Satellites Earth Stations and Systems (SES); Radio Frequency and Modulation Standard for Telemetry, Command and Ranging (TCR) of Geostationary Communications Satellites
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Foreword

This European Standard (Telecommunications series) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES), and is now submitted for the Public Enquiry phase of the ETSI standards Two-step Approval Procedure.

The contents of the present document are subject to continuing work within TC-SES and may change following formal TC-SES approval. Should TC-SES modify the contents of the present document it will then be republished by ETSI with an identifying change of release date and an increase in version number as follows:

Version 1.m.n

Where:

- The third digit (n) is incremented when editorial only changes have been incorporated in the specification;
- The second digit (m) is incremented for all other types of changes, i.e. technical enhancements, corrections, updates, etc.

### Proposed national transposition dates

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of latest announcement of this EN (doa):</td>
<td>3 months after ETSI publication</td>
</tr>
<tr>
<td>Date of latest publication of new National Standard or endorsement of this EN (dop/e):</td>
<td>6 months after doa</td>
</tr>
<tr>
<td>Date of withdrawal of any conflicting National Standard (dow):</td>
<td>6 months after doa</td>
</tr>
</tbody>
</table>
1 Scope

The present document applies to Geostationary Communications Satellites operating their Telemetry, Command and Ranging (TCR) systems in C- and Ku-Band.

The present document sets out the minimum performance requirements and technical characteristics of the ground/satellite Radio Frequency (RF) interface partially based on Spread Spectrum Multiple Access (SSMA).

With the growing number of satellites, the co-location constraints and the maximization of bandwidth for Communications Missions, and interference has motivated the elaboration of the present document for geostationary satellites based on Spread Spectrum techniques.

The present document addresses the following requirements:

- Telemetry;
- Command (Telecommand);
- Ranging.

Currently, no RF and Modulation standard exists for the TCR of geostationary communication satellites. The aim of the present document is to respond to such requirements. There are consequently similarities with existing agency standards, like [2], [3] and [4], although some specifics have been introduced to respond to the requirement of multiple access for collocated geostationary communication satellites.

2 References

The following documents contain information, which through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication and/or edition number or version number) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.


3 Definitions and abbreviations

3.1 Definitions

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

**Equivalent Isotropic Radiated Power (EIRP):** product of transmitter power and maximum antenna gain, equivalent to an isotropic source radiating uniformly in all directions
**Binary Channel**: binary communications channel (BPSK has 1 channel, QPSK has 2 channels)

**Spread Spectrum Multiple Access** (==Code Division Multiple Access): modulation of a carrier by a code sequence, with association of a code to each user

**Data Rate**: total number of uncoded data bits per second after packet and frame encoding

NOTE 1: See figure 1 and figure 2. This is the Data Rate used in Link Budgets in [1]

**Symbol Rate**: total symbol rate after FEC coding

NOTE 2: See figure 1 and figure 2.

**Channel Symbol Rate**: symbol rate per channel after FEC channel coding and channel allocation

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

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

---

**Figure 1**: Functional stages of transmit chain for standard modulation
3.2 Abbreviations

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

- **BPSK**: Binary Phase Shift Key
- **CDMA**: Code Division Multiple Access
- **COM**: COMmunication channel
- **CW**: Continuous Wave
- **DS**: Direct Sequence
- **DSSS**: Direct Sequence Spread Spectrum
- **DRSS**: Data Relay Satellite System (ESA)
- **DRTS**: Data Relay & Tracking System (NASDA)
- **ECSS**: European Co-operation for Space Standardization
- **EIRP**: Equivalent Isotropic Radiated Power
- **FEC**: Forward Error Correction
- **FM**: Frequency Modulation
- **GTO**: Geostationary Transfer Orbit
- **HPA**: High Power Amplifier
- **IEE**: Institution of Electrical Engineers
- **LEOP**: Launch and Early Orbit Phase
- **MTC1**: TeleCommand mode 1
- **MTC2**: TeleCommand mode 2
- **MTM1**: TeleMetry mode 1
- **MTM2**: TeleMetry mode 2
- **MTM3**: TeleMetry mode 3
- **NASA**: National Aeronautics and Space Administration (USA)
- **NASDA**: National Astronautics and Space Development Administration (Japan)
- **NRZ-L**: Non Return to Zero-Level
- **NRZ-M**: Non Return to Zero-Mark
- **OQPSK**: Offset Quadrature Phase Shift Key
- **PCM**: Pulse Coded Modulation
- **PDF**: Probability Density Function
- **PM**: Phase Modulation
4 Applicability

The present document applies to the typical TCR scenario shown in figure 3. The scenario comprises k satellites, which may be co-located on the same orbital position. Each satellite also goes through other mission phases like LEOP, drift and possibly emergency mode. These satellites may be controlled/monitored by N different TCR Ground Stations. The TCR links defined in the present document have to coexist with the Communication ground terminals and associated links also shown in figure 3.

The present document defines the modulation on the TCR links. Modulation formats are described in clause 5 modulation requirements, and the associated mission phases are described in annex A.

\[\text{Figure 3: Typical applicable scenario}\]
5 Modulation Requirements

5.1 General

The generic system functional block diagram is shown in figure 4. Modulation modes and configurations are shown in table 1.

![Generic system functional block diagram]

Figure 4: Generic system functional block diagram

Table 1: Modulation Modes and Potential Configurations

<table>
<thead>
<tr>
<th></th>
<th>All Standard Mode</th>
<th>All Spread Mode</th>
<th>Hybrid Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uplink</strong></td>
<td>MTC1: PCM/BPSK/FM</td>
<td>MTC2: PCM/SRRC-UQPSK</td>
<td>MTC2: PCM/SRRC-UQPSK</td>
</tr>
<tr>
<td><strong>Downlink (with Ranging (see note): requires uplink present)</strong></td>
<td>MTM1: PCM/BPSK/PM</td>
<td>MTM2: PCM/ SRRC-OQPSK (PN code clock/epoch sync to uplink clock/epoch)</td>
<td>MTM1: PCM/BPSK/PM</td>
</tr>
<tr>
<td><strong>Downlink (without ranging: can operate without uplink present)</strong></td>
<td>MTM1: PCM/BPSK/PM</td>
<td>MTM3: PCM/ SRRC-OQPSK (PN code clock/epoch independent of uplink clock/epoch)</td>
<td>MTM1: PCM/BPSK/PM</td>
</tr>
</tbody>
</table>

**NOTE:** Further definition of ranging signals is given in following clauses.

In order to retain backward compatibility with existing ground networks and to allow simple operation during LEOP, in addition to the new Spread Spectrum modes, the existing "standard" FM/PM modulation modes are retained. It is envisaged that telecommand and telemetry modulation formats shall be independently configurable, allowing for example the following configuration possibilities (see also annex A for implementations and TR 101 956 [1]):

- all standard mode (as has existed in previous systems) using tone ranging on FM uplink (MTC1) and PM (MTM1) downlink;
- all spread mode (Direct Sequence Spread Spectrum: DSSS) using PN spreading code regenerative ranging on suppressed carrier up-and down-links (MTC2 and MTM2);
- hybrid mode using PN spreading code ranging on suppressed carrier DSSS uplink (MTC2), and tone ranging on PM downlink (MTM1).
In addition, on the spread spectrum (DSSS) mode downlink, there are 2 PN code sets defined, for coherent and non-coherent modes (modes MTM2 and MTM3 respectively). The physical partitioning of the functions may not exactly follow that shown in the system functional block diagram. The modulation configuration of the various modes is described in the rest of clause 5 modulation requirements. Possible allocation of modes to mission phases is defined in annex A.

5.2 Standard modulation

The Standard mode modulation formats shall be Frequency Modulation (FM) on Telecommand uplink and Phase Modulation (PM) on Telemetry downlink. The standard modes shall be known as MTC1 and MTM1 respectively.

5.2.1 Modulating waveforms

The following modulating waveforms are permitted in standard modes:

- Telemetry (mode MTM1): a sine wave sub carrier, itself BPSK modulated by PCM data;
- Telecommand (mode MTC1): a sine wave subcarrier, itself BPSK modulated by PCM data;
- Ranging (mode MTC1 + MTM1): an unmodulated sinewave subcarrier or combination of a number of such subcarriers.

5.2.2 PCM waveforms and symbol rates

PCM data signals shall be limited to the waveforms and symbol rates given in table 2.

<table>
<thead>
<tr>
<th>Function</th>
<th>Symbol rate (symbols/second)</th>
<th>PCM waveform</th>
<th>Special Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommand</td>
<td>Between 8 symbols/s up to 4 000 symbols/s (see note)</td>
<td>NRZ-L NRZ-M</td>
<td>n=0 is limited for use with 16 kHz subcarrier</td>
</tr>
<tr>
<td>Telemetry</td>
<td>Between 64 symbols/s up to 20 k symbols (see note)</td>
<td>NRZ-L NRZ-M SP-L</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Coherency between symbols and sub-carrier is required.

5.2.3 Use of subcarriers

The subcarriers and modulating waveforms that shall be used are listed in table 3.

<table>
<thead>
<tr>
<th>Function</th>
<th>Subcarrier (kHz)</th>
<th>Modulation Waveform</th>
<th>Subcarrier Waveform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommand</td>
<td>8 or 16</td>
<td>NRZ-L NRZ-M</td>
<td>Sine</td>
</tr>
<tr>
<td>Telemetry</td>
<td>0,1 to 1 000</td>
<td>NRZ-L NRZ-M SP-L</td>
<td>Sine</td>
</tr>
<tr>
<td>Ranging</td>
<td>0,1 to 100</td>
<td>None (CW Tone)</td>
<td>Sine</td>
</tr>
</tbody>
</table>

5.2.4 Choice of Subcarrier Frequencies

For telecommand transmission using a subcarrier, only two subcarrier frequencies are permitted.
The subcarrier frequency shall be 8 kHz for all telecommand rates up to 2 000 sym/s. A 16 kHz subcarrier shall be used only in cases where the 4 000 sym/s symbol rate is needed or when required by the operator.

The choice of the ranging and telemetry subcarrier frequencies shall take into account the requirements of:

- carrier acquisition by the ground receivers;
- compatibility between ranging and telemetry;
- occupied bandwidth.

Modulation of subcarriers used for telemetry and telecommand shall be BPSK (for ranging the subcarriers are unmodulated tones).

The following requirements shall be met for TC and TM subcarriers:

- for NRZ-L and NRZ-M signal waveforms, the subcarrier frequency shall be a multiple (integer) of the symbol rate from 4 to 1 024;
- for SP-L signal waveforms, the subcarrier frequency shall be an even integer multiple of the symbol rate from 4 to 1 024;
- at each transition in the PCM waveform, the subcarrier shall be reversed in phase;
- the transitions in the PCM waveform shall coincide with a subcarrier zero crossing to within ±2.5 % of a subcarrier period;
- at all times, for more than 25 % of a subcarrier period after a phase reversal, the phase of the modulated subcarrier shall be within ±5° of that of a perfect BPSK signal;
- for NRZ-L and SP-L waveforms, the beginning of the symbol intervals shall coincide with a positive-going subcarrier zero crossing for symbols “1” and with a negative-going zero crossing for symbols “0”;
- for NRZ-M waveforms, the beginning of the symbol intervals shall coincide with a subcarrier zero crossing.

5.2.5 Uplink carrier deviation (Frequency Modulation)

The FM deviation (modulation depth) is stated in table 4.

Table 4: FM uplink frequency deviation

<table>
<thead>
<tr>
<th>Function</th>
<th>Deviation (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommand (PCM/FM) (Mode MTC1)</td>
<td>Up to ±400 kHz</td>
</tr>
<tr>
<td>Ranging Earth-to-space (FM) (Mode MTC1) (total deviation of all simultaneous major and minor tones)</td>
<td>Up to ±400 kHz</td>
</tr>
</tbody>
</table>

5.2.6 Downlink PM modulation index

Minima and maxima of the modulation index are stated in table 5.

Table 5: PM modulation index

<table>
<thead>
<tr>
<th>Function</th>
<th>Min. (radians peak)</th>
<th>Max. (radians peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telemetry (PCM/NRZ/PM) (Mode MTM1)</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>Ranging space-to-Earth (PM) (Mode MTM1)</td>
<td>0,01</td>
<td>1,5</td>
</tr>
</tbody>
</table>
5.2.7 PM sense of modulation

A positive-going video signal (modulated TM subcarrier and/or ranging) shall result in an advance of the phase of the downlink Radio Frequency carrier.

5.3 Spread Spectrum Modulation

The spread modulation formats shall be:

- Telecommand Uplink: Square Root Raised Cosine filtered Unbalanced QPSK (SRRC-UQPSK);
- Telemetry Downlink: SRRC filtered Offset QPSK (SRRC-OQPSK).

The spread modulation modes shall be as follows:

- Mode MTC2: spread spectrum telecommand uplink;
- Mode MTM2: spread spectrum telemetry downlink, coherent mode (long PN code);
- Mode MTM3: spread spectrum telemetry downlink, non-coherent mode (short PN code).
The Spread Spectrum modulation characteristics shall be as defined in table 6. The modulation modes listed shall be available for communications between the Spacecraft and the Earth Terminal for a range of data rates. Symbol rates referred to in the present document include the channel coding overhead whenever channel coding is applied. The Symbol rate shall be selected depending on requirements, link budget and multiple access capabilities. Modulator imperfections are defined in annex C.

### Table 6: Spread Spectrum Link Modulation Modes

<table>
<thead>
<tr>
<th></th>
<th>Telecommand link, Mode MTC2</th>
<th>Coherent Telemetry link, Mode MTM2</th>
<th>Non-Coherent Telemetry Link, Mode MTM3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Symbol Rate</strong></td>
<td>$4 \times 2^n$ $n=0,1..9$</td>
<td>$2^n$ $n=6..14$</td>
<td>$2^n$ $n=6..14$</td>
</tr>
<tr>
<td><strong>Channel Symbol rate on I channel (sym/s)</strong></td>
<td>Symbol Rate</td>
<td>Symbol Rate (Same symbols on both channels)</td>
<td>Symbol Rate (Same symbols on both channels)</td>
</tr>
<tr>
<td><strong>Channel Symbol rate on Q channel (sym/s)</strong></td>
<td>PN code only</td>
<td>Symbol rate (Same symbols on both channels)</td>
<td>Symbol rate (Same symbols on both channels)</td>
</tr>
<tr>
<td><strong>Data format</strong></td>
<td>NRZ-L</td>
<td>NRZ-L</td>
<td>NRZ-L</td>
</tr>
<tr>
<td></td>
<td>NRZ-M</td>
<td>NRZ-M</td>
<td>NRZ-M</td>
</tr>
<tr>
<td><strong>PN code family I channel</strong></td>
<td>Gold code</td>
<td>Truncated m-sequence</td>
<td>Gold code</td>
</tr>
<tr>
<td><strong>PN Code length I channel</strong></td>
<td>$2^{10} \times 256$</td>
<td>$2^{10} \times 256$</td>
<td>$2^{11} \times 1$</td>
</tr>
<tr>
<td><strong>Code I epoch reference</strong></td>
<td>None</td>
<td>Received Q code of MTC2</td>
<td>None</td>
</tr>
<tr>
<td><strong>PN code family Q channel</strong></td>
<td>Truncated m-sequence</td>
<td>Truncated m-sequence</td>
<td>Gold code</td>
</tr>
<tr>
<td><strong>PN Code length Q channel</strong></td>
<td>$(2^{10} \times 256)$</td>
<td>$2^{10} \times 256$</td>
<td>$2^{11} \times 1$</td>
</tr>
<tr>
<td><strong>Code Q epoch reference</strong></td>
<td>I code</td>
<td>$x + 1/2$ chips Delay w.r.t I ch of MTM2</td>
<td>1/2 chip delay w.r.t I of non-coherent mode return link</td>
</tr>
<tr>
<td><strong>Spreading code rate (Mc/s)</strong></td>
<td>1 Mchip/s or 3 Mchip/s</td>
<td>Identical to Received code</td>
<td>1 Mchip/s or 3 Mchip/s</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>SRRC-UQPSK</td>
<td>SRRC-OQPSK</td>
<td>SRRC-OQPSK</td>
</tr>
<tr>
<td><strong>I/Q power ratio</strong></td>
<td>10:1</td>
<td>1:1</td>
<td>1:1</td>
</tr>
<tr>
<td><strong>Ranging service possible</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

### Modulator Imperfections (see annex C):

<table>
<thead>
<tr>
<th></th>
<th>Phase Imbalance (°)</th>
<th>Amplitude Imbalance (dB)</th>
<th>Data asymmetry</th>
<th>Data bit jitter</th>
<th>PN code chip asymmetry</th>
<th>PN code chip jitter</th>
<th>Chip transition time</th>
<th>I/Q data bit skew</th>
<th>I/Q PN code chip skew</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$&lt;2^°$</td>
<td>$&lt;0.25$</td>
<td>$&lt;0.03$</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.05$</td>
<td>$&lt;0.01$</td>
<td>$&lt;0.01$</td>
</tr>
</tbody>
</table>

The Telecommand uplink signal in mode MTC2 shall be a spread spectrum SRRC-UQPSK modulated signal with the data and a short PN code on the I Channel and a long PN code on the Q channel. It has Square Root Raised Cosine (SRRC) chip shaping.

The coherent mode telemetry downlink signal in mode MTM2 shall be a spread spectrum SRRC-OQPSK modulated signal with data on the Q channel and on the I channel. MTM2 supports ranging by transmission of a long PN code on the downlink I channel synchronized to the code received on the mode MTC2 uplink Q channel. A delayed version of this code is transmitted on the downlink Q channel.

Mode MTM3 shall be a spread spectrum SRRC-OQPSK modulated signal with the data on the Q channel and on the I channel. MTM3 does not support ranging. A short (Gold) PN code is transmitted on the I channel and a half chip delayed Gold code is transmitted on the Q channel.

For all spread PN coded transmissions, the data shall be modulo-2 added asynchronously to the PN code and any pulse shaping (i.e. SRRC) performed before being applied to the carrier modulator.
5.3.1 Chip shaping

Pulse or chip shaping shall be applied to the baseband signal prior to linear modulation, in order to achieve bandwidth restriction of the spread spectrum signal. To implement a symmetric band limited channel, Square Root Raised Cosine (SRRC) filtering (see annex D) shall be used at both the transmitter and the receiver on the telecommand and telemetry links.

SRRC filtering is defined in terms of a roll off factor $\alpha$ which has a value between 0 and 1, with the RF bandwidth of the spread spectrum signal given by $(1 + \alpha)R_c$, where $R_c$ is the chip rate.

For the purposes of the present document $\alpha = 0.5$ shall be used, giving an RF bandwidth of $1.5R_c$.

5.4 Coherency properties

In mode MTM1 and MTC1, coherency between symbols rate and sub-carrier is required.

In non-coherent spread mode (MTM3), all of the clocks/carriers shall be derived from references local to the spacecraft and independent of the uplink: downlink RF carrier, TM data clock, PN chip clock and PN Epoch shall be local to the spacecraft.

In coherent spread mode (MTM2), the downlink PN code Epoch and chip clock shall be synchronized to the uplink Q channel PN code. However, other downlink clocks/carriers may be local to the spacecraft and independent of the uplink: downlink RF carrier and TM data shall be local to the spacecraft.

5.4.1 FEC Channel Coding

In order to achieve all requirements for the present document (see [1], annex B), following the analysis documented in [1], it has been concluded that a minimum FEC coding gain of up to 5 dB may be required in spread spectrum modes on both Telecommand and Telemetry links. Selection of FEC code type is outside the scope of the present document. An example of a coding scheme that can achieve such gain is documented in annex G.

6 Requirements on transmitted signals

6.1 Frequency stability requirements

6.1.1 Uplink

In mode MTC2 (spread spectrum), the on-board receiver shall tolerate:

- A frequency shift due to Doppler effect of 1.4 ppm (for RF carrier, chip rate and data rate);
- A ratio $\frac{\text{Doppler rate}}{\text{Frequency}}$ of $1.2 \times 10^{-9}$ Hz (for RF carrier, chip rate and data rate).

In mode MTC1 (FM), the on-board receiver shall tolerate:

- A frequency shift due to Doppler effect of 22 ppm (for RF carrier, subcarrier and data rate);
- A ratio $\frac{\text{Doppler rate}}{\text{Frequency}}$ of $1.7 \times 10^{-6}$ Hz (for RF carrier, subcarrier and data rate).

The ground contribution to those deviations shall be negligible.
6.1.2 Downlink

The Doppler values to take into account for the downlink shall be identical to uplink.

The stability of the on-board generated RF frequency (for modes MTM1 or MTM2) shall be better than 5 ppm (end of life).

The stability of the on-board generated downlink chip rate (for mode MTM3) shall be better than 5 ppm (end of life).

6.2 Turnaround frequency ratio

No turnaround frequency ratio is required between the up and down RF links, since there shall be no coherency between uplink and downlink carriers.

6.3 Polarization

Polarization is operator and mission phase dependent, and its definition is beyond the scope of the present document.

6.4 Phase noise

The phase noise measured on a unmodulated carrier between 10 Hz and 100 kHz around the carrier shall be less than:

<table>
<thead>
<tr>
<th>Frequency w.r.t. the carrier</th>
<th>Noise density (dBc/Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-35</td>
</tr>
<tr>
<td>100</td>
<td>-63</td>
</tr>
<tr>
<td>1 000</td>
<td>-63</td>
</tr>
<tr>
<td>10 000</td>
<td>-72</td>
</tr>
<tr>
<td>100 000</td>
<td>-105</td>
</tr>
</tbody>
</table>

7 Link Acquisition requirements

The acquisition time of the uplink signal shall be better than 3 s, with a success probability better than 99 %.

For the downlink, the acquisition time of the downlink signal shall be better than 10 s, with a success probability better than 99 %.

In Modes MTC2, MTM2 and MTM3, the maximum Doppler that can be acquired without precompensation is specified in clause 6 requirements on transmitted signals. For mission phases where Doppler is greater than this amount, either Standard Mode (MTC1/MTM1) shall be used, or Doppler precompensation shall be used to reduce the uncertainty below that specified in clause 6 requirements on transmitted signals.

In Mode MTM3, a long (truncated m-sequence) PN code is used, of length $256 \times 1023$ chips. In order for the Ground demodulator to acquire this code, epoch estimation is required. This estimation shall be within ±1 000 chips, as used on Agency Data Relay Systems.
Annex A (informative): Operational configuration

Communications satellites faces different radio-frequency environment, depending on mission phase. There are 4 main different mission phases to consider: LEOP phase, drift orbit, nominal on station phase and emergency on station phase.

Depending of the on-board implementation of the standard, spread spectrum or standard modulation can be used for uplink or downlink. The aim of this annex is to describe the operational configuration of three different possible implementations of the standard.

These three configurations are:

- Configuration 1: on board dual mode receiver and on board dual mode transmitter;
- Configuration 2: on board dual mode receiver and Standard transmitter;
- Configuration 3: on board dual mode receiver, Standard transmitter and dedicated RG SS transmitter.

A typical frequency plan is shown in figure 5.

36 MHz channels with center frequency separation of 40.00 MHz

**UPLINK**: (13.7 - 14.5 GHz)

Vertical polarization

**DOWNLINK**: (11.4 - 12.2 GHz)

Vertical polarization

This frequency plan defines various TCR frequencies, but depending of the implementation; some of the frequencies are not used. It has been assumed for the analysis of SS modes (see [1]) that any TC-echo effect on the TM signal is negligible.

**Uplink:**

- $f_2$ is the SS frequency;
- $f_1$ and $f_1'$ are in the same bandwidth as $f_2$.

**Downlink:**

- $f_1$ is the SS frequency;
- $f_2$ and $f_2'$ are the STD modulation frequency, in a different bandwidth than the SS bandwidth.

For each configuration below, the modulation mode (MTC1, MTC2, MTM1, MTM2, MTM3) refers to the definition given in clause 5 modulation requirements.
A.1 Configuration 1: on board dual mode receiver and on board dual mode transmitter

On board the satellite, a dual mode receiver shall be used, enabling the demodulation of either spread spectrum or standard modulation signal (both demodulations are done in parallel but only one is successful, depending of the modulation of the uplink signal). Dual mode transmitters (or two different transmitters, one for STD and one for SS modulation) are used for the downlink.

The receiver and the transmitter simultaneously use spread spectrum in Spread Spectrum mode, and simultaneously use standard modulation in Standard Mode.

![Configuration 1 typical TCR/RF architecture](image)

Figure 6: Configuration 1 typical TCR/RF architecture

The associated on-board TCR/RF architecture is shown in figure 6.

The different operational configurations and the associated bandwidth are described in table 7.

### Table 7: Configuration 1 frequency and modulation assignment

<table>
<thead>
<tr>
<th>Beginning of the LEOP</th>
<th>LEOP, apogee phase (low Doppler, possibility of jamming with Geo satellites)</th>
<th>Drift orbit (low Doppler, possibility of jamming with Geo satellites)</th>
<th>On station nominal</th>
<th>On station emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td><strong>TC STD (MTC1), F1 or F'1</strong></td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
</tr>
<tr>
<td>TM</td>
<td><strong>TM STD (MTM1), f2 or/and f2</strong></td>
<td>SS (MTM2 or 3), f1</td>
<td>SS (MTM2 or 3), f1</td>
<td>SS (MTM2 or 3), f1</td>
</tr>
<tr>
<td>RG</td>
<td>Idem TC/TM (see note 1)</td>
<td>Idem TC/TM (see note 2)</td>
<td>Idem TC/TM (see note 2)</td>
<td>Idem TC/TM (see note 2)</td>
</tr>
</tbody>
</table>

**NOTE 1:** TC and RG can be done simultaneously, depending of RF link budget margin and compatibility between RG tones and TC sub-carrier.

**NOTE 2:** TC and RG can be done simultaneously.
Note that for the emergency:

- it may be necessary to command sequentially each satellite of a fleet of collocated satellites using the same bandwidth;
- it may be necessary to foresee for the downlink an additional bandwidth ("emergency bandwidth"), distinct from the nominal TM bandwidth.

### A.2 Configuration 2: on board dual mode receiver and Standard transmitter

On board the satellite, a dual mode receiver shall be used, enabling the demodulation of either spread spectrum or standard modulation signal (both demodulations are done in parallel but only one is successful, depending of the modulation of the uplink signal). Standard transmitters are used for the downlink, whatever the mission phase of the satellites. A specific process (see annexe) enables the transformation of a PN code into a RG tone, so that for certain phases of life, SS modulation can be used for the uplink (including RG) while STD modulation is used for the downlink.

![Figure 7: Configuration 2 typical TCR/RF architecture](image)

The associated on-board TCR/RF architecture is presented in figure 7.

The different operational configurations and the associated bandwidth are described in table 8.
### Table 8: Configuration 2 frequency and modulation assignment

<table>
<thead>
<tr>
<th>Beginning of the LEOP</th>
<th>LEOP, apogee phase (low Doppler, possibility of jamming with Geo satellites)</th>
<th>Drift orbit (low Doppler, possibility of jamming with Geo satellites)</th>
<th>On station nominal</th>
<th>On station emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>STD (MTC1), F1 or F'1</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
</tr>
<tr>
<td>TM</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
</tr>
<tr>
<td>RG</td>
<td>Idem TC/TM (hybrid RG) (see note 1)</td>
<td>Idem TC/TM (hybrid RG) (see note 2)</td>
<td>Idem TC/TM (hybrid RG) (see note 2)</td>
<td>Idem TC/TM (hybrid RG) (see note 2)</td>
</tr>
</tbody>
</table>

**NOTE 1:** TC and RG can be done simultaneously, depending on RF link budget margin and compatibility between RG tones and TC sub-carrier.

**NOTE 2:** TC and RG can be done simultaneously.

Note that for the emergency:

- it may be necessary to command sequentially each satellite of a fleet of collocated satellites using the same bandwidth;
- no additional bandwidth ("emergency bandwidth") is required for the emergency downlink.

### A.3 Configuration 3: on board dual mode receiver, Standard transmitter and dedicated RG SS transmitter

On board the satellite, a dual mode receiver shall be used, enabling the demodulation of either spread spectrum or standard modulation signal (both demodulations are done in parallel but only one is successful, depending of the modulation of the uplink signal). Standard transmitters are used for the downlink TM, whatever the mission phase of the satellites. Concerning the RG, a dedicated SS transmitter is used each time SS RG is used for the uplink.

![Figure 8: Configuration 3 typical TCR/RF architecture](image)

The associated on-board TCR/RF architecture is presented in figure 8.
The different operational configurations and the associated bandwidth are described in table 9.

**Table 9: Configuration 3 frequency and modulation assignment**

<table>
<thead>
<tr>
<th></th>
<th>Beginning of the LEOP</th>
<th>LEOP, apogee phase (low Doppler, possibility of jamming with Geo satellites)</th>
<th>Drift orbit (low Doppler, possibility of jamming with Geo satellites)</th>
<th>On station nominal</th>
<th>On station emergency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TC</strong></td>
<td>STD (MTC1), F1 or F1</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
<td>SS (MTC2), F2</td>
</tr>
<tr>
<td><strong>TM</strong></td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
<td>STD (MTM1), f2 or/and f2</td>
</tr>
<tr>
<td><strong>RG</strong></td>
<td>Idem TC/TM (see note 1)</td>
<td>SS up F2, SS down f1 (see notes 2 and 3)</td>
<td>SS up F2, SS down f1 (see notes 2 and 3)</td>
<td>SS up F2, SS down f1 (see notes 2 and 3)</td>
<td>STD up F2, STD down f1 (see note 2)</td>
</tr>
</tbody>
</table>

**NOTE 1:** TC and RG can be done simultaneously, depending of RF link budget margin and compatibility between RG tones and TC sub-carrier.

**NOTE 2:** TC and RG can be done simultaneously.

**NOTE 3:** The modulation used for RG is identical to MTM2 (see clause 5 modulation requirements) except that no TM data is down linked.

Note that for the emergency:

- it shall be necessary to command sequentially each satellite of a fleet of collocated satellites using the same bandwidth;
- it shall also be necessary for the system to foresee 2 downlink bandwidths, one for SS RG, and one for STD modulation TM&RG.
Annex B (informative):
Hybrid Ranging process description

The hybrid RG process enables the use of spread spectrum RG for the uplink, and the use of standard RG tone for the downlink.

B.1 Presentation

For the uplink, a RG PN code is transmitted to the satellite, in accordance with the standardized modulation of clause 4 applicability.

The satellite receives the uplink spread spectrum signal (PN code) and uses the clock of this PN code to generate some synchronized RG tones. The phase of the tone corresponds to the beginning of the PN code, and there is an integer multiple of tone periods during the PN code epoch. This ranging is transmitted to the ground by using standard modulation (PM modulation), and the ground baseband unit measured the delay between this tone and the original transmitted PN code (see figure 9).

![Figure 9: Hybrid Ranging presentation](image)

The timing diagram of the sequence is detailed in figure 10.
B.2 Distance ambiguity resolution

The ambiguity of the distance is resolved by using major and minor tones. The generation of the different tones is processed on board, as explained through figure 11.

Figure 10: RG hybrid timing diagram

Figure 11: Hybrid ranging on board processor architecture

A first DAC delivers virtual tones, from 8 Hz to 20 kHz.

The second DAC delivers the major tone.
The RG measurement is performed:

- with the major tone for the accurate measurement (but the ambiguity will have to be solved);

- with the minor tones sent sequentially, but simultaneous with the major tone to solve ambiguity. Virtual minor tones being difficult to send (very low frequency), real tones equal to linear combination of those tones can be sent.

The on board processor will have to send sequentially each minor tone (for example we change of minor tone each N chips epochs).

At ground level, the RG tones null is compared to the origin of the PN code epoch, and this measured delay is used to determine (with the ambiguity of the major tone) the distance. This measurement is repeated for every minor tone, so that at the end of the measure, the ambiguity is solved (existing ambiguity resolution algorithm shall be used).

### B.3 Calibration

For the RG calibration (estimation of the on board delay and/or of the ground delay), short loop (connection of the ground baseband unit output directly to the ground baseband unit input) is possible, but more difficult than using standard modulation, as uplink and downlink modulation are different. Details of the implementation are given in [1].

Another solution is to measure with the real ground equipment, and the satellite hardware, the delay of the link, without knowing what is specifically the on-board or the ground contribution.

Once in orbit, the ground station can be re-calibrated frequently in relative value, through the temporarily use (for the calibration phase) of standard modulation.
Annex C (informative):
Modulator imperfections

C.1 Phase imbalance

The modulated signal, at the output of the modulator, is a sum of two signal components called In Phase Channel (I-channel) and Quadrature Phase Channel (Q-channel) respectively. The two signal components have the same carrier with an ideal phase difference of 90°.

The modulated signal has two signal states for BPSK modulation and four signal states for QPSK modulation. Each signal state, N, is characterized by an amplitude, A(N), and a phase, Φ(N), where Φ(N) is defined as the difference between the phase of the modulated carrier, when in state N, and the phase of the unmodulated carrier.

C.2 BPSK phase imbalance

For BPSK the ideal phase between the two signal states, with phase Φ(1), where Φ(2) respectively, is 180°. The phase imbalance is defined as:

\[
\text{BPSK Phase Imbalance (deg) = } 180° - |Φ(1) - Φ(2)|
\]

where \(|\text{argument}|\) denotes the absolute value of the argument.

C.3 QPSK phase imbalance

For QPSK the ideal phase between the four signal states depend on the ideal In Phase to Q channel power ratio. The ideal phase difference, θ\text{ideal}, is provided in versus In Phase to Q channel (I/Q) power ratio.

<table>
<thead>
<tr>
<th>I/Q Power Ratio</th>
<th>θ\text{ideal}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>90°</td>
</tr>
<tr>
<td>1:10</td>
<td>35.1° and 144.9°</td>
</tr>
</tbody>
</table>

Let Φ(N) denote the phase difference between the actual signal states. The phase (N) imbalance is then defined as:

\[
\text{QPSK Phase Imbalance (deg) = Maximum (|Φ(N) - Φ(\text{ideal})|, N =1, 2, 3, 4)}
\]

C.4 Amplitude imbalance

The modulated signal has two signal states for BPSK and four signal states for QPSK modulation. Each signal state, N, is characterized by an amplitude, A(N), and a phase, Φ(N). The modulated signal from a Phase Shift Keying modulator, being either BPSK, QPSK, UQPSK or OQPSK, is ideally a constant envelope signal or the ratio between the maximum and minimum signal state amplitude is 1:1. Let A_{max} and A_{min} denote the actual amplitudes for the signal state with the maximum amplitude and the signal state with the minimum amplitude as follows:

\[
A_{\text{max}} = \text{Maximum}(A(N), N = 1, 2, 3, 4)
\]
\[
A_{\text{min}} = \text{Minimum}(A(N), N = 1, 2, 3, 4).
\]
The amplitude imbalance is then defined as:

$$\text{Amplitude Imbalance (dB)} = 20 \times \log(A_{\text{max}}/A_{\text{min}}).$$

C.5 Data asymmetry

The data signal is a continuous sequence of symbols. For NRZ data format, two different symbols exist where one denotes logical zero and the other logical one. The length or duration of the symbol denoting logical zero is ideally equal to the length of the symbol denoting logical one.

The actual length of the symbol denoting logical zero might not be equal to the actual length of symbol denoting logical one. Let $L_1$ denote the average length of symbols denoting logical one in a data sequence and $L_0$ denote the average length of symbols denoting logical zero in the data sequence. The data asymmetry is defined as:

$$\text{Data Asymmetry} = \left| \frac{L_0 - L_1}{L_0 + L_1} \right|$$

C.6 Data bit jitter

The data signal is a continuous sequence of symbols. For NRZ data format, two different symbols exist where one denotes logical zero and the other logical one. The length or duration of the symbol denoting logical zero is ideally equal to the length of the symbol denoting logical one.

The actual length of the symbol denoting logical zero might not be equal to the actual length of symbol denoting logical one. Let $L_1$ denote the average length of symbols denoting logical one in a data sequence and $L_0$ denote the average length of symbols denoting logical zero in the data sequence. Moreover, let $V_{L_0}$ denote the variance of the length of symbols denoting logical zero, which is defined as the average of $(\text{length of logical zero symbol } L_0)^2$, and let $V_{L_1}$ denote the variance of the length of symbols denoting logical one. The data bit jitter is defined as:

$$\text{Data Bit Jitter} = \frac{\sqrt{V_{L_1} + V_{L_0}}}{L_1 + L_0}$$

C.7 PN code asymmetry

Defined as for data asymmetry but with chips in place of bits.

C.8 PN code chip jitter

Defined as for data bit jitter but with chips in place of bits.

C.9 Chip Transition Time

The modulated signal has two signal states for BPSK modulation and four signal states for QPSK modulation. Each signal state, $N$, is characterized by an amplitude, $A_{(N)}$, and a phase, $\Phi_{(N)}$, where $\Phi_{(N)}$ is the steady state phase angle.

Ideally the phase $\Phi_{(N)}$ changes from the one signal state to the other signal state in an infinitely short time. The actual transition time from the phase $\Phi_{(1)}$ for signal state 1, to change to the subsequent phase $\Phi_{(2)}$, for signal state 2, lasts a finite duration.

$$\text{Chip Transition Time} = \text{the time duration to switch from } 90\% \text{ of } \Phi_{(1)} \text{ to } 90\% \text{ of } \Phi_{(2)} \text{ divided by the average chip duration}$$
C.10 I/Q Data Bit Skew

When the data rate modulating the I channel and the data rate modulating the Q channel are the same, there is an ideal relative time delay between the instants of data transitions on the one channel and the instants of data transitions on the other channel. The I/Q data bit skew defines the deviation from this ideal relative time delay. For QPSK the ideal relative time delay is zero whereas for staggered QPSK the relative time delay is 0.5.

Let \( t(I_i) \) and \( t(Q_i) \) denote the actual data bit transition instants on the I channel and the Q channel respectively. Moreover, let \( L_d \) denote the average length of the data bits and let \( \delta \) denote the ideal relative time delay. The I/Q data bit skew is defined as:

\[
\text{I/Q Data Bit Skew} = \frac{\text{Average}((t(I_i) - t(Q_i)))}{L_d} - \delta
\]

where \( i \) denotes the data bit number \( i \) in a data sequence and the average is taken over all data bits in the complete data sequence.

C.11 I/Q PN Code Chip Skew

Defined as for data bit skew but with chips in place of bits.
Annex D (informative):
SRRC Chip filtering

Transfer Function:

The transfer function for the SRRC filter \( H(f) \) is detailed below.

\[
H(f) / \sqrt{T} = 1 \quad \text{for} \quad 0 \leq |f| \leq (1 - \alpha) / 2T
\]
\[
H(f) / \sqrt{T} = \left( 0.5 \left[ 1 + \cos \left( \frac{\pi T}{\alpha} \left( f - \frac{1}{2} \frac{(1 - \alpha)}{2T} \right) \right) \right] \right)^{1/2} \quad \text{for} \quad (1 - \alpha) / 2T \leq |f| \leq (1 + \alpha) / 2T
\]
\[
H(f) / \sqrt{T} = 0 \quad \text{for} \quad (1 + \alpha) / 2T \leq |f|
\]

The bandwidth of the SRRC filter is a function the roll off factor \( \alpha \), which has a value between 0 and 1. The RF bandwidth of the filtered signal is given by:

\[
B = (1 + \alpha) / T = (1 + \alpha)Rc
\]

Where \( Rc \) is the chip rate of the spreading sequence.

Impulse Response:

The corresponding impulse response for the SRRC filter is detailed below.

\[
h(t) / \sqrt{T} = \frac{4\alpha T}{\pi} \cos \left( \frac{(1 + \alpha)\pi}{T} \right) + \sin \left( \frac{(1 - \alpha)\pi}{T} \right)
\]

For a roll off factor \( \alpha = 0.5 \) frequency and time domain responses are shown in figure 12 and figure 13 respectively.

![Figure 12: SRRC Frequency Response for Alpha = 0.5](image-url)
Figure 13: SRRC Impulse Response for Alpha = 0,5
Annex E (normative):
PN Code Allocation, Assignment and Generation

E.1 PN Code Allocation

PN spreading codes to be used for the present document are from the same family as those used for Space Agency Data Relay systems: ESA DRSS (Artemis), NASA TDRSS and NASDA DRTS. The codes, when added modulo 2 to data (Direct Sequence Spread Spectrum), give the potential for Code Division Multiple Access, resistance to jamming, and minimized jamming to other users.

Because the present document is aimed at Geostationary satellites which operate at different TC/TM frequencies from any of the Agency Data Relay systems, the existing code configuration libraries can be re-used without any co-ordination problems for this application. These libraries contain 85 code sets per agency (total 255 code sets). For the purposes of the present document, only the ESA code set shall be adopted. This code set is defined in ESA standards [3] and repeated later in this annex.

E.2 PN Code Assignment

One set of PN codes must be assigned per satellite and each set comprises:

- Uplink (Mode MTC2) PN code: Telecommand or In-phase channel, 1 023 chip length Gold code;
- Uplink (Mode MTC2) PN code: Ranging or quadrature channel, maximal length sequence of \(2^{18} - 1\) chips truncated to \(256 \times 1 023\) chips;
- Downlink PN code:
  - Coherent Ranging Mode (Mode MTM2): Telemetry and ranging, a maximal length sequence of \(2^{18} - 1\) chips truncated to \(256 \times 1 023\) chips;
  - Non Coherent Mode (Mode MTM3): Telemetry only, a Gold code sequence of \(2^{11} - 1\) chips.

Each user satellite must request an assignment from the competent body responsible, applicable to the present document. The competent body is TBD.

E.3 PN Code Generation

E.3.1 Telecommand Uplink or In-phase Channel (Mode MTC2)

In mode MTC1, the PN codes for the Telecommand data channel, the In-phase channel, are Gold codes with a length of 1 023 chips. These codes are balanced and give good cross-correlation performance, allowing their use for Code Division Multiple Access with the advantage of relatively short acquisition times.

The uplink PN Gold code generator is shown in figure 14 and consists of two maximal length generators. In order to ensure generation of balanced codes, the register contents (initial seed value) or relative phases must be specified. Register B has a fixed initial seed value and feedback taps as shown in figure 14. For the purposes of the present document, the configuration of bits A and B of Register A relative to different operators shall be the same as that for ESA. Register A contents for ESA is given below:

- ESA Register A initial seed value assignment: \(A = B = 1\), \(X\) from library assignment.

The 7 bits of register A from PN code library assignment (see clause E.5) give at least 85 balanced Gold codes.
E.3.2 Ranging Uplink or Quadrature Channel (Mode MTC2)

In mode MTC2, the PN codes used for the uplink ranging or quadrature channel are maximum length sequences with a code length given by \((2^{18} - 1)\) but truncated to length \((256 \times 1023)\). This is done in order to synchronize them to an integral number of the short (Gold) command code epoch lengths. This aids in acquiring the longer ranging code since now only 256 ranging code positions need be searched following Gold code acquisition.

The Uplink Ranging code generator configuration is shown in figure 15. The number of feed back taps should generally not be too large (e.g. of order 6) in order to minimize implementation complexity. The feed back tap configurations are specified in the PN code library (see clause E.5).

E.4 Telemetry Downlink

E.4.1 Coherent Ranging Mode (Mode MTM2)

In this mode (MTM2) the uplink ranging PN code epoch timing is coherently transferred to the downlink PN code, as is the PN code chip clock. This thus allows two-way ranging with ambiguity resolution.

The PN code for the telemetry downlink is a maximal length sequence used for the In-phase channel with a phase shifted version of it used for the Quadrature channel. The Coherent downlink PN code generator configuration is shown in figure 16. The telemetry and ranging downlink PN codes, as for the uplink ranging code, have length truncated to \((256 \times 1023)\) chips. The feedback tap configuration is specified in the PN code library (see clause E.5).
E.4.2 Non Coherent Mode (Mode MTM3)

This downlink mode operates if there is no Telecommand and Ranging uplink present at the satellite. PN code generator configurations for ESA format is shown in figure 17. Having different PN codes for the in phase and quadrature channels solves channel ambiguity.

Register B values ensure that the code generator produces balanced codes. The contents of the other registers are determined the PN code libraries (see clause E.5).

E.5 PN code libraries

The numbers in table 11 are the initial register loading and feedback tap connections in octal presentation. The only exception is the forward in-phase channel, where binary representation was selected. For the command channel, stage 1 is always 0 and stages 9 and 10 are agency specific and both set to 1 for ESA.
Table 11: PN Code Set Assignments (ESA only)

<table>
<thead>
<tr>
<th>Code Set</th>
<th>Forward In-Phase Channel</th>
<th>Mode 2 Return Link</th>
<th>Forward Quadrature Channel</th>
<th>Mode 1 and 3 Return Link</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial Register Loading</td>
<td>Feedback Tap Connections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0101101</td>
<td>0514 0752</td>
<td>1124013</td>
<td>1320067</td>
</tr>
<tr>
<td>2</td>
<td>0100001</td>
<td>1231 1725</td>
<td>1624021</td>
<td>1105265</td>
</tr>
<tr>
<td>3</td>
<td>1011011</td>
<td>2462 3653</td>
<td>1524003</td>
<td>1062127</td>
</tr>
<tr>
<td>4</td>
<td>0011001</td>
<td>1144 3526</td>
<td>1550005</td>
<td>1211465</td>
</tr>
<tr>
<td>5</td>
<td>0010001</td>
<td>2310 3254</td>
<td>1011505</td>
<td>1036123</td>
</tr>
<tr>
<td>6</td>
<td>0110011</td>
<td>0621 2531</td>
<td>1240423</td>
<td>1406551</td>
</tr>
<tr>
<td>7</td>
<td>0110111</td>
<td>1443 1262</td>
<td>1006113</td>
<td>1146065</td>
</tr>
<tr>
<td>8</td>
<td>0100110</td>
<td>3107 2544</td>
<td>1221411</td>
<td>1023551</td>
</tr>
<tr>
<td>9</td>
<td>0110110</td>
<td>2176 3101</td>
<td>1502025</td>
<td>1041467</td>
</tr>
<tr>
<td>10</td>
<td>0100101</td>
<td>0375 2203</td>
<td>1014027</td>
<td>1071701</td>
</tr>
<tr>
<td>11</td>
<td>1111010</td>
<td>0772 0407</td>
<td>1110311</td>
<td>1126611</td>
</tr>
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<td>12</td>
<td>0010111</td>
<td>1765 1017</td>
<td>1001651</td>
<td>1442625</td>
</tr>
<tr>
<td>13</td>
<td>1000100</td>
<td>3753 2036</td>
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Note that the loading for the shift registers is given from left to right whereas the feedback tap connections are specified from right to left according to mathematical definitions. See also figure 14, figure 15, figure 16 and figure 17. An example for the loading and for the tap connections is given below based on code set 1.

Gold Code on Forward I-Channel (Initial loading): 0101101 -&gt; 1101011010
Gold Codes on Return Channels (Initial loading): I: 0514 -&gt; [0]0010100110
Q: 0752 -&gt; [0]0011110101
Maximum Length Codes Forward Channel (feedback taps): 1124013 -&gt; [00]100101010000000101[1]
Maximum Length Codes Return Channels (feedback taps): 1320067 -&gt; [00]101101000000011011[1]

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Annex F (informative): Performance computations

For performance computations, refer to TR 101 956 [1].
Annex G (informative): FEC coding example

In order to achieve all requirements for the present document (see [1], annex B), following the analysis documented in [1], it has been concluded that a minimum FEC coding gain of up to 5 dB may be required in spread spectrum modes on both Telecommand and Telemetry links. Selection of FEC code type is outside the scope of the present document.

One coding scheme that achieves the required 5 dB gain is the rate 1/2, constraint length 7 convolutional code as defined in [5].
Annex H (informative):  
Bandwidth considerations and assumptions

In order to guarantee sufficient protection between TCR and COM channels, the following has been assumed for the background analysis to the present document for SS modes (see [1]):

- COM channel suppression in TC and TM bands has been assumed for the analysis to be < -25 dBc in relation to the COM channel PSD.

- TC and TM suppression in COM bands shall be < -25 dBc in relation to the TC and TM PSD respectively. This is achieved by the selected Spread Spectrum Modulations:
  - Uplink Mode MTC2: SRRC-UQPSK modulation through linear Groundstation HPA gives TC Bandwidth of 1,5 × Rc (1,5 MHz or 4,5 MHz, where Rc = chip rate).
  - Downlink Mode MTM2: SRRC-OQPSK modulation (almost constant amplitude envelope) through (possibly saturated) Spacecraft HPA gives TM Bandwidth of 1,5 × Rc (1,5 MHz or 4,5 MHz, where Rc = chip rate).
History

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