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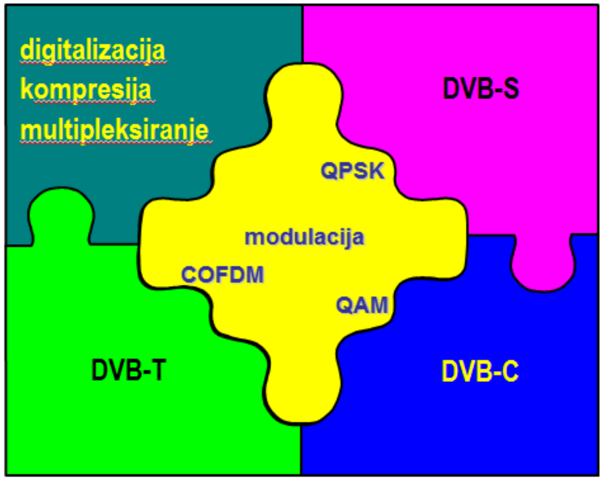
DBBT

Digital Broadcasting & Broadband Technologies

Digitalni radiodifuzni sistemi i tehnologije

DVB



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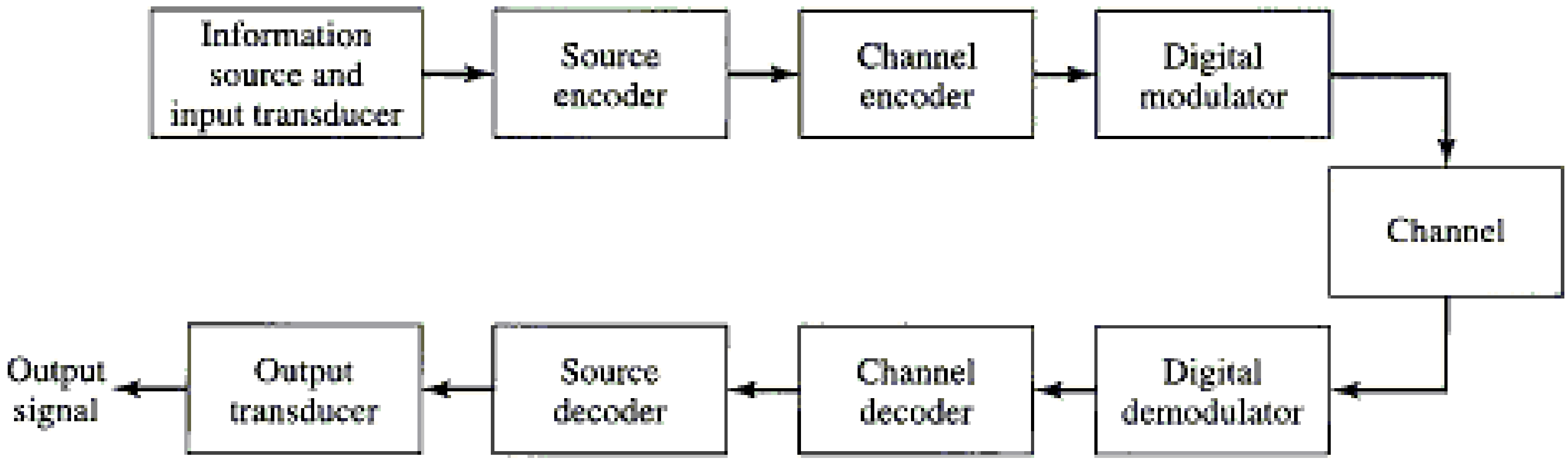
Banja Luka,2017.

Overview

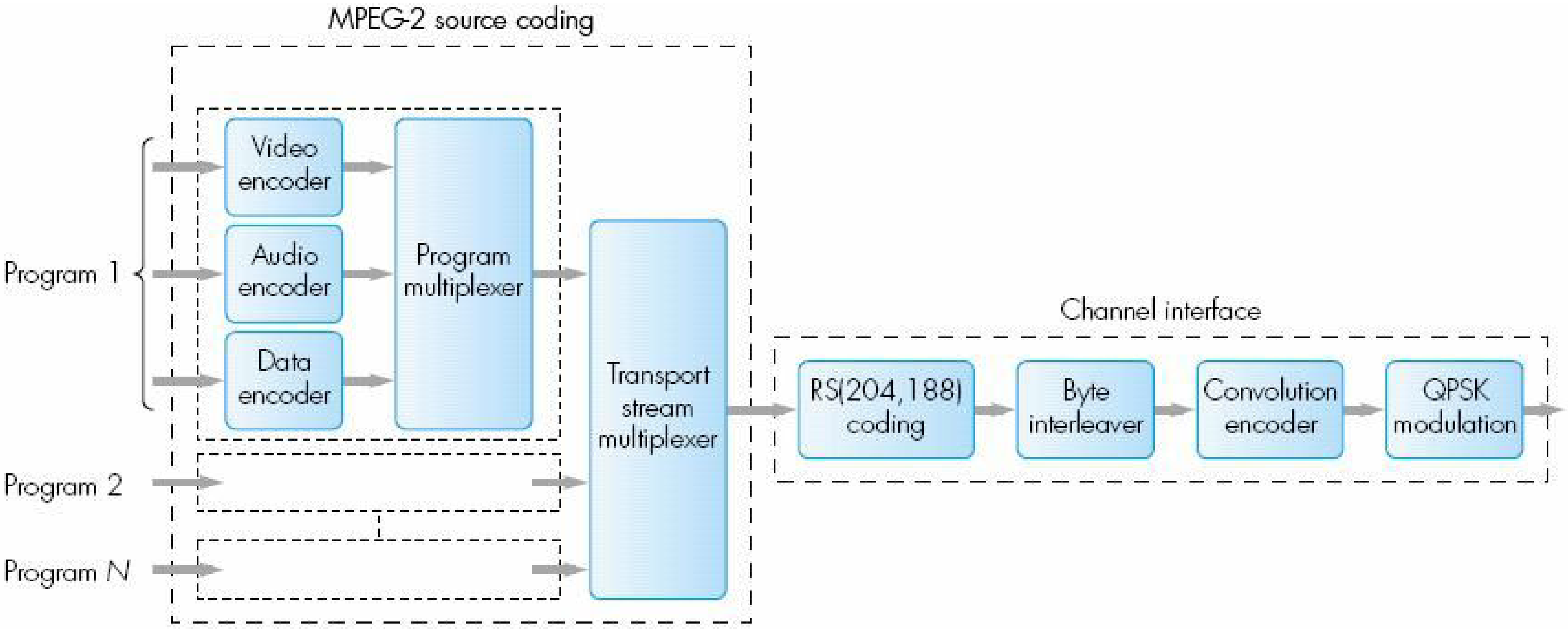
- **Digital Communication System**
- **Digital Transmission block scheme**
- **Error Correction**
- **Scrambling**
- **Digital Modulation**
- **Satellite television principles**
  - Satellites, Antennas, Encoding
- **Digital terrestrial television principles**
  - Multipath problems, Encoding, System

Digital Communication

- Information source – MPEG stream
- Source coding – RLC, Huffman Coding
- Channel coding – Scrambling, Error Correction…
- Modulation – bits into waveform



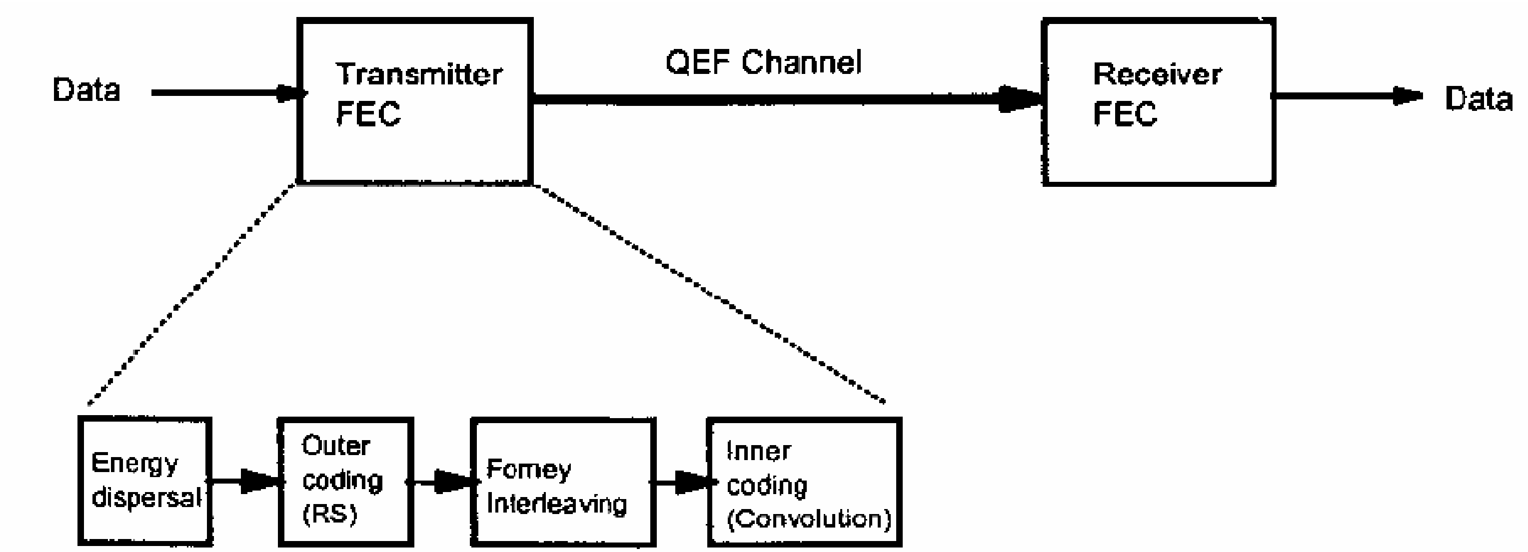
DVB-S Transmission Scheme



Satellite digital television channel interface

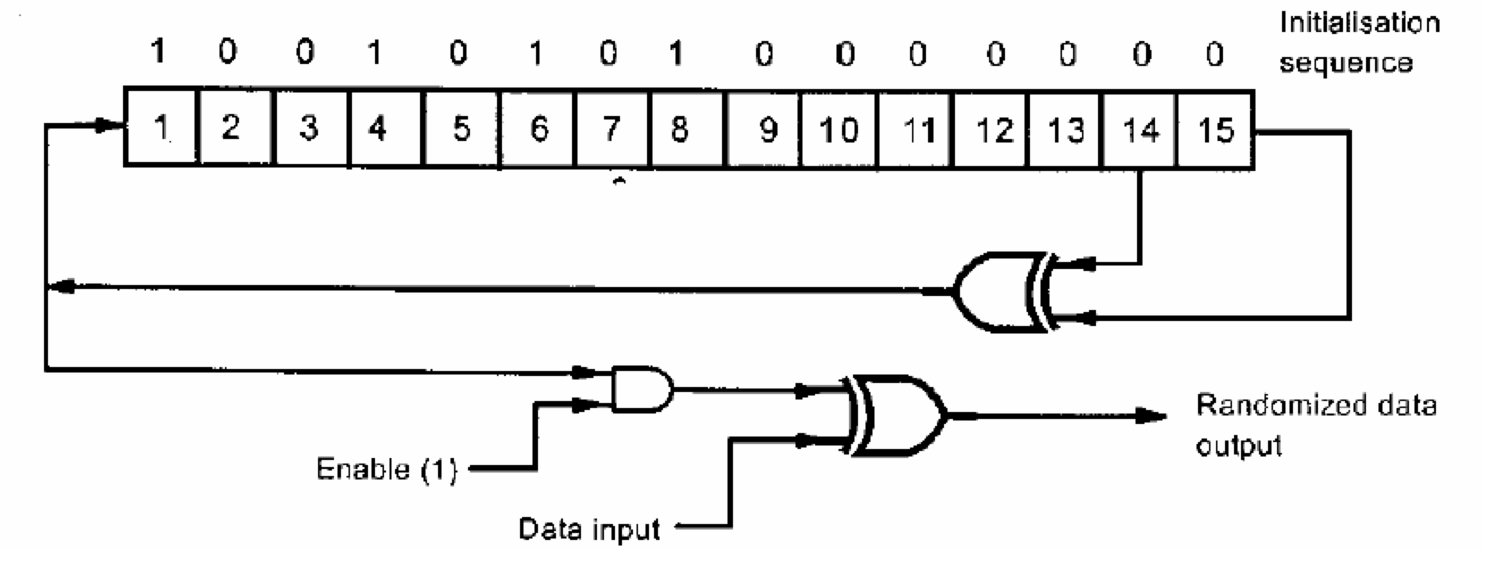
Error Correction

- The Transport stream should be transmitted over a Quasi Error Free (QEF) channel – Bit Error Ratio : BER < 10^{-10}
- TCP is resending lost packets
- Resending 3 times and voting on the correct – inefficient



Scrambling – Energy dispersal

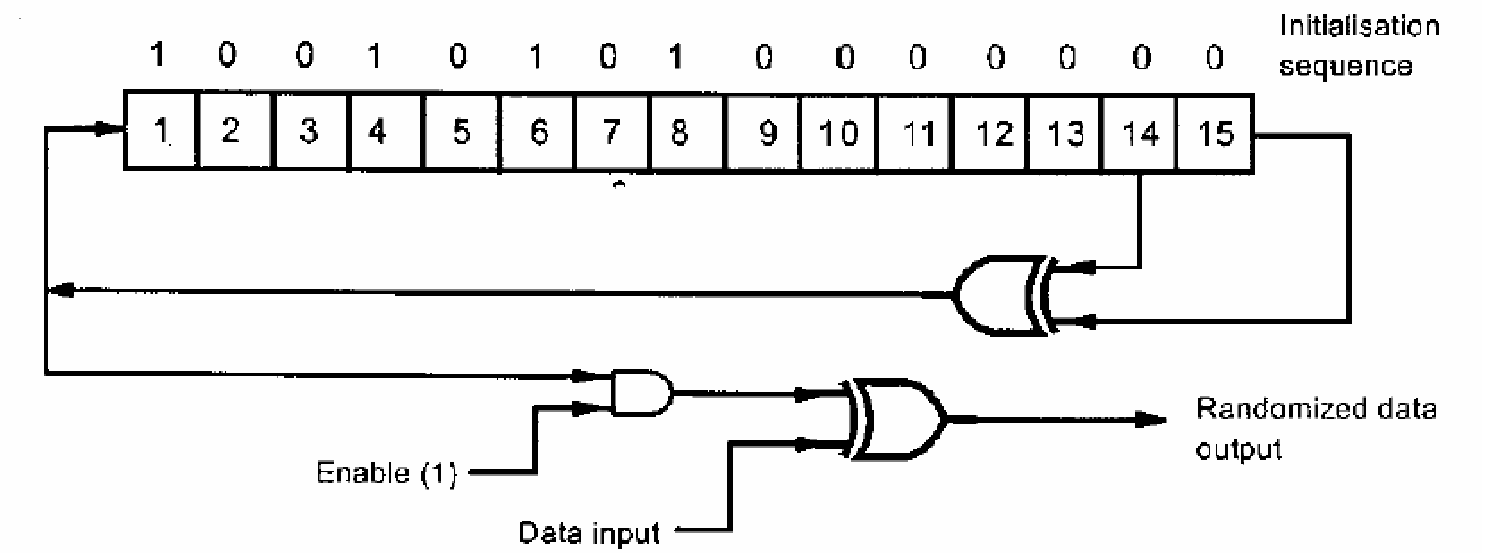
• Long runs of 0's or 1's generate a temporal DC coefficient
• Elementary way of encryption
• Start code and packet sync is not scrambled
• Pseudo Random Binary Sequence (PRBS)
– Scatters bits to make energy distribution more even
– Generated by formula : $1+X^{14}+X^{15}$ – using shift register



Scrambling Example

Test:
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

PRBS:
0 0 0 0 0 0 1 0 1 0 1 0 0 1 1 1 1 1 1 1 0 1 0 1 0 1 1 0 0 0 0 0 0 0



Reed-Solomon (Outer) coding

• Block level code (works on bytes)

– Adds extra bytes for error correction

– Need for a block synchronization

• Characteristics: n, k, t

– n = 204 Final transport packet length

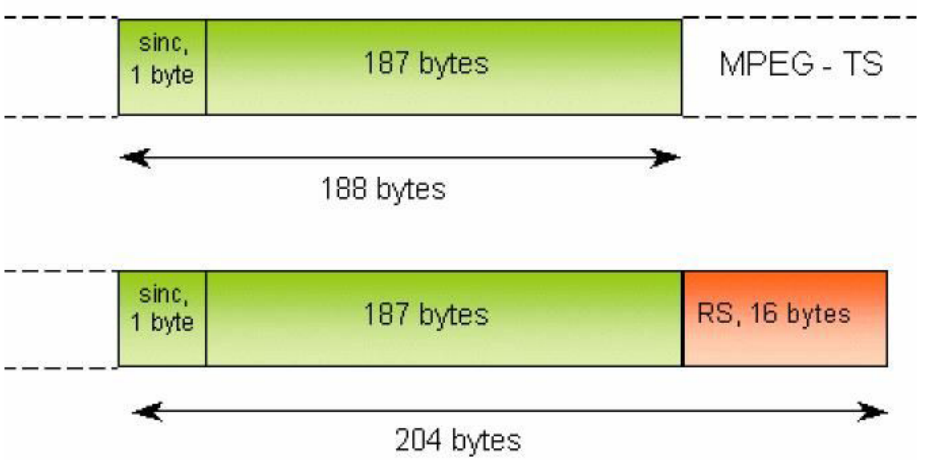
– k = 188 Original correctable bytes

– t = 8 Number of correctable bytes

• RS(204, 188) EU

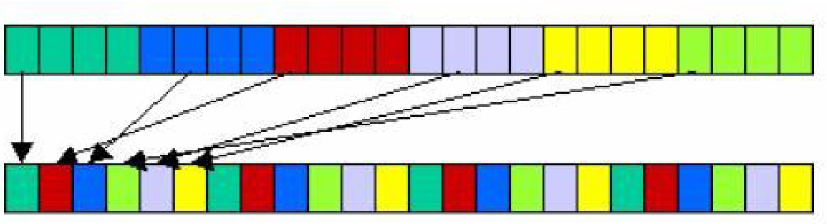
• RS(207,187) USA

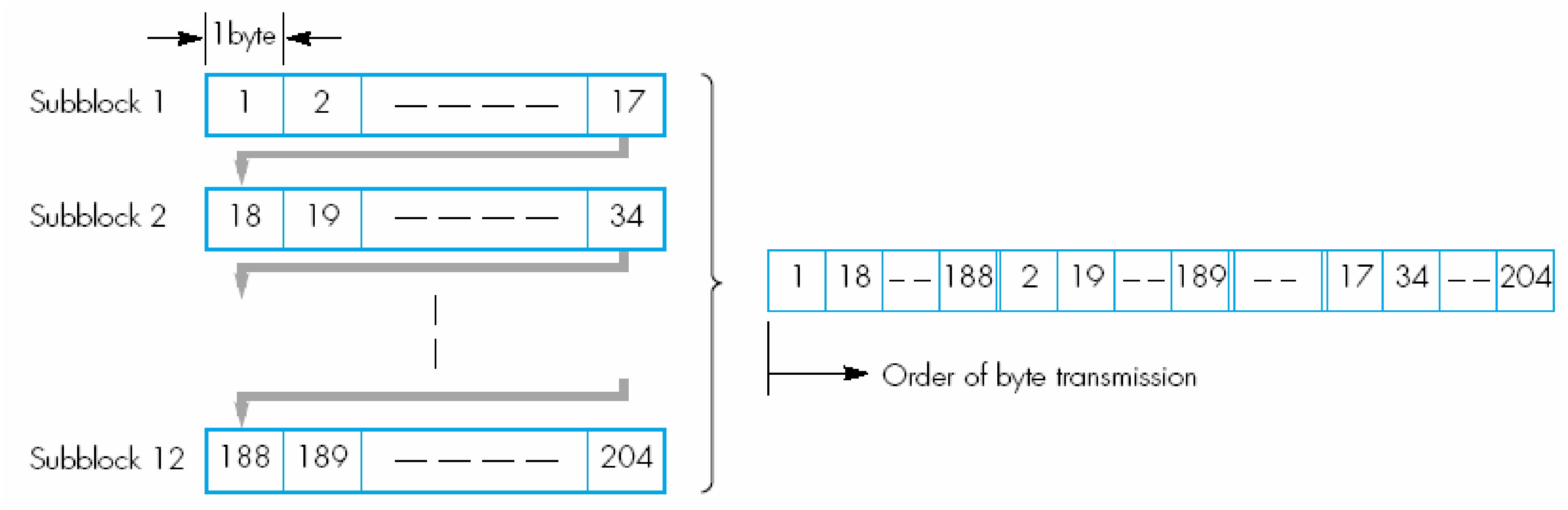
• Can detect (n-k)/2 errors



Interleaving

- *Interleaving – breaking down very long error bursts for FEC*
- *By rearranging the order of transmission of the bytes*

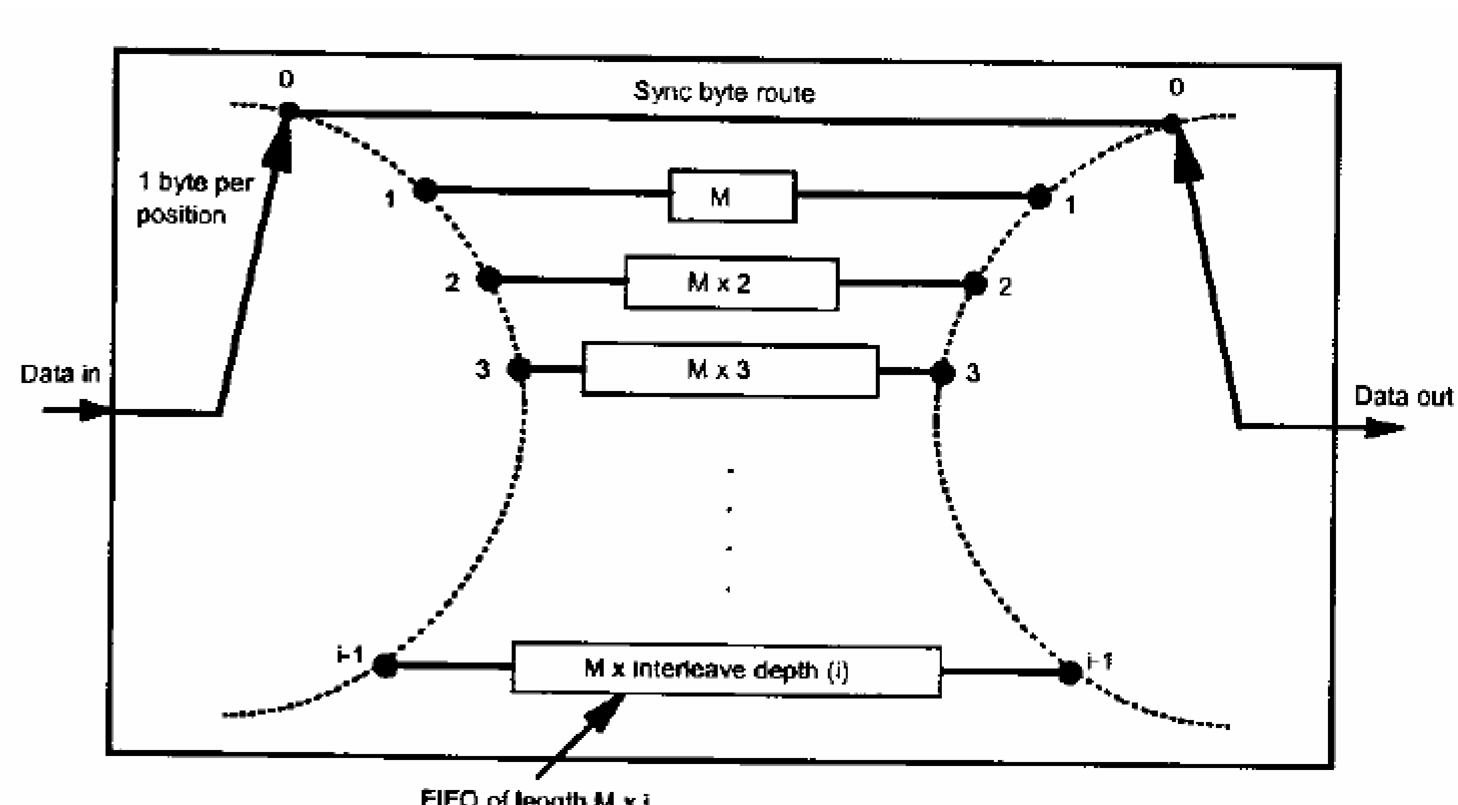




Forney (Outer) interleaving

- To spread out the error bits –more efficient outer coding
- For DVB with i=12 branches and L=204 packet length,

M=(L/i)xj is FIFO buffer size, j=0…11



Interleaving & Error Correction

Frequency-selective fading are indicated by **F** and errors due to time fading are indicated by ***T***.

After demodulation

```
.rirfcFFFrgeltndao
es yr FFFAic cei c
 ernn FFFdueVet hi
sn dr FFF it ner T
TTTTTTFFFTTTTTTTTT
  nearFFFdtsa onre
  eiefFFFriixrc ui
l ndhqFFFrtb lodml
  vnh FFFc sama ot
yrtoezFFFeec nimtf
geianvFFFnateeea i
 rniitFFFah.grseat
 o-eyaFFFseuiott b
  emoiFFFrdni nr b
 n ennFFFvbl  ient
 rpoixFFFudarbedee
```

After de–interleaving

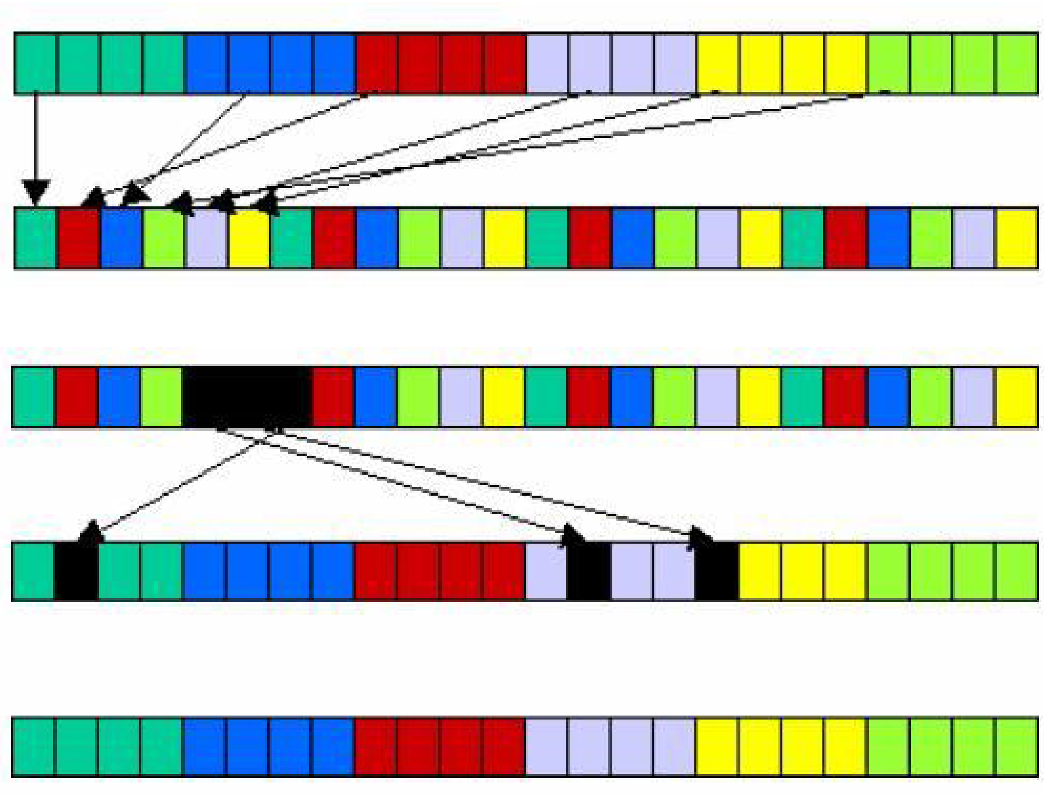
```
This is aF FxampFe
of text cFnFainiFg
error burFtF TotF
in columnF FndTiFT
lines cauFeF by F
TTannel sFlFctiTF
fading. AFTFr deF
interTeavFnF in F
time anT FrFquenFy
theTe errFrFThavF
been randFmFzed Fs
indiTaTedF FfterF
error corFeFtionF
by a VitTFbF de-F
coder theFoFiginFl
teTt is rFcFvereF.
```

After error correction

```
This is an example
of text containing
error bursts both
in columns and in
lines caused by
channel selective
fading. After de-
interleaving in
time and frequency
these errors have
been randomized as
indicated. After
error correction
by a Viterbi de-
coder the original
text is recovered.
```

Decoding with Errors

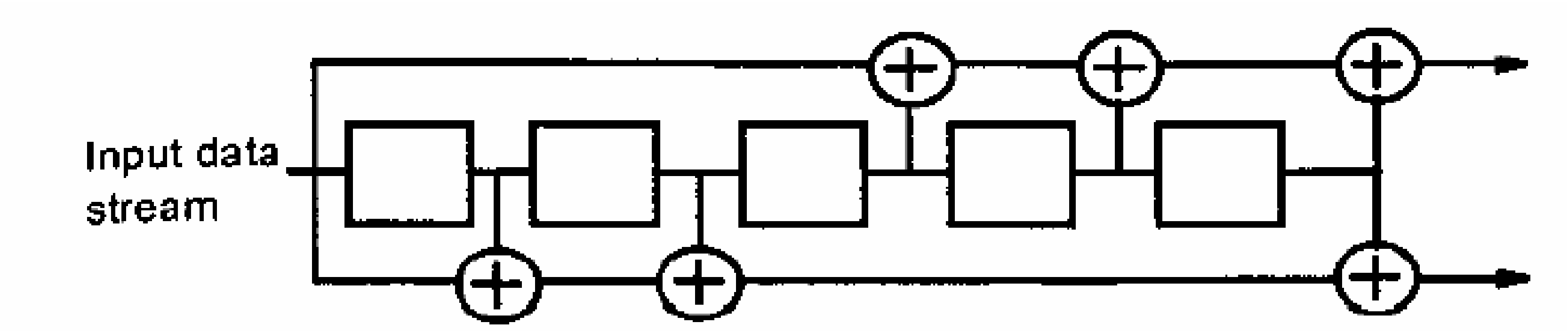
- Interleaving
- No Error
- Error burst
- Deinterleaving
- Viterbi and Reed-Solomon



Viterbi (Inner) Coding

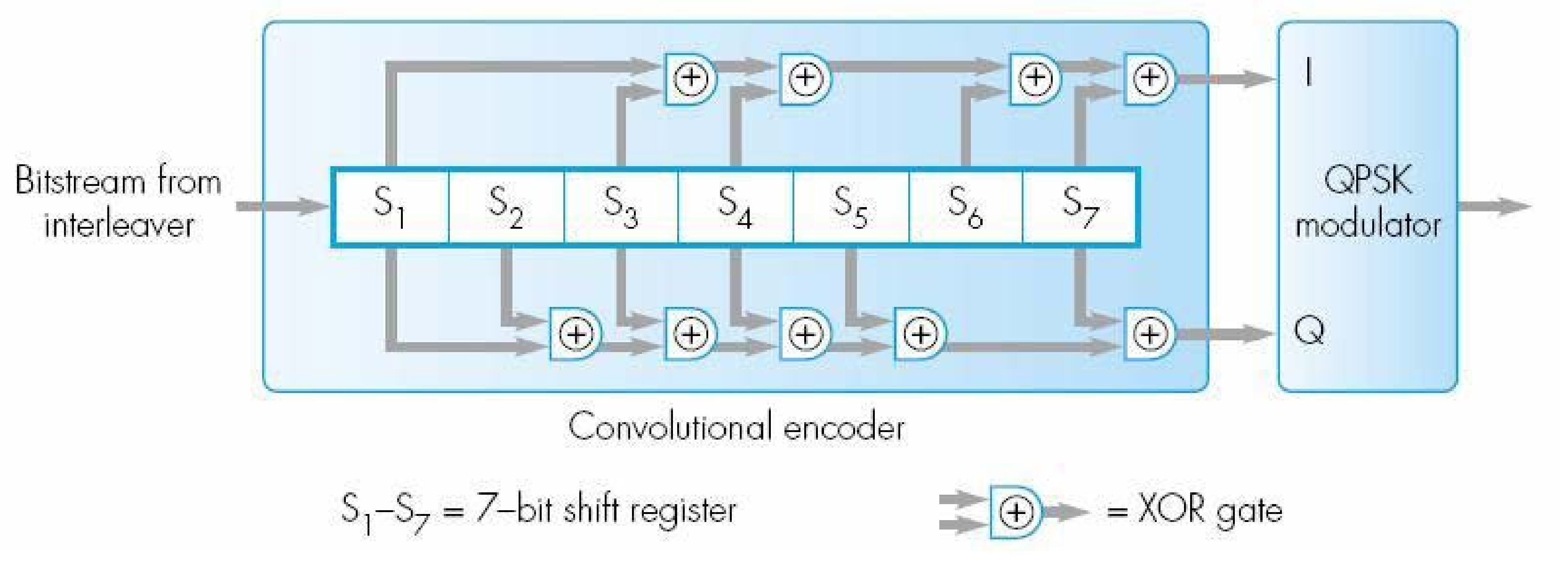
- Convolution Code – bit level
- Memory and computationally more efficient
- 2-3 data streams are produced – redundancy
- Codes system states rather than signals involved
- Calculates the probabilities of state transitions
- Trellis diagram: Decoding at the receiver side

133/171



Channel Encoding

- *Convolutional encoder*
- *Hamming distance*
- *Puncturing*



Channel Encoding

- *Convolutional encoder*
- *Hamming distance*
- *Puncturing*

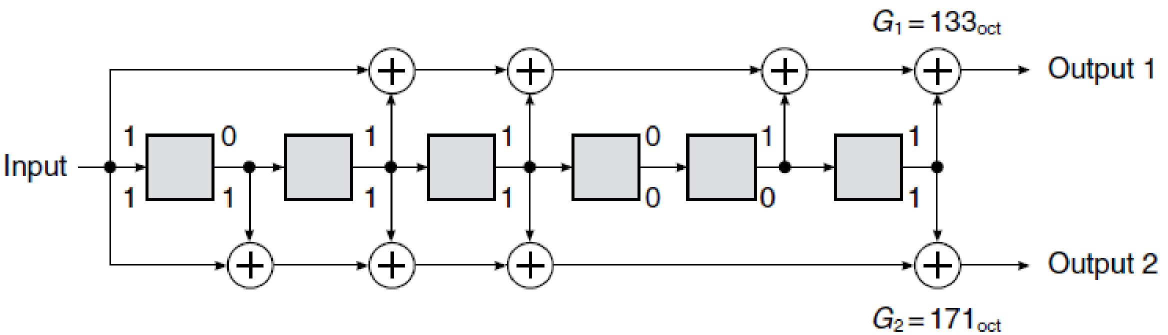


Figure 6.8 Principle diagram of the DVB-S convolutional coder.

Table 6.1 Basic parameters of the DVB convolutional code.

Parameter	Abbreviation	Value
Code rate	R_c	1/2
Constraint length	K	7
First polynomial generator	G_1	171_{oct}
Second polynomial generator	G_2	133_{oct}
Free distance	d_{free}	10

Puncturing

- Code redundancy introduces more bit rate
- More bit rate – more errors!
- Shortening the code word – puncturing
- Periodical removal of the certain coded bits
- Regular pattern to be able to decode
- Not as prone to errors
- Trade of between the error resilience and redundancy

Puncturing

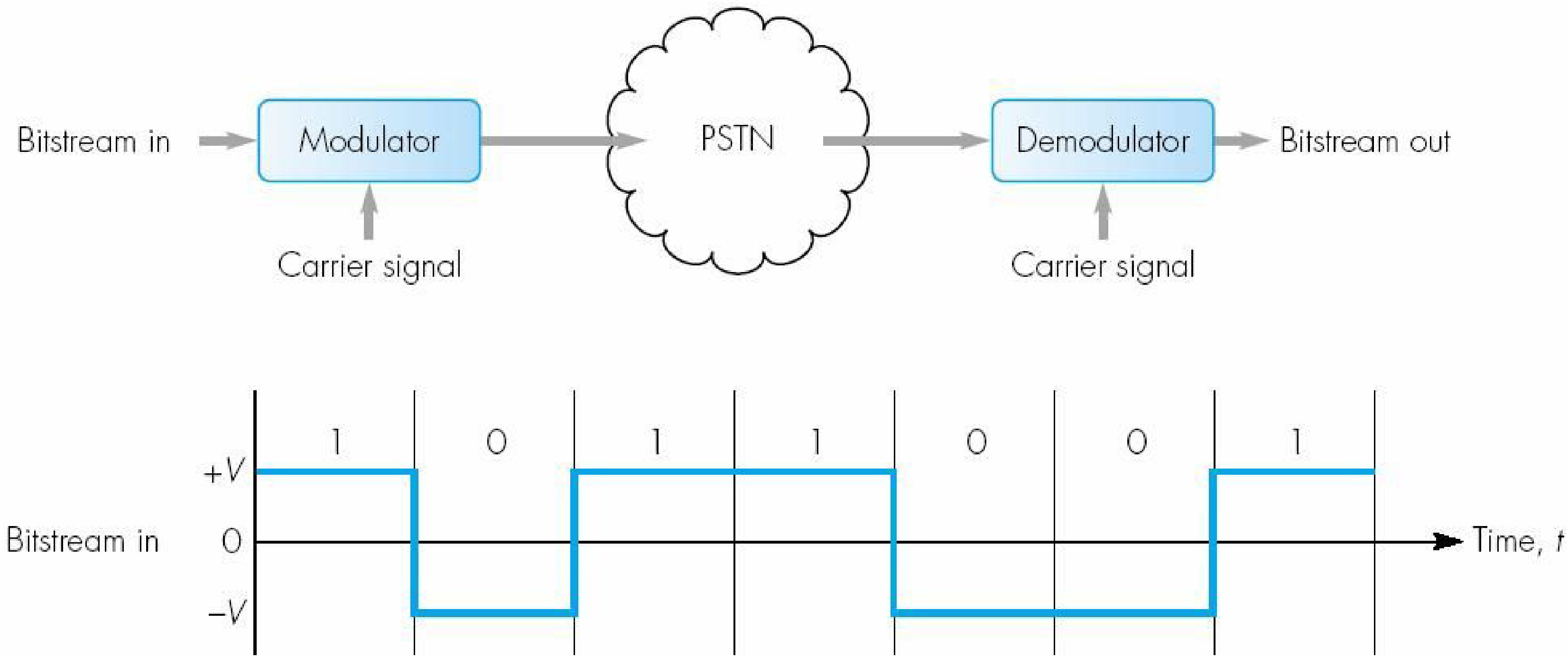
Table 6.2 DVB inner coding characteristics (derived from prETS 300 421).

R_c	1/2	2/3	3/4	5/6	7/8
d_{free}	10	6	5	4	3
X	1	10 10	101	10101	1000101
Y	1	11 11	110	11010	1111010
I	X_1	$X_1\,Y_2\,Y_3$	$X_1\,Y_2$	$X_1\,Y_2\,Y_4$	$X_1\,Y_2\,Y_4\,Y_6$
Q	Y_1	$Y_1\,X_3\,Y_4$	$Y_1\,X_3$	$Y_1\,X_3\,X_5$	$Y_1\,Y_3\,X_5\,X_7$
S_{OFDM}	$X_1\,Y_1$	$X_1\,Y_1\,Y_2\,X_3\,Y_3\,Y_4$	$X_1\,Y_1\,Y_2\,X_3$	$X_1\,Y_1\,Y_2\,X_3\,Y_4\,X_5$	$X_1\,Y_1\,Y_2\,Y_3\,Y_4\,X_5\,Y_6\,X_7$

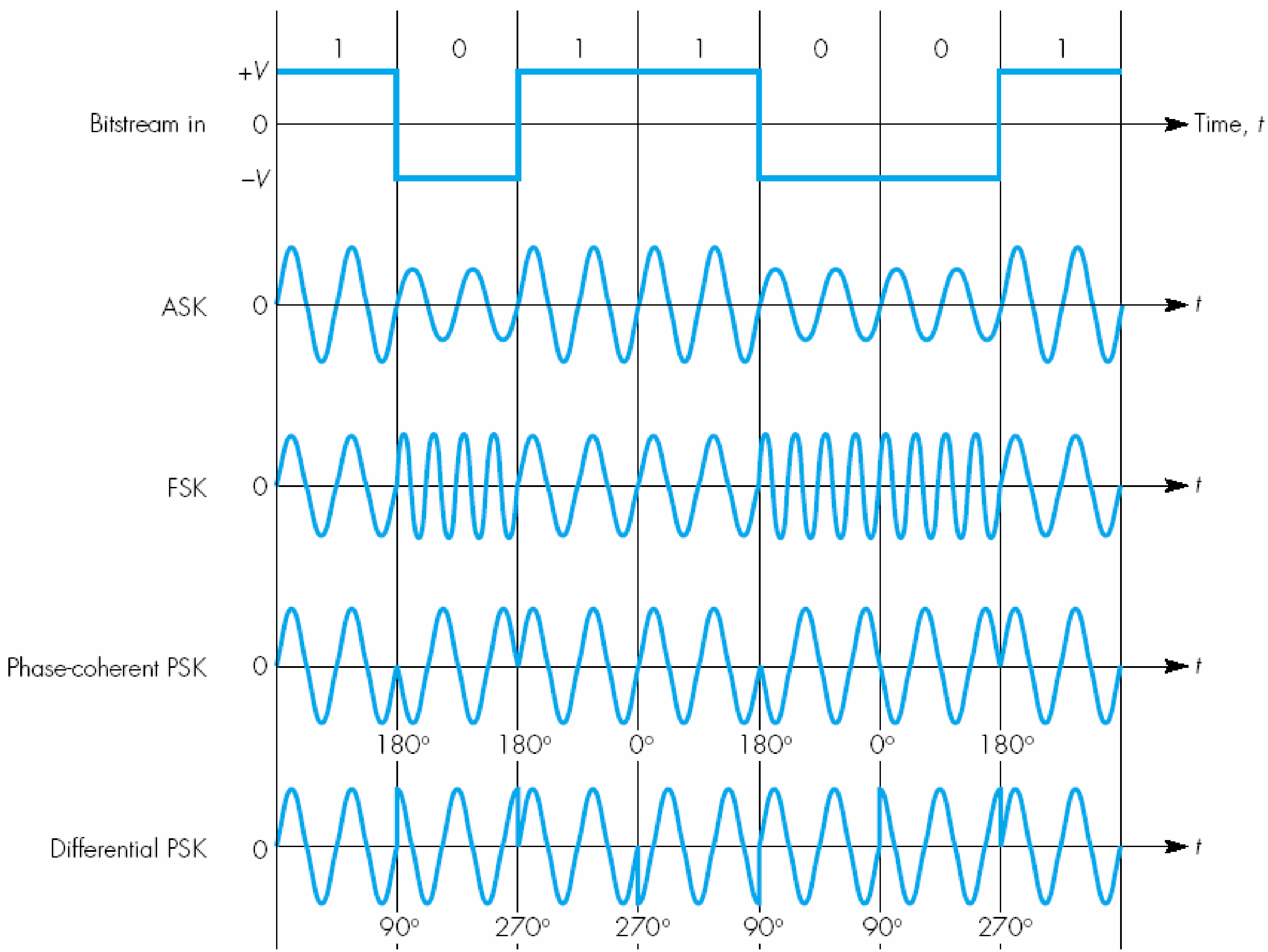
Notes:
On lines X and Y, '0' denotes a suppressed bit, '1' denotes a transmitted bit. For terrestrial transmissions based on OFMD modulation, additional steps are required after the inner coding: serialization of the bitstream, inner interleaving and symbol mapping to adapt the bitstream format to the high number of carriers used (see Chapter 7). The last line of the table. S_{OFDM}, represents the serialized bitstream (obtained by alternating I and Q lines) applied to the inner interleaving circuit used in the case of terrestrial OFDM transmission.

Digital Modulation

- Adapting the source signal to the transmission medium



Digital Modulation



Shannon's Theorem

- The capacity *C* of a channel

$C = B \times \log_2(1+SNR)$

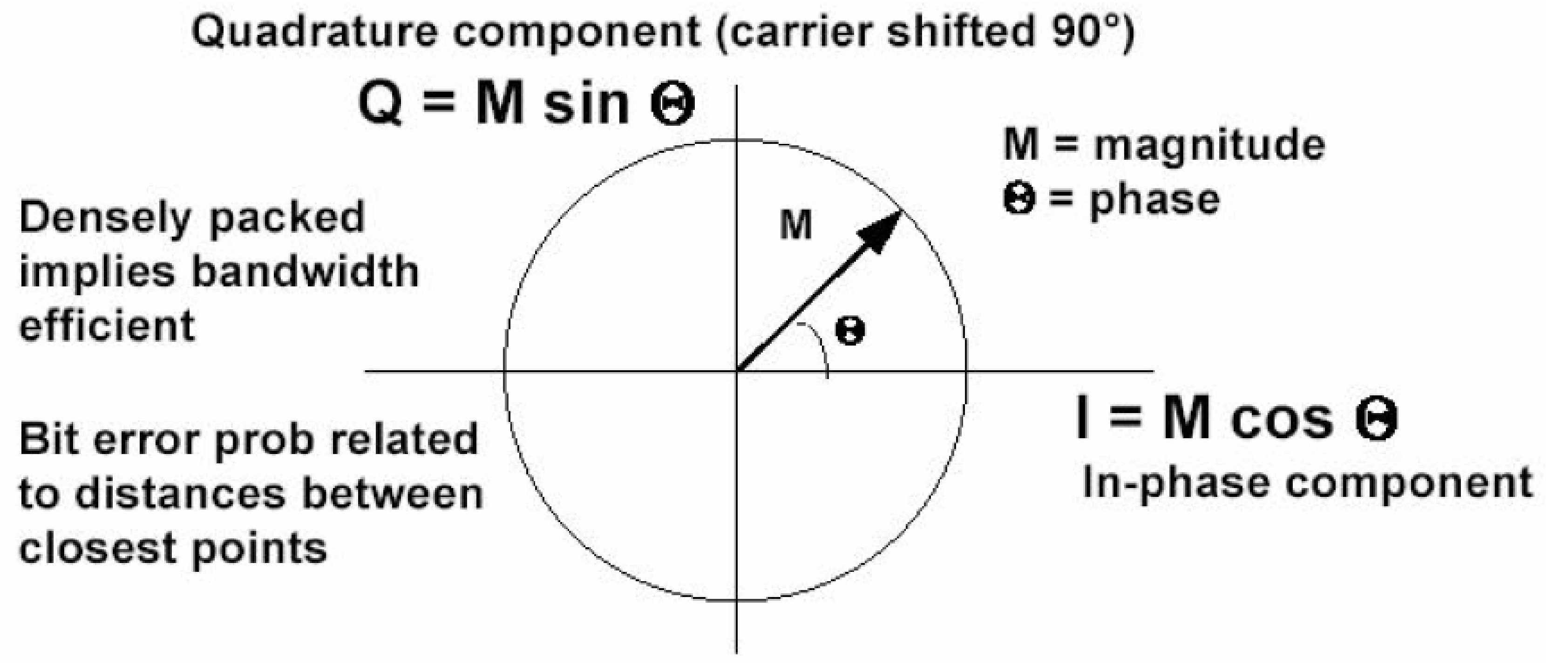
B - bandwidth

SNR - signal to noise ratio

- PAL analogue 6MHz studio: S/N = 65 dB -> 129 Mbit/s
- PAL analogue 6MHz broadcast: S/N = 21 dB -> 42 Mbit/s
- Practical for digital applications: S/N = 15 dB -> 30 Mbit/s
- Normal digital applications: 6 bps / Hz

Modulation Notation

- Modify carriers amplitude and/or phase (and frequency)
- Constellation map: Vector notation/Complex frequency coordinates

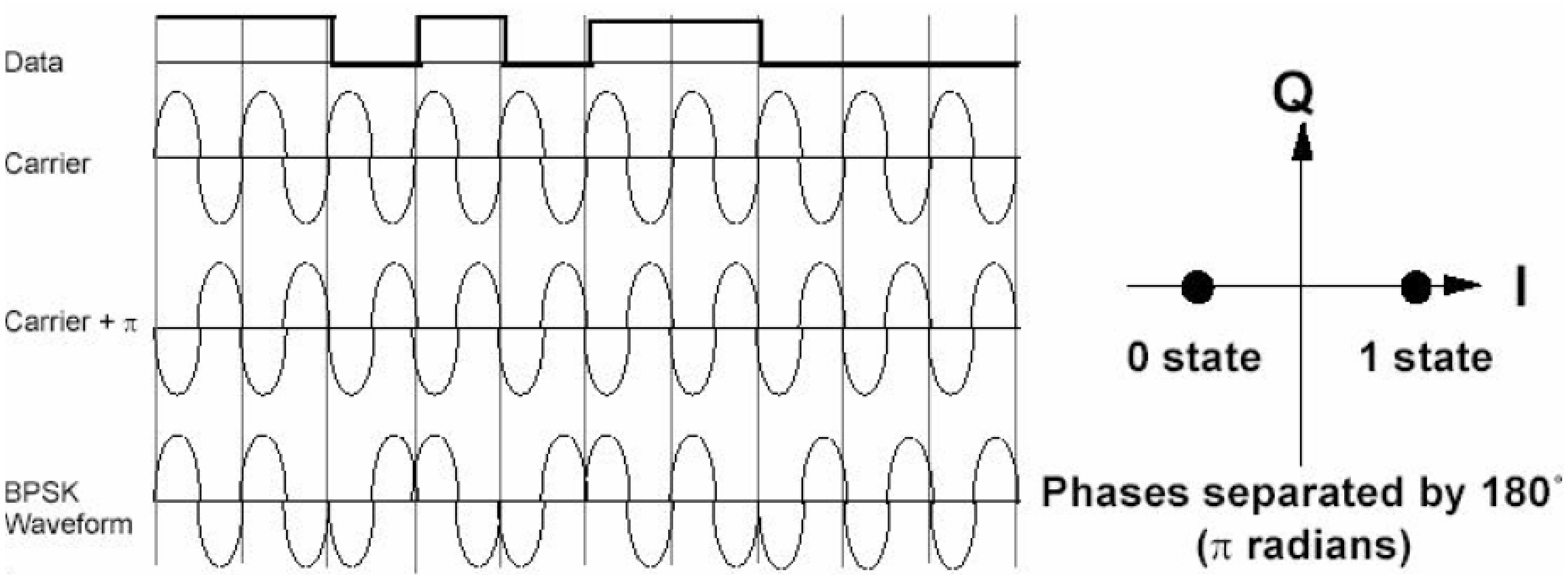


Binary modulations

- Binary phase shift keying (BPSK)

– Simple to implement, inefficient use of bandwidth

– Very robust, used in satellite communications

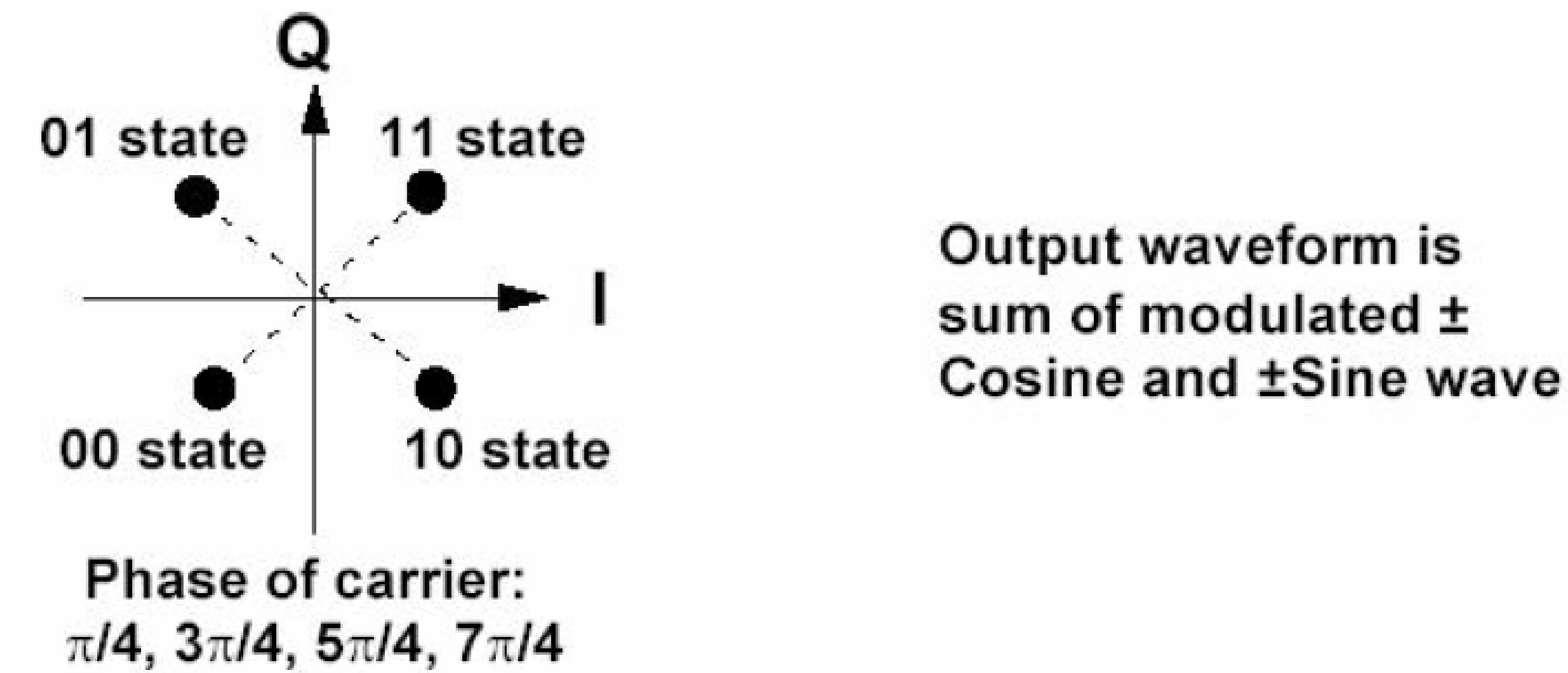


Phase Key Shifting (PSK)

- Quadrature Phase Shift Keying (QPSK)

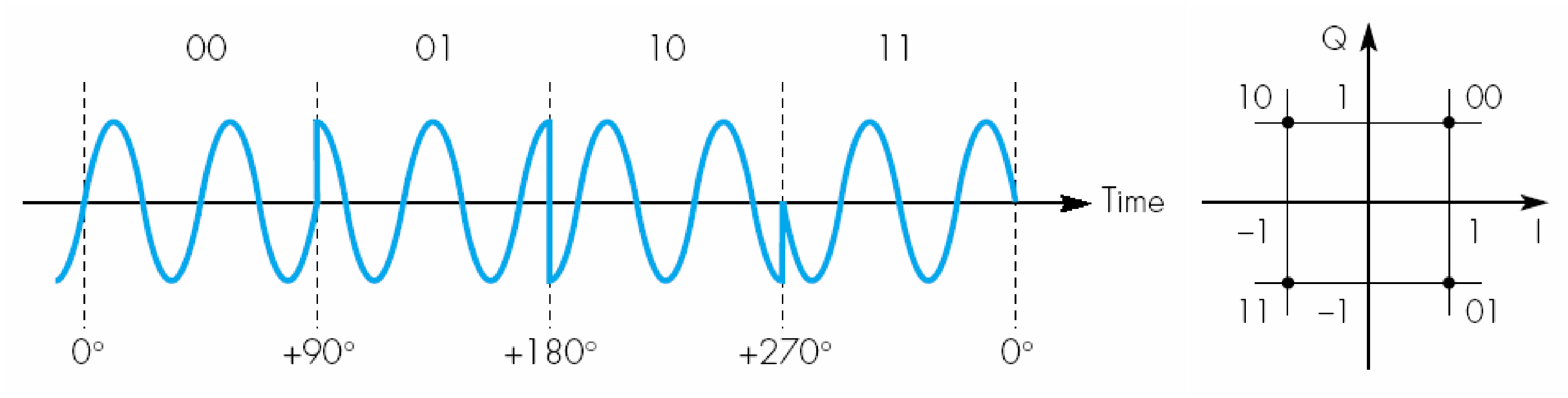
– Multilevel modulation technique: 2 bits per symbol

– More spectral efficiency, more complex receiver

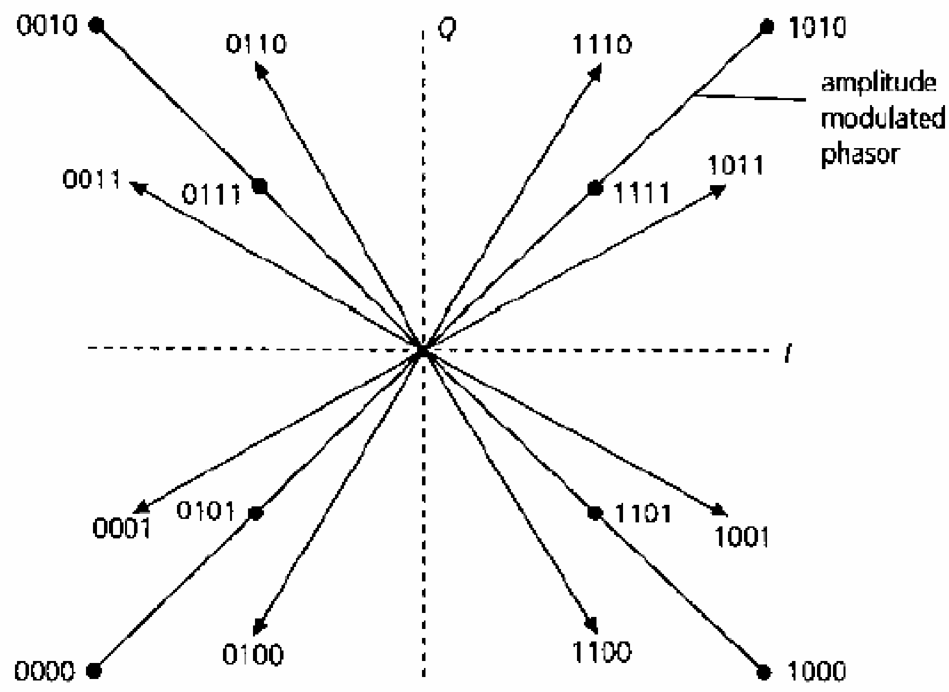


QAM

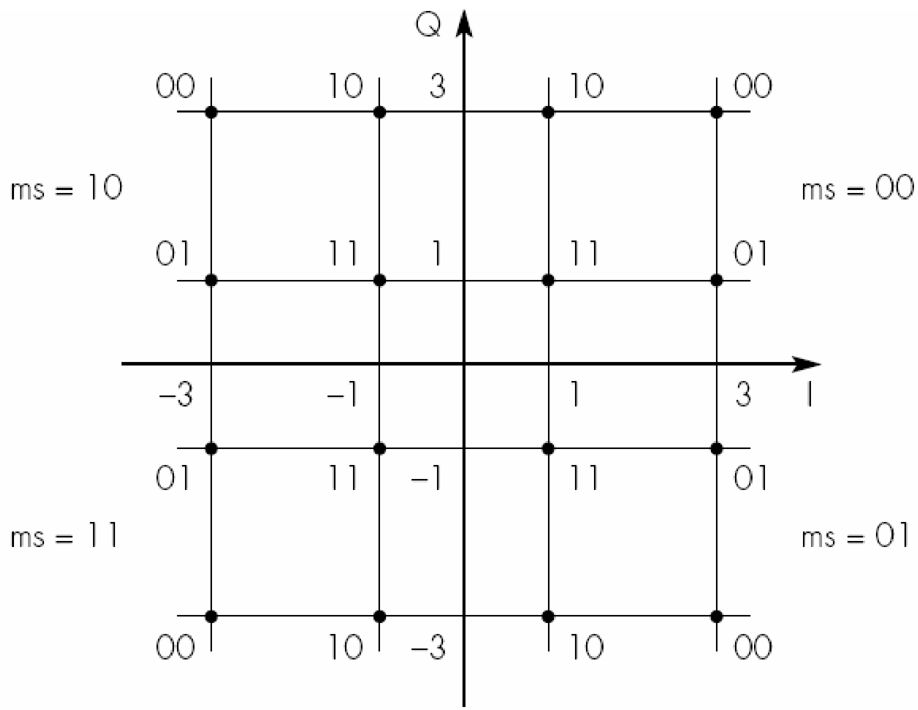
- Quadrature Amplitude Modulation (QAM)
– Amplitude modulation on both quadrature carriers
– 2n discrete levels, if n=2 then same as QPSK
- Extensively used in microwave links
- DVB-T uses QAM
- 4-QAM



16-QAM

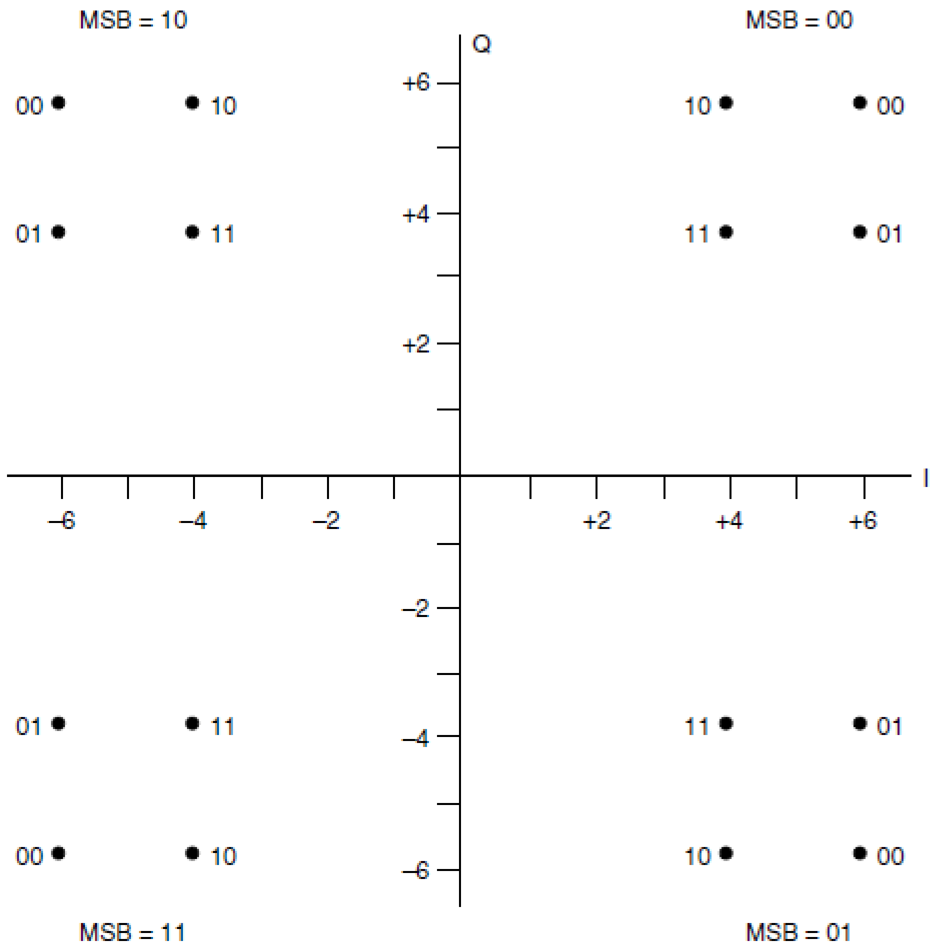


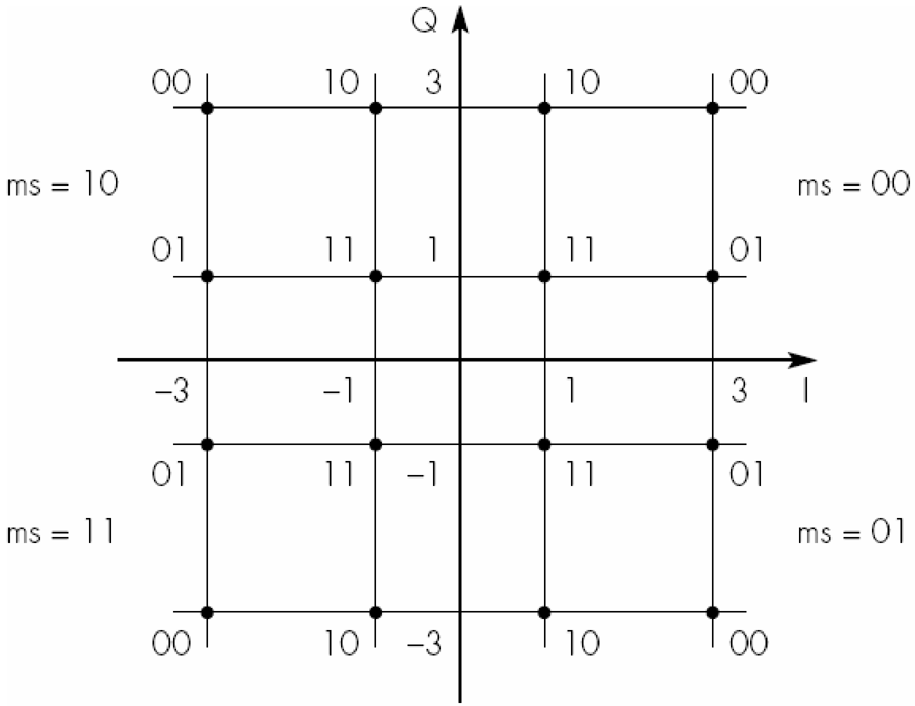
0010
0110
Q
1110
1010
amplitude modulated phasor
0011
0111
1111
1011
I
0001
0101
1101
1001
0000
0100
1100
1000



Q
00
10
3
10
00
ms = 10
ms = 00
01
11
1
11
01
−3
−1
1
3
I
01
11
−1
11
01
ms = 11
ms = 01
00
10
−3
10
00

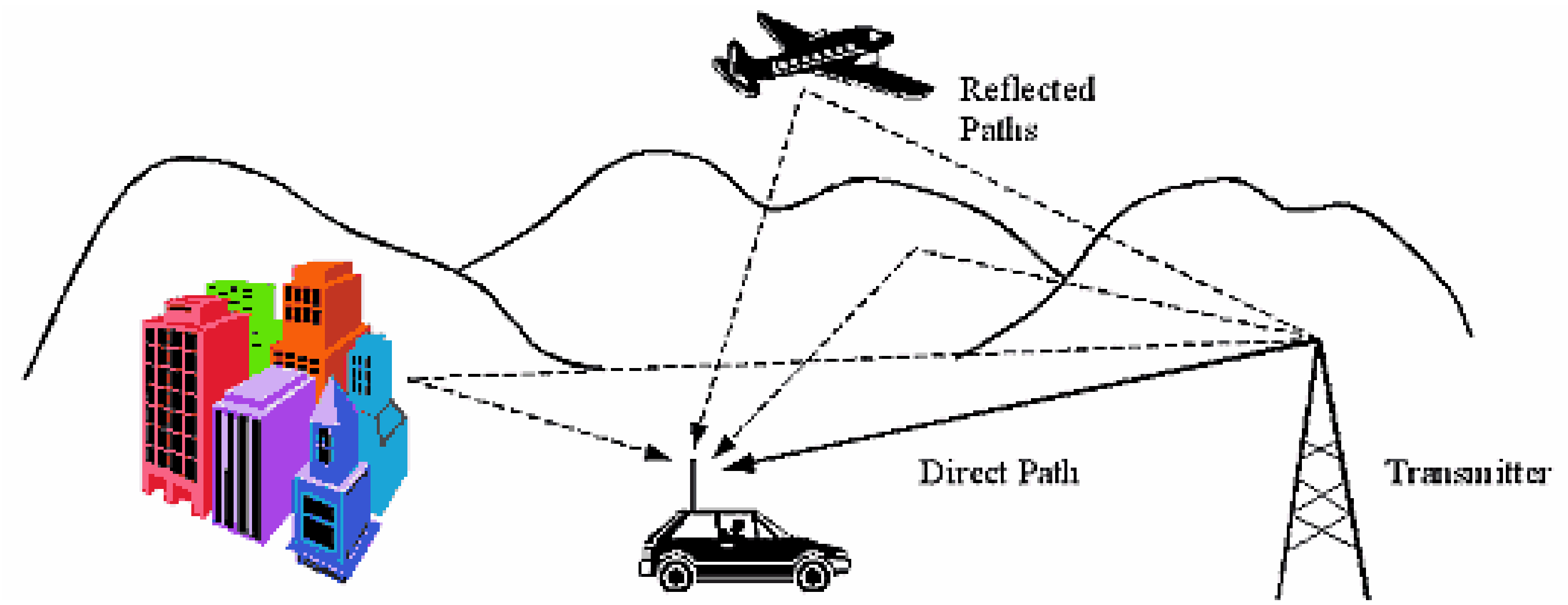
16-QAM


MSB = 10
MSB = 00
Q
+6
00
10
10
00
+4
01
11
11
01
+2
I
–6
–4
–2
+2
+4
+6
–2
01
11
11
01
–4
00
10
10
00
–6
MSB = 11
MSB = 01

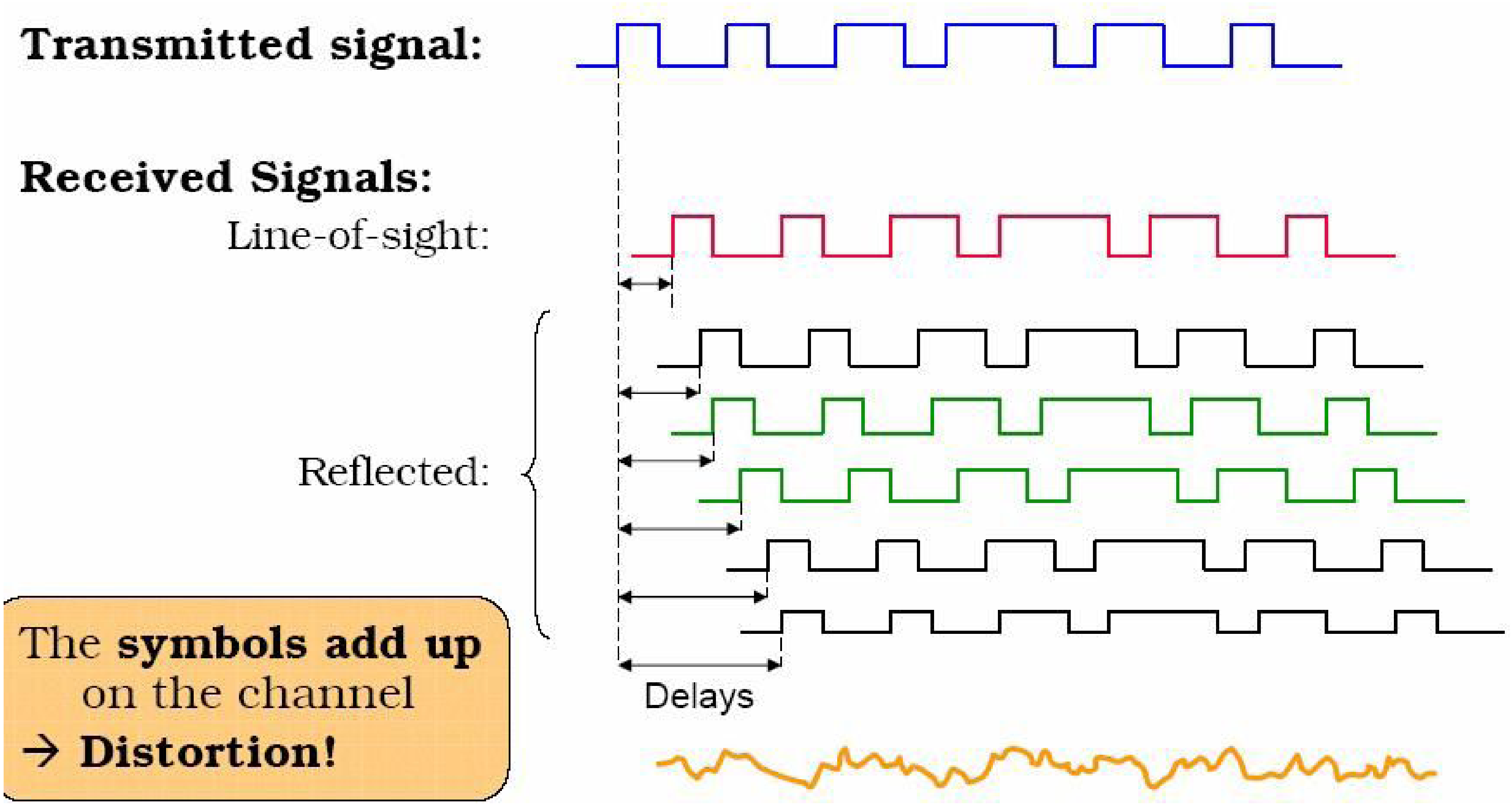

Q
00
10
3
10
00
ms = 10
ms = 00
01
11
1
11
01
–3
–1
1
3
I
01
11
–1
11
01
ms = 11
ms = 01
00
10
–3
10
00

OFDM

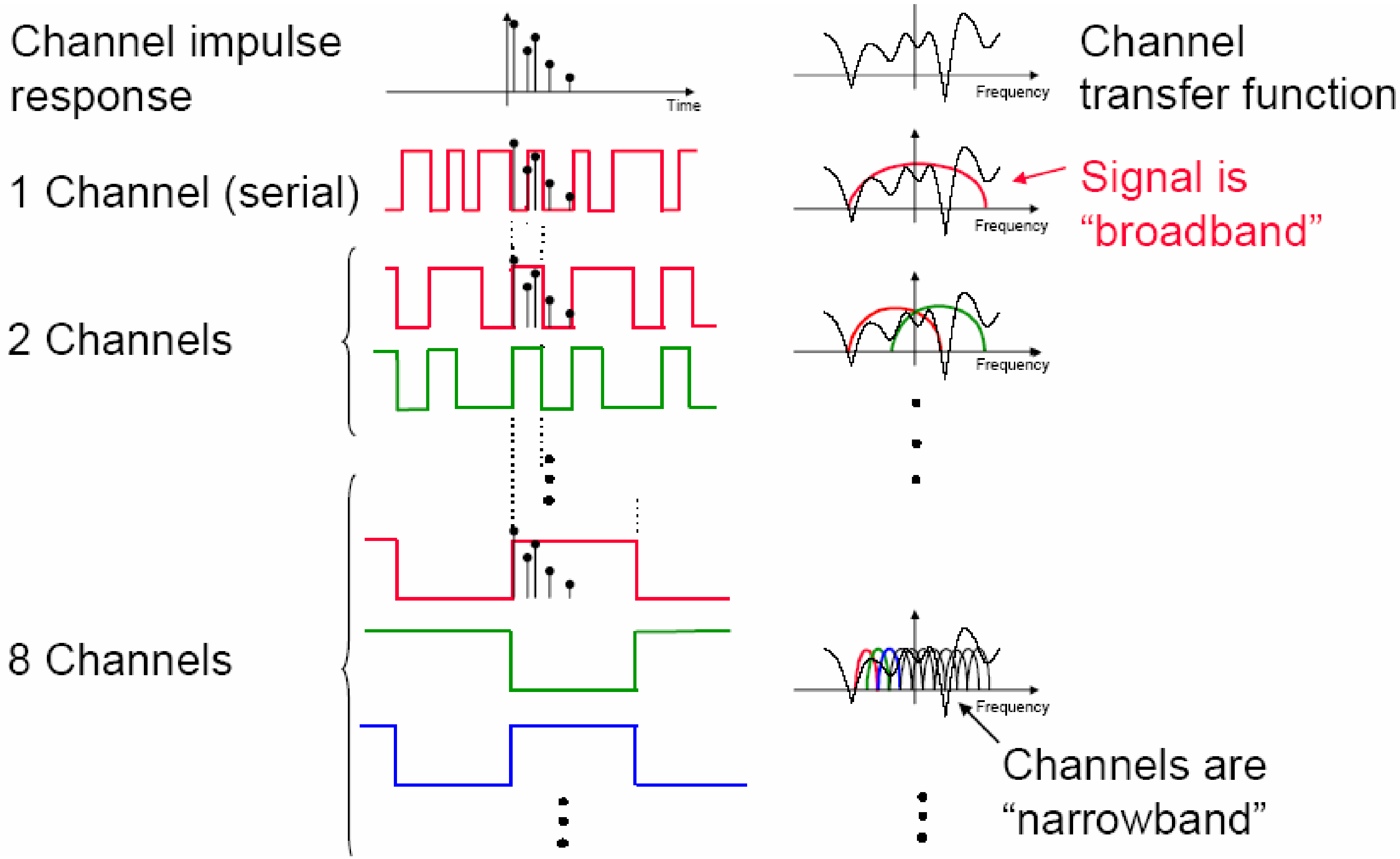
- Orthogonal Frequency Division Multiplex
- Satellite and Terrestrial
- Multipath signals
- Ghosting



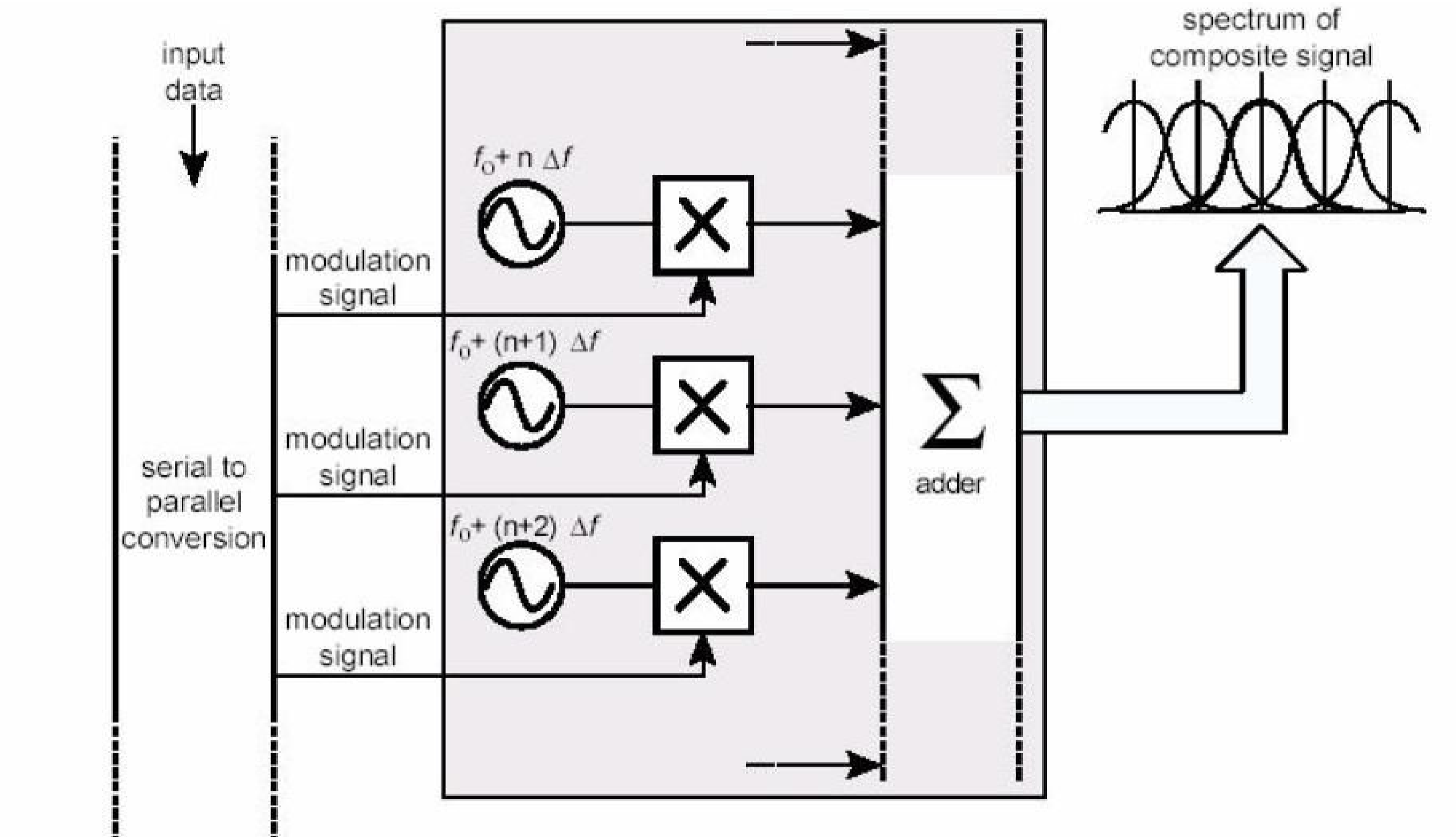
Inter-Symbol Interference



Parallel Transmission

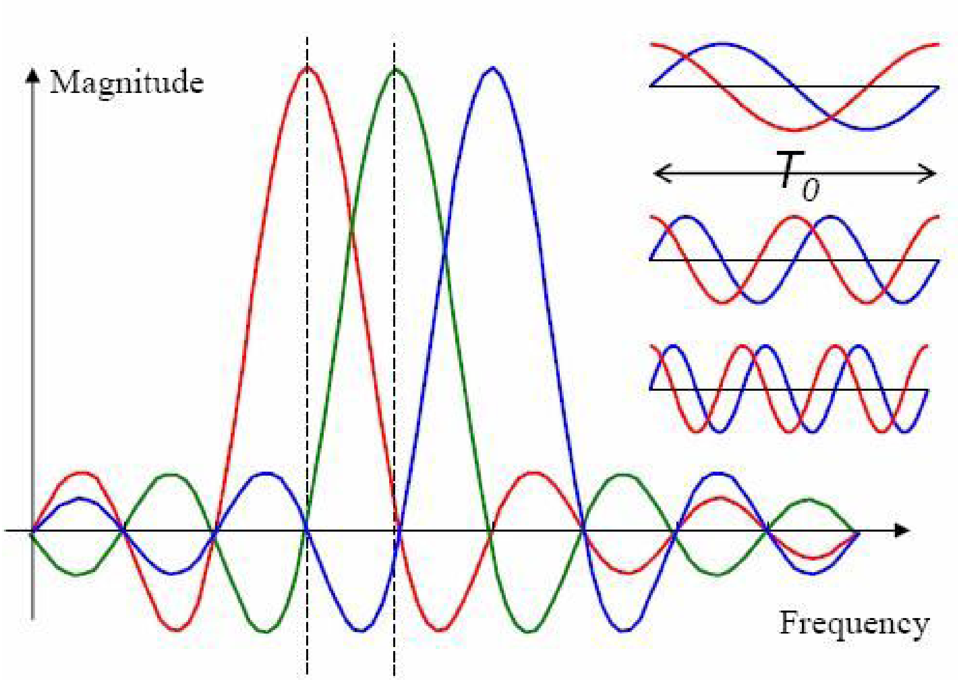


Visualization of OFDM



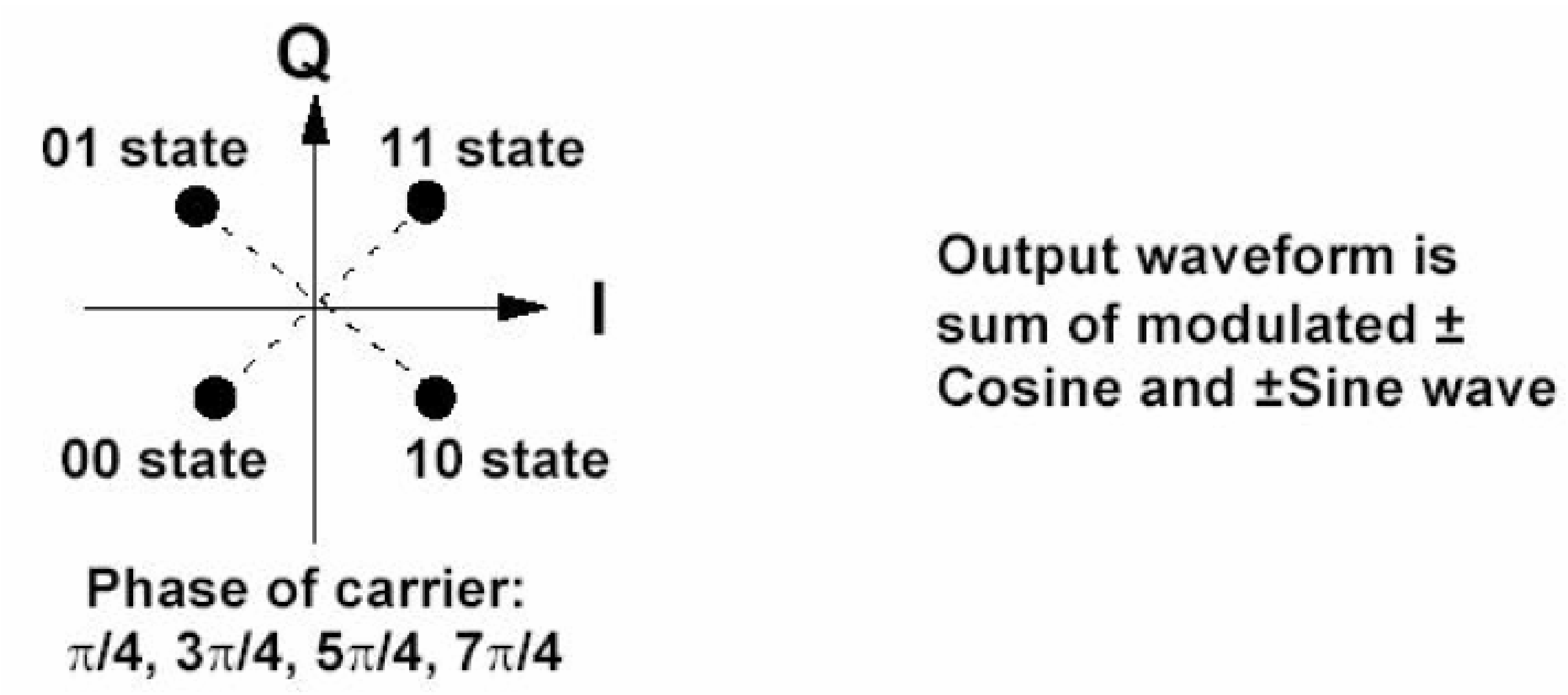
Spectrum of the modulated data symbols

- Rectangular Window of duration *T0*
- Has a sinc-spectrum with zeros at 1/*T0*, other carriers are put in zeros
- Sub-carriers are orthogonal



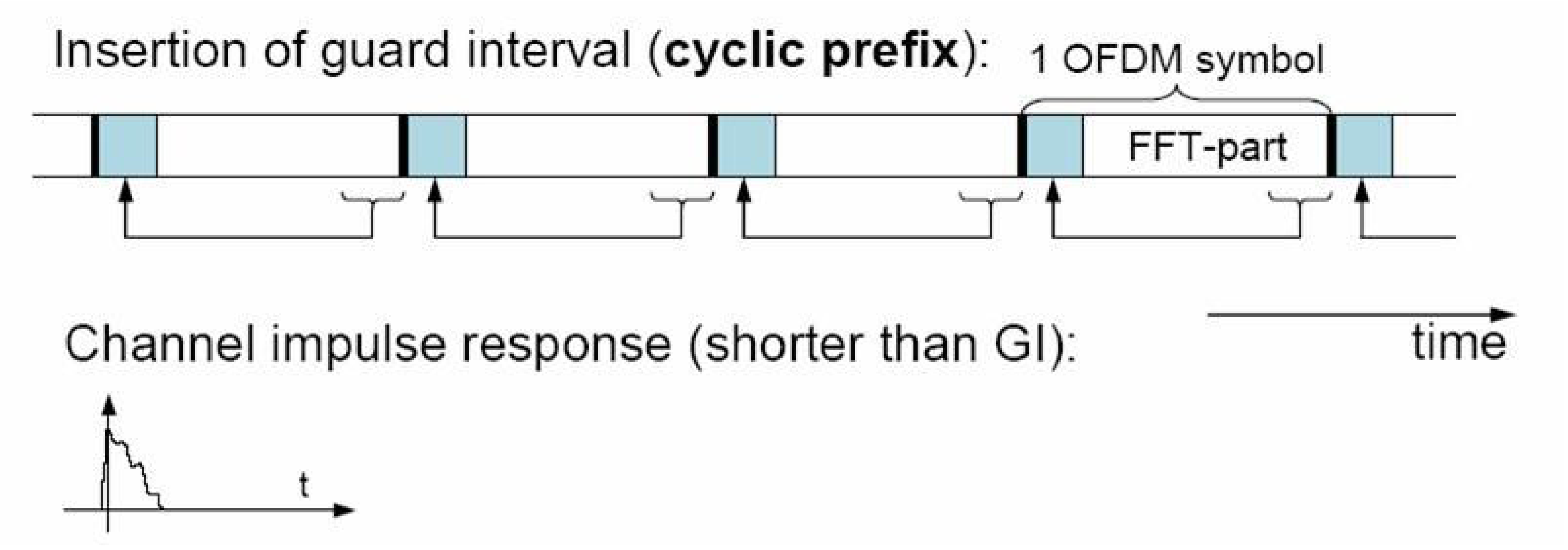
Carrier Modulation

- Symbol of sub-carrier is QPSK moduleted
- Other symbol-alphabets can be used as well (BPSK, m-QAM)

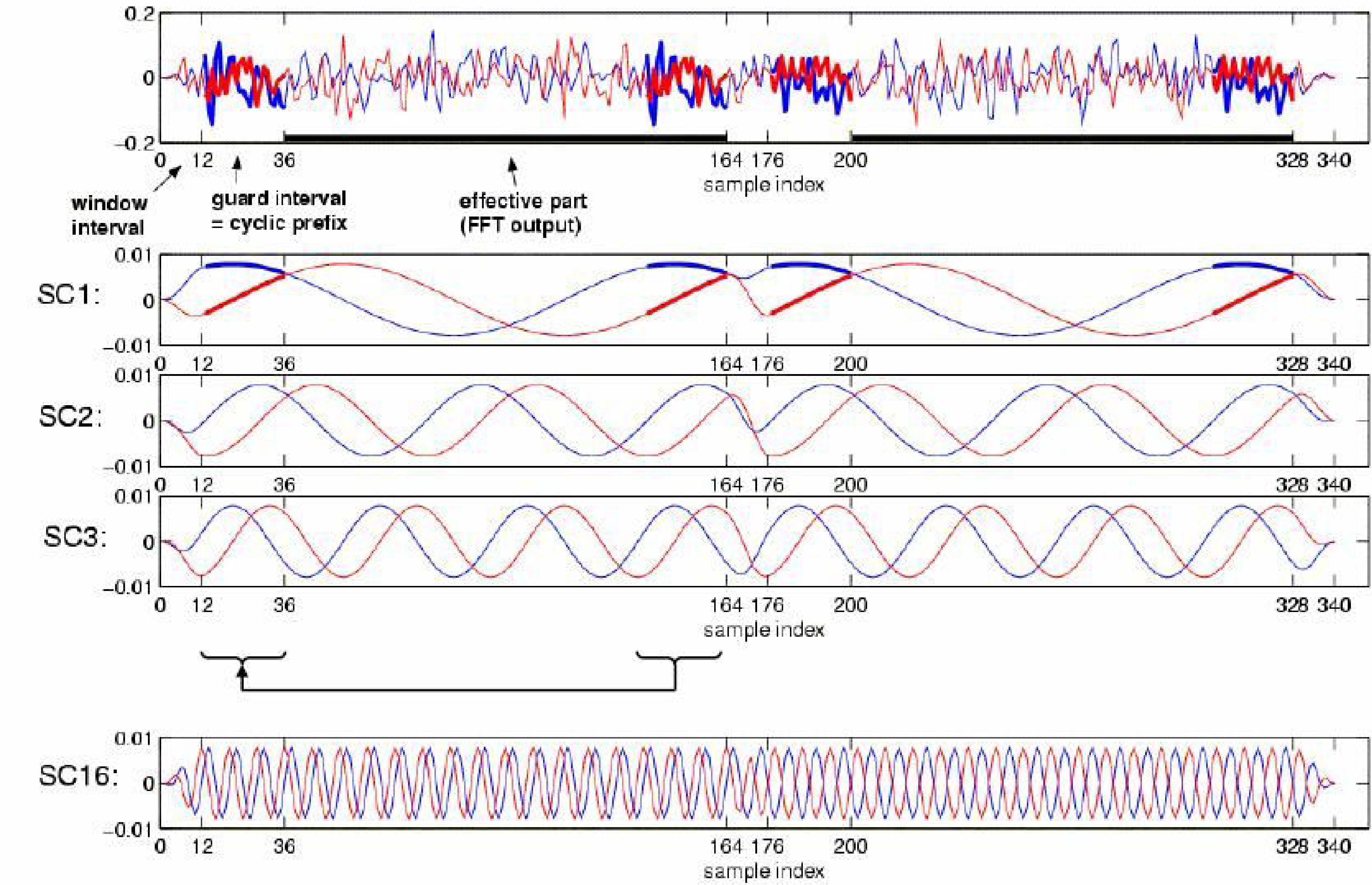


Guard Interval - GI

- During the most of the symbol duration – signals in phase
- The only problem – transition due to the channel
- Channel response in time

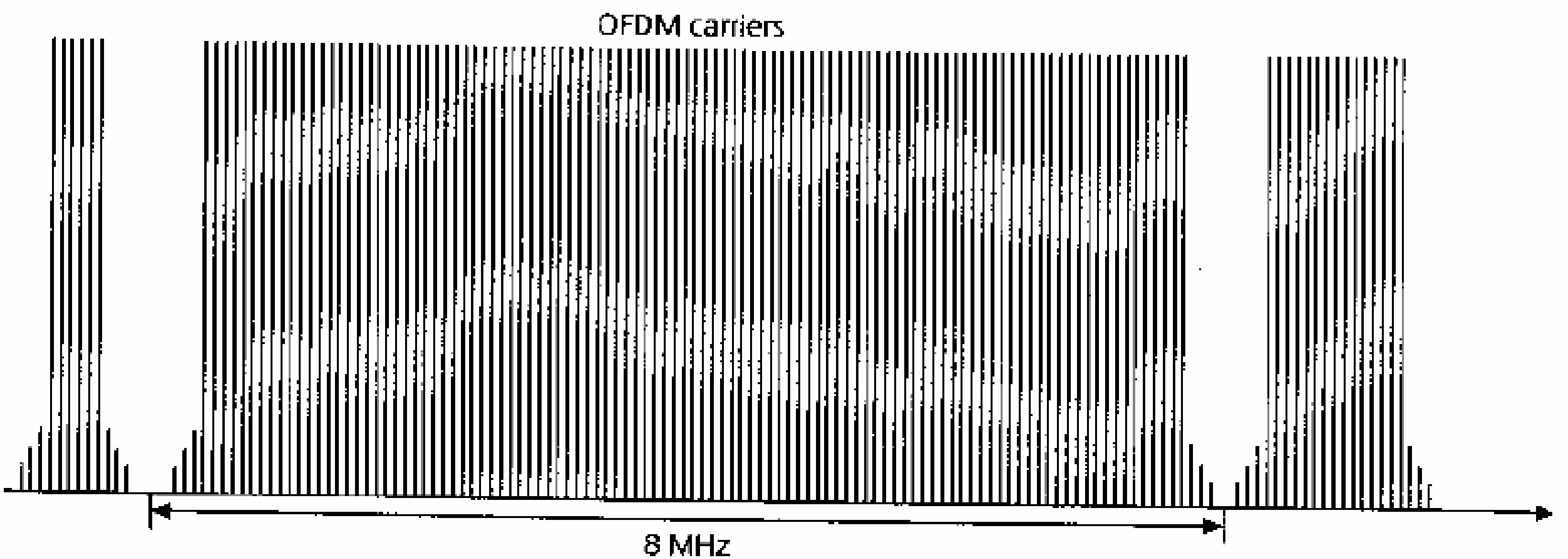


time–domain OFDM signal:



OFDM Spectrum

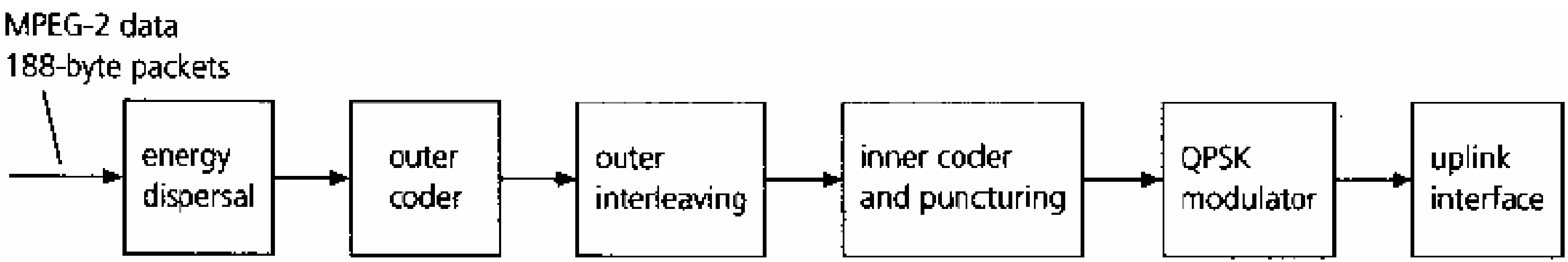
• Uniformly distributed – power efficiency
• The same as a conventional TV channel – 8MHz
• Same transmitter
• High tolerance to fading and multipath interference
Good for single channel frequency network SFN

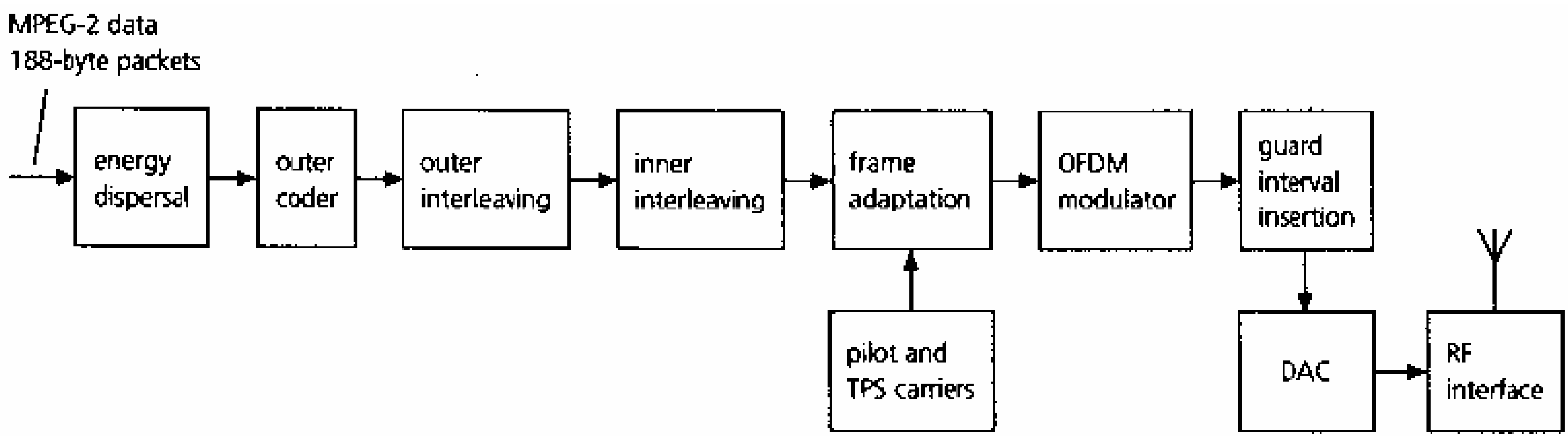


COFDM

- Includes powerful FEC – thus Coded
- Monitors the channel noise and narrow band interference
- Used in DVB-T
- 2k - 2048 carriers, 8k - 8192

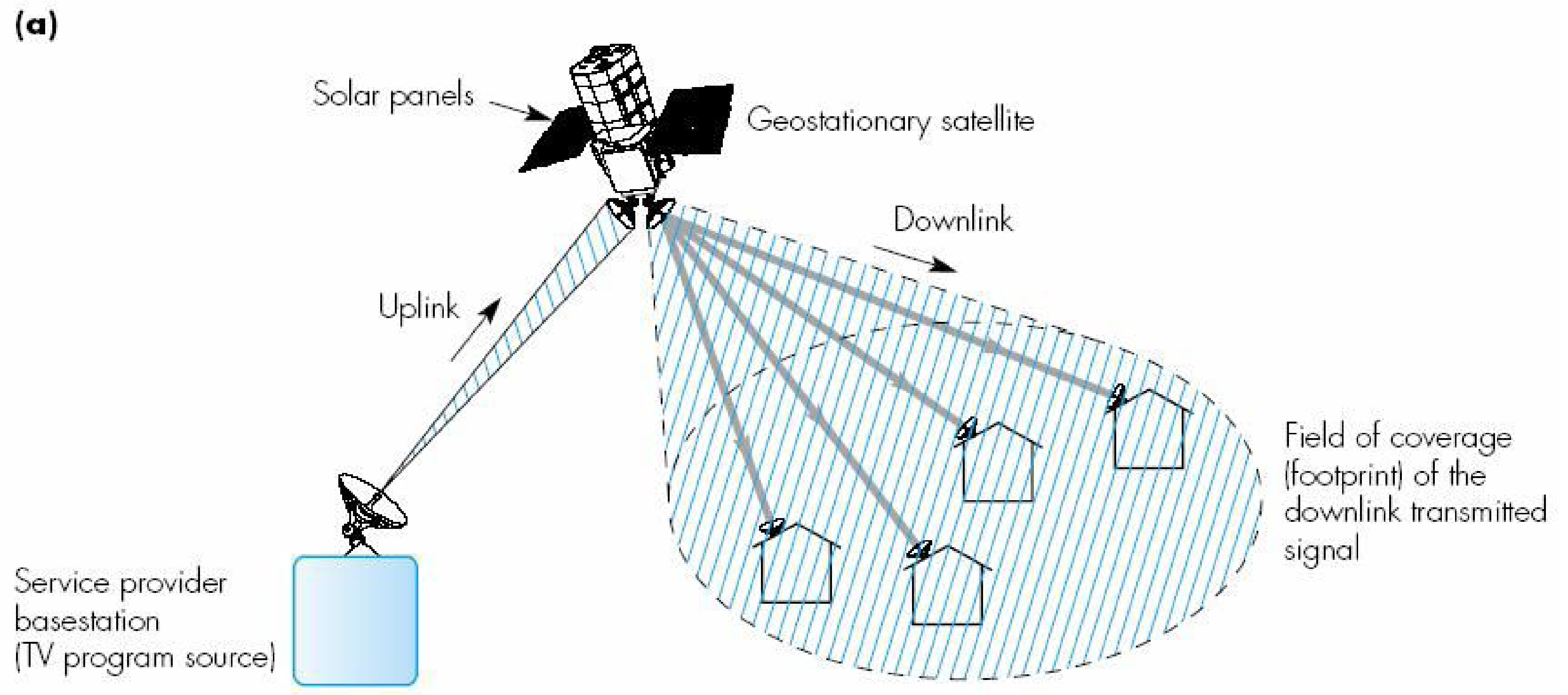
DVB-S and DVB-T





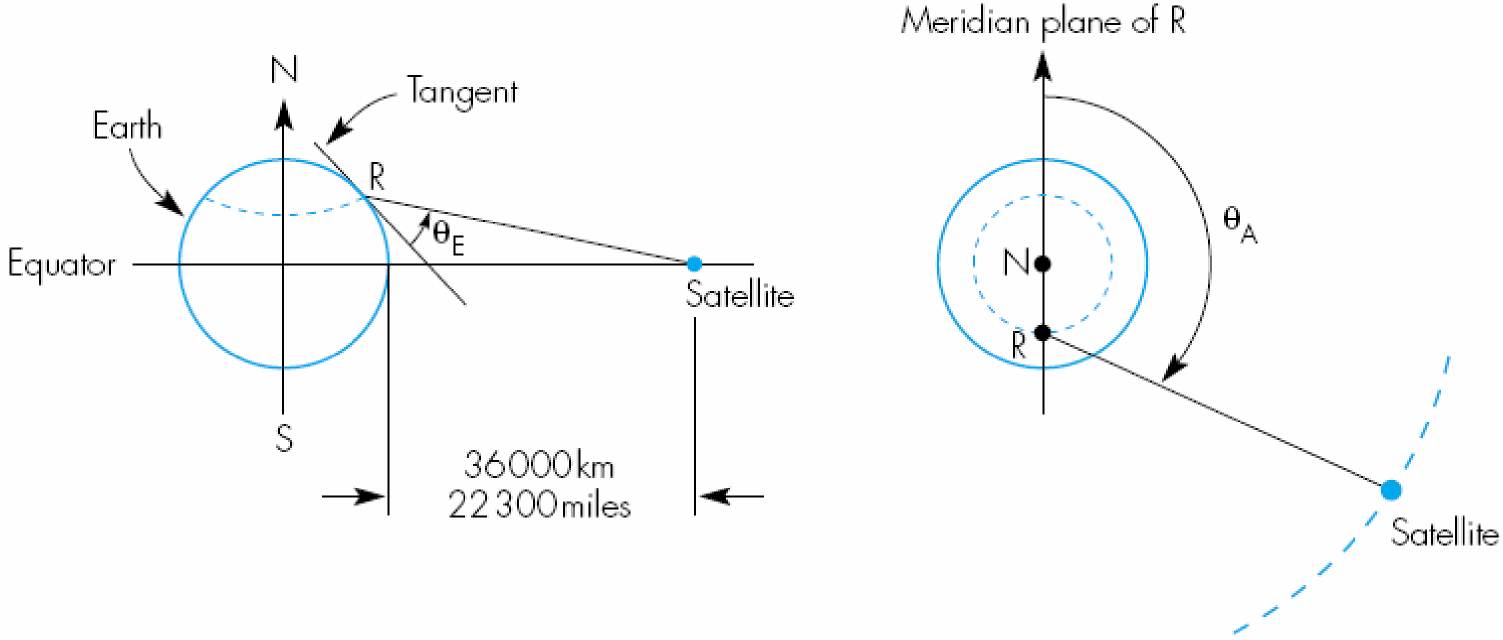
Satellite TV

- *Geostationary satellites: satellites are geosynchronous*
- *36000km above equator*



Satellite positioning

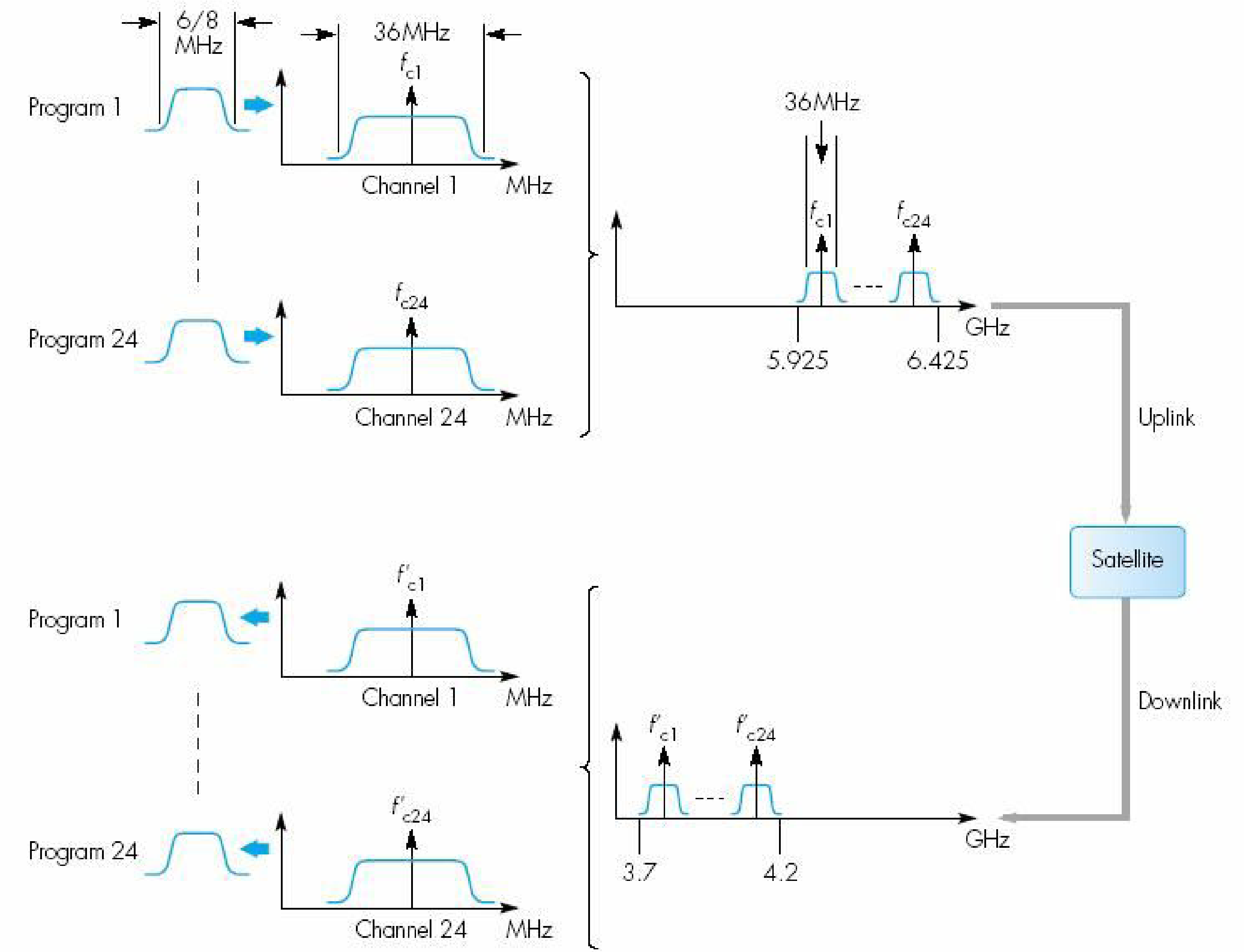
- *On-board motors make sure that the tolerance is 0.2º*
- *Elevation and Azimuth define satellite's position*



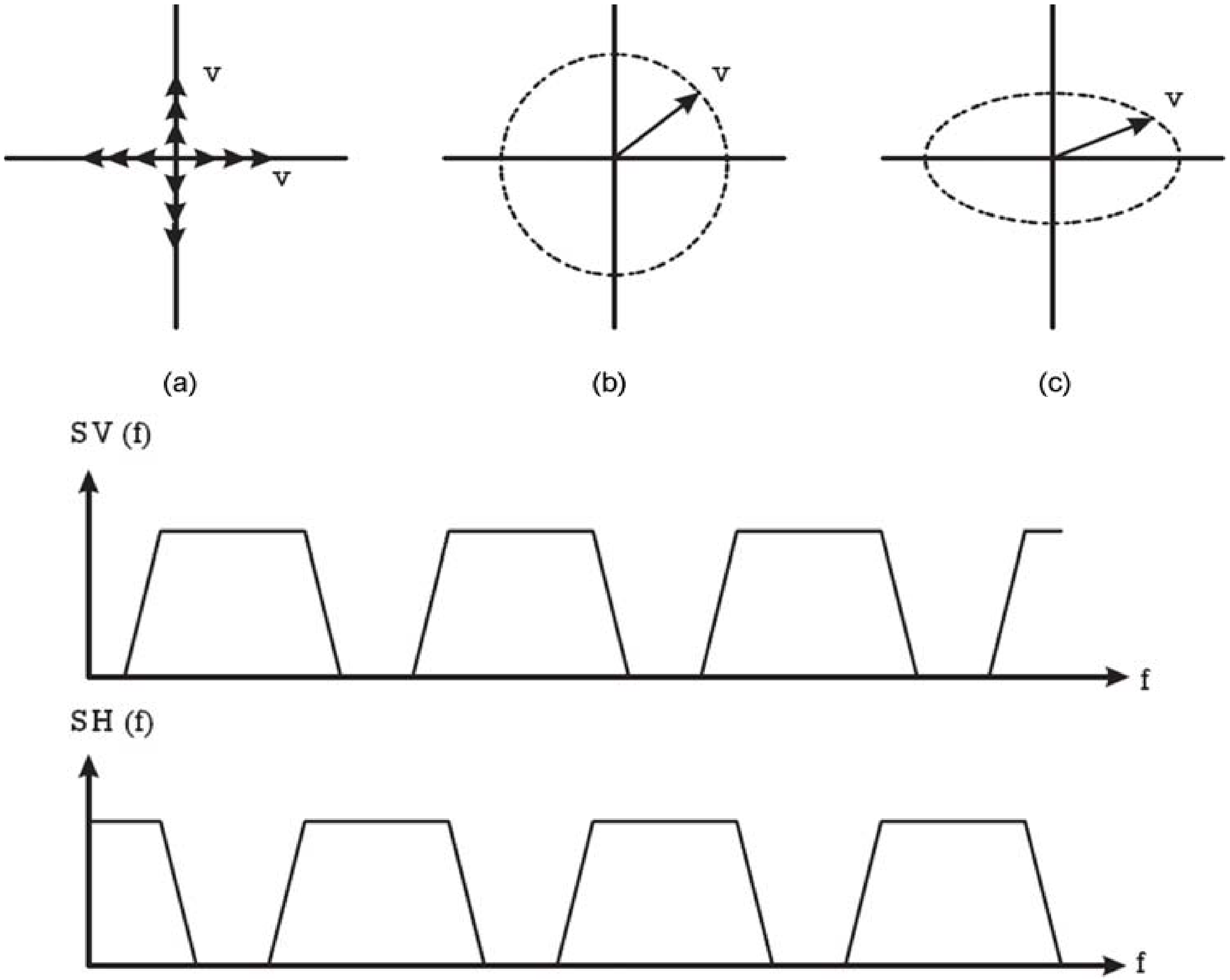
θ_E = angle of elevation θ_A = azimuth

(N = north, S = south, R = point of reception on earth's surface)

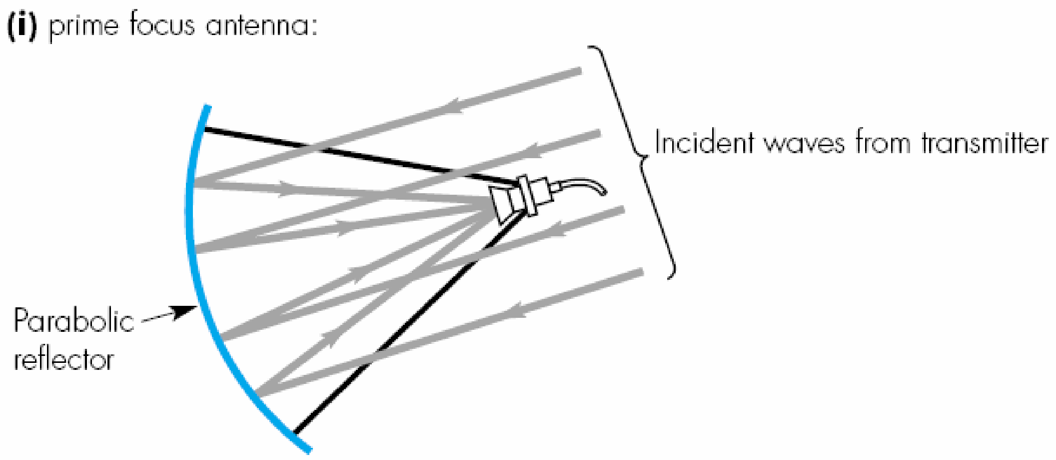
Frequency allocation

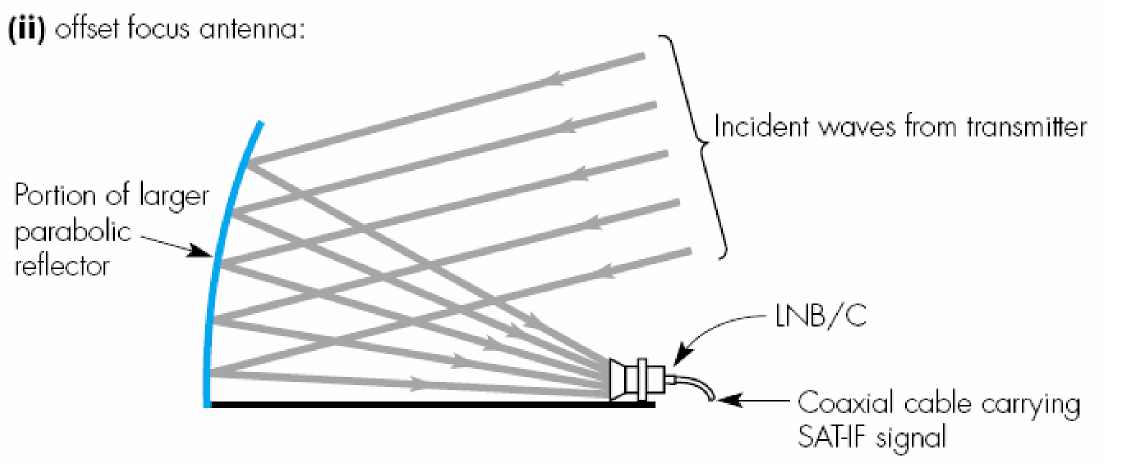


Orthogonal polarization



Antenna designs



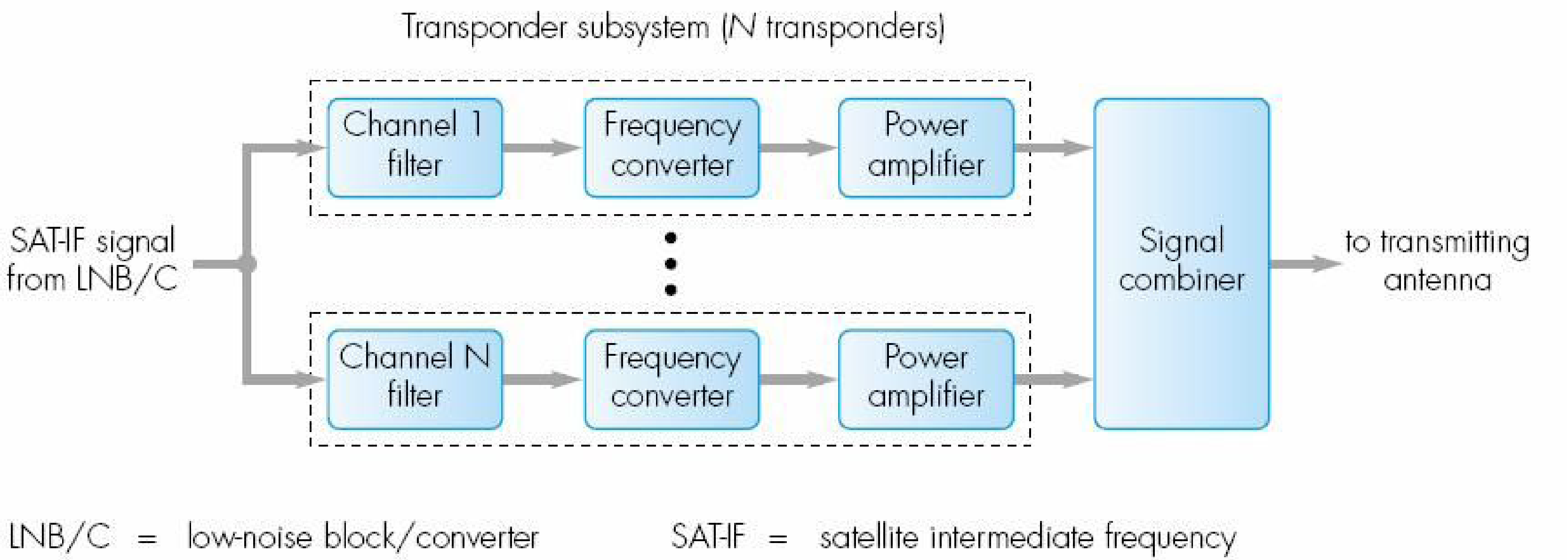


Low-noise block converter – LNB/C

Satellite intermediate frequency (SAT-IF)

Transponder

- *Microwave power amplifiers*
- *Channels separated*
- *Combined signal is broadcasted to footprint*
- *At receiver side - inversion*



Digital Television

- *QPSK = 4-QAM, 2b/symbol*
- *DTV KU band – 10.7 – 14.5 GHz*
- *Downlink*

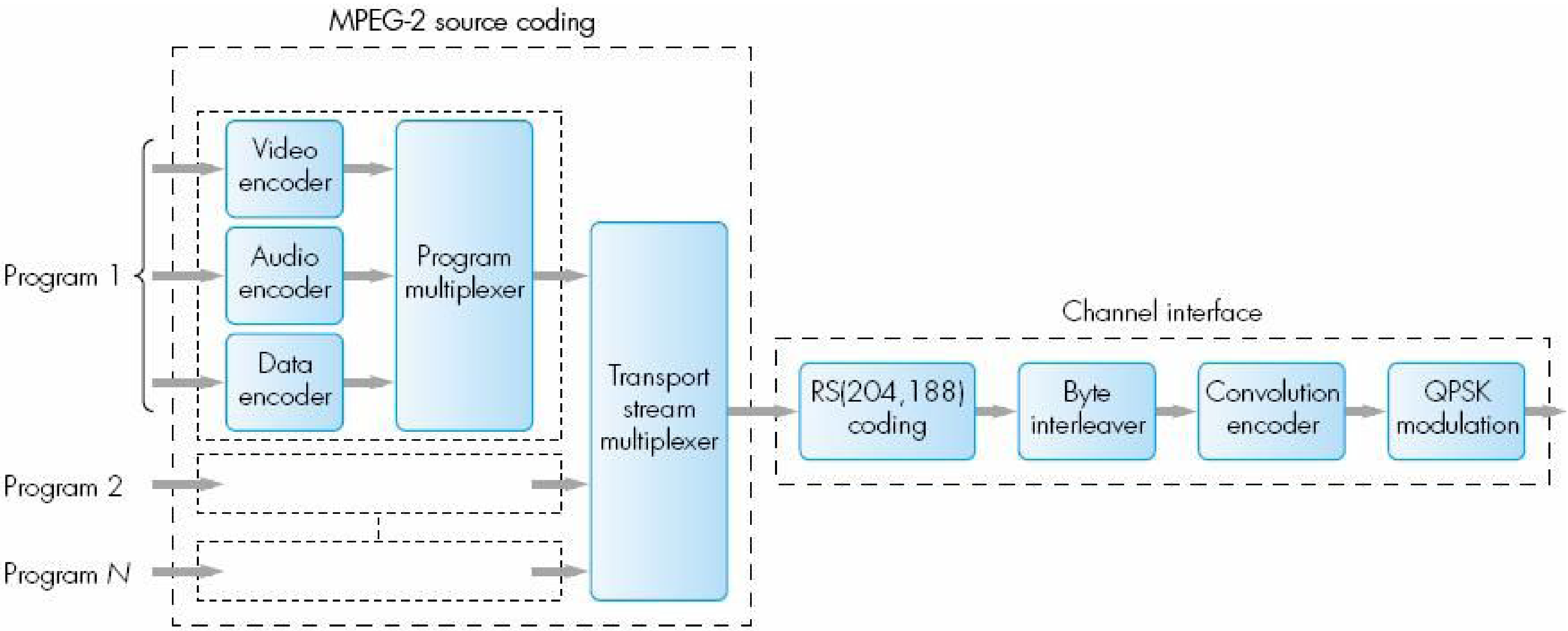
– 10.7-11.7GHz analogue TV

– 12.2-12.7GHz digital TV USA, 11.7-12.5GHz EU

- *DBS, USA, 32x24MHz – 40Mbps*
- *DVB-S, EU, 40x33MHz – 55Mbps*

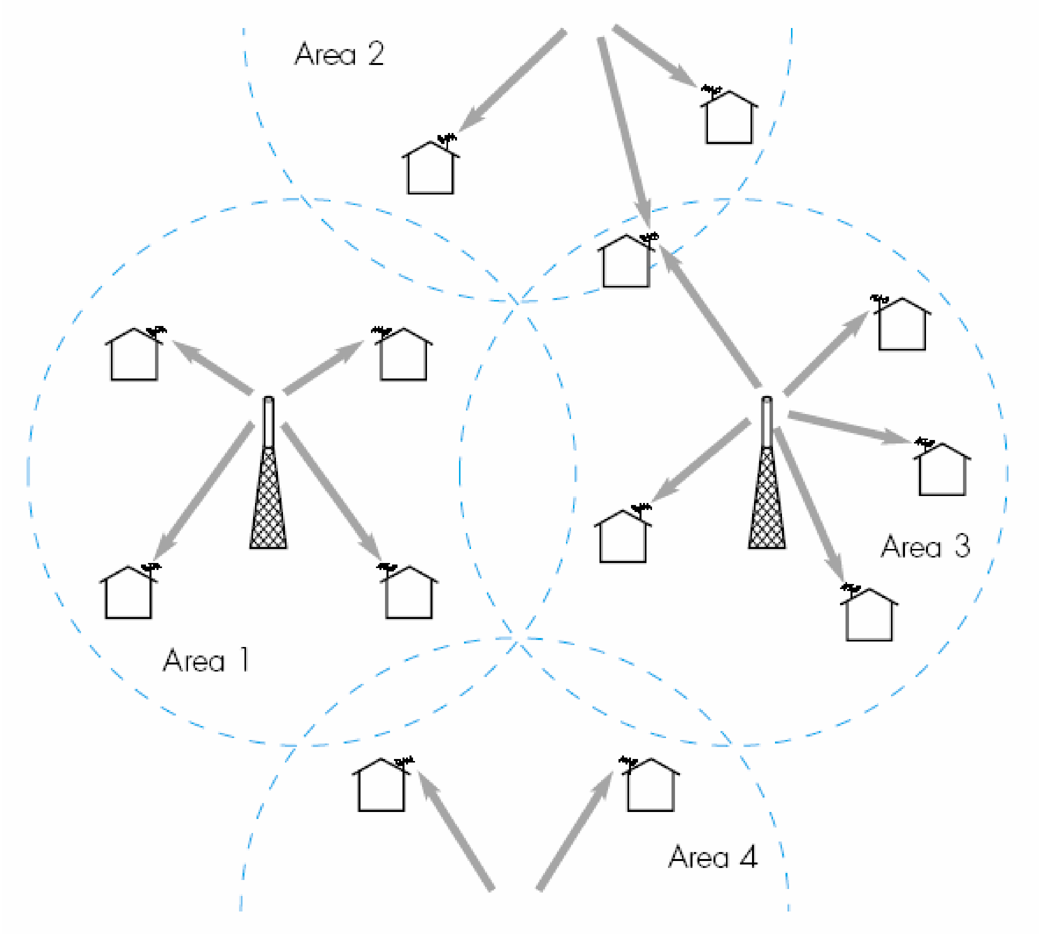
SATV Channel Interface

- *MPEG-2 Transport stream multiplex*

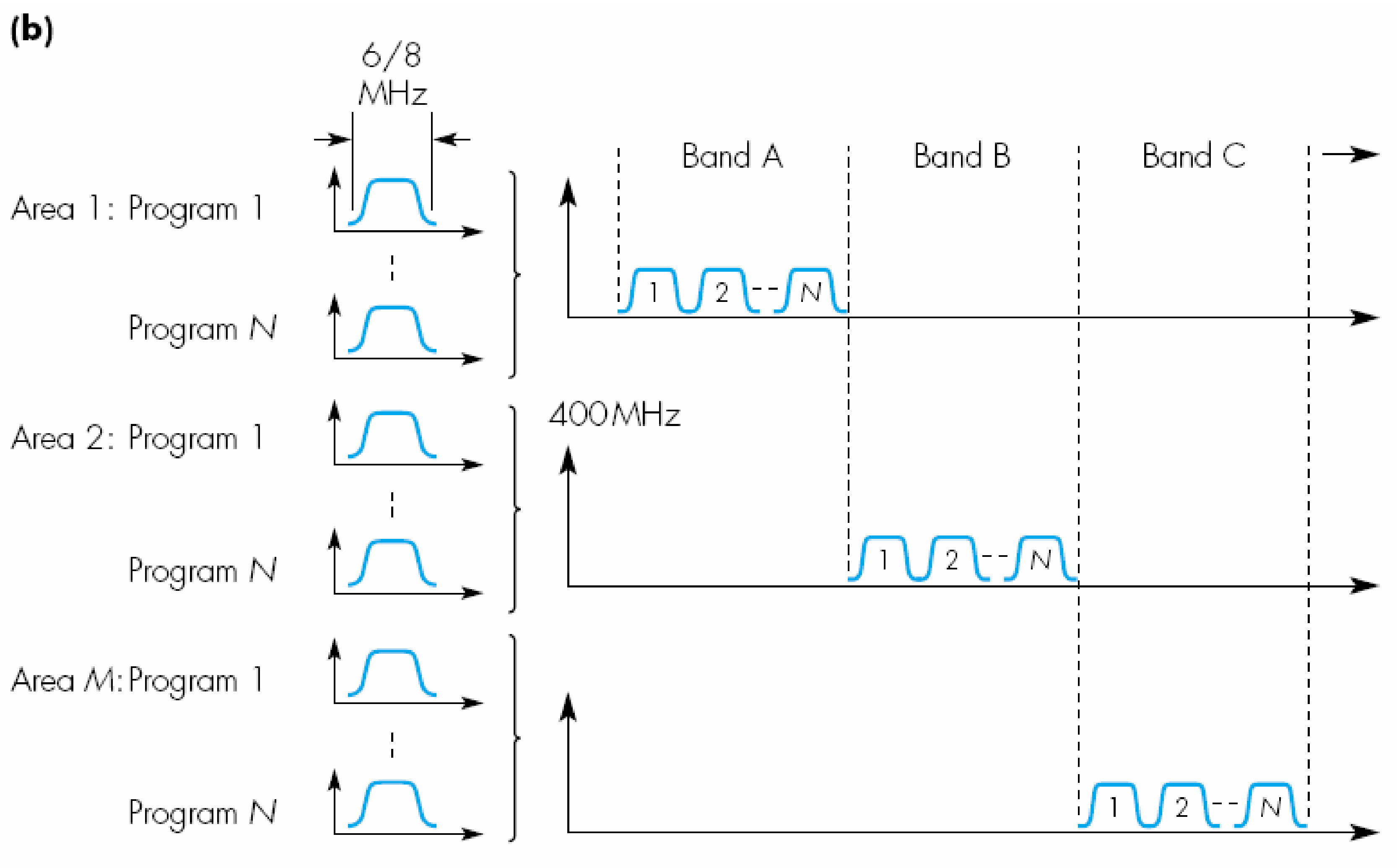


Terrestrial Television

- *VHF*
- *UHF*
- *47-860MHz*
- *>100MHz – linear*
- *More transmitters*
- *MFN - depicted*

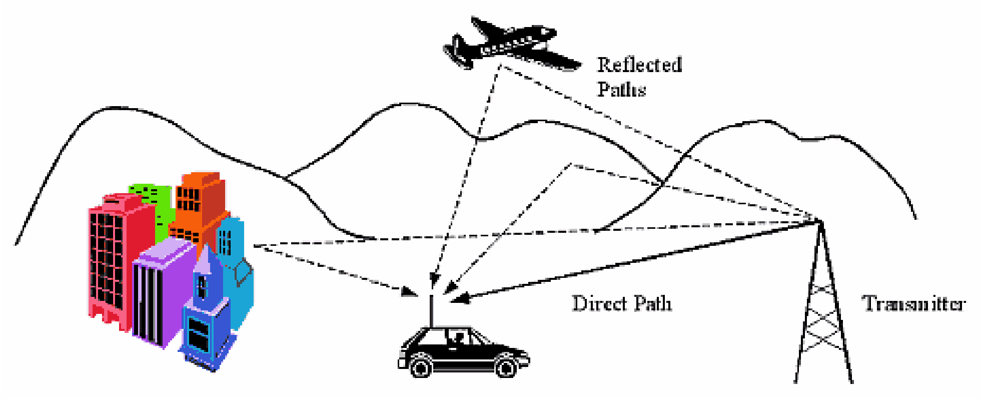


MFN Frequency Usage

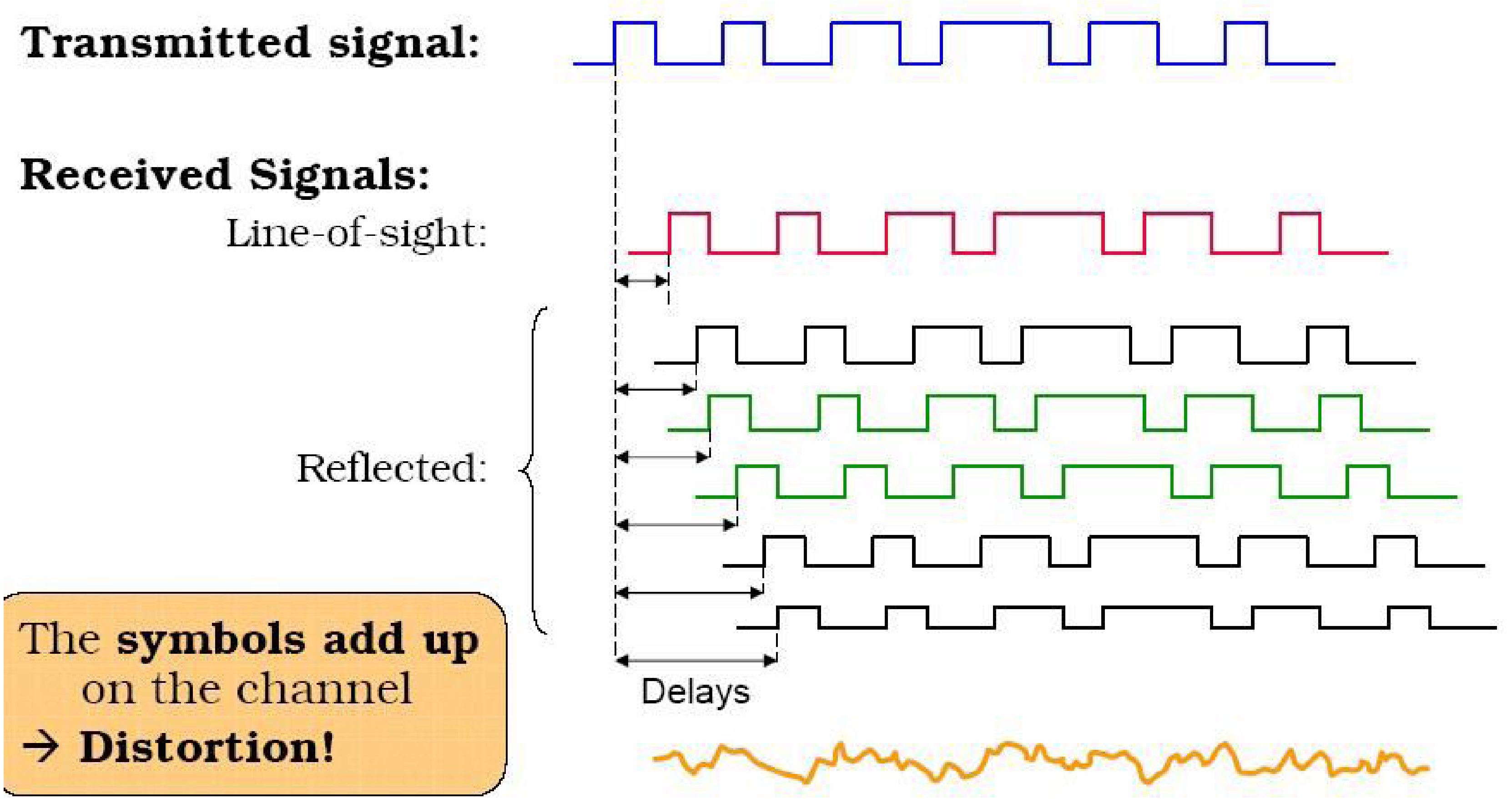


Digital Terrestrial TV

- *Different modulation*
- *Microwaves reflect from objects*
- *Multipath transmission*
- lambda = *c/f = 3x10⁸ / 500x10⁶ =0.6m*
- *Reflection, refraction*
- *Multipath dispersion, delay spread*
- *Inter-symbol interference*
- *Solution COFDM – coded OFDM*

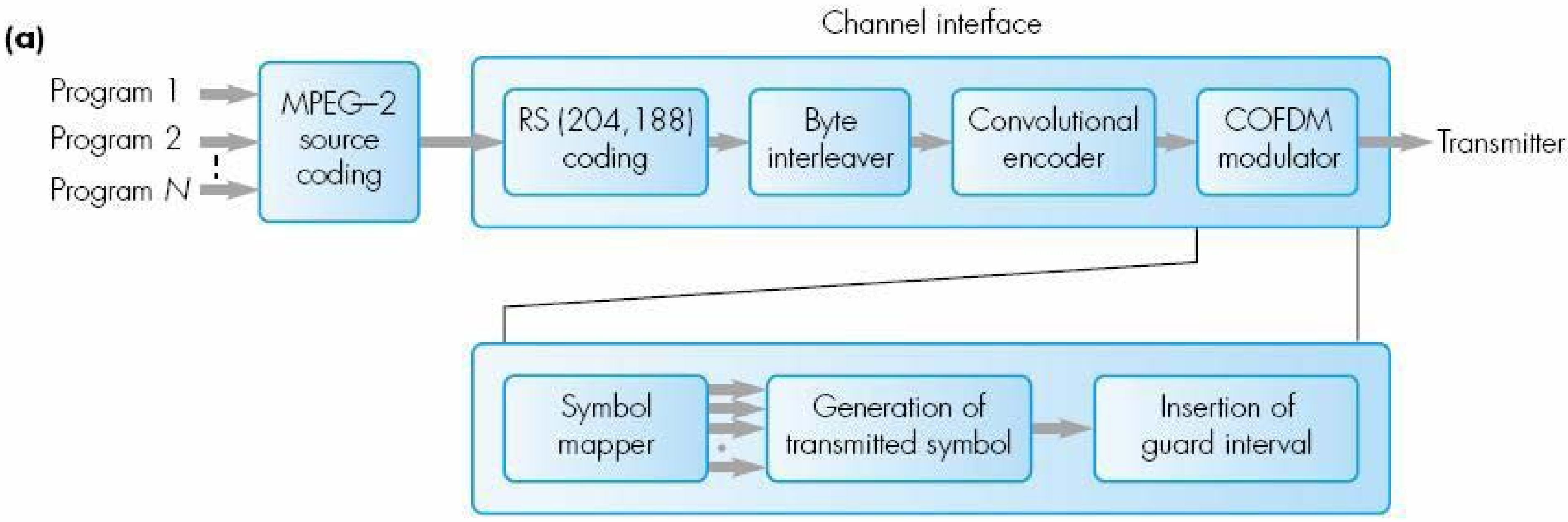


Inter-Symbol Interference



Channel Interface

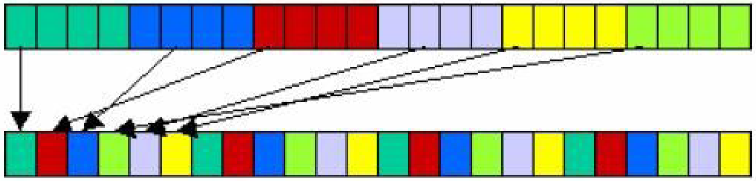
- *RS(204,188)*
- *Interleaving – breaking down very long error bursts for FEC*
- *By rearranging the order of transmission of the bytes*

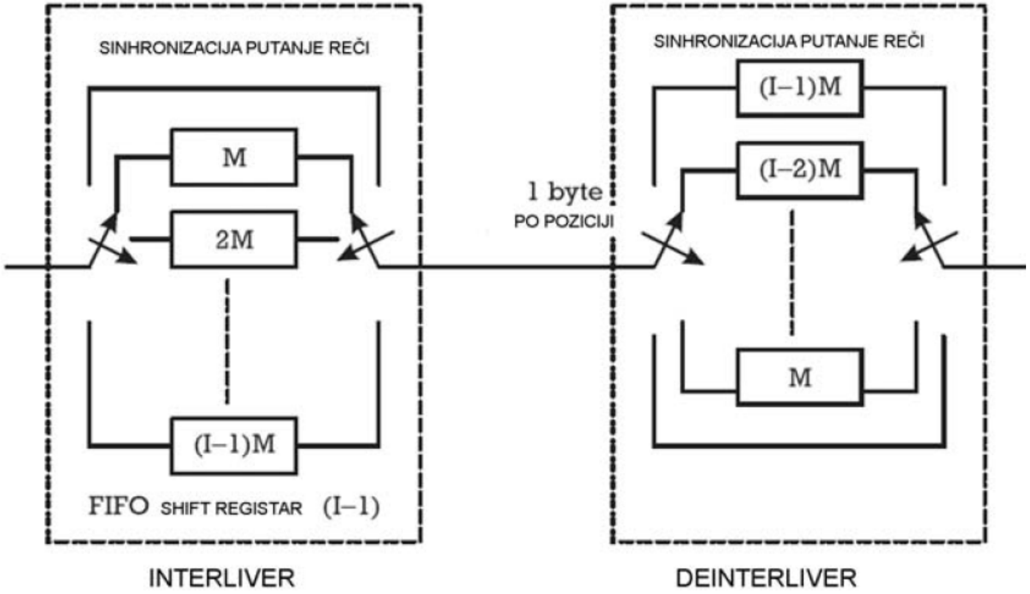


Forney interleaving

- *To spread out the error bits – enables more efficient outer coding*
- *DVB-T: i=12 branches L=204 packet length,*

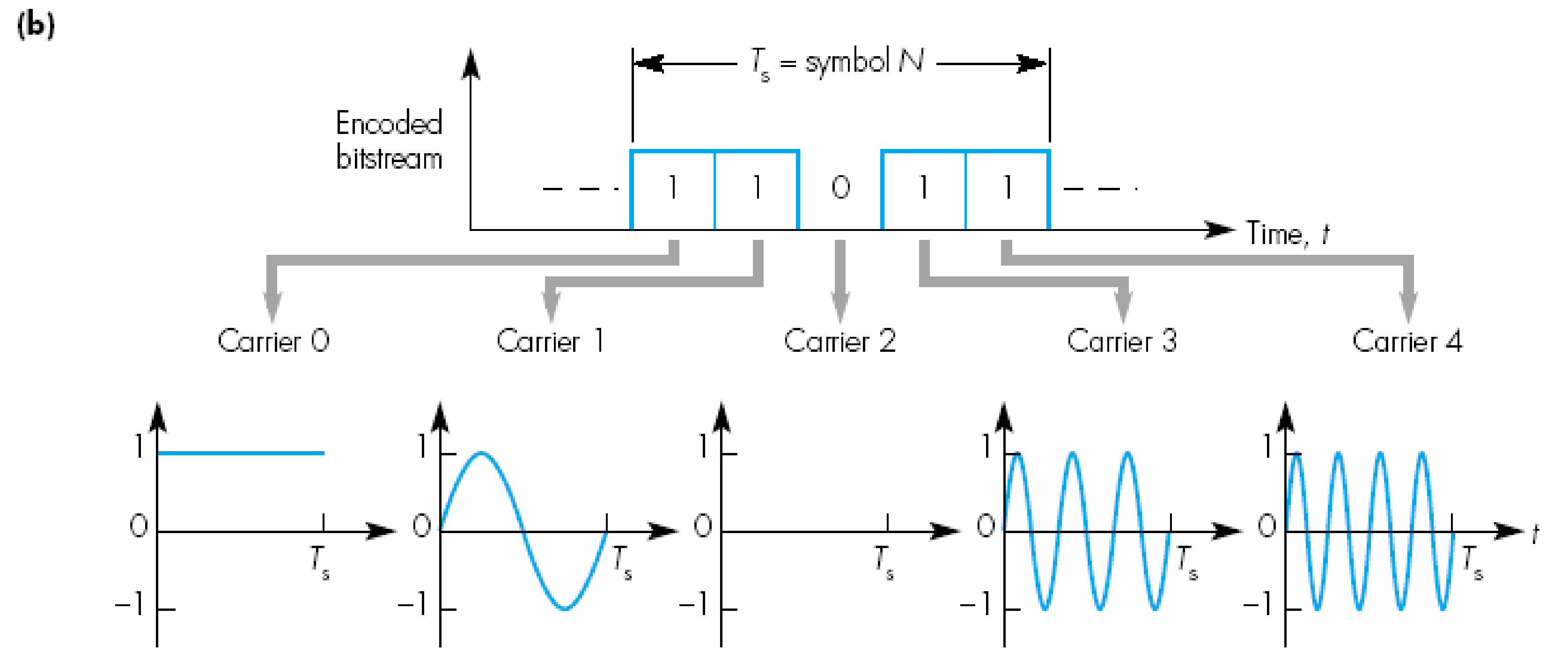
M=(L/i)xj - FIFO buffer size, j=0,11





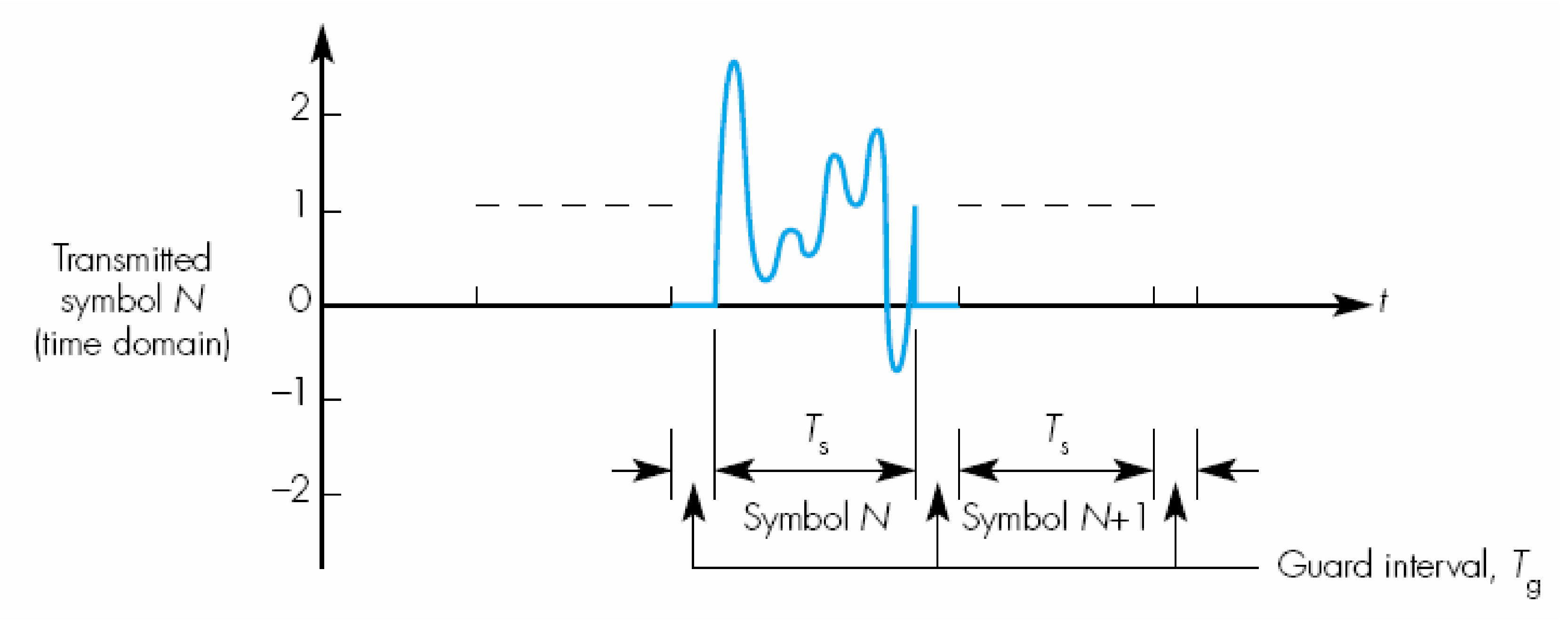
COFDM Principles

- *Example of multiple orthogonal carrier modulation*
- *5 carriers, ASK on-off keying, frequencies fs , 2fs , 3fs , and 4fs*
- *In the real DVB-T case, QPSK, N=[2k, 8k] carriers*



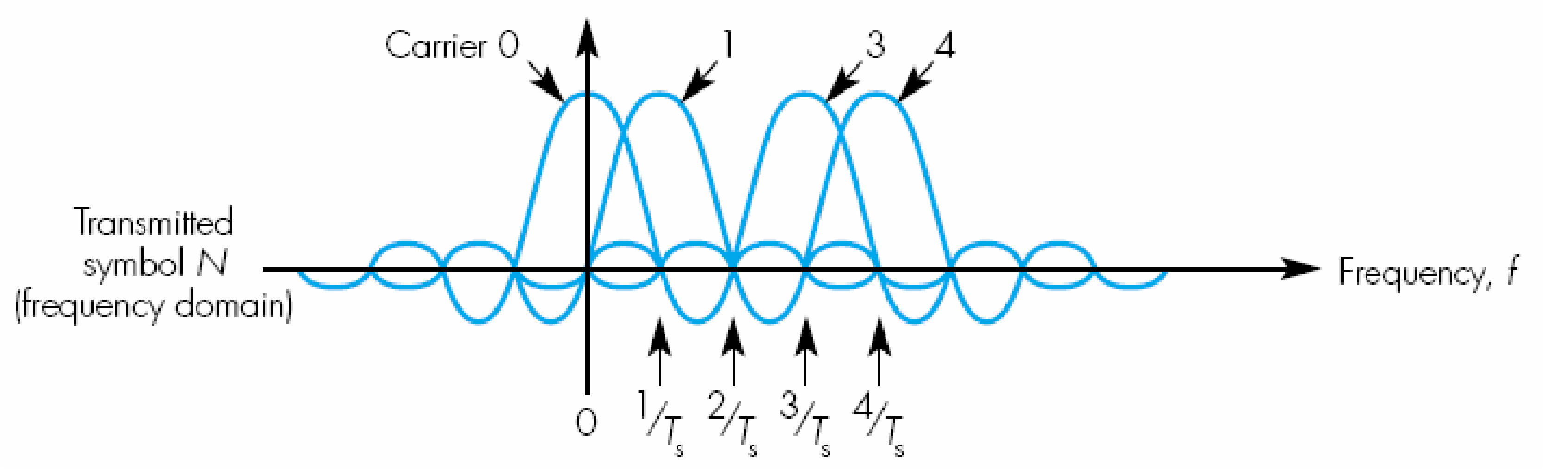
Guard interval

• *Receiver waits Tg (guard interval) before starting to process the symbol*
• *In order to make sure all delayed versions of the symbol have arrived*



Orthogonal carriers

- *To be able to determine which subset of the carrier-ensemble is present in a given symbol, carriers need to be ORTHOGONAL*
- *At carrier frequency ALL other carriers are ZERO*
- *Strict fixed spacing of 1/Ts between adjacent carriers*



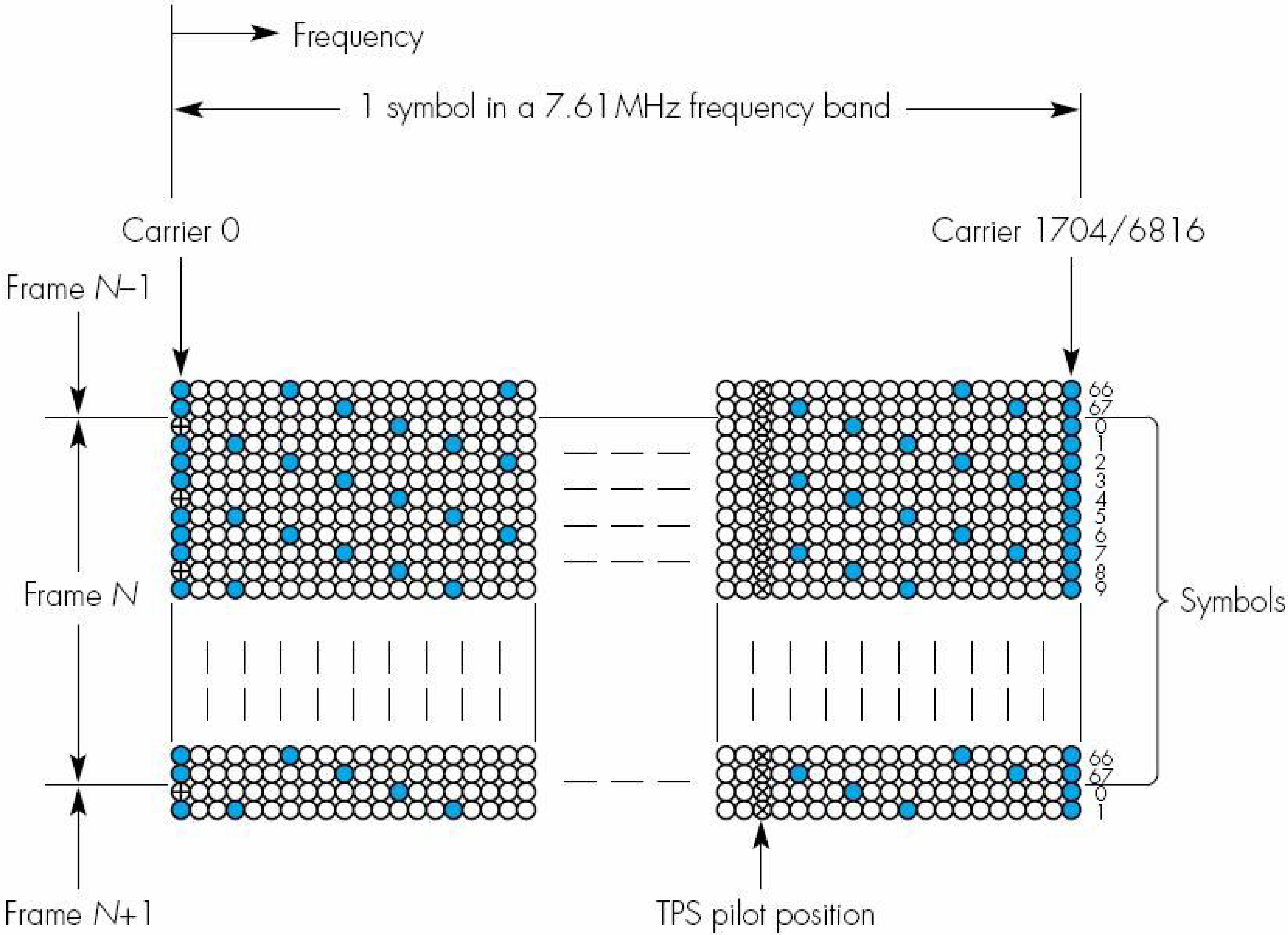
Receiver Synchronisation

- *Synchronising symbols essential*
- *Stream of symbols is divided into 68-symbol FRAMES*
- *Number of active carriers 2k – 1705, 8k – 6817*
- *Each carrier modulated with*

4-QAM 16-QAM or 64-QAM

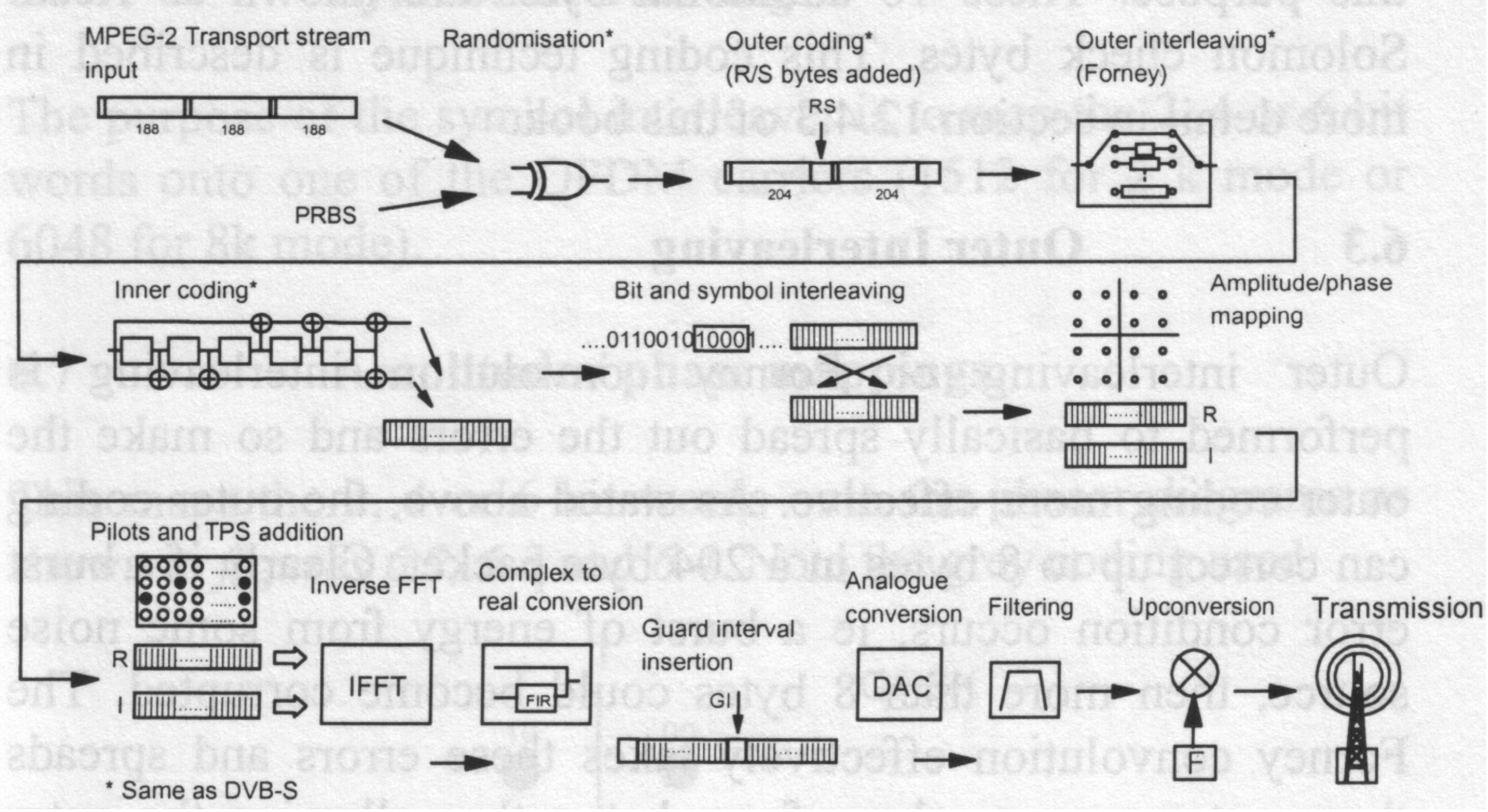
2, 4 or 6 bits/signal transition

- *Continual pilot*
- *Scattered pilot*
- *TPS pilot – information on operational parameters*



Frequency
1 symbol in a 7.61MHz frequency band
Carrier 0
Carrier 1704/6816
Frame N–1
Frame N
Frame N+1
66
67
0
1
2
3
4
5
6
7
8
9
Symbols
TPS pilot position

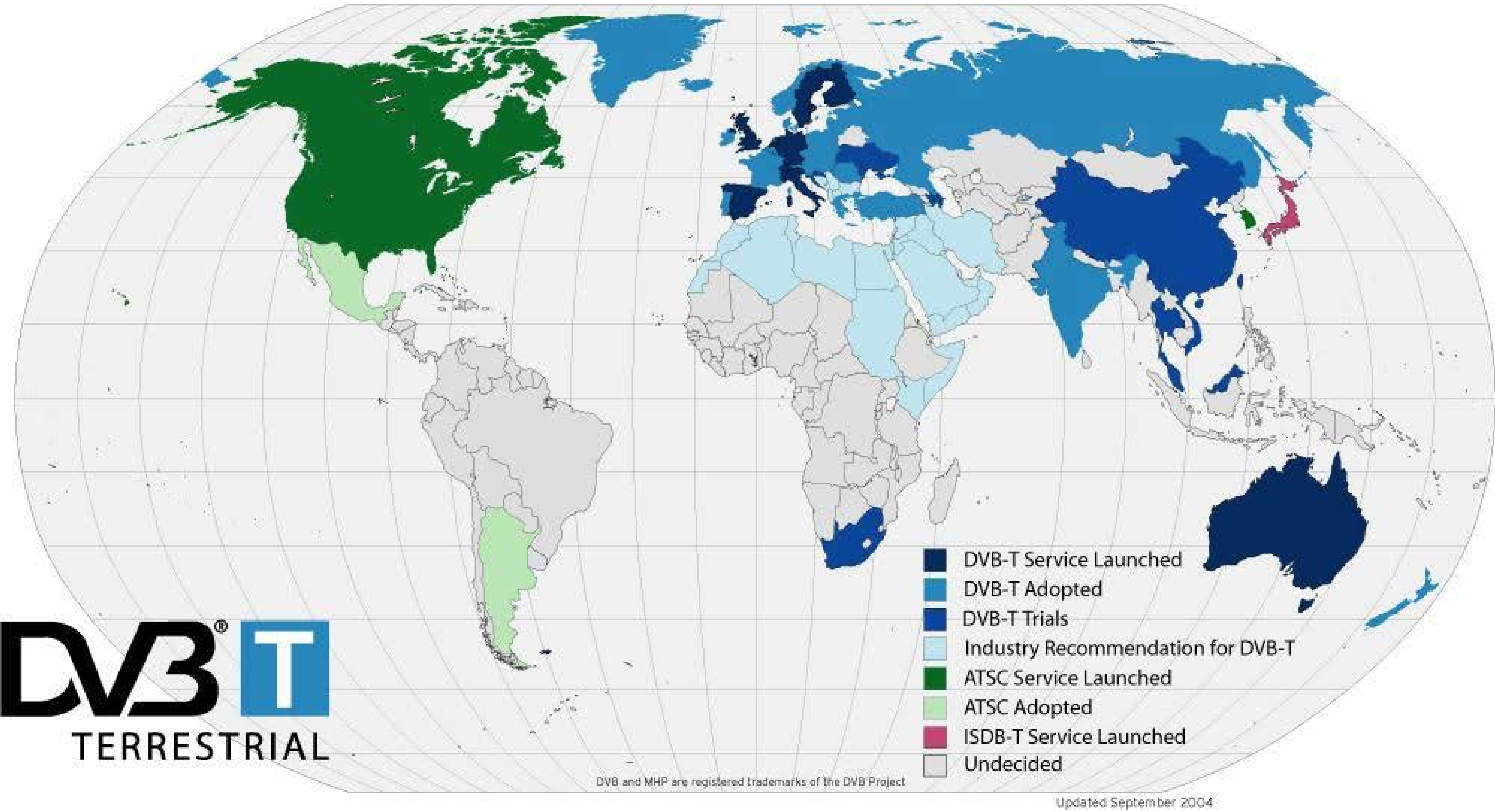
DVB-T Transmission System



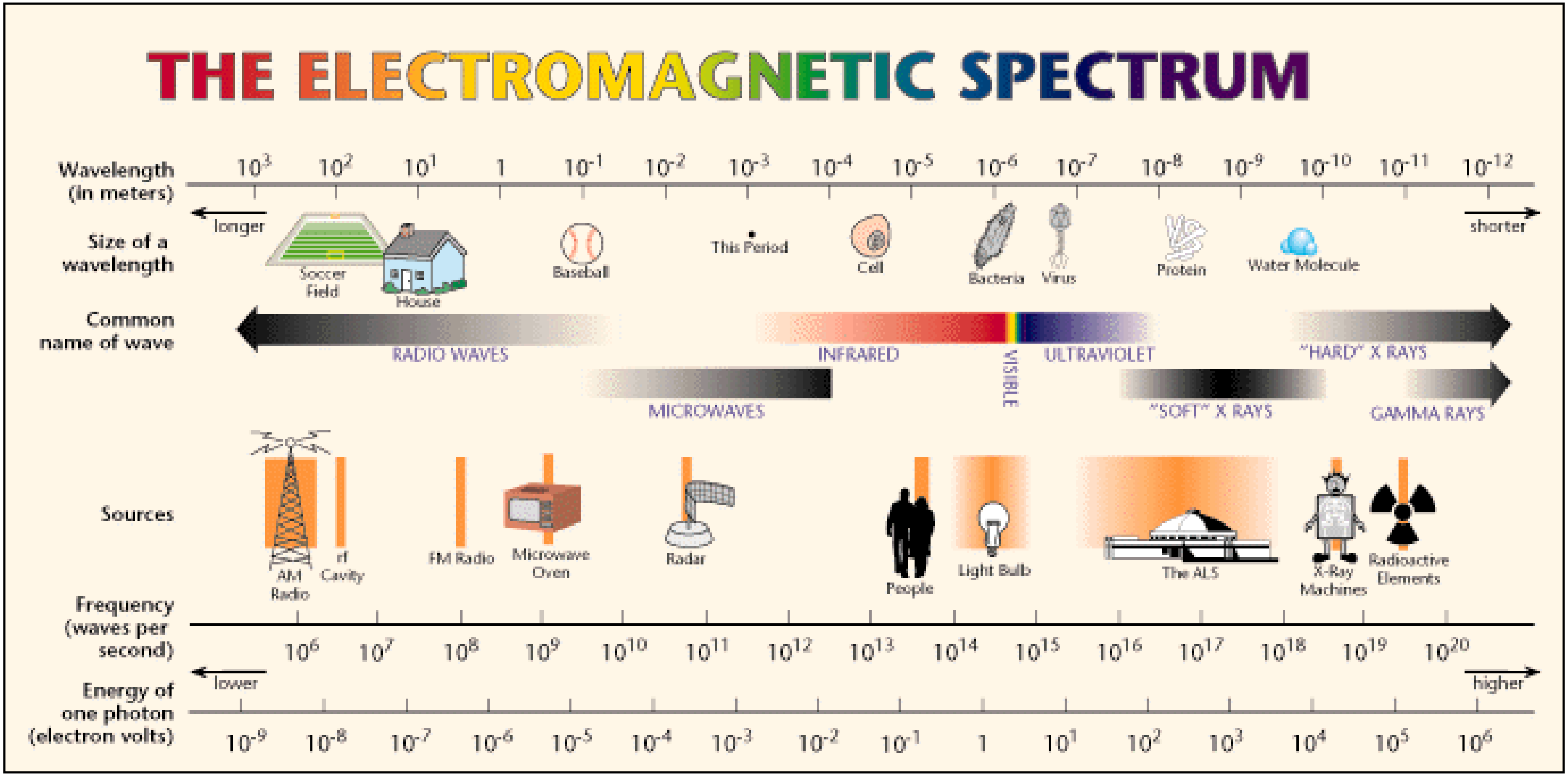
DVB-T Bandwidth

- *6/8 Mhz broadcast channels*
- *For 2k 16-QAM modulated carriers, removing pilots, guard, etc. the bandwidth is 24Mbps*
- *FEC and convolutional coder reduce this to 16Mbps*
- *This can be used to carry 4x4Mbps TV programmes in each 8MHz broadcast channel*

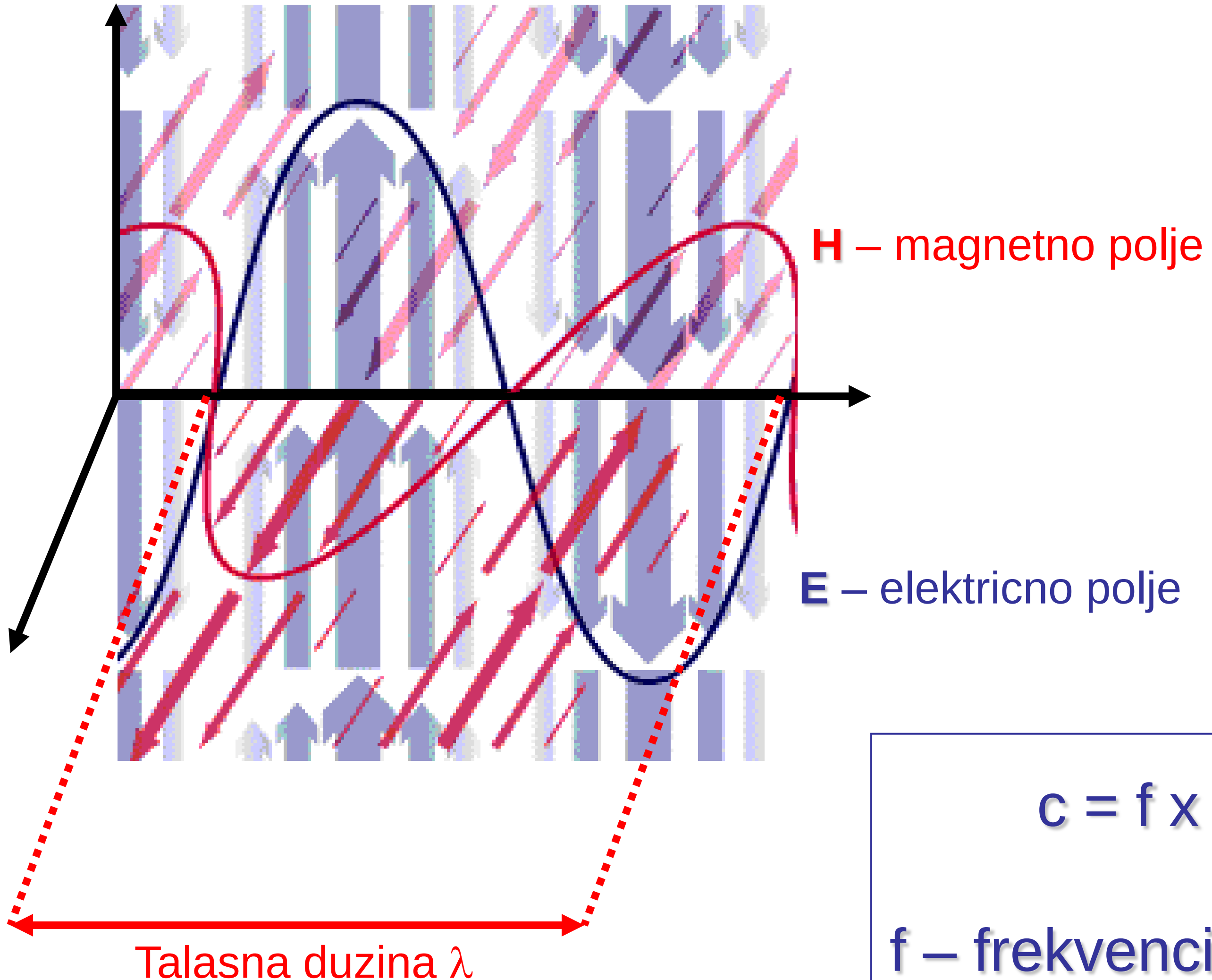
DVB-T Coverage



DVB® T
TERRESTRIAL

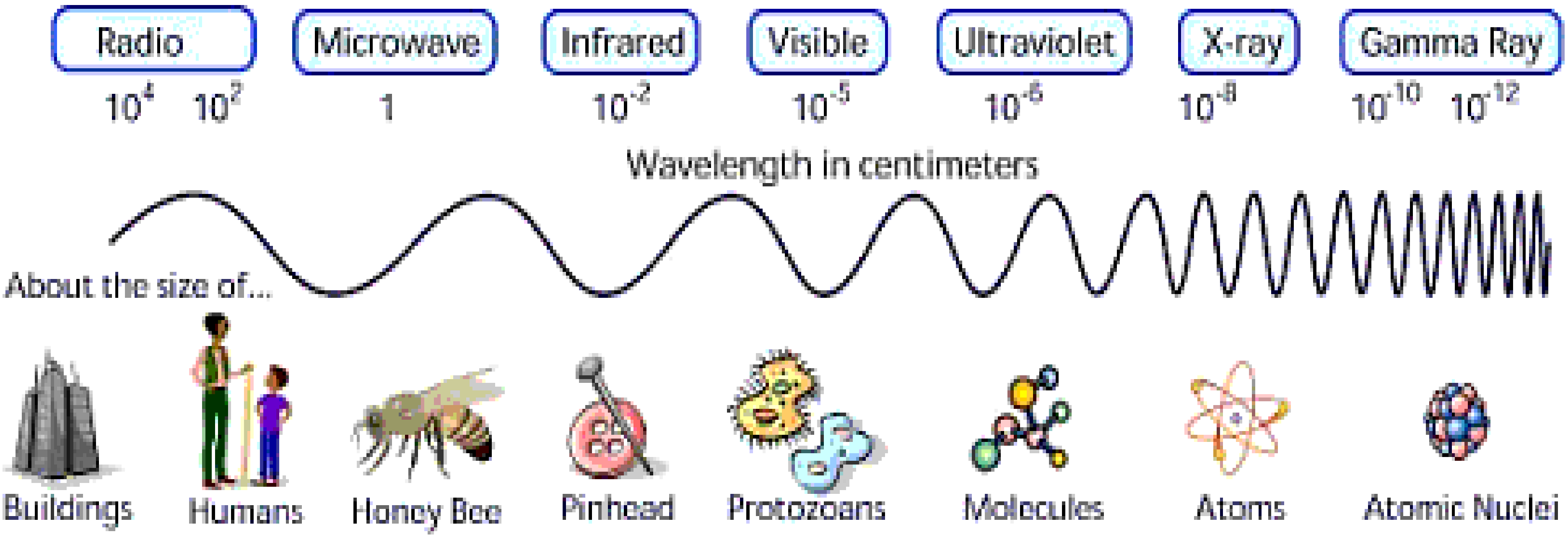


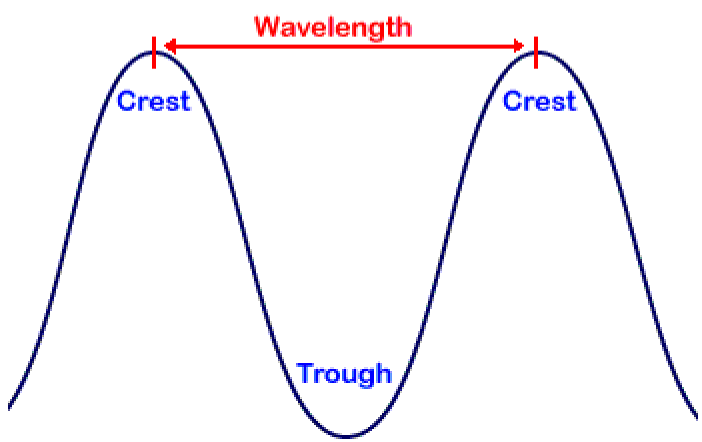
THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6



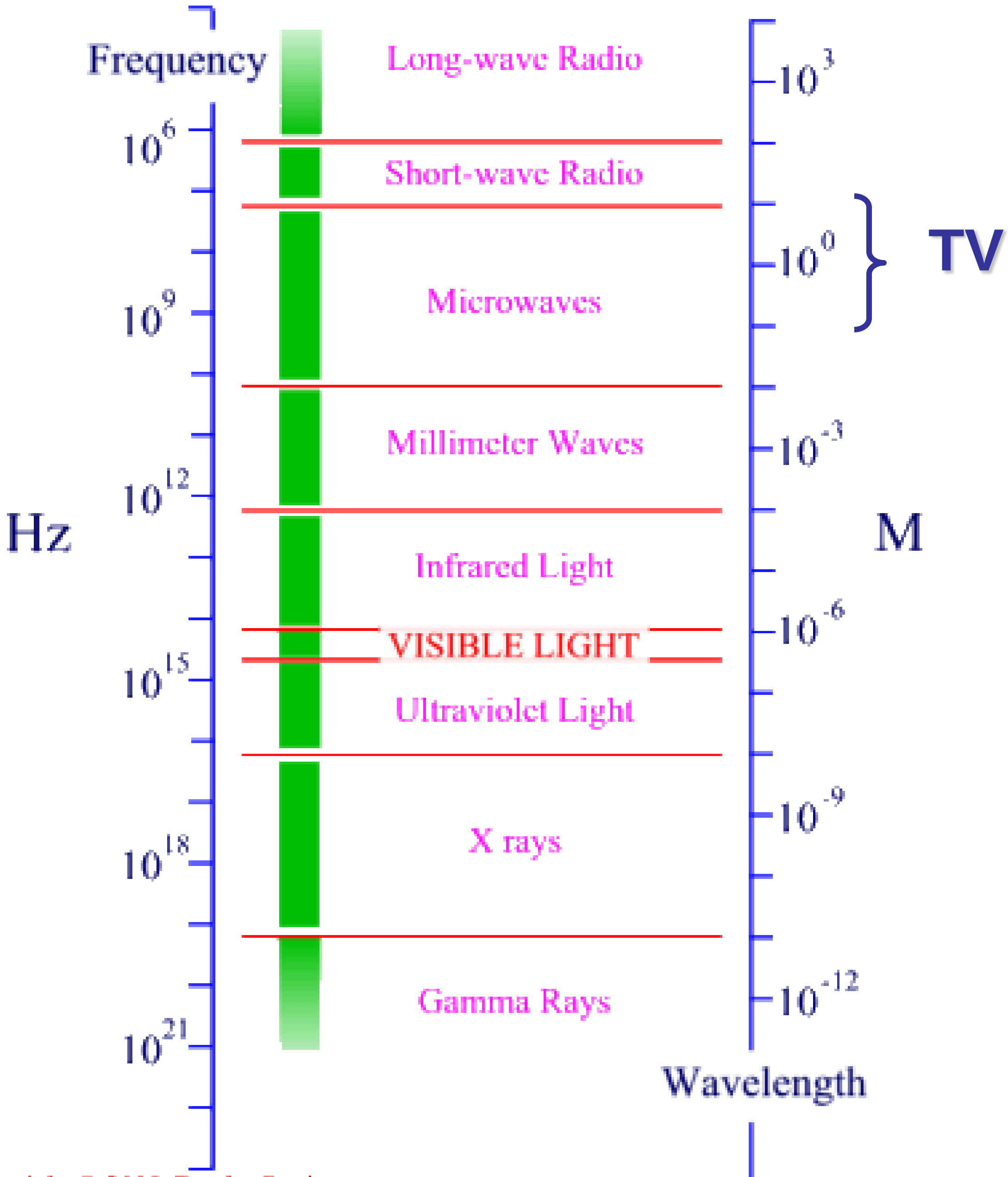
$$c = f \times \lambda$$

f – frekvencija
c – brzina svetlosti
λ - talasna duzina

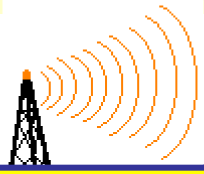

Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{4} 10^{2}
1
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10} 10^{-12}
Wavelength in centimeters
About the size of...
Buildings
Humans
Honey Bee
Pinhead
Protozoans
Molecules
Atoms
Atomic Nuclei


Wavelength
Crest
Crest
Trough

The Electromagnetic Spectrum



Radio Waves	10^4 - 10^{-2} m/10^4 - 10^{10} Hz
ultra-low frequency (ULF)	3 - 30 Hz
extremely low frequency (ELF)	30 - 300 Hz
voice frequencies (VF)	300 Hz - 3 kHz
very low frequency (VLF)	3 kHz - 30 kHz
low frequency (LF)	30 kHz - 300 kHz
medium frequency (MF)	300 kHz - 3 MHz
high frequency (HF)	3 MHz - 30 MHz
very high frequency (VHF)	30 MHz - 300 MHz
ultra high frequency (UHF)	**300 MHz - 3 GHz**
super high frequency (SHF)	3 GHz - 30 GHz
extremely high frequency (EHF)	30 GHz - 300 GHz
Far infra-red	300 GHz - 3THz
Heating	3THz - 30THz
Light	**300 THz**



Prodiranje ispod zemljine povrsine

Talasi vođeni između jonosfere i Zemlj površine

Troposferski i površinski

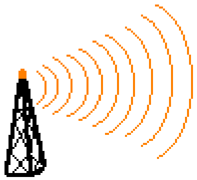
Jonosferski

Direktni ili pros

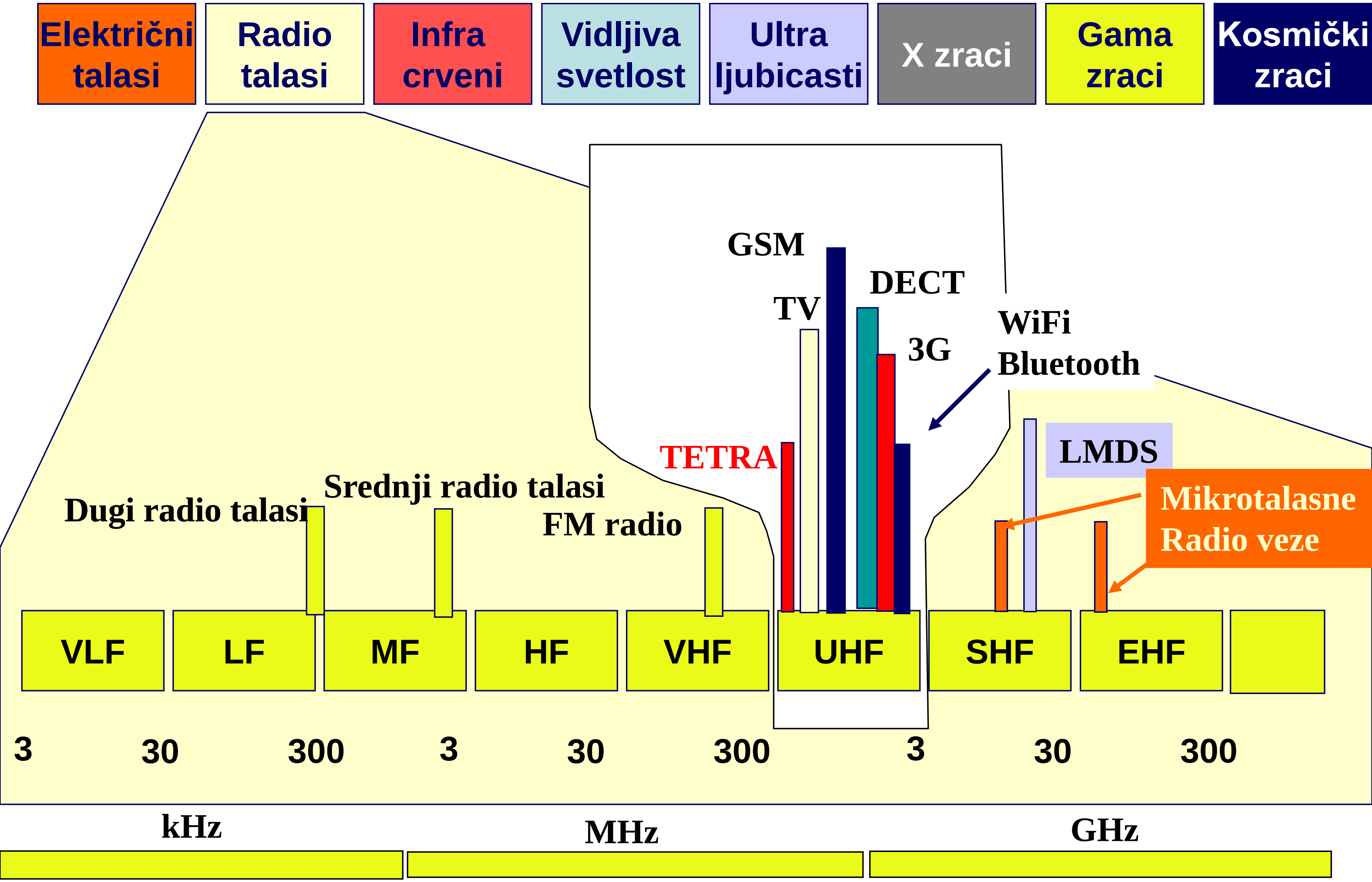
Apsorpcija o

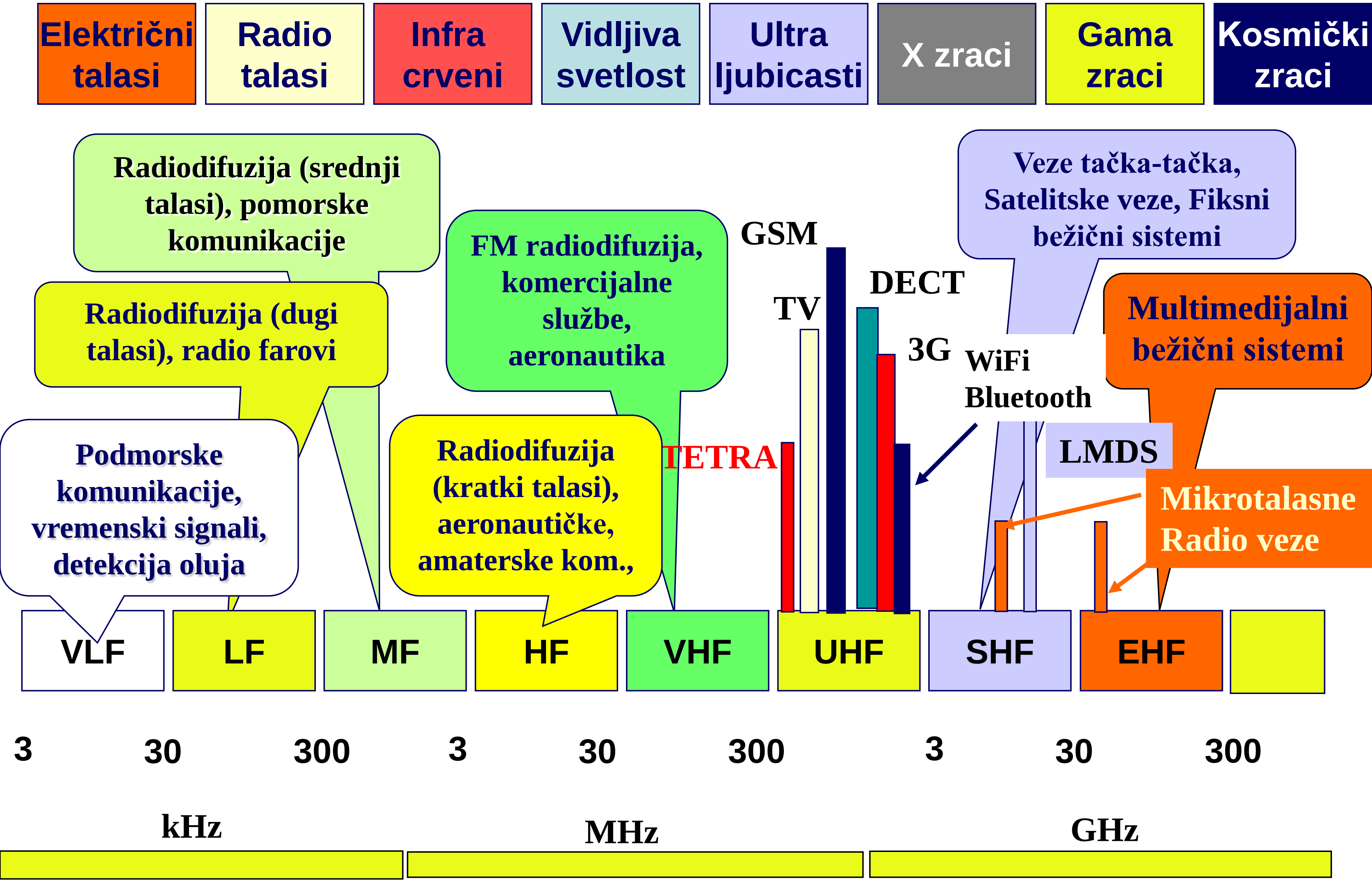
Apsorpcija od gasa i kise

Radio Waves	10^4 - 10^{-2} m/10^4 - 10^{10} Hz	
	ultra-low frequency (ULF)	3 - 30 Hz
	extremely low frequency (ELF)	30 - 300 Hz
	voice frequencies (VF)	300 Hz - 3 kHz
	very low frequency (VLF)	3 - 30 kHz
	low frequency (LF)	30 - 300 kHz
	medium frequency (MF)	300 kHz - 3 MHz
	high frequency (HF)	3 - 30 MHz
	very high frequency (VHF)	**30 - 300 MHz**
	ultra high frequency (UHF)	**300 MHz - 3 GHz**
	super high frequency (SHF)	3 - 30 GHz
	extremely high frequency (EHF)	30 - 300 GHz
	shortwave	MF, HF
	television	**VHF, UHF**
	microwave	30 cm - 1 mm/1-300 GHz

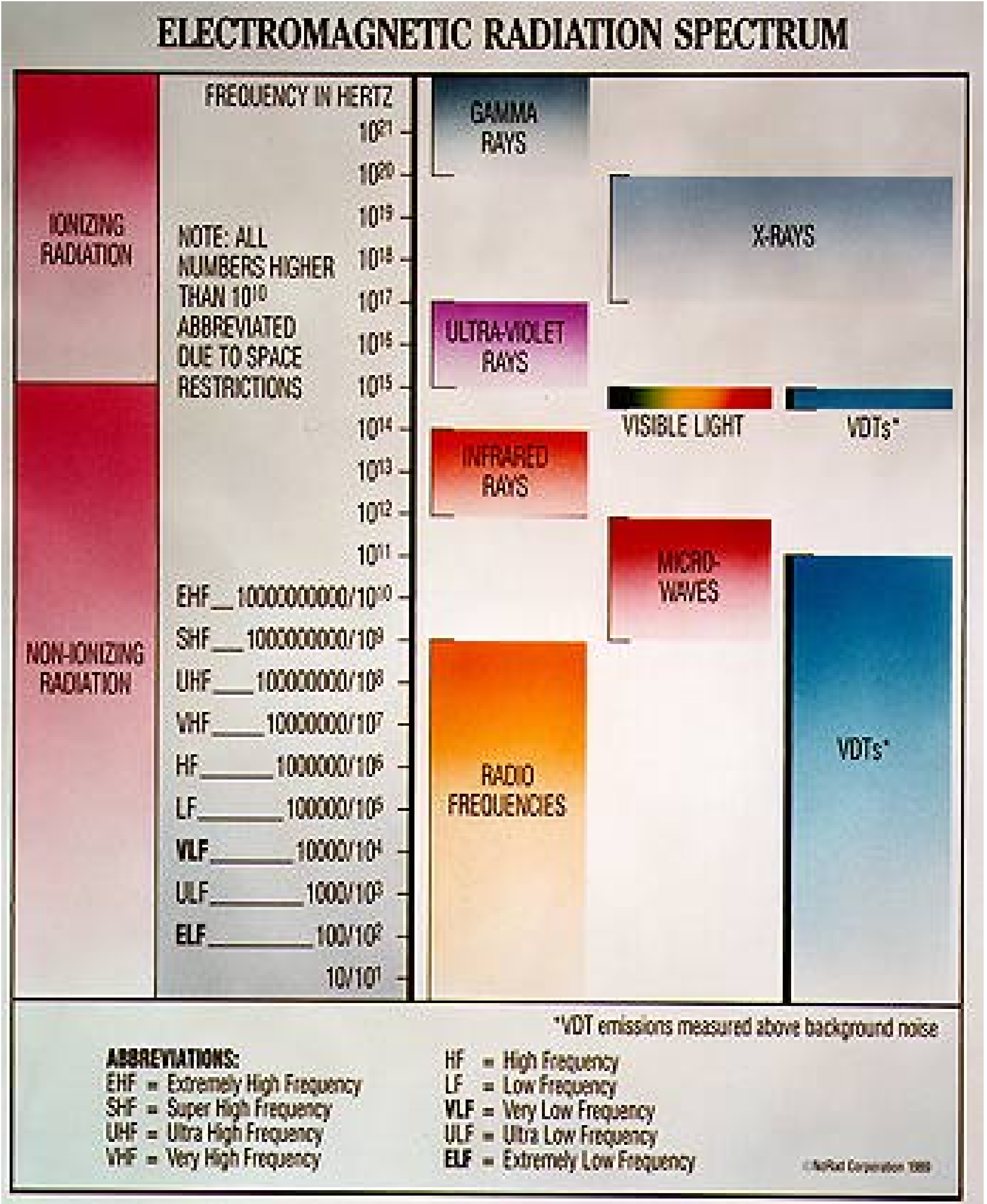


Digitalna TV
(474 – 858 MHz)


Električni talasi
Radio talasi
Infra crveni
Vidljiva svetlost
Ultra ljubicasti
X zraci
Gama zraci
Kosmički zraci
GSM
TV
DECT
3G
WiFi
Bluetooth
LMDS
TETRA
Srednji radio talasi
Dugi radio talasi
FM radio
Mikrotalasne
Radio veze
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
3
30
300
3
30
300
3
30
300
kHz
MHz
GHz

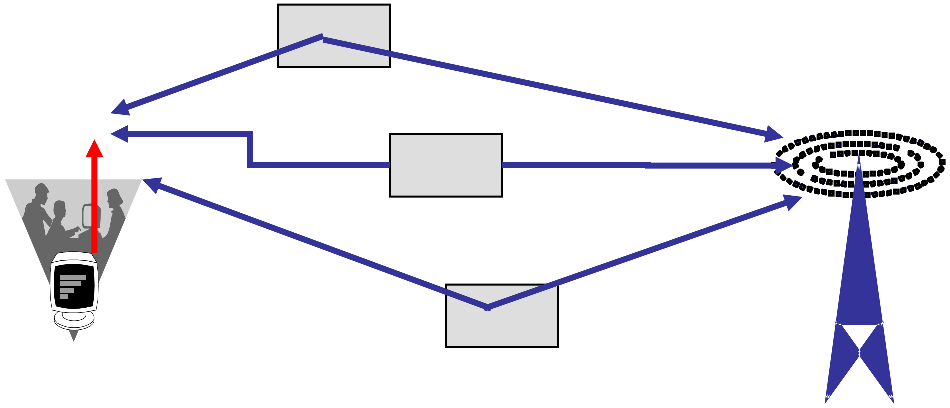


Električni talasi
Radio talasi
Infra crveni
Vidljiva svetlost
Ultra ljubicasti
X zraci
Gama zraci
Kosmički zraci
Radiodifuzija (srednji talasi), pomorske komunikacije
Radiodifuzija (dugi talasi), radio farovi
Podmorske komunikacije, vremenski signali, detekcija oluja
FM radiodifuzija, komercijalne službe, aeronautika
Radiodifuzija (kratki talasi), aeronautičke, amaterske kom.,
GSM
TV
DECT
3G
TETRA
WiFi
Bluetooth
Veze tačka-tačka, Satelitske veze, Fiksni bežični sistemi
Multimedijalni bežični sistemi
LMDS
Mikrotalasne Radio veze
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
3
30
300
3
30
300
3
30
300
kHz
MHz
GHz



ELECTROMAGNETIC RADIATION SPECTRUM
IONIZING RADIATION
NON-IONIZING RADIATION
FREQUENCY IN HERTZ
10^21
10^20
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^12
10^11
NOTE: ALL NUMBERS HIGHER THAN 10^10 ABBREVIATED DUE TO SPACE RESTRICTIONS
EHF 10000000000/10^10
SHF 1000000000/10^9
UHF 100000000/10^8
VHF 10000000/10^7
HF 1000000/10^6
LF 100000/10^5
VLF 10000/10^4
ULF 1000/10^3
ELF 100/10^2
10/10^1
GAMMA RAYS
X-RAYS
ULTRA-VIOLET RAYS
VISIBLE LIGHT
VDTs*
INFRARED RAYS
MICRO-WAVES
RADIO FREQUENCIES
VDTs*
*VDT emissions measured above background noise
ABBREVIATIONS:
EHF = Extremely High Frequency
SHF = Super High Frequency
UHF = Ultra High Frequency
VHF = Very High Frequency
HF = High Frequency
LF = Low Frequency
VLF = Very Low Frequency
ULF = Ultra Low Frequency
ELF = Extremely Low Frequency

Gubici pri prenosu



- Apsorpcioni gubici
- Uticaj senke
- Višestruka propagacija:

i. Feding (Flat fading)

ii. Širenje usled Doplerovog efekta

iii. Širenje kašnjenja

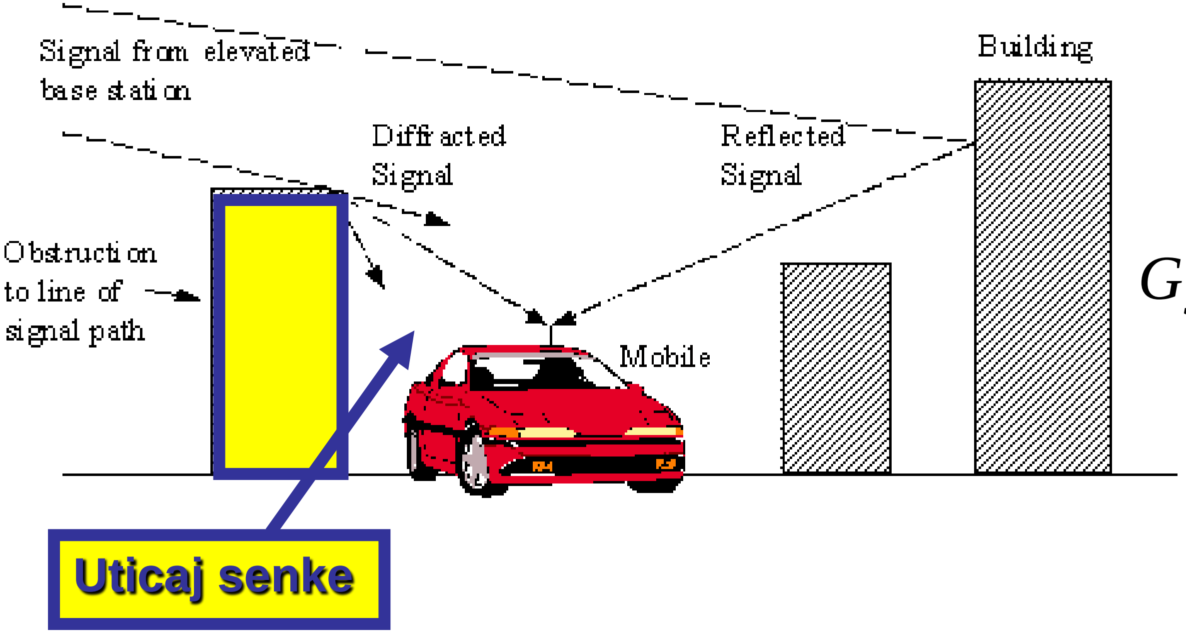
- Interferencija

Apsorpcioni gubici

- Za različita okruženja (planinski predeli, urbane sredine, ..., različiti tipovi drveća, ...) potrebno je koristiti različite modele.
- Jednostavan model gubitaka

$$L = \frac{\overline{P_r}}{P_t} = K \frac{1}{d^{\alpha}}$$

- P_r lokalna srednja snaga prijemnog signala
- P_t snaga predajnika
- d rastojanje od predajnika
- Eksponent α=2 za slobodan prostor, tipično 2<=α<=4



$$P_r(dB) = \overline{P}(dB) + G_S$$

$$G_S \sim N(0, \sigma_S^2), 4 \leq \sigma_S \leq 10\, dB$$

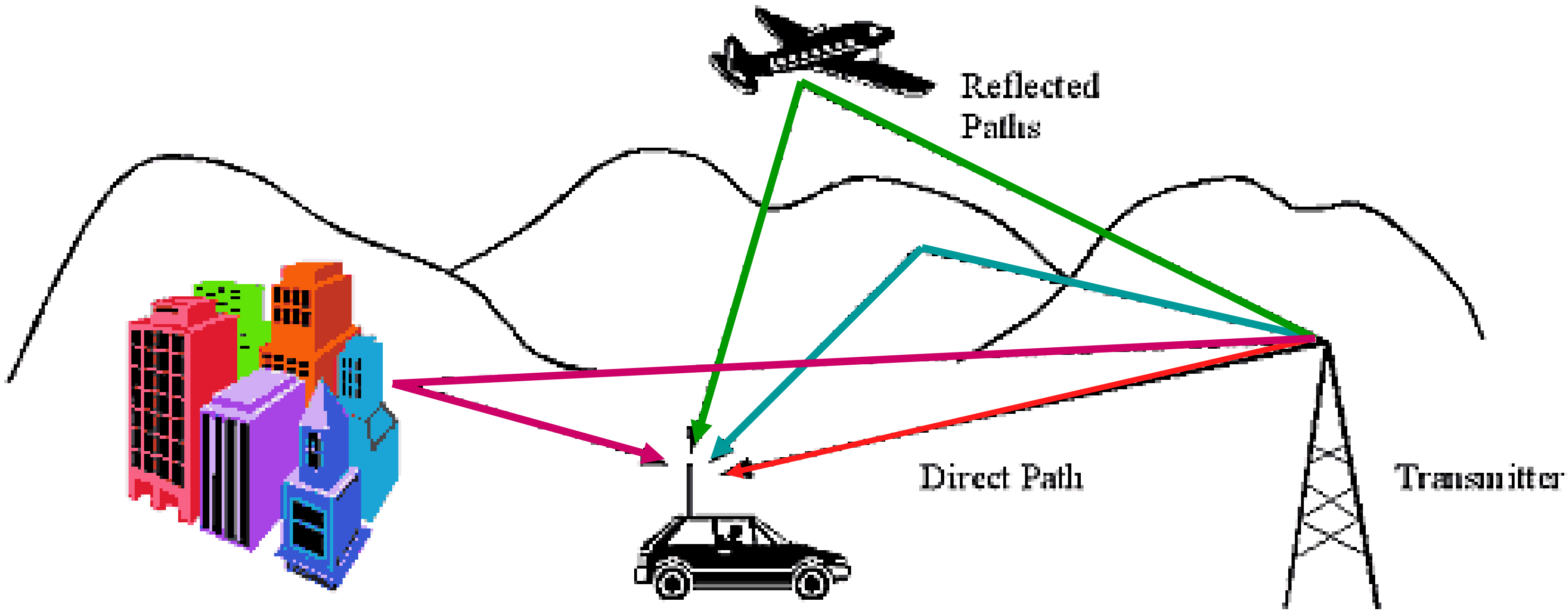
Senke nastaju kad postoji prepreka između predajnika i prijemnika, na pr. iza brda, a najgore su u urbanim sredinama (zgrade).

Difrakcija zavisi od frekvencije – izraženija pojava pri niskim frekvencijama.

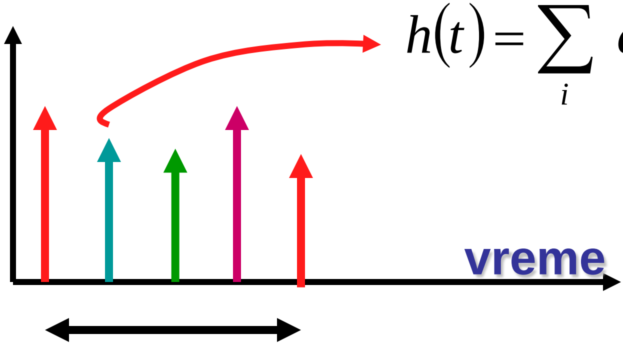
Ovo je uzrok sporog fedinga (log-normalnog fedinga).

Posledica:
- neuniformno pokrivanje
- povećanje potrebne snage predajnika

Višestruka propagacija



Prijemna snaga

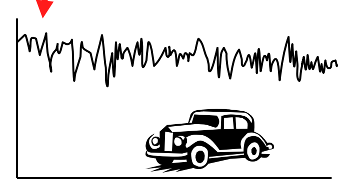


"raspršivanje" kašnjenja

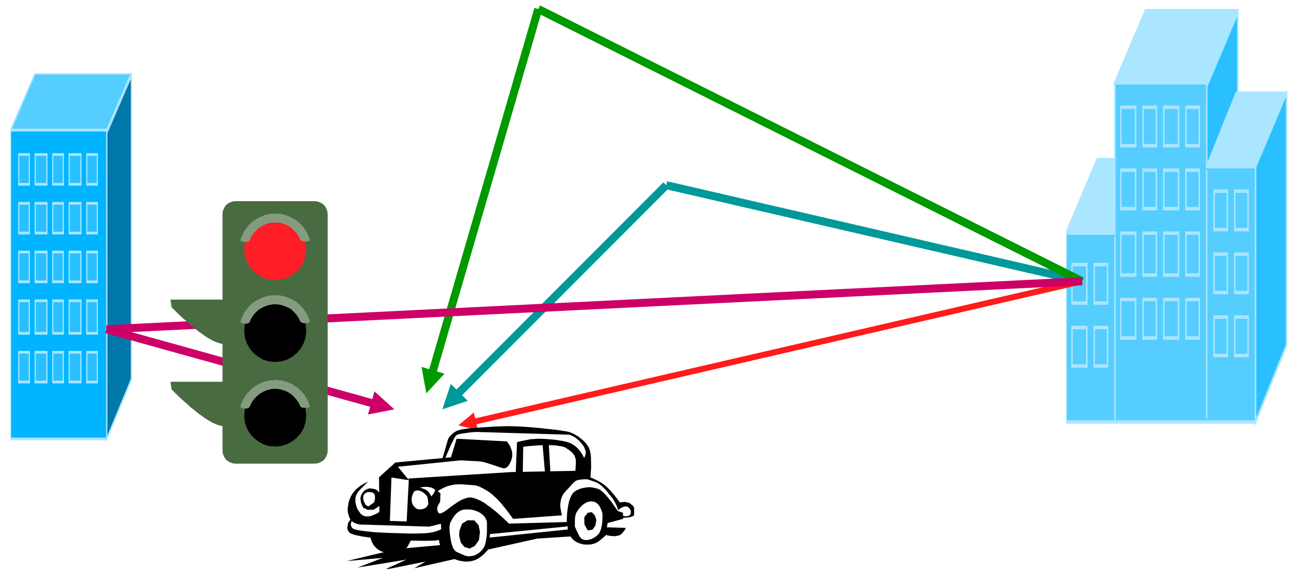
$$h(t)=\sum_i a_i \, e^{j\theta_i} \, \delta(t-t_i)$$

Interferencije:

- Konstruktivne, i
- destruktivne

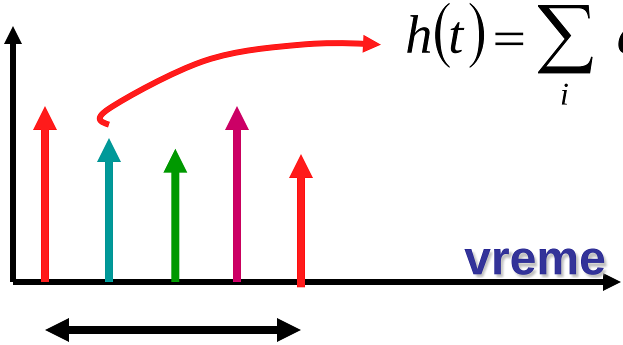


“red-light effect”



$$h(t) = \sum_i a_i \, e^{j\theta_i} \, \delta(t - t_i)$$

Prijemna snaga



“raspršivanje” kašnjenja

Interferencije:

- Konstruktivne, i
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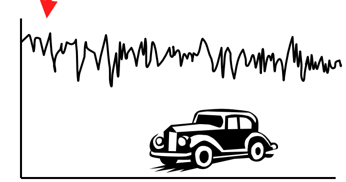
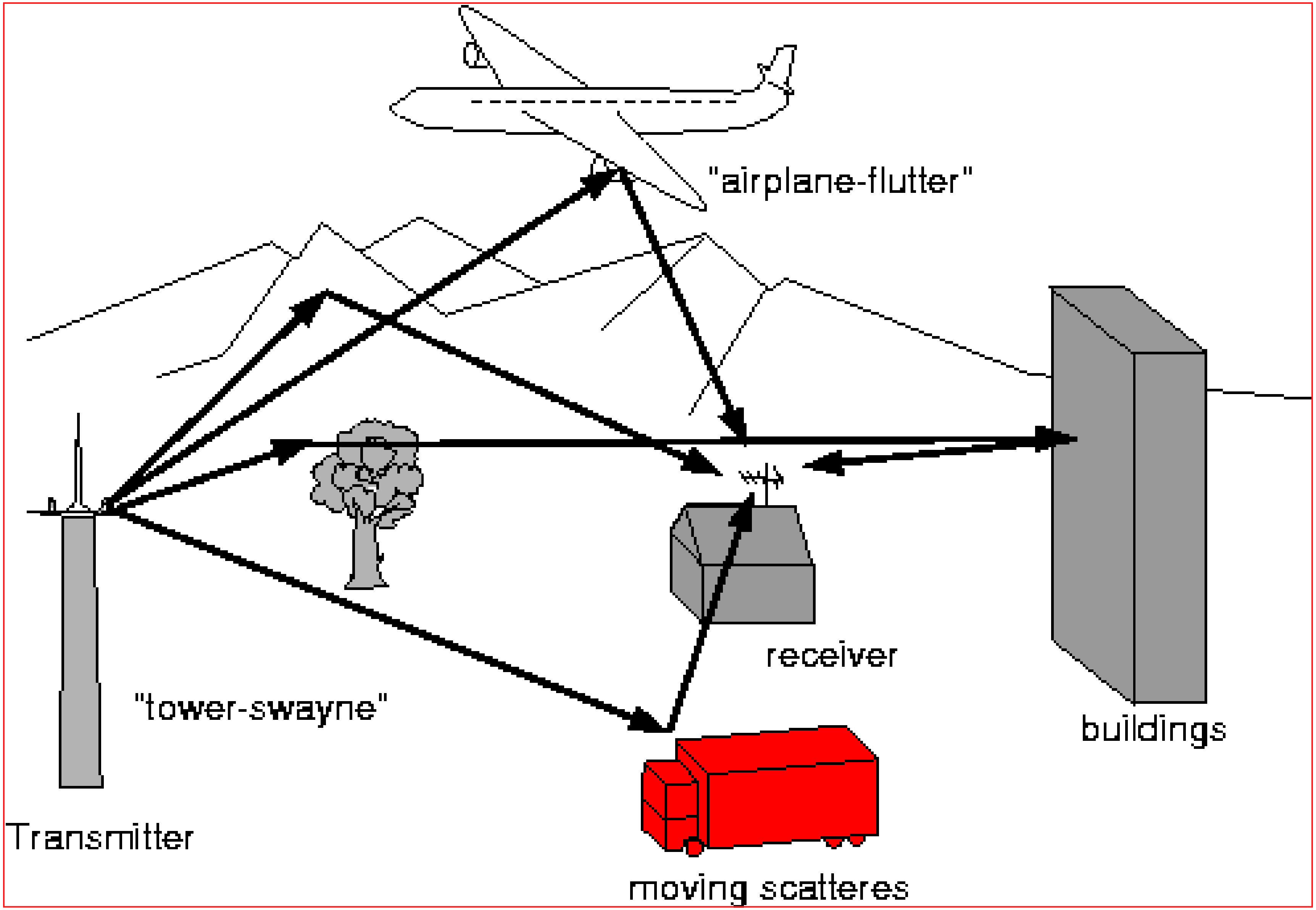




"airplane-flutter"
"tower-swayne"
receiver
buildings
Transmitter
moving scatteres

Feding (flat fading – ravni feding)

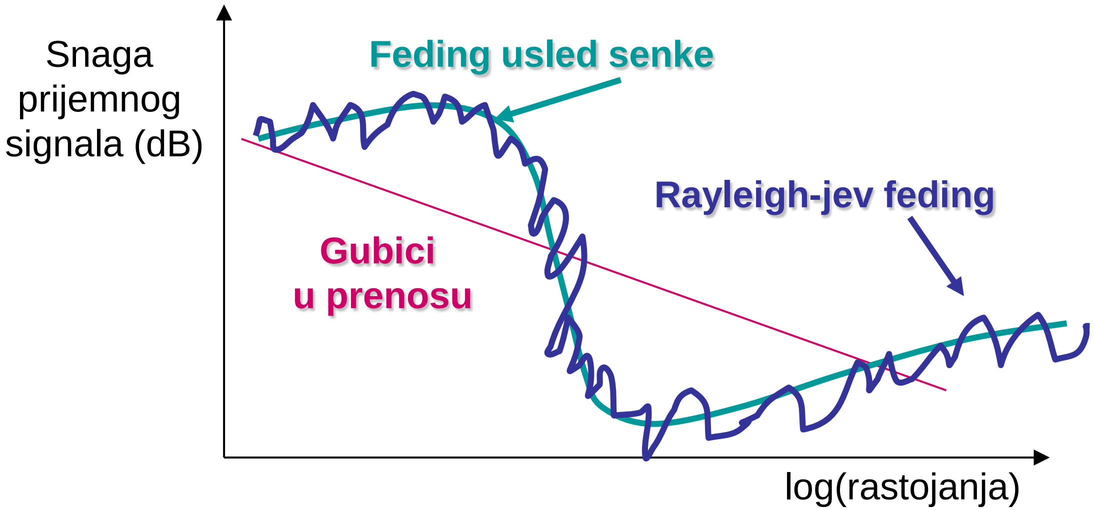
- Ako je raspršivanje kašnjenja malo u poređenju sa periodom simbola
- Anvelopa prijemnog signala, r, raspodeljena je po Rice-ovoj ili Raylegh-lijevoj raspodeli

$$P_r(dB) = \overline{P}(dB) + G_S + 20\log(r)$$

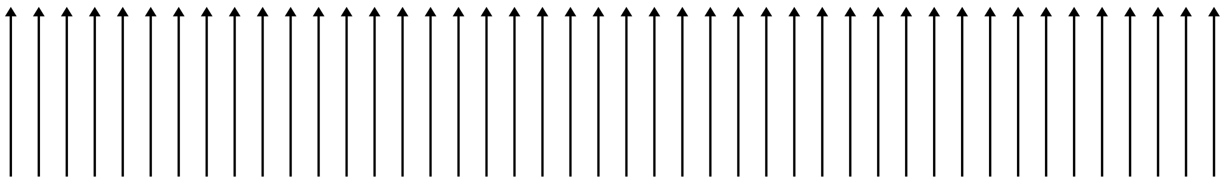
- Posledice:

povećanje potrebne snage predajnika

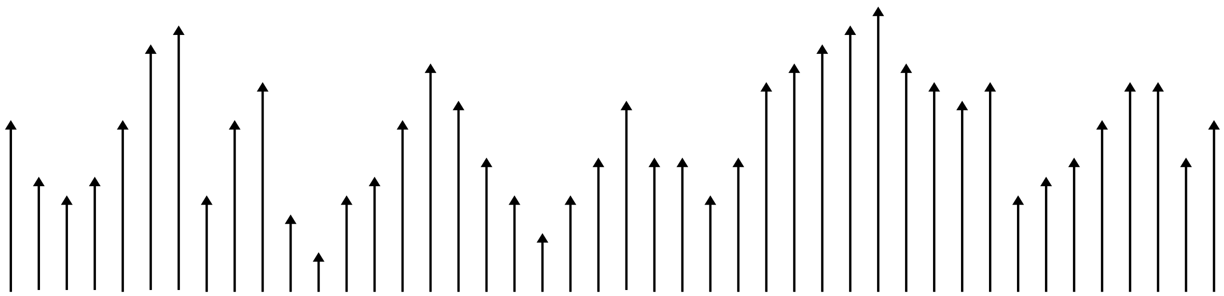
burst-ovi grešaka



Uticaj fedinga



Amplitude nosioca pre fedinga



Posle fedinga

Širenje usled Doplerovog efekta

$$\Delta f \approx \pm f_0 \frac{v}{c}$$

Primer: *za* f_o= 1GHz, i za *v* = 60km/h (16.7m/s), Doppler-ov pomeraj iznosi:

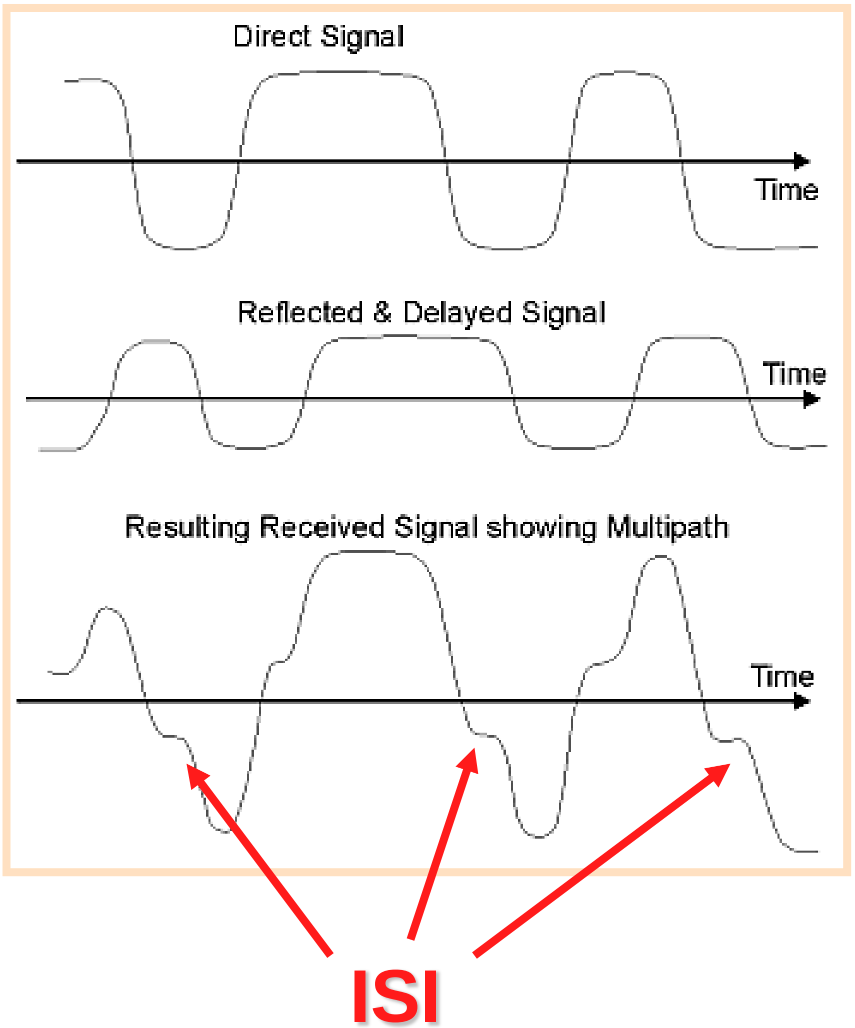
$$\Delta f \approx \pm 10^9 \frac{16.7}{3 \cdot 10^8} = 55.5\ Hz$$

- Pri približavanju, frekvencija prijemnog signala postaje viša od frekvencije izvora.
- Doplerov efekat utiče na tehnike prenosa osetljive na frekvencijski offset (COFDM), odnosno na one u kojima je velika brzina *v* (LEO sateliti).

Posledica:

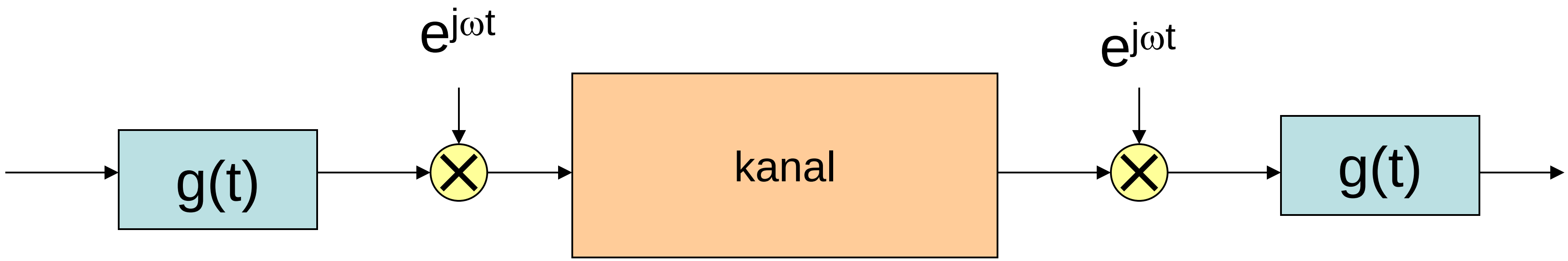
Amplituda i faza su dekorelisane posle perioda srazmernog ($1/f_d$)

Širenje kašnjenja – vreme između prve i poslednje značajne komponente signala u višestrukoj propagaciji



Posledice ISI se mogu smanjiti:

- smanjujući protok u svakom kanalu (na pr. podelom opsega pomoću frekvencijskog multipleksiranja, ili OFDM)
- Korišćenjem šema kodovanja koje su manje osetljive na ISI kao što je CDMA.

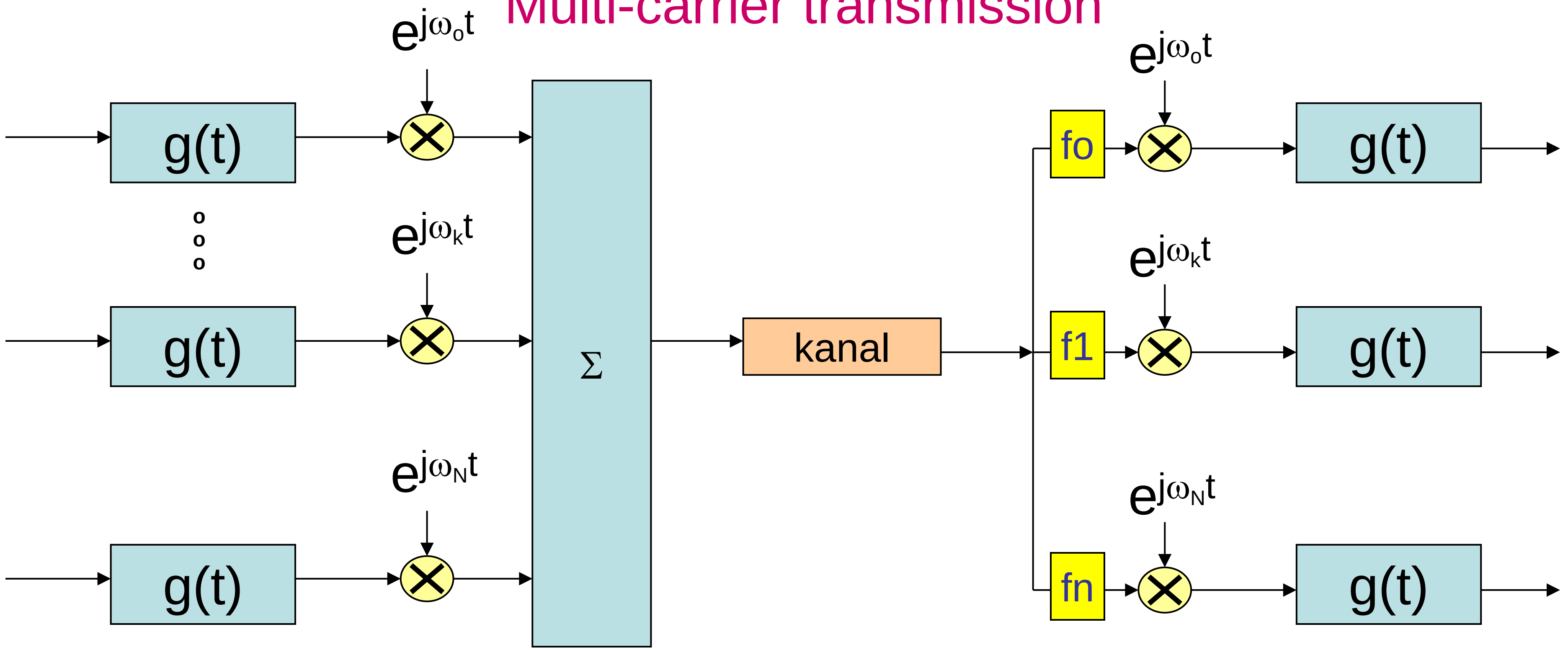


Single-carrier transmission

Sa jednim nosiocem, protoci simbola mogu lako dostici 1-30 Msym/s,
čemu odgovara perioda simbola reda veličine 1μs.
Eho moze biti veličine 100-250 μs.

Ideja je
da se poveća perioda simbola, toliko da smanji ISI, i
da se dodaju pauze kao zaštitni vremenski intervali.

Multi-carrier transmission



•Spektar signala se deli u mnogo uzanih podopsega (potkanala) koji se prenose paralelno
•Idelalno-svaki kanal je dovoljno uzan tako da proizvodi samo “flat fading” (pa nema ISI)

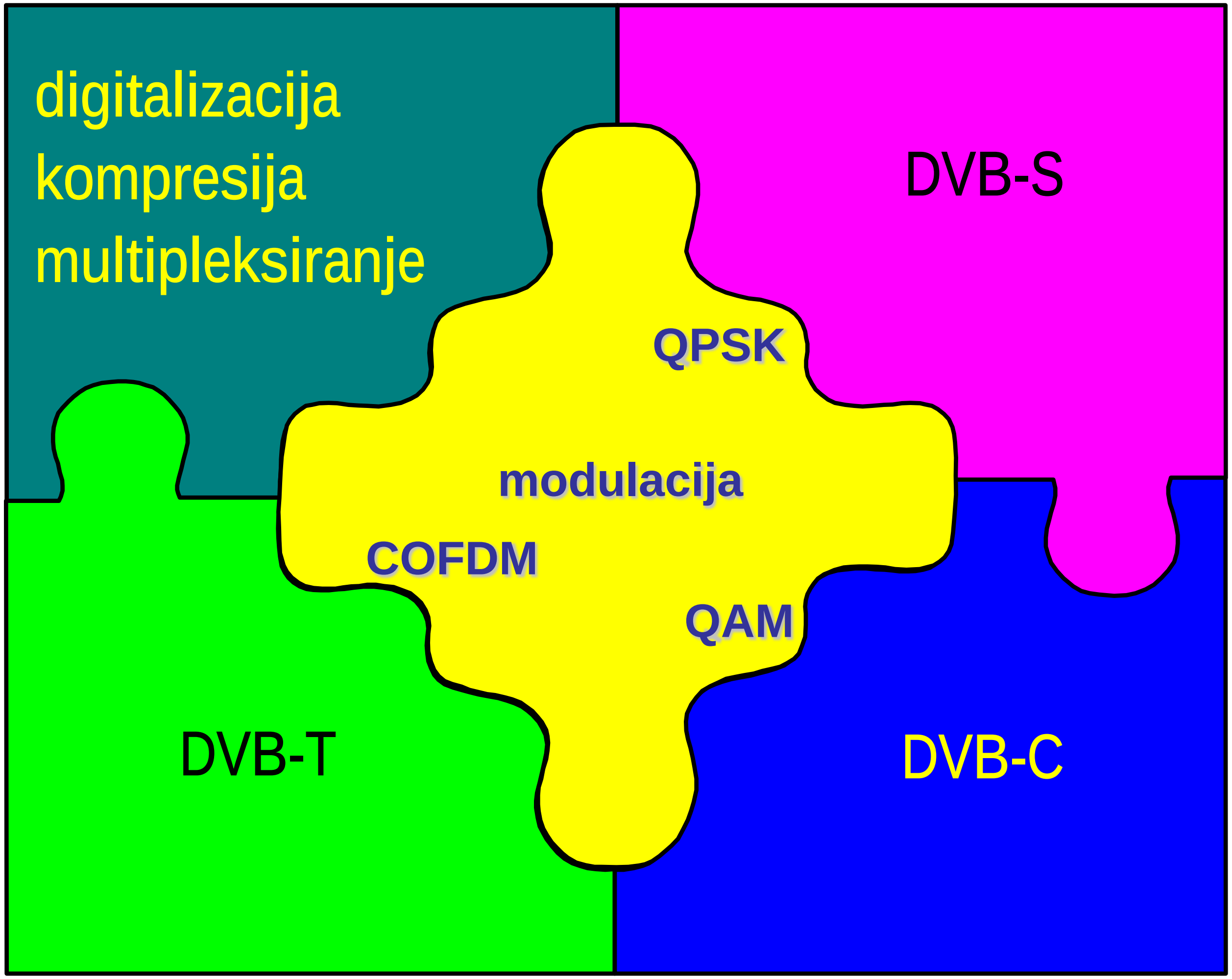
Nedostaci:

- zahteva se banka filtara na prijemu
- spektralno je neefikasan metod

Zaključak

Potražiti neku drugu vrstu modulacije
sa sličnom postavkom

DVB standard



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