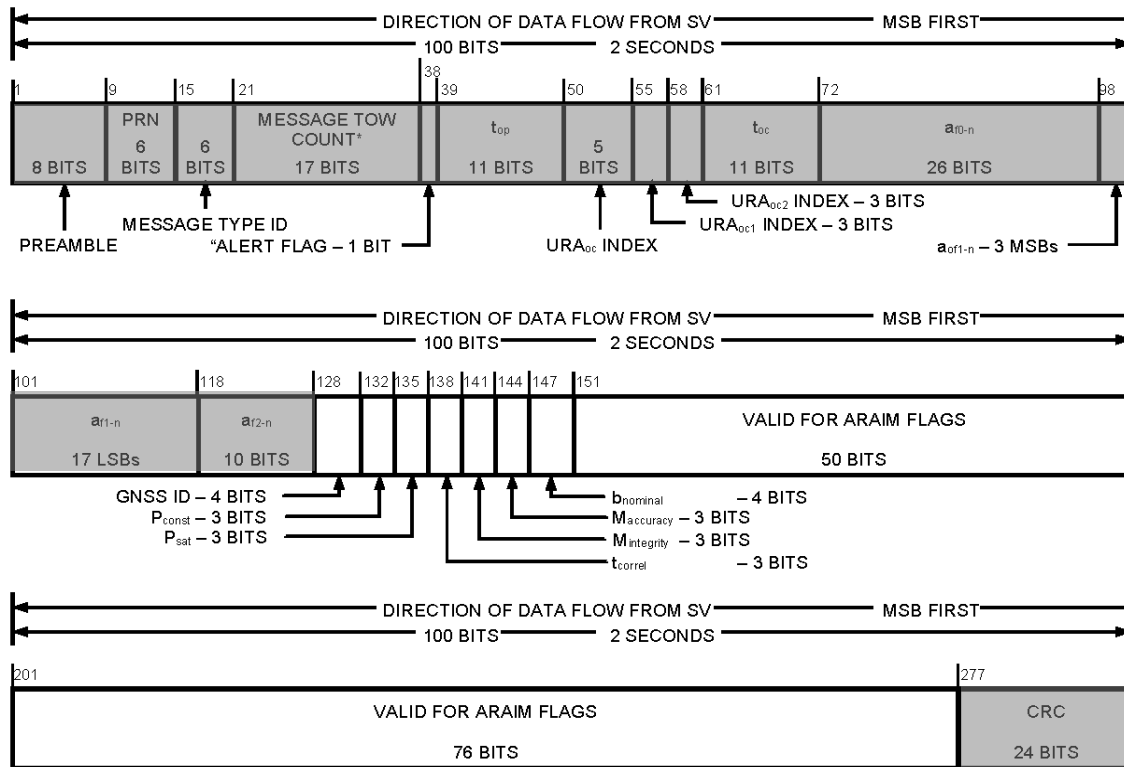
* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-15. Message Type 38 – Off-Line Integrity Support Message (ISM)



GPS MT-38 Details – I

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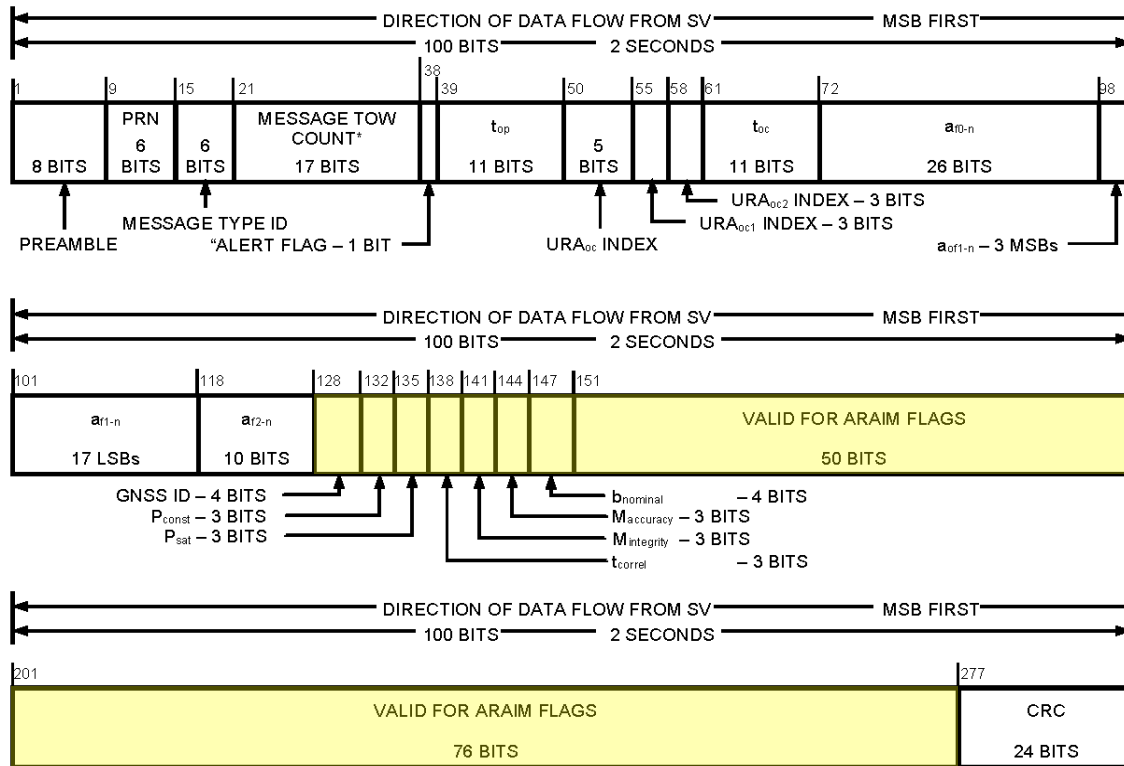
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Figure 20-15. Message Type 38 – Off-Line Integrity Support Message (ISM)



GPS MT-38 Details – I

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Figure 20-15. Message Type 38 – Off-Line Integrity Support Message (ISM)



GPS MT-38 Details – II

ENTER

Table 20-XII. ISM Parameters					
Parameter		No. of Bits**	Scale Factor (LSB)	Effective Range****	Units
GNSS ID	GNSS Constellation ID	4	1	8	see text
P_{const}	Probability of constellation integrity fault	3			see text
P_{sat}	Probability of satellite integrity fault	3			see text
t_{correl}	Correlation time constant	3			see text
$M_{integrity}$	URA multiplier for integrity	3			see text
$M_{accuracy}$	URA multiplier for accuracy	3			see text
$b_{nominal}$	Nominal pseudorange bias	4			see text
Flags	Valid for ARAIM flags	63 x (2)			see text
<p>* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB. ** See Figure 20-15 for complete bit allocation in Message Type 38. *** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.</p>					



GPS MT-38 Details – III

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20.3.3.10.2 GNSS Constellation ID.

Bits 129 through 131 of message type 38 shall identify the other GPS-like navigation system to which the associated ISM parameters apply. The four bits are defined as follows:

- 0000 = No data available
- 0001 = Galileo
- 0010 = GLONASS
- 0011 = BeiDou
- 0100 = GPS
- 0101 = SBAS
- 0110 = QZSS
- 0111 = IRNSS
- 1000 through 1111 = Reserved for other systems



GPS MT-38 Details – IV

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Table 20-XIII. ARAIM Validity Flag Mapping

Bits	Galileo	GLONASS	BeiDou	GPS	SBAS	QZSS	IRNSS
151-152	SVID 1	Freq. 1	RCN 1	PRN 1	PRN 120	PRN 183	PRN 1
153-154	SVID 2	Freq. 2	RCN 2	PRN 2	PRN 121	PRN 184	PRN 2
155-156	SVID 3	Freq. 3	RCN 3	PRN 3	PRN 122	PRN 185	PRN 3
157-158	SVID 4	Freq. 4	RCN 4	PRN 4	PRN 123	PRN 186	PRN 4
159-160	SVID 5	Freq. 5	RCN 5	PRN 5	PRN 124	PRN 187	PRN 5
161-162	SVID 6	Freq. 6	RCN 6	PRN 6	PRN 125	PRN 188	PRN 6
163-164	SVID 7	Freq. 7	RCN 7	PRN 7	PRN 126	PRN 189	PRN 7
165-166	SVID 8	Freq. 8	RCN 8	PRN 8	PRN 127	PRN 190	Invalid
167-168	SVID 9	Freq. 9	RCN 9	PRN 9	PRN 128	PRN 191	Invalid
169-170	SVID 10	Freq. 10	RCN 10	PRN 10	PRN 129	PRN 192	Invalid
171-172	SVID 11	Freq. 11	RCN 11	PRN 11	PRN 130	PRN 193	Invalid
173-174	SVID 12	Freq. 12	RCN 12	PRN 12	PRN 131	PRN 194	Invalid
175-176	SVID 13	Freq. 13	RCN 13	PRN 13	PRN 132	PRN 195	Invalid
177-178	SVID 14	Freq. 14	RCN 14	PRN 14	PRN 133	PRN 196	Invalid
179-180	SVID 15	Freq. 15	RCN 15	PRN 15	PRN 134	PRN 197	Invalid
181-182	SVID 16	Freq. 16	RCN 16	PRN 16	PRN 135	PRN 198	Invalid
183-184	SVID 17	Freq. 17	RCN 17	PRN 17	PRN 136	PRN 199	Invalid
185-186	SVID 18	Freq. 18	RCN 18	PRN 18	PRN 137	PRN 200	Invalid
187-188	SVID 19	Freq. 19	RCN 19	PRN 19	PRN 138	PRN 201	Invalid
189-190	SVID 20	Freq. 20	RCN 20	PRN 20	PRN 139	PRN 202	Invalid
191-192	SVID 21	Freq. 21	RCN 21	PRN 21	PRN 140	Invalid	Invalid
193-194	SVID 22	Freq. 22	RCN 22	PRN 22	PRN 141	Invalid	Invalid
195-196	SVID 23	Freq. 23	RCN 23	PRN 23	PRN 142	Invalid	Invalid
197-198	SVID 24	Freq. 24	RCN 24	PRN 24	PRN 143	Invalid	Invalid
199-200	SVID 25	Freq. 25	RCN 25	PRN 25	PRN 144	Invalid	Invalid
201-202	SVID 26	Freq. 26	RCN 26	PRN 26	PRN 145	Invalid	Invalid
203-204	SVID 27	Freq. 27	RCN 27	PRN 27	PRN 146	Invalid	Invalid
205-206	SVID 28	Freq. 28	RCN 28	PRN 28	PRN 147	Invalid	Invalid
207-208	SVID 29	Freq. 29	RCN 29	PRN 29	PRN 148	Invalid	Invalid
209-210	SVID 30	Freq. 30	RCN 30	PRN 30	PRN 149	Invalid	Invalid
211-212	SVID 31	Freq. 31	RCN 31	PRN 31	PRN 150	Invalid	Invalid
213-214	SVID 32	Freq. 32	RCN 32	PRN 32	PRN 151	Invalid	Invalid
215-216	SVID 33	Invalid	RCN 33	PRN 33	PRN 152	Invalid	Invalid
217-218	SVID 34	Invalid	RCN 34	PRN 34	PRN 153	Invalid	Invalid
219-220	SVID 35	Invalid	RCN 35	PRN 35	PRN 154	Invalid	Invalid
221-222	SVID 36	Invalid	RCN 36	PRN 36	PRN 155	Invalid	Invalid
223-224	Invalid	Invalid	RCN 37	PRN 37	PRN 156	Invalid	Invalid
225-226	Invalid	Invalid	Invalid	PRN 38	PRN 157	Invalid	Invalid
227-228	Invalid	Invalid	Invalid	PRN 39	PRN 158	Invalid	Invalid
229-230	Invalid	Invalid	Invalid	PRN 40	Invalid	Invalid	Invalid
231-232	Invalid	Invalid	Invalid	PRN 41	Invalid	Invalid	Invalid
233-234	Invalid	Invalid	Invalid	PRN 42	Invalid	Invalid	Invalid
235-236	Invalid	Invalid	Invalid	PRN 43	Invalid	Invalid	Invalid
237-238	Invalid	Invalid	Invalid	PRN 44	Invalid	Invalid	Invalid



GPS MT-38 Details – V

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20.3.3.10.9 Valid for ARAIM Flags.

Bits 151 through 276 of message type 38 shall provide the assumed validity flags for ARAIM at the current time for the associated GNSS constellation. Two bits are allocated to each satellite in the associated GNSS constellation as follows:

- 00 = No such satellite exists or this satellite is not addressed in this ISM
- 01 = Do not use this satellite
- 10 = OK to use these ISM parameters for this satellite
- 11 = Do not use these ISM parameters for this satellite

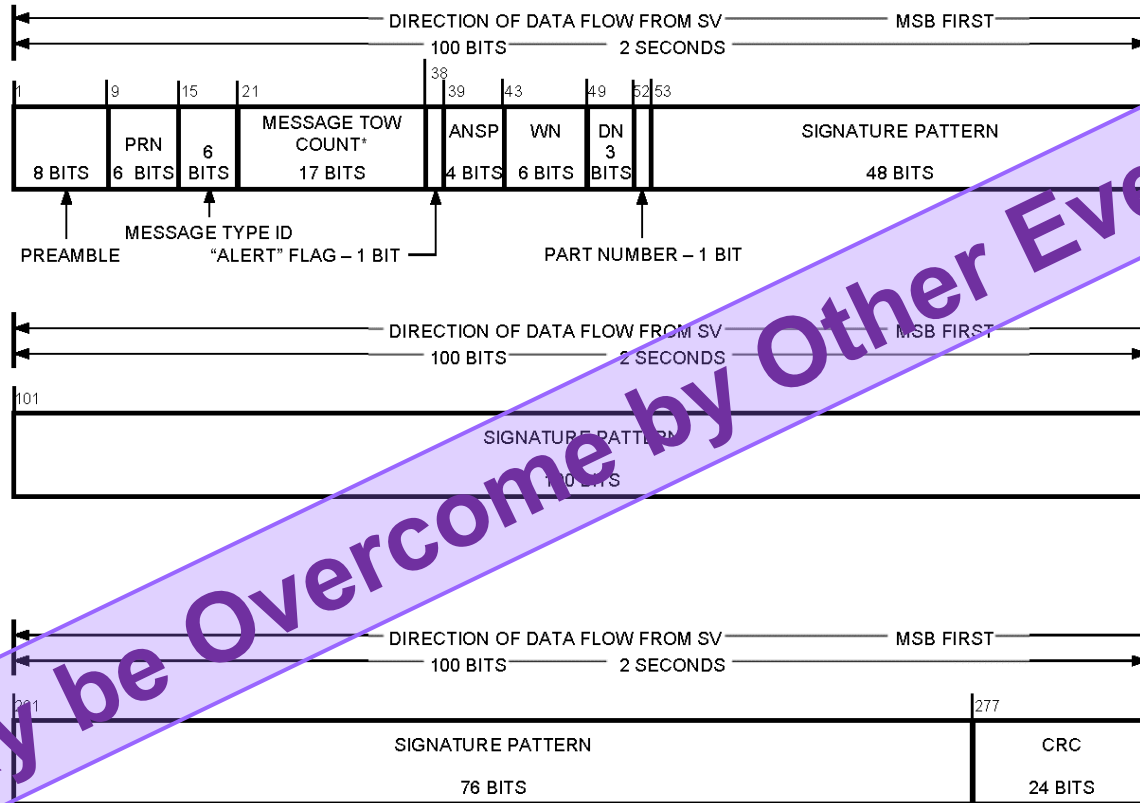
The mapping of the two-bit validity flags to the particular satellites in each specified GNSS constellations is given in Table 20-XIII.

The competing 1-bit flag proposal was found to be inadequate to handle the Galileo event in July 2019



GPS MT-39 Details

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May be Overcome by Other Events

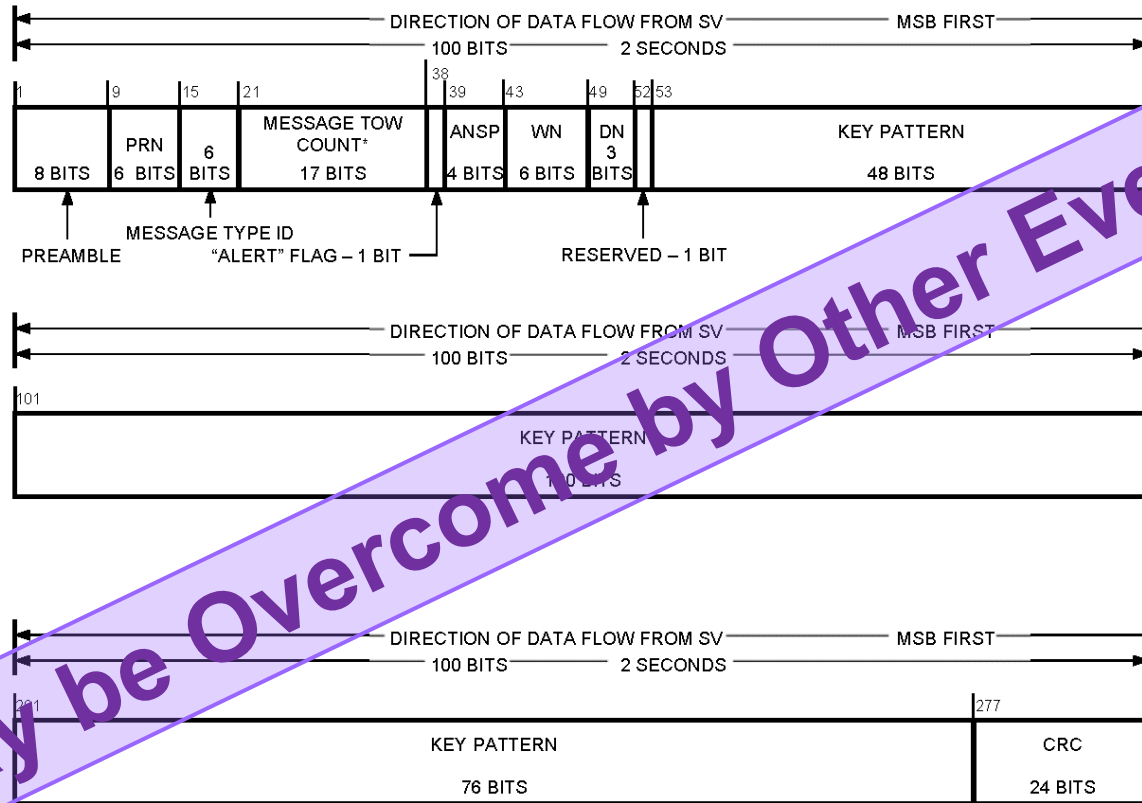
* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-16. Message Type 39 – ISM Management Message (IMM)



GPS MT-40 Details

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May be Overcome by Other Events

* MESSAGE TOW COUNT = 17 MSB OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-17. Message Type 40 – ISM Signature Key Message (IKM)



Outline

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Way Forward

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- **Develop Necessary PPCNs**
 - “Preliminary Proposed Change Notice”
 - Basically a draft PCN
 - Complete details of MT39 and MT40
- **One more round of PPCN review with stakeholders**
 - GP internal
 - FAA
 - DoD stakeholders
 - US-EU Working Group C (including Galileo)
- **Teeing-up for RFC and PCNs at future PICWG**
 - A ‘live sky demo’ would be desirable before PCN finalization