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TECHNICAL REPORT

## Satellite Earth Stations and Systems (SES); SC-FDMA based radio waveform technology for Ku/Ka band satellite service

Reference

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Keywords

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# Foreword

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

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# 1 Scope

The present document aims at assessing the performance of a SC-FDMA-based radio waveform over geostationary satellites in Ku/Ka band. Moreover, it aims at defining an evaluation framework for performance comparison with existing waveform technologies (e.g. DVB-S2, DVB-S2X and DVB-RCS2), focusing on the radio and physical layers.

The present document deals with satellite return link only. The forward link is for further study. For the return link, two use cases have been identified and treated so far, Satellite News Gathering (DSNG) and Broadband Access.

The present document provides a description of the waveforms to be compared; it identifies their key characteristics, defines the system model used for comparison and presents comparative performance results in terms of spectral efficiency. A complexity analysis is also performed.

# 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 302 307: "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)".

[i.2] DVB Document A83-2: "Digital video broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for broadcasting, interactive services, news gathering and other broad-band satellite applications, Part II: S2-Extensions (DVB-S2X)-(Optional)", March 2014.

[i.3] ETSI TS 136 211 (V8.3.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 8.3.0 Release 8)".

[i.4] DVB BlueBook A160: "Digital Video Broadcasting (DVB); Next Generation broadcasting system to Handheld, physical layer specification (DVB-NGH)".

[i.5] Ciochina-Duchesne C., Castelain D., Bouttier A.: "Satellite profile in DVB-NGH," Advanced Satellite Multimedia Systems Conference (ASMS) and 12th Signal Processing for Space Communications Workshop (SPSC), Baiona, Spain, 5-7 September 2012.

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[i.17] U. Mengali and M. Morelli: "Data-aided frequency estimation for burst digital transmission" Communications, IEEE Transactions on, vol. 45, no. 1, pp. 23-25, January 1997.

[i.18] P. H. Moose: "A technique for orthogonal frequency division multiplex- ing frequency offset correction," Communications, IEEE Transactions on, vol. 42, no. 10, pp. 2908-2914, October 1994.

[i.19] Global Positioning System Standard Positioning Service Performance Standard, 4th edition, September 2008.

[i.20] B. M. Popović: "Efficient Matched Filter for the Generalized Chirp-Like Polyphase Sequences" IEEE Transactions on Aerospace and Electronic Systems, Vol. 30, No. 3, pp. 769-777, July 1994.

[i.21] Panasonic: "R1-071517: RACH Sequence Allocation for Efficient Matched Filter Implementation", www.3gpp.org, 3GPP TSG RAN WG1, meeting 48bis, St Julians, Malta, March 2007.

[i.22] D. Castelain, C. Ciochina-Duchesne, J. Guillet and F. Hasegawa: "SC-OFDM, a Low-Complexity Technique for High Performance Satellite Communications", ICSSC"2014, San Diego, August 2014.

# 3 Symbols and abbreviations

## 3.1 Symbols

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

| | |
|---|---|
| $\alpha$ | Roll-off factor |
| $M$ | DFT precoding size |
| $N$ | IDFT size |
| $Ncar$ | Number of carriers per transponder |
| $N_{CP}$ | CP length |
| $N_{guard}$ | Number of guard subcarriers |
| $N_{taps}$ | Number of taps for the finite impulse response filter |
| $ovs$ | Oversampling factor |
| $\rho$ | Code rate |
| $Rs$ | Symbol rate (baud) |

## 3.2 Abbreviations

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

| | |
|---|---|
| 3GPP | Third Generation Partnership Project |
| AM/AM | Amplitude Modulation/Amplitude Modulation |
| AM/PM | Amplitude Modulation/Phase Modulation |
| APSK | Amplitude Phase Shift Keying |
| AWGN | Additive White Gaussian Noise |
| BER | Bit-Error Ratio |
| BICM | Bit Interleaved Coded Modulation symbols |
| CAZAC | Constant Amplitude Zero AutoCorrelation |
| CCDF | Complementary Cumulative Distribution Function |
| CFO | Carrier Frequency Offset |
| CP | Cyclic Prefix |
| DFT | Discrete Fourier Transform |
| DL | DownLink |
| DSNG | Digital Satellite News Gathering |
| DVB | Digital Video Broadcasting |
| DVB-NGH | DVB New Generation Handheld |
| DVB-RCS | DVB Return Channel via Satellite |
| DVB-S | Digital Video Broadcasting via Satellite |
| FDE | Frequency Domain Equalization |
| FDMA | Frequency Division Multiple Access |
| FDT | Frequency Domain Transmitter |
| FFT | Fast Fourier Transform |
| FIR | Finite Impulse Response |
| GEO | Geostationary Orbit |
| GPS | Global Positioning System |
| GT | Guard Time |
| HPA | High Power Amplifier |
| IBO | Input Back-Off |
| ICI | Inter-Carrier Interference |
| IDFT | Inverse Discrete Fourier Transform |
| IMI | Inter-Modulation Interference |
| IMT | International Mobile Telecommunications |
| IMUX | Input MUltipleXer filter |
| ISI | Inter-Symbol Interference |
| INP | Instantaneous Normalized Power |
| ITU-R | International Telecommunication Union-Radiocommunications sector |
| LTE | Long Term Evolution |
| MAI | Multiple Access Interference |
| MLE | Maximum Likelihood Estimator |

| | |
|---|---|
| MODCOD | Modulation & Coding |
| MSE | Mean-Squared Error |
| NC | Not Compensated |
| NCC | Network Control Centre |
| NR | New Radio |
| OFDM | Orthogonal Frequency Division Multiplex |
| PAPR | Peak to Average Power Ratio |
| PER | Packet Error Rate |
| PN | Phase Noise |
| PRACH | Physical Random Access CHannel |
| PSK | Phase Shift Keying |
| OBO | Output Back-Off |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OMUX | Output Multiplexer Filter |
| QAM | Quadrature Amplitude Modulation |
| QPSK | Quaternary Phase Shift Keying |
| RA | Random Access |
| RACH | Random Access Channel |
| RCST | Return Channel Satellite Terminal |
| RF | Radio Frequency |
| RTT | Round Trip Time |
| SC | Single Carrier |
| SC-FDMA | Single Carrier-Frequency Division Multiple Access |
| SC-OFDM | Single Carrier-Orthogonal Frequency Division Multiplexing |
| SC-TDM | Single Carrier-Time Division Multiplexing |
| SE | Spectral Efficiency |
| SIR | Signal-to-Interference Ratio |
| SNG | Satellite News Gathering |
| SNR | Signal-to-Noise Ratio |
| SRRCF | Square Root Raised Cosine Filter |
| SSPA | Solid State Power Amplifier |
| TD | Total Degradation |
| TDE | Time Domain Equalization |
| TDM | Time Division Multiplexing |
| TDMA | Time Division Multiple Access |
| TDT | Time Domain Transmitter |
| TE | Timing Error |
| TWT | Travelling Wave Tube |
| TWTA | Travelling Wave Tube Amplifier |
| UE | User Equipment |
| UL | Uplink |
| ZC | Zadoff-Chu |



# 4 Introduction

The return link in satellite may correspond to different use cases.

The present document evaluates the performance of SC-FDMA radio interface for satellite broadband systems operating in Ku or Ka band, focusing on the physical layer.

The presentdocument deals with satellite return link only. The forward link part is for further study. For the return link, two use cases have been identified and treated so far, DSNG and Broadband access.

# 5 Return link

## 5.1 Introduction

The return link in satellite may correspond to different use cases.

The first use case that is described and simulated in the present document is a professional return link use case, in practice a typical DSNG use case. Different relatively wide-band SC-OFDM signals (i.e. SC-FDMA with full subcarrier allocation) are transmitted to the satellite by a few transmitters in the same band. The multiple access scheme is thus FDMA and not SC-FDMA. These signals are not assumed synchronized neither in time nor in frequency, which implies that a slight frequency guard band is sometimes needed, depending on the robustness of the modulation. This use case is the same as the return link professional one considered in DVB-S2x [i.2]. This DSNG use case is illustrated in Figure 1.

Broadband access (DVB-RCS2) corresponds to another important return link use case. This use case is similar to LTE uplink, where the different signals (not as wideband as in previous case), with SC-FDMA multiple access, are assumed synchronized in time and frequency, which implies new constraints for insuring this synchronization. The number of signals simultaneously transmitted in the same band is much higher than in the previous use case, which explains the choice of the SC-FDMA multiple access scheme for obtaining a good efficiency. In this use case, the cyclic prefix [i.4], [i.5] and [i.9] is used to relax the constraints on the synchronization, which means that its size are dimensioned for this purpose. However and contrary to the DSNG use case, a frequency guard band is generally not necessary. This broadband access use case is illustrated in Figure 1.

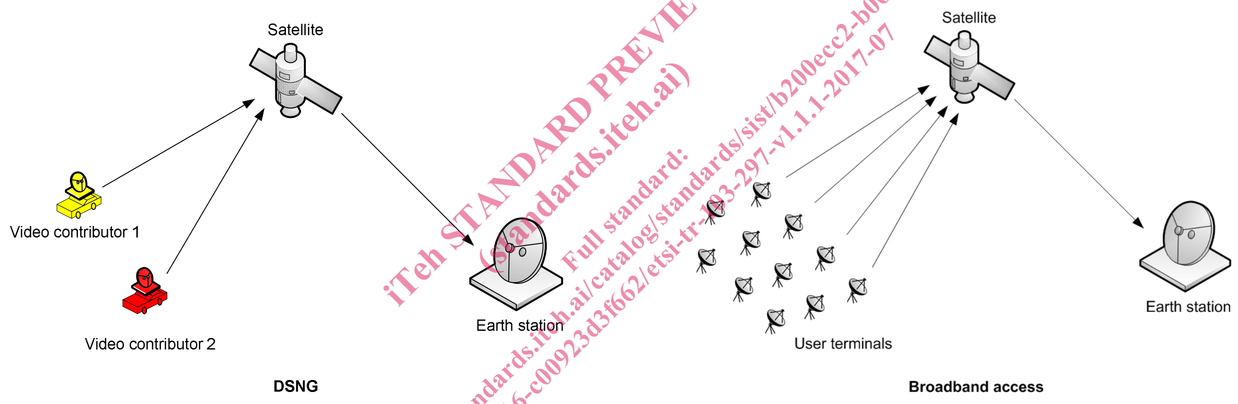




**Figure 1: Return link use cases**

**Table 1: Return link use cases**

| | DSNG use case | Broadband access use case |
|---|---|---|
| Radio resource assigned per terminal | One or several full SC-FDMA carrier(s) | Several sub-carriers of a SC-FDMA carrier |
| Operational constraints | No need for synchronization between satellite terminals | Need for synchronization between satellite terminals |
| Multiple access scheme | FDMA type: Single terminal per SC-FDMA carrier | SC-FDMA: Several terminals per SC-FDMA carrier |
| Comparison with existing waveform technologies | DVB-S2x | DVB-RCS2 |

In particular, the present document compares the performances for the return link of two types of radio interface:

- SC-TDM: this refers to current satellite communication standards such as DVB-S2 [i.1] and DVB-S2X [i.2]. It corresponds to single carrier sequential transmission of modulation signals, with a spectrum shaped by a root-raised cosine filter with different roll-off factors $\alpha$. It was designed for satellite communications to maximize the efficiency of HPA on-board satellite by minimizing the envelope variation of the signal and then limiting the non-linear effects.

- SC-FDMA is a transmission technique derived from OFDMA via DFT precoding. SC-FDMA is exhibiting low envelope variations and is having a natural compatibility with zero roll-off. As is the case for OFDMA and all its precoded counterparts, SC-FDMA allows low complexity per-subcarrier equalization in the frequency domain. In its full spectral allocation version, SC-FDMA is also coined SC-OFDM [i.22].
  In the present document, the performance of the access scheme is not taken into account. Hence, the performance of both SC-TDM and SC-FDMA waveform signals are compared by applying the same access scheme to the spectrum.

The differences between the different signal types are illustrated in Table 2.

**Table 2: The analysed signals**

| | SC-FDMA | SC-TDM = TDM | SC-OFDM |
|---|---|---|---|
| Carrier multiplexing in a channel bandwidth | Single analogue carrier per Channel | One or Multiple analogue carriers per Channel | One or Multiple analogue carriers per Channel |
| Examples | LTE uplink | DVB-S2, DVB-S2X | DVB-NGH |

This evaluation is performed in similar configurations as existing standards.

# 5.2 DSNG use case

## 5.2.1 Introduction

The most straightforward way of transmitting modulated information consists in using single carrier sequential transmission of modulation signals as described in Figure 2. Bit interleaved coded modulation symbols (e.g. X-APSK symbols) are mapped into physical layer frames of specified formats. Base-Band Filtering and quadrature modulation shape the signal spectrum (for example squared-root raised cosine with different roll-off factors) before sending it in the RF satellite channel. In the present document this waveform will be denoted as SC-TDM.




**Figure 2: SC-TDM waveform generation**

DVB-S2 [i.1] and DVB-S2X [i.2] use SC-TDM waveform. DVB-S2 employs QPSK, 8PSK, 16APSK and 32APSK with $\alpha$ = 0,35 or 0,25 or 0,20. DVB-S2X reuses the DVB-S2 physical layer and employs in addition higher modulation orders (64APSK, 128APSK and 256APSK) and sharper roll-off factors ($\alpha$ = 0,15 or 0,10 or 0,05) to improve the spectral efficiency.

SC-FDMA is a waveform that was introduced to improve the spectral efficiency in terrestrial networks. The goal of the present document is to show that it is suitable for satellite communications too.

SC-FDMA waveform has been adopted for the uplink air interface of 3GPP LTE [i.3], in commercial use since 2009. In a 3GPP LTE context, SC-FDMA represents not only the uplink waveform but also the multiple access scheme, the users sharing the uplink channel in the frequency domain by being allocated different groups of adjacent subcarriers like in a classic OFDMA system.

In the satellite world, SC-FDMA has been adopted as one of the waveforms for the satellite profile of DVB-NGH [i.4] under its full spectral allocation form SC-OFDM [i.5]. SC-FDMA was also acknowledged as a promising technique for future developments of DVB-RCS2 ([i.6], annex C). Moreover, the ITU-R recently issued its Recommendations [i.7] for the satellite component of the IMT-Advanced radio interface(s) where both validated air interfaces rely on SC-FDMA-based waveforms.

A SC-FDMA transmitter can be implemented in the frequency domain under the form of Discrete Fourier Transform (DFT) - precoded OFDM waveform as described in Figure 3.