ETSI TR 103 956 V1.1.1 (2018-12)

TECHNICAL REPORT

**Satellite Earth Stations and Systems (SES);
Technical analysis for the Radio Frequency, Modulation and Coding for Telemetry Command and Ranging (TCR) of Communications Satellites**

Reference
DTR/SES-00428

Keywords
coding, modulation, satellite, telemetry

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

Modal verbs terminology

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Executive summary

The present document provides the rationale for the revision of the ETSI TCR Standard [i.1].

The need for such revision appeared mainly as a consequence of the evolution of satellites, with new operational frequency bands and configurations like mega-constellations; the progress on spread spectrum technology; the quest for more flexibility in frequency planning and operations on geostationary telecommunication satellite fleets; and novel demands concerning the accommodation of hosted payloads and their segregated operations in those satellites.

Therefore, the existing standard was revised in the following areas: frequency plan, operational phases, hosted payload management application, mega-constellation application, spread spectrum modulation, phase and frequency modulation and finally, coding and interleaving.

The revision has borrowed from the experience acquired by suppliers, operators and space agencies as well as from standards produced in other relevant standardization fora like the European Cooperation for Space Standardization (ECSS) or the Consultative Committee for Space Data Systems (CCSDS).

In summary, the present document provides a sufficient justification of the revision with pointers to annexes and relevant references for those readers seeking further detail.

Introduction

The European Telecommunication Standards Institute (ETSI) established a telemetry, command and ranging (TCR) standard ETSI EN 301 926 [i.2] in 2002.

In recent years telecommunication satellite operators have shown a renewed interest in spread spectrum systems. Their improved performance under interference over the classical frequency modulation (FM) or phase modulation (PM) could ease operations. In mission phases like orbit drift the TCR can be subject to interference while crossing the equatorial orbital arc. With the emergence of electric orbit raising strategies, this phase has actually become much longer making resistance to interference even more relevant.

In addition, hosted payloads are emerging as an attractive business proposition for telecommunication satellite operators. The capability to have direct telecommand (TC) and telemetry (TM) communications with segregated radiofrequency (RF) carriers and avionics could off-load to some extent hosted payload operations from satellite operations. In addition, it could limit the interface impact between the satellite and the hosted payload respective ground and space segments.

Meanwhile the technology of transponders/receivers as well as ground modems have evolved to support spread spectrum modulation as well as frequency flexibility on FM/PM. For instance, the ability to acquire and track a spread spectrum signal under high dynamics is no longer considered an issue, in contrast to the times when the first version of the ETSI TCR standard was published. Such capability could simplify satellite TT&C sub-systems by eliminating the need for dual-mode transponders (FM/PM and spread spectrum).

Moreover, mega-constellations for telecommunication missions are currently being developed. To accommodate a very large number of new TCR carriers on existing bands, spread spectrum modulation could offer an efficient solution.

In consideration of all the above, ETSI initiated a work item to revise the standard in 2015. The goal was to match the revised standard with the current and expected capabilities of transponders and ground modems for future telecommunication missions, not only geostationary. ETSI EN 301 926 [i.1] revision has been published in 2017. The present document, therefore, provides a description and justification of this revision.

Readers are encouraged to take into account that the present document builds upon and complements ETSI TR 101 956 [i.3]. ETSI EN 301 926 (V1.3.1) [i.1] has not questioned the existing modulation trade-offs carried out for the definition of the first issue of the standard.

Furthermore, it does not question the concept of Collocated Equivalent Capacity (CEC). However, it is recognized that the addition of channel coding and interleaving will impact CEC by allowing to enhance capacity with respect to the first version of the standard.

Following this introduction, the present document is organized as follows.

Clause 1 outlines the scope of the standard revision.

Clause 2 provides relevant informative references that can assist readers seeking a more detailed understanding of some modifications.

Clause 3 recalls the terms and abbreviations employed throughout the document.

Clause 4 discusses the modifications impacting frequency planning and operational scenarios.

Clause 5 provides a detailed discussion of the key modifications affecting spread spectrum modulation like the extension of the Pseudo-noise code family and others.

Clause 6 addresses key modifications affecting non-spread modulations.

Clause 7 introduces coding and interleaving options added to the standard.

Clause 8 gives a conclusion.

Finally, annexes A and B complement the main body of the document addressing detailed aspects, annex C provides information for future possible work.

1 Scope

The present document provides the rationale for the revision of the ETSI TCR Standard ETSI EN 301 926 [i.1] in the following areas:

- frequency plan;
- operational phases;
- hosted payload management application;
- mega-constellation application;
- spread spectrum modulation;
- phase and frequency modulation; and
- coding and interleaving.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 301 926 (V1.3.1) (10-2017): "Satellite Earth Stations and Systems (SES); Radio Frequency and Modulation Standard for Telemetry, Command and Ranging (TCR) of Communications Satellites".

[i.2] ETSI EN 301 926 (V1.2.1) (06-2002): "Satellite Earth Stations and Systems (SES); Radio Frequency and Modulation Standard for Telemetry, Command and Ranging (TCR) of Geostationary Communications Satellites".

[i.3] ETSI TR 101 956: "Satellite Earth Stations and Systems (SES); Technical analysis of Spread Spectrum Solutions for Telemetry Command and Ranging (TCR) of Geostationary Communications Satellites".

[i.4] CCSDS 231.0-B-x: "TC Synchronization and Channel Coding".

[i.5] CCSDS 131.0-B-x: "TM Synchronization and Channel Coding".

NOTE: CCSDS standards always include the issue number on their numbering system; the parameter 'x' on references [i.4] and [i.5] is understood as the highest published number and therefore latest issue of the standard.

[i.6] IEEE Transactions on Information Theory: "Optimal Binary Sequences for Spread Spectrum Multiplexing", R. Gold, vol. IT-13, no. 1, pp. 619-621, 1967.

[i.7] NASA Publication Contract NAS 5-22546: "TDRSS Telecommunication System PN Code Analysis final Report Addendum", R. Gold, Sept. 1977.

[i.8] Space Network Interoperability Group: "Space Network Interoperable PN Code Libraries", Revision 1, Sept. 1998.

[i.9] CCSDS 230.1-G-x: "TC Synchronization and Channel Coding - Summary of Concept and Rationale".

[i.10] CCSDS 130.1-G-x: "TM Synchronization and Channel Coding - Summary of Concept and Rationale".

NOTE: CCSDS reports always include the issue number on their numbering system; the parameter 'x' on references [i.9] and [i.10] is understood as the highest published number and therefore latest issue of the standard.

[i.11] R. L. Miller, L. J. Deutsch, and S. A. Butman: "On the Error Statistics of Viterbi Decoding and the Performance of Concatenated Codes". JPL Publication 81-9. Pasadena, California: JPL, September 1, 1981.

[i.12] L. Deutsch, F. Pollara, and L. Swanson: "Effects of NRZ-M Modulation on Convolutional Codes Performance". TDA Progress Report 42-77, January-March 1984 (May 15, 1984): 33-40.

[i.13] Space Network Users' Guide (SNUG). Revision 10. 450-SNUG. Greenbelt, Maryland: NASA Goddard Space Flight Center, August 2012.

[i.14] I. Aguilar Sánchez et al.: "The Navigation and Communication Systems for the Automated Transfer Vehicle", proceedings of the IEEE 49th Vehicular Technology Conference, Vol. 2, pp. 1187-1192, 1999.

[i.15] G. Lesthievent et al.: "Concatenating the convolutional (7,1/2) code with the BCH in TED mode with CRC for improved TC link in the CNES Myriad satellites family", Paper SLS-NGU-10-CNES01, CCSDS Next Generation Uplink Working Group, London (UK), October 2010.

[i.16] CCSDS 231.1-O-1: "Short Block Length LDPC Codes for TC Synchronization and Channel Coding".

[i.17] ECSS-E-ST-50-05C Rev. 2: "Space Engineering - Radio frequency and modulation", European Cooperation for Space Standardization, 4 October 2011.

[i.18] NIST: "Advanced Encryption Standard (AES)", Federal Information Processing Standard Publication 197, United States, November 26, 2001.

[i.19] NIST Special Publication 800-38A: "Recommendation for Block Cipher Modes of Operation: Methods and Techniques", United States, December 2001.

3 Definition of terms and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

binary channel: binary communications channel (BPSK has 1 channel, QPSK has 2 channels)

channel symbol rate: rate of binary elements, considered on a single wire, after FEC coding and channel allocation

NOTE: See Figures 2, 3 and 4. This applies only to multi-channel modulations, thus to spread spectrum QPSK modes and not to PM/FM modes.

Co-located Equivalent Capacity (CEC): number of collocated satellites that can be controlled with a perfect power balanced link between the ground and the satellite

Code Division Multiple Access (CDMA): technique for spread-spectrum multiple-access digital communications that creates channels through the use of unique code sequences

Command Link Transmission Unit (CLTU): telecommand protocol data structure providing synchronization for the codeblock and delimiting the beginning of user data

NOTE: See [i.4], section 4 for further details.

data rate: total number of uncoded data bits per second after packet and frame encoding

NOTE: See Figures 1 to 4. This is the data rate used in link budgets in ETSI TR 101 956 [i.3].

Direct Sequence Spread Spectrum (DSSS): form of modulation where a combination of data to be transmitted and a known code sequence (chip sequence) is used to directly modulate a carrier, e.g. by phase shift keying

symbol rate: rate of binary elements, considered on a single wire, after FEC coding

NOTE: See Figures 1 to 4.

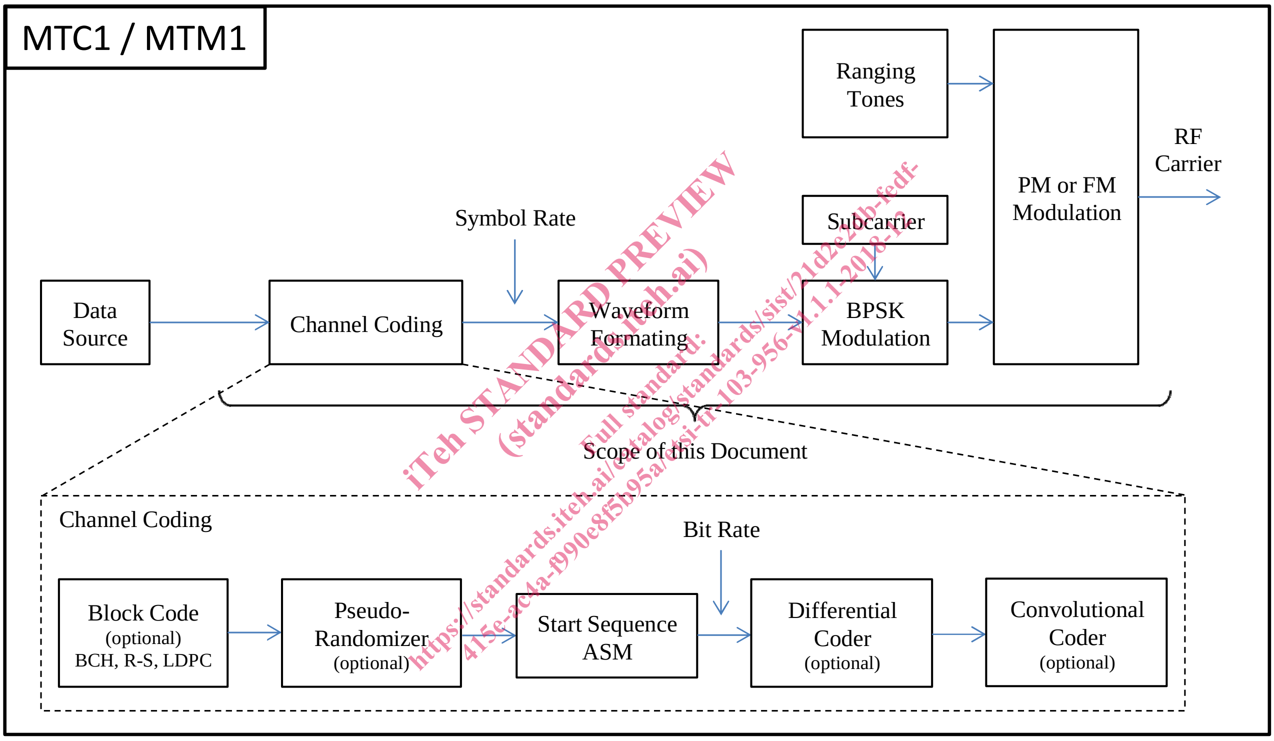

Figure 1: Functional stages of transmit chain for FM/PM modulation (MTC1/MTM1)

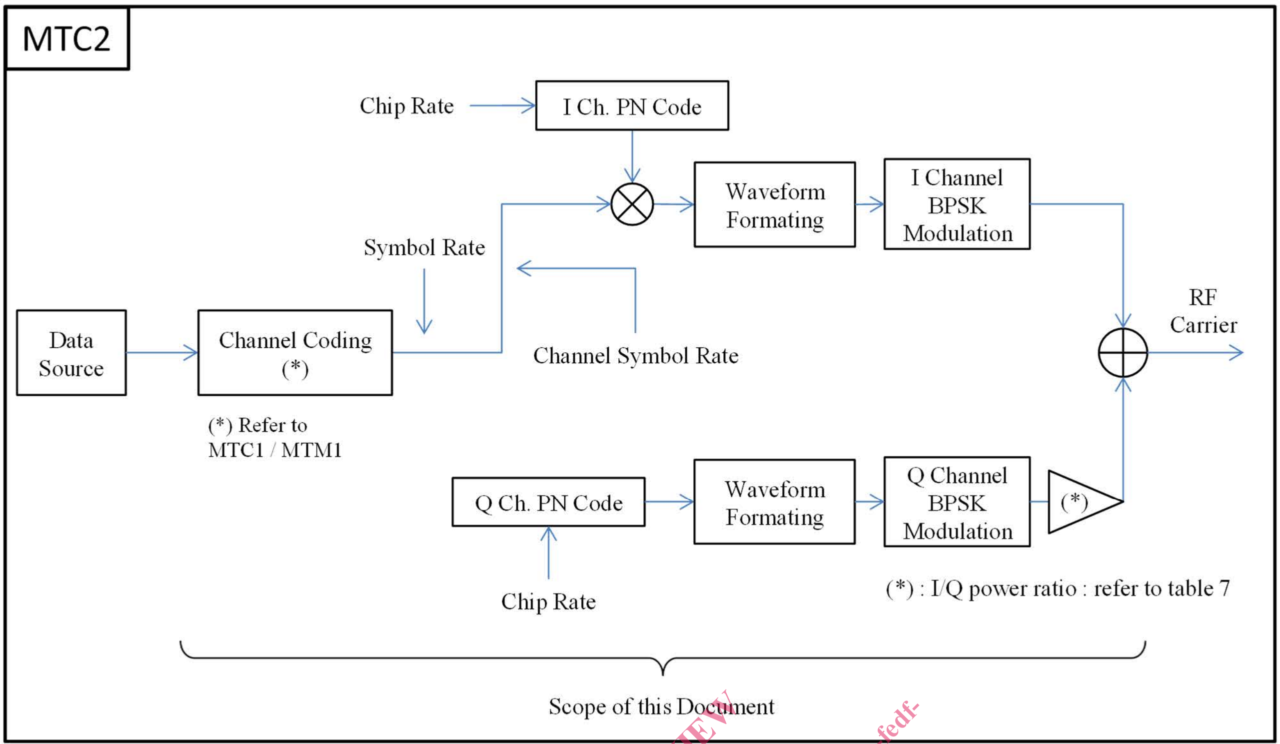

Figure 2: Functional stages of transmit chain for spread spectrum modulation MTC2

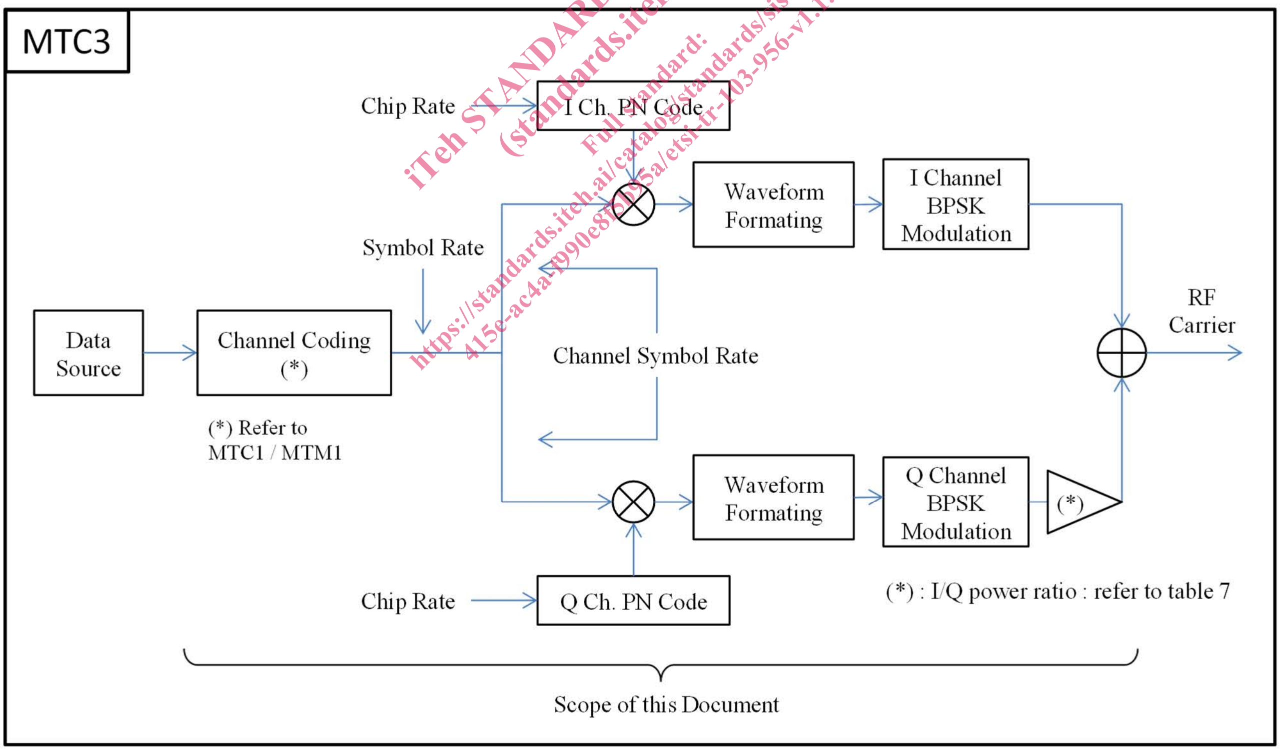

Figure 3: Functional stages of transmission chain for spread spectrum modulation MTC

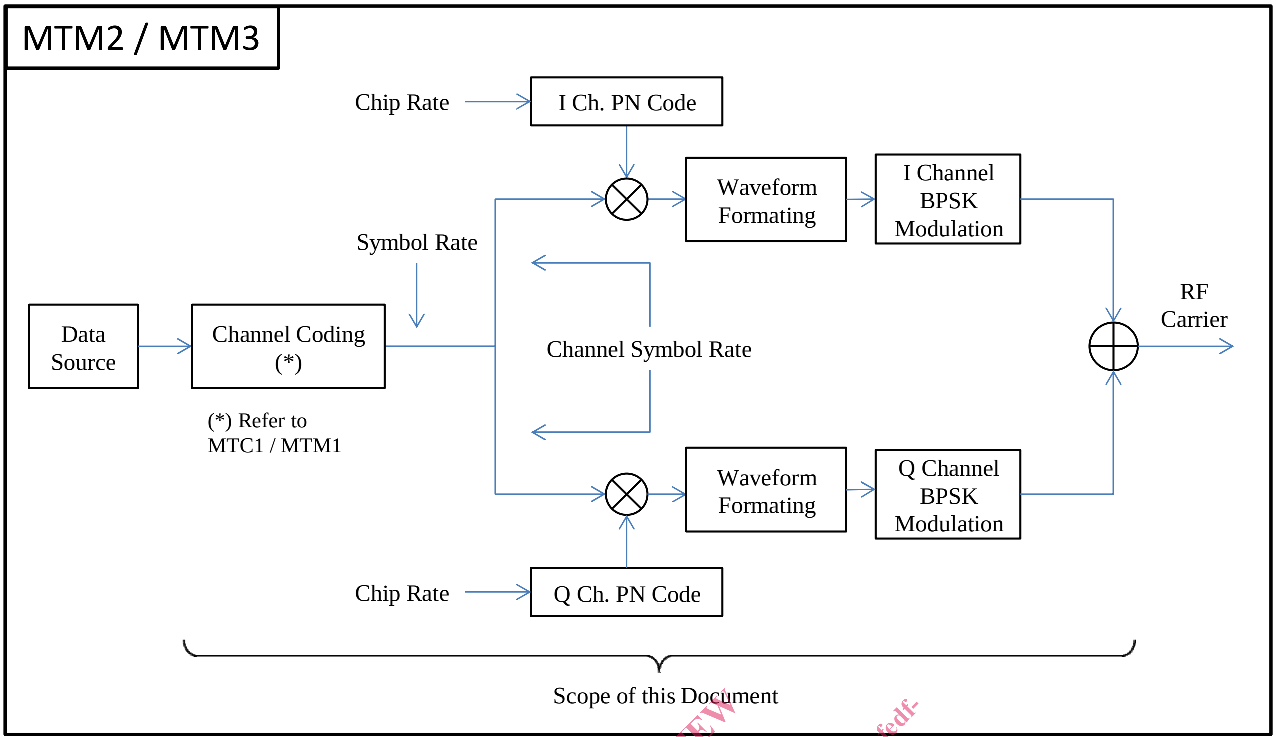

Figure 4: Functional stages of transmission chain for spread spectrum modulation MTM2/MTM3

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AES	Advanced Encryption Standard
ATV	Automated Transfer Vehicle
BCH	Bose-Chaudhuri-Hocquenghem
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
CCSDS	Consultative Committee for Space Data Systems
CDMA	Code Division Multiple Access
CEC	Co-located Equivalent Capacity
CLTU	Command Link Transmission Unit
CMM	Carrier Modulation Modes
CNES	Centre National d'Etudes Spatiales
CRC	Cyclic Redundancy Check
CW	Continuous Wave
DC	Direct Current
DSSS	Direct Sequence Spread Spectrum
ECSS	European Cooperation for Space Standardization
FEC	Forward Error Correction
FM	Frequency Modulation
GSID	Ground-to-Satellite Interface Specification
GSO	Geo-Stationary Orbit
GTO	Geostationary Transfer Orbit
I	In-phase
LDPC	Low Density Parity Check
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
MAI	Multiple Access Interference
MTC1	TeleCommand Mode 1
MTC2	TeleCommand Mode 2
MTC3	TeleCommand Mode 3
MTM1	TeleMetry Mode 1

MTM2	TeleMetry Mode 2
MTM3	TeleMetry Mode 3
NASA	National Aeronautics and Space Administration (USA)
NIST	National Institute of Standards and Technology
NRZ	Non-Return Zero
NRZ-L	Non Return to Zero-Level
NRZ-M	Non Return to Zero-Mark
NTIA	National Telecommunications Industry Association
PDF	Probability Density Function
PED	Phase Error Detector
PLL	Phase Locked Loop
PLOP	Physical Layer Operating Procedures
PM	Phase Modulation
PN	Pseudo Noise
Q	Quadrature
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RS	Reed-Solomon
SEC	Single Error Correction
SER	Symbol Error Rate
SNR	Signal to Noise Ratio
SSTO	Single-Stage-To-Orbit
TC	TeleCommand
TCR	Telemetry, Command and Ranging
TDRSS	Tracking and Data Relay Satellite System (NASA)
TED	Triple Error Detection
TM	TeleMetry
TT&C	Telemetry, Tracking and Command
VLSI	Very Large Scale Integration

4 Frequency Planning and Operational Scenarios

4.1 Frequency Planning

4.1.1 Frequency Bands

a) C-band: 5 850 MHz to 6 725 MHz uplink, 3 400 MHz to 4 200 MHz downlink;

b) Ku-band: 12 750 MHz to 14 800 MHz and 17 300 MHz to 18 100 MHz uplink, 10 700 MHz to 12 750 MHz downlink;

c) Commercial Ka-band: 27 500 MHz to 30 000 MHz uplink, 17 700 MHz to 20 700 MHz downlink.

It should be noted that these bands are due to prevailing regulations, not physics. Possible usage of the TCR techniques considered in the present document and ETSI EN 301 926 [i.1] in adjacent bands between 1 GHz and 44 GHz may be envisaged.

4.1.2 Frequency Flexibility

Modern command receivers and telemetry transmitters often utilize fractional N phase-locked loop (PLL) synthesizers for frequency generation. It is possible to generate different output frequencies from a single input reference frequency using this technology. The frequency resolution of such synthesizers is very high, in the order of a few Hertz, which is clearly more than needed for communication satellite transceivers.

For practical purposes, a 100 kHz resolution is recommended. This is based on experience from commercial programs, which already use frequency flexibility and also the fact that the resolution does not need to be higher than the downlink frequency stability requirement of ±5 ppm [i.1], clause 5.1.2.