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International Week of Telecommunication - IWT 2004

# Digital TV Systems and Standards

ATSC, ADTB, DVB and ISDB Standards

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## Agenda

- **Part I**
  - **Overview of digital television systems;**
- Part II
  - RF / Transmission subsystems for terrestrial broadcast systems (ATSC, DVB-T, ISDB-T);
- Part III
  - Interactivity in cable, satellite and terrestrial networks;
  - Return channel for terrestrial networks: DVB-RCT standard;

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# Digital TV systems

- Substantially improves the quality of the received signal;
- Increases the number of possible services to be offered;
- Video, audio and data can be multiplexed together to form a program;
- Interactive services if a return channel is available;

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# Status of DTV in Brazil

- Satellite
  - DirecTV, Sky
- Cable
  - Digital trial in Sorocaba (2001)
  - Net and TVA announcement (2004)
- Terrestrial
  - Field trial with DVB-T, ATSC and ISDB-T (2000)
  - SBTVD (targeted to 2006)
  - Partnership of Inatel, Linear and FINEP

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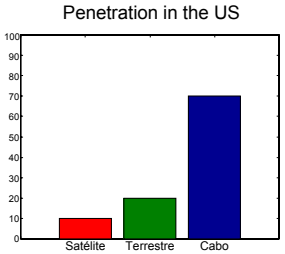
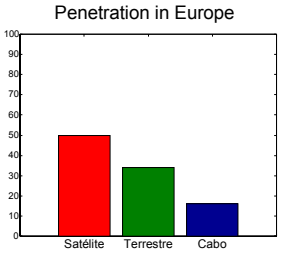
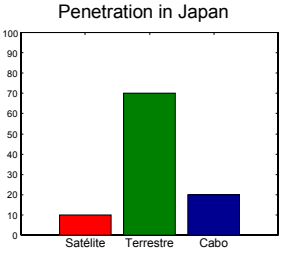
# How do people watch TV?

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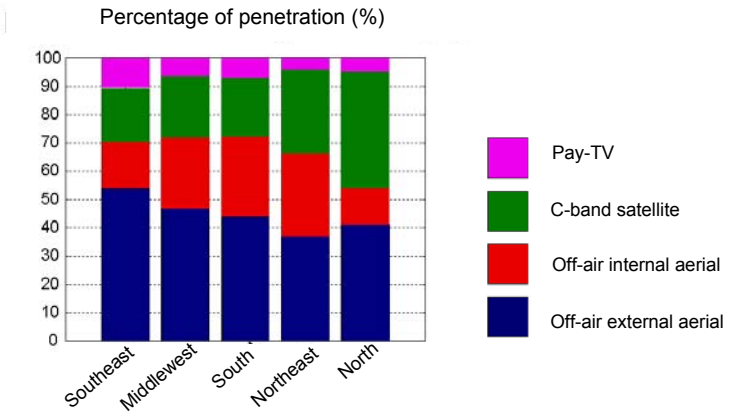
# How do people watch TV in Brazil?




Total number of homes with TV sets: ≅ 60 million

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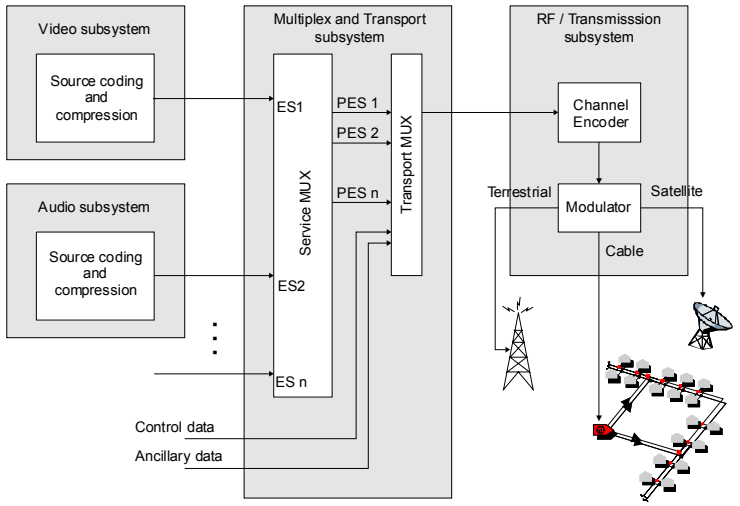
# A DTV broadcast system model

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# Source coding subsystems

- Video compression subsystem
  - Spatial and temporal redundancies
  - MPEG-2: Video (ISO/IEC 13818-2)
- Audio compression subsystem
  - MPEG-2: Audio (ISO/IEC 13818-3), Layers 1, 2 and 3
  - Dolby AC-3: ATSC A/52 standard

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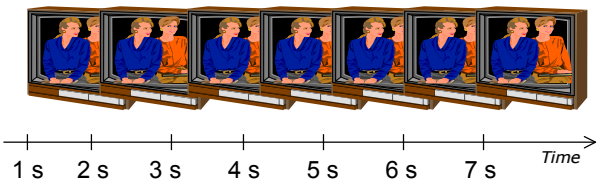
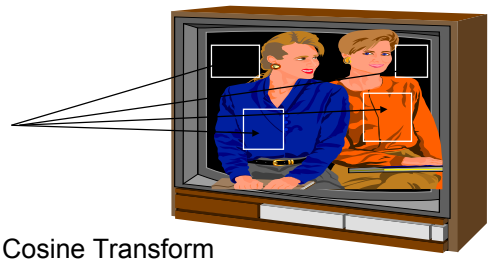
# Source coding: Video

*Redundancy in time*




Removed by: Motion Compensation

*Spacial redundancy*



Removed by: Discrete Cosine Transform

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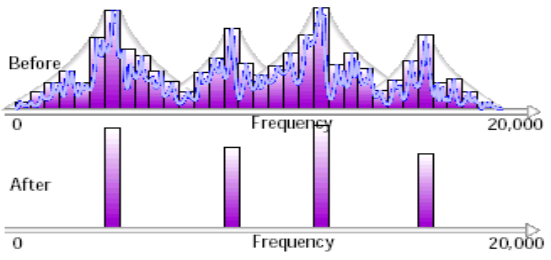
# Source coding: Audio

- System relies on masking tones at either side of hi-power tone
- If you can't hear it, don't code it



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# Multiplex and Transport subsystem

- MPEG standard (ISO-13818-1) defines ways of multiplexing more than one stream (video, audio and data) in order to produce one program
- A program consists of one or more elementary streams, which may or may not be MPEG encoded
  - Currently programs consist of primarily one video channel and possible multiple audio channels
  - Multiple video streams for the same program (different camera shots of a soccer game!!)
- Two schemes for the multiplexing process of the PES:
  - Program streams
  - Transport streams

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# Multiplex and Transport subsystem

- Program Stream
  - Primarily intended for storage and retrieval from storage media
  - Grouping of video, audio, and data elementary streams that have a common time base
  - Each program stream consists of only one program
  - Useful in error free environments
  - Large packet size
  - DVD standard uses the MPEG-2 Program Stream

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# Multiplex and Transport subsystem

- Transport Stream
  - Combines multiple programs into a single stream
  - The programs may or may not have common time base
  - Fixed length packet size
  - Intended for non error free environments
  - Variable rate with insertion of null packets

**RF/Transmission Subsystem uses TS at its input!**

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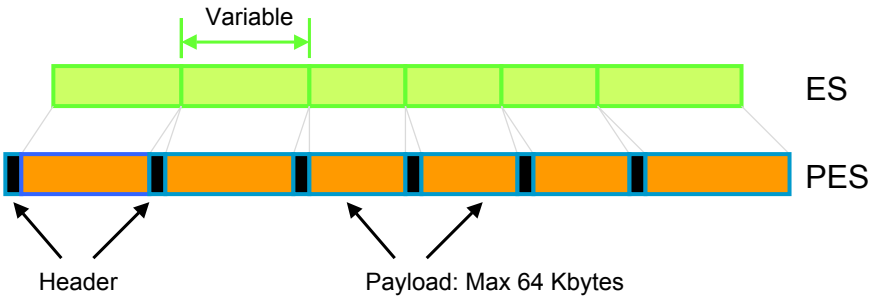
# Multiplex and Transport subsystem

From ES to PES



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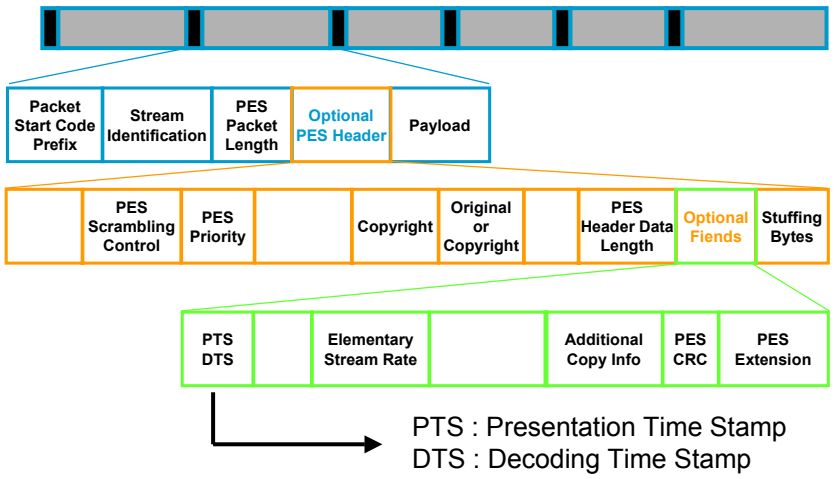
# PES packet

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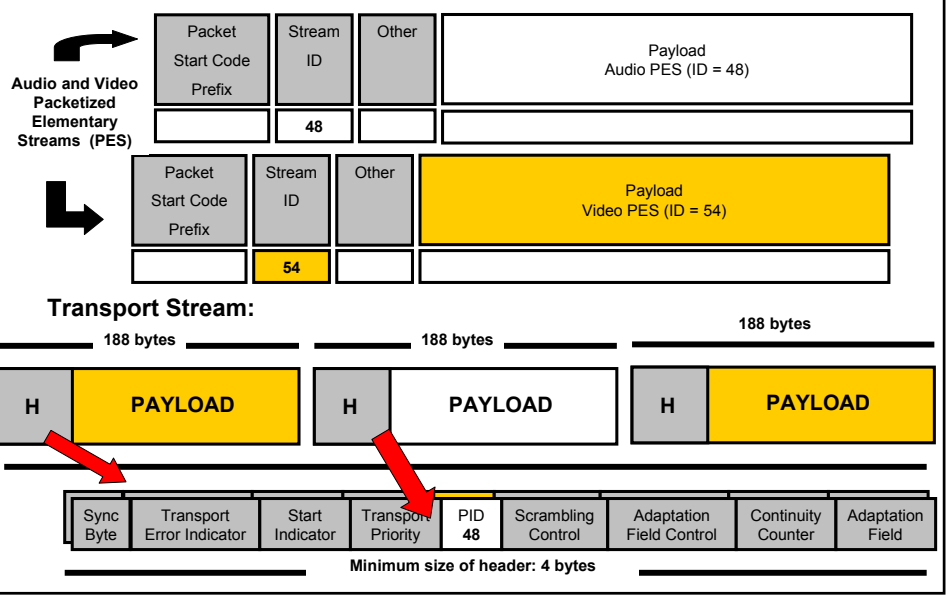
# Multiplex and Transport subsystem

From PES to SPTS



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## Program Specific Information

- PSI transport packets - used by decoder to learn about the transport stream
  - Program Association Table (PAT)
    - Contains complete list of all programs in the transport stream along with the PID for the PMT for each program
    - Transmitted in transport packets with PID 0
  - Program Map Table PMT
    - contains the PID for each of the channels associated with a particular program

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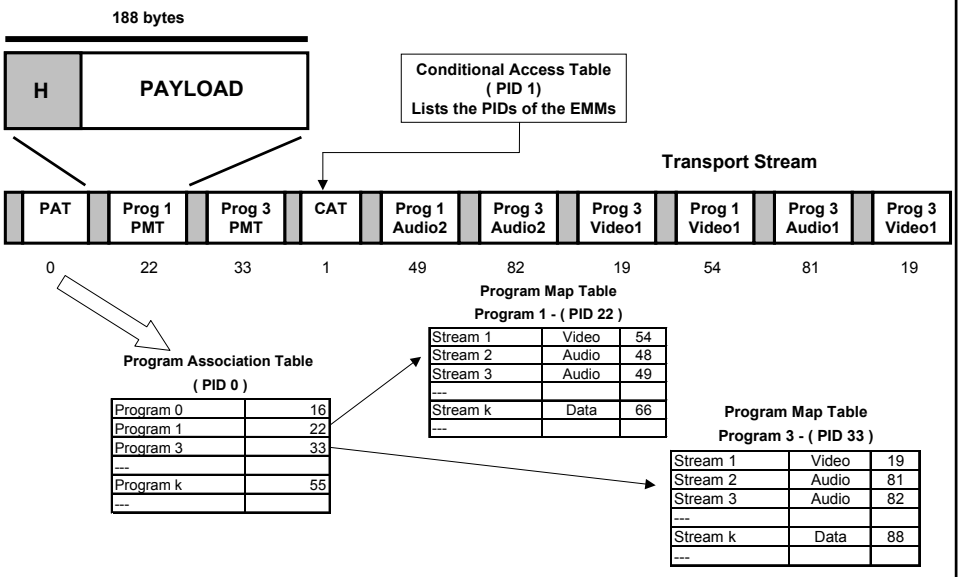
## Conditional Access

- Traditional role is to ensure that viewers see only those prgrams that they have paid to view;
- In addition, it is possible to target programming, advertisements, and promotions to subscribers by geographic area, by market segment, or according to subscribers' personal preferences;
- EMM (Entitlement Management Messages): distributes management information such as access permits to specific users, access revocations, etc.;
- ECM (Entitlement Control Messages): delivers the key that will enable unscrambling at the receiver;

# Program Specific Information




# RF / Transmission subsystem

- Satellite
  - ETSI EN 300 421 (DVB - Framing structure, channel coding and modulation for 11/12 GHz satellite services)
- Cable
  - ITU-T J-83 (Digital multi-programme systems for television, sound and data services for cable distribution)
- **Terrestrial**
  - **ATSC**
  - **DVB-T**
  - **ISDB-T**
  - **ADTB**

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# DTV Standard with Single-carrier Modulation

**ATSC**
**8 VSB**

**A**dvanced **T**elevision **S**ystem **C**ommittee
8 level - **V**estigial **S**ide **B**and
Origin: USA

**ADTB**
**OQAM**

**A**dvanced **D**igital **T**elevision **B**roadcasting
**O**ffset **Q**uadrate **A**mplitude **M**odulation
Origin: China

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# ATSC Standard

- On May 24, 1993, the three groups that had developed the four final digital systems agreed to produce a single, best-of-the best system to propose as the standard.
- The three groups (AT&T and Zenith Electronics Corporation; General Instrument Corporation and the Massachusetts Institute of Technology; and Philips Consumer Electronics, Thomson Consumer Electronics, and the David Sarnoff Research Center) have been working together as the “Digital HDTV Grand Alliance.”
- The Digital Television Standard describes a system designed to transmit high quality video and audio and ancillary data over a single 6 MHz channel.
- The system can deliver reliably about 19 Mbps of throughput in a 6 MHz terrestrial broadcasting channel and about 38 Mbps of throughput in a 6 MHz cable television channel.

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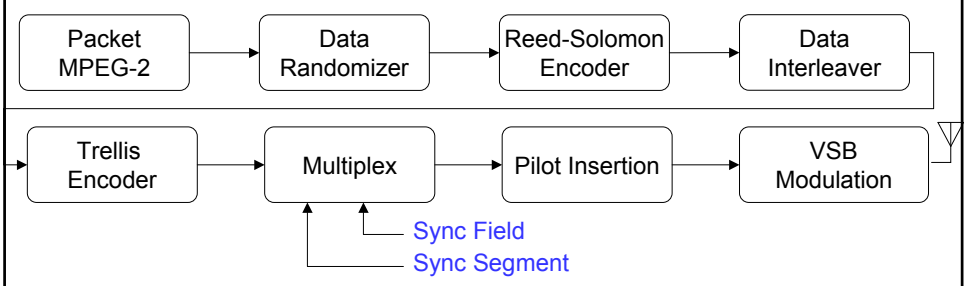
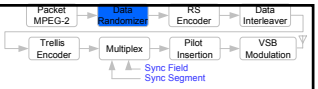
# Transmitter System Block Diagram

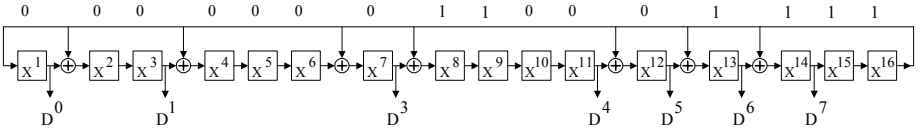




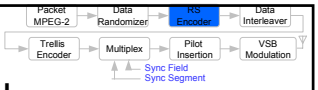

# Data Randomizer

- Randomize all input data in data payload.
- The data randomizer XORs all the incoming data bytes with the PRBS.
- The PRBS generator is initialized at the beginning of the Data Field.
- Generator Polynominal G (16) = $X^{16}+X^{13}+X^{12}+X^{11}+X^{7}+X^{6}+X^{3}+X+1$

The initialization (pre-load) to F180 hex (load to 1) occurs during the Data Segment Sync (set to 1: $X^{16}$ $X^{15}$ $X^{14}$ $X^{13}$ $X^{9}$ $X^{8}$)



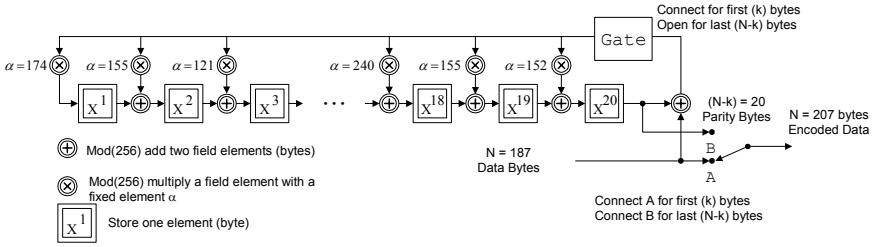



# Reed-Solomon Encoder

- The RS code used in the VSB transmission subsystem shall be a RS(207,187,10) code.
- The RS data block size is 187 bytes, with 20 RS parity bytes added for error correction.
- A total RS block size of 207 bytes is transmitted per Data Segment.
- The 20 RS parity bytes shall be sent at the end of the Data Segment.

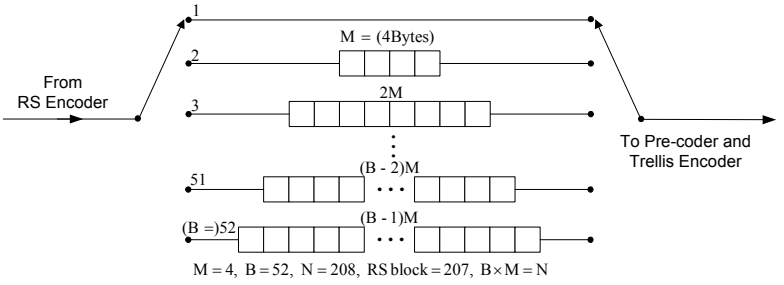
# Reed-Solomon Encoder





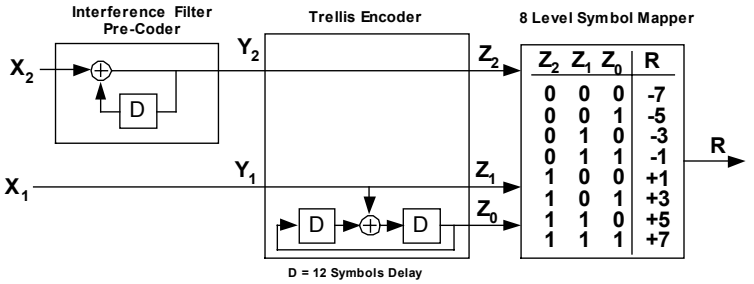

# Data Interleaver

- The interleaver shall be a 52 data segment (intersegment) convolutional byte interleaver.
- Only data bytes shall be interleaved.
- The interleaver shall be synchronized to the first data byte of the data field.



# Trellis Encoder

- The system shall employ a 2/3 rate ($R$ = 2/3) trellis code.
- One input bit is encoded into two output bits using a 1/2 rate convolutional code while the other input bit is precoded.
- The signaling waveform used with the trellis code is an 8-level (3 bit) one-dimensional constellation.
- A 4-state trellis encoder shall be used.




| $Z_2$ | $Z_1$ | $Z_0$ | R |
|---|---|---|---|
| 0 | 0 | 0 | -7 |
| 0 | 0 | 1 | -5 |
| 0 | 1 | 0 | -3 |
| 0 | 1 | 1 | -1 |
| 1 | 0 | 0 | +1 |
| 1 | 0 | 1 | +3 |
| 1 | 1 | 0 | +5 |
| 1 | 1 | 1 | +7 |

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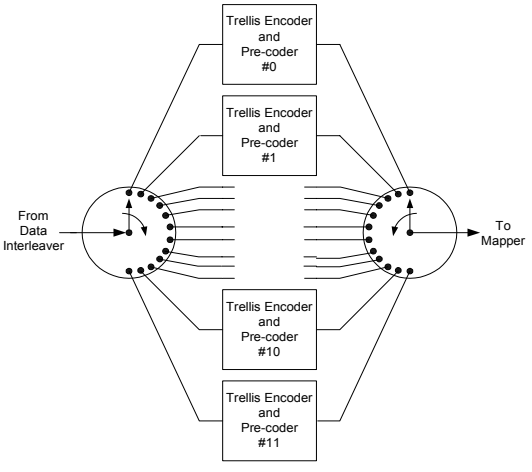
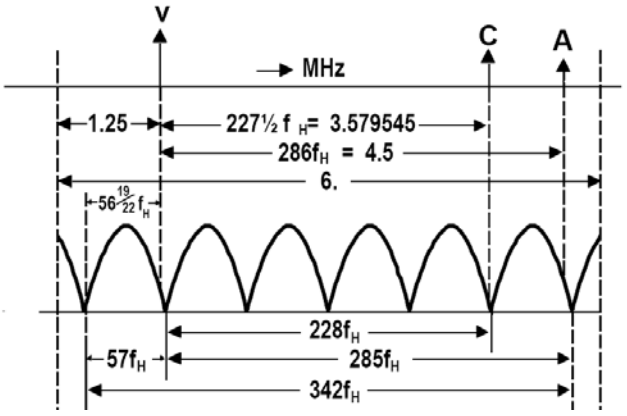
Packet MPEG-2 | Data Randomizer | RS Encoder | Data Interleaver
Trellis Encoder | Multiplex | Pilot Insertion | VSB Modulation
Sync Field
Sync Segment

# Trellis Code Intrasegment Interleaving

- Intrasegment interleaving is also performed for the benefit of the trellis coding process.

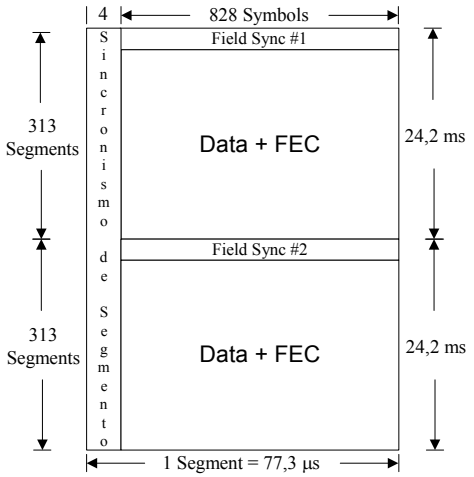


# Location of NTSC carriers — comb filtering

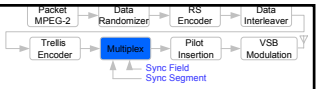





# VSB Data Frame

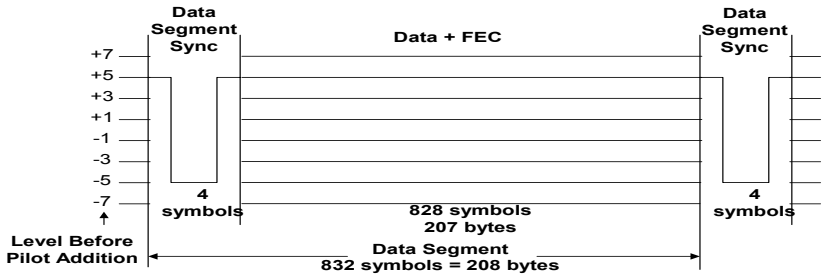



- The adaptive equalization is performed using the Field Sync.




# Data Segment

- A 4-symbol Data Segment Sync shall be inserted into the 8-level digital data stream at the beginning of each Data Segment.
- The MPEG sync byte shall be replaced by Data Segment Sync.
- The Data Segment Sync is binary (2-level).
- A segment shall consist of 832 symbols:
  4 symbols for Data Segment Sync, and 828 data plus parity symbols.
- The Data Segment Sync are not Reed-Solomon or trellis encoded, nor are they interleaved.

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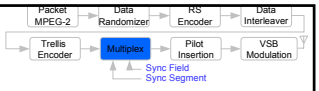
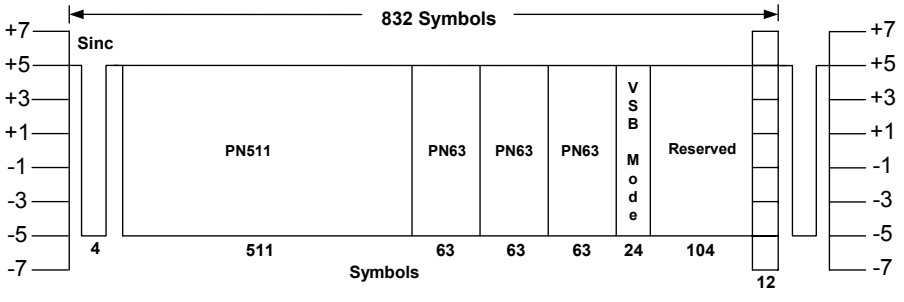



# Data Field Sync

- The data are not only divided into Data Segments, but also into Data Fields, each consisting of 313 segments.
- Each Data Field (24.2 ms) shall start with one complete Data Segment of Data Field Sync.
- Each symbol in the sync segment represents one bit of data (2-level).



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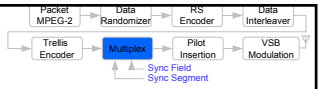
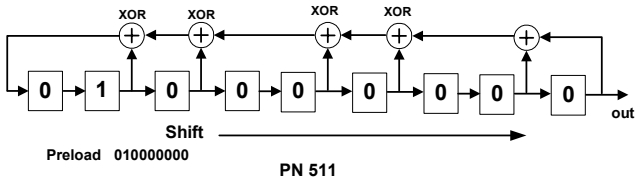
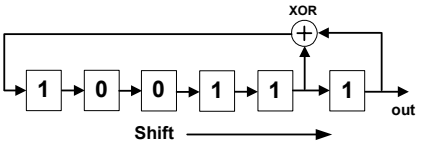



# Sync Segment

• The data for Sync Segment are generated using PN sequences, defined as




PN 511




PN 63

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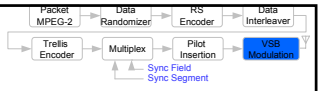


# 8VSB - Modulation

• Vestigial Side Band - 8 Level

| Parameter | Terrestrial | Cable |
|---|---|---|
| **Channel bandwidth** | 6 MHz | 6 MHz |
| **Excess bandwidth** | 11.5% | 11.5% |
| **Symbol Rate** | 10.76 Msymbols/s | 10,76 Msymbols/s |
| **Symbol Duration** | 92.917 ns | 92.917 ns |
| **Bits per symbol** | 3 | 4 |
| **Trellis coded modulatoin** | 2/3 | - |
| **Reed-Solomon** | RS(207,187,10) | RS(207,187,10) |
| **Segment length** | 832 symbols | 832 symbols |
| **Segment sync** | 4 symbols | 4 symbols |
| **Frame sync** | 1 for 313 segments | 1 for 313 segments |
| **Payload data rate** | 19.28 Mb/s | 38.57 Mb/s |
| **NTSC co-channel rejection Filter** | NTSC rejection filter in receiver | N/A |
| **Pilot power contribution** | 0.3 dB | 0.3 dB |
| **C/N threshold** | 14.9 dB | 28.3 dB |

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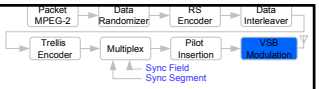
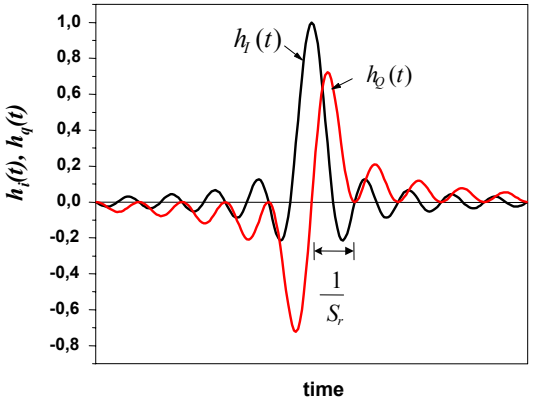



# 8VSB - Modulation

- Vestigial Side Band - 8 Level

$$h_I(t) = \frac{\text{sen}(4\pi\Delta ft)}{4\pi\Delta ft} \times \frac{\cos(2\alpha\pi\Delta ft)}{1-(4\alpha\Delta ft)^2} \qquad h_Q(t) = \frac{sen\,(2\pi\Delta ft)^2}{2\pi\Delta ft} \times \frac{\cos(\,2\alpha\pi\Delta ft\,)}{1-(4\alpha\Delta ft)^2}$$

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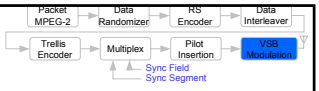
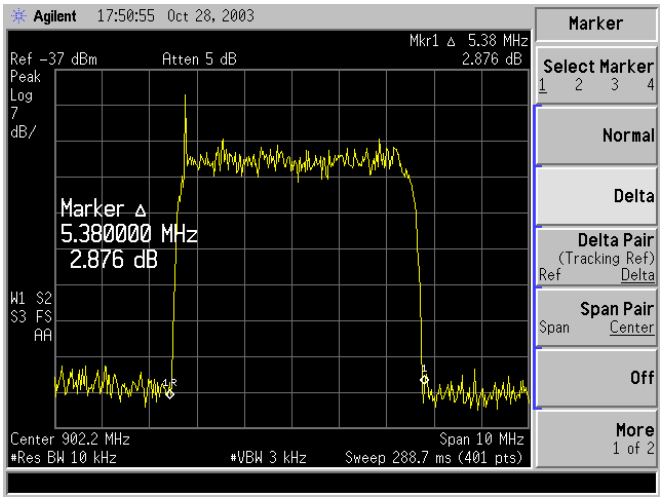



# 8VSB - Modulation

- Vestigial Side Band Spectrum



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## **A**dvanced **D**igital **T**elevision **B**roadcasting Standard

- Design based:
  - on geographical environment.
  - on city construction characteristics.
  - with enhanced functionalities to best fit the needs of both, industry and consumers, on new applications.
  - for different applications
    - fixed reception: outdoor/indoor for HDTV/SDTV
    - mobile reception: portable/mobile for SDTV/LDTV
    - mobile data reception: mobile for reliable data reception
- Support for single frequency networks and channel repeaters.
- The system also includes easy extension to cable modes.

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## Technical Requirements

- High efficiency, high data rate to support HDTV programs
- Low reception threshold to maximize coverage
- Mixed mode operation to provide different services
- Handles strong ghosts and fast varying ghosts
- Improved dynamic performance for indoor and mobile reception
- Co-existence with analog TV services
- Resistance to large impulse noise and large phase noise

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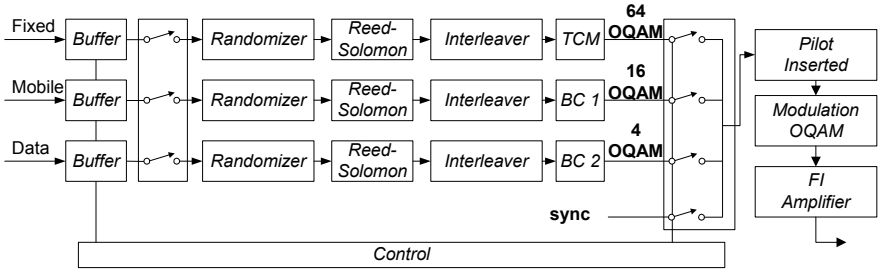
# ADTB Standard




| Parameter | Terrestrial Mode | | |
|---|---|---|---|
| | Fixed | Mobile | Data |
| **Channel bandwidth** | 8 MHz | 8 MHz | 8 MHz |
| **Modulation** | 64 OQAM | 16 OQAM | 4 OQAM |
| **Excess of bandwidth** | 12% | 12% | 12% |
| **Inner coding** | RS | RS | RS |
| **Extern coding** | TCM (2/3) | Block (1/2) | Block (1/2) |
| **Payload data rate** | 25,24 Mbps | 12,62 Mbps | 6,31 Mbps |
| **Pilot Tom** | 2 | 2 | 2 |

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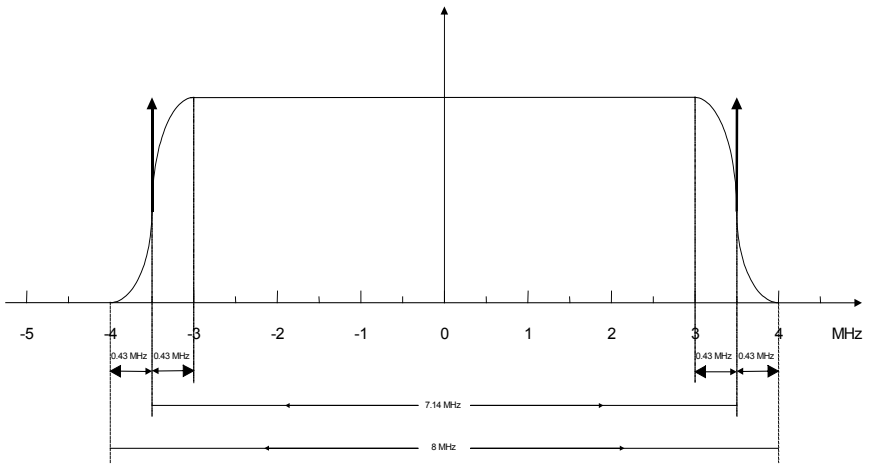
# OQAM Signal Spectrum



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## Mixed Mode Operation

- Different transmission modes mixed in a TDM manner in the same 8 MHz channel
- Bandwidth allocation for different service can be dynamically adjusted
- Different transmission modes mixed in the unit of a field
- Transmission mode of each field defined by system information
- **Single Transmission Mode**
  - TCM-64-OQAM: 25.24 Mbps
  - ***OR*** Block code-16-OQAM: 12.62 Mbps
  - ***OR*** Block code-4-OQAM: 6.31 Mbps
- **Mixed Transmission Mode Example**
  - TCM-64-OQAM: 15 Mbps for one EDTV program
  - ***PLUS*** Block code-16-OQAM: 4 Mbps for one SDTV program
  - ***PLUS*** Block code-4-OQAM: 512 kbps for mobile data service

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## Synchronization

• Based on redundant information included in the OQAM signal:

• 2 pilot carriers.

• Segment sync.

• Field sync/Frame sync.

• Coding, Trellis/Block Modulation and Reed-Solomon.

• Optimal equalizer structure is less sensitive to carrier phase and timing errors.

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# DTV with Multi-carrier Modulation

**DVB COFDM**

**D**igital **V**ideo **B**roadcasting
**C**oded **O**rthogonal **F**requency **D**ivision **M**ultiplexing
Origin: Europe

**ISDB BST-OFDM**

Integrated Service Digital Broadcasting
**I**ntegrated **S**ervice **D**igital **B**roadcasting
**B**andwidth **S**egmented **T**ransmission
**O**rthogonal **F**requency **D**ivision **M**ultiplexing
Origin: Japan

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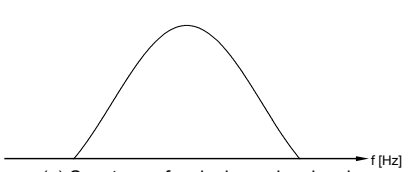
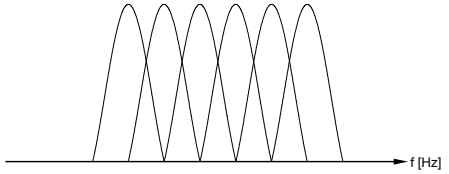
# Introduction to OFDM

- The principle of the OFDM system is to transmit *N* parallel data stream with *N* sub-carriers instead of using only one carrier to transmit all data.
- The bandwidth occupied by each sub-carrier is *N* times smaller than the bandwidth occupied by the single carrier signal.
- To improve the spectral efficiency, the sub-carriers are orthogonal between each other and separated by the OFDM symbol data rate.



(a) Spectrum of a single carrier signal



(b) Spectrum of a multi carrier signal

- The minimal frequency interval between each sub-carrier that has practical use is given by

$$\Delta_{f_{\min}} = R_{mc} = \frac{1}{T_{OFDM}}$$

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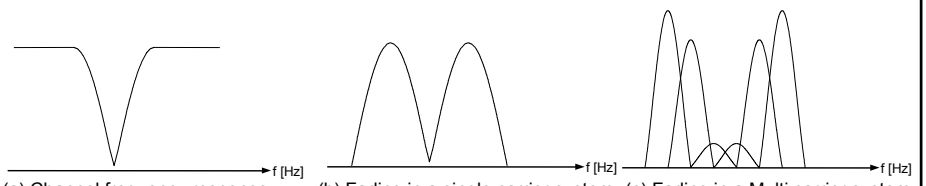
# Introduction to OFDM

- The main aim of this approach is to avoid intersymbol interference, that is introduced by a multipath channel.
- A selective fading channel for a single carrier signal becomes a flat fading channel for each sub-carrier of the OFDM signal.
- Only the carriers around the channel nulls suffer the interference of the channel.




(a) Channel frequency response (b) Fading in a single carrier system (c) Fading in a Multi carrier system

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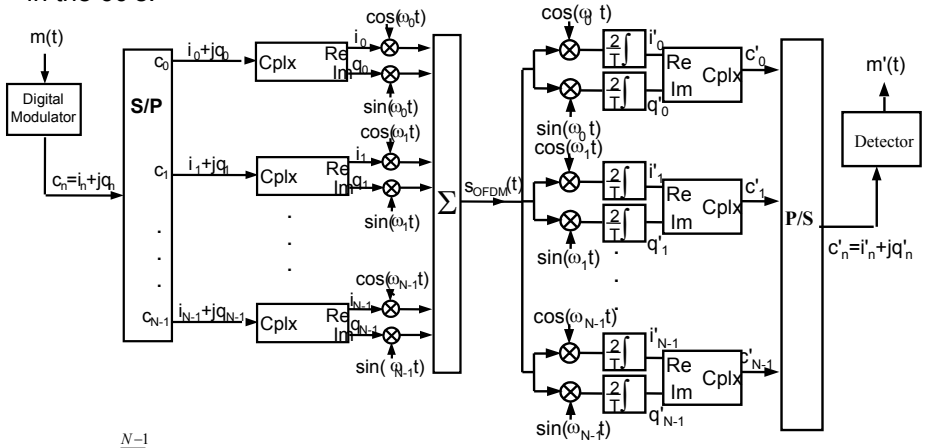
# Introduction to OFDM

- The first approach to generate an OFDM system has been proposed in the 60's.




$$s_{OFDM}(t) = \sum_{n=0}^{N-1} i_n \cos(\omega_n t) + q_n \sin(\omega_n t)$$

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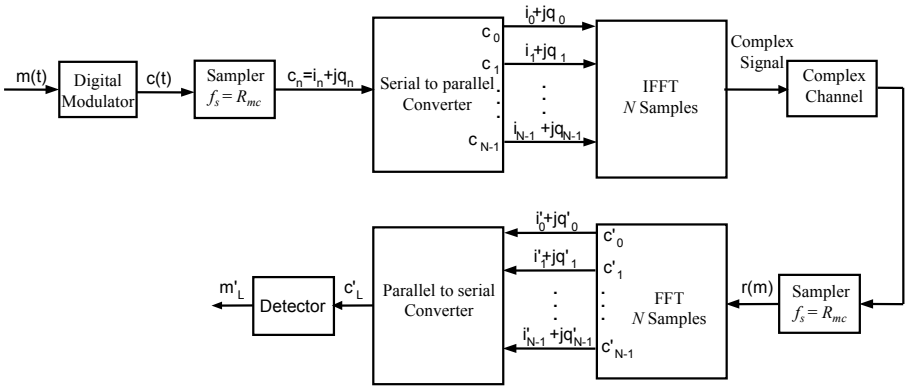
# FFT/IFFT for OFDM

• To avoid these problems, the OFDM symbol can be generated using the Inverse Fast Fourier Transform and can be detected using the Fast Fourier Transform, as shown in the block diagram bellow.

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# DVB-T Standard - Introduction

• DVB-T was created in 1993 by a group called ELG.

• To attend the demand of every country in Europe, the DVB-T must be a robust system.

• The ELG decided to use Coded Orthogonal Frequency Multiplexing (COFDM) to mitigate the ISI introduced by the channel.

• In 1995 the first transmissions using the DVB-T have been made.

• Today, the DVB-T has been adopted by several countries all over the world.

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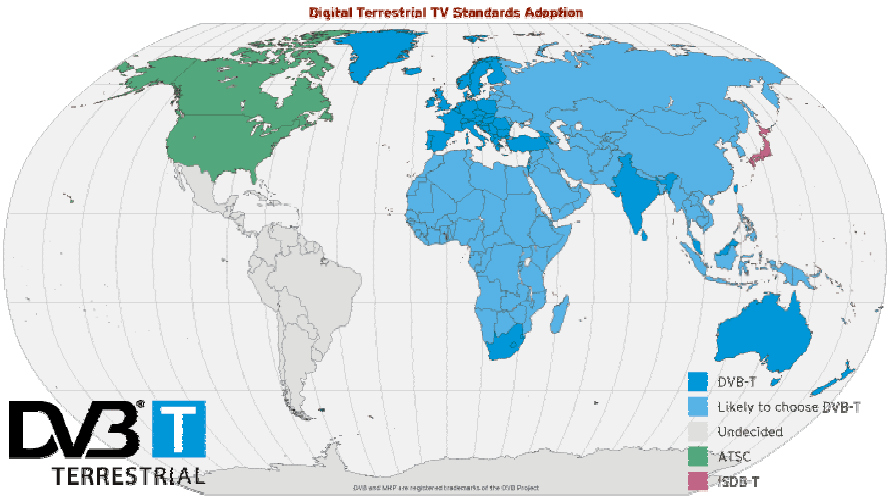
# DVB-T Standard - Introduction

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# DVB-T Standard - Main Characteristics

- The system is directly compatible with MPEG-2 TV signals.

- The DVB-T must coexist with the analog standards (PAL, SECAM, NTSC) and must be robust against co-channel interference.

- DVB-T must present high bandwidth efficiency, mainly when operating in VHF and UHF bands.

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# DVB-T Standard - Main Characteristics

• The DVB-T standard is specified to 6,7 and 8MHz bandwidths.

• This flexible specification has been proposed to guarantee that the DVB-T can be used in countries that uses different channel bandwidth to broadcast TV signal.

• DVB-T standard also uses different guard time to increase the system performance in a multipath environment and also to permit the use of Single Frequency Networks to cover a large area with high spectrum efficiency.

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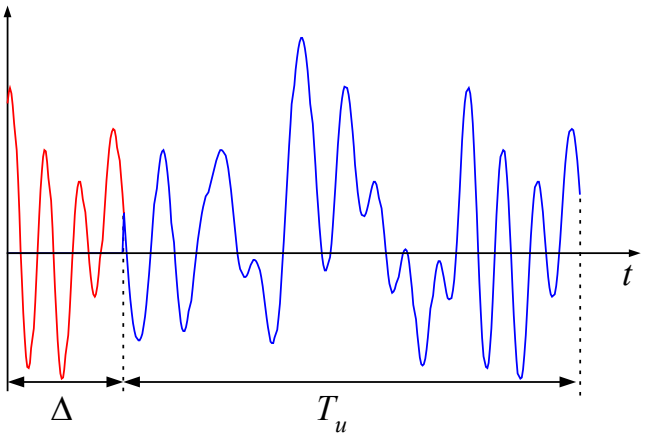
# DVB-T Standard - Guard Interval

• The guard time in a OFDM system is a cyclical extension of the symbol, as shown bellow.



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## DVB-T Standard - Main Characteristics

- The DVB-T presents two operational mode called 2k and 8k modes.
- 2k mode is used for single transmitter configuration or for small SFN's.
- 8k mode is used for large SFN's or in channels with severe multiple paths.
- The main difference between these two modes is the number of subcarriers and, consequently, the OFDM symbol time.

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## DVB-T Standard

- DVB-T can provide different trade-off between data rate and robustness.
- Beside the two available operational modes, there are several guard time and code rates that can be used to obtain either higher data rates or higher protection for the data.
- DVB-T also allows the use of different constellations to improve the the data rate or the robustness of the signal.
- DVB-T presents the possibility to use non-hierarchical and hierarchical transmission modes, as described following.

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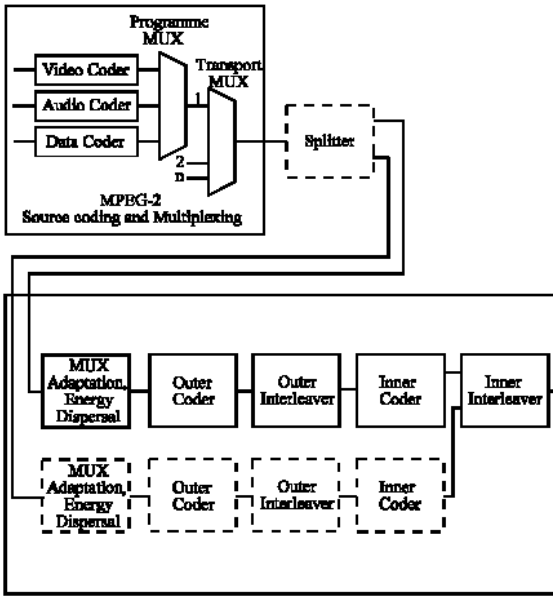
# DVB-T Standard

- The dashed blocks are used only in hierarchical mode.

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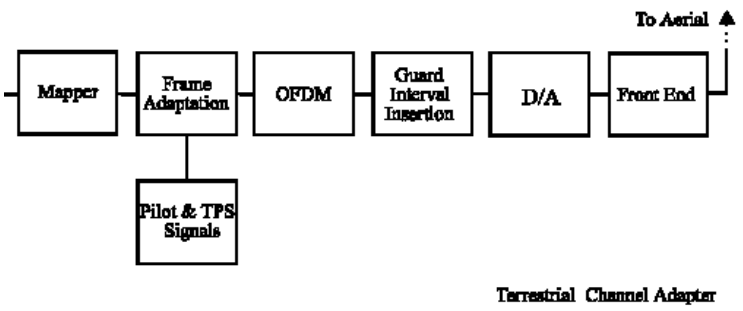
# DVB-T Standard

- The dashed blocks are used only in hierarchical mode.



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## DVB-T Standard - Main Characteristics

• The Splitter is used to separate the high priority information from the low priority information.

• The hierarchical process is restricted in the modulation and encoding to guarantee that a non-hierarchical receiver is able to decode the information.

• The source encoding is the same for the hierarchical and non-hierarchical transmissions.

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## DVB-T Standard - Main Characteristics

• With hierarchical transmission, it is possible to simultaneously transmit

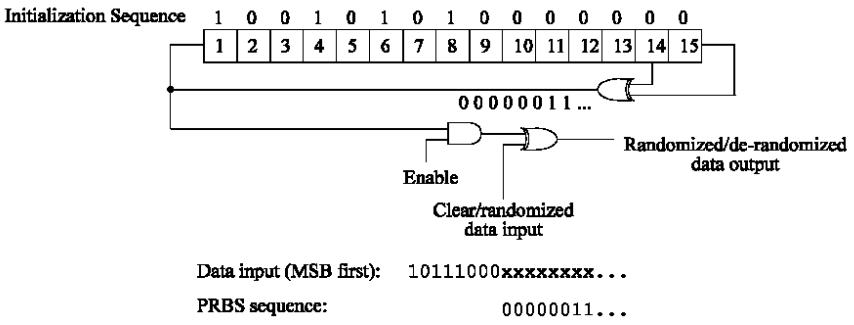
a) the desired video and audio information at a high data rate and a EPG information at a low data rate or;

b) two versions of the same program, one with high robustness and low data rate and another with low robustness and high data rate.

• The hierarchical and non-hierarchical receivers are the same. The only difference is the ability to select one or another program.

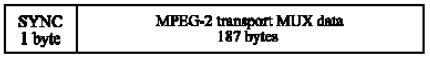
# DVB-T Standard - Energy Dispersion

- The main aim of this block is to uniformly distribute the energy of the MPEG-2 packages in the available bandwidth.
- The MPEG-2 frame is composed by 188 bytes, 187 bytes of information and 1 byte for synchronism ($47_H$).
- The energy dispersion is realized by na OR-Exclusive operation between the incoming data bytes and the bytes given by a PN generator.

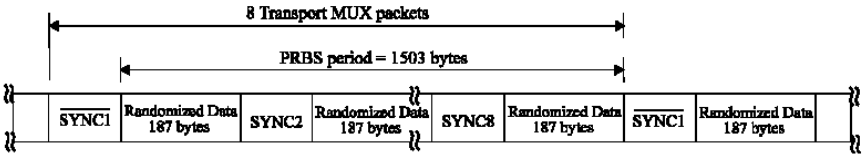



# DVB-T Standard - Energy Dispersion

- The PN generator polynomial is given by $g(X)=1+X^{14}+X^{15}$.
- The initial seed is $4A80_H$ and the generator must be reinitialized with this seed every 8 MPEG-2 packages.
- To provide a synchronism to the receiver, the sync byte is inverted every 8 packages, which means that the data $B8_H$ is transmitted instead of $47_H$.



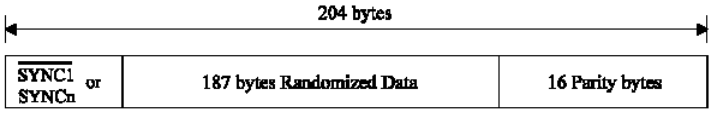

a) MPEG-2 transport MUX packet




b) Randomized transport packets: Sync bytes and Randomized Data bytes

# DVB-T Standard - Outer Code

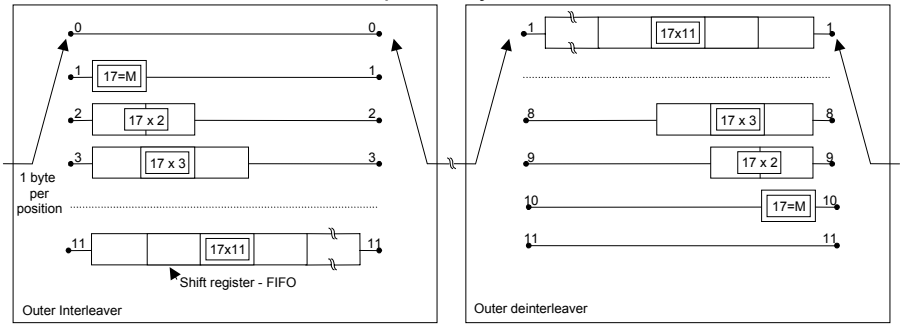
- The channel error code is a process where redundancies are inserted in the data stream to allow the receiver to identify and correct the errors introduced by the channel.
- The outer code used in DVB-T standard is a Reed Solomon code where 16 parity bytes are introduced for each MPEG-2 package, what results in a 204 bytes package.
- The error correction capability of this code is 8 bytes in a block of 204 bytes RS(204,188,8).
- Code generator polynomial - $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^1)\cdots(x+\lambda^{15})$ where $\lambda = 02_H$.

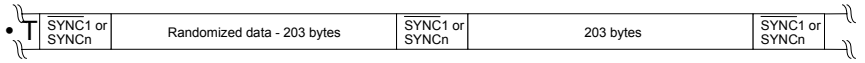



c) Reed-Solomon RS(204,188,8) error protected packets

# DVB-T Standard - Outer Interleaver

- The aim of this block is to “scramble” the coded symbol to avoid burst errors in the reception.
- The DVB-T interleaver is composed by 12 branches, as shown bellow.




d) Data structure after the interleaver

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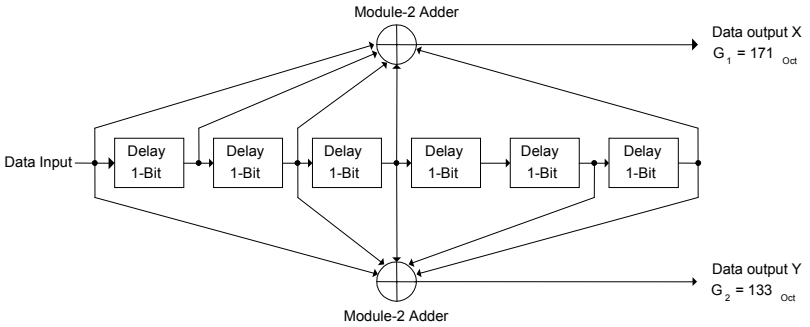
# DVB-T Standard - Inner Code

- DVB-T standard also uses a convolutional code to increase the BER performance of the system.
- The convolutional code introduces redundant bits.
- The generator polynomial used in this code are

$G1(X)=1+X+X^2+X^3+X^6$ or $G1=171_O$
$G2(Y)=1+Y^2+Y^3+Y^5+Y^6$ or $G2=133_O$

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# DVB-T Standard - Inner Interleaver

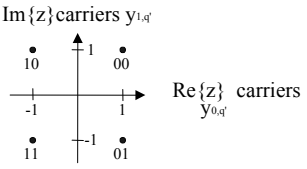
- The Inner interleaver is also used to void burst errors that can reduce the performance of the inner code.

- The inner interleaver is composed by a bit interleaver followed by a symbol interleaver.

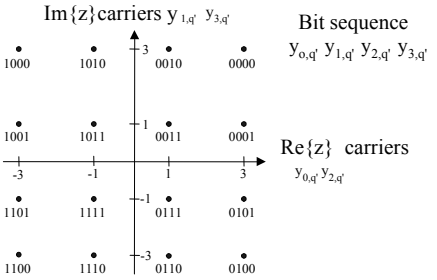
- The bit interleaver depends on the modulation that is being used. It also depends if the transmission is hierarchical or non-hierarchical.

# DVB-T Standard - Constellation and Mapping

- The DVB-T uses three different modulations to transmit the data symbols: QPSK, 16-QAM and 64-QAM.
- The 16-QAM and 64-QAM can be uniform or non-uniform, depending of the hierarchical or non-hierarchical modes.
- The shape of the constellation depends on the parameter a that can assume the values 1, 2 or 4.




Non-hierarchical QPSK
Hierarchical QPSK with $\alpha$=1
Bit sequence: $y_{o,q'}$ $y_{1,q'}$




Non-hierarchical 16QAM
Hierarchical 16QAM with $\alpha$=1


# DVB-T Standard - Constellation and Mapping


- The $\alpha$ parameter is defined as the smallest distance between two high priority symbols divided by the smallest distance between two low priority symbols.
- The high priority symbols are always mapped in the corners of the 16-QAM and 64-QAM.
- A QPSK receiver can always demodulate the the high priority information.
- The high priority bits are transmitted in the symbols $y_{0,q'}$ and $y_{1,q'}$.
- To receive the low priority information it is necessary to decode the whole constellation.

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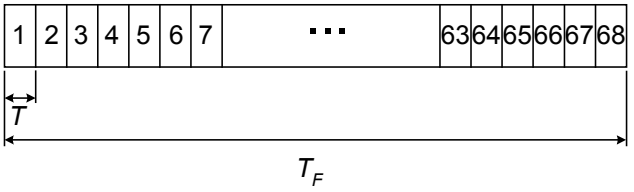
# DVB-T Standard - OFDM Frame Structure

- The information is structured in frames.
- Each frame is composted by 68 OFDM symbols with time duration of $T_F$ seconds.




$T_F$

- In the 2k mode, the OFDM symbol is composed by 1705 carriers.
- In the 8k mode, the OFDM symbol is composed by 6817 carriers.
- OFDM symbol time: $T = T_u + \Delta$ where $T_u$ is the useful time and $\Delta$ is the guard time interval.
- The available guard time interval are $T_u/4$, $T_u/8$, $T_u/16$ and $T_u/32$.

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# DVB-T Standard - OFDM Frame Structure

- In a OFDM frame there are four types of carriers:

1) Data carriers: transmit the video and audio data.

2) Continual pilot carriers: reference for frequency equalization and synchronization.

3) Scattered pilot carriers: reference for frequency equalization and synchronization.

4) TPS carriers: used to transmit the parameters used in the transmission.

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# DVB-T Standard - OFDM Frame Structure

• The scattered pilots changes its spectral position from OFDM symbol to OFDM symbol. A scattered carrier coincides with a continual carrier every fourth symbols.

• The number of useful carriers in a OFDM symbol is constant: 1512 in mode 2k and 6048 in mode 8k.

• The frequency distance between two adjacent carriers is given by $1/T_u$.

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# DVB-T Standard - OFDM Frame Structure

• Table bellow shows the main parameters of the OFDM symbol for 2k and 8k modes in different channel bandwidths.

| Parameter | 8k | | | 2k | | |
|---|---|---|---|---|---|---|
| | 8MHz | 7MHz | 6MHz | 8MHz | 7MHz | 6MHz |
| Number of carriers (K) | 6817 | 6817 | 6817 | 1705 | 1705 | 1705 |
| $K_{min}$ | 0 | 0 | 0 | 0 | 0 | 0 |
| $K_{max}$ | 6816 | 6816 | 6816 | 1704 | 1704 | 1704 |
| OFDM Symbol Time $T_U$ [μs] | 896 | 1024 | 1194,67 | 224 | 256 | 298,67 |
| Carrier distance $1/T_U$ [Hz] | 1116 | 976,563 | 837,054 | 4464 | 3906,25 | 3348,21 |
| Occupied bandwidth $(K-1)/T_U$ [MHz] | 7,61 | 6,66 | 5,71 | 7,61 | 6,66 | 5,71 |

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# DVB-T Standard - OFDM Frame Structure

• The following tables present the available guar time intervals, for the different bandwidths.

| Mode | 8k | | | | 2k | | | |
|---|---|---|---|---|---|---|---|---|
| Time guard interval $\Delta/T_U$ | 1/4 | 1/8 | 1/16 | 1/32 | 1/4 | 1/8 | 1/16 | 1/32 |
| Useful symbol duration $T_U$ | 8 192 * T<br>896 µs | | | | 2 048 * T<br>224 µs | | | |
| Time guard duration $\Delta$ | 2048*T<br>224 µs | 1024*T<br>112 µs | 512*T<br>56 µs | 256*T<br>28 µs | 512*T<br>56 µs | 256*T<br>28 µs | 128*T<br>14 µs | 64*T<br>7 µs |
| Symbol duration $T_S = \Delta + T_U$ | 10240*T<br>1120 µs | 9216*T<br>1008 µs | 8704*T<br>952 µs | 8448*T<br>924 µs | 2560*T<br>280 µs | 2304*T<br>252 µs | 2176*T<br>238 µs | 2112*T<br>231 µs |

BW=8MHz

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DVB-T Standard - OFDM Frame Structure

• The following tables present the available guar time intervals, for the different bandwidths.

| Mode | 8k | | | | 2k | | | |
|---|---|---|---|---|---|---|---|---|
| Time guard interval $\Delta/T_U$ | 1/4 | 1/8 | 1/16 | 1/32 | 1/4 | 1/8 | 1/16 | 1/32 |
| Useful symbol duration $T_U$ | 8 192 * T<br>1024 µs | | | | 2 048 * T<br>256 µs | | | |
| Time guard duration $\Delta$ | 2048*T<br>256 µs | 1024*T<br>128 µs | 512*T<br>64 µs | 256*T<br>32 µs | 512*T<br>64 µs | 256*T<br>32 µs | 128*T<br>16 µs | 64*T<br>8 µs |
| Symbol duration $T_S = \Delta + T_U$ | 10240*T<br>1280 µs | 9216*T<br>1152 µs | 8704*T<br>1088 µs | 8448*T<br>1026 µs | 2560*T<br>320 µs | 2304*T<br>288 µs | 2176*T<br>272 µs | 2112*T<br>264 µs |

BW=7MHz

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# DVB-T Standard - OFDM Frame Structure

• The following tables present the available guar time intervals, for the different bandwidths.

| Mode | 8k | | | | 2k | | | |
|---|---|---|---|---|---|---|---|---|
| Time guard interval $\Delta/T_U$ | 1/4 | 1/8 | 1/16 | 1/32 | 1/4 | 1/8 | 1/16 | 1/32 |
| Useful symbol duration $T_U$ | 8 192 * T<br>1194,67 µs | | | | 2 048 * T<br>298,67 µs | | | |
| Time guard duration $\Delta$ | 2048*T<br>298,67 µs | 1024*T<br>149,33 µs | 512*T<br>74,67 µs | 256*T<br>37,33 µs | 512*T<br>74,67 µs | 256*T<br>37,33 µs | 128*T<br>18,67 µs | 64*T<br>9,33 µs |
| Symbol duration $T_S = \Delta + T_U$ | 10240*T<br>1493,3 µs | 9216*T<br>1344 µs | 8704*T<br>1269,3 µs | 8448*T<br>1232 µs | 2560*T<br>373,3 µs | 2304*T<br>336 µs | 2176*T<br>317,3 µs | 2112*T<br>308 µs |

BW=6MHz

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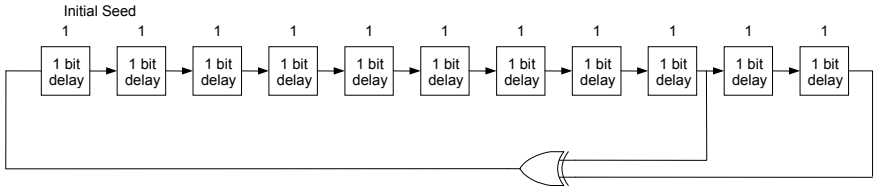
# DVB-T Standard - Reference Signals

• Some carriers are used to transmit reference signals that are known a priori by the receiver.

• The values transmitted by the continual and scattered pilot carriers are derived from a Pseudo Random Bit Sequence (PRBS).

• The PRBS used to modulate the pilot carriers is obtained from the circuit bellow with the following generator polynomial: $g(X)=X^{11}+X^2+1$




PRBS: $w_k$= 1111111111100...

• The first bit of the PRBS coincides with the first active carrier. The index k is the number of the pilot carrier.

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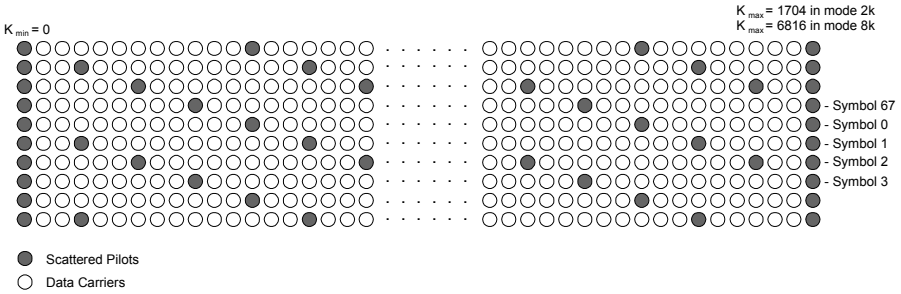
# DVB-T Standard - Scattered Pilots Position

- The Scattered Pilots carriers are transmitted with boosted power, which means that its amplitude is 16/9 times higher than the amplitude of a data carrier.
- Figure bellow presents the position of the scattered pilots for different OFDM symbols.

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# DVB-T Standard - Continual Pilot Position

- There are 45 continual pilot carriers in 2k mode and 177 in 8k mode.
- Continual pilot carriers are transmitted at boosted power level.

| Continual pilot carrier position ( index number k ) | |
|---|---|
| **2k mode** | **8k mode** |
| 0 48 54 87 141 156 | 0 48 54 87 141 156 192 201 255 279 282 333 432 450 483 525 531 |
| 192 201 255 279 282 | 618 636 714 759 765 780 804 873 888 918 939 942 969 984 1050 |
| 333 432 450 483 525 | 1101 1107 1110 1137 1140 1146 1206 1269 1323 1377 1491 1683 |
| 531 618 636 714 759 | 1704 1752 1758 1791 1845 1860 1896 1905 1959 1983 1986 2037 |
| 765 780 804 873 888 | 2136 2154 2187 2229 2235 2322 2340 2418 2463 2469 2484 2508 |
| 918 939 942 969 984 | 2577 2592 2622 2643 2646 2673 2688 2754 2805 2811 2841 2844 |
| 1050 1101 1107 1110 | 2850 2910 2973 3027 3081 3195 3387 3408 3456 3462 3495 3549 |
| 1137 1140 1146 1206 | 3564 3600 3609 3663 3687 3690 3741 3840 3858 3891 3933 3939 |
| 1269 1323 1377 1491 | 4026 4044 4122 4167 4173 4188 4212 4281 4296 4326 4347 4350 |
| 1683 1704 | 4377 4392 4458 4509 4515 4518 4545 4548 4554 4614 4677 4731 |
| | 4785 4899 5091 5112 5160 5166 5199 5253 5268 5304 5313 5367 |
| | 5391 5394 5445 5544 5562 5595 5637 5643 5730 5748 5826 5871 |
| | 5877 5892 5916 5985 6000 6030 6051 6054 6081 6096 6162 6213 |
| | 6219 6222 6249 6252 6258 6318 6381 6435 6489 6603 6795 6816 |

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# DVB-T Standard - Transmission Parameter Signaling

- The TPS is used to inform the receiver which configuration is being used to broadcast the data, as modulation scheme, code rate, etc.
- These data are transmitted in every OFDM symbol.
- The TPS carriers are transmitted with the same power used to transmit the data.
- The TPS carriers are modulated using DBPSK modulation.
- There are 17 TPS carriers in 2k mode and 68 in 8k mode.
- The position of each TPS carrier is defined in the following table.

| 2k mode | 8k mode |
|---|---|
| 34 50 209 346 413 569 595 | 34 50 209 346 413 569 595 688 790 901 1073 1219 |
| 688 790 901 1073 1219 1262 | 1262 1286 1469 1594 1687 1738 1754 1913 2050 2117 |
| 1286 1469 1594 1687 | 2273 2299 2392 2494 2605 2777 2923 2966 2990 3173 |
| | 3298 3391 3442 3458 3617 3754 3821 3977 4003 4096 |
| | 4198 4309 4481 4627 4670 4694 4877 5002 5095 5146 |
| | 5162 5321 5458 5525 5681 5707 5800 5902 6013 6198 |
| | 6374 6398 6581 6706 6799 |

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# DVB-T Standard - Bit Rate

- 

| Modulation | Code Rate | Time guard interval | | | |
|---|---|---|---|---|---|
| | | 1/4 | 1/8 | 1/16 | 1/32 |
| QPSK | 1/2 | 4,98 | 5,53 | 5,85 | 6,03 |
| | 2/3 | 6,64 | 7,37 | 7,81 | 8,04 |
| | 3/4 | 7,46 | 8,29 | 8,78 | 9,05 |
| | 5/6 | 8,29 | 9,22 | 9,76 | 10,05 |
| | 7/8 | 8,71 | 9,68 | 10,25 | 10,56 |
| 16-QAM | 1/2 | 9,95 | 11,06 | 11,71 | 12,06 |
| | 2/3 | 13,27 | 14,75 | 15,61 | 16,09 |
| | 3/4 | 14,93 | 16,59 | 17,56 | 18,10 |
| | 5/6 | 16,59 | 18,43 | 19,52 | 20,11 |
| | 7/8 | 17,42 | 19,35 | 20,49 | 21,11 |
| 64-QAM | 1/2 | 14,93 | 16,59 | 17,56 | 18,10 |
| | 2/3 | 19,91 | 22,12 | 23,42 | 24,13 |
| | 3/4 | 22,39 | 24,88 | 26,35 | 27,14 |
| | 5/6 | 24,88 | 27,65 | 29,27 | 30,16 |
| | 7/8 | 26,13 | 29,03 | 30,74 | 31,67 |

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# ISDB-T Standard - Introduction

• The Integrated Service Digital Broadcasting - Terrestrial has been proposed by Japan in 1999.

• It has been based on the European standard and presents some improvements to support mobile digital television.

• MPEG-2 is used as video and audio source compression.

• Spectral segmentation allows partial reception of the transmitted data.

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# ISDB-T Standard - Introduction

• Channel error control and interleaving are the same used in DVB-T.

• A differential modulation has been introduced to allow mobile reception.

•The hierarchical transmission is realized using the band segmented transmission (BST).

• Up to three segments are allowed. Channel coding is applied for each segment.

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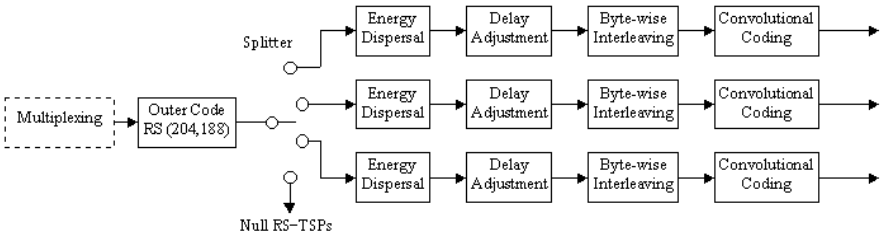
# ISDB-T Standard - Introduction

Block diagram of the ISDB-T transmitter

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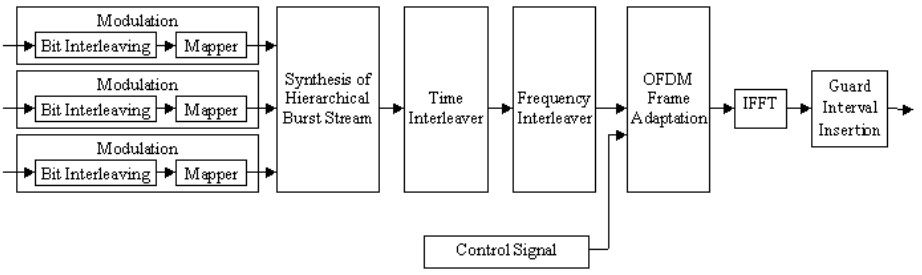
# ISDB-T Standard - Introduction

Block diagram of the ISDB-T transmitter



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# ISDB-T Standard - Specifications

| Mode | | Mode 1 | | Mode 2 | | Mode 3 | |
|---|---|---|---|---|---|---|---|
| Bandwidth | | 6000/14 = 428.57... kHz | | | | | |
| Carrier Spacing | | 6000/(14×108) = 3.968... kHz | | 6000/(14×216) = 1.9841... kHz | | 6000/(14×432) = 0.99206... kHz | |
| Number of Carriers | Total | 108 | 108 | 216 | 216 | 432 | 432 |
| | Data | 96 | 96 | 192 | 192 | 384 | 384 |
| | SP*1 | 9 | 0 | 18 | 0 | 36 | 0 |
| | CP*1 | 0 | 1 | 0 | 1 | 0 | 1 |
| | TMCC*2 | 1 | 5 | 2 | 10 | 4 | 20 |
| | AC1*3 | 2 | 2 | 4 | 4 | 8 | 8 |
| | AC2*3 | 0 | 4 | 0 | 9 | 0 | 19 |
| Carrier Modulation | | 16QAM, 64QAM, QPSK | DQPSK | 16QAM, 64QAM, QPSK | DQPSK | 16QAM, 64QAM, QPSK | DQPSK |
| Number of Symbol per Frame | | 204 | | | | | |
| Effective Symbol Duration | | 252 μs | | 504 μs | | 1008 μs | |
| Guard Interval | | 63 μs (1/4), 31.5 μs (1/8), 15.75 μs (1/16), 7.875 μs (1/32) | | 126 μs (1/4), 63 μs (1/8), 31.5 μs (1/16), 15.75 μs (1/32) | | 252 μs (1/4), 126 μs (1/8), 63 μs (1/16), 31.5 μs (1/32) | |
| Frame Duration | | 64.26 ms (1/4), 57.834 ms (1/8), 54.621 ms (1/16), 53.0145 ms (1/32) | | 128.52 ms (1/4), 115.668 ms (1/8), 109.242 ms (1/16), 106.029 ms (1/32) | | 257.04 ms (1/4), 231.336 ms (1/8), 218.464 ms (1/16), 212.058 ms (1/32) | |
| FFT sample clock | | 512/63 = 8.126984... MHz | | | | | |
| Inner Code | | Convolutional Code (1/2, 2/3, 3/4, 5/6, 7/8) | | | | | |
| Outer Code | | RS (204,188) | | | | | |

*1: SP (Scattered Pilot), and CP (Continual Pilot) can be used for frequency synchronisation and channel estimation.
*2: TMCC (Transmission and Multiplexing Configuration Control) carries information on transmission parameters.
*3: AC (Auxiliary Channel) carries ancillary information for network operation.

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# ISDB-T Standard - Data Rates

- The minimum and maximum data rates are:

1) For a 6MHz channel: 3.65Mbps up to 23.23Mbps.

2) For a 7MHz channel: 4.26Mbps up to 27.11Mbps.

3) For a 8MHz channel: 4.87Mbps up to 30.98Mbps.

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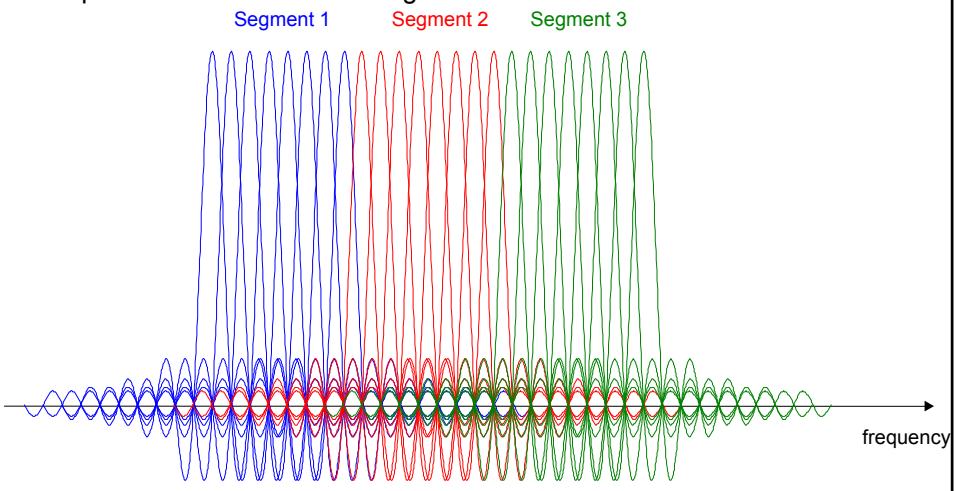
# ISDB-T Standard - BST Transmission

- Spectrum of a BST-OFDM signal.

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# Agenda

- Part I
  - Overview of digital television systems;
- Part II
  - RF / Transmission subsystems for terrestrial broadcast systems (ATSC, DVB-T, ISDB-T);
- **Part III**
  - **Interactivity in cable, satellite and terrestrial networks;**
  - **Return channel for terrestrial networks: DVB-RCT standard;**

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# What is interactive TV?

- Interactive TV is a broad term that includes any services which enhance the TV viewing experience and add new functionality to the TV;
- It enables viewers to play along with TV game shows, vote, answer quiz questions, win prizes, or request information through an interactive advertisement;
- It can also mean t-commerce applications that enable viewers to purchase merchandise using their TV remote control, rather than ordering from the Internet or by telephone;
- Electronic Program Guides, Home banking or ordering pizza;

**Passive experience x Active entertainment**

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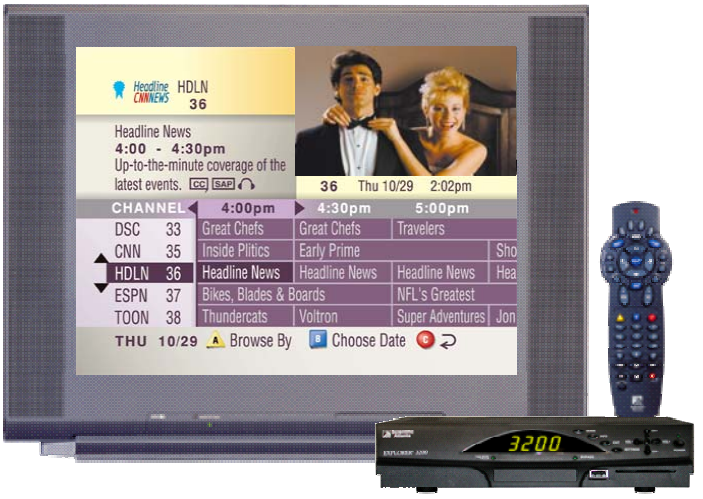
# Electronic Program Guide



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# Walled Garden


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# E-mail

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## Infrastructure needed for interactivity

- **Create content**: interactive content is a combination of text, graphics and video, which require a set of tools to be pulled together into a coherent unit;
- **Transmit content**: like traditional TV programming, the interactive content must be transmitted to the viewer. It has to be scheduled, optionally linked or even real-time synchronized with particular TV programming, and sent to the viewers in the transmission stream;
- **Deliver and deploy content:** the set-top box must know how to handle synchronization, display the various types of text, video and graphics, and support viewer interactions locally or via a return path.

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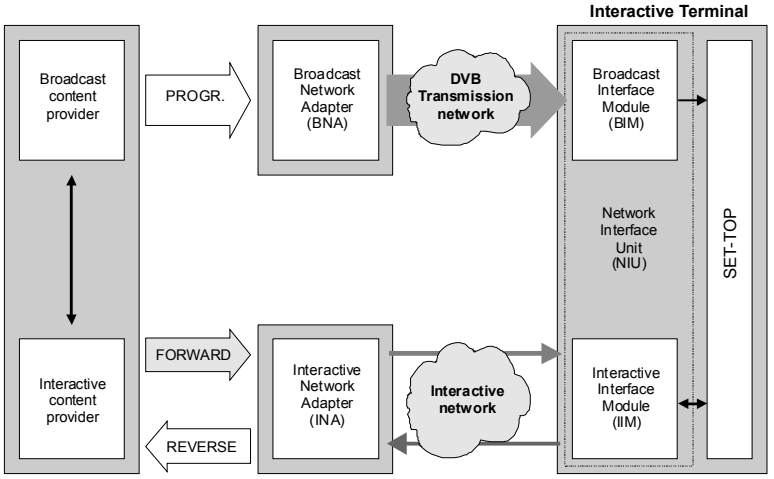
## Interactivity in DTV systems

- Unidirectional architecture described in Part I is enough to provide broadcast services with standalone applications;
- To support Internet-based applications or pay-per-view, a two-way link between the content provider and the set-top box is necessary;
- The type of platform – cable, satellite or terrestrial – dictates the applications possible to be offered, given the return path available.

# Interactive DTV architecture I

Generic reference model




# Interactivity in DTH

- DTH pioneered digital TV in Brazil;
- Best position to introduce new services to existing base;
- Currently, almost only standalone applications, due to limitations in the return path via PSTN;
- Broadband internet connection
  - Higher prices than xDSL or cable modem
  - No restriction on geographic location
- EN 300 800 – DVB-RCS; Interaction channel for satellite distribution system.

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## Interactivity in cable TV networks

- Brazilian cable operators still broadcasting analog;
- Pay-per-view still being handled through telephone calls;
- Most operators already have their HFC network two-way capable;
- Cable modem is a reality and ADSL is its main competitor;
- Recent announcement from NET and TVA favorable to DVB-C at the physical layer;

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## Interactivity in cable TV networks

- DOCSIS (Data Over Cable Service Interface Specifications): uses 64-QAM or 256-QAM in the forward path, with rates up to 42.884 Mbit/s, QPSK or 16-QAM in the reverse path, with rates from 0.32 to 10.24 Mbit/s.
- ANSI/SCTE 55-1 (former DVS-178): developed by GI, uses MPEG-2 TS at 2.048 Mbit/s, ATM at 256 kbit/s in the return path, QPSK modulation;
- ANSI/SCTE 55-2 (former DVS-167): developed by SA, uses ATM cells and maximum rate is 3.088 Mbit/s, QPSK modulation.

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# Interactivity in terrestrial DTV systems

- Current discussions in Brazil more focused in the physical layer of the broadcast channel;
- Interactive applications still a question mark;
- One alternative for the return path is specified by the DVB-RCT standard (EN 301 958 v1.1.1);
  - Defines the physical and MAC layers for a wireless return path using the VHF/UHF bands;
  - Designed to work with DVB-T

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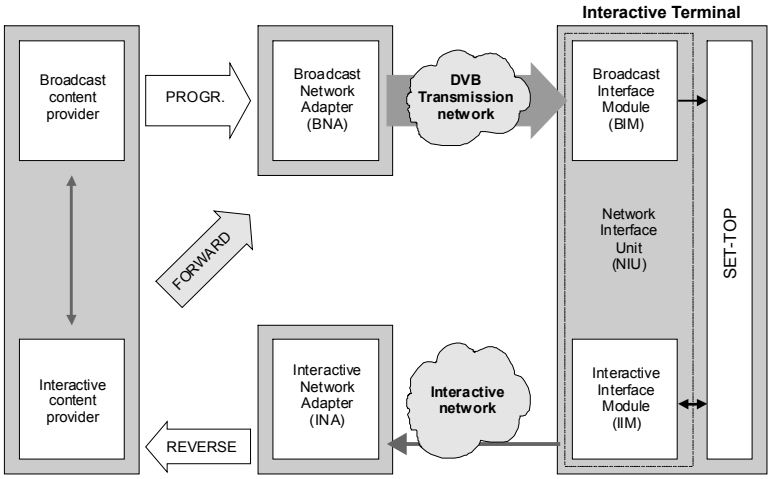
# Interactive DTV architecture II

Reference model for the DVB-RCT



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# Physical layer of DVB-RCT

- DVB-T x DVB-RCT
  - DVB-T: same data sequence sent to all users;
  - DVB-RCT: multiple users share the same resource;
- OFDMA multiple access
  - On-demand allocation of carriers to users;
- Use of subchannels, with carriers spread along the frequency spectrum;
  - Mitigate effects due to selective fading;
  - Ability to concentrate power in certain subchannels to improve coverage;
- Pulse shaping at the transmission
  - Rectangular shaping;
  - Nyquist shaping

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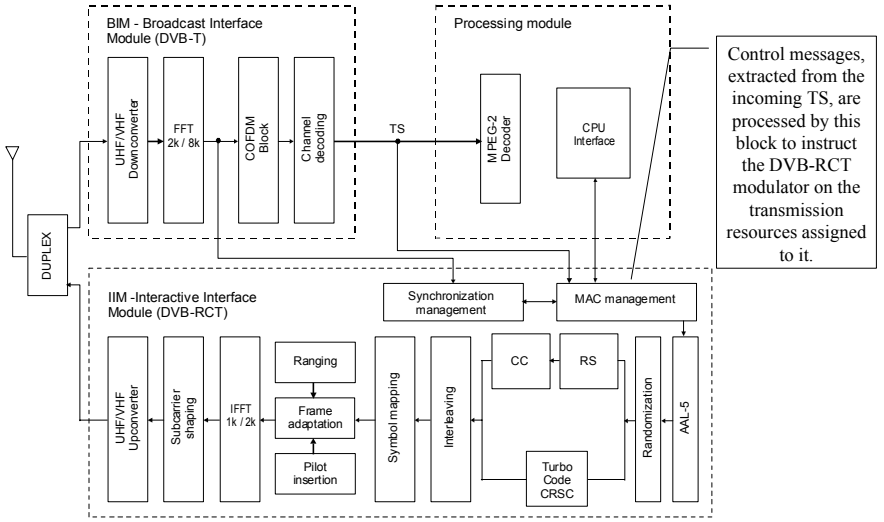
# What is OFDMA?

- **O**rthogonal **F**requency **D**ivision **M**ultiple **A**ccess;
- OFDMA combines modulation and a multiple access scheme;
- OFDMA is based on OFDM, multiple narrowband sub-modulated carriers transmitted in parallel;
- OFDMA combines time division and frequency division multiple access techniques;

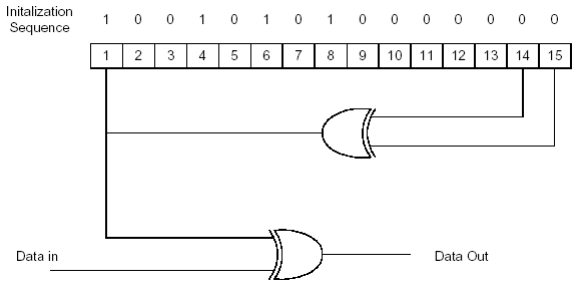
# Physical layer of DVB-RCT




# DVB-RCT: Randomization

The shift-register of the randomizer shall be initialized for each new data payload with the binary value: 100101010000000 (45 200 in octal). Each data byte to be transmitted shall enter sequentially into the randomizer, MSB first.

The Pseudo Random Binary Sequence (PRBS) generator shall be $1 + X^{14} + X^{15}$.




The objective of randomization is to perform energy dispersion in the available bandwidth

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# DVB-RCT: channel encoding

- Two channel encoding methods are defined:
  - Concatenated Reed-Solomon encoding and convolutional encoding
  - Turbo encoding
- Whatever the method used, the data bursts, produced after the encoding and physical modulation processes, have a fixed length of 144 modulated symbols

| Modulation | Rate | Input block |
|---|---|---|
| QPSK | ½ | 18 bytes |
| | ¾ | 27 bytes |
| 16-QAM | ½ | 36 bytes |
| | ¾ | 54 bytes |
| 64-QAM | ½ | 54 bytes |
| | ¾ | 81 bytes |

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# DVB-RCT channel encoding (Reed Solomon + Convolutional)

- Each RS symbol contains $m$ = 6 bits and the code is capable of correcting up to $t$ = 4 errors.
- The resulting RS code follows the conventional form:

$$(N, K) = (2^m - 1, 2^m - 1 - 2t) = (63, 55)$$

| Global Code rate | Reed-Solomon Code rate | Convolutional Code rate |
|---|---|---|
| 1/2 | 3/4 | 2/3 |
| 3/4 | 9/10 | 5/6 |

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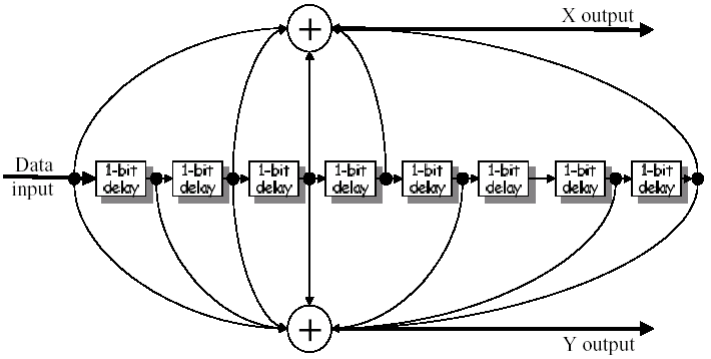
# DVB-RCT channel encoding (Reed Solomon + Convolutional)

- Non Systematic Convolutional encoder parameters are: $r$ = ½, $K$ = 9, $G_1 = 576_{oct}$ and $G_2 = 753_{oct}$

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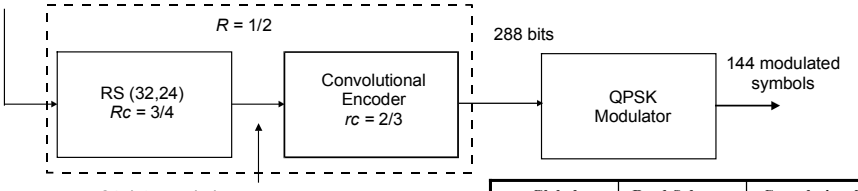
# 18-byte input RS + CC

144 bits = 24 RS data symbols
+ 31 RS null symbols
= 55 RS input symbols



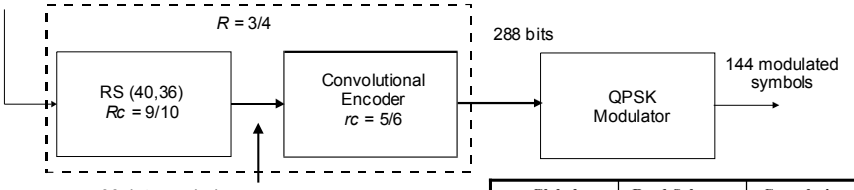

24 data symbols
+ 8 parity symbols
= 32 output symbols
= 192 bits

| Global Code rate | Reed-Solomon Code rate | Convolutional Code rate |
|---|---|---|
| 1 / 2 | 3 / 4 | 2 / 3 |
| 3 / 4 | 9 / 10 | 5 / 6 |

| RS Code Rate | Encoding scheme | Transmitted scheme |
|---|---|---|
| 3/4 | 31 zero symbols,<br>24 Data symbols,<br>No erasures - Using 8 parity symbols. | 32 symbols |
| 9/10 | 19 zero symbols,<br>36 Data symbols,<br>4 erasures - Using first 4 parity symbols of the 8 parity symbols. | 40 symbols |

# 27-byte input RS + CC

216 bits = 36 RS data symbols
+ 19 RS null symbols
= 55 RS input symbols



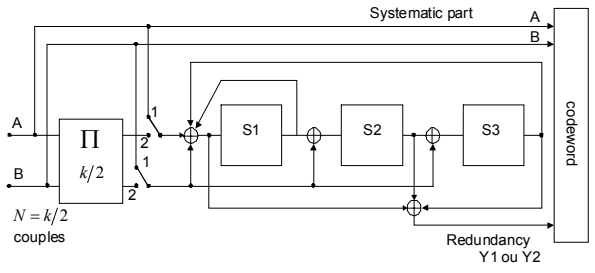

36 data symbols
+ 4 parity symbols
= 40 output symbols
= 240 bits

| Global Code rate | Reed-Solomon Code rate | Convolutional Code rate |
|---|---|---|
| 1 / 2 | 3 / 4 | 2 / 3 |
| 3 / 4 | 9 / 10 | 5 / 6 |

| RS Code Rate | Encoding scheme | Transmitted scheme |
|---|---|---|
| 3/4 | 31 zero symbols,<br>24 Data symbols,<br>No erasures - Using 8 parity symbols. | 32 symbols |
| 9/10 | 19 zero symbols,<br>36 Data symbols,<br>4 erasures - Using first 4 parity symbols of the 8 parity symbols. | 40 symbols |

# DVB-RCT channel encoding (Turbo CRSC)

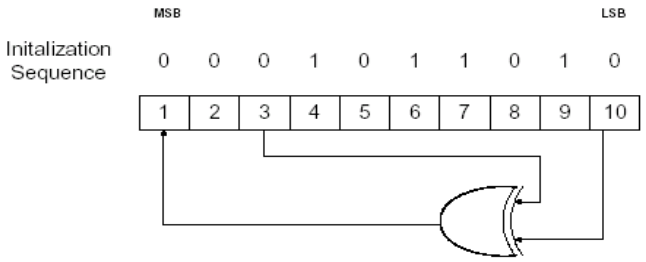
- **C**ircular **R**ecursive **S**ystematic **C**onvolutional encoding;
- Parallel concatenation of two RSC component encoders, each one with two inputs;
- "Circular" because it uses a technique such that, at the end of the encoding operation, the encoder comes back to an "initial" state and there's no need for zero-padding to terminate the block;



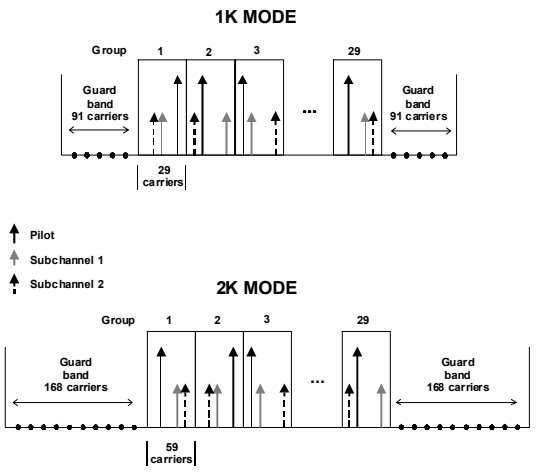

A puncturing device is used to adapt coding rate to ½ or ¾

# Interleaving

- PRBS generator produces an index value, which corresponds to the output position of the input bit into the interleaved data burst (i.e., the new position is the value of the PRBS memory register).




# DVB-RCT in the frequency domain




| Nº carriers | 2.048 | 1.024 |
|---|---|---|
| Nº useful carriers | 1,712 | 842 |
| CS1 | 837 Hz | 837 Hz |
| Useful symbol duration | 1.195 µs | 1.195 µs |
| BW | 1,433 MHz | 0,705 MHz |
| CS2 | 1.674 Hz | 1.674 Hz |
| Useful symbol duration | 597 µs | 597 µs |
| BW | 2,866 MHz | 1,410 MHz |
| CS3 | 3.348 Hz | 3.348 Hz |
| Useful symbol duration | 299 µs | 299 µs |
| BW | 5,732 MHz | 2,819 MHz |

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# DVB-RCT system clock

- The time reference is derived from the DVB-T downstream. In EN 300 744 the DVB-T reference clock is defined as 149 ns for 6 MHz systems.
- Accordingly, the DVB-RCT system clock is defined as:
  - four times the DVB-T system clock period in the case of CS1;
  - two times the DVB-T system clock period in the case of CS1;
  - one time the DVB-T system clock period in the case of CS1.

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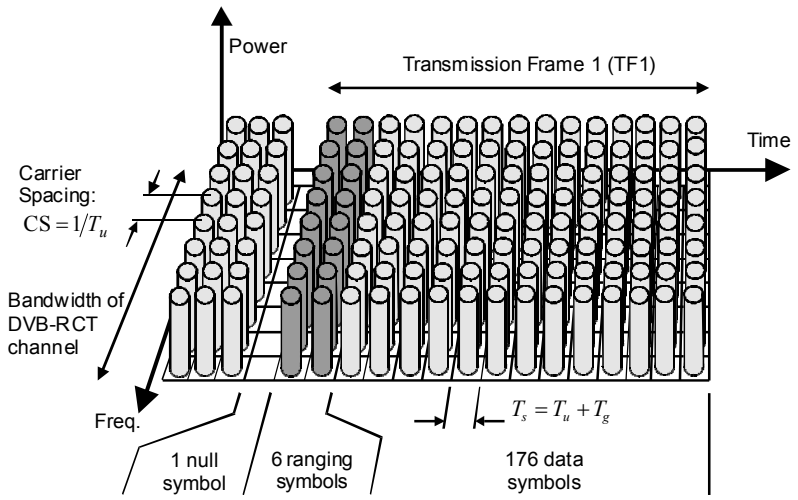
# DVB-RCT in the time domain



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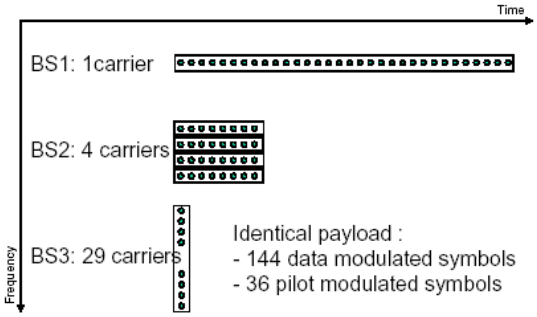
# DVB-RCT: three Burst Structures




The mapping of the Burst Structures onto the Transmission Frames is done by the MAC layer

Shorter burst duration is more robust against interference, but it requires more than one carrier to be allocated in parallel to a single user for a single bandwidth request.

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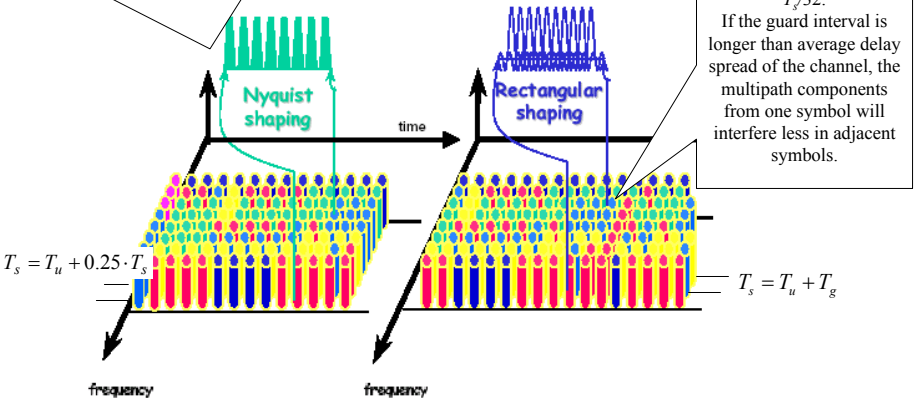
# Pulse shaping

Pulse shape in the time domain yields a time-limited square root raised cosine pulse with a roll-off factor equal to 0.25. Provides more immunity against ICI because the resulting spectrum decays more rapidly than when rectangular shaping is being used

A guard interval $T_g$ is included between symbols. $T_g$ can be equal to $T_s/4$, $T_s/8$, $T_s/16$ or $T_s/32$.
If the guard interval is longer than average delay spread of the channel, the multipath components from one symbol will interfere less in adjacent symbols.



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# DVB-RCT: Transmission parameters

- Number of subcarriers: 1K or 2K
- Carrier spacing: 837 Hz, 1674 Hz, 3348 Hz
- Carrier shaping: Nyquist or rectangular
- Channel coding: Turbo codes or Concatenated Reed-Solomon & CC
- Coding rates: ½ or ¾
- Physical modulation: QPSK, 16-QAM, 64-QAM
- Burst size: 144 symbols + 32 pilots
- Burst structures: BS1, BS2, BS3
- Payload per burst: 18, 27, 36, 54, 81 bytes

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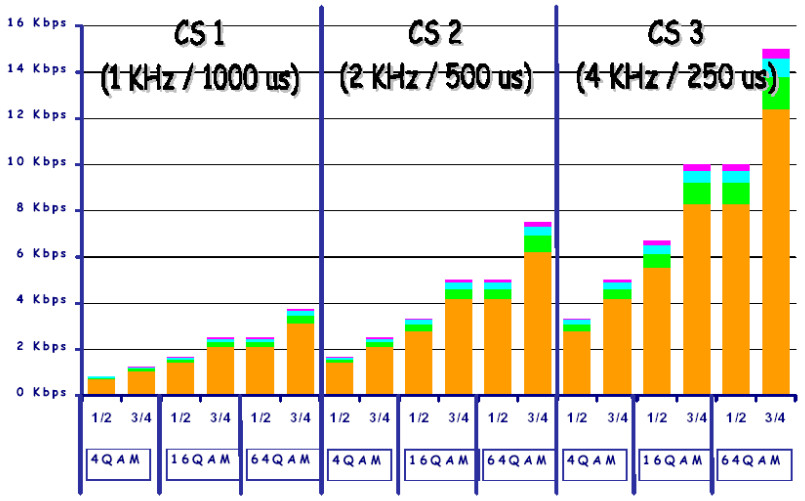
# DVB-RCT: Bit rate per carrier



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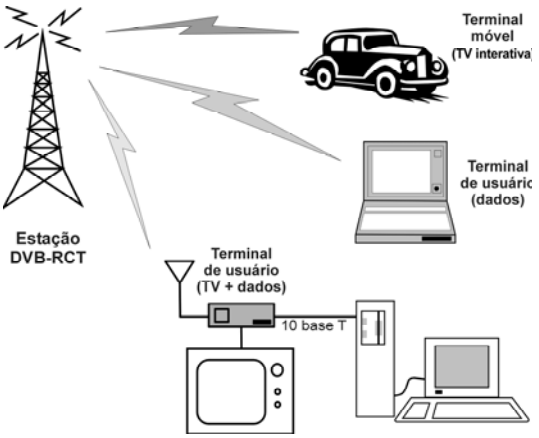
# Case study




*Calculate:*

- Maximum number of users in one cell;
- Number of 6 MHz channels required in *downstream*;

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# Case study (premises)

- One 6 MHz channel dedicated to upstream;
- Required code rate per user: 128 kbit/s;
- Concentration factor γ = 0,30;
- Asymetry factor ρ = 0,25;

- Guard interval: $T_g = 1/32 \times T_s$;
- Propagation model: NLOS;
- Transmission power of the DVB-RCT module: $P_{usuário}$ = 1 W;
- Transmission power of the DVB-T signal at the base station: $P_{rbs}$ = 100 W;
- Antenna gain at the user side: $G_{usuário}$ = 18 dBi;
- Antenna gain at the base station side: $G_{rbs}$ = 18 dBi;
- Antenna height at the base station: 50 m;
- Noise figure at the base station receiver: 5 dB;
- Noise figure at the user's terminal: 6 dB;
- Fading margin at the base station: 5 dB;
- Fading margin at the set-top return module: 5 dB;

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# Case study

- Without considering the header of above layers, the total capacity of the system in terms of the maximum number of users can be expressed by this simple equation:

$$N_{\max} = \frac{R_{available}}{\rho \cdot \gamma \cdot R_{user}}$$

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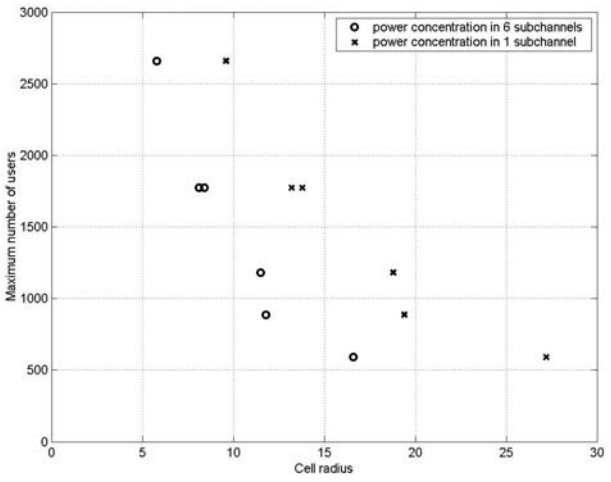
# Case study




A minimum of three 6-MHz channels would be necessary for the downlink

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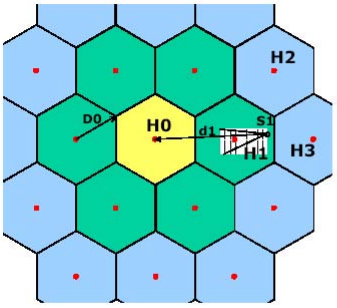
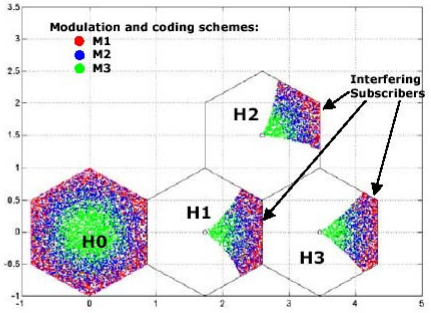
# Interfering scenario




Cellular layout. First two layers interfering with H0.




H0: Allocation of modulation and coding schemes to subscribers.
H1,H2, H3: Only for the subscribers interfering with H0

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# Interfering scenario

| | M1 | M2 | M3 |
|---|---|---|---|
| Modulation | QPSK | 16-QAM | 64-QAM |
| Coding | Turbo $R_C$ = 1/2 | Turbo $R_C$ = 1/2 | Turbo $R_C$ = 1/2 |
| $m$ | 2 | 4 | 6 |
| $G_P$ [dB] | 14.7 | 11.7 | 9.9 |
| $E_B/N_0$ [dB] | 5 | 9 | 13 |
| $C/I$ [dB] | -9.7 | -2.7 | 3.1 |
| Throughput per subchannel [Kb/s] | 96.1 | 192.3 | 288.4 |
| Total Channel Payload Throughput [Mb/s] | 5.67 | 11.35 | 17.0 |

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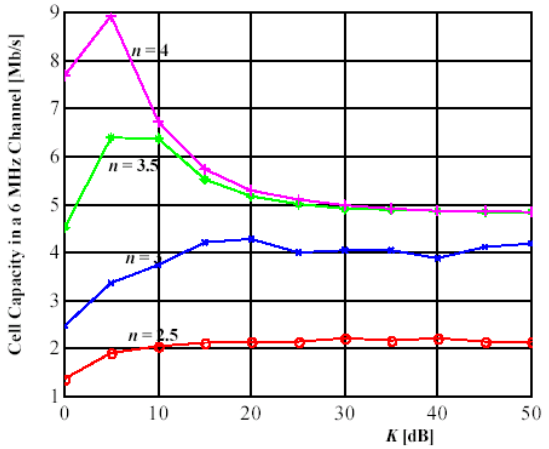
# Interfering scenario

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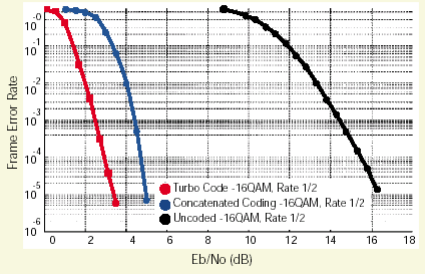
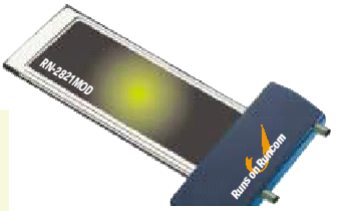
# Chipset

**Forward Error Correction:**




**RN-2821MOD**




**RN-2821MOD Specifications**

| Item | Description |
|---|---|
| Chip Set | RN-2821, 32 bit MIPS core CPU, SDRAM and FLASH |
| Configuration | Single board |
| RF Front End | RN-2821UHF |
| Network Interface | Ethernet 10/100 BaseT, RJ45 USB or RS-232 |
| Application Processor I/F | DVB-CI |
| DC Input | 3A @ 15VDC |
| Operating Temperature | $0^0$ C - $50^0$ C |

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## Summary

- Overview of DTV architectures;
- Details about the physical layer for the standards available today that govern the broadcast channel in terrestrial networks;
- Overview about interactive DTV;
- Description of the physical layer of a wireless return channel for terrestrial DTV: the DVB-RCT standard.

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## Final remarks

- Interactive DTV applications are a reality for subscribers of CATV outside Brazil;
- For terrestrial DTV, several alternatives exist for the return path: PSTN, cellular, ADSL or the DVB-RCT;
- In Brazil, viewers currently make use of phone calls to participate in interactive programming and to purchase products announced by merchandising;
- Operation of DVB-RCT together with ATSC;
- Some results from field trials of the DVB-RCT are available in the literature.