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DSNG

– auxiliary co-ordination channels

A. Morello, V. Mignone and W. Cascianelli
RAI Research Centre

In July 1997, the Technical Module of the DVB Project set up an ad hoc group on DSNG under the chairmanship of RAI, with the tasks (i) to define the specification for modulation/channel coding for DSNG and other contribution applications by satellite, (ii) to define the specification for the auxiliary co-ordination channels and (iii) to co-operate with other DVB groups in defining the user guidelines for source coding, Service Information (SI) and scrambling for Conditional Access (CA).

The specification for the auxiliary co-ordination channels was finalized by the group in Autumn 1998 and approved within DVB and ETSI in Spring 1999. It consists of a specification for a set of two-way (i.e. full-duplex) satellite communication circuits to allow for SNG technical and/or programme co-ordination between the DSNG terminal, the broadcaster, the DSNG operator (when required) and the satellite operator – particularly useful in areas where access to the public switched or cellular telephone networks is difficult or impossible. The specified system is based on Direct Sequence Spread Spectrum and QPSK modulation, convolutionally coded with rate 1/2, and allows for voice, data and fax transmissions.

Introduction

In modern-day broadcasting, dominated by increasing competition, the real-time acquisition of news events (e.g. sports meetings, interviews, concerts, calamities) – in both the domestic and international environments – is a major factor in the search for audience ratings. In this context, Satellite News Gathering (SNG) [1] – provided by light-weight transmit terminals with reduced-size antennas (e.g. 90 to 150 cm) – is the solution for establishing rapid connections between OB vans to the TV studios, without requiring local access to the fixed telecom network.

In Summer 1997, the DVB Project gave RAI the responsibility to develop a new specification for DSNG, based on the DVB-S system [2][3] but with a number of new features in order to cover the commercial and operational requirements that are typical of contribution applications. The standardization activity led to the DVB-DSNG system specifica-

Abbreviations

8PSK	Eight-phase-shift keying
16-QAM	16-state quadrature amplitude modulation
ADPCM	Adaptive differential pulse code modulation
AWGN	Additive white Gaussian noise
BER	Bit error rate
BPSK	Binary phase-shift keying
C/N	Carrier-to-noise ratio
CA	Conditional access
CDMA	Code division multiple access
CM	(DVB) Commercial Module
DS-SS	Direct sequence – spread spectrum
DSNG	Digital satellite news gathering
DVB	Digital Video Broadcasting
Eb/No	Ratio between the energy-per-useful-bit and the spectral density of the noise
ETSI	European Telecommunication Standards Institute
FDM	Frequency division multiplex
FEC	Forward error correction
IF	Intermediate frequency
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radiocommunication Sector
ITU-T	International Telecommunication Union, Telecommunication Standardization Sector
ML	Maximum-length
MPEG	Moving Picture Experts Group
NB	Narrow-band
NRZ	Non-return-to-zero
OB	Outside broadcast
PCM	Pulse code modulation
PSTN	Public switched telephone network
QPSK	Quadrature (quaternary) phase-shift keying
RF	Radio-frequency
SI	(DVB) Service Information
SNG	Satellite news gathering
SS	Spectrum spreading
TM	(DVB) Technical Module

tion [4] in Spring 1998, based on MPEG-2 coding algorithms and on the DVB-S standard and other optional transmission modes, using trellis-coded 8PSK and 16QAM modulations, for contribution applications [5].

To allow for DSNG technical and programme co-ordination, optional auxiliary co-ordination channels were specified by the group in Autumn 1998 and approved within DVB and ETSI in Spring 1999 [6]. This specification consists of a set of two-way (i.e. full-duplex) satellite communication circuits to allow for communication between the DSNG terminal, the broadcaster, the DSNG operator (when required) and the satellite operator. For these purposes, the same antennas of the DSNG stations may often be used, and the same frequency resources (or at least the same satellite transponder) as the main DSNG signal may be exploited. Other frequency resources may also be chosen according to the operational conditions and requirements.

This article gives an overview of the technical and operational issues that are relevant to the transmission of the co-ordination signals, including service performance and interference limits to and from the main DSNG signal.

Basic user requirements

The technical characteristics of the DVB systems are largely market-driven. This is achieved by means of a specific DVB Commercial Module (CM), which analyses the market needs and the business models, and produces “Commercial users’ requirements” on behalf of the DVB Technical Module (TM), which is responsible for developing the specifications.

In accordance with the ITU, the CM has adopted the following definition of SNG (ITU Rec. SNG.770-1): *“Temporary and occasional transmissions with short notice of television or sound for broadcasting purposes, using highly portable or transportable up-link earth stations operating in the framework of the Fixed-Satellite Service (FSS)”*. The ETSI specification EN 301 210 [4] describes the frame structure, channel coding and modulation system for DSNG.

A DSNG “terminal” or “up-link” is a portable (or transportable) earthstation which can be moved to a remote location in order to transmit back the video programme, with its associated sound, or the sound programme signals, either “off-tape” or “live”. It can be packaged in “fly-away” form (i.e. in cases suitable for air transportation) or integrated into a vehicle.

In particular, for SNG technical and/or programme co-ordination, and for interruptible feedback, ITU-R Recommendation SNG.771-1 recommends *“that SNG earth stations should be equipped to provide two-way satellite communication circuits which must be available prior to, during and after, the transmission of the vision and associated sound or sound programme signal. These circuits will provide communications between the*

SNG operator, the satellite operator and the broadcaster; that two or more duplex circuits should be provided, whenever possible within the same transponder as the programme vision and associated sound or sound programme signal". This equipment should provide voice transmission for pure communication purposes, but also data transmission and faxes.

The same Recommendation considers "*that throughout the world, where news events take place, uniform technical and operational standards for communication should be established to ensure prompt activation of the SNG service*". In remote locations where transmissions have to take place, access to the public switched or cellular telephone networks may sometimes be difficult or even impossible; therefore the availability of co-ordination (communication) circuits by satellite may be particularly useful. For these purposes, specially dedicated resources (terminals and transponder frequencies) can be envisaged, according to the operational conditions and requirements; but, in order to reduce the terminal size and weight, the possibility of using the same antennas of the DSNG stations and the same frequency resources (or at least the same satellite transponder) of the main DSNG signal should be a key feature of the system. Of course, the integration of this system in a DSNG station is optional, and the possibility of using other communication systems (e.g. PSTN, cellular phones connected to terrestrial or satellite networks) is maintained, with a choice being made according to the prevailing operational needs.

System description

A schematic diagram of the system is shown in *Fig. 1*. It consists of the source coding, multiplexing, channel coding and modulation systems which carry, via satellite, up to four full-duplex co-ordination (voice) channels at 8 kbit/s, or data capacity for other applications and faxes. Following the DVB philosophy of a "common solution" for coding and multiplexing, which has contributed to the success of the DVB standards, maximum compatibility with existing ETSI and ITU standards is maintained.

a) Source coding and multiplexing

The system source coding and multiplexing allows the transmission of one, two or four 8 kbit/s channels, or one channel at 16 kbit/s or at 32 kbit/s, carrying voice, data or faxes.

In particular, voice coding is performed according to ITU-T Recommendation G.729 [7], which gives an algorithm for high voice quality at 8 kbit/s (i.e. better than ADPCM at 32 kbit/s), transparent also to fax signals. This coder is designed to operate with a digital signal obtained by first performing telephone bandwidth filtering (according to ITU-T Recommendation G.712 [8]) of the analogue input signal, then sampling it at 8 kHz, followed by conversion to 16-bit linear PCM for the input to the encoder. Following Recommendation G.729, other input characteristics – such as those specified by

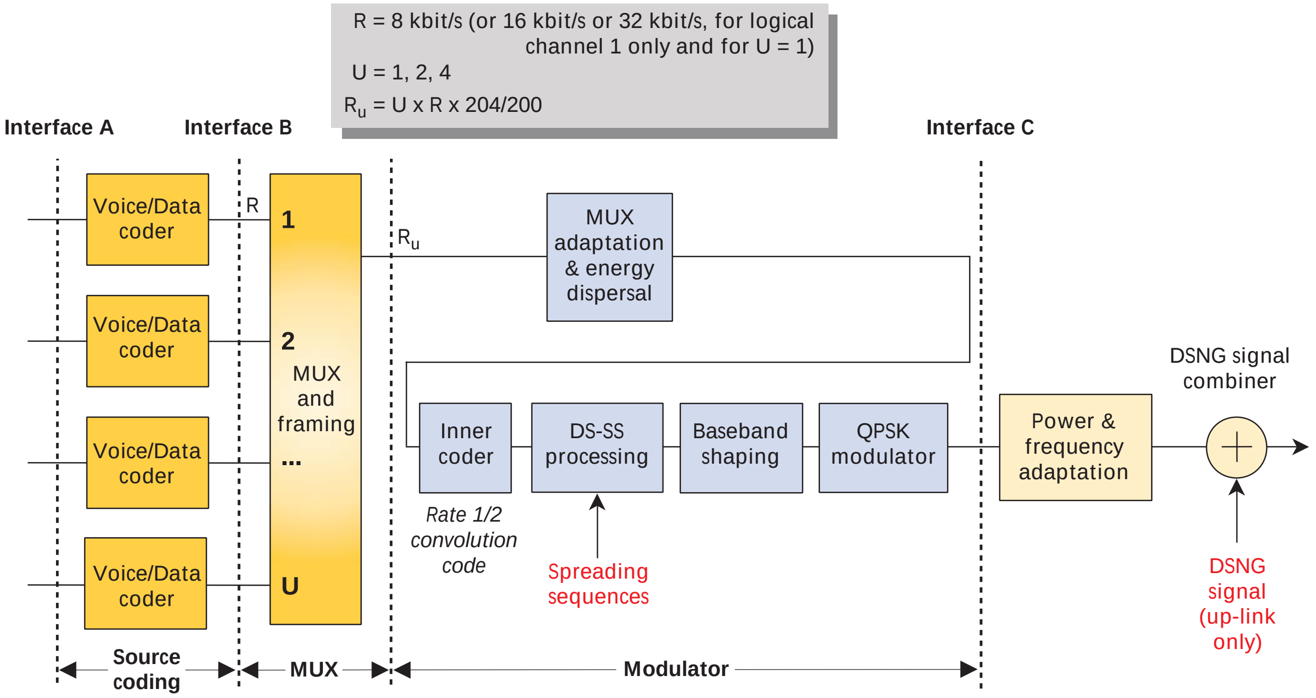


Figure 1
Functional block diagram of the system.

Recommendation G.711 for 64 kbit/s PCM data [9] – should be converted to 16-bit linear PCM before encoding. The bitstream at the encoder output is defined by ITU-T Recommendation G.729. To overcome the effects of the satellite transmission delay on voice signals, echo cancellation may be implemented in the receiver.

Data transmission is performed in synchronous RS-422 format, at bit-rates of 8, 16, or 32 kbit/s. Optionally, it may also be performed in asynchronous RS-232 format at a maximum bit-rate of 9.6, 19.2 or 38.4 kbit/s. In this case a data encoder allows reliable reconstruction of the RS-232 characters in the receiver, also in the presence of burst errors after Viterbi decoding.

For connection to the PSTN, voice-band signalling may be carried out using multi-frequency (MF) devices.

A fixed time-division-multiplexing of the input channels is carried out by taking one byte per signal. Then the multiplexed datastream is framed in packets of 200 payload bytes, at the beginning of which are inserted four additional bytes:

- a two-byte synchronization word (for easy acquisition in the de-multiplexer and during the QPSK phase ambiguity removal stage);
- one byte for signalling the multiplexing configuration to the receiver;
- one spare byte reserved for future use.

Finally, the total output bit-rate becomes:

- one, two or four times 8.16 kbit/s, respectively, in the cases of one, two or four 8 kbit/s channels;
- 16.32 kbit/s in the case of one input channel at 16 kbit/s;
- 32.64 kbit/s in the case of one input channel at 32 kbit/s.

b) Channel coding and modulation

The system provides randomization for energy dispersal and inner convolutional coding (rate 1/2 only) for error correction, to achieve high ruggedness against noise and interference. Reed-Solomon coding and convolutional interleaving, generally present in the DVB systems, are not used in this system as the target BER (10^{-3}) after FEC decoding is adequate for voice communication using ITU-T Rec. G.729 and, additionally, since they would generally introduce a large end-to-end delay which may cause problems on voice communications by satellite.

Two possible modulation schemes were investigated in the study phase of the standardization process: a conventional Narrow Band (NB) Quaternary Phase Shift Keying (QPSK) modulation scheme, and a Direct-Sequence Spread-Spectrum (DS-SS) scheme [10][11], applied before QPSK modulation. The DS-SS processing generates a modulated signal whose bandwidth occupation is expanded by a factor equal to the spreading factor L and whose power spectral density level is reduced accordingly.

In both cases, NB and DS-SS, the group investigated the possibility of sharing the same bandwidth used by the main DSNG service, by exploiting the roll-off region of the DSNG signal or by superimposing the signals. It was found that, in the presence of communication channel interference, the performance degradation of the main signal depends only on the total in-band power interference, and not on the shape of the power spectrum of the interference (NB or DS-SS). Furthermore, DS-SS and NB systems have the same performance, in terms of E_b/N_0, over the AWGN channel, and the same performance when suffering interference from the DSNG main signal; they also potentially cause the same interference to the DSNG signal. Furthermore, the spectrum efficiency of the multiplexing systems, synchronized DS-SS and FDM associated with NB signals, is somewhat comparable.

The Spread-Spectrum scheme was finally preferred on the basis of two key advantages with respect to the NB one. First of all, the DS-SS technique permits the superimposition of a number of co-ordination signals in the frequency domain (CDMA), using the same centre frequency. This implies a simplification of the link set-up procedure, avoiding precise frequency tuning. The second advantage of DS-SS over NB solutions is the rejection of narrow-band interference (e.g. analogue TV in the cross-polar transponder), corresponding to a gain G = 10 Log (L) (see *Appendix 1).* Furthermore, the group discovered that, compared to conventional modulation techniques, DS-SS signals also produce less intermodulation noise density over a non-linear transponder, and require less frequency precision in the transmission/reception equipment.

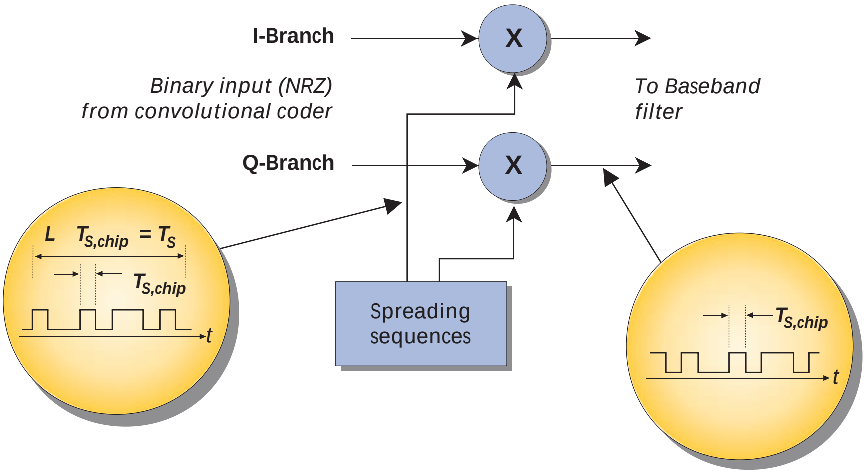


Figure 2
Basic principle of Direct-Sequence Spread-Spectrum coding.

DS-SS coding is applied to the output datastream of the convolutional encoder. According to *Fig. 2*, DS-SS consists of multiplying (digital EX-OR) each symbol of duration T_s by a defined binary sequence of length L (the spreading factor). The duration of the symbol of the spreading sequence, i.e. the “chip”, is $T_{s,chip}$, where $T_{s,chip} = T_s / L$. Therefore the data rate and also the RF bandwidth are increased by the factor L. Independent spreading sequences are applied to the I-Branch and to the Q-Branch (dual BPSK mode), in order to minimize possible I-Q crosstalk effects.

The system allows us to implement five spreading factors, L = 31, 63, 127, 255 and 511 in order to offer flexibility in spectrum occupation. The relevant bandwidth occupations (at – 3 dB after baseband filtering), corresponding also to the chip symbol rates, is given by $R_{S,chip} = L\ R_S$ (where R_s is the unspread symbol rate). *Table 1* gives the bandwidth occupation versus the number of channels and the spreading factor L.

The spreading sequences are based on Gold sequences and their generating Maximum Length (ML) sequences, chosen for their properties of quasi orthogonality [12][13] (see *Appendix 1* for details).

For each of the spreading lengths L, two ML-sequences $R_L(n)$ and $S_L(n)$, produced by the generator polynomials $G_{LR}(x)$ and $G_{LS}(x)$ are used, according to *Table 2*.

To implement a number of bi-directional co-ordination channels, Gold sequences are adopted, produced by fixing the $R_L(n)$ ML-sequence, and performing a bit-by-bit EX-OR with the $S_L(n + i)$ ML-sequence, corresponding to the $S_L(n)$ sequence, cyclically shifted by i positions (i = 0, 1, 2, . . .). The number of DS-SS channels which may be superimposed is limited by mutual interference. For system simplicity, the standard considers spreading processes which are asynchronous at each terminal. In this case, accepting a C/N degradation of 1 ÷ 1.5 dB, the maximum number of DS-SS carriers (uni-directional links) sharing the same RF bandwidth has been fixed to (see *Appendix 3)*:

- four for L = 31;
- eight for L = 63;
- 16 for L = 127;
- 32 for L = 255;
- 64 for L = 511.

In order to reduce the mutual interference between DS-SS channels, the spreading sequences and the carriers should be synchronized. This process is generally complex for remote stations, but it can be achieved easily when the carriers are generated at the same location, and if the modems are suitably designed. In this case, mutual interference is very much reduced, and no longer represents a limitation on the maximum number of users (see *Appendix 3)*.

Finally the system performs conventional Gray-coded bit-mapping into a QPSK constellation with absolute mapping in accordance with EN 300 421 and, prior to modulation, the I and Q signals are square-root-raised cosine filtered, with a roll-off factor $\alpha = 0.35$.

Table 1
Bandwidth occupation (MHz) at – 3 dB of the co-ordination channels.

No. of channels	Total data rates at interface B	L = 31	L = 63	L = 127	L = 255	L = 511
1	8 kbit/s [a]	0.25296	0.51408	1.03632	2.08080	4.16976
2	16 kbit/s	0.50592	1.02816	2.07264	4.16160	8.33952
4	32 kbit/s	1.01184	2.05632	4.14528	8.32320	Not allowed

a. When bit-rates of 16 kbit/s and 32 kbit/s are used at logical channel 1, the bandwidth figures relevant to two channels and four channels apply, respectively.

Table 2
Generator polynomials and initial values (in octal notation) of the adopted ML-sequence.

Spreading Factor L	Sequence	Generator polynomial [a] $G_{LR}(x)$ (OCT)	Initial value (OCT)	Sequence	Generator polynomial [a] $G_{LS}(x)$ (OCT)	Initial value (OCT)
31	$R_{31}(n)$	45	1	$S_{31}(n)$	67	35
63	$R_{63}(n)$	103	1	$S_{63}(n)$	147	32
127	$R_{127}(n)$	211	1	$S_{127}(n)$	277	177
255	$R_{255}(n)$	435	1	$S_{255}(n)$	675	222
511	$R_{511}(n)$	1021	1	$S_{511}(n)$	1333	733

a. Highest degree term on the left.

The system spectral efficiency before spreading is 0.9804 bit/symbol. The target system performance, connected in IF loop, corresponds to 3.6 dB of required E_b/N_0 (dB) for BER equal to 10^{-3}, corresponding to the threshold of tolerance for voice services. The figure of E_b/N_0 refers to the bit-rate before convolutional coding (i.e. R_u) and includes a modem implementation margin of 0.8 dB. Lower BER levels may be required for some data services; in this case, additional error protection should be applied externally to the modem.

Example of possible uses of the system

A DSNG transmission may consist of the main DSNG signal, compliant with the DSNG specification [4], plus various co-ordination signals which implement full-duplex links. To achieve a two-way (i.e. full-duplex) communication channel, two independent carriers have to be transmitted, one from the DSNG terminal, the other from a fixed station. Depending on the service requirements, various scenarios are possible, some of which require reduced communication capacity, while others are more demanding (in terms of the number of required connections and up-link facilities).

Fig. 3 shows two examples of implementation of the co-ordination channels between the DSNG terminal, the broadcaster, the DSNG operator (when required) and the satellite operator. In scenario A (two up-links for co-ordination carriers), the DSNG terminal and a central station (e.g. the broadcaster’s fixed station) each up-link a single co-ordination carrier, containing U multiplexed circuits. In this scenario, the terrestrial infrastructure (e.g. PSTN) is used to forward the co-ordination circuits from the central station to the DSNG operator and the satellite operator. The co-ordination equipment at the DSNG terminal thus has to transmit and receive a single co-ordination carrier. In scenario B (four up-links for co-ordination carriers), the DSNG terminal up-links a single co-ordination carrier, containing three multiplexed channels ($U = 3$), while the broadcaster, the DSNG operator and the satellite operator up-link a total of three co-ordination carriers, each with a single circuit. In this scenario, the co-ordination equipment at the DSNG terminal has to transmit a single co-ordination carrier, and to receive three carriers at the same time.

Flexible, user-definable frequency assignments are available for the co-ordination channels, allowing the selection on a case-by-case basis of the best FDM configuration in the satellite transponder, depending on the available bandwidth, the spectrum occupancy of the main DSNG transmission, the number of co-ordination channels, and other service requirements. The system is capable of operating, if required, within the same frequency slot as the main DSNG signal, while keeping the level of mutual interference between the main DSNG signal and the co-ordination carriers at an acceptable level, and accepting some performance degradation for both the co-ordination signals and the DSNG signal. To achieve this, the co-ordination channels may be superimposed onto the main DSNG signal (e.g. the same centre frequency), at the cost of some performance degradation due to mutual interference, which may be more or less critical – depending on the modulation/coding scheme of the DSNG system and on the mutual signal levels. As an alternative, the co-ordination channels using a low spreading factor (e.g. 0.5 MHz or 1 MHz bandwidth occupancy) may be allocated within the "roll-off" region of the DSNG signal, in order to reduce the mutual interference between co-ordination and DSNG signals. The superimposed configuration has the operational advantage of using the same centre frequency for the DSNG carrier ($f_{0,DSNG}$) as for the co-ordination carriers ($f_{0,COOR}$), while the roll-off configuration has the advantage of reducing the mutual interference between the DSNG and co-ordination signals, thus allowing better RF performance. In other cases, a clear frequency slot may be allocated to the co-ordination

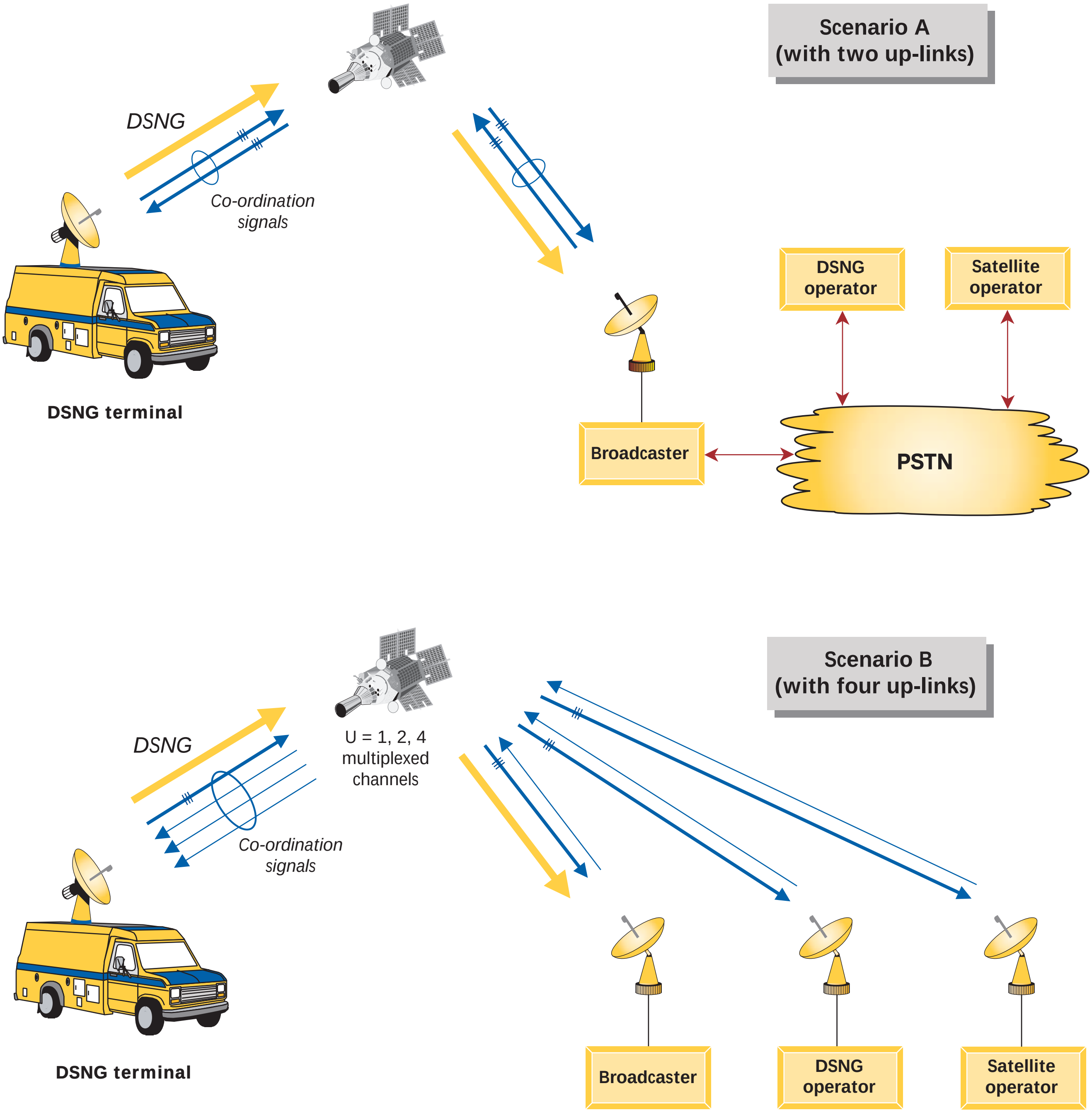


Figure 3
Example environments for DSNG and co-ordination transmissions by satellite.

channels, on the same transponder as the DSNG signal, or even on another transponder/satellite, according to the service requirements.

The co-ordination channels which are sharing the same DSNG frequency slot may use different bit-rates, spreading sequences and spectral density levels, according to the operational requirements. Nevertheless the number of co-ordination channels should be maintained as low as the operational requirements permit, in order to limit the mutual DSNG/co-ordination channels interference. Furthermore, to guarantee an adequate mutual signal-to-interference ratio due to the other co-ordination channels, the different co-ordination channels should be kept at the same spectral density level. In the following, some examples of possible scenarios are considered. All the modes of the DSNG specification (QPSK 1/2, 2/3, 3/4, 5/6, 7/8, plus 8PSK 2/3, 5/6, 8/9, and 16QAM 3/4, 7/8) have been considered – with a symbol rate of 6.666 MBaud, thus occupying a frequency slot of 9 MHz – as well as the bit-rates of the co-ordination signals and the possible frequency allocations in the DSNG frequency slot.

When the main DSNG signal and the co-ordination signals share the same frequency slot, the co-ordination carriers are generally transmitted at a power level significantly lower than that of the DSNG carrier, since their bit-rate is typically some hundred times lower than the DSNG bit-rate. Therefore, they do not significantly modify the transponder operating point, and the link budgets. For these considerations, the results reported in the following refer to the AWGN channel; for link budget consideration, reference could be made to [5]. *Appendix 3* reports on the equations proposed by RAI to evaluate the results approximately, based on the hypothesis of noise-like interference for both the DSNG and the co-ordination signals. These equations have been verified by computer simulations under a variety of operational conditions.

Assuming superimposed frequency-sharing – as in *Fig. 4 (left)* – *Figs. 5* and *6* give examples of the main DSNG signal E_b/N_0 performance degradation Δ_{DSNG}. A fixed degradation of the co-ordination channel performance Δ_{COOR} of 4.33 dB has been imposed, due to interference from the DSNG signal and from the other co-ordination channels, corresponding to fixed BER of about 10^{-5} after Viterbi decoding in the absence of thermal noise. The required $(E_b/N_0)_{COOR}$ is 3.6 dB at a target BER of 10^{-3} (see *Table 3*). The DSNG schemes considered are QPSK, 8PSK and 16QAM, assuming the IF-loop performance given in [5]. In *Figs. 5* and *6*, the adopted Γ-factor is also given, representing the ratio between the DSNG and co-ordination channel spectral density, divided by the spreading factor L. Other Γ-factors may be chosen, according to the performance requirements. Lower Γ figures improve the performance of the co-ordination channels, while larger Γ figures improve the DSNG performance.

Assuming a DSNG signal using QPSK FEC rate 2/3, from *Fig. 5* (8 kbit/s channels) an estimated DSNG degradation of 0.7 dB is obtained for M = 6 (three bi-directional co-ordination links) and L = 63. By decreasing the number of co-ordination channels, it is possible to increase the modulation and coding rate. However, for the highest DSNG spectrum efficiency modes (e.g. 8PSK 8/9, 16QAM 3/4 and 7/8), the interference degradation rapidly increases and becomes impractical.

For two 32 kbit/s unidirectional co-ordination channels (M = 2), a degradation on the DSNG signal, lower than 1 dB, can be achieved in the case of QPSK 1/2, 2/3 and 3/4 modes *(Fig. 6)*.

As indicated in *Fig. 4 (right)*, to reduce mutual interference, the co-ordination channels may be placed in the roll-off region of the DSNG signal. In order to minimize the mutual

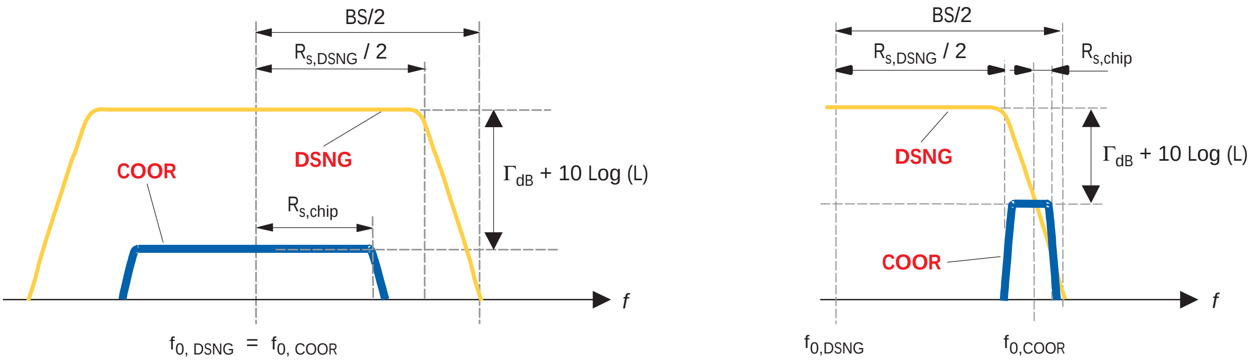
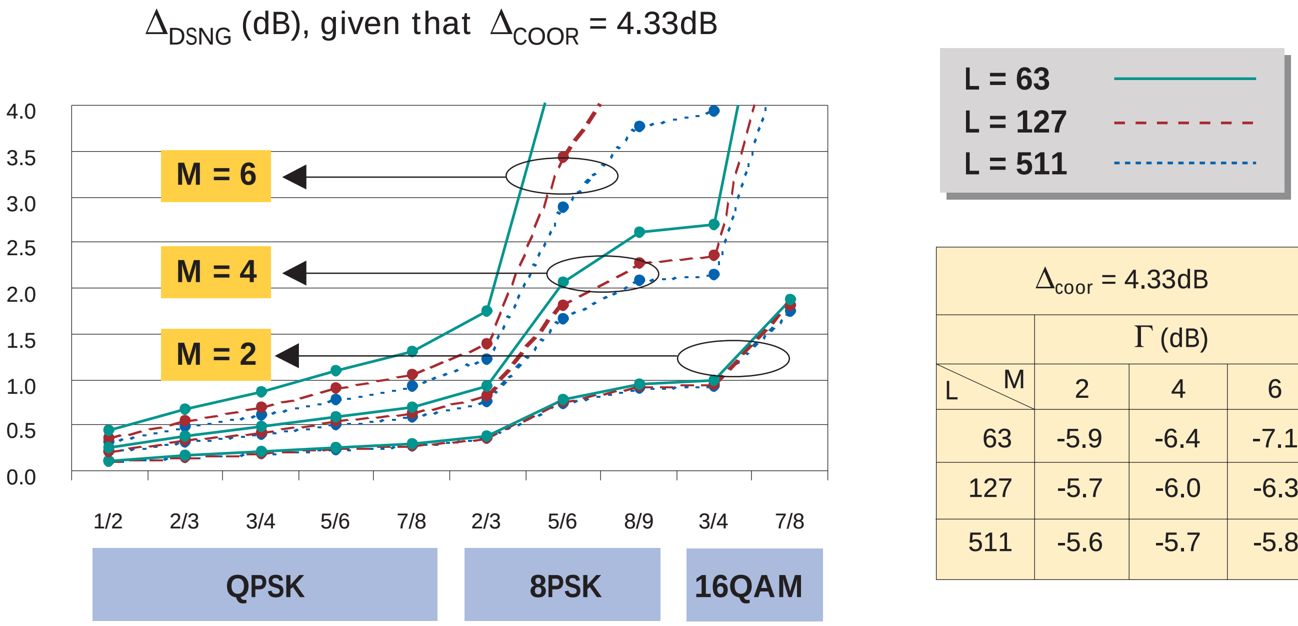
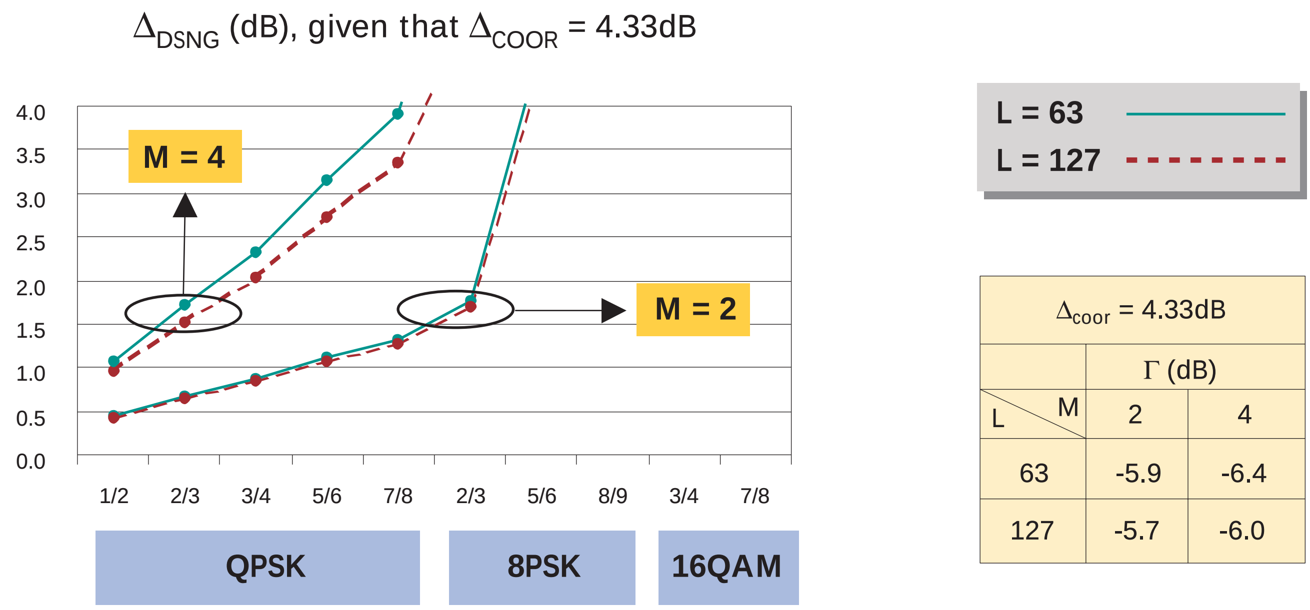


Figure 4
Possible frequency allocations of the co-ordination signals in the DSNG frequency slot: *(left)* superimposed to the DSNG signal; *(right)* in the roll-off region of the DSNG signal



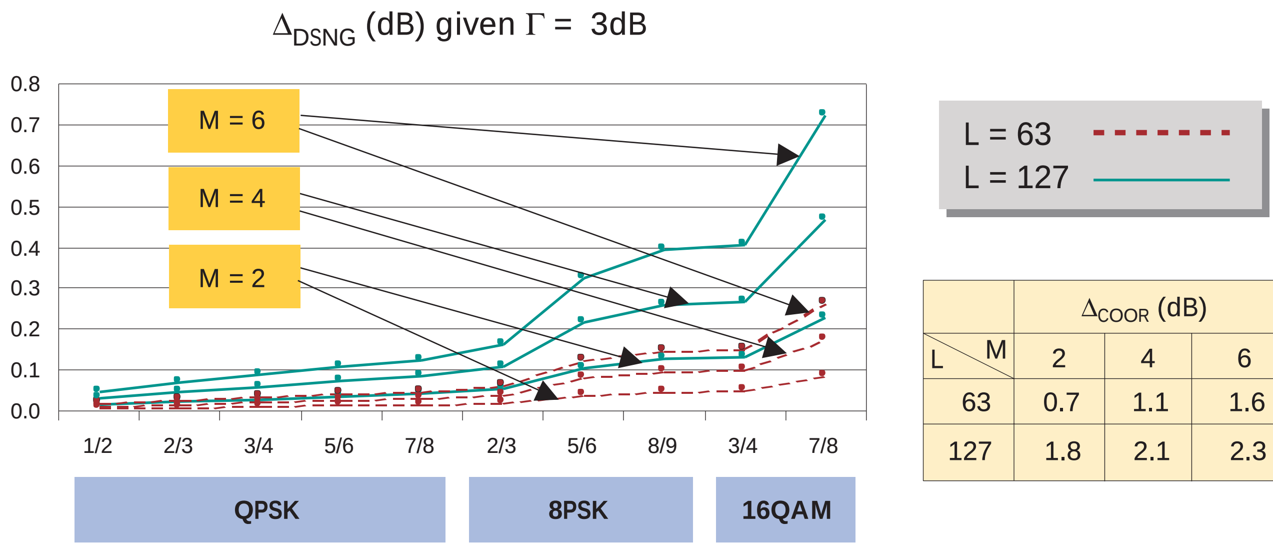
Δ_{coor} = 4.33dB			
	Γ (dB)		
L M	2	4	6
63	-5.9	-6.4	-7.1
127	-5.7	-6.0	-6.3
511	-5.6	-5.7	-5.8

Figure 5
8 kbit/s co-ordination channels superimposed on to DSNG. Example performance degradation of DSNG (RS = 6.666 MBaud) interfered with by M co-ordination signals, with L = 63, L = 127 and L = 511. The degradation of the co-ordination channels has been assumed to be D_{COOR} = 4.33 dB.



Δ_{coor} = 4.33dB		
	Γ (dB)	
L \ M	2	4
63	-5.9	-6.4
127	-5.7	-6.0

Figure 6
32 kbit/s co-ordination channels superimposed on to DSNG. Example performance degradation of DSNG (R_S = 6.666 MBaud) interfered with by M co-ordination signals, with L = 63 and L = 127. The degradation of the co-ordination channels has been assumed to be D_{COOR} = 4.33 dB.



	Δ_{COOR} (dB)		
L \ M	2	4	6
63	0.7	1.1	1.6
127	1.8	2.1	2.3

Figure 7
8 kbit/s co-ordination channels in the “roll-off” region of DSNG – Example performance degradation of DSNG (R_S = 6.666 MBaud) interfered with by M co-ordination signals, with L = 63 and L = 127. The ratio between the DSNG and each co-ordination channel spectral density, divided by the spreading factor L, has been assumed to be $\Gamma = -3$ dB.

interference, the co-ordination signals may use a low spreading factor (i.e. L = 31, L = 63 or L = 127, according to the co-ordination channel bit-rate) and may be placed, for example, in the upper part of the frequency slot allocated to DSNG. In this configuration, the centre frequency $f_{0,\ COOR}$ of the co-ordination signals may be computed by the following equation:

$$f_{0,COOR} = f_{0,DSNG} + BS/2 - (1.35/2)\ R_{S,COOR}$$

where $f_{0,DSNG}$ is the centre frequency of the DSNG signal, B_S is the bandwidth of the frequency slot, and $R_{S,COOR} = R_{S,chip}$ is the co-ordination channel symbol rate.

In the following, the achievable performance is given for two example configurations, based on the frequency allocations of the above equation and choosing Γ equal – 3 dB as a reasonable practical upper limit for the power density level of the co-ordination channels.

In the first example, M uni-directional co-ordination channels are considered, each at 8 kbit/s, with spreading factors of 63 and 127. The main DSNG signal has a symbol rate of 6.666 MBaud, thus occupying a frequency slot of 9 MHz. The roll-off region, from the – 3 dB point to the slot margin, is 1.167 MHz wide, while the co-ordination signal bandwidth is about 0.5 MHz for spreading factor 63, and 1 MHz for spreading factor 127. Due to the roll-off filter effect, the mutual interference suppression A is about 5.5 dB for L = 127 and 9.7 dB for L = 63. The resulting performance degradations of the DSNG signal are shown in *Fig. 7*, assuming a Γ factor [1] of – 3 dB (the "–" sign indicates that the co-ordination channels before SS have a spectral density higher than that of the DSNG signal). In the example,

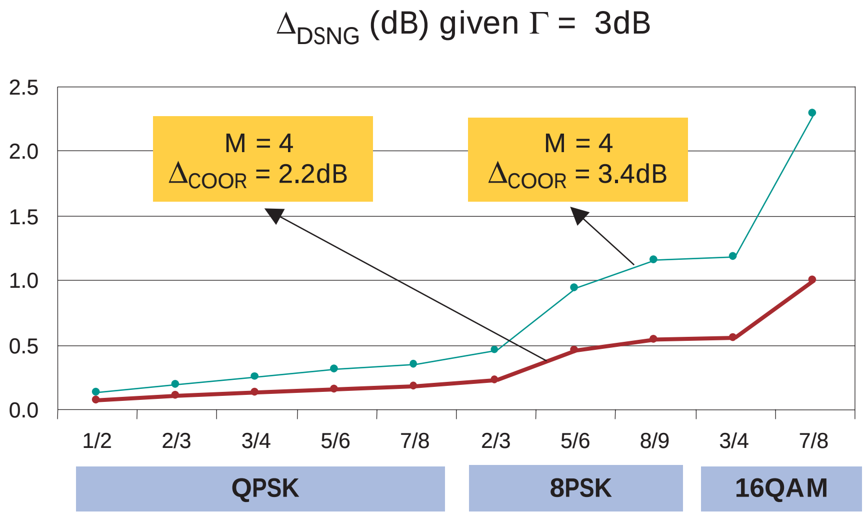


Figure 8
32 kbit/s co-ordination channels in the "roll-off" region of DSNG – Example performance degradation of DSNG (RS = 6,666 MBaud) interfered with by M co-ordination signals, with L = 31. The ratio between the DSNG and each co-ordination channel spectral density divided by the spreading factor L has been assumed to be Γ = – 3 dB.

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[1] The ratio between the DSNG and each co-ordination channel spectral density, divided by the spreading factor L.

even in the case of M = 6 the DSNG degradation may be maintained below 0.5 dB for DSNG modulations up to 16QAM FEC rate 3/4.

In the second example, M unidirectional co-ordination channels are considered, each at 32 kbit/s, with a spreading factor of 31. The main DSNG signal has a symbol rate of 6.666 MBaud, thus occupying a frequency slot of 9 MHz. The roll-off region (from the – 3 dB point to the slot margin) is 1.167 MHz wide, while the co-ordination signal bandwidth is about 1 MHz. Due to the roll-off filter effect, the mutual interference suppression A is about 5.5 dB. The resulting performance degradations of the DSNG signal are shown in *Fig. 8*, assuming a Γ factor of – 3 dB (the "–" sign again indicates that the co-ordination channels before SS have a spectral density higher than the DSNG channel). In the example, in the case of M = 4, the DSNG degradation may be maintained below 0.5 dB for DSNG modulations up to 8PSK FEC rate 2/3.

Conclusions

This article describes the newly standardized system for providing optional co-ordination signals associated with DSNG transmissions. Thanks to its flexibility, the system allows a user selection – on a case-by-case basis – of the best FDM configuration in the satellite transponder. According to service requirements and operational conditions, the system can share the bandwidth of the main DSNG signal, a clear frequency slot on the same transponder as the DSNG signal, or even on another transponder/satellite. In-band co-ordination channels are possible for the lower DSNG modes at the expense of some performance degradation of the main signal, with a small increase in the circuit complexity. For example, a DSNG link using QPSK 3/4 and a bit-rate of approximately 9 Mbit/s and two in-band bi-directional 8 kbit/s co-ordination signals could be set up, with a performance degradation of about 0.5 dB in the case of the main DSNG signal, and 4.33 dB for the co-ordination signals. In the case of roll-off co-ordination signals, less degraded performance could be obtained, at the expense of an increase in the equipment complexity: for example, two bi-directional 8 kbit/s co-ordination signals could be set up with a performance degradation of 1.1 dB for the co-ordination signals, assuming a main DSNG signal using 16 QAM 3/4 with a degradation of about 0.2 dB.

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Alberto Morello graduated in Electronic Engineering from Turin Polytechnic in 1982 and took his doctorate degree in 1987. He joined the Research and Technical Innovation Centre of RAI-Radiotelevisione Italiana in 1984 where he is now Director. Prior to this recent appointment, he was engaged in research on digital modulation and coding techniques for video, audio and data transmission and broadcasting, via terrestrial and satellite channels.

Dr Morello is a member of several international EBU, ITU-R and CEPT groups and has participated in various EUREKA and ACTS projects. He was Chairman of the DVB ad-hoc groups which defined the technical specifications for the DVB-S and DVB-DSNG systems. He is the author of various technical and scientific articles and has presented numerous papers relevant to his studies and research work at national and international events.

Vittoria Mignone was born in 1966 and received the "Laurea in Ingegneria Elettronica" degree from Turin Polytechnic in 1990.

In 1991, in co-operation with the Electronics Department of Turin Polytechnic, Ms Mignone was engaged in studies on satellite broadcasting, on behalf of the National Research Council. Since 1992, she has been with the RAI Research and Technical Innovation Centre in Turin, involved in studies to define the ETSI Standards for digital television broadcasting via satellite, cable and terrestrial channels and, more recently, for DSNG. Her current activities are in the field of advanced digital modulation and channel coding techniques for satellite and terrestrial transmissions. She is the author of various technical papers.

Walter Cascianelli was born in 1973 and graduated in Telecommunications Engineering from Turin Polytechnic in December 1998. He developed his Master Thesis at RAI Research Centre – involved in studies to define the ETSI Standard for the co-ordination channels associated with DSNG.

Since last December, Mr Cascianelli has been working at the Turin Motorola Technology Centre.

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Appendix 1
Spread spectrum and Gold sequences

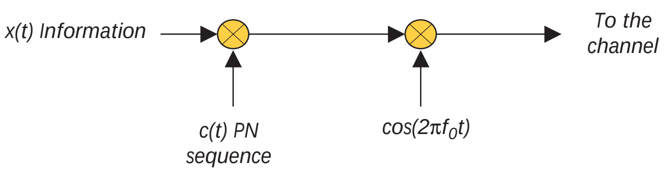
Spread-Spectrum processing is a technique characterized by having a transmitted bandwidth much larger than the minimum bandwidth required to transmit the information and a C/N ratio very low: it is therefore an ideal scheme for those application where an essential point is to transmit low powers, even below the noise and interference levels.

The main advantages of this modulation scheme are:

- high ruggedness against intentional interference (especially narrow-band interference);
- possibility of using CDMA techniques;
- low power spectral density level of the signal;
- communication security.

A Direct-Sequence Spread-Spectrum (DS-SS) modulator and demodulator block diagram is shown in *Fig. A1.1*. By multiplying information signal x(t), having a data rate R_s, with a PN code sequence c(t), having a code symbol rate $R_{c,chip}$ (chip rate), the signal power remains unchanged, while the bandwidth increases. If the data signal is narrowband compared to the spreading signal, the resulting power spectrum expands by a factor $L = R_{c,chip}/R_s$, where L is the spreading factor and, therefore, in order to maintain the whole power unchanged, it is correspondingly reduced in terms of amplitude.

a) Modulator



b) Demodulator

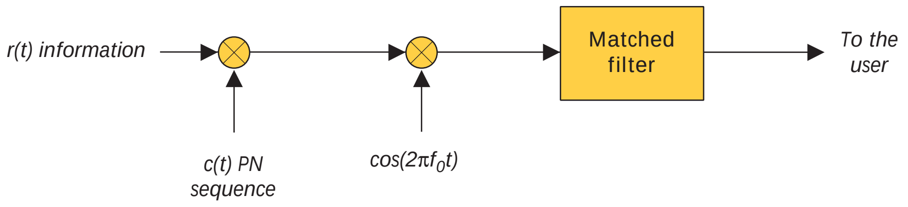


Figure A1.1
DS-SS processing at the transmitter and receiver.

At the receiver side (not considering, for simplicity, the noise), the signal is multiplied by a replica of the spreading code signal, and matched filtered, in order to remove the spurious higher frequency components.

In presence of interference i(t) from a narrow-band signal, the multiplication by c(t) will spread the undesired signal to a bandwidth equal to that of the spreading signal, thus reducing its power spectral density level by a factor of L. The demodulation filter then allows us to reduce the interference power by a factor of L, also called “processing gain”. The essence is that multiplication once by the spreading signal spreads the signal’s bandwidth: multiplication twice, followed by filtering, recovers the original signal. Since the interfering signals get multiplied only once, Spread-Spectrum systems result in a high ruggedness against narrow-band interference (e.g. analogue TV in the cross-polar transponder), with a rejection capability of $\Gamma = 10 \text{ Log } (L)$. Thus, the higher the spreading factor L, the better the interference rejection. Also, intentional interference is efficiently rejected by a factor of L, by the receiver, because only a receiver which knows the right code sequence is able to recover the data signal.
In the case of Coded Division Multiple Access (CDMA), the choice of the spreading sequence is very important, since its properties determine the possibility of simultaneously transmitting several signals, with relatively low interference from the others. Referring to the receiver scheme *(Fig. A1.1)*, <u>if</u> the code sequences $\{c_i(t)\}$ are mutually orthogonal, which means that:

$$\int_0^{T_b} c_i(t)c_j(t)dt = 0 \qquad \mathrm{i} \neq j$$

where T_b is the information symbol duration, <u>then</u> signals that come from other transmitting stations are erased by the receiver.

To achieve this ideal situation, the receiver must know exactly the corresponding transmitter code (even its phase) and, moreover, the code of other users must be in phase alignment. In the absence of alignment (ϑ is linked to different distances from the transmitter), the above expression changes to:

$$\int_0^{T_b} c_i(t)c_j(t-\theta)dt \neq 0 \qquad \mathrm{i} \neq j$$

and MAI (Multiple Access Interference) appears. In order to reach alignment with the transmitted code, the receiver has to compute the correlation between the received code and the transmitted code.

The ideal behaviour of the correlation function $\Phi(n)$ is the following:

$$\Phi(n) = \begin{cases} A & \text{for } n = 0 \\ 0 & \text{for } 0 < |n| < L \end{cases}$$

If a single maxima is present, then compensation is possible.

On the basis of the above considerations, auto-correlation and cross-correlation functions assume a key role in evaluating the performance.

Walsh-Hadamard sequences are orthogonal, but show some disadvantages. Codes do not present a single and narrow auto-correlation peak and, therefore, synchronization becomes difficult. There is not an efficient spread of the energy. Even if cross-correlation is equal to zero, it is not the same for partial cross-correlation, which often has to be implemented at the receiver. Therefore the advantage of using orthogonal codes, when all the users are not synchronized on the same time-clock, is lost. The orthogonality property is even partially lost due to channel properties (for example in the presence of multipath propagation).

Maximal Length (ML) sequences are generated from a shift register with m stages and have the property that the sequence length is $L = 2^m - 1$. Their auto-correlation function $\Phi(n)$ is:

$$\Phi(n) = \begin{cases} L & \text{for } n = 0 \\ -1 & \text{for } 0 < |n| < L \end{cases}$$

The ratio between the auto-correlation value, in the absence of alignment, and the one with perfect alignment is equal to:

$$\frac{\Phi(k)}{\Phi(0)} = -\frac{1}{2^m - 1} = -\frac{1}{L} \qquad \forall k \neq 0$$

Table A1
Adopted SS sequences (L indicates the spreading factor).

channel #	Link type	Modulator I-Branch	Modulator Q-branch
1	DSNG terminal → Fixed station Fixed station → DSNG terminal	$R_L(n)$ [a] $R_L(n) * S_L(n)$	$S_L(n)$ [b] $R_L(n) * S_L(n+1)$
2	DSNG terminal ↔ Fixed station [c] Fixed station → DSNG terminal	$R_L(n) * S_L(n+2)$ $R_L(n) * S_L(n+4)$	$R_L(n) * S_L(n+3)$ $R_L(n) * S_L(n+5)$
3	DSNG terminal → Fixed station Fixed station → DSNG terminal	$R_L(n) * S_L(n+6)$ $R_L(n) * S_L(n+8)$	$R_L(n) * S_L(n+7)$ $R_L(n) * S_L(n+9)$
j (for j>1)	DSNG terminal → Fixed station Fixed station → DSNG terminal	$R_L(n) * S_L[n+4j-6)$ $R_L(n) * S_L(n+4j-4)$	$R_L(n) * S_L(n+4j-5)$ $R_L(n) * S_L(n+4j-3)$

a. ML-sequence generated by $G_{LR}(x)$ according to *Table 2*.

b. ML-sequence generated by $G_{LS}(x)$ according to *Table 2*.

c. Channel 2 may be a backward channel to implement scenario B in *Fig. 3*.

which tends towards zero as L increases.

Therefore ML sequences have an auto-correlation function very similar to the wanted ones. Unfortunately, these sequences have generally very high cross-correlation values, and so they are not the best solution to our problem. Nevertheless, there are some ML sequences showing low cross-correlation values; these sequences, known as “preferred sequences”, have a cross-correlation function with three possible values, {-1, -t(m), t(m) – 2}, where:

$$t(m) = \begin{cases} 2^{\frac{m+1}{2}} + 1 & \text{for m odd} \\ 2^{\frac{m+2}{2}} + 1 & \text{for m even} \end{cases}$$

depending on the value of the sequence length. The problem with these sequences lies in their low number; eventually, for m multiples of four, there is only one preferred sequence. Fortunately, modulo 2 addition of the shifted version of two preferred sequences gives new sequences, the so-called Gold sequences. These have cross-correlation functions with the same values as their generating sequences (excluding the case where m is a multiple of 4). Thanks to their good properties, Gold sequences are optimal for use as code sequences in the system for DSNG co-ordination signals. In particular, the sequences used by the system are shown in *Table 2*. For L = 255, corresponding to m = 8, we have the so-called “pseudo-Gold sequences”: only one of the generating sequences of *Table 2* is a preferred sequence, while the other one is an ML sequence of period L/3 (where L is the first sequence period). There is no deterioration of the cross-correlation maximum peak, even if the number of possible cross-correlation values ≠ 3. Problems may appear with synchronization, but once coupling is reached, the performance is as good as that of Gold sequences.

Appendix 2
Synchronization of code sequences

For system simplicity, the European Norm (EN 301 222) about co-ordination channels associated with DSNG provides for asynchronous spreading processes at each transmitting terminal. However, asynchronous operations limit the number of channels that may be superimposed, since mutual interference must be maintained at an acceptable level.

The mutual interference between co-ordination channels may be reduced by synchronizing the spreading sequences and the carriers, which means guaranteeing a correct alignment at the receiver of all the sequences, in terms of code sequence period, and using the same central frequency for each transmitting terminal [12].

In this hypothesis, there is an improvement in the mutual interference between co-ordination signals by a factor of L, the code sequence period, thanks to the “quasi orthogonality” property of Gold sequences. Nevertheless, care should be taken in the choice of the sequence for a synchronized application. The problem is as follows.

The BER is directly linked to the value of mutual cross-correlation $\Phi_{i,j}(\vartheta)$ between code sequences:

$$\Phi_{i,j}(\vartheta) = \sum_{k=1}^{L} c_i(k) c_j(k+\vartheta) \qquad (1)$$

where c_i and c_j are respectively the binary digits of the two code sequences, L is the code sequence period and ϑ is the delay affecting the *j*-th signal.

In the case of synchronous sequences, *Equation (1)* becomes:

$$\Phi_{i,j}(\vartheta) = \sum_{k=1}^{L} c_i(k) c_j(k) \qquad (2)$$

If the two sequences used are of the type $c_i(n) = R(n)S(n+i)$, *Equation (2)* becomes:

$$\Phi_{i,j}(0) = \sum_{k=1}^{L} R(k)S(k+i)R(k)S(k+j)$$

$$= \sum_{k=1}^{L} S(k+i)S(k+j)$$

And, since S(n) is an ML sequence,

$$\Phi_{i,j}(0) = -1$$

The same applies when the sequence R(n) is used (i.e. Channel #1, I-branch, link from the DSNG terminal to the fixed station in *Table A1)*:

and, being S(n) balanced (the number of ones is greater of one unity respect the number of zeros):

$$\Phi_{i,j}(0) = -1$$

$$\Phi_{i,j}(0) = \sum_{k=1}^{L} R(k)R(k)S(k+j)$$

$$= \sum_{k=1}^{L} S(k+j)$$

On the contrary, when the sequence S(n) is used (i.e. Channel #1, Q-branch, link from the DSNG terminal to the fixed station in *Table A.1)*:

$$\Phi_{i,j}(0) = \sum_{k=1}^{L} S(k)R(k)S(k+j)$$

that, generally, may assume the three possible values {–1, t(m) – 2, –t(m)} (see *Appendix 1)*.

Therefore, by using S(n) as the code sequence, the value of mutual cross-correlation may not be – 1, with a consequent degradation of performance in terms of error probability.

Fig. A2.1 shows the simulated BER versus E_b/N_0 respectively for the asynchronous case, the synchronous case using S(n) as the code sequence, and the synchronous case using a different sequence, for the code sequence of period L = 31 and four uni-directional channels (M = 4).

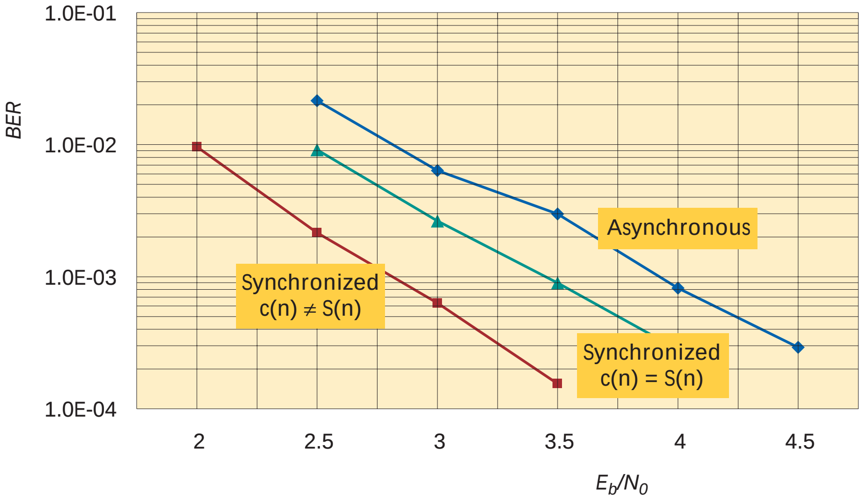


Figure A2.1
Simulated BER versus E_b/N_0 for (i) the asynchronous case, (ii) the synchronous case using S(n) as the code sequence and (iii) the synchronous case using a different sequence, for the code sequence period L = 31 and four uni-directional channels.

In a synchronized system, using the sequence S(n) leads, for BER = 10^{-3}, to a degradation in terms of E_b/N_0 of about 0.5 dB compared to the case when S(n) is not used. As a conclusion, in cases where there is synchronization between the transmitting terminals, the sequence S(n) is not optimal and should therefore not be used.

Appendix 3
Approximated method for DSNG and co-ordination channel performance estimation

To estimate, to a first approximation, the impact of the co-ordination channels on the DSNG signal performance, the following two hypotheses have been adopted: (a) the transponder is operating in a quasi-linear mode, and (b) the interference of the DSNG signal on the co-ordination channels (and vice versa), and the co-ordination channel interference due to the other co-ordination channels, is equivalent to Gaussian noise of the same power. The first approximation applies generally in FDM transmission, and especially when high-order modulations (16QAM) are used for the main DSNG signal. Generally, the latter approximation may be slightly pessimistic compared to digitally-modulated signals.

Software simulations have been carried out to verify its validity, which demonstrated that, in the presence of communication-channel interference on the main DSNG signal and vice versa [11][14], the performance degradation of the wanted signal depends largely on the total in-band power interference, and not on the shape of the power spectrum of the interference and that, to a first approximation, it can be considered noise-like. Furthermore, the same rule can be applied in the evaluation of mutual co-channel interference of co-ordination channels, under the assumption of non-synchronized and therefore non-orthogonal spreading sequences. In this case, the co-ordination channel signal-to-interference ratio due to the other co-ordination channels can be approximated by the power ratio L/(M – 1), where L indicates the spreading factor and M is the number of co-

Equation (3)

$$\begin{cases} \Delta_{DSNG} = \rho_{DSNG} / (\rho_{DSNG} - 1) \\ \rho_{DSNG} = R_{DSNG}\, A^2 / (M\, R_{COOR} (E_b/N_0)_{COOR} (E_b/N_0)_{DSNG}\, \rho_{COOR} \eta_{DSNG}^2\ ) \\ \rho_{COOR}^{-1} = 1 - \Delta_{COOR}^{-1} - ((L/(M-1))/(E_b/N_0)_{COOR})^{-1} \end{cases}$$

Where: M indicates the number of communication carriers (M = 2 corresponds to a single full-duplex connection);

R_{DSNG} and R_{COOR} are the useful bit-rates for the main and co-ordination signals respectively;

h_{DSNG} is the modulation/coding spectral efficiency (bit/symbol) of the DSNG signal;

D_{COOR} is the E_b/N_0 performance degradation of the co-ordination signal;

r indicates the margin of the carrier-to-interference ratio above the threshold of the receiver without noise and is related to the ratio between C/N and C/I.

A is the mutual interference power suppression of the DSNG and each co-ordination channel, due to the baseband filtering in the transmitters and receivers, assuming matched filters. A may be computed by using Equation (4). (A = 1 for the case where the co-ordination signal is superimposed on the DSNG signal.)

Equation (4)

$$A = \frac{1}{R_{S,COOR}} \int_{-\infty}^{\infty} H_{DSNG}^{2}(f)\; H_{COOR}^{2}\,[f-(f_{0,COOR}-f_{0,COOR})]\,df$$

Where: H_{DSNG} is the transfer function of the DSNG receive / transmit baseband filters;

H_{COOR} is the transfer function of the co-ordination receive/ transmit baseband filters (ideally corresponding to square-root raised cosines).

ordination carriers in CDMA. When the co-ordination channels are synchronized, the signal-to-interference power ratio can be approximated by the ratio $L^2/(M-1)$, with an increase over the asynchronous case of factor L, due to the higher mutual interference rejection of synchronized sequences (see *Appendix 2)*.

Following the above-mentioned hypothesis, the E_b/N_0 performance degradation of the main DSNG signal Δ_{DSNG}, due to the co-ordination channel interference, can be computed with *Equations (3*) and *(4)*.

Given a maximum acceptable E_b/N_0 performance degradation of the co-ordination signal Δ_{COOR} and therefore the factor ρ_{COOR} , the ratio Γ between the spectral densities of the DSNG signal and of each co-ordination signal, divided by the spreading factor L, can be estimated as:

$$\Gamma = A/((E_b/N_0)_{COOR}\,\rho_{COOR}\,\eta_{COOR})$$

where η_{COOR} is the modulation/coding spectral efficiency (bit/symbol) of the co-ordination signal, equal to 0.9804.