Flexible Transponder Turnaround Frequency Ratios for MSPA Revisited (Draft Recommendation 2.6.13)

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I. Introduction

Action item AI_19-01 was issued at the Spring 2019 RFM working group meeting to revisit draft Recommendation 2.6.13 on flexible transponder turnaround frequency ratios, reflecting discussions which occurred during that meeting. One of the comments was that only two simultaneous spacecraft could be supported with MSPA (Multiple Spacecraft Per Aperture) under the current version of the draft recommendation. This was insufficient to meet the MSPA requirements of at least one CCSDS member space agency, which desires to support up to four spacecraft simultaneously with a single antenna.

SLS-RFM_19-07 [1] proposed some additional revisions to the draft recommendation which were incorporated, and that version of the Recommendation is used as the starting point for this paper.

II. Flexible Transponder Turnaround Ratios

Under the flexible TTFR for MSPA concept, multiple spacecraft will share a common uplink frequency but downlink on different frequencies using different TTFRs for each spacecraft. In the original flexible TTFR for MSPA study, one of the constraints that limited the number of flexible turnaround ratios was the need to have an odd number in the numerator of the turnaround ratio (the uplink multiplier), while having an even number in the denominator. This was to avoid the possibility of harmonics of the downlink intermediate frequency (IF) products causing interference to the on-board uplink receiver.

While this is true for transponder designs using analog multipliers, it does not necessarily apply for designs of modern software defined radios (SDRs). As an example, the Proximity-1 physical layer standard (CCSDS 211.1-B-4) specifies a turnaround ratio of 1348/1452 for Channel 1. In this case, the turnaround ratio has even numbers in both the numerator and denominator. The 1348/1452 turnaround ratio has been successfully implemented and tested in the Electra UHF radio for a number of Mars missions, without any reports of self-interference issues. Also note that in this case, the TTFR has common factors in the numerator and denominator which was another previous selection constraint which could be relaxed.

It is proposed in this paper to relax the odd-numerator/even-denominator constraint on the flexible TTFRs for MSPA, while adding a note in the recommendation that radio designers should take care to avoid potential interference from IF products in the downlink transmitter chain to the on-board uplink receiver. Table 1 revisits the candidate TTFRs for MSPA without this odd/even constraint.

In SLS-RFM_19-07, it was proposed to include the following 3 TTFRs: 749/880, 749/884, and 749/878. Here it is proposed to add three more TTFRs to that list –

namely, 749/879, 749/882, and 749/876. The TTFRs would be divided into two groupings; one grouping could support up to 4 simultaneous spacecraft in the flexible turnaround ratio MSPA configuration while the other can support up to 3 simultaneous spacecraft.

Table 1. Candidate Flexible Turnaround Ratios for MSPA

Turn-around Ratio	Downlink Multiple Factor-ization	Uplink Freq Range (deep space), MHz	Downlink Freq Range (deep space), MHz	Uplink Freq Range (near-Earth), MHz	Downlink Freq Range (near-Earth), MHz
749/876	2, 2, 3, 73	7182.192 - 7190	8400 - 8409.132	7224.943 – 7235	8450 - 8461.762
749/877	877	7174.000 - 7190	8400 – 8418.732	7216.705 – 7235	8450 - 8471.442
749/878	2, 439	7165.831 – 7190	8400 – 8428.331	7208.485 – 7235	8450 – 8481.081
749/879	3, 293	7157.679 – 7190	8400 – 8437.931	7200.284 – 7235	8450 – 8490.741
749/880	2,2,2,2,5, 11	7149.545 – 7190	8400 – 8447.530	7192.102 – 7234.659	8450 – 8500
749/881	881	7145 – 7183.939	8404.199 - 8450	7190 - 7226.447	8457.130 – 8500
749/882	2, 3, 3, 7,7	7145 – 7175.794	8413.738 – 8450	7190 – 7218.254	8466.729 – 8500
749/883	883	7145 – 7167.667	8423.278 - 8450	7190 - 7210.079	8476.328 – 8500
749/884	2, 2, 13,17	7145 – 7159.559	8432.817 – 8450	7190 – 7201.923	8485.928 – 8500

The first grouping would include the 749/876, 749/878, 749/879, and 749/880 TTFRs. The common uplink carrier frequency would be in the range of 7182.192 to 7190 MHz. In practice, the uplink frequency would have to be less than 7190 MHz in order to avoid emissions from the uplink and downlink modulation sidebands into the adjacent frequency band. To maximize the allowable downlink bandwidth while allowing room for the uplink modulation, one could chose a common uplink frequency of 7188 MHz. The corresponding downlink frequencies for the four MSPA spacecraft would be 8406.793 MHz, 8425.987 MHz, 8435.583 MHz, and 8445.180 MHz, which leaves plenty of bandwidth for each spacecraft downlink.

The second MSPA grouping would consist of TTFRs 749/880, 749/882, and 749/884. In this case, the common uplink frequency is constrained to be in the range between 7149.545 MHz and 7159.559 MHz. To maximize the available downlink bandwidth, the common uplink is chosen to be around 7154.5 MHz. In this case, the corresponding three downlink frequencies would be 8405.821 MHz, 8424.925 MHz, and 8444.029 MHz. This would allow a downlink bandwidth of almost 12 MHz per spacecraft.

III. Summary

It is proposed to add three new TTFRs for MSPA to draft Recommendation 2.6.13. These new TTFRs are 749/876, 749/879, and 749/882.

Of the three new TTFRs, two of them were considered previously. The 749/876 TTFR was previously rejected because its frequency coverage was small. However, it is sufficient to provide at least 4 MHz bandwidth on the uplink and more than 10 MHz bandwidth on the downlink under the envisioned four spacecraft MSPA system. The 749/879 was previously not considered because both the numerator and denominator in the TTFR were odd numbers. However, this does not seem to be an insurmountable design problem for modern SDRs. Finally 749/882 was previously rejected because it had a common factor of 7 in both the numerator and denominator. However with sufficient care in the RF design of the transponder, the potential for self-interference can be mitigated. The addition of these three TTFRs will provide two groupings of spacecraft using MSPA with flexible turnaround ratios; one which can support up to 4 spacecraft and another which can support up to 3 spacecraft.

The proposed revision of the draft Recommendation 2.6.13 is attached.

References

[1] E. Vassallo, "ESA's Input on Flexible Turnaround Ratios MSPA Recommendation 2.6.13", SLS-RFM_19-07, May 6-9, 2019.

2.6.13 TRANSPONDER TURNAROUND FREQUENCY RATIOS FOR MULTIPLE SPACECRAFT PER APERTURE SUPPORT IN THE 7145 – 7235 MHz AND 8400-8500 MHz BANDS

The CCSDS,

considering

(a) that there are several methods[1], broadly called Multiple Spacecraft Per Aperture (MSPA), whereby a single earth station antenna can be used to support multiple spacecraft located within its antenna beamwidth;

(b) that several space agencies have already used MSPA to simultaneously receive downlink telemetry from multiple spacecraft using a single earth station antenna, in cases where each spacecraft is transmitting on a different frequency;

(c) that there are various approaches[1] for MSPA on the uplink, which have their own relative merits and drawbacks in terms of implementation complexity and operational impacts;

(d) that the preferred approach[1] for MSPA may be different depending on the time frame being considered;

(e) that one of the recommended MSPA methods consists of having a common uplink frequency but different downlink frequencies among the MSPA supported spacecraft;

(f) that this method requires implementation of flexible Transponder Turnaround Frequency Ratios (TTFRs) on some or all of the spacecraft transponders;

(g) that current usage of MSPA is typically limited to ~~three~~ four spacecraft or less;

(h) that software defined radios may offer the flexibility of implementing an almost arbitrary TTFR;

(i) that for reasons of maintaining compatibility with existing spacecraft receiver designs and with the TTFR recommendation[2] for the 7/8 GHz band, the flexible TTFRs should contain the number "749" in the numerator;

~~(j) that an odd number (749) has been selected as an uplink factor (numerator of the TTFR), and thus an even number should be selected as the denominator of the flexible TTFR's to prevent downlink harmonic interference with uplink signals;~~

recommends

[1] See CCSDS Recommendation 401 (3.1.7)

[2] See CCSDS Recommendation 401 (2.6.2)

that agencies planning on implementing MSPA with Flexible Transponder Turnaround Frequency Ratios (TTFRs) in the 7/8 GHz bands use the ~~following~~ TTFR[3,4] in the following configurations ~~order of preference~~:

– ~~-~~749/880, 749/878~~84~~, 749/876 and 749/879~~8~~ for up to four simultaneous spacecraft per aperture; or

– 749/880, 749/882, and 749/884 for up to three simultaneous spacecraft per aperture.~~-~~

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[3] On-board implementations may result in deviations from these values and in a significant delay of downlink carrier relative to the uplink carrier; mission designers have to take these factors into consideration when computing the orbit determination performance.

[4] Transponders with flexible turnaround ratios should be designed carefully to avoid self-interference to the on-board uplink receiver from frequency harmonics in the downlink transmitter chain, particularly for the 749/879 and 749/882 TTFRs.

Table 2.6.13-1. Available Two-way Coherent Frequency Range for the Recommended 7/8 GHz Flexible TTFRs

Transonder Turn-around Frequency Ratio (E-S/S-E)	**Category A**		**Category B**	
	Available Earth-to-Space Frequency Range, MHz	Available Space-to-Earth Frequency Range, MHz	Available Earth-to-Space Frequency Range, MHz	Available Space-to-Earth Frequency Range, MHz
749/876	7224.943–7235	8450-8461.762	7182.192-7190	8400-8409.132
749/878	7208.485–7235	8450–8481.081	7165.831–7190	8400–8428.331
749/879	7200.284–7235	8450–8490.741	7157.679-7190	8400–8437.931
749/880	~~7190–7235~~7192.102–7234.659 ~~MHz~~	8450–8500~~500~~ ~~MHz~~	7149.545–7190 ~~MHz~~	8400–8447.530 ~~MHz~~
749/882	7190–7218.254	8466.729–8500	7145–7175.794	8413.738–8450
749/884	7190–7201.923 ~~MHz~~	8485.928–8500 ~~MHz~~	7145–7159.559 ~~MHz~~	8432.817–8450 ~~MHz~~
~~749/878~~	~~7208.485–7235 MHz~~		~~7165.831–7190 MHz~~	~~8400–8428.331 MHz~~