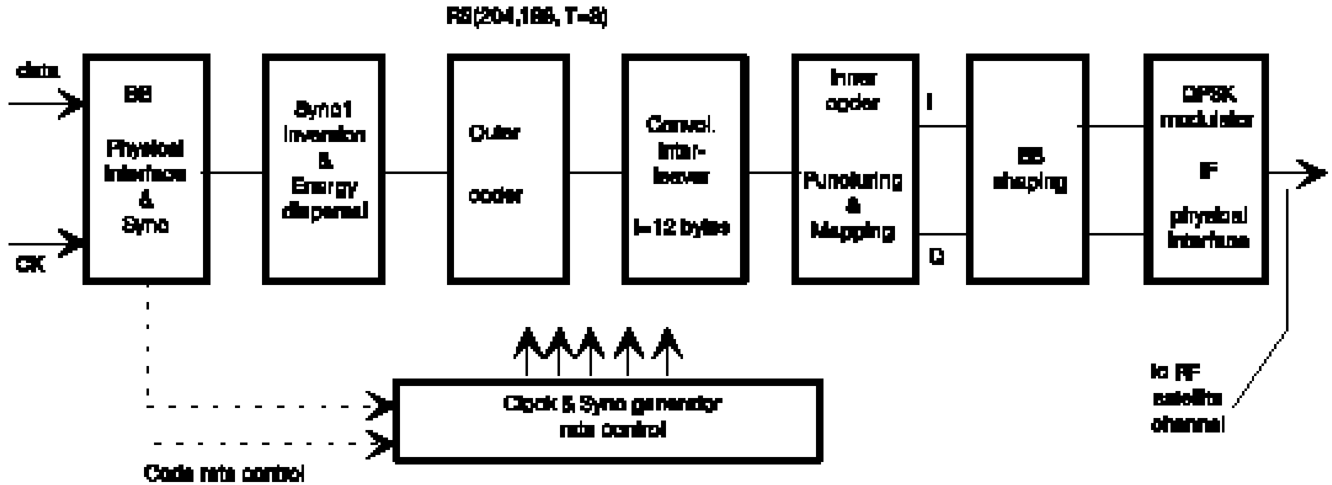
Lecture 7

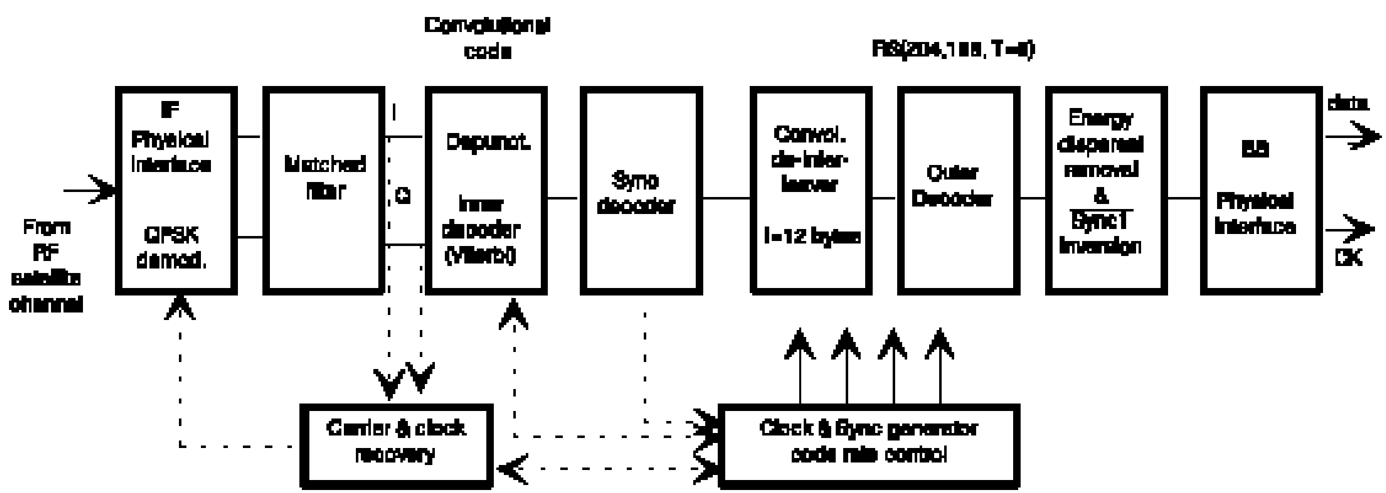
Digital television

Coded Orthogonal Frequency Division Multiplexing

- Need for a good transmission technique
- Explanation of the different parts
  - Coded
  - Frequency Division Multiplexing
  - Orthogonal

DVB-S


RS(204,188, T=8)
data
CK
BB
Physical
Interface
&
Sync
Sync1
Inversion
&
Energy
dispersal
Outer
coder
Convol.
Inter-
leaver
I=12 bytes
Inner
coder
Puncturing
&
Mapping
I
Q
BB
shaping
QPSK
modulator
IF
physical
interface
Clock & Sync generator
rate control
Code rate control
to RF
satellite
channel


Convolutional
code
RS(204,188, T=8)
From
RF
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IF
Physical
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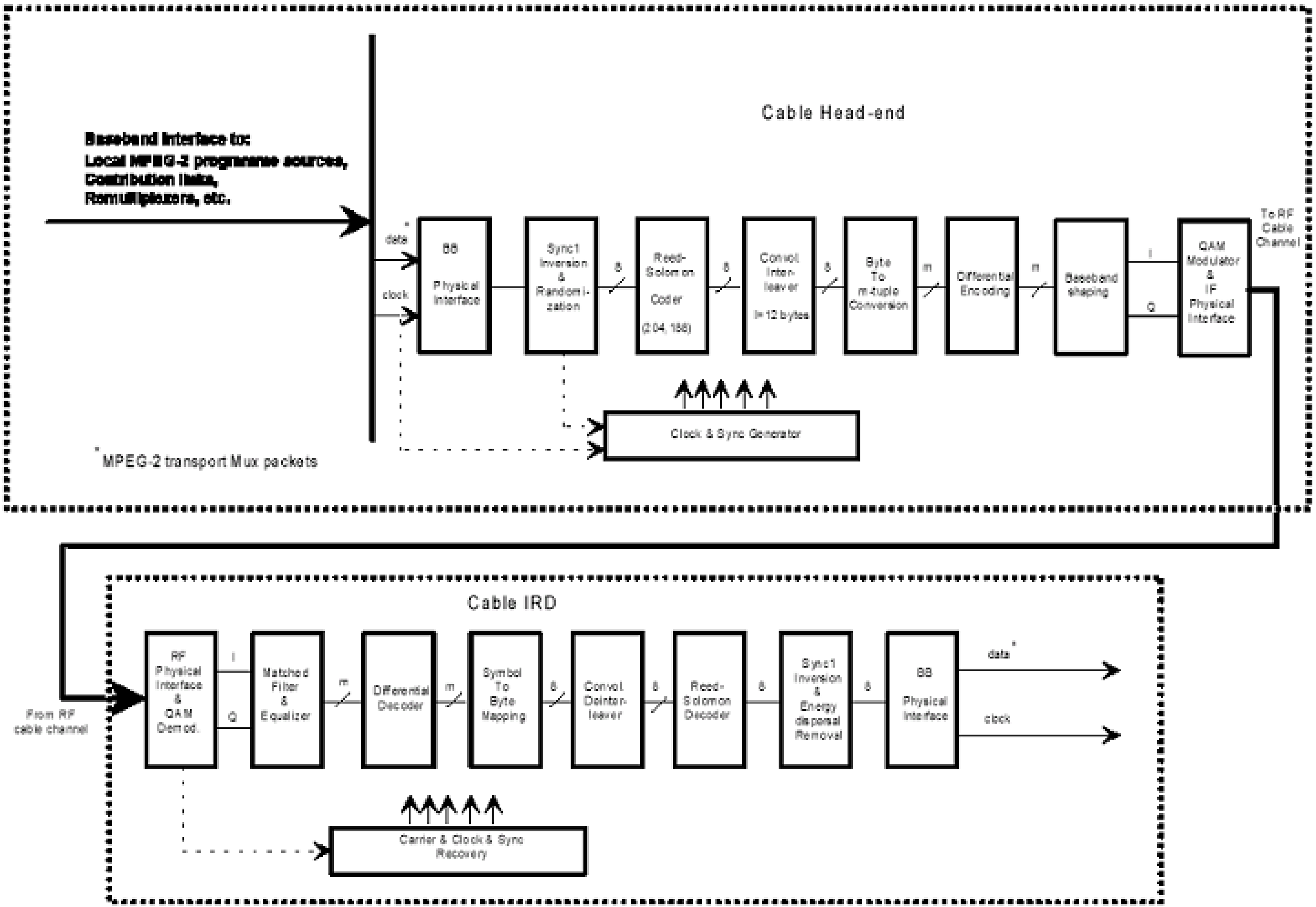
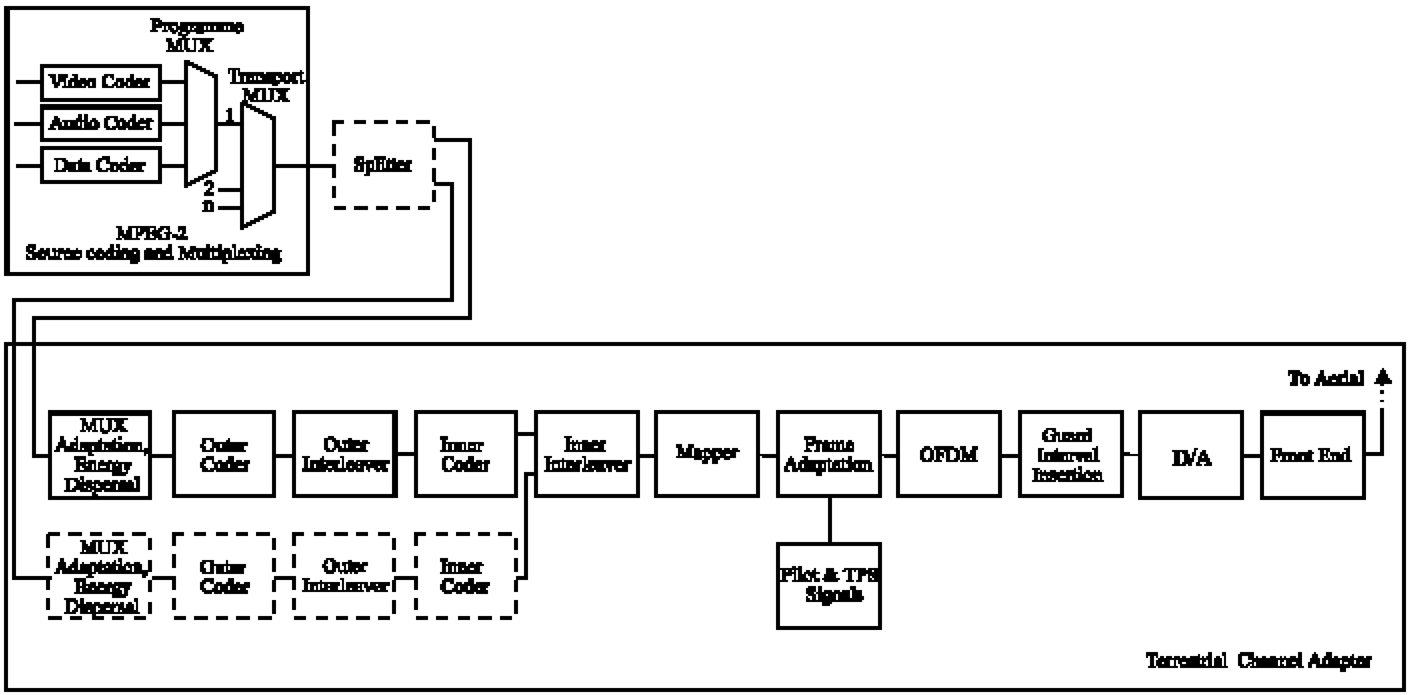
Inner
decoder
(Viterbi)
Sync
decoder
Convol.
de-inter-
leaver
I=12 bytes
Outer
Decoder
Energy
dispersal
removal
&
Sync1
inversion
BB
Physical
Interface
data
CK
Carrier & clock
recovery
Clock & Sync generator
code rate control

DVB-C



Cable Head-end
Baseband Interface to:
Local MPEG-2 programme sources,
Contribution links,
Remultiplexers, etc.
data*
clock
BB Physical Interface
Sync1 Inversion & Randomization
Reed-Solomon Coder (204, 188)
Convol. Inter-leaver I=12 bytes
Byte To m-tuple Conversion
Differential Encoding
Baseband shaping
QAM Modulator & IF Physical Interface
To RF Cable Channel
Clock & Sync Generator
*MPEG-2 transport Mux packets
Cable IRD
From RF cable channel
RF Physical Interface & QAM Demod.
Matched Filter & Equalizer
Differential Decoder
Symbol To Byte Mapping
Convol. Deinter-leaver
Reed-Solomon Decoder
Sync1 Inversion & Energy dispersal Removal
BB Physical Interface
data*
clock
Carrier & Clock & Sync Recovery

DVB-T



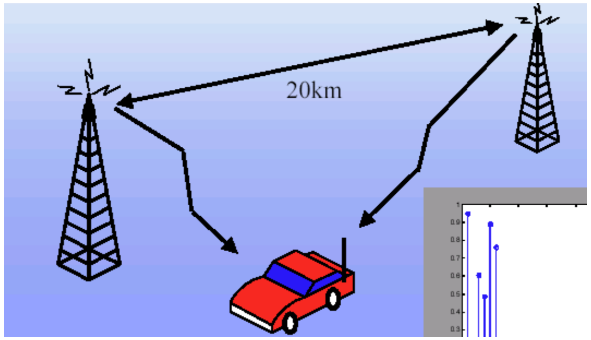
Programme MUX
Video Coder
Audio Coder
Data Coder
Transport MUX
1
2
n
MPEG-2
Source coding and Multiplexing
Splitter
To Aerial
MUX Adaptation, Energy Dispersal
Outer Coder
Outer Interleaver
Inner Coder
Inner Interleaver
Mapper
Frame Adaptation
OFDM
Guard Interval Insertion
D/A
Front End
MUX Adaptation, Energy Dispersal
Outer Coder
Outer Interleaver
Inner Coder
Pilot & TPS Signals
Terrestrial Channel Adapter

DVB-S/C/T Comparison

	S	C	T
Energy dispersal	X	X	X
Outer coding (Reed-Solomon (204,188))	X	X	X
Outer interleaving	X	X	X
Byte to m-tuple conversion		X	
Differential encoding		X	
Baseband shaping / QAM modulation		X	
Inner coding	X		X
Inner interleaving	X		X
Mapping and modulation (QAM / QPSK)	X		X
OFDM			X

Design goals for digital terrestrial video broadcasting

- Single Frequency Network (SFN)
- Mobile reception
- Problems
  - Multipath interference - ghosts
  - Noise interference – snow
  - Variable path attentuation – fading
  - Interference to existing services
  - Interference from other services



Standard	Meaning	Carrier Freq.	Rate (Mbps)	Applications
DAB	Digital Audio Broadcasting	FM	0.008-0.384	Audio broadcasting
DVB-T	Digital Video Broadcasting	UHF	3.7 - 32	Digital TV broadcasting
IEEE 802.11a	Wireless LAN	5.2GHz	6 - 54	Wireless networks
IEEE 802.16.3	Fixed Wireless Access	2.1GHz	0.5 - 12	Internet/voice access

Mobile reception

ProTeleVision (Denmark) builds SFN network in Singapore

Interior view of a bus

Mobile Television onboard
a tram in Cologne, Germany

Mobile television in Turku bus

Mobile reception

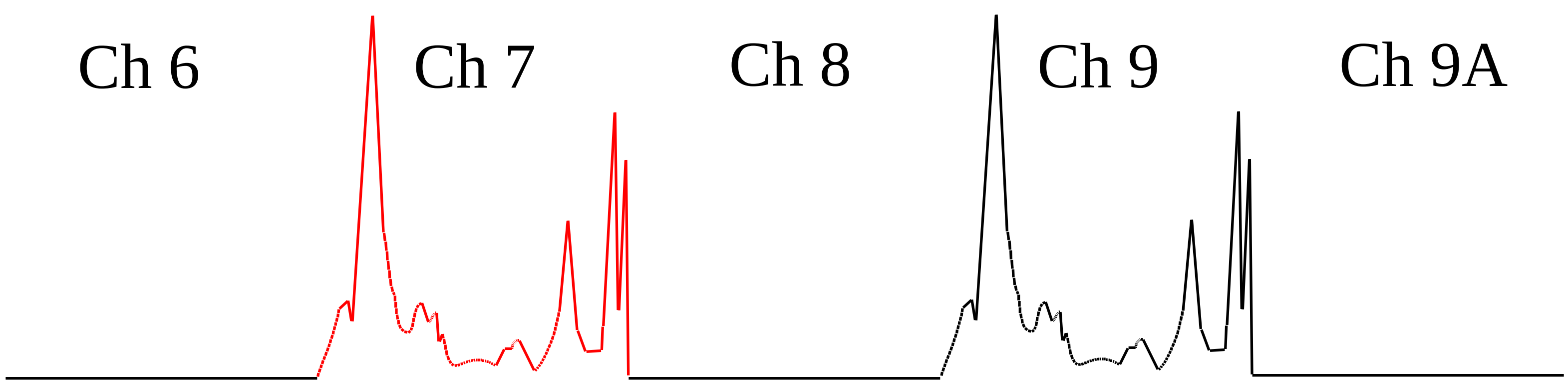
- Developed by the digital video broadcasting project group - DVB
- Uses similar technology to DRB (DAB)
- Uses 1705 or 6817 carriers
- Variable carrier modulation types are defined allowing data rates of 5-27 Mb/s in 7 MHz
- Developed for 8 MHz channels
  - A 7 MHz variant has been produced and tested
- Can use single frequency networks - SFNs
- New technology with scope for continued improvement & development

BST OFDM Japan

- BST-OFDM is a variant of the European COFDM system which allows segmenting of the data spectrum into 100 kHz blocks.
- 2 receiver bandwidths proposed.
  - 500 kHz portable / mobile for sound and data
  - 5.6 MHz fixed / mobile for SDTV and LDTV
  - 5.6 MHz fixed for HDTV
- Individual band segments can be allocated to separate services which can use different modulation systems

Channel spacing

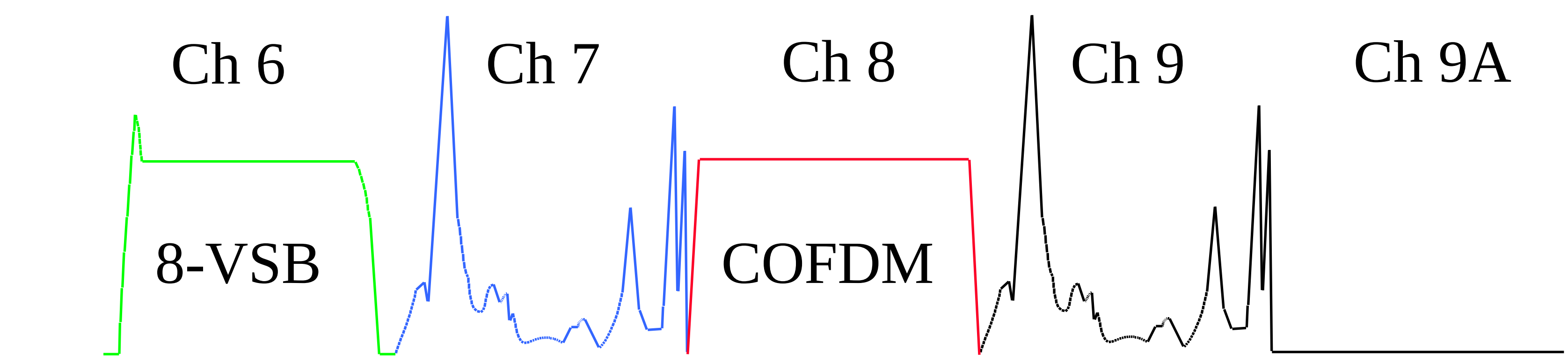
- Existing analog TV channels are spaced so they do not interfere with each other.
- Gap between PAL TV services
  - VHF 1 channel
  - UHF 2 channels
- Digital TV can make use of these gaps



VHF Television Spectrum

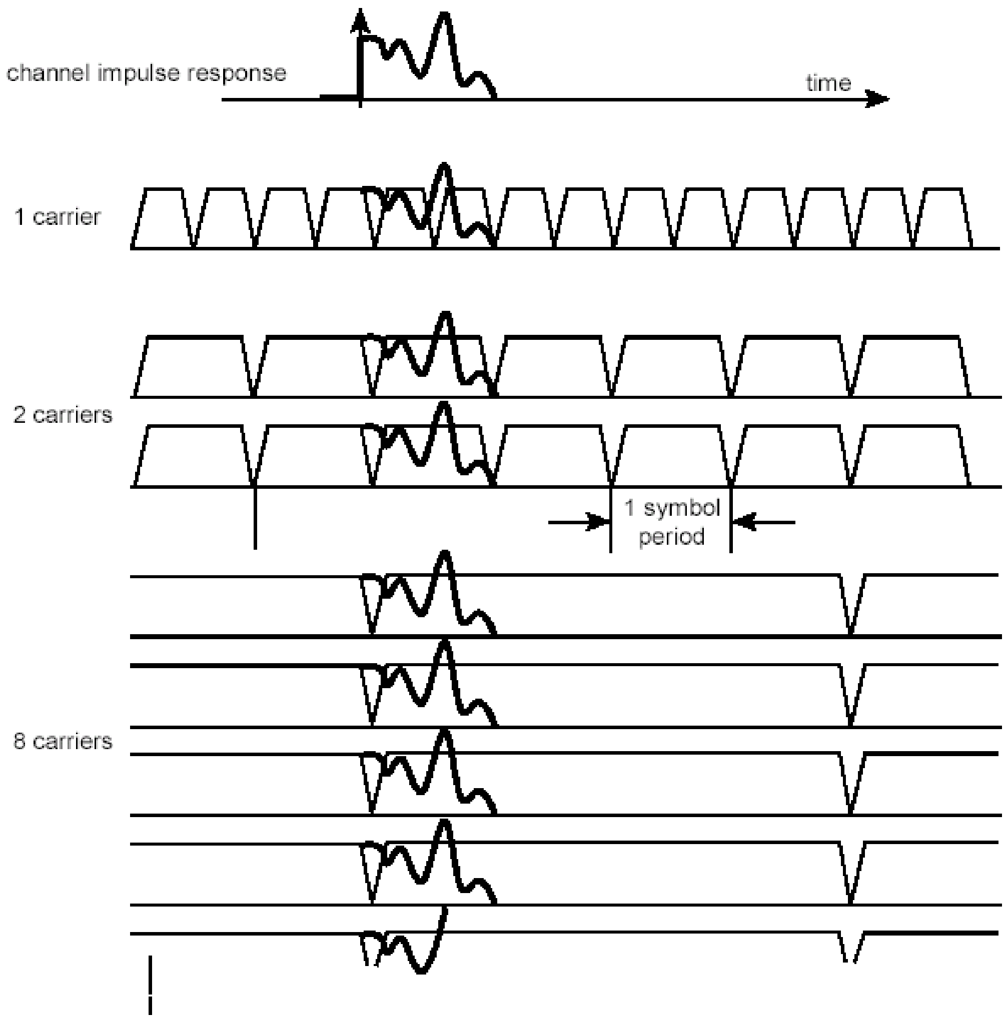
Digital challenges

- Digital TV must co-exist with existing PAL services
  - DTV operates at lower power
  - DTV copes higher interference levels
  - Share transmission infra-structure
  - DTV needs different planning methods



VHF Television Spectrum

The effect of a multicarrier system



Mathematical description of COFDM

Each carrier is modulated $s_c(t) = A_c(t)e^{j[\omega_c t + \phi_c(t)]}$

Several carriers are summed $s_s(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_n(t)e^{j[\omega_n t + \phi_n(t)]}$

$$\omega_n = \omega_0 + n\Delta\omega$$

Takes fixed values

$$\phi_c(t) \Rightarrow \phi_n$$

$$A_c(t) \Rightarrow A_n$$

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j[(\omega_0 + n\Delta\omega)kT + \phi_n]}$$

…Mathematical description of COFDM

Zeroth frequency -> 0 gives

$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} \boxed{A_n e^{j\phi_n}} e^{j(n\Delta\omega)kT}$$

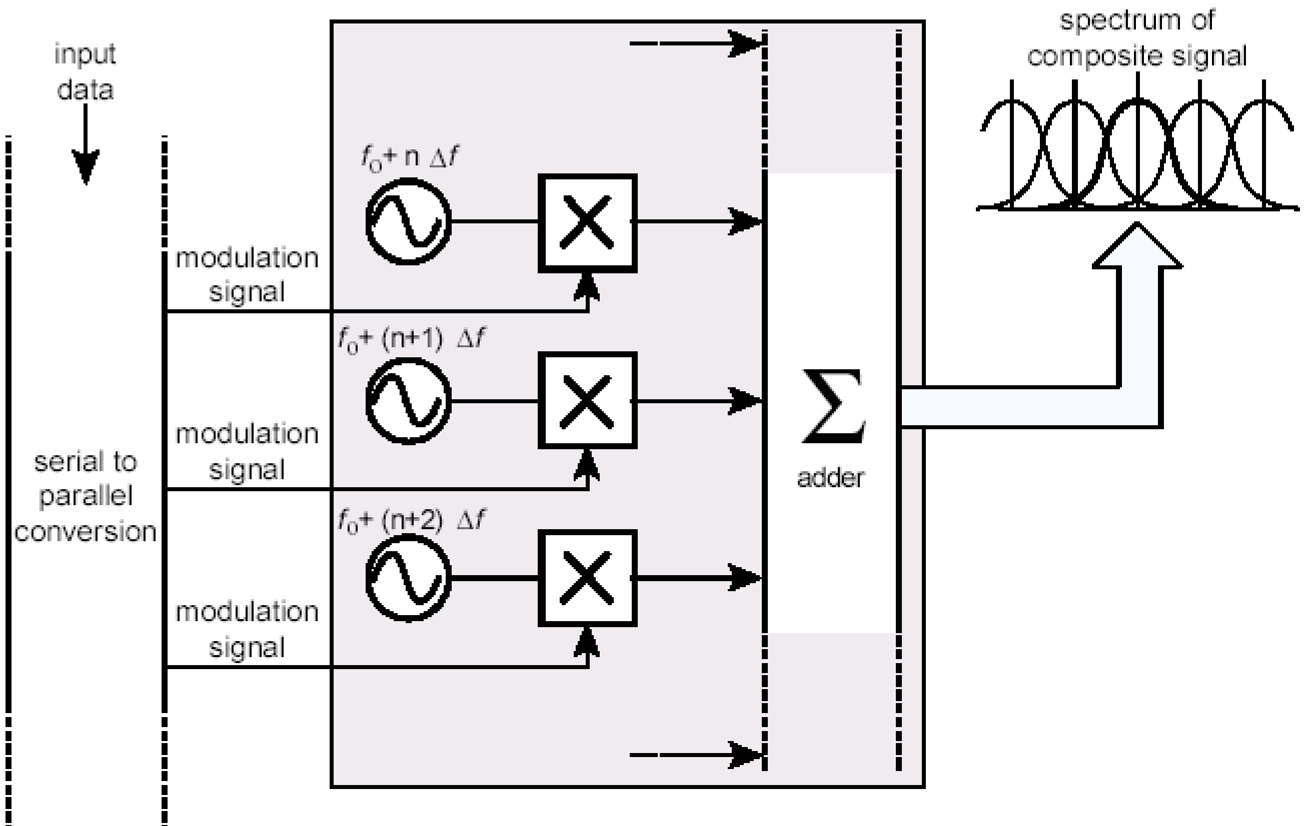
Compare with IFT

$$g(kT) = \frac{1}{N}\sum_{n=0}^{N-1} G\left(\frac{n}{NT}\right) e^{j2\pi nk/N}$$

Equivalent if

$$\Delta f = \frac{1}{NT} = \frac{1}{\tau}$$

Visualization of COFDM



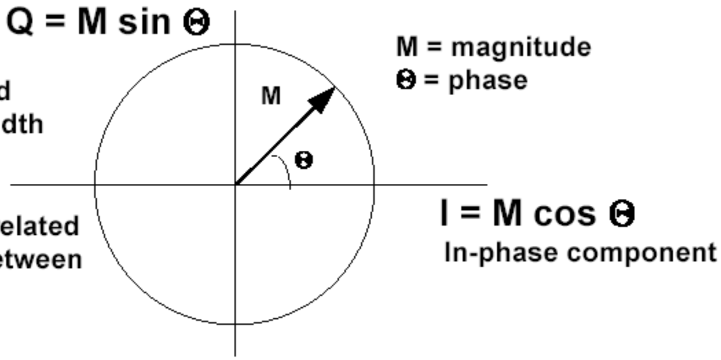
Modulation of subcarriers

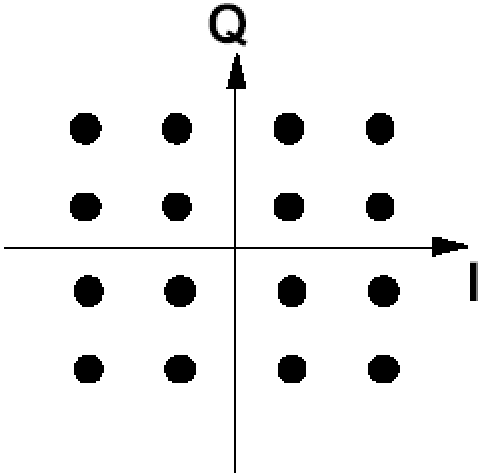
$$s_s(kT) = \frac{1}{N}\sum_{n=0}^{N-1} A_n e^{j\phi_n} e^{j(n\Delta\omega)kT}$$

Quadrature component (carrier shifted 90°)

Densely packed implies bandwidth efficient

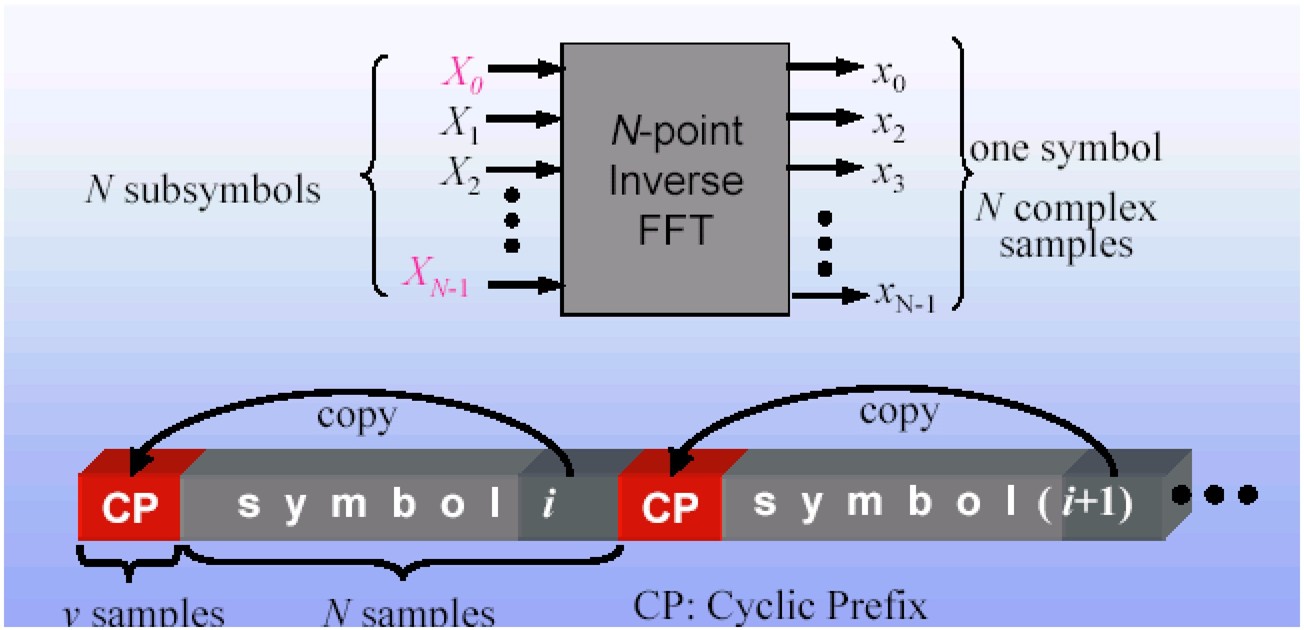
Bit error prob related to distances between closest points





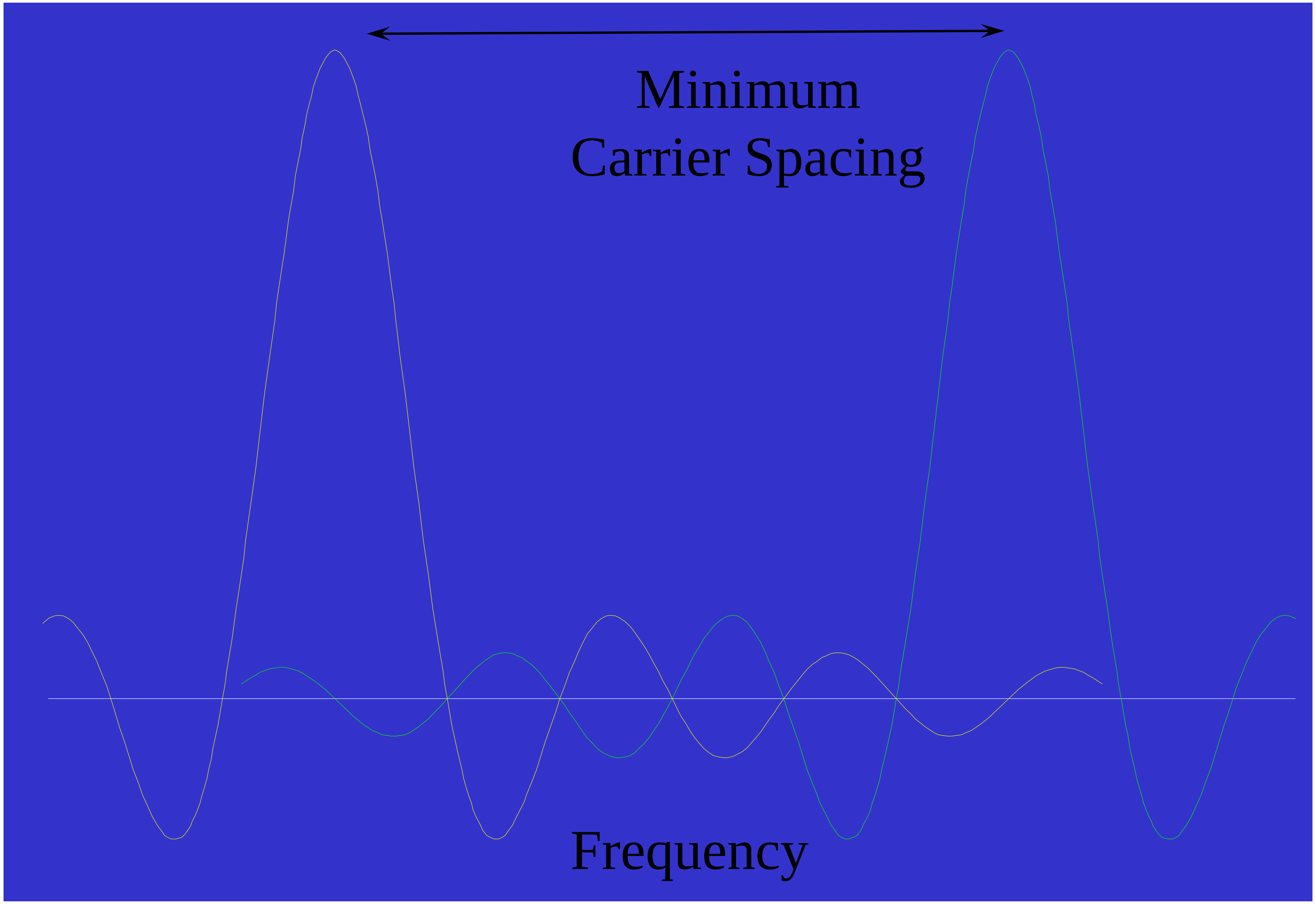
16 Level QAM

COFDM principle

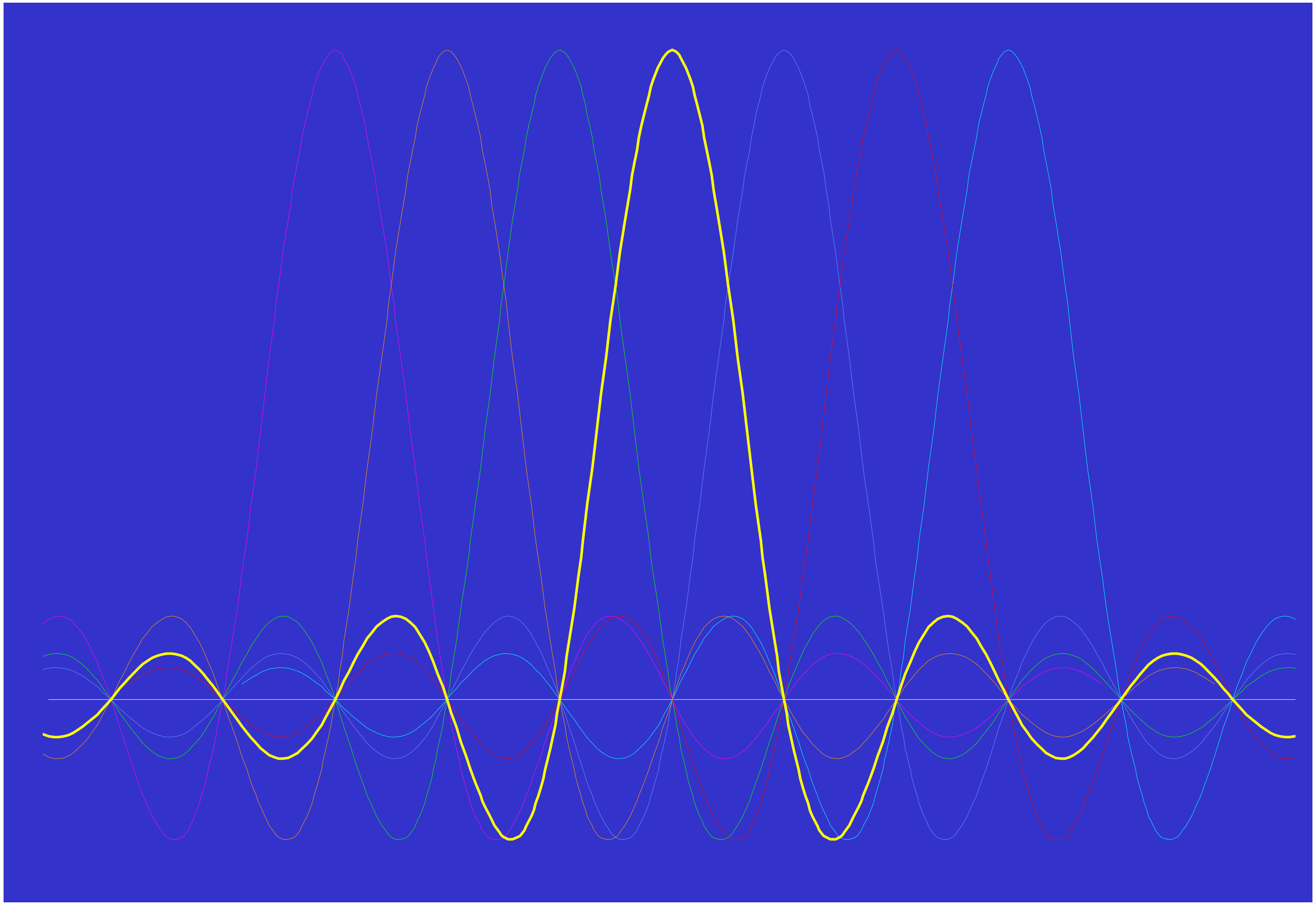


– Transmit: $y(t) = \mathrm{Re}\{(I(t)+jQ(t)) \exp(j2\pi f_c t)\}$
$= I(t) \cos(2\pi f_c t) - Q(t) \sin(2 \pi f_c t)$

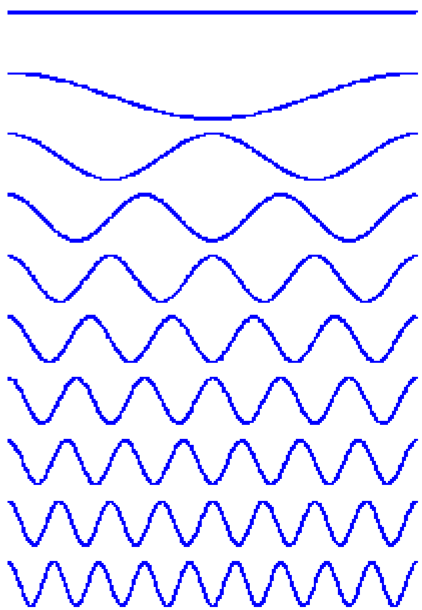
Traditional SCPC Modulation



COFDM Orthogonal carriers



COFDM Orthogonal carriers



$$\int_a^b \Psi_p(t)\Psi_q^*(t)\,dt = \int_a^b e^{j[2\pi(p-q)t/\tau]}\,dt$$

$$= (b-a) \text{ for } p = q$$

$$= \frac{e^{j[2\pi(p-q)b/\tau]} - e^{j[2\pi(p-q)/\tau]}}{j2\pi(p-q)/\tau}$$

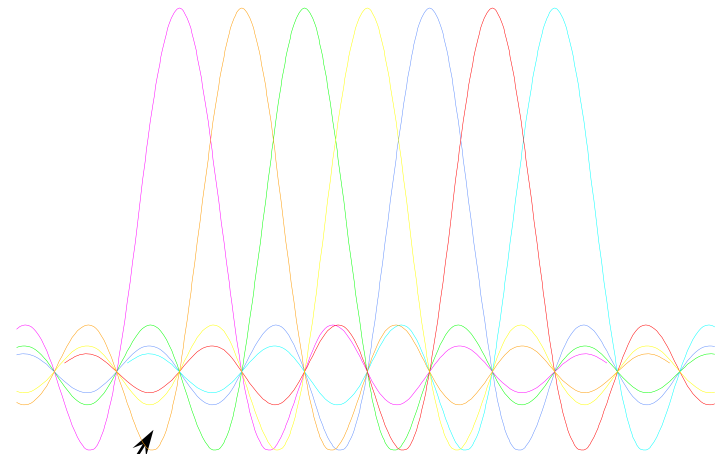
$$= \frac{e^{j[2\pi(p-q)b/\tau]}\left[1 - e^{j[2\pi(p-q)(a-b)/\tau]}\right]}{j2\pi(p-q)/\tau}$$

$$= 0 \quad \text{for } p \neq q \text{ and } (b-a) = \tau$$

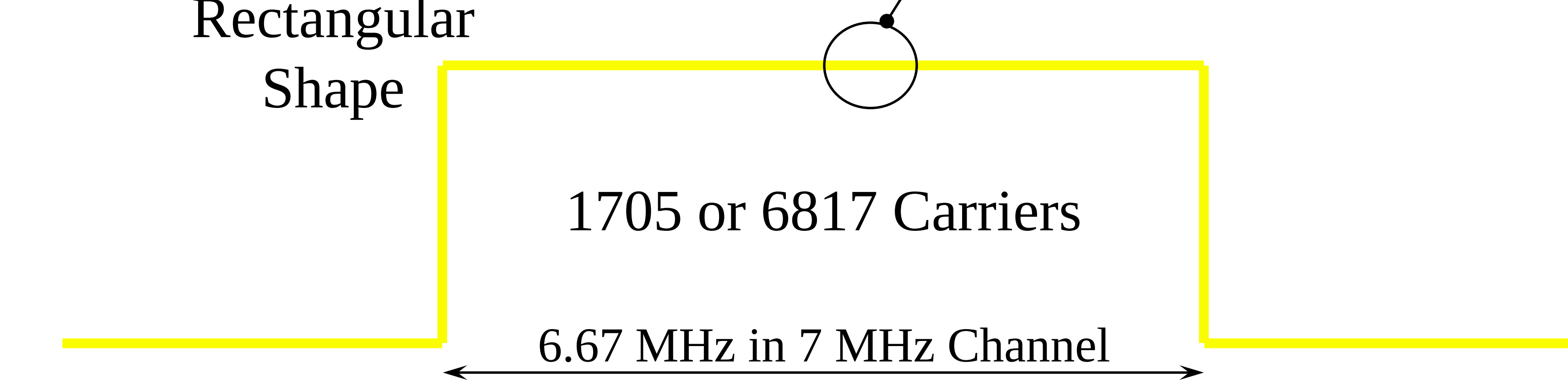
(remember that p and q are integers)

Spectrum of COFDM

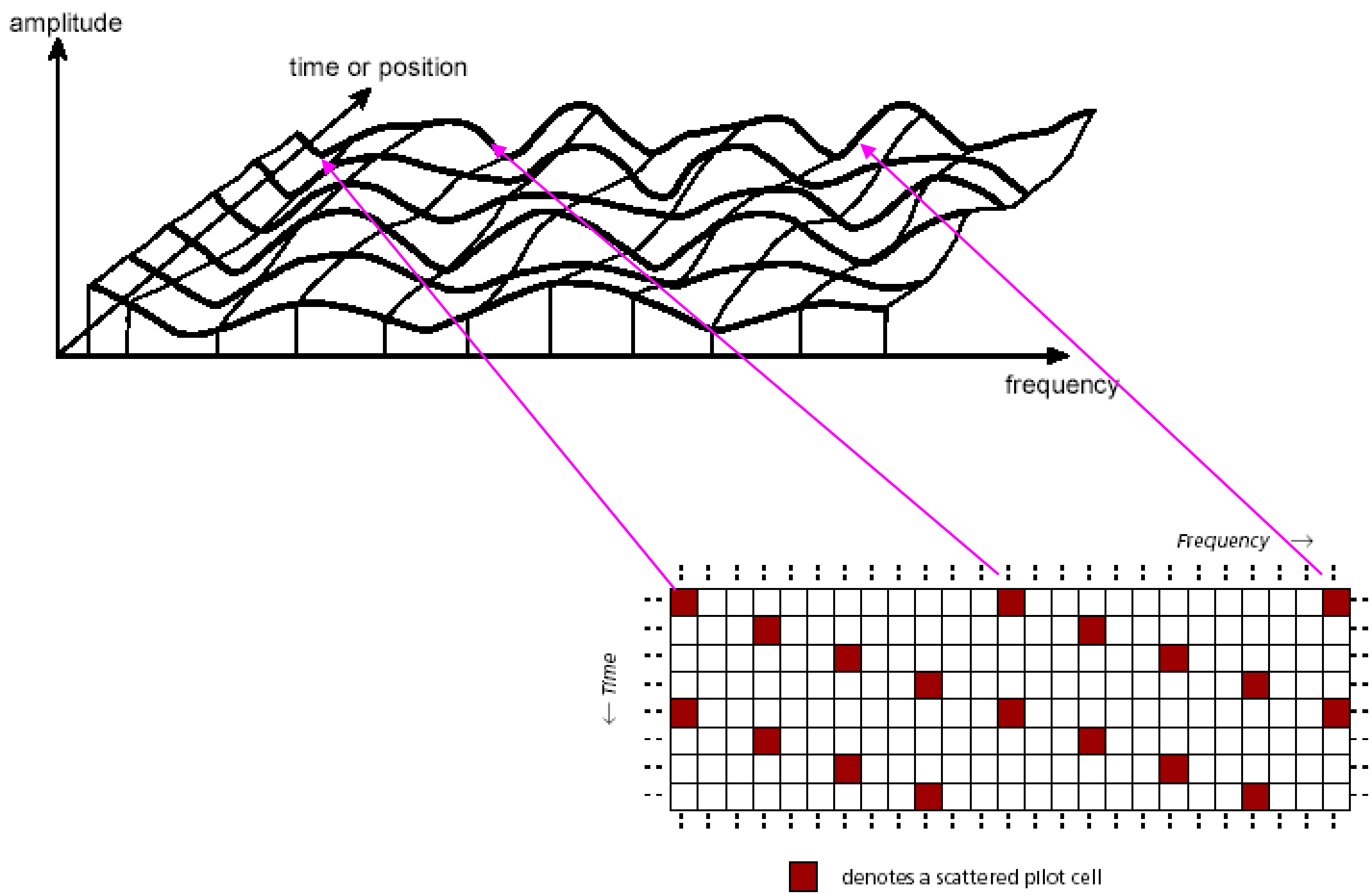
Carrier Spacing
2k Mode 3.91 kHz
8k Mode 0.98 kHz



Almost
Rectangular
Shape



Subchannel response - pilots



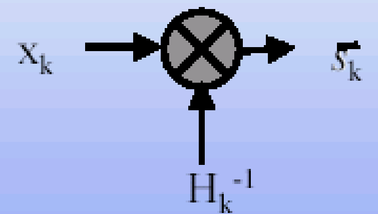
Subchannel response - pilots

- For the k-th carrier:

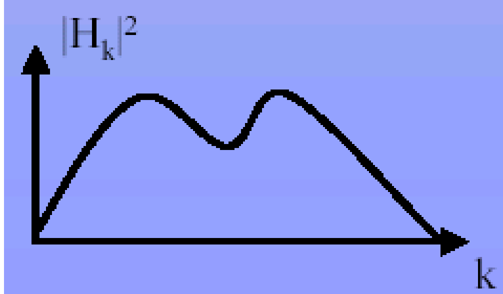
$$x_k = H_k\, s_k + v_k$$

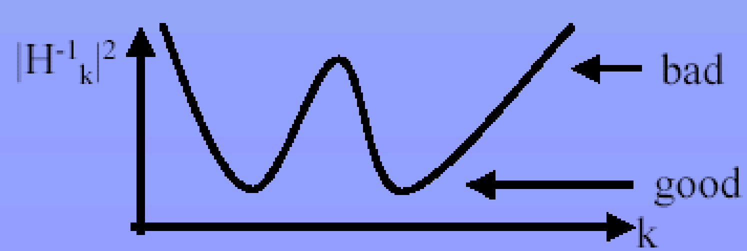
where $H_k = \sum_{n=0}^{N-1} h_k(nT_s) \exp(j2\pi\, k\, n / N)$

- Frequency domain equalizer



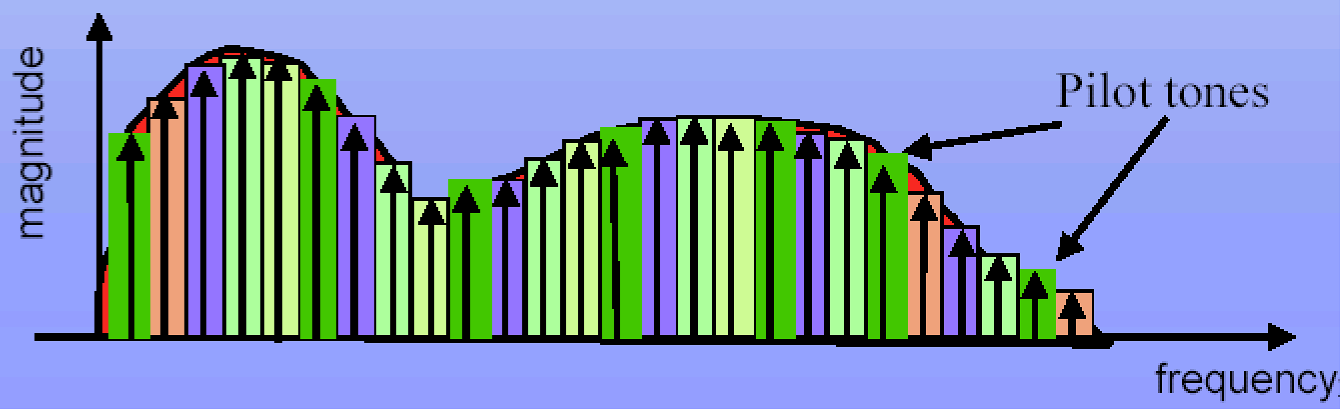
- Noise enhancement factor $\hat{\sigma}_k^2 = \sigma_k^2 |H_k^{-1}|^2$



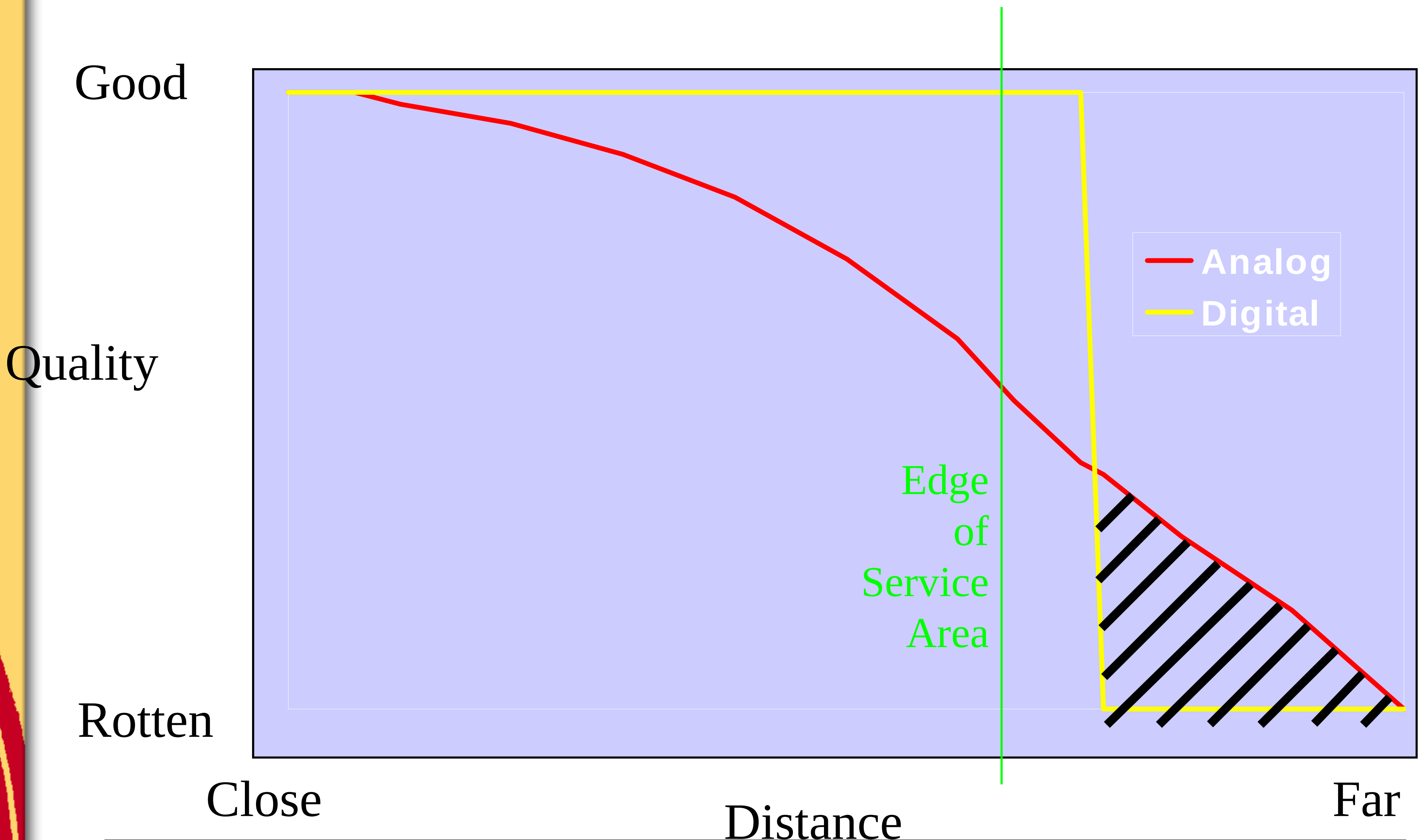


Subchannel response - pilots

- **Many systems use pilot tones – known symbols**
  - Given s_k, for $k=k_1, k_2, k_3, \ldots$ solve $x_k = \sum_{l=0}^{L} h_l e^{-j2\pi k l/N} s_k$ for h_l
  - Find $H_k = \sum_{l=0}^{L} h_l e^{-j2\pi k l/N}$ (significant computation)
- **More pilot tones**
  - Better noise resiliance
  - Lower throughput (pilots are *not* informative)



System failure characteristics



COFDM parameters

- Carrier modulation: 2k, 8k
- Type of modulation QPSK, 16QAM, 64QAM
- Guard interval ¼, 1/8, 1/16, 1/64
- Inner coder puncture rates: ½, 2/3, ¾, 5/6, 7/8
- Hierarchical modes
- Selection of transmission bandwidth (6/7/8 MHz)

DVB in Finland / Others

A+B

Parameters:

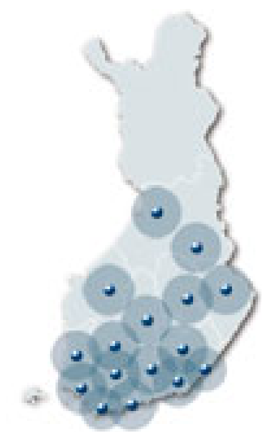
FINLAND :COFDM, 8k, 64QAM, 2/3 Code, Guard interval 1/8

SWEDEN: COFDM, 8k, 64QAM, 2/3 Code, Guard interval 1/8

UK: COFDM, 2k, 64QAM, 2/3 Code, Guard 1/32

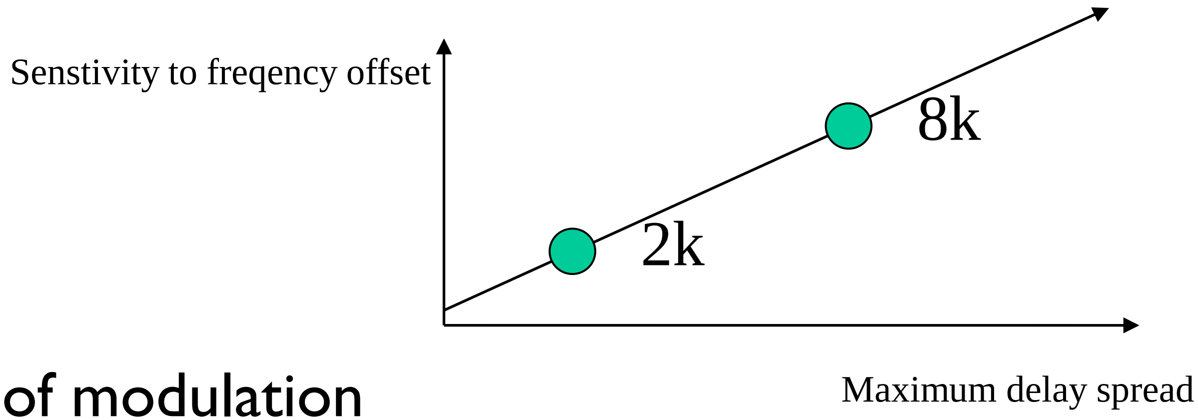
ITALY: COFDM, 8k, 64QAM, 2/3 Code, Guard 1/4
COFDM, 8k, 64QAM, 3/4 Code, Guard 1/32

C



DVB-T Parameter selection

- Number of carriers (2k / 8k)
  - Intercarrier spacing is a function of number of carriers
    - More carriers: More sensitive to frequenqy offsets, less sensitive to maximum delay spread



- Type of modulation
  - Higher order: More bits on air, more sensitive to noise
- Code rate
  - Capability of correcting errors (decrease with increaseing code rate
- Gard interval
  - Longer gard interval: Increased maximum delay spread, less data

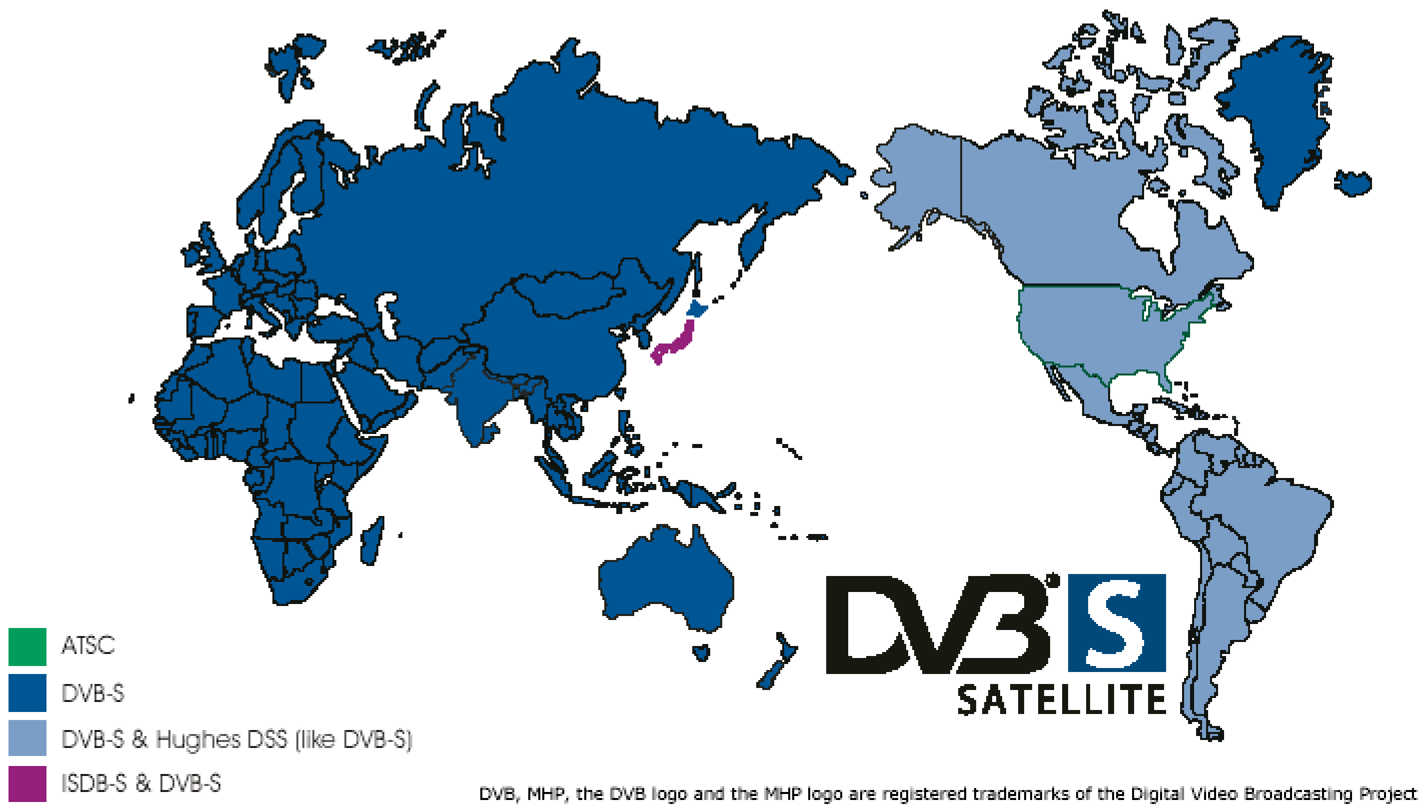
OFDM Planning example

- 8 MHz bandwidth
- 8k system, 64 QAM, 2/3 code, GI 1/8
- Bandwidth: 8MHz
- Subcarrier spacing : Δf = 8MHz / 8192 = 976 Hz
- OFDM symbol duration: $T_{FFT} = 1/\Delta_f$ = 1024us
- Cyclic prefix duration: T_{GI} = 128us (1/8)
- Symbol duration: $T_{symbol} = T_{FFT} + T_{GI}$ = 1152us
- Symbol frequency $f_{symbol} = 1/T_{symbol}$ = 868 s^{-1}
- Bits per carrier (64QAM) 6
- Active carriers per symbol
- → 22,7 Mbits/s

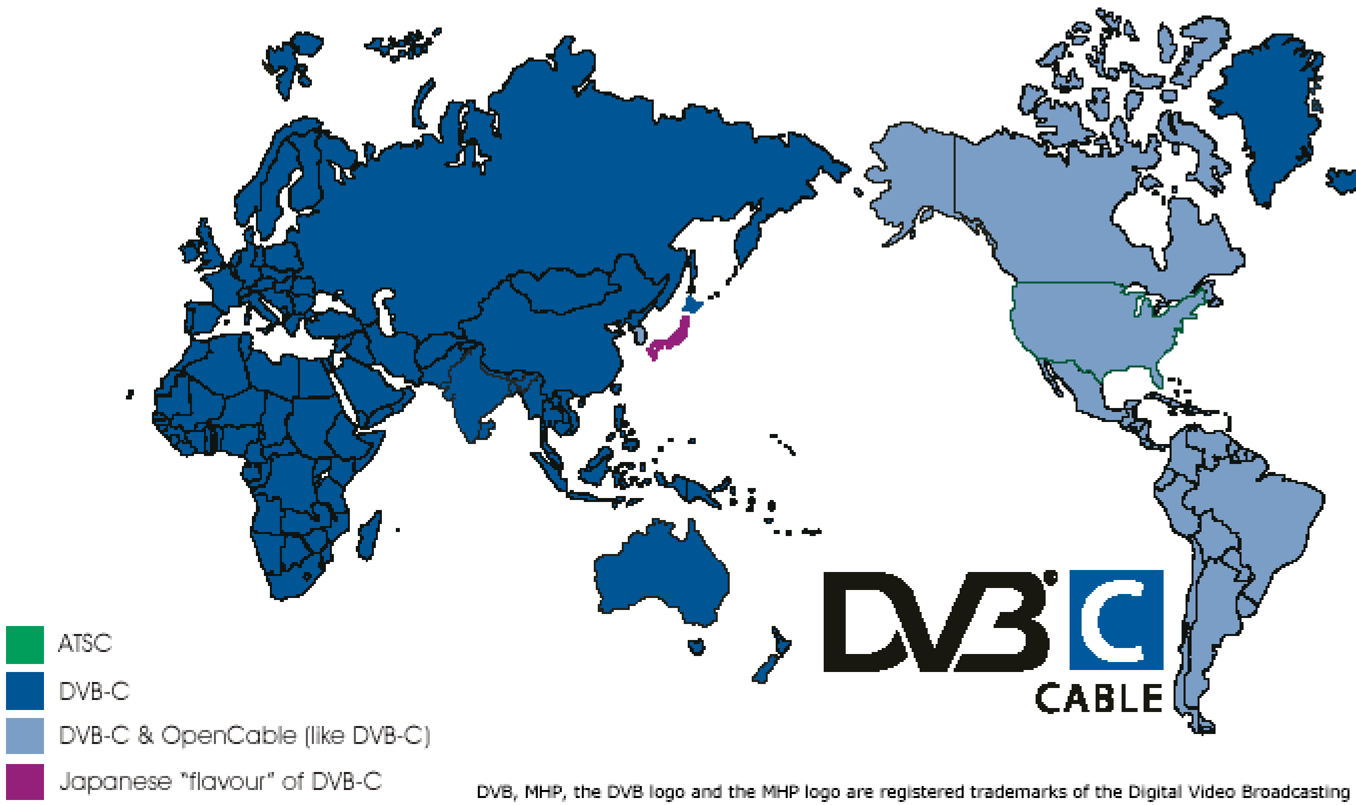
The DVB-T standard gives specific values used in implementations

Mode	8 k mode				2 k mode			
Guard interval Δ / T_U	**1/4**	**1/8**	**1/16**	**1/32**	**1/4**	**1/8**	**1/16**	**1/32**
Duration of symbol part T_U	8 192*T 896 µs				2 048*T 224 µs			
Duration of guard interval Δ	2 048*T 224 µs	1 024*T 112 µs	512*T 56 µs	256*T 28 µs	512*T 56 µs	256*T 28 µs	128*T 14 µs	64*T 7 µs
Symbol duration $T_S = \Delta + T_U$	10 240*T 1 120 µs	9 216*T 1 008 µs	8 704*T 952 µs	8 448*T 924 µs	2 560*T 280 µs	2 304*T 252 µs	2 176*T 238 µs	2 112*T 231 µs

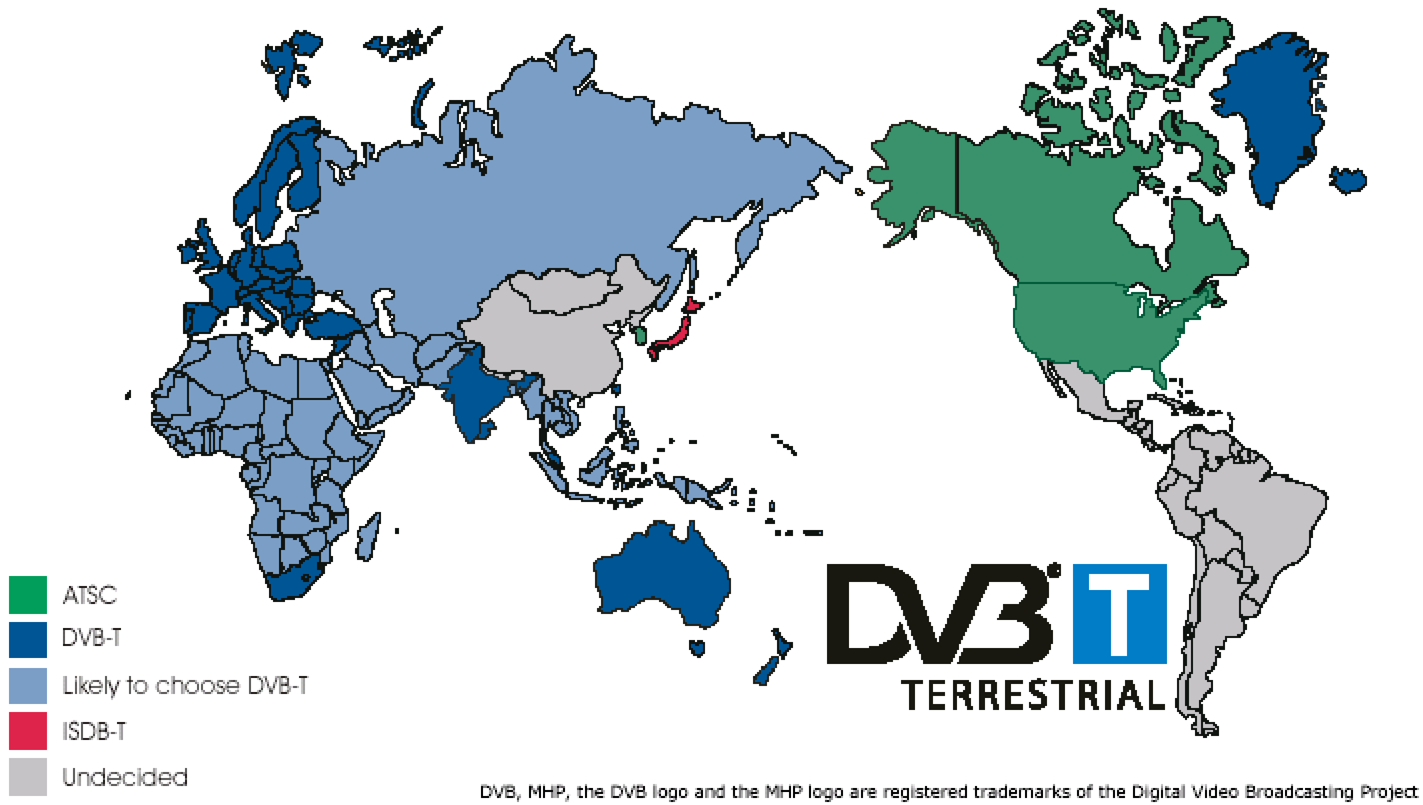
DVB-S in the World



DVB-C in the World



DVB-T in the World



Case study IEEE 802.11a WLAN

- **System parameters**

– FFT size: 64

– Number of tones used 52 (12 zero tones)

– Number of pilots 4 (data tones = 52-4 = 48 tones)

– Bandwidth: 20MHz

– Subcarrier spacing : Δf = 20MHz / 64 = 312.5 kHz

– OFDM symbol duration: $T_{FFT} = 1/\Delta_f$ = 3.2us

– Cyclic prefix duration: T_{GI} = 0.8us (1/4)

– Signal duration: $T_{signal} = T_{FFT} + T_{GI}$

Case study IEEE 802.11a WLAN

- Modulation: BPSK, QPSK, 16-QAM, 64-QAM
- Coding rate: 1/2, 2/3, 3/4
- FEC: K=7 (64 states) convolutional code