COFDM

- A brief history
- COFDM principles
- DVB-T framing structure
- COFDM transmission sequence
- Countering against echoes and reflections
- DVB-T variable parameters

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A brief history of COFDM - 1

- OFDM grew out of Multi Carrier Modulation (MCM)
  - Military HF radio (late 1950's)
  - Divides stream into several parallel bit streams
  - Bit streams used to modulate several carriers

- OFDM - A special form of MCM
  - Patent issued in the US in 1970 (number 3,488445) submitted by R.W. Chang in 1966

- Time domain signals used to ensure subcarrier orthogonality
  - Major contribution by Shannon in defining waveforms in Euclidean space, allowing definitions of orthogonality
  - No need for steep band pass filters
  - Sub-carrier spectra allowed to overlap
  - Need for real time FFT's

- Popular in the 1980's and used for digital audio broadcasting (DAB)
  - OFDM + QPSK modulation

A brief history of COFDM - 2

- Various associated bodies
  - 1992 DVB (Digital Video Broadcast - voluntary group of 200 companies)
    - ✓ DVB-S, DVB-C in 1994 and DVB-T in early 1997
  - dTTb (digtial Terrestrial Television broadcast project)
    - ✓ Demonstrator to show the feasibility of a commercial receiver
  - DVBird (Digital Video Broadcast integrated receiver decoder)
    - ✓ Technical specifications needed and partitioning of electronic functions
  - DTG (UK based Digital Terrestrial Group, set up in 1995 to make a working broadcast solution for the UK to meet Government plans)
    - ✓ First commercial broadcasts in late 1998 with simulcast and later OnDigital services.

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What is COFDM ?

C - Coded

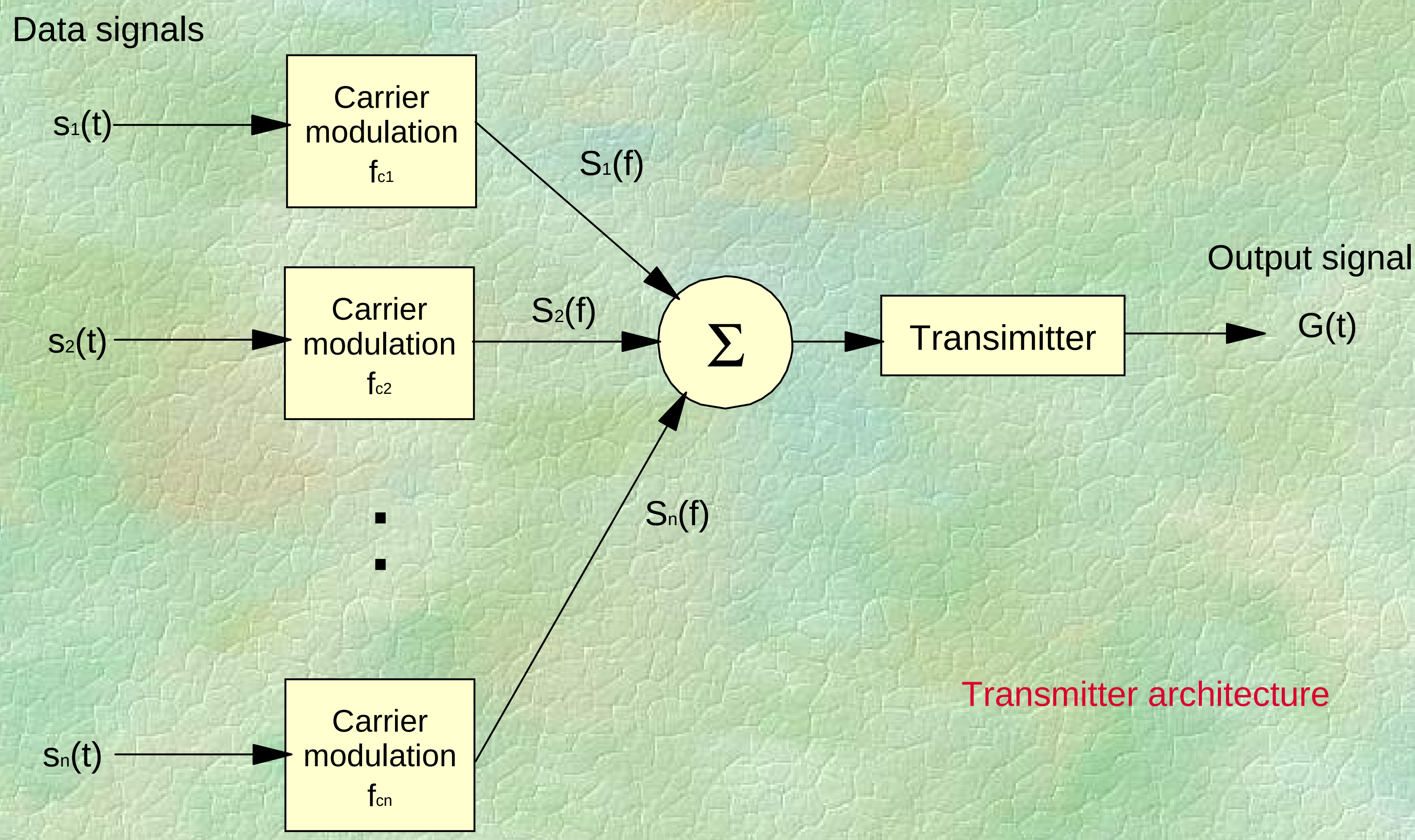
O - Orthogonal

F - Frequency

D - Division

M - Multiplex

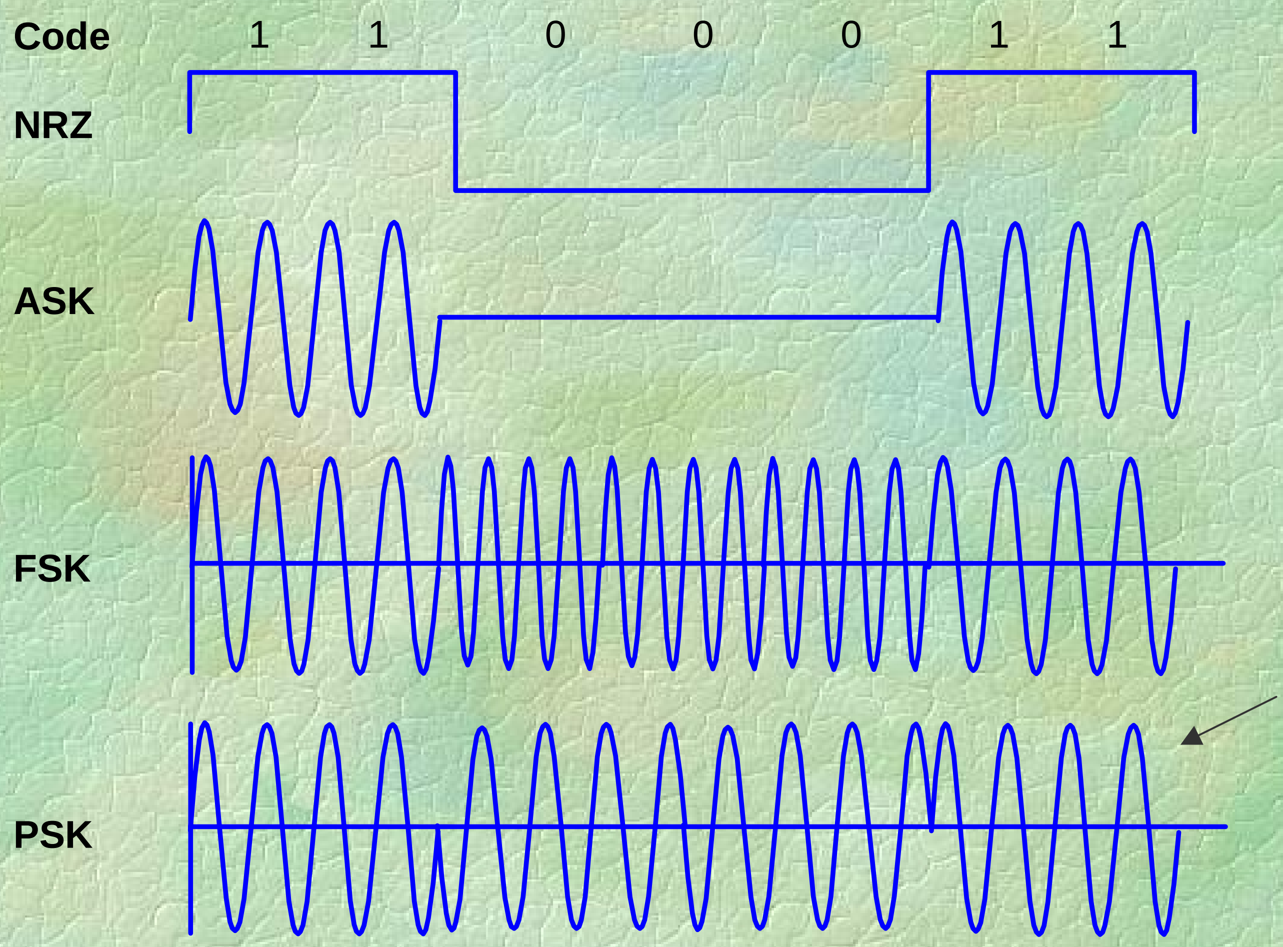
FDM (Frequency Division Multiplex)



Transmitter architecture

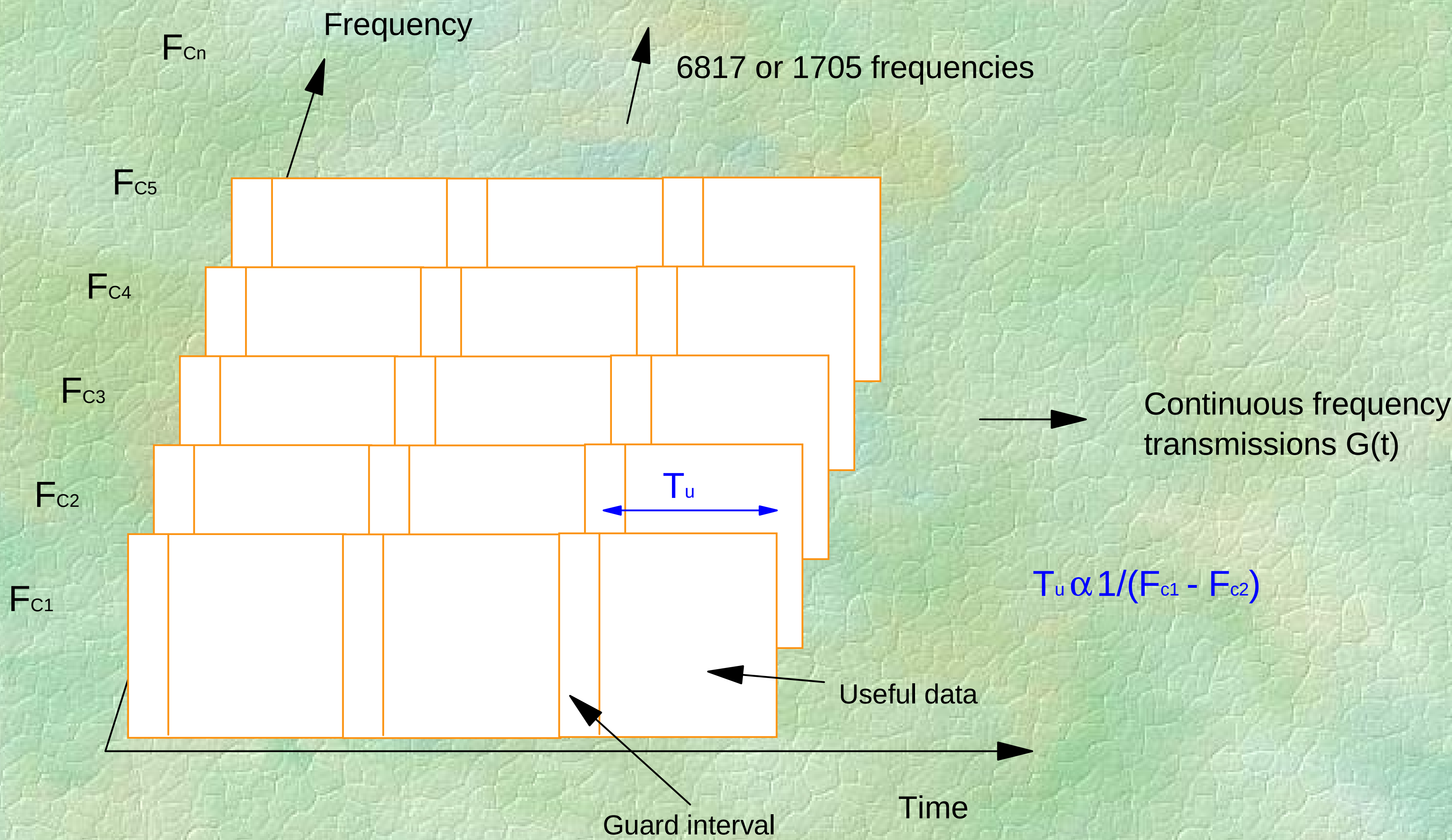
FDM (Frequency Division Multiplex)

- Modulation

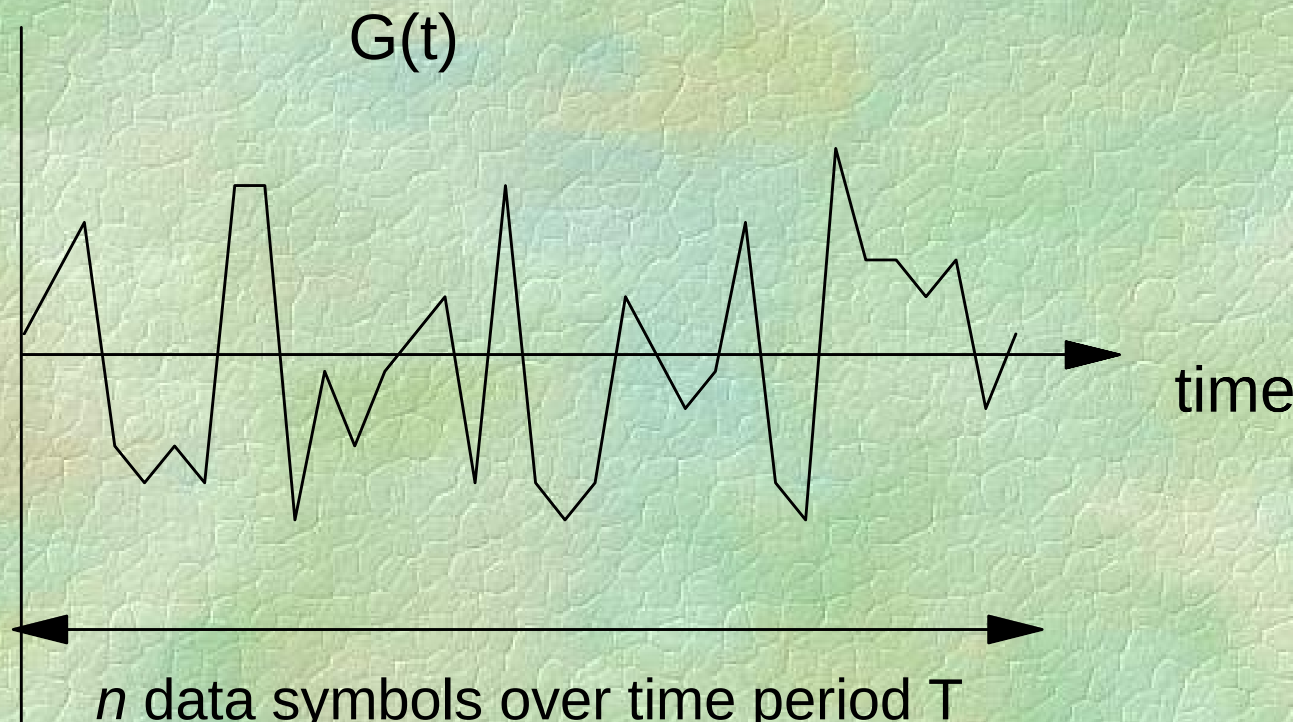


Quadrature (QAM) phase shift uses a π/2 phase shift.
π phase shift is shown here

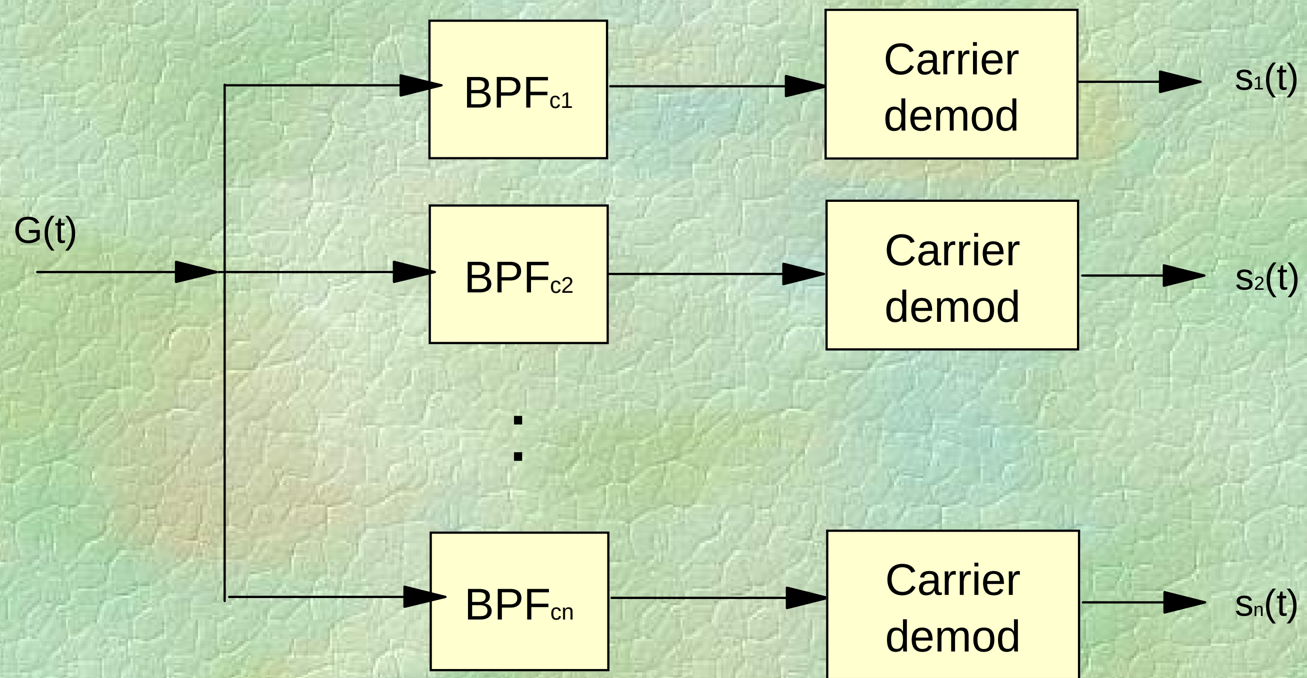
FDM (Frequency Division Multiplex)



FDM (Frequency Division Multiplex)



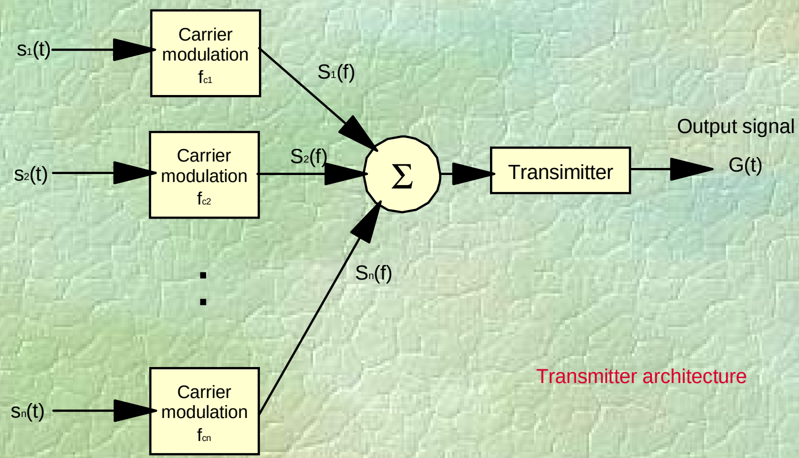
FDM (Frequency Division Multiplex)



Receiver architecture

BPF = Band pass filter

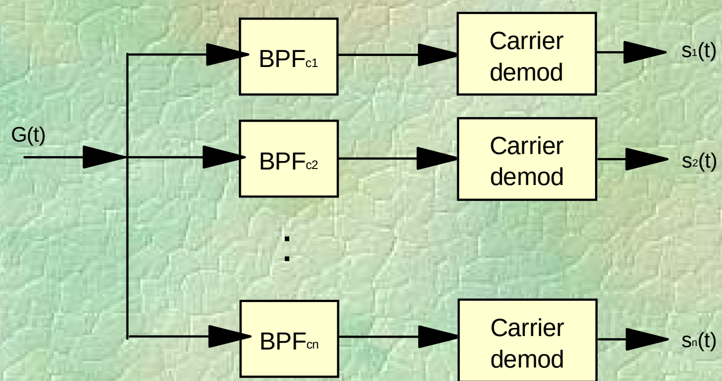
FDM (Frequency Division Multiplex)



Transmitter architecture

≡ IDFT

$$s(t_i) = \frac{2W}{N} \sum_{f_k=1}^{N} S(f_k) e^{j2\pi f_k t_i / N}$$



Receiver architecture

BPF = Band pass filter

≡ DFT

$$S(f_k) = \frac{T}{N} \sum_{t_i=1}^{N} s(t_i) e^{-j2\pi f_k t_i / N}$$

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DVB-T framing structure

- Fixed number of carriers used
  - ✓ Allows receiver to lock onto signal
  - ✓ Keeps constant power levels
  - ✓ '2K' system in UK (1705 carriers)
  - ✓ '8K' also an option (6817 carriers)
- Carrier types
  - ✓ Data carriers - 2,4 or 6 bits per symbol, per carrier
  - ✓ TPS carriers - Transmission information
  - ✓ Pilot carriers -Channel estimation at receiver, Tx at boosted power levels
    - ➢ Continual - 177 in '8K' mode, 45 in '2K' always in same position within symbol
    - ➢ Scattered - 524 in '8K' mode, 121 in '2K' pseudo random within symbol
- Modulation used
  - ✓ Increases number of bits that can be transmitted
  - ✓ Eg each carrier transports 4 bits for QAM-16

DVB-T framing structure

Single frequency carrier.

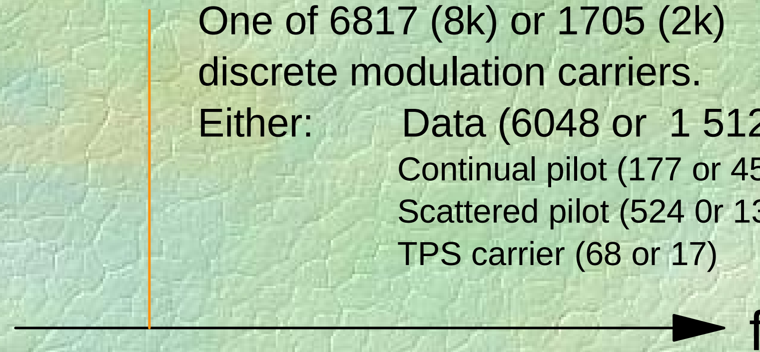
One of 6817 (8k) or 1705 (2k) discrete modulation carriers.

Either: Data (6048 or 1 512)

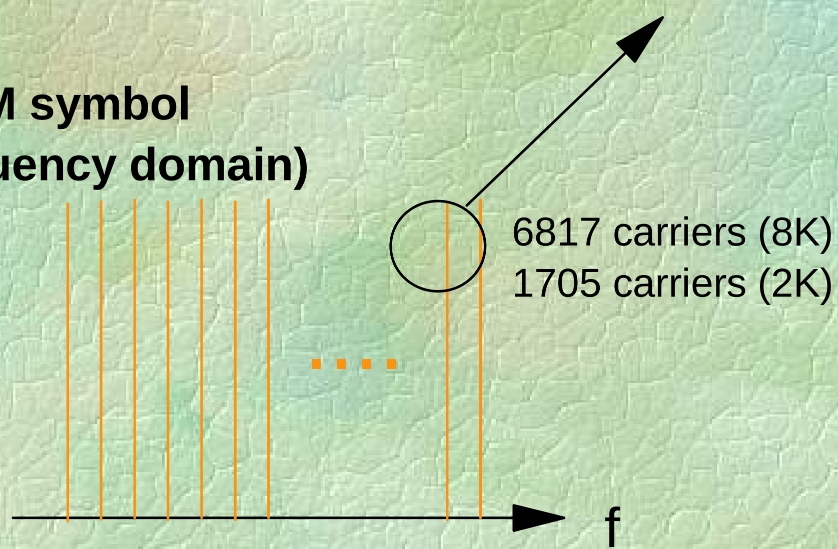
Continual pilot (177 or 45)

Scattered pilot (524 0r 131)

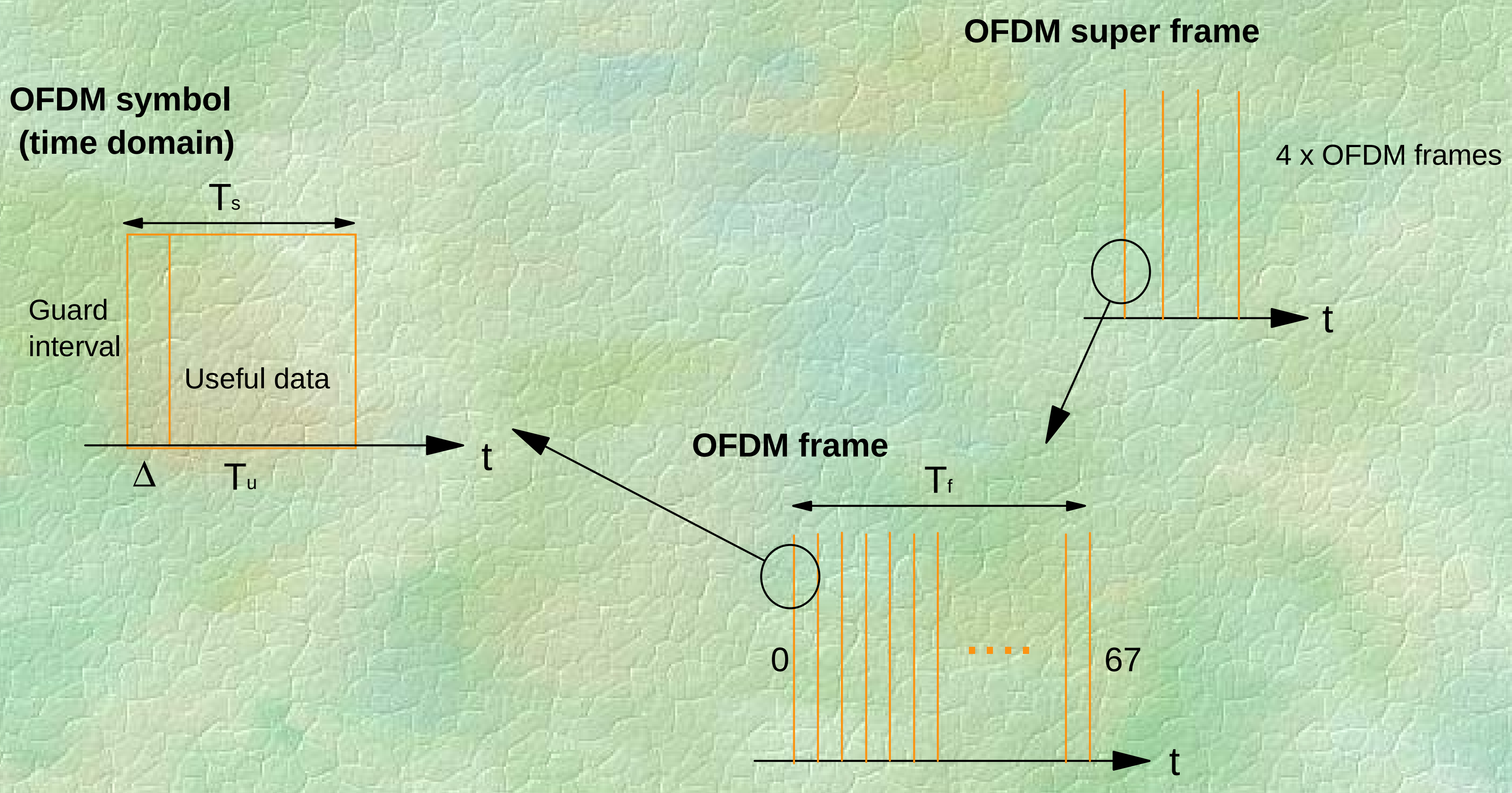
TPS carrier (68 or 17)



OFDM symbol (frequency domain)



DVB-T framing structure



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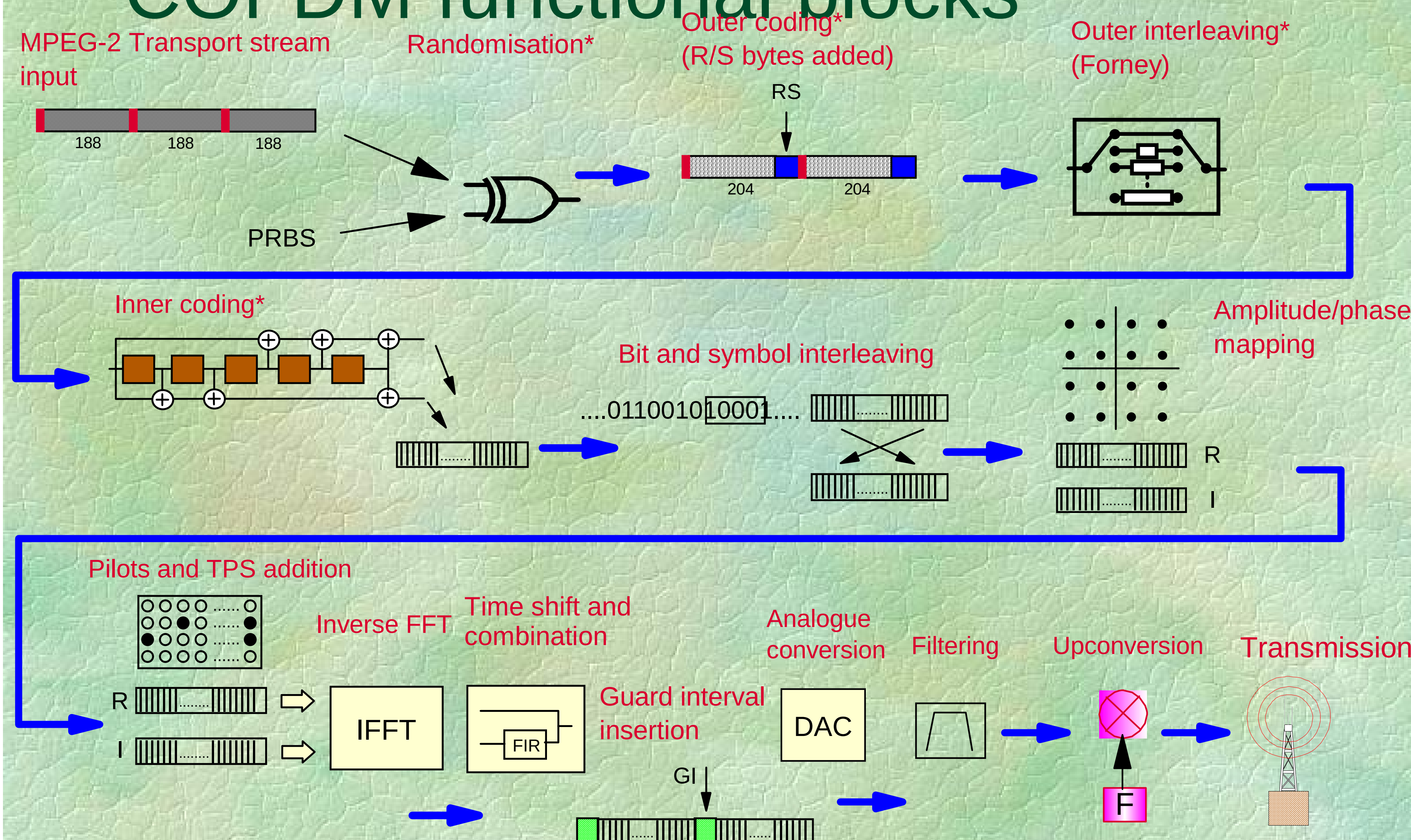
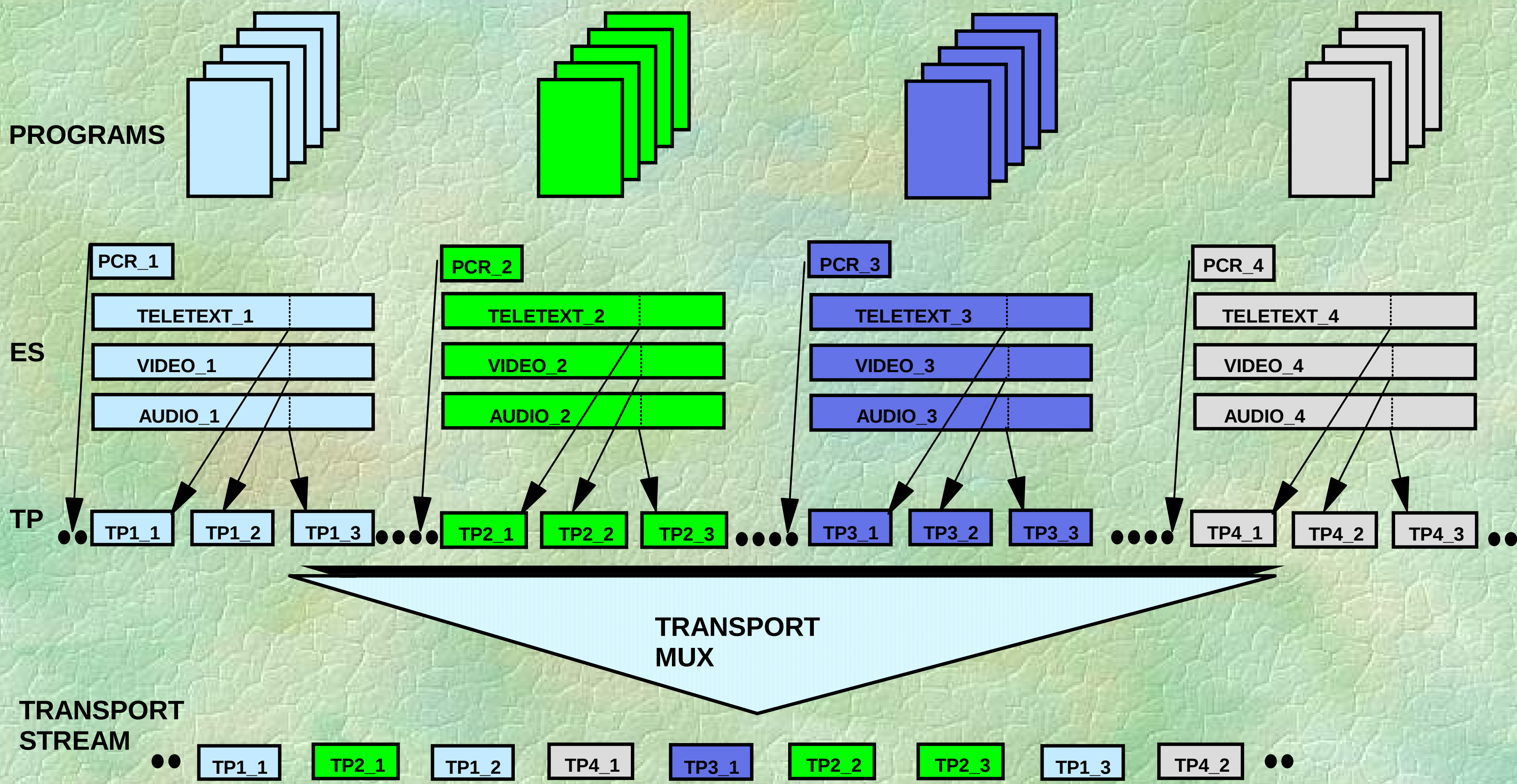
COFDM functional blocks



* Same as DVB-S

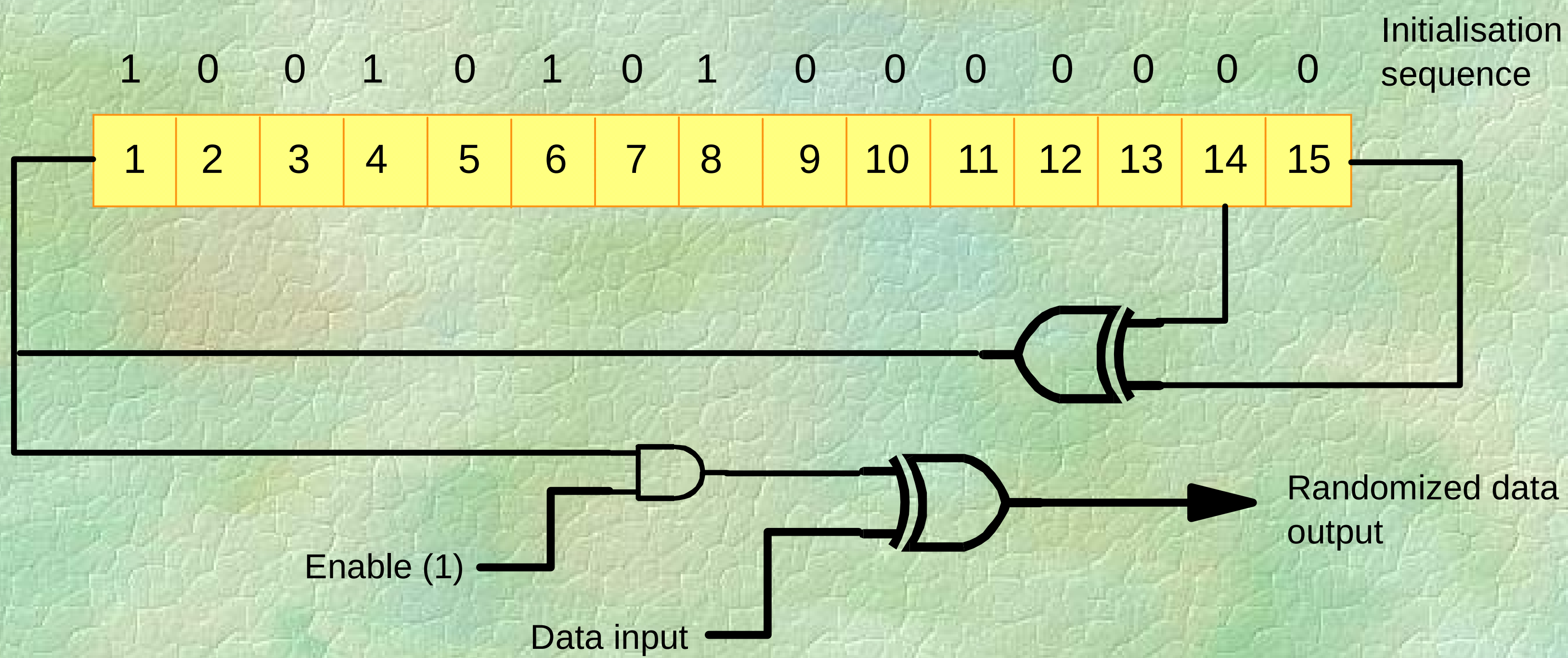
DVB transport stream



Data scrambling

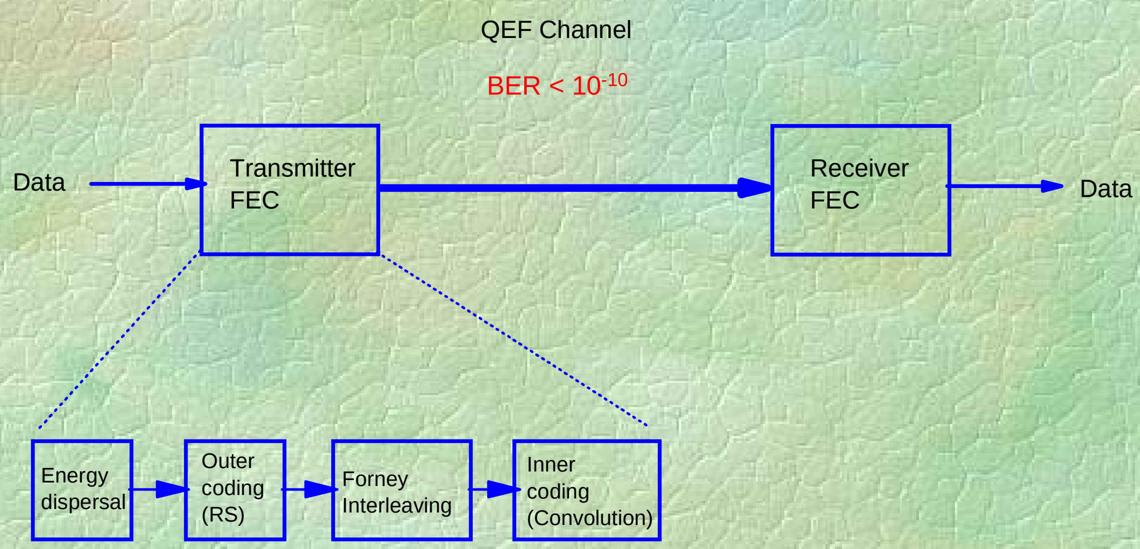
Pseudo Random Binary Sequence (PRBS)

- ✓ Energy dispersal to ensure adequate binary transitions



Error correction

- Error prone environment hence small packets (188 bytes) with additional error correction data (16 bytes)
  - Known as Forward Error Correction (FEC)
  - Also known as channel coding
  - Two main parts:
    - Outer coding for burst errors (Reed - Solomon and Forney)
    - Inner coding (Convolution coding)



Outer coding

- Reed Solomon
  - Operates over individual packets
  - Corrects up to 8 erroneous bytes per packet
  - Non correctable flag for > 8 byte errors
  - Bandwidth overhead is 8%
- Forney convolution interleaving
  - Increases efficiency of the RS coding
  - Spreads errors over a greater area

Inner coding

- Convolution coding
  - 2 identical streams produced from outer coded stream
  - Output stream formed from combination of these new streams
  - Not all simultaneous bits taken - hence rate defined

    (DVB-T code rates: 1/2, 2/3, 3/4, 5/6, 7/8)
- Puncture rate impact on data rate
  - Puncture rate of 3/4 means 1 out of 4 bits is removed
  - Data rate becomes: (1/2)*(4/3) = 2/3 of original (ie code rate is 2/3)

No puncturing data rate is halved since convolution encoder produces two identical streams

Every 4th bit removed

Bit and Symbol Interleaving

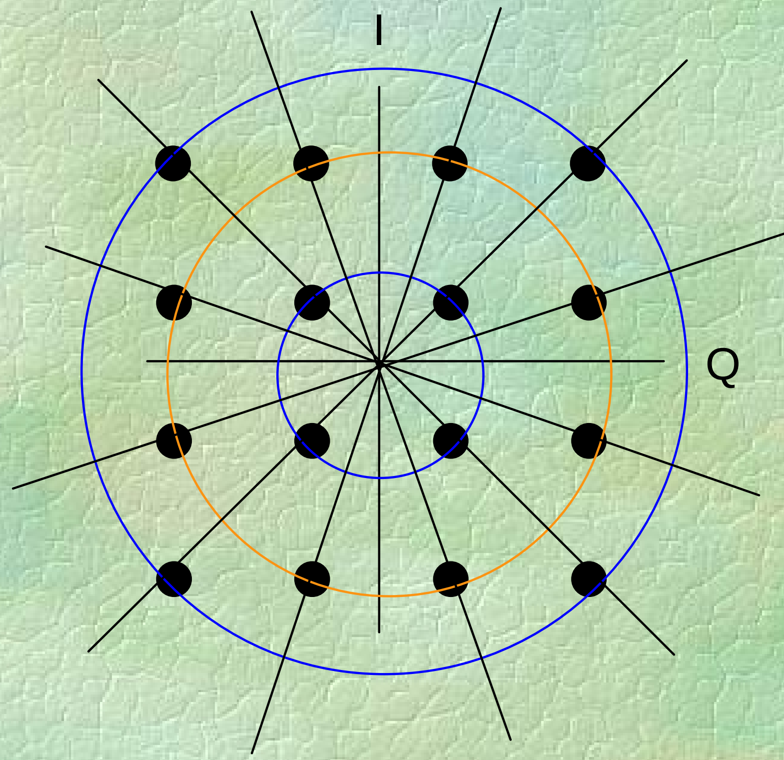
- Bite-wise interleaving
  - Inner coder has two output streams
  - Bit wise interleaver produces 2, 4 or 6 streams for QPSK, 16-QAM and 64-QAM respectively

- Symbol interleaving
  - The 2, 4 or 6 bit words are mapped onto the OFDM carriers
  - 1512 for 2k mode or 6048 for 8K mode

Amplitude and Phase Mapping (example)

12 phases / 3 amplitudes
2 amplitudes appear on 4 phases
1 amplitude appears on 8 phases

16-QAM



Pilots and TPS addition

- Pilots
  - Continual pilots
    - ✓ Always in the same place within the OFDM symbol
    - ✓ 45 in 2k mode, 177 in 8k mode
    - ✓ Transmitted at increased power levels
    - ✓ Used to estimate the channel characteristics and therefore make corrections
  - Scattered pilots
    - ✓ Located as a pre-defined pattern such that there is an equal number per symbol
    - ✓ 131 in 2K mode, 524 in 8k mode
    - ✓ Transmitted at increased power levels
    - ✓ Used in conjunction with continual pilots to estimate the channel distortion

Pilots and TPS addition

- TPS (Transmission Parameter Signalling)
  - Type of modulation used
  - Hierarchy information
  - Guard interval
  - Inner code rates
  - Transmission mode (ie 2k or 8k)
  - Frame number within a super frame (ie 0 to 3)
  - DPSK (Differential Phase Shift Keying) modulation used due to robustness

IFFT, time shift and combination

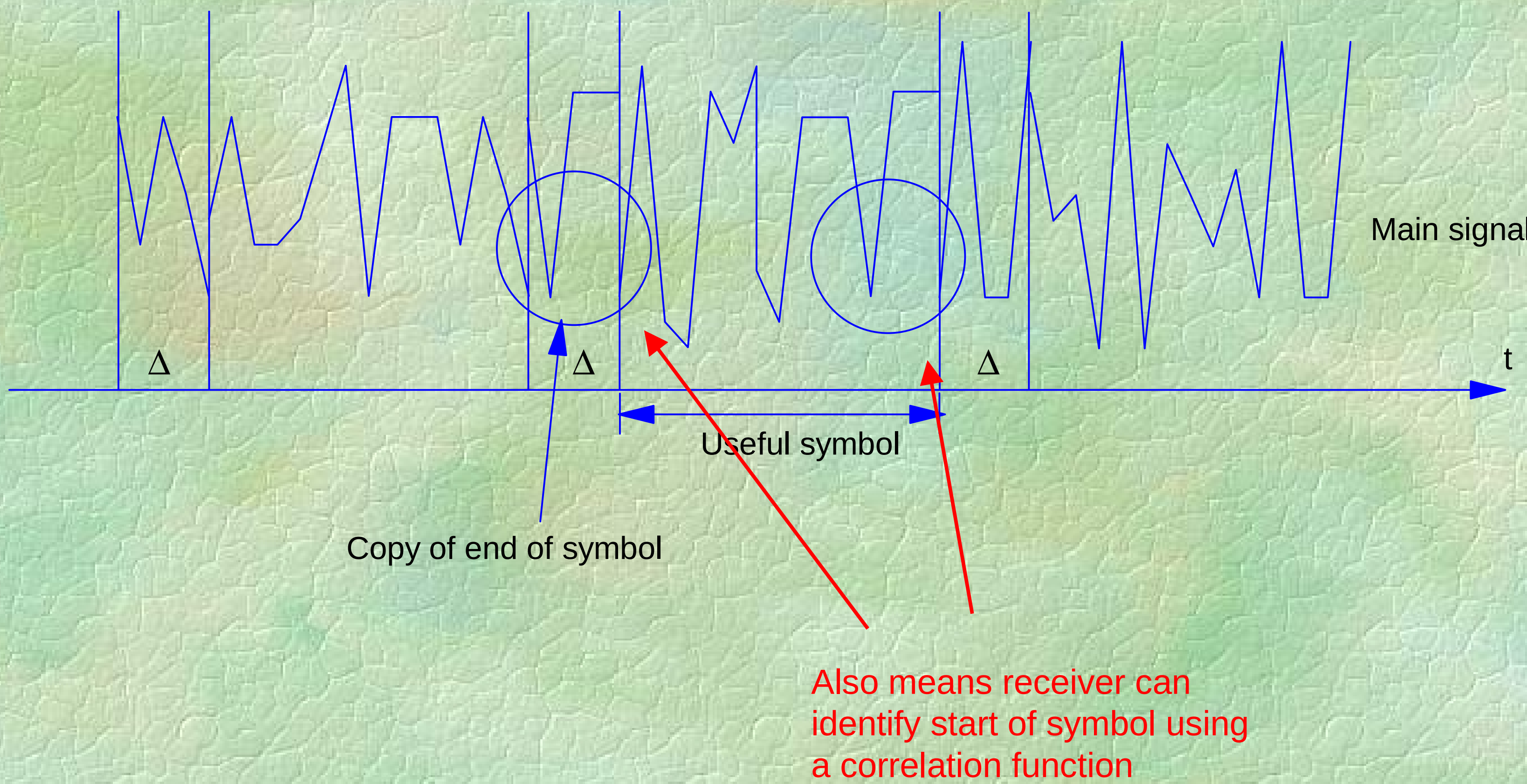
- IDFT at transmitter, DFT at receiver
  - FFT actually used (computational algorithm) for summing operation
  - FFT's must be powers of 2, hence '2k' or '8k' modes
  - Much faster that normal DFT
  - Eg if 8k point DFT takes 670 ms then the FFT takes .53 ms

N^2 $\quad\quad\quad$ $\frac{N}{2}\log N$

- Complex to real conversion
  - Q (real) and I (Imaginary) are added, sampled and output

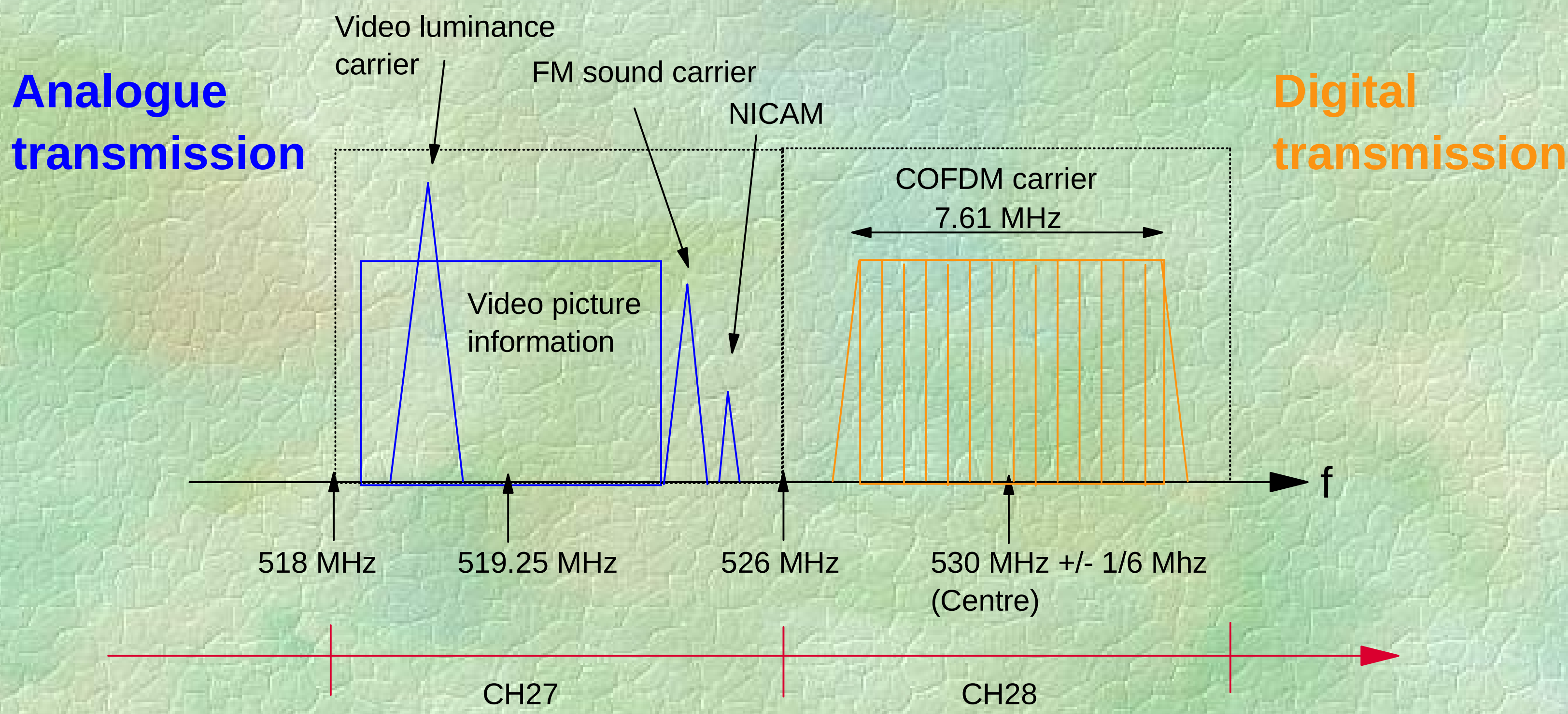
Guard Interval Insertion

- Replication of end of symbol placed at beginning



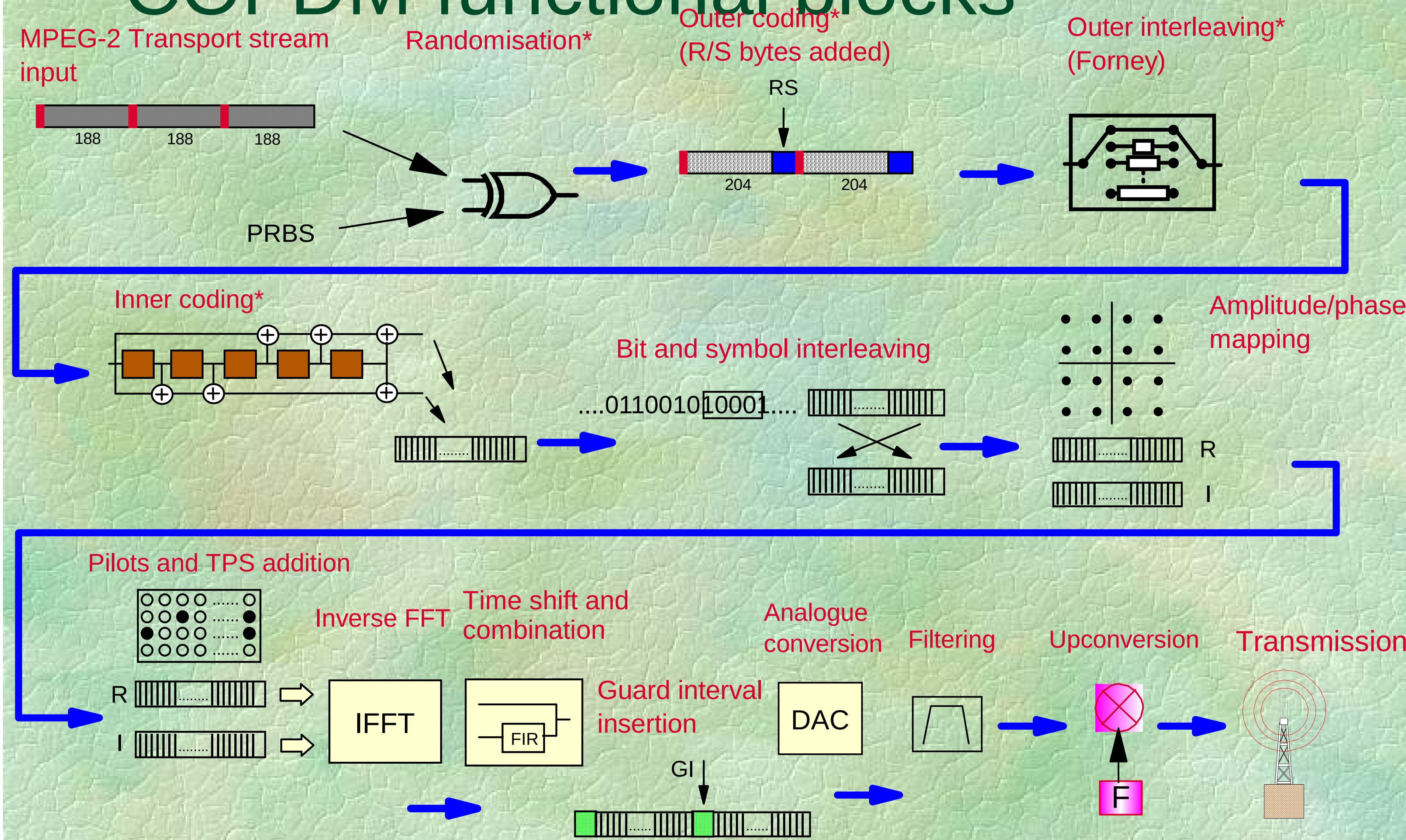
Final stages - Transmission

- D/A conversion
- Filtering
- Upconversion and transmission



Example: UK transmission in channel 28

COFDM functional blocks



* Same as DVB-S

What is COFDM ?

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O - Orthogonal

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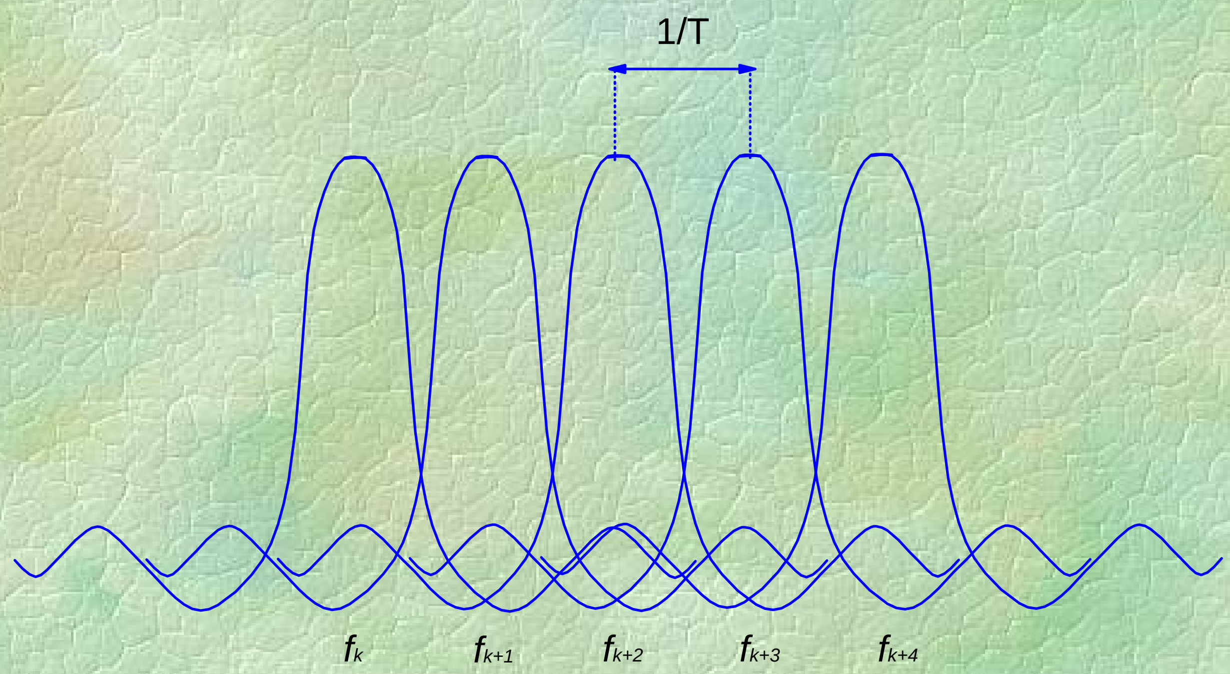
M - Multiplex

Orthogonality

- Definition possible due to signals being described as vectors
- Spacing between carriers is minimised
  - Results close to theoretical maximum are achieved ($\Delta f \propto 1/T$)
  - Expensive in analogue FDM due to costly band pass filters



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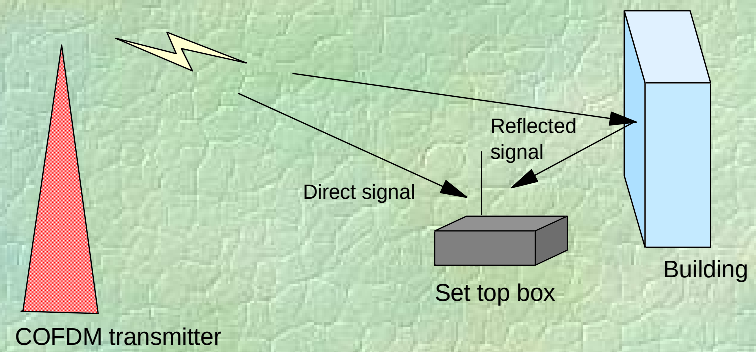
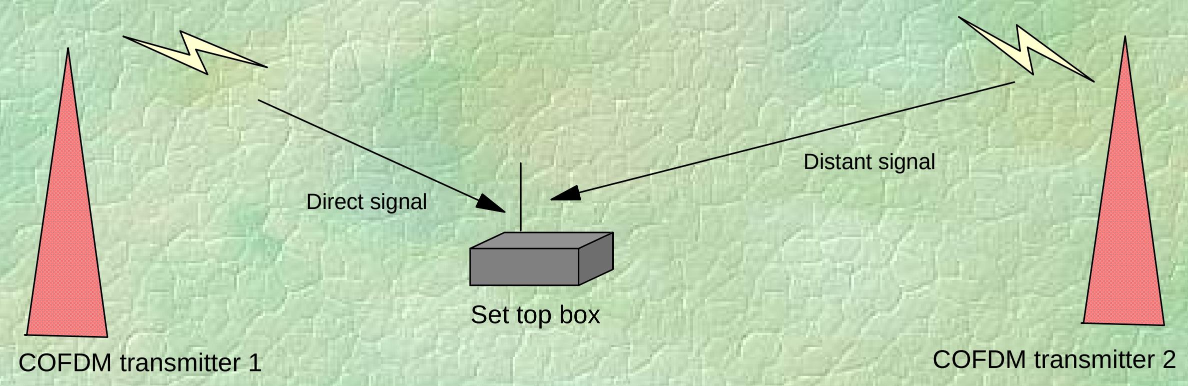
Countering against echoes and reflections

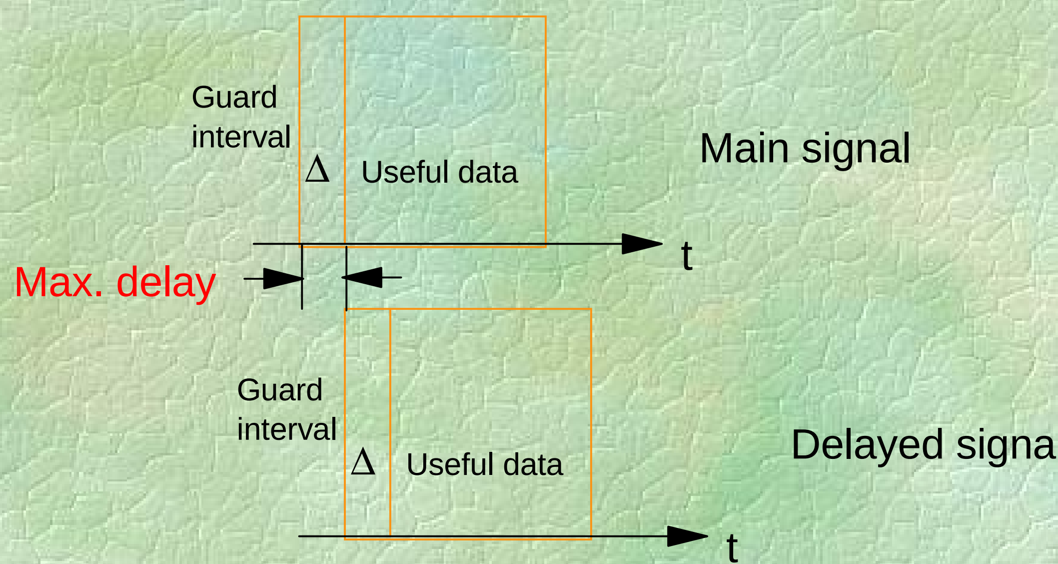
- Repetition of signal to counter echoes
  - Echoes caused by
    - Moving receiver
    - Moving transmitter
    - Reflection from moving or static objects
    - Single Frequency Networks (SFN's)





Countering against echoes and reflections

- Echo length is easily calculated
  - Assuming 2k Mode with Guard interval 1/32
  - 1/32 of the symbol transmits in 7 us
  - Maximum delay = 7 us
  - Distance = 3×10^8 m/s x 7 us
  - Distance = 2.1 km



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DVB-T variable parameters

- Carrier mode: 2k or 8k
- Type of modulation: QPSK, 16-QAM, 64-QAM
- Guard Interval: 1/4, 1/8, 1/16, 1/64
- Inner code rate: 1/2, 2/3, 3/4, 5/6, 7/8
- Hierarchical modes
- Selection of transmission bandwidth (6/7/8 MHz)

DVB-T variable parameters

Useful data rate (M bits / sec)

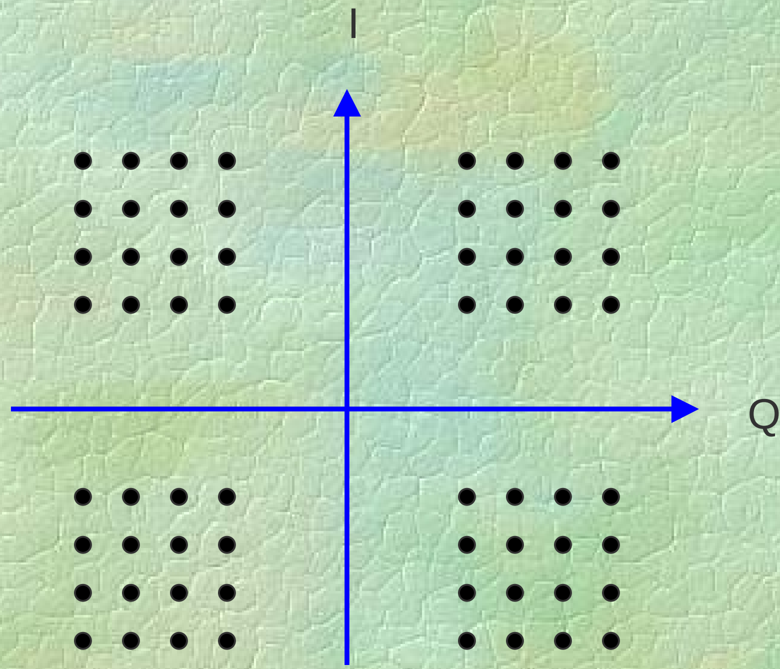
Modulation	*Code rate*	*Guard interval*			
		1/4	*1/8*	*1/16*	*1/32*
QPSK	1/2	4.98	5.53	5.85	6.03
	2/3	6.64	7.37	7.81	8.04
	3/4	7.46	8.29	8.78	9.05
	5/6	8.29	9.22	9.76	10.05
	7/8	8.71	9.68	10.25	10.56
16-QAM	1/2	9.95	11.06	11.71	12.06
	2/3	13.27	14.75	15.61	16.09
	3/4	14.93	16.59	17.56	18.10
	5/6	16.59	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

DVB-T variable parameters

- Significance of mode and guard interval
  - ‘8k’ system allows good reception with long multi-path echoes
  - ‘8k’ system is therefore suitable for single frequency networks (SFN’s)
  - ‘2k’ system more suited to multi frequency or single transmitter networks
  - A larger guard interval implies a lower bit-rate efficiency
  - The guard interval value is therefore a trade-off between bit-rate and network tolerance to echoes and reflections

DVB-T hierarchy coding

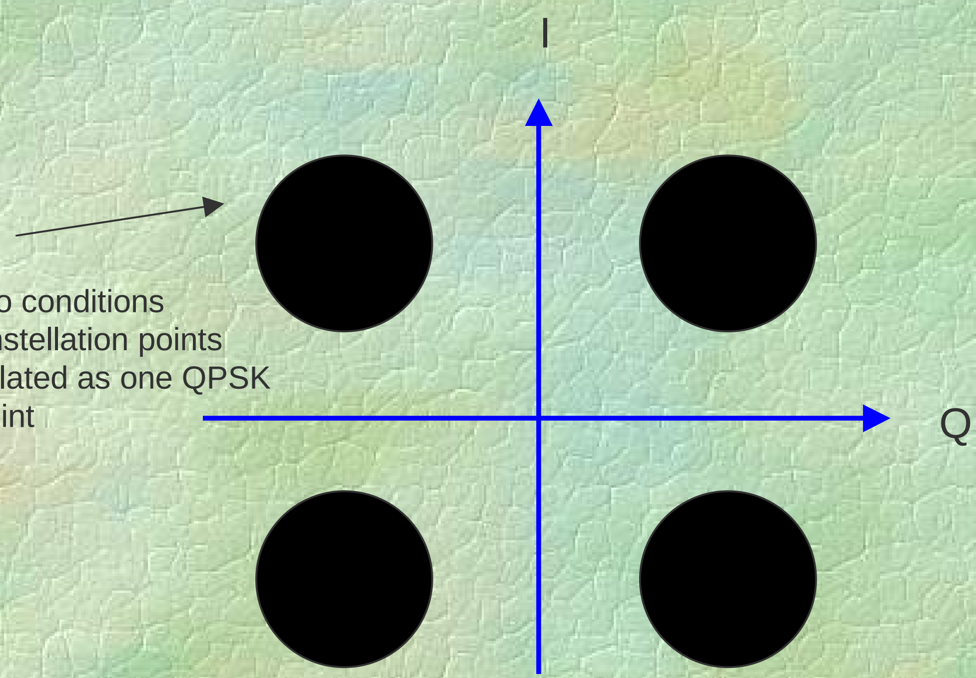
64 QAM constellation



Low priority carriers

DVB-T hierarchy coding

In poor S/N ratio conditions
16 64-QAM constellation points
can be demodulated as one QPSK
constellation point



High priority carriers

DVB-T hierarchy coding

- Transmission of the same or different data for:
  - Same or different program can be transmitted in HD and SD + greater error recovery
  - Poor reception areas can view SD if HD not possible
- Transmission of different resolutions / characteristics:
  - Reception by different cost receivers (high end, low end, mobile, portable)
- Other data can be transmitted related to the program