GPS and GLONASS Satellite Transmit Power: Update for IGS repro3

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1 Revision History

Revision	Date	Author(s)	Description
1.0	11 July 2019	PS, ST, OM	Initial release
1.1	21 October 2019	PS, ST	Reduced GLONASS R720 transmit power

2 Introduction

Knowledge of the GNSS satellite transmit power is a prerequisite for the computation of antenna thrust caused by the transmission of navigation signals. Antenna thrust mainly acts in radial direction, depends on the satellite mass and the transmit power (Milani et al., 1987) and can reach up to 3 cm for current navigation satellites (Steigenberger et al., 2018). The received power of GNSS signals on the Earth surface can be measured with a high-gain antenna. The equivalent isotropically radiated power (EIRP) can then be obtained by correcting these measurements for freespace and atmospheric losses along the propagation path between satellite and ground antenna. The transmit power can be estimated from the ratio of the measured EIRP and the satellite transmit antenna gain.

This report provides an update of the GPS and GLONASS satellite transmit power values presented in Steigenberger et al. (2018) as basis for the 3rd reprocessing campaign of the International GNSS Service (IGS; Johnston et al., 2017). Measurements with DLR's 30 m high-gain antenna in Weilheim (Germany) of newly launched GPS and GLONASS satellites as well as assumptions for spacecraft without transmit power estimates are presented. Up-to-date transmit power values are included in the IGS metadata SINEX file available at the website of the IGS multi-GNSS pilot project: `http://mgex.igs.org/IGS_MGEX_Metadata.php`.

3 GPS

No EIRP measurements are available for the GPS Block I and Block II satellites. Therefore, the measured mean value of the Block IIA satellites with 50 W is assumed for both blocks, see Table 2. Block-specific values were recommended in Steigenberger et al. (2018) for the GPS IIR-A, IIR-B, IIR-M, and IIF satellites. These values remain unchanged in Table 2 as no additional launches of

Table 2: GPS satellite transmit power. Measured values are given in black, assumed values in red.

Block	SVN	Transmit Power
I	G001 – G006, G008 – G011	50 W
II	G013 – G021	50 W
IIA	G022 – G040	50 W
IIR-A/B	G041, G043 – G047, G051, G054, G056, G059 – G061	60 W
IIR-M	G048 – G050, G052, G053, G055, G057, G058	145 W
IIF	G062 – G073	240 W
III	G074	300 W

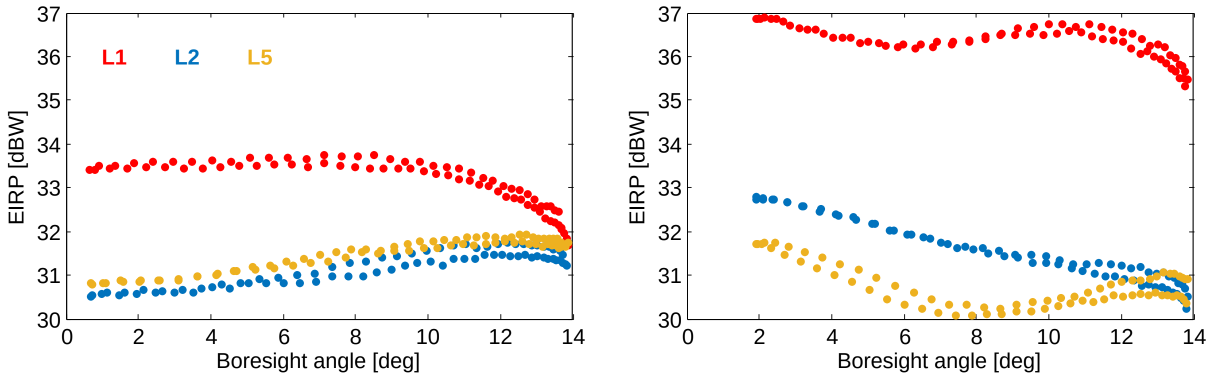

Fig. 1: EIRP measurements for the GPS Block IIF satellite G065 (left) and the Block III satellite G074 (right).

these satellite blocks occurred. In December 2018, the first GPS Block III satellite (Marquis and Shaw, 2011), was launched. This generation of satellites transmits an additional civil signal on L1, namely L1C (Thoelert et al., 2019).

EIRP measurements of the Block III satellite G074 are shown in Fig. 1 as well as for the Block IIF satellite G065. The nadir angle dependence of the EIRP measurements differs significantly for both satellite types indicating a different transmit antenna gain pattern. As no transmit antenna gain pattern is available for GPS III, no transmit power could be estimated. Therefore, a total power of 300 W is assumed based on Block IIF transmit power, the additional L1C signal, and slightly increased power levels for other signals (IS-GPS-200J, 2018; IS-GPS-705E, 2018). Two further launches of GPS III satellites are planned for 2019.

Flex Power Flex power denotes the redistribution of transmit power between different GNSS signal components. Thoelert et al. (2018) and Steigenberger et al. (2019) report different modes of flex power on GPS Block IIR-M and IIF satellites. A different power distribution for the L1 signals of the Block IIR-M satellites is effective since February 2017 (Thoelert et al., 2018). The L1 C/A and L1 P(Y) power is increased whereas the M-code power and the power of the intermodulation product are reduced. However, this redistribution does not affect the total transmit power.

Since January 2017, a regional flex power mode is active for the L1 signals of ten Block IIF satellites (Steigenberger et al., 2019) resulting in increased L1 C/A and P(Y) power due to the temporary deactivation of the M-code as well as the intermodulation product. As a consequence, the total transmit power on L1 decreases by 16 – 20 % corresponding to 13 – 16 W. In view of the total transmit power of 240 W and the uncertainty of the transmit power estimates, this effect is considered negligible.

In April 2018, a different mode of flex power was observed for all Block IIR-M and IIF satellites (Steigenberger et al., 2019) resulting in a 5 − 6 dB power increase of L1 and L2 P(Y). This power increase was possible due to a deactivation of the M-code. In contrast to the flex power mode mentioned above, the total transmit power stayed constant. For another type of flex power that occurred on three days in April/May 2018, no high-gain antenna measurements are available. Carrier-to-noise density observations (C/N_0) indicate an increased L1 and L2 P(Y) code power but no statement about changes in total transmit power is possible.

On June 20 and 21, 2019, another global flex power operations took place. Flex power started subsequently for all healthy Block IIR-M and IIF satellites on June 20 between 15:18 and 17:49 UTC. C/N_0 of the P(Y)-code tracking increased by roughly 10 dB for all healthy Block IIR-M and IIF satellites whereas C/N_0 of the C/A-code decreased by about 2 − 3 dB for the healthy IIR-M satellites only. The changes in power levels are similar to flex power mode III discussed in Steigenberger et al. (2019). All satellites returned to normal power levels on June 21 between 6:00 and 10:00 UTC.

4 GLONASS

EIRP measurements for nine GLONASS satellites have been conducted in early 2019. Results for two of them have already been reported in Steigenberger et al. (2018), namely R802, R851, the other seven are newly observed (R723, R852, R853, R854, R856, R857, R858). The transmit power values of the re-observed satellites agree well within the formal errors with the previous measurements. Therefore, the original values of these satellites are kept in Table 3. An overview of the total transmit power determined from high-gain antenna measurements is given in Fig. 2.

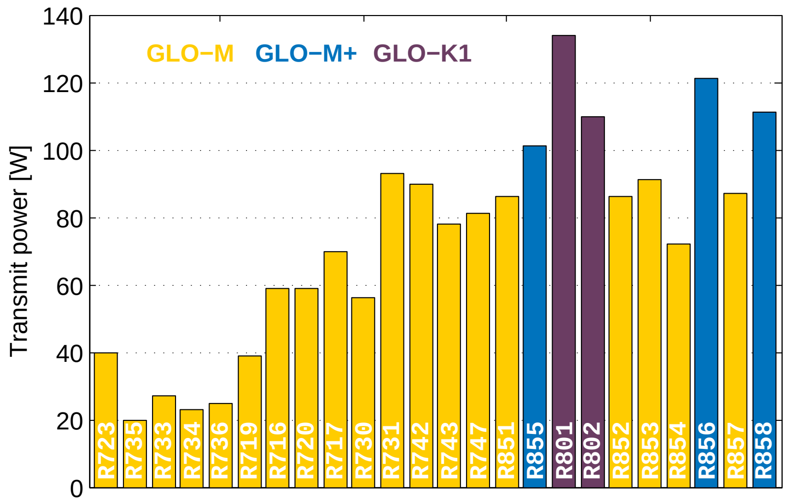

Fig. 2: GLONASS total transmit power obtained from high-gain antenna measurements. Please note that the R723 transmit power refers to single-frequency L1 transmission.

For the GLONASS-M satellites, three different power levels (low, medium, high) are present for the L1 and L2 frequency band, respectively. Six different combinations of L1 and L2 transmit power are listed in Table 3 with total power values between 20 and 85 W. The assignment to these different groups in Steigenberger et al. (2018) was based on high-gain antenna measurement (if available) or analysis of C/N_0 from GNSS receivers. For GLONASS R854, the assignment to group L1H/L2H with a total power of 85 W was based on C/N_0 analysis. The new high-gain antenna measurements resulted in an L1 transmit power of 47 W that does not fit into any of the original groups. Therefore, the total transmit power of 72 W was rounded to 70 W and a new group consisting only of this satellite was added to Table 3. For GLONASS R853, the high-gain anntenna measurements confirmed the C/N_0-based assignment to group L1H/L2H. Since end of 2016, the GLONASS-M satellite R723 only transmits on the L1 frequency. An L1 transmit power of 40 W was measured in early 2019. As no L2 measurements are available, the default value of 50 W is recommended for this satellite.

GLONASS-M+ satellites are capable of transmitting on a third frequency, namely L3. For the 2nd GLONASS-M+ satellite R856, a total power of 120 W was measured in 2019. This is an increase of 20 % compared to the 1st GLONASS-M+ satellite R855. The 3rd GLONASS-M+ satellite R858 has a slightly lower transmit power of 110 W. The GLONASS-K satellites are also able to transmit L3 signals. Whereas GLONASS K1-A (R801) utilizes a dedicated transmit antenna for L3, GLONASS K1-B (R802) has a common antenna for all three L-band frequencies (Montenbruck et al., 2015), like the GLONASS-M+ satellites. The satellites with single L-band antenna have an L3 transmit power of about 25 W whereas R801 with the dedicated L3 antenna has a higher power of 40 W. Further launches of GLONASS-K1 as well as the next generation K2 satellites are planned for 2019. As GLONASS-K2 will transmit additional CDMA (code division multiple access) signals on L1 and L2 (Revnivykh et al., 2017), a higher transmit power can be expected.

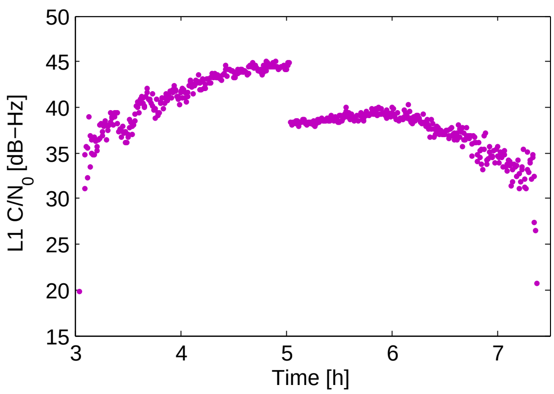

Fig. 3: GLONASS R720 L1 C/A carrier-to-noise density ratio of the IGS station Noumea, New Caledonia (NRMG00NCL).

A reduction of 6 − 7 dB in the L1 C/A signal power of GLONASS R720 could be observed on 4 April 2019 at 5:02, see Fig. 3. High-gain antenna measurements in October 2019 also revealed an L2 power reduction on the level of about 2 dB compared to earlier measurements from 2017, see Fig. 4. The total transmit power is reduced from 59 W to 17 W.

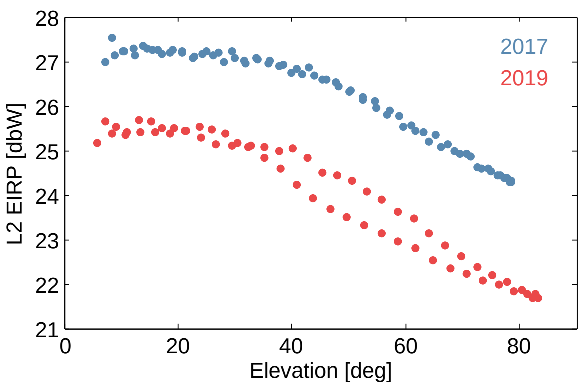

Fig. 4: GLONASS R720 L2 EIRP measurements obtained with the Weilheim 30 m dish antenna on 9 June 2017 and 15 October 2019.

Table 3: GLONASS satellite transmit power. Measured values are given in black, assumed values in red. All measured values are rounded to 5 W. Group assignments of underlined SVNs are attributed to C/N_0 analysis. Abbreviations: L1L - L1 low power, 17 – 21 W; L1M - L1 medium power, 38 – 39 W; L1H - L1 high power, 50 – 68 W; L2L - L2 low power 1 W; L2M - L2 medium power, 6 – 7 W; L2H - L2 high power, 19 – 26 W.

Block	Group	SVN	Transmit Power
M	L1L/L2L	R720[1], R735[2]	20 W
	L1L/L2M	R715, R721, R733, R734, R735[3], R736	25 W
	L1L/L2H	R719	40 W
	L1M/L2H	R716, R720[4]	60 W
	L1H/L2M	R717, R730, R732	65 W
	L1H/L2H	R731, R742, R743, R744, R745, R747, R851, R852, R853, R857	85 W
		R854	70 W
	default	default value for all other GLONASS-M satellites	50 W
K1		R801	135 W
		R802	105 W
M+		R855	100 W
		R856	120 W
		R858	110 W

[1] since 4 Apr. 2019
[2] since 2 Feb. 2016
[3] until 2 Feb. 2016
[4] until 4 Apr. 2019

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