



# Validation of GPS III antenna patterns

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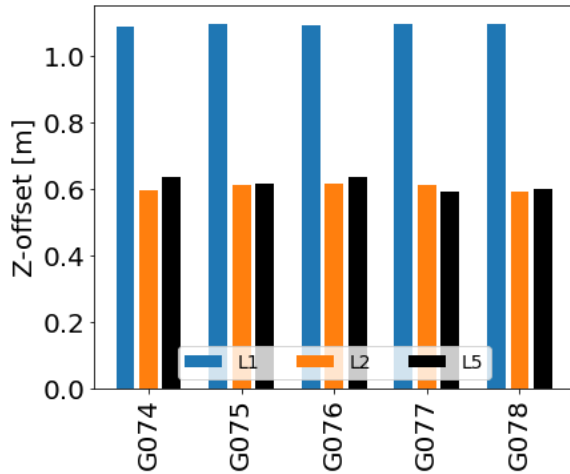


Knowledge for Tomorrow

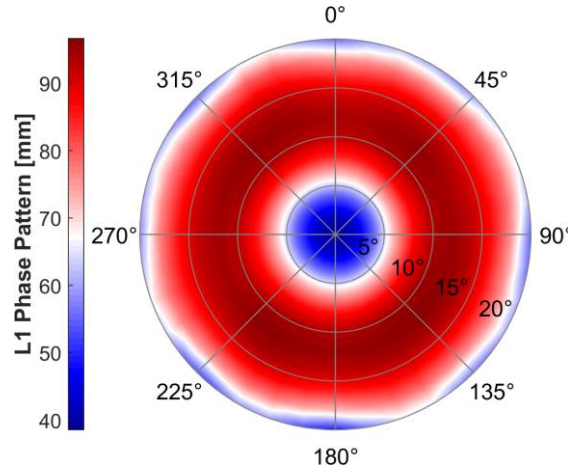


# Introduction

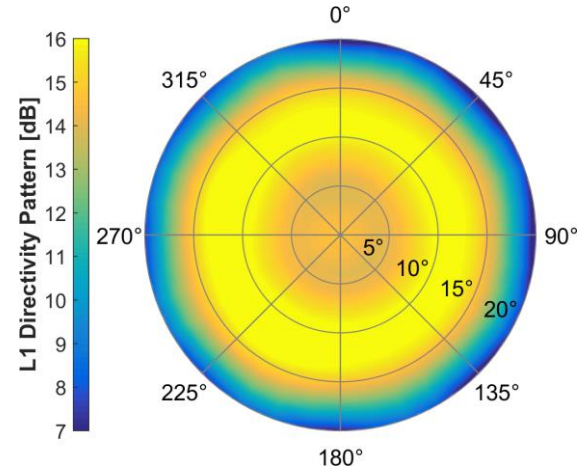
Publication of GPS III satellite metadata by manufacturer Lockheed Martin (LM)



**Phase Center Offsets**



**Phase Patterns**



**Directivity Patterns**

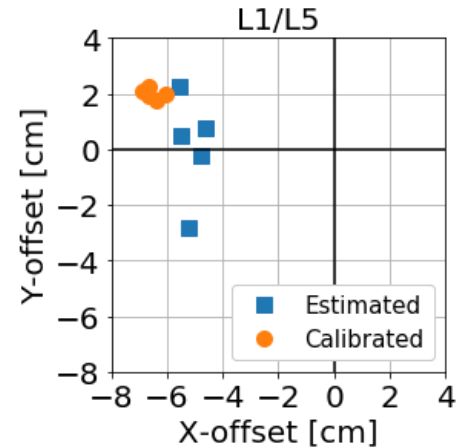
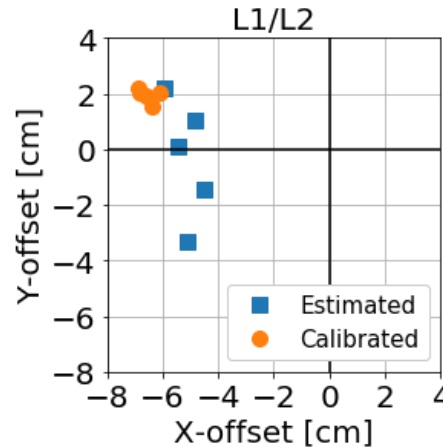
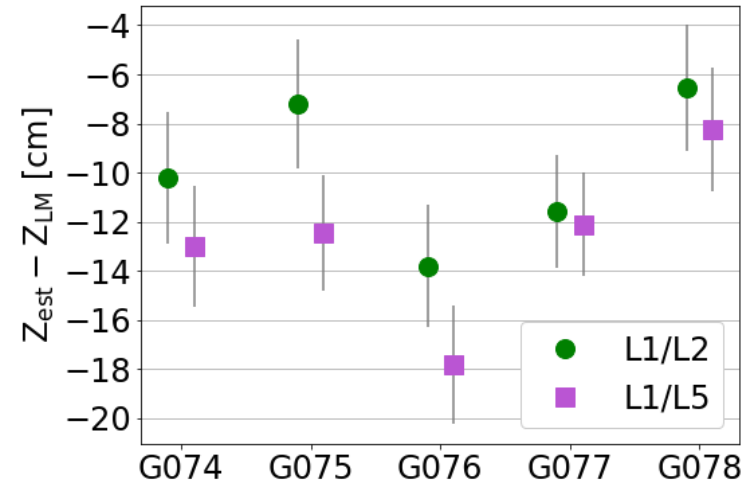


# Phase Center Offsets

PCO estimation with NAPEOS:

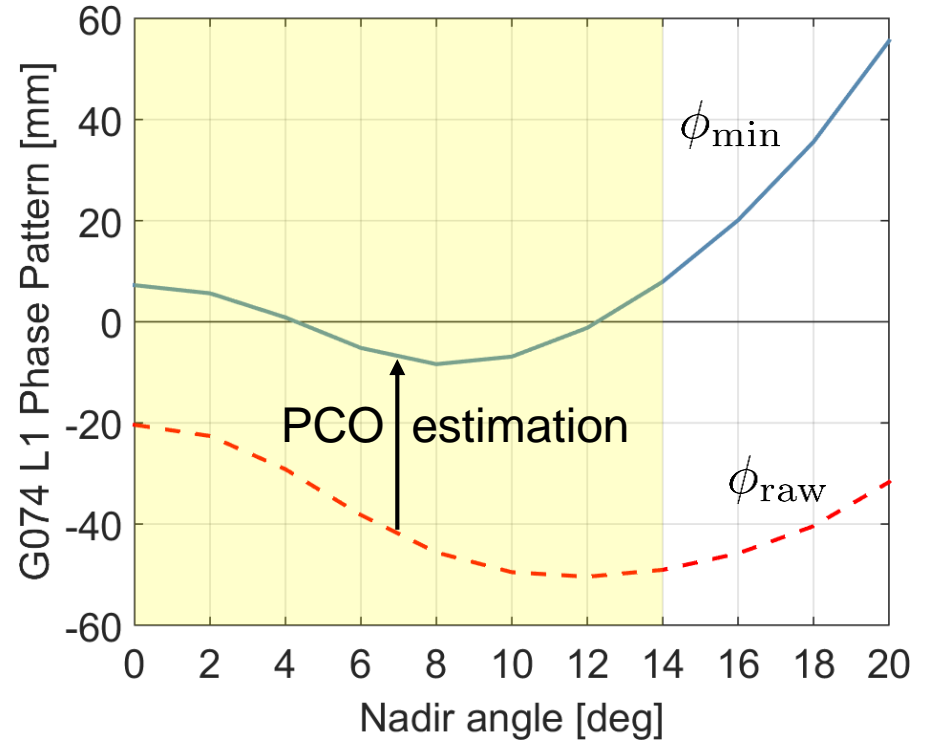
- 140 GPS and Galileo stations with multi-frequency receiver antenna calibrations
- Ionosphere-free linear combinations of L1/L2 and L1/L5
- IGS20 scale fixed
- 14 months of data

GPS III igs20.atx PCOs: LM values shifted by 8.9 cm



# Manufacturer Phase Pattern

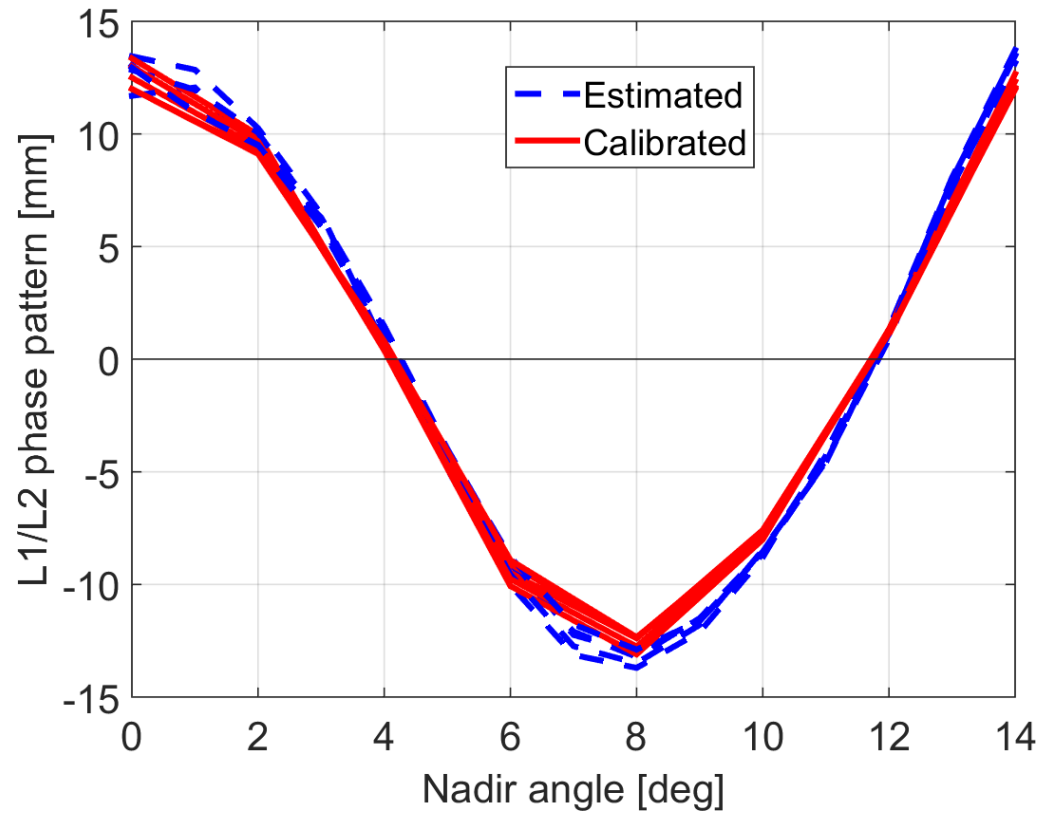
- Raw phase pattern  $\phi_{\text{raw}}$  w.r.t. unknown calibration reference point for phase calibration
- Estimation of minimized phase pattern  $\phi_{\text{min}}$  :
  - grid values from 0 to 14°
  - equal weighting



# Estimated Phase Pattern

Phase pattern estimation with  
Bernese GNSS Software:

- L1/L2 ionosphere-free
- 14 months of data
- IGS20 scale fixed
- 1 deg nadir-dependent



# EIRP Measurements

Measurement of equivalent isotropic radiated power with 30 m high-gain antenna

$$P_r = P_s + D_s + G_{cf} + G_r - L_0 - L_a$$

$P_r$  received power [dBW]

$P_s$  transmitted power [dBW]

$D_s$  transmit antenna directivity [dB]

$G_{cf}$  gain correction factor [dB]

$G_r$  receive antenna gain [dB]

$L_0$  free space loss [dB]

$L_a$  atmospheric loss [dB]

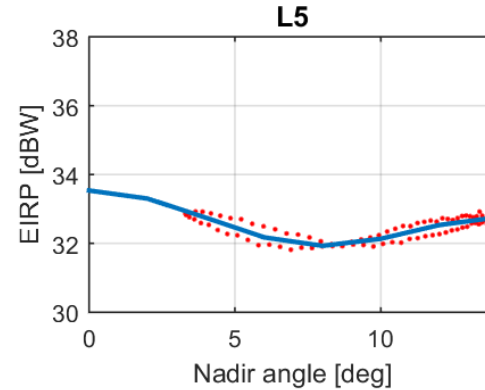
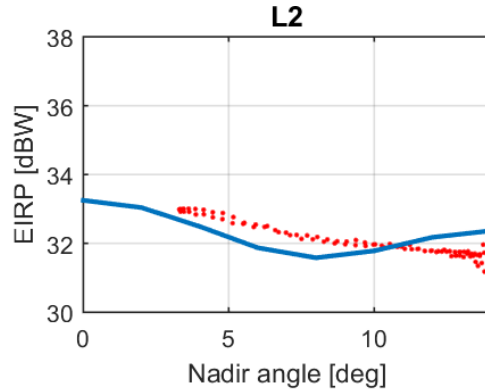
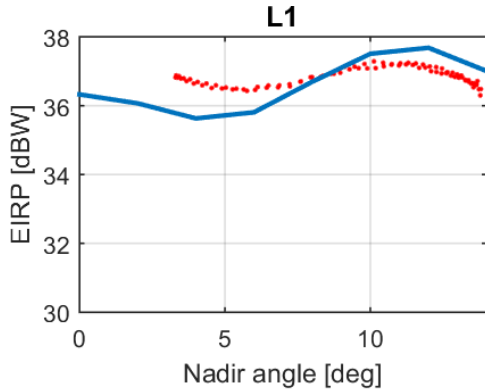
measured

modeled

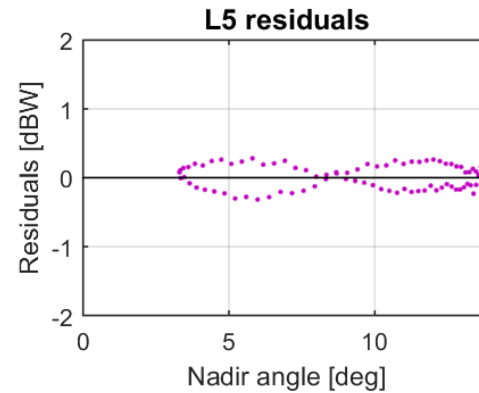
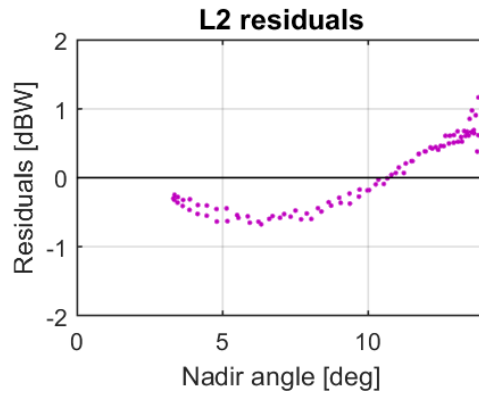
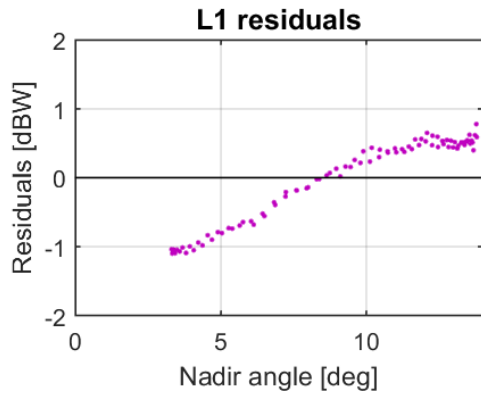
unknown



# EIRP Measurements G075



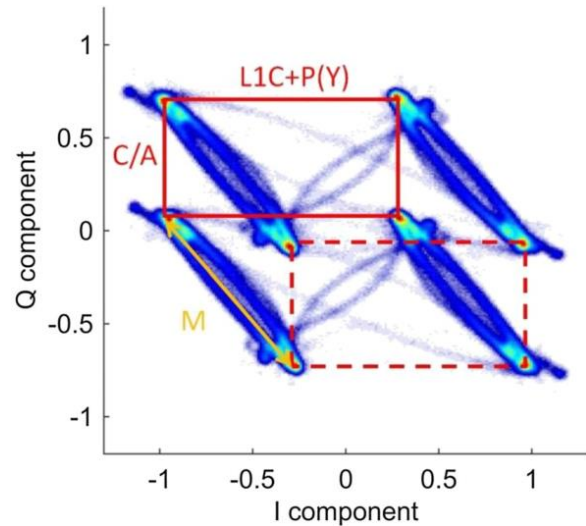
● Measured  
— Modeled



# GPS III Transmit Antennas

Main L-Band Navigation  
Antenna Array

M-Code Antenna Array



Thoelert S, Steigenberger P, Montenbruck O,  
Meurer M (2019) Signal analysis of the first  
GPS III satellite. GPS Solutions 23.

<https://doi.org/10.1007/s10291-019-0882-7>

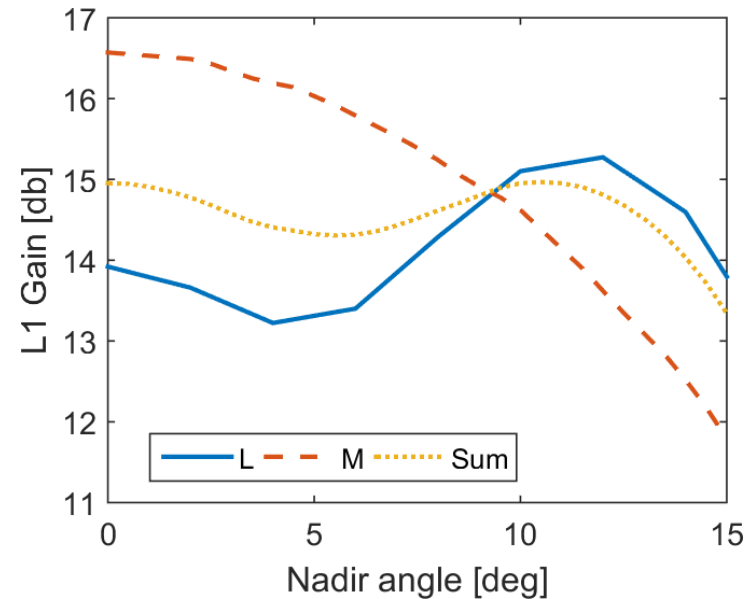
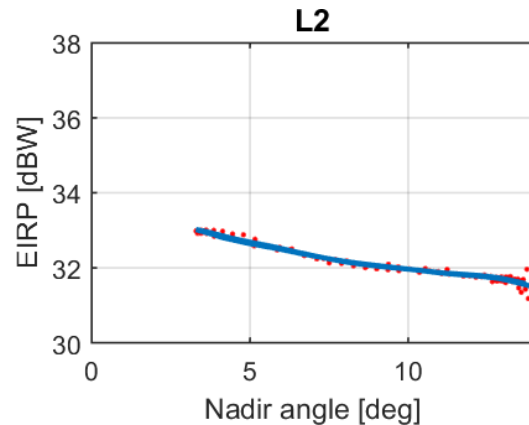
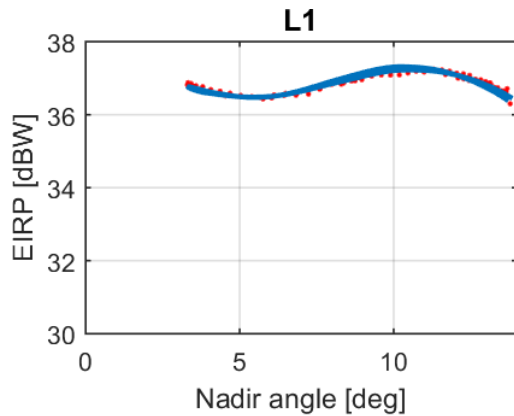




# EIRP Residuals with Adjusted Gain Patterns

Assumptions:

- Gain pattern of M-Ant identical with inner ring of L-Ant of Brumbaugh et al. (1976)
- -1.0 dB gain correction factor for L-Ant



# Summary and Conclusions

## Phase center offsets

- LM PCOs show systematic offset of 10 cm w.r.t. estimates with ITRF2020 scale
- cm-level consistency of L1/L2 and L1/L5

## Phase pattern

- Minimization of raw pattern: 1 mm-level agreement of LM calibrations with estimates

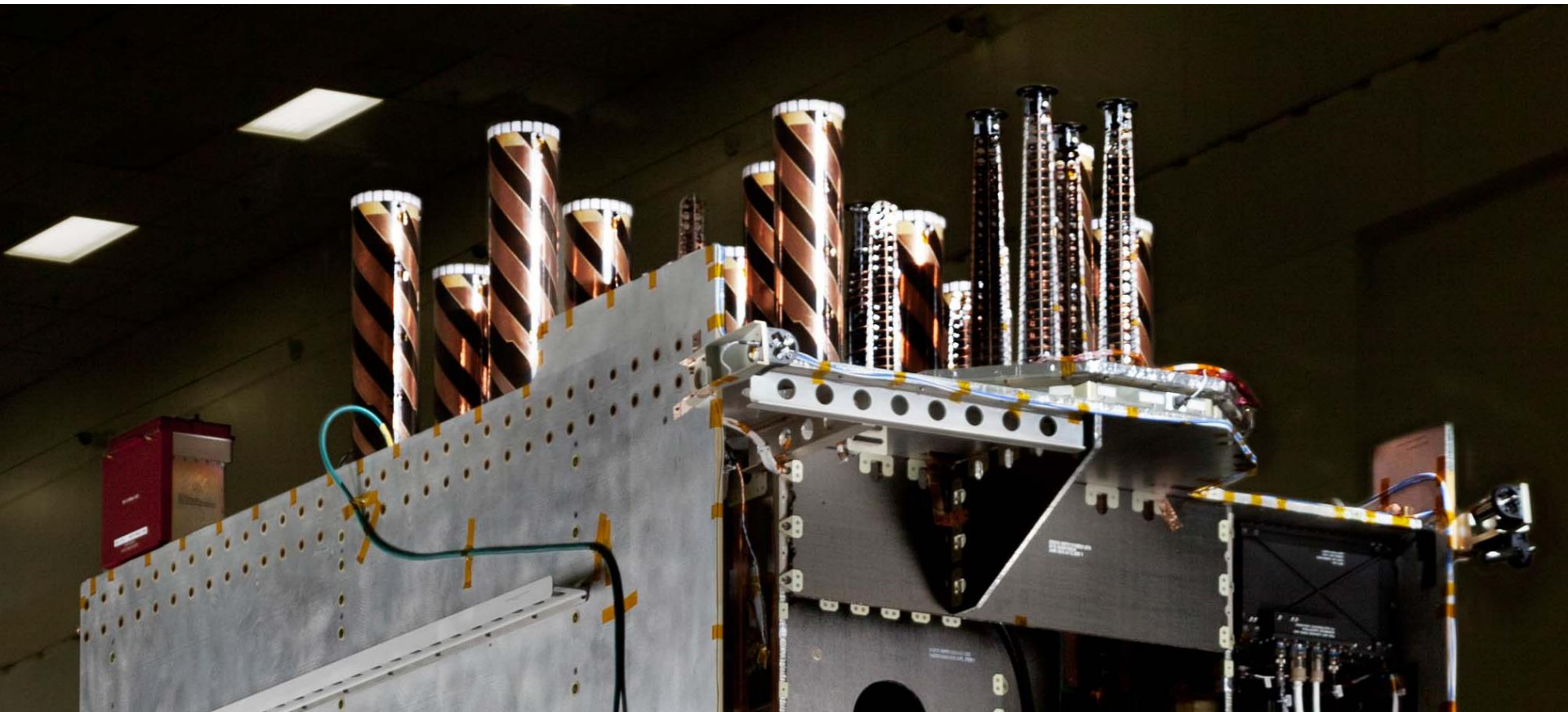
## Directivity pattern

- M-code antenna significantly impacts measured EIRP patterns

## Recommendations

- Inclusion of minimized GPS III phase pattern in igs20.atx
- Update and publication of further GPS III metadata





# Resources

- GPS Satellite Antenna Panel Patterns:  
<https://www.navcen.uscg.gov/gps-technical-references>
- Marquis W, Shaw M (2011) Design of the GPS III Space Vehicle, ION ITM 2011, pp. 3067–3075
- Thoelert S, Steigenberger P, Montenbruck O, Meurer M (2019) Signal analysis of the first GPS III satellite, GPS Solutions, 23(4), <https://doi.org/10.1007/s10291-019-0882-7>
- Marquis WA, Reigh DL (2015) The GPS Block IIR and IIR-M Broadcast L-band Antenna Panel: Its Pattern and Performance, Navigation, 62(4):329–347, <https://doi.org/10.1002/navi.123>
- Brumbaugh CT, Love AW, Randall GM, Waineo DK, Wong SH (1976) Shaped Beam Antenna for the Global Positioning Satellite System, 1976 Antennas and Propagation Society International Symposium, pp. 117–120, <https://doi.org/10.1109/aps.1976.1147624>

