University of Canberra
Analog & Digital Communications

Elements of Digital Television

Lecture 6
Digital
Modulation Systems

by: Neil Pickford

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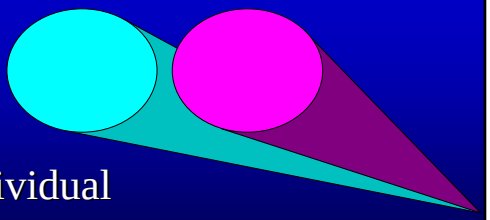
Enabling Technologies

- Source digitisation (Rec 601 digital studio)
- Compression technology (MPEG, AC-3)
- Data multiplexing (MPEG)
- Transmission technology (modulation)

2

Digital TV Transmission Technology

- The transmission system is used to transport the information to the consumer.
- The system protects the information being carried from the transmission environment
- The transmission system is a "data pipe"
- Transports data rates of around 20 Mb/s
- Transports data in individual containers called packets



3

Digital TV Transmission Systems

DTV & HDTV systems fall into three groupings

- Europeans
  - Digital SDTV
  - 8 MHz on UHF
  - DVB-T (COFDM)
- Americans
  - Digital HDTV
  - 6 MHz VHF/UHF
  - ATSC (8-VSB)
- Japanese
  - Integrated Broadcasting
  - ISDB (BST-OFDM)

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8-VSB - USA

- Developed by the advance television systems committee ATSC
- Developed for use in a 6 MHz channel
  - A 7 MHz variant is possible but has not been produced.
- Uses a single carrier with pilot tone
- 8 level amplitude modulation system
- Single Payload data rate of 19.39 Mb/s
- Relies on adaptive equalisation
- Existing AM technology highly developed

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COFDM - Europe

- Developed by the digital video broadcasting project group - DVB
- Uses similar technology to DRB
- Uses 1705 or 6817 carriers
- Variable carrier modulation types are defined allowing Payload data rates of 5-27 Mb/s in 7 MHz
- Developed for 8 MHz channels
  - A 7 & 6 MHz variants have been produced and tested.
- Can use single frequency networks - SFNs
- New technology with scope for continued improvement & development

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ISDB - Japan

- Japanese are developing integrated services digital broadcasting (ISDB)
- System integrates all forms of broadcasting services into one common data channel which can be passed by satellite, cable or terrestrial delivery systems
- Video services
  - Sound services
  - Bulk data services
  - Interactive data services

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ISDB - Concept

- Uses Band Segmented Transmission - Orthogonal Frequency Division Multiplex (BST-OFDM)

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Terrestrial Transmission Problems

- ✘ Multipath interference - ghosts
- ✘ Noise interference - snow
- ✘ Variable path attenuation - fading
- ✘ Interference to existing services
- ✘ Interference from other services
- ✘ Channel frequency assignment - where to place the signal

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Digital Modulation - Functions

- ✔ Spreads the data evenly across the channel
- ✔ Distributes the data in time
- ✔ Maintains synchronisation well below data threshold
- ✔ Employs sophisticated error correction.
- ✔ Equalises the channel for best performance

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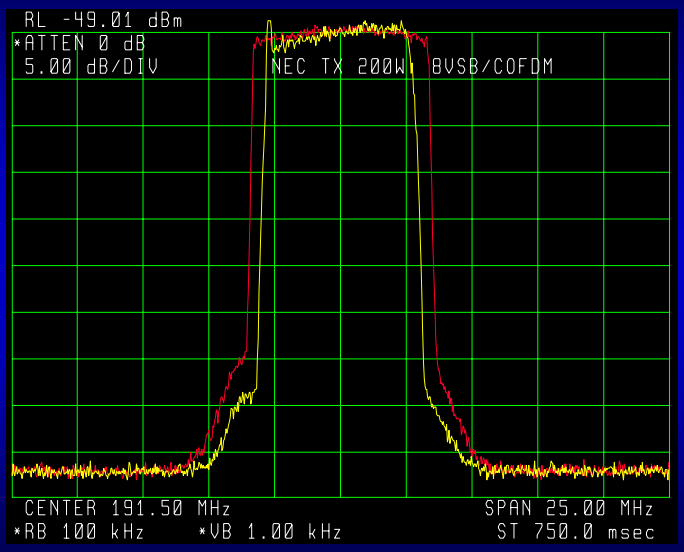
Digital Modulation

Two techniques:

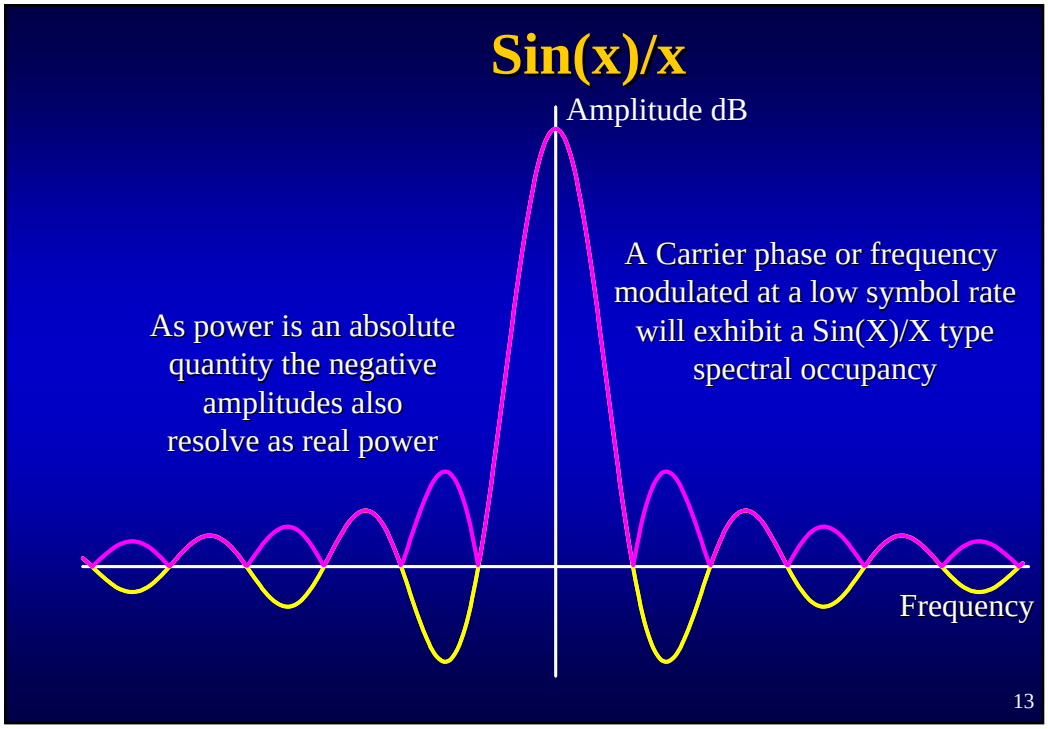
- **Conventional Single Carrier**
  - ***8VSB, QPSK or QAM***
- **Multicarrier/Spread Spectrum**
  - ***OFDM***

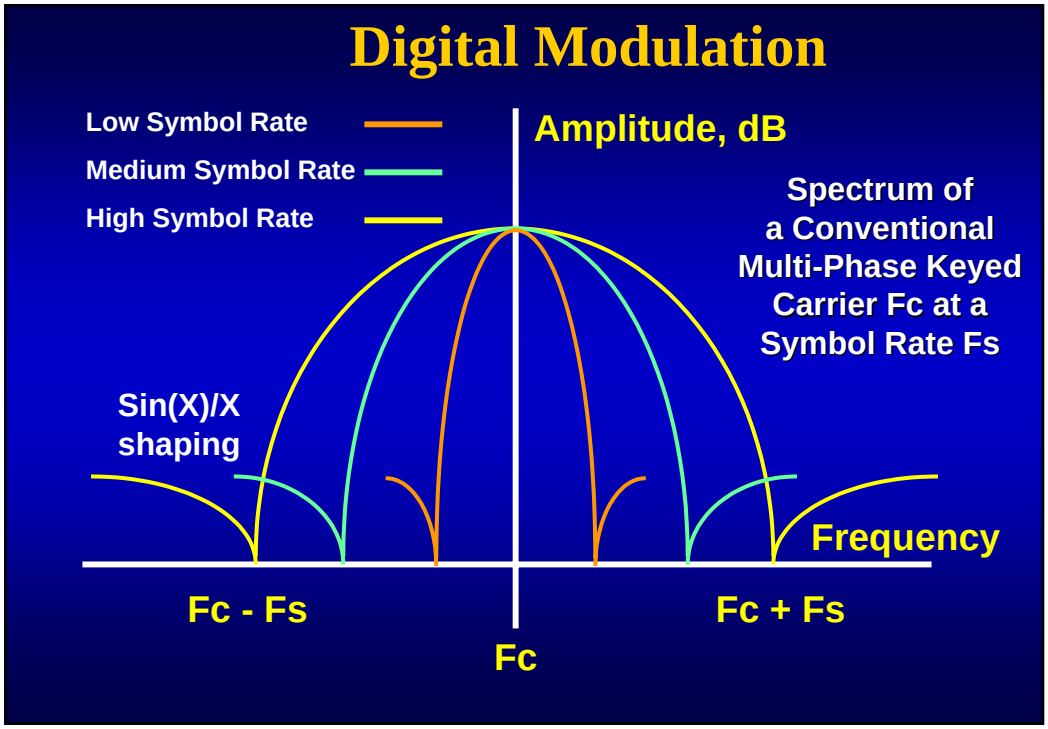
8-VSB & COFDM - Spectrum



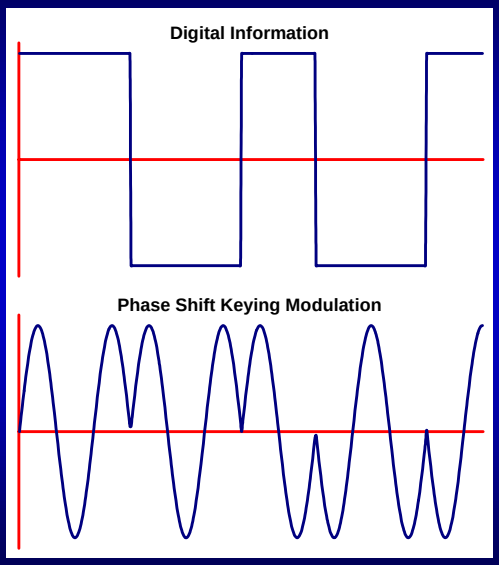
8-VSB
COFDM

12


Sin(x)/x
Amplitude dB
A Carrier phase or frequency modulated at a low symbol rate will exhibit a Sin(X)/X type spectral occupancy
As power is an absolute quantity the negative amplitudes also resolve as real power
Frequency
13


Digital Modulation
Low Symbol Rate
Medium Symbol Rate
High Symbol Rate
Amplitude, dB
Spectrum of a Conventional Multi-Phase Keyed Carrier Fc at a Symbol Rate Fs
Sin(X)/X shaping
Frequency
Fc - Fs
Fc + Fs
Fc

PSK



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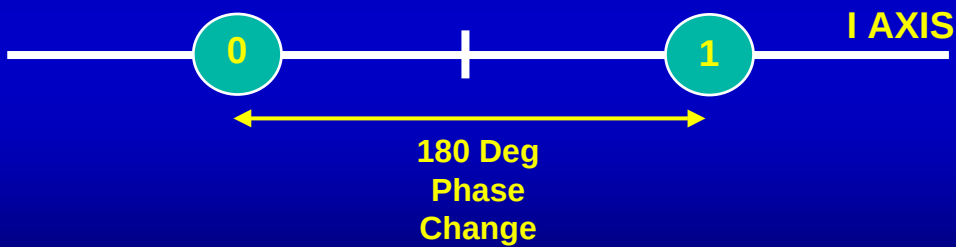
BPSK Modulation



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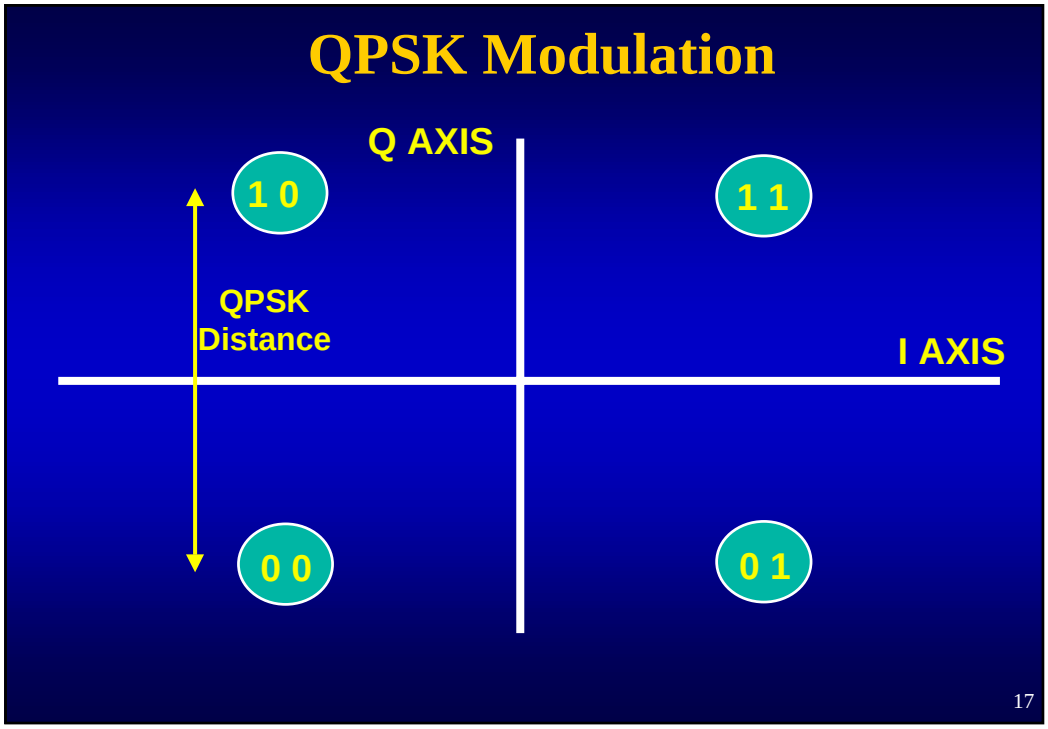
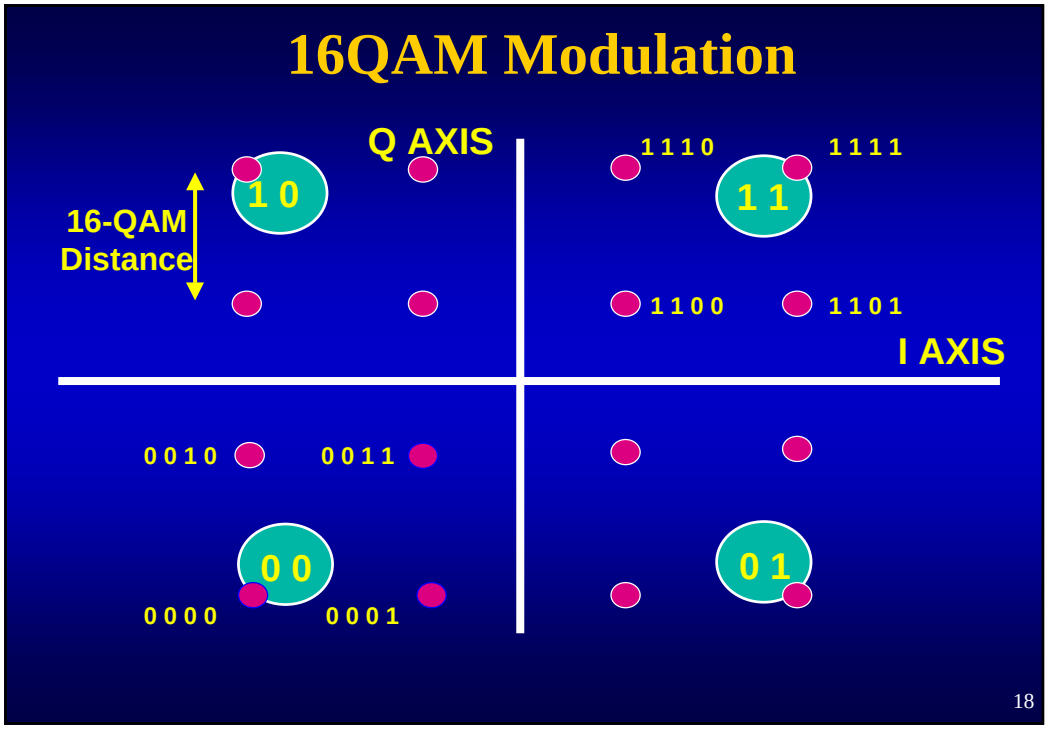
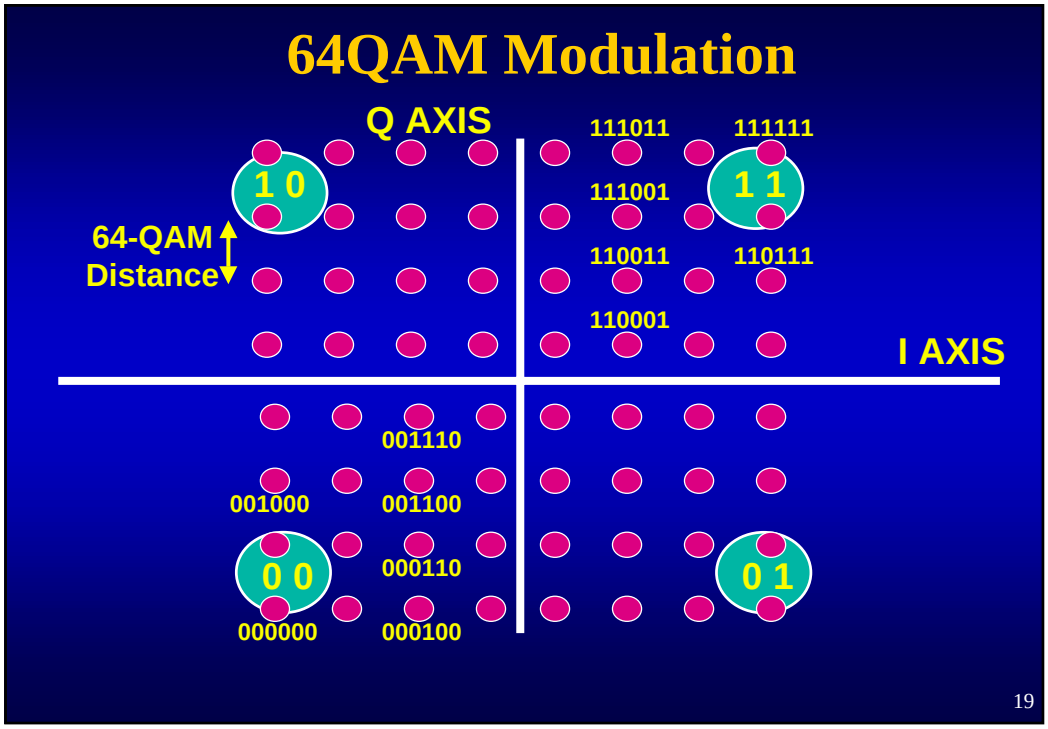
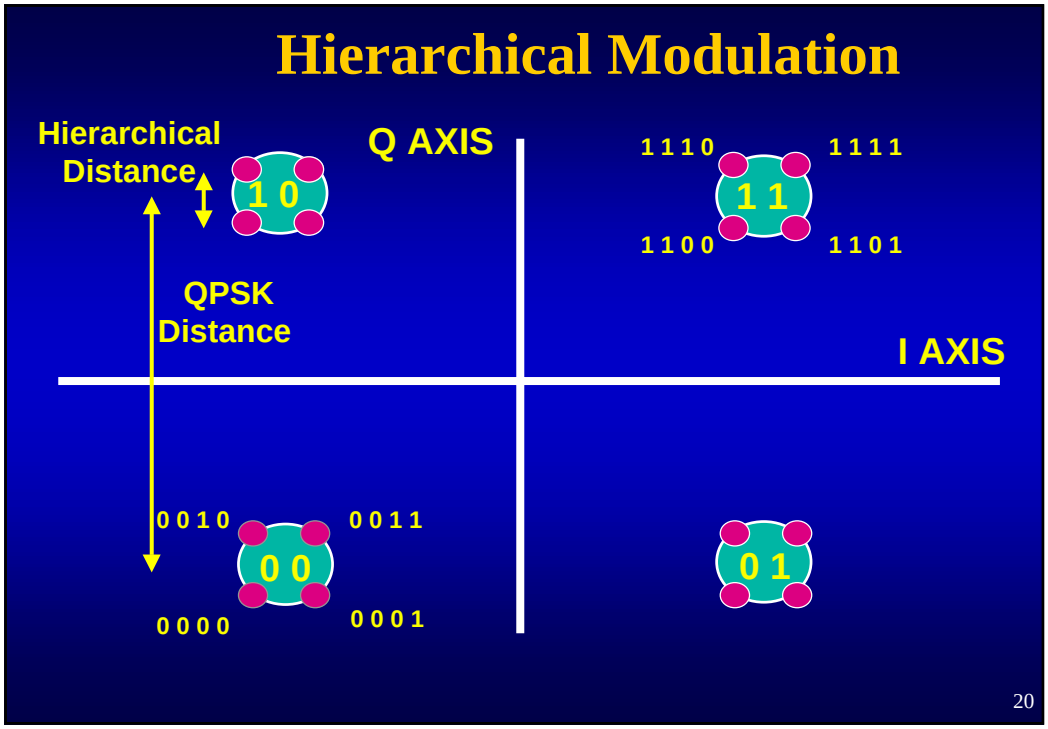
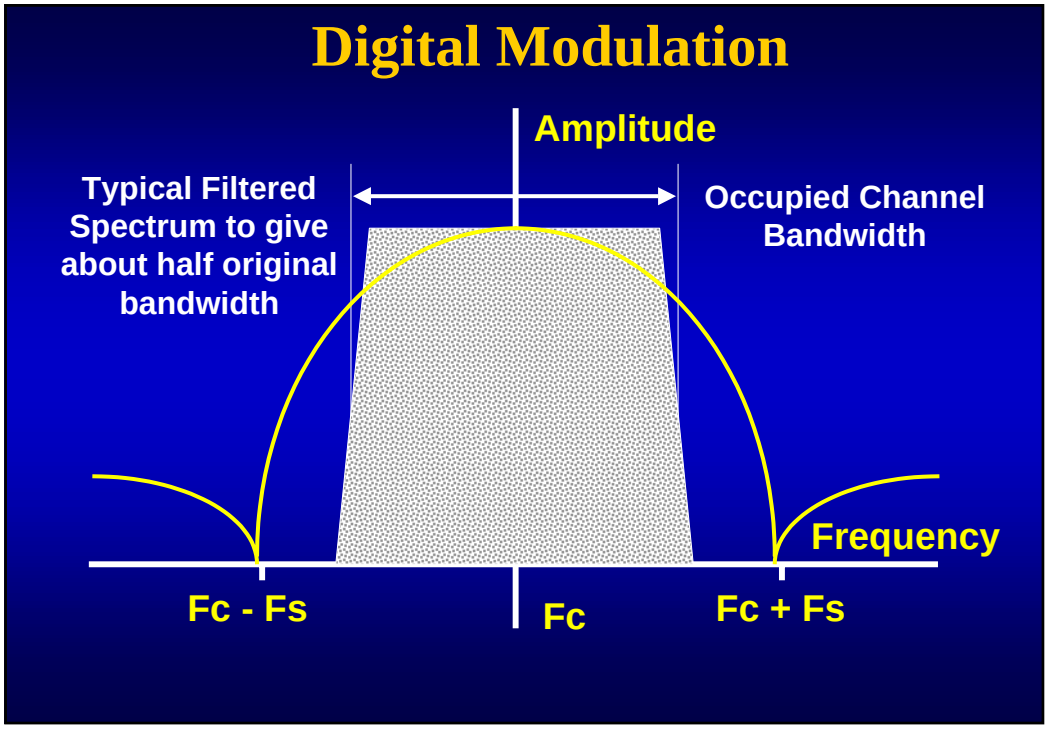
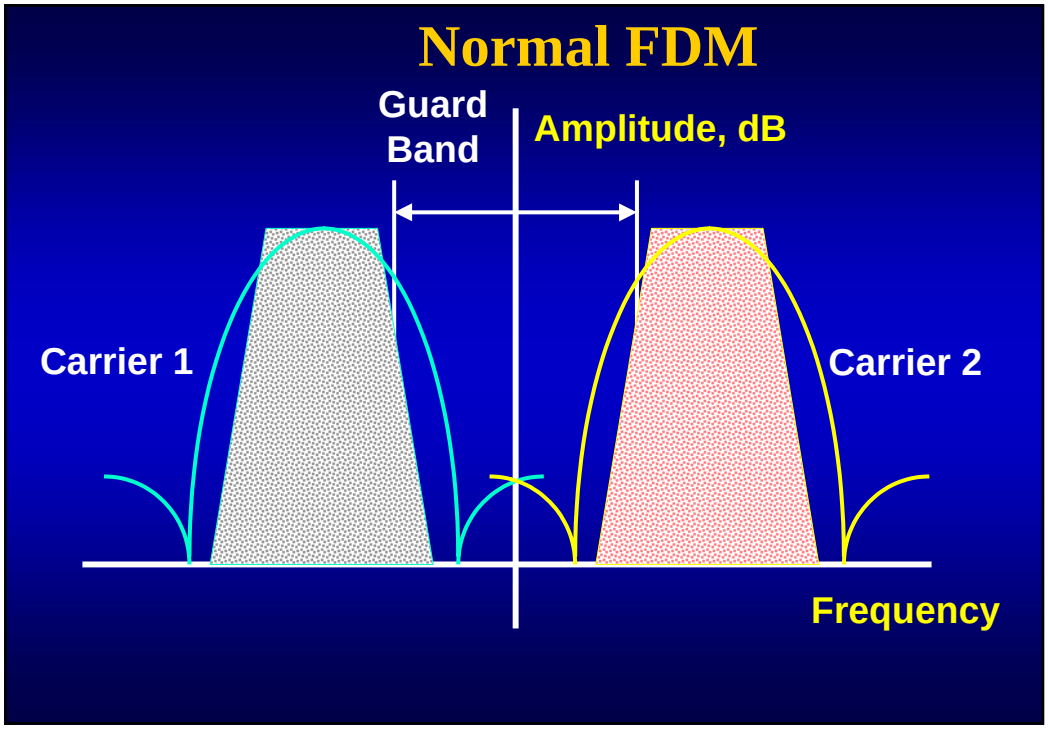

QPSK Modulation
Q AXIS
1 0
1 1
QPSK
Distance
I AXIS
0 0
0 1
17

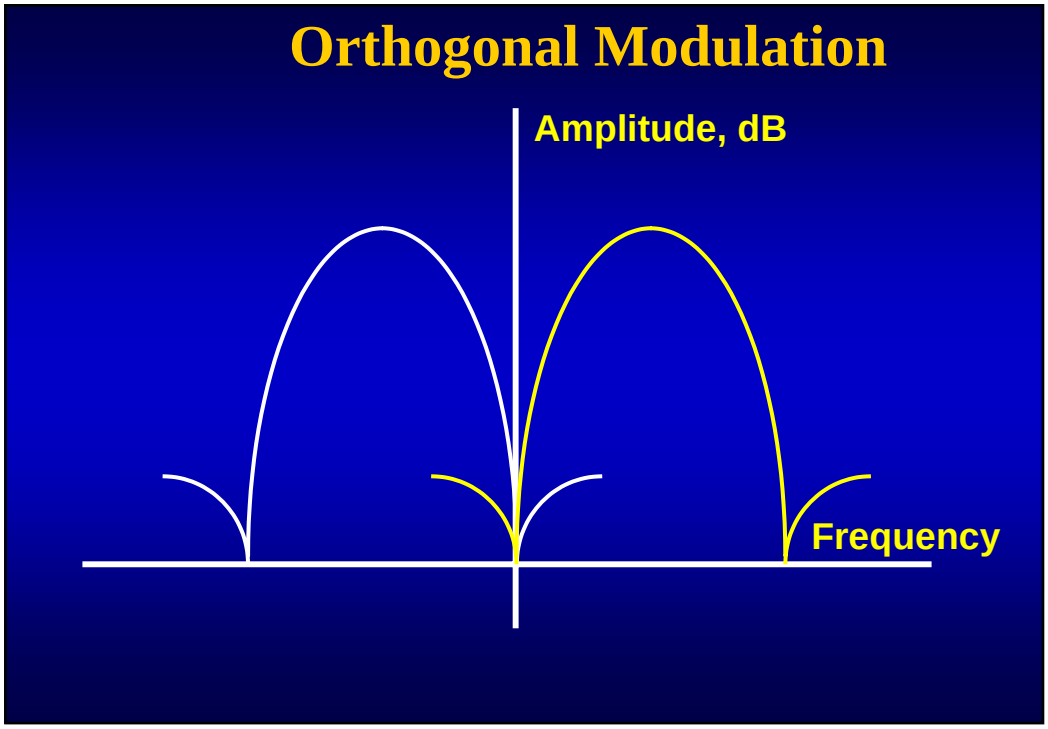

16QAM Modulation
Q AXIS
1 0
1 1
16-QAM
Distance
1110
1111
1100
1101
I AXIS
0010
0011
0 0
0 1
0000
0001
18

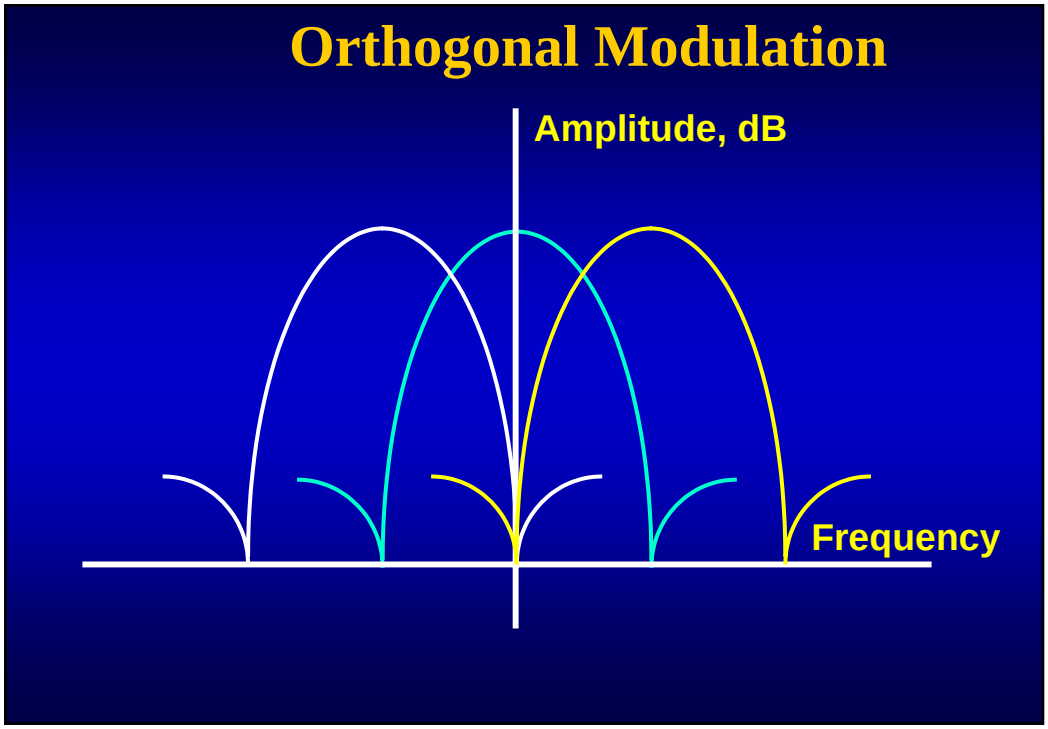

64QAM Modulation
Q AXIS
I AXIS
64-QAM Distance
1 0
1 1
0 0
0 1
111011
111111
111001
110011
110111
110001
001110
001000
001100
000110
000000
000100
19


Hierarchical Modulation
Hierarchical Distance
Q AXIS
I AXIS
QPSK Distance
1 0
1 1
0 0
0 1
1110
1111
1100
1101
0010
0011
0000
0001
20

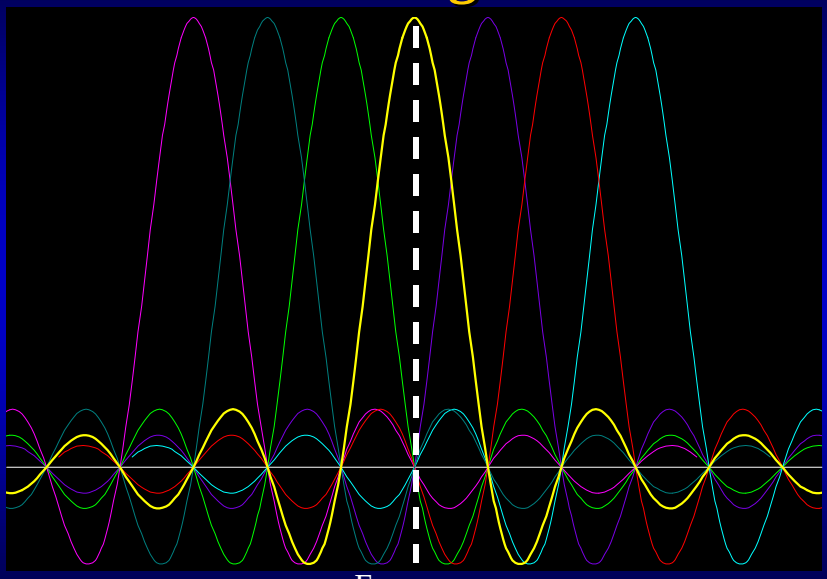

Digital Modulation
Amplitude
Typical Filtered Spectrum to give about half original bandwidth
Occupied Channel Bandwidth
Frequency
Fc - Fs
Fc
Fc + Fs


Normal FDM
Guard Band
Amplitude, dB
Carrier 1
Carrier 2
Frequency


Orthogonal Modulation
Amplitude, dB
Frequency


Orthogonal Modulation
Amplitude, dB
Frequency

COFDM - Orthogonal Carriers



Frequency

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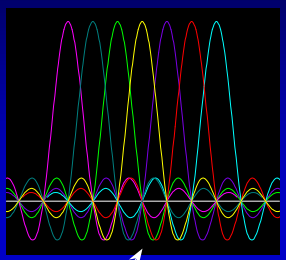
Spectrum of COFDM DTTB

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



Almost
Rectangular
Shape

1705 or 6817 Carriers

6.67 MHz in 7 MHz Channel

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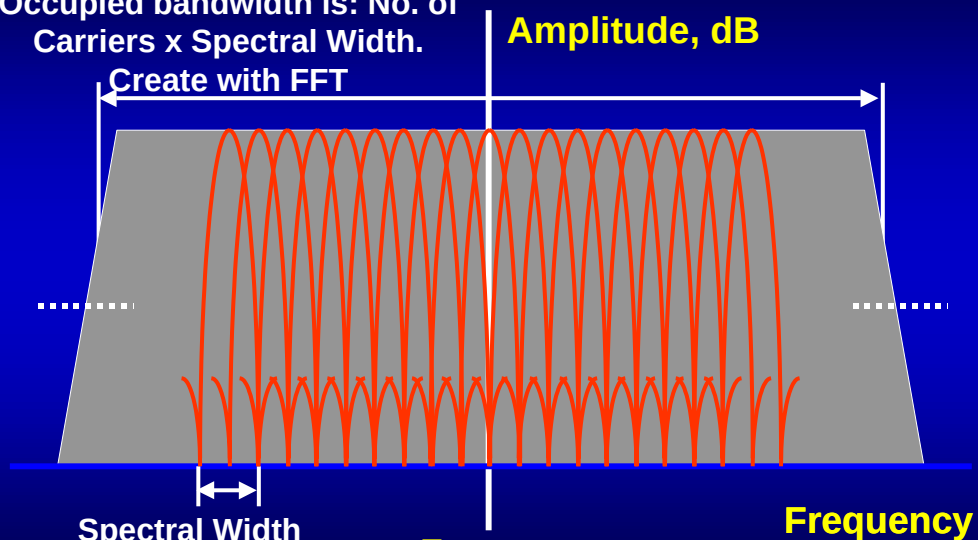
OFDM

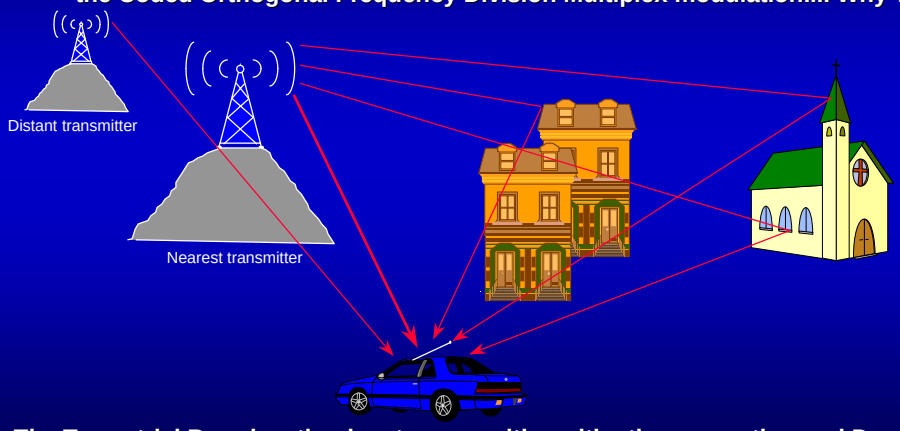
Occupied bandwidth is: No. of Carriers x Spectral Width. Create with FFT



2k is 4x wider than 8k

DIGITAL TERRESTRIAL BROADCASTING

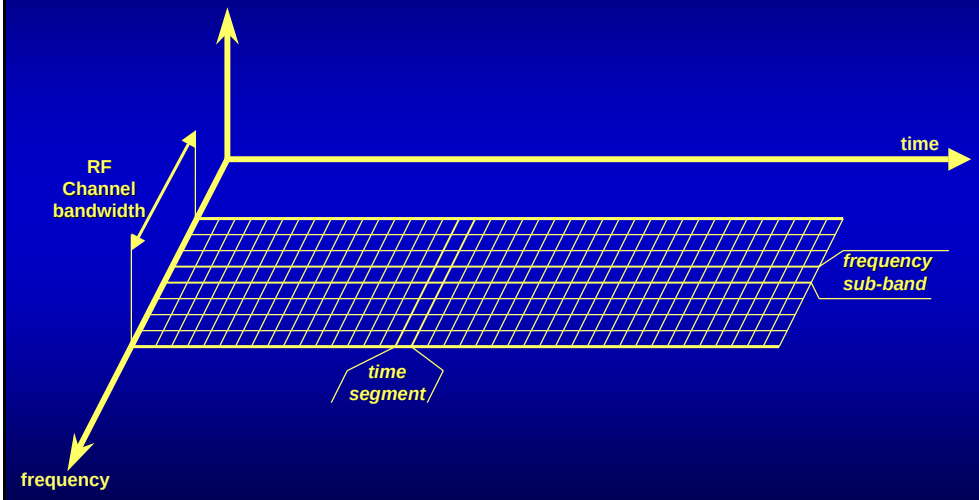
Among the four Digital Broadcasting standards available, three are based on the Coded Orthogonal Frequency Division Multiplex modulation.... Why ?



The Terrestrial Broadcasting has to cope with multipath propagation and Doppler effects: COFDM is the response for these impairments !

COFDM : HOW ?

- 1 - Organize time & frequency partitions in the RF channel



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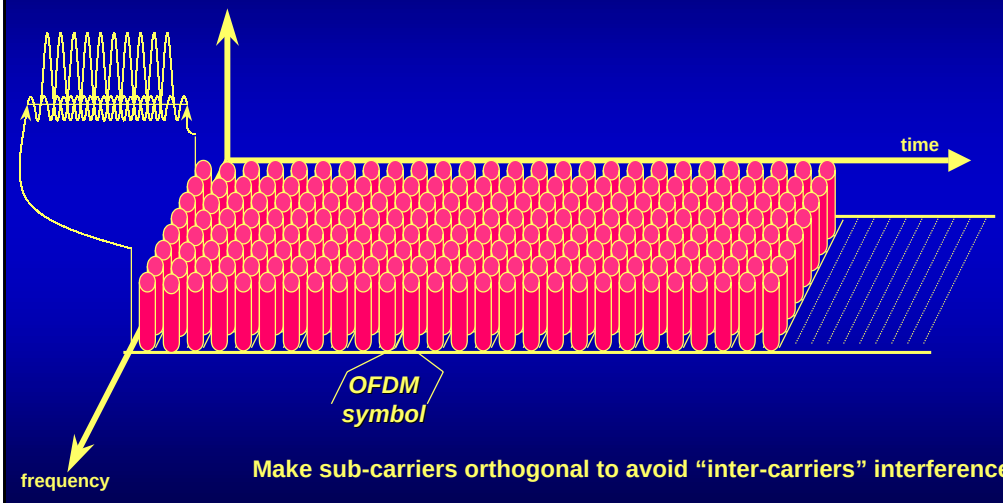
COFDM : HOW ?

- 2 - Spread sub-carriers over “time vs frequency” cells



Make sub-carriers orthogonal to avoid “inter-carriers” interference

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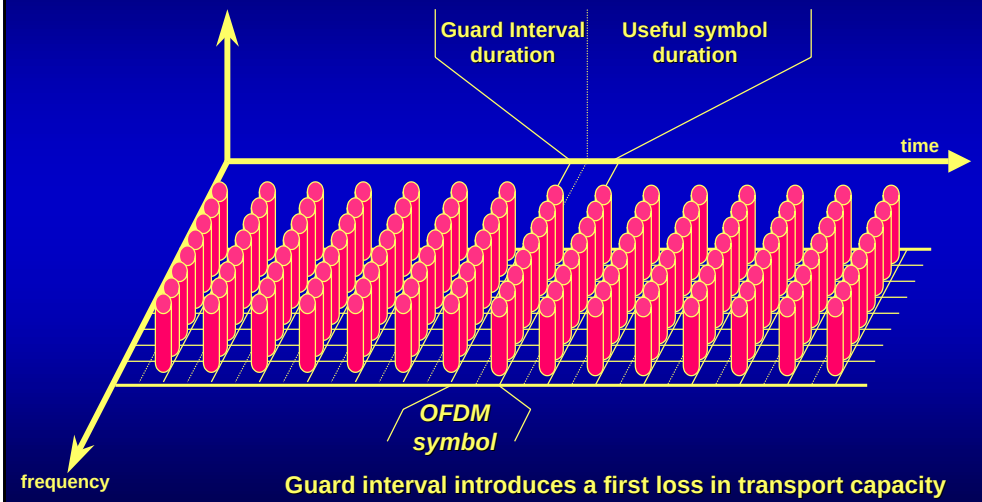
COFDM : HOW ?

- 3 - Insert Guard Interval to avoid “inter-symbol” interference



Guard interval introduces a first loss in transport capacity

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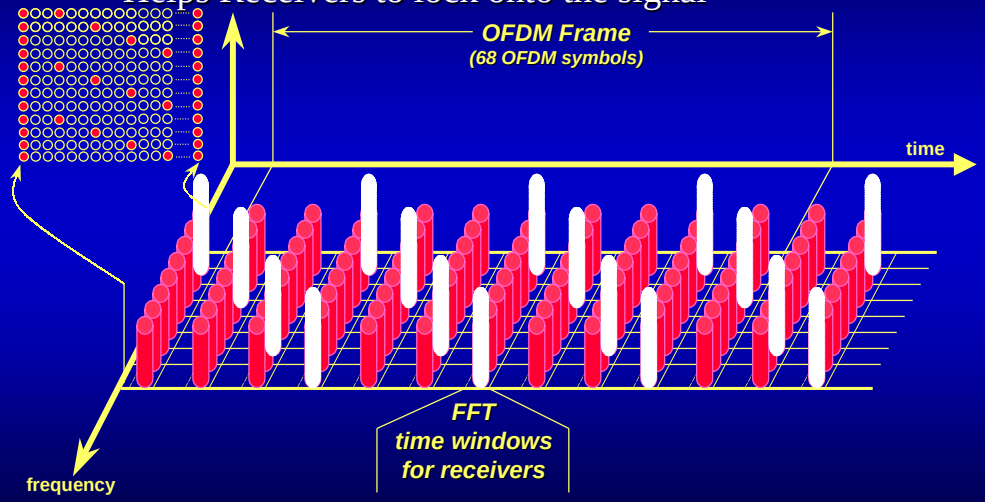
COFDM : HOW ?

- 4 - Insert “Synchronization Pilots”
  Helps Receivers to lock onto the signal



Synchronization markers introduce the second loss in transport capacity

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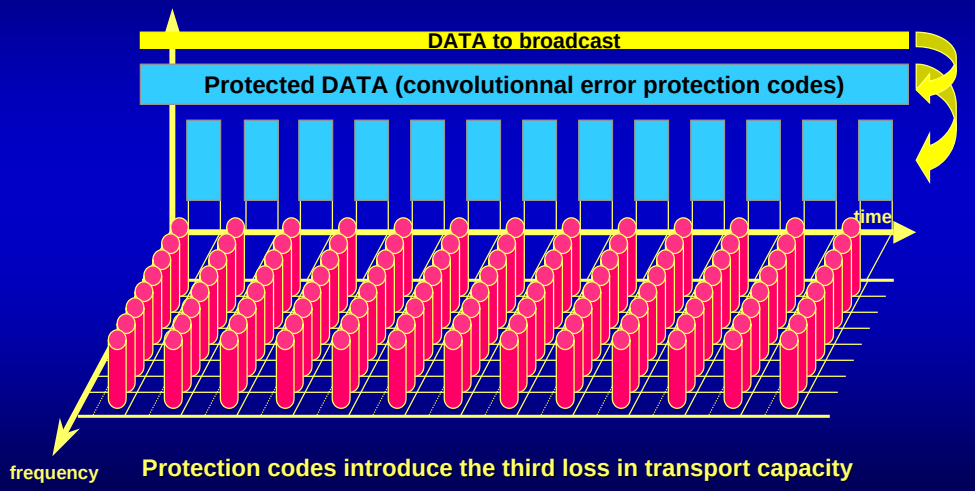
COFDM : HOW ?

- 5 - Prepare data to be carried on OFDM symbols



Protection codes introduce the third loss in transport capacity

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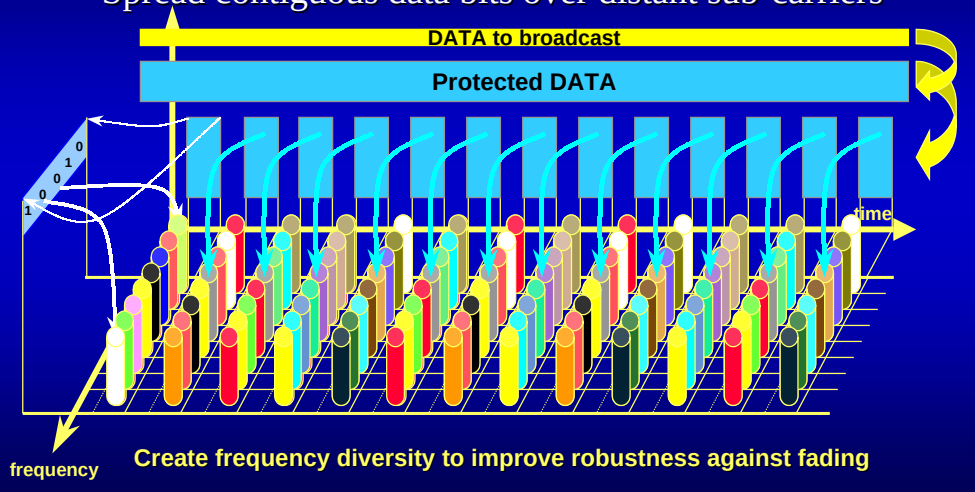
COFDM : HOW ?

- 6 - Map bits onto OFDM:
  Spread contiguous data bits over distant sub-carriers



Create frequency diversity to improve robustness against fading

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DTTB - Channel Estimation

- The Terrestrial transmission channel is continuously varying (position & time)
- Variations occur in Amplitude, Phase & Frequency
- To correct for this variation Information needs to be added to the transmission to quantify the channels response at any instant - Pilots
- Equalisers in the Digital receiver use this information to remove these transmission impairments

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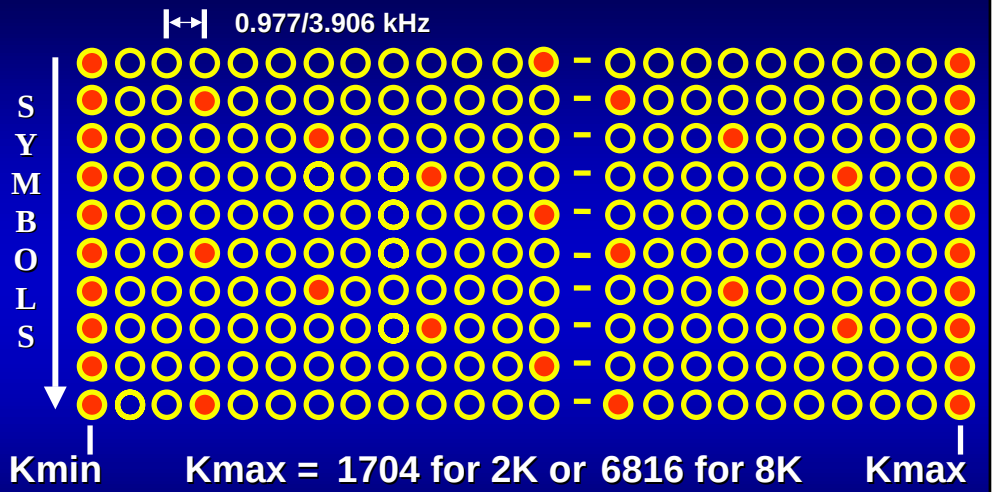
DVB-T - *Carriers + Pilots*



SYMBOLS IN SEQUENCE - 68 PER BLOCK.

Modulated Carriers

Scattered Pilots

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TPS Pilots

- Transmission Parameter Signalling is added on selected carriers within the OFDM spectrum (17 pilots for 2k & 68 pilots for 8k)
- TPS pilots Carry:
  - Frame Number in Super Frame: 00 / 01 / 10 / 11
  - Constellation Type QPSK / 16-QAM / 64-QAM
  - OFDM Mode 2k or 8k
  - Constellation Mode Normal/Hierarchical + α value
  - Inner FEC Code rate (1/2, 2/3, 3/4, 5/6, 7/8)
  - Guard Interval (1/4, 1/8, 1/16, 1/32)
  - System Bandwidth (6, 7, 8 MHz)

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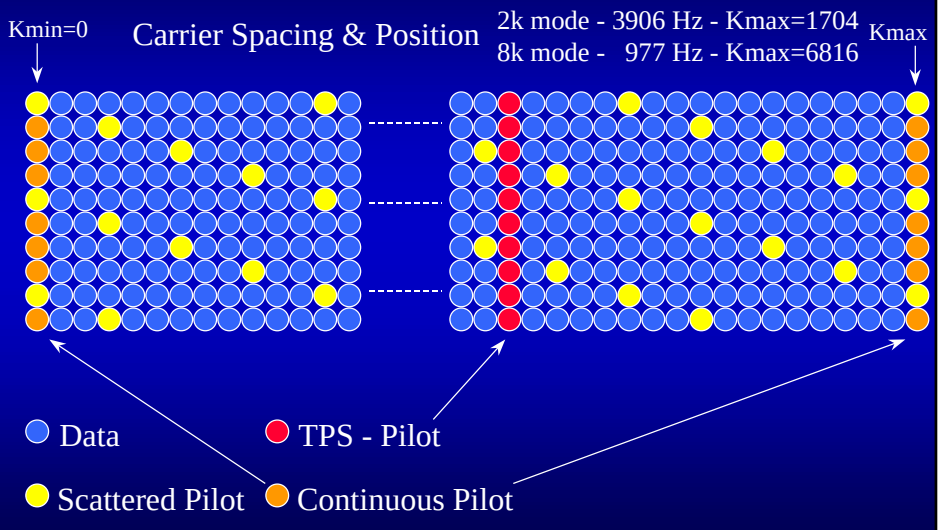
DVB-T Transmission Frame



Symbol Duration 256 us (2k) or 1024 us (8k)

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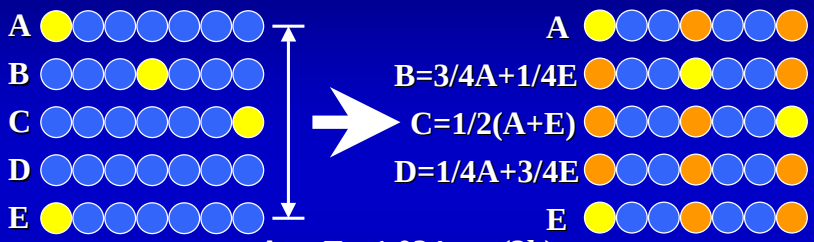
DVB-T - Estimating the Channel



A to E - 1.024 ms (2k)
- 4.096 ms (8k)

For a varying transmission channel
DVB-T estimation is 23.5 times faster than ATSC

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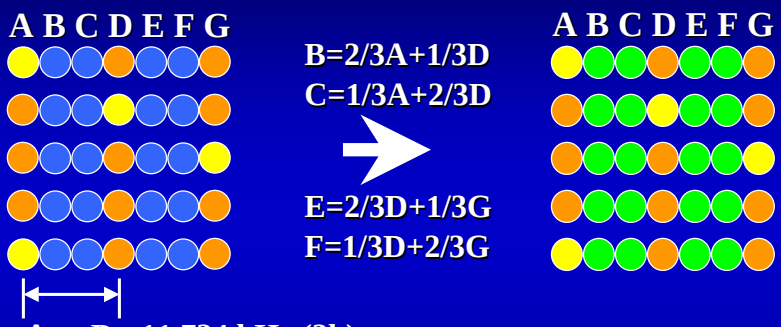
DVB-T - Estimating the Channel



A to D - 11.724 kHz (2k)
- 2.931 kHz (8k)

For a varying transmission channel
DVB-T estimation is 23.5 times faster than ATSC

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Estimation Rate DVB-T

- Equaliser is updated every symbol period (256 us). $^{1}/_{12}$ of data carriers are pilots
- Full Channel estimate is available every 4 symbols (1.024 ms)

Guard Interval

- OFDM is better than Single carrier systems under Multipath Echo conditions due to the addition of a Guard interval in the modulation system.
- The Guard interval is added onto the symbol time wasting some potential data capacity.

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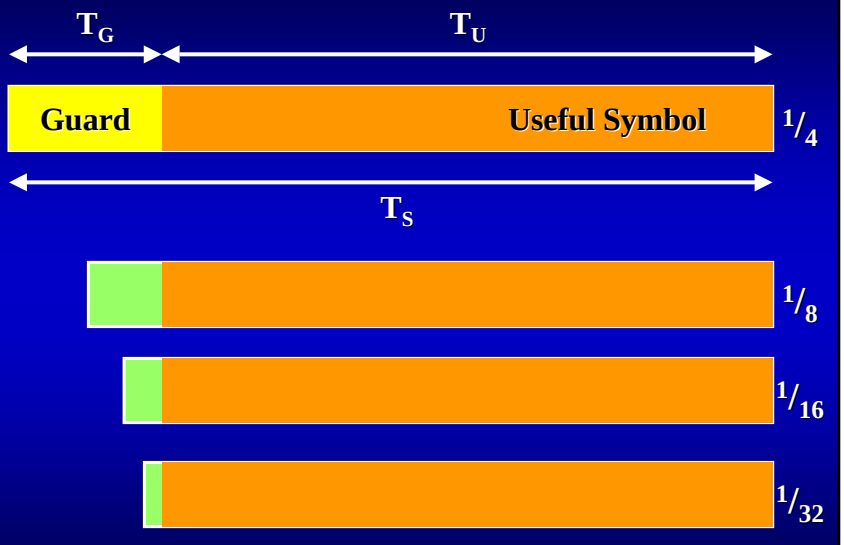
Guard Interval



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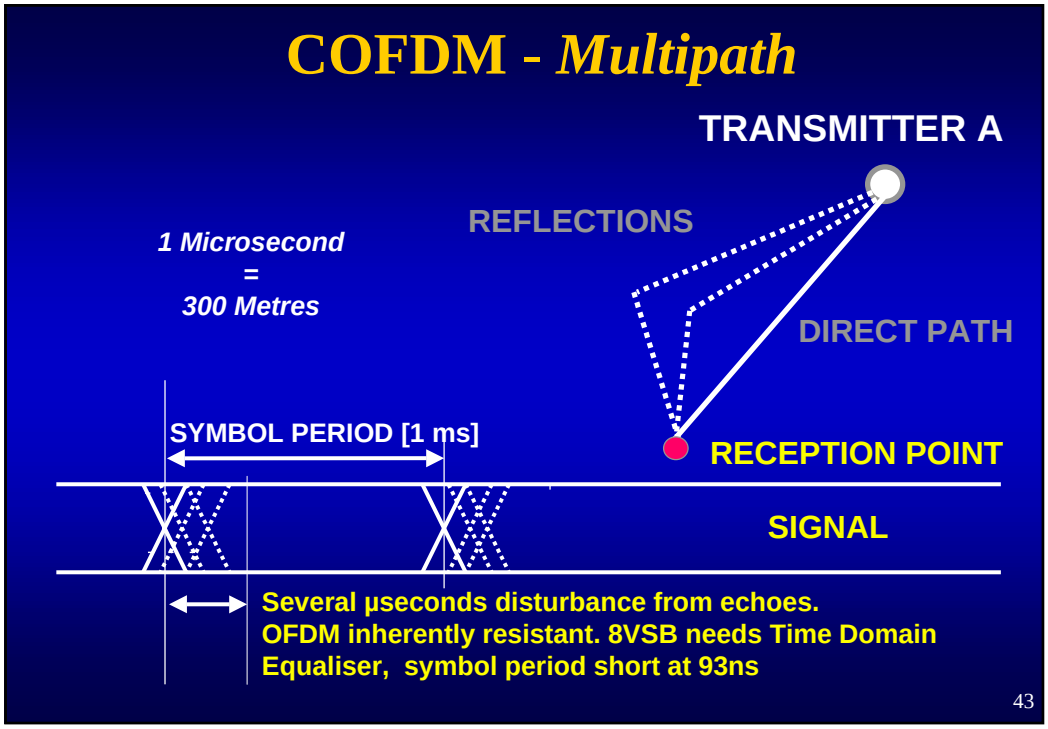
COFDM - Multipath
TRANSMITTER A
REFLECTIONS
1 Microsecond
=
300 Metres
DIRECT PATH
SYMBOL PERIOD [1 ms]
RECEPTION POINT
SIGNAL
Several µseconds disturbance from echoes.
OFDM inherently resistant. 8VSB needs Time Domain
Equaliser, symbol period short at 93ns
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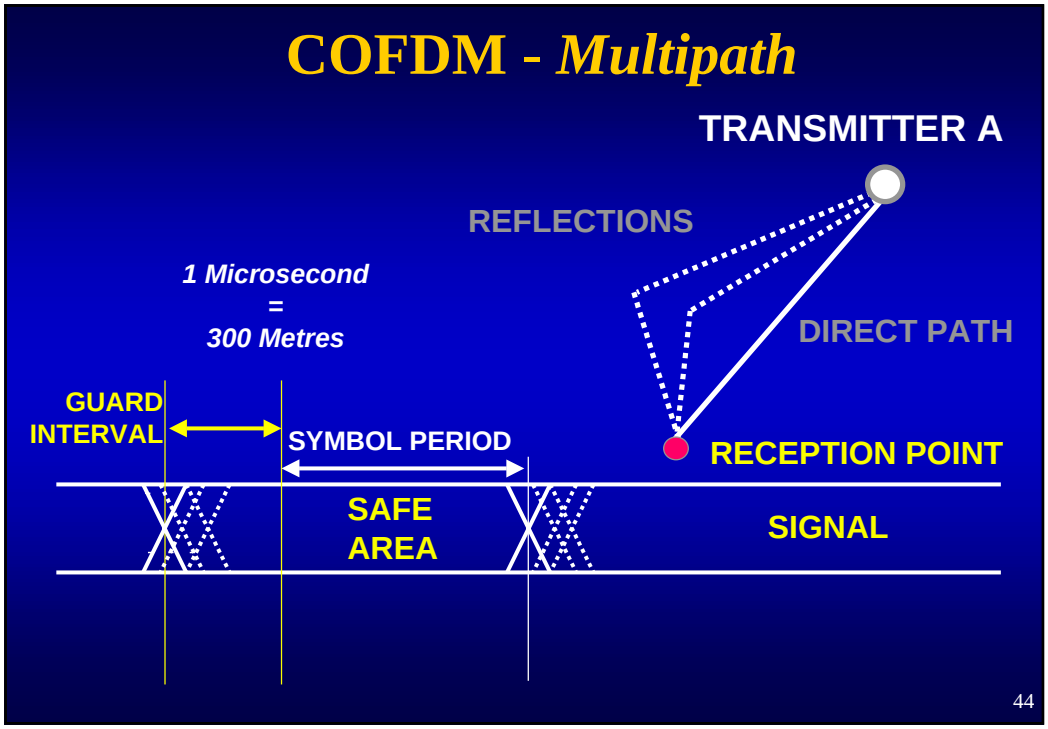
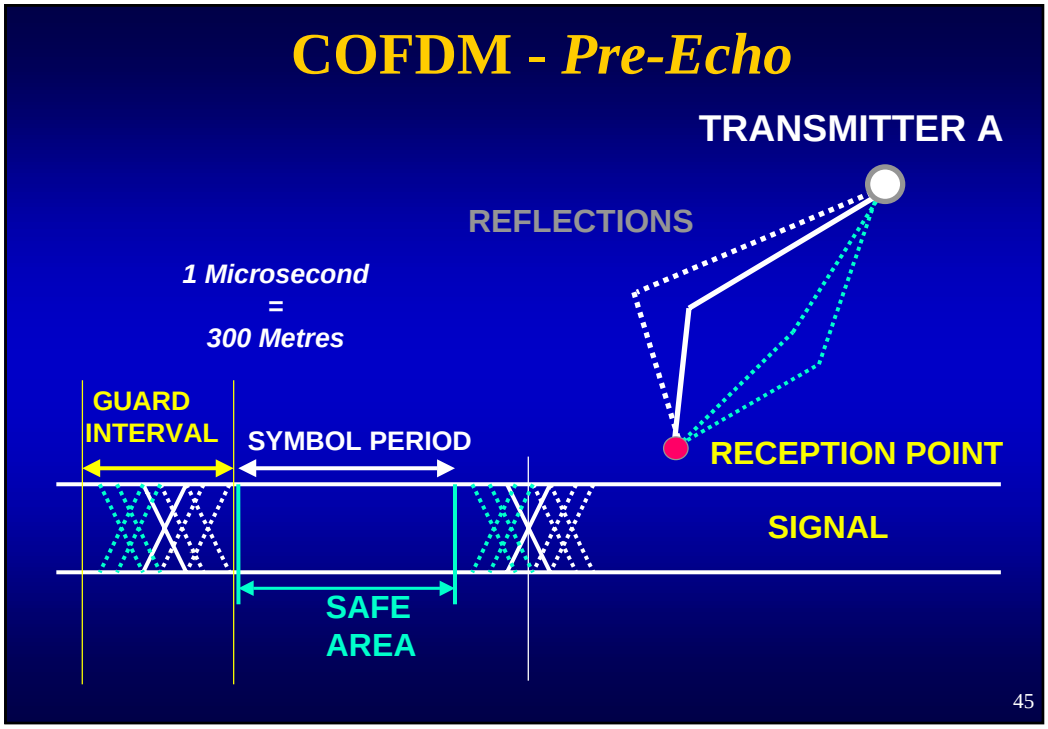
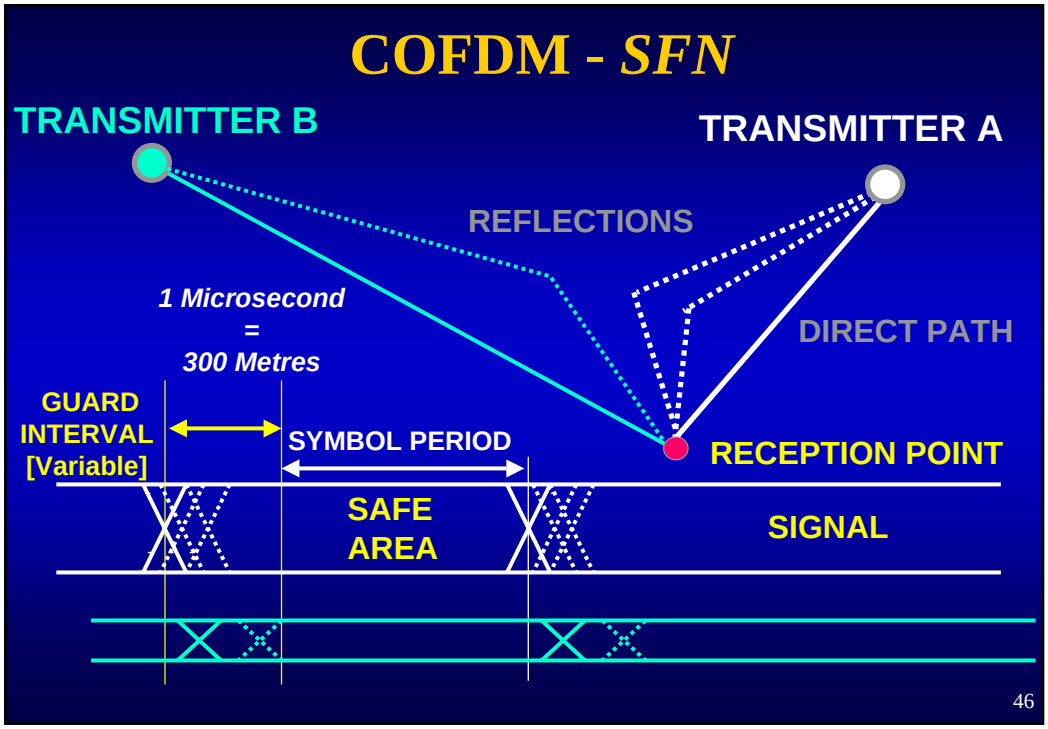

COFDM - Multipath
TRANSMITTER A
REFLECTIONS
1 Microsecond
=
300 Metres
DIRECT PATH
GUARD
INTERVAL
SYMBOL PERIOD
RECEPTION POINT
SAFE
AREA
SIGNAL
44


COFDM - Pre-Echo
TRANSMITTER A
REFLECTIONS
1 Microsecond
=
300 Metres
GUARD
INTERVAL
SYMBOL PERIOD
RECEPTION POINT
SIGNAL
SAFE
AREA
45


COFDM - SFN
TRANSMITTER B
TRANSMITTER A
REFLECTIONS
1 Microsecond
=
300 Metres
DIRECT PATH
GUARD
INTERVAL
[Variable]
SYMBOL PERIOD
RECEPTION POINT
SAFE
AREA
SIGNAL
46

Mobile Services

- **Antenna Performance**
  - *Poor Directivity, Low Gain*
  - *Multipath Dominated environment*
- **Doppler**
  - *High Speeds for Main Roads and Railways*
  - *Low Speeds for Public Transport in Cities*
- **Needs to be Rugged**
  - *Choose version of DVB-T that is suitable*
  - *Low Bit Rate, Low C/N, Long Guard Interval?*

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Bus Route 7 Singapore - 1999

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OFDM - *Features*

- **Multicarrier** - *many carriers sharing*
- **Reduced C/N compared to Analogue**
- **Resistant to echoes, Interference etc**
- **Low symbol rate per carrier**
  - *~ 1 kBaud: Long Symbol Period, can Extend with Guard Interval*
- **With FEC becomes COFDM**
- **Uses Fast Fourier Transform [FFT]**
  - *"2k" and "8k" versions*
- **Single Frequency Networks [SFN]**

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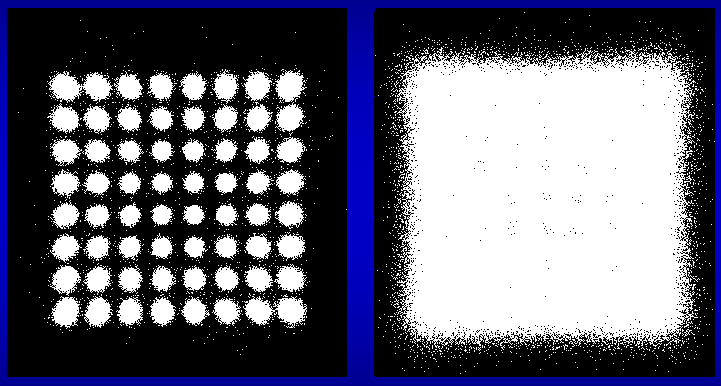
64-QAM - Perfect & Failure



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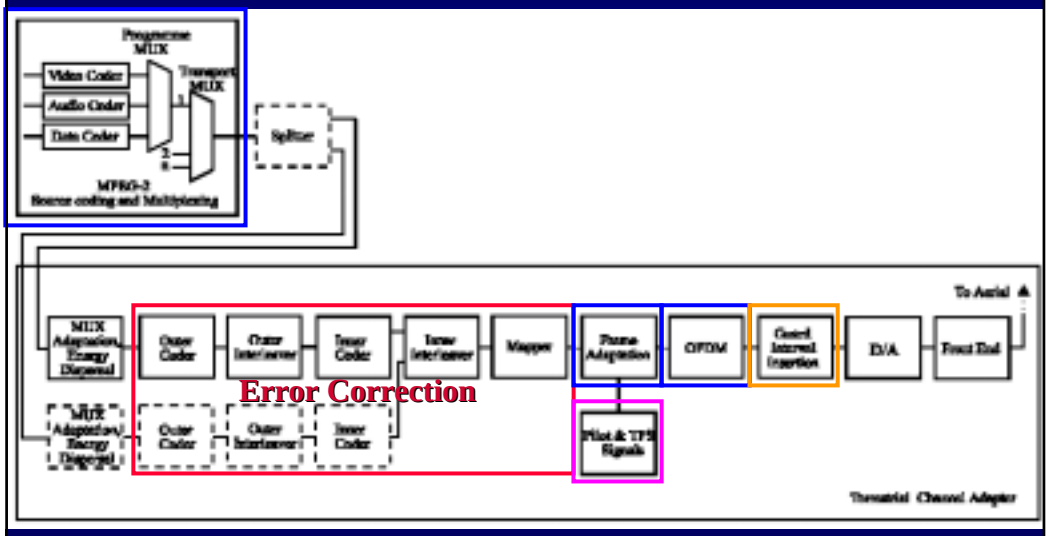
COFDM DTTB Block Diagram



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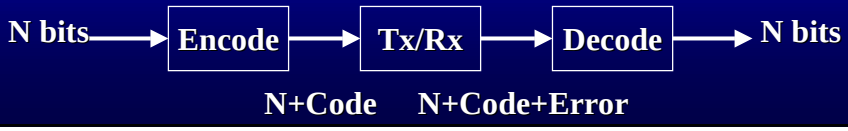
Forward Error Correction (FEC)

- Broadcast transmission
  - One way process - Tx to Rx
  - Not possible to repeat any errored data
- Forward Error Correction is a technique used to improve the accuracy of data transmission
- Extra redundant bits are added to the data stream
- Error correction algorithms in the demodulator use the extra FEC bits to correct data errors
- C OFDM uses a Convolutional FEC code



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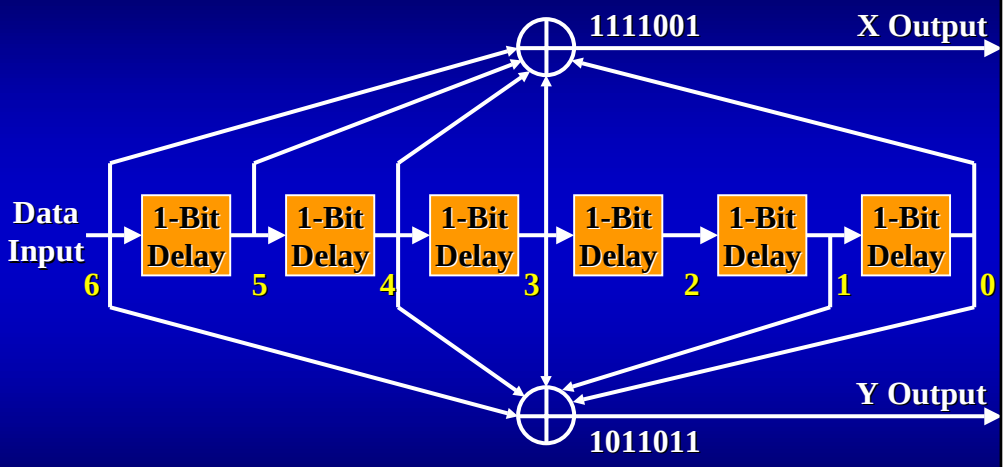
Convolutional Coder



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Puncturing Codes (FEC)

- The X and Y outputs of the Convolutional coder are selected in a Puncturing pattern

Code Rates r	Puncturing pattern	Transmitted sequence (after parallel-to-serial conversion)
1/2	X: 1 Y: 1	$X_1 Y_1$
2/3	X: 1 0 Y: 1 1	$X_1 Y_1 Y_2$
3/4	X: 1 0 1 Y: 1 1 0	$X_1 Y_1 Y_2 X_3$
5/6	X: 1 0 1 0 1 Y: 1 1 0 1 0	$X_1 Y_1 Y_2 X_3 Y_4 X_5$
7/8	X: 1 0 0 0 1 0 1 Y: 1 1 1 1 0 1 0	$X_1 Y_1 Y_2 Y_3 Y_4 X_5 Y_6 X_7$

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Inner Coding

- Convolutional coder generates the X & Y codes
- Puncturing operation selects X & Y in sequence
- Result then scrambled with an interleaver

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Viterbi Decoder

- A special type of data decoder designed to work with convolutional FEC codes
- Uses the past history of the data to identify valid future data values
- Element in the Receiver Only

56

Reed Solomon (RS)

- RS is a Block data correcting Code
- Hamming type cyclic Polynomial sequence
  - Code Generator Polynomial:
    $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)...(x+\lambda^{15})$, λ=02 Hex
  - Field Generator Polynomial:
    $p(x) = x^8 + x^4 + x^3 + x^2 + 1$
- Has special ability to correct multiple bursts of errors in a code block
- DVB-T uses 204 bytes for each 188 byte Packet
  (ATSC uses 207 bytes for each 187 byte Packet)
- Can correct 8 bytes in each 204 byte packet

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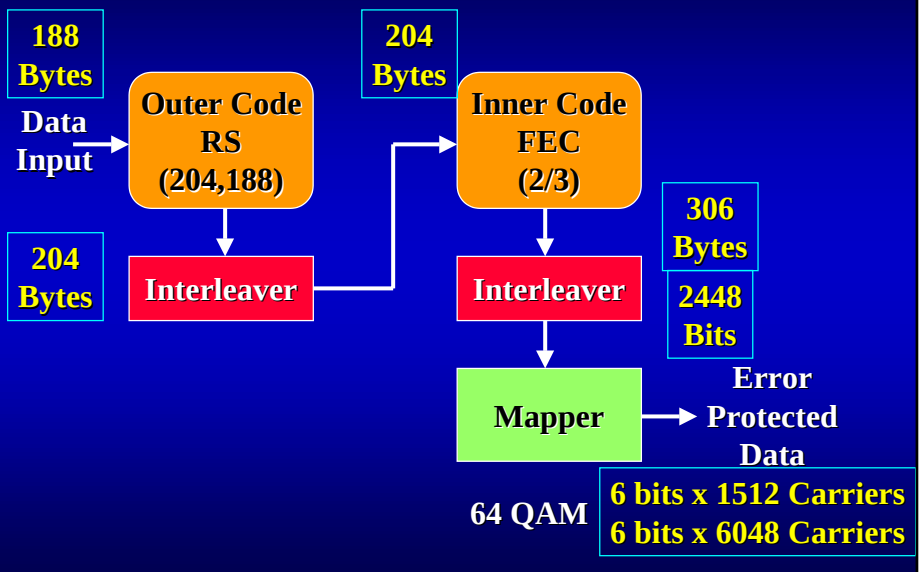
Error Protection - Order



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DVB-T - *Bit Rates [2k]*

7 MHz	D/Tu = 1/4 64 us			D/Tu = 1/8 32 us			D/Tu = 1/32 8 us		
Code Rate	QPSK	16 - QAM	64 - QAM	QPSK	16 - QAM	64 - QAM	QPSK	16 - QAM	64 - QAM
1/2	4.35	8.71	13.06	4.84	9.68	14.51	5.28	10.56	15.83
2/3	5.81	11.61	17.42	6.45	12.90	19.35	7.04	14.07	21.11
3/4	6.53	13.06	19.59	7.26	14.51	21.77	7.92	15.83	23.75
5/6	7.26	14.51	21.77	8.06	16.13	24.19	8.80	17.59	26.39
7/8	7.62	15.24	22.86	8.47	16.93	25.40	9.24	18.47	27.71

Page 21 Table A1 - AS4599-1999

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DVB-T - *C/N Values*

	GAUSSIAN			RICEAN			RAYLEIGH		
Code Rate	QPSK	16 - QAM	64 - QAM	QPSK	16 - QAM	64 - QAM	QPSK	16 - QAM	64 - QAM
1/2	3.10	8.80	14.4	3.60	9.60	14.70	5.40	11.20	16.00
2/3	4.90	11.1	16.5	5.70	11.60	17.10	8.40	14.20	19.30
3/4	5.90	12.5	18.00	6.80	13.00	18.60	10.70	16.70	21.70
5/6	6.90	13.5	19.30	8.00	14.40	20.00	13.10	19.30	25.30
7/8	7.70	13.9	20.10	8.70	15.00	21.00	16.30	22.80	27.90

Simulated Theoretical Thresholds (bandwidth independent)

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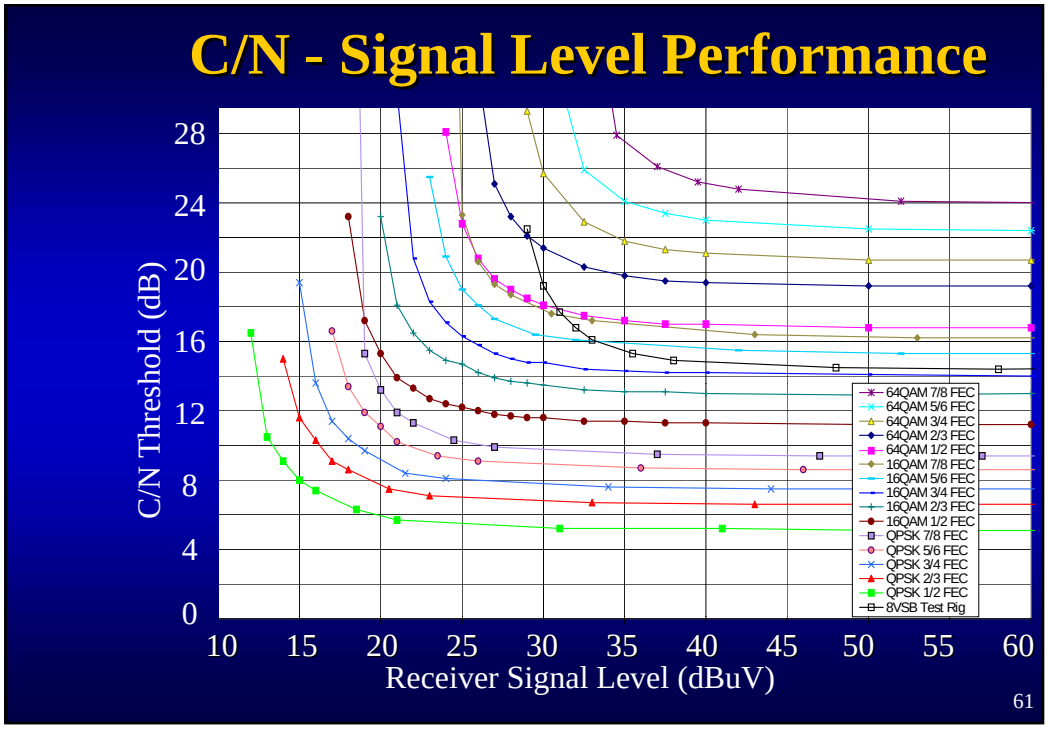
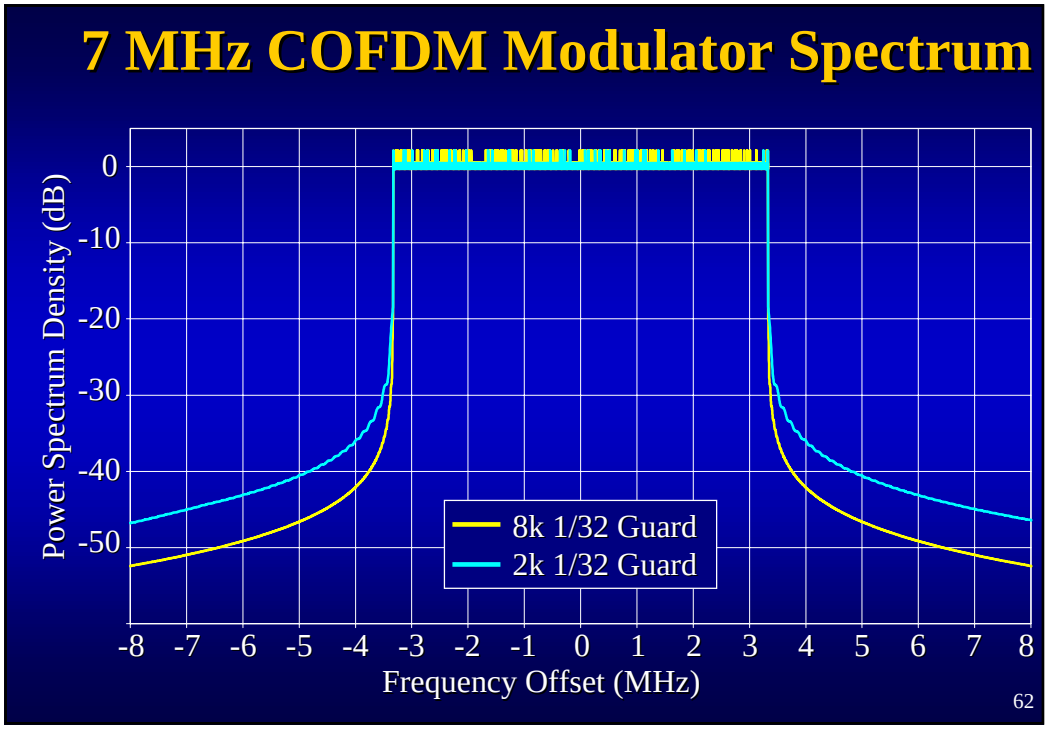

C/N - Signal Level Performance
C/N Threshold (dB)
0
4
8
12
16
20
24
28
10
15
20
25
30
35
40
45
50
55
60
Receiver Signal Level (dBuV)
64QAM 7/8 FEC
64QAM 5/6 FEC
64QAM 3/4 FEC
64QAM 2/3 FEC
64QAM 1/2 FEC
16QAM 7/8 FEC
16QAM 5/6 FEC
16QAM 3/4 FEC
16QAM 2/3 FEC
16QAM 1/2 FEC
QPSK 7/8 FEC
QPSK 5/6 FEC
QPSK 3/4 FEC
QPSK 2/3 FEC
QPSK 1/2 FEC
8VSB Test Rig
61


7 MHz COFDM Modulator Spectrum
Power Spectrum Density (dB)
0
-10
-20
-30
-40
-50
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
Frequency Offset (MHz)
8k 1/32 Guard
2k 1/32 Guard
62

Frequency Planning

- **Fundamental Matter** - ***Scarce Resource***
- **Analogue Rules set limit to more Services**
- **No NEW TV Spectrum is Available**
- **Digital Transmission changes Rules**
  - ***Signals have different behaviour***
- **Digital Signals can occupy unused space** - ***"Taboos"***
- **Digital Needs to fit in with Existing PAL**
- **Eventually Digital Only** - ***but long wait??***

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Digital Has to Fit In With PAL

- World TV channel bandwidths vary
  - USA / Japan 6 MHz

  - Australian 7 MHz

  - Europeans 8 MHz

- Affects:- tuning, filtering, interference & system performance

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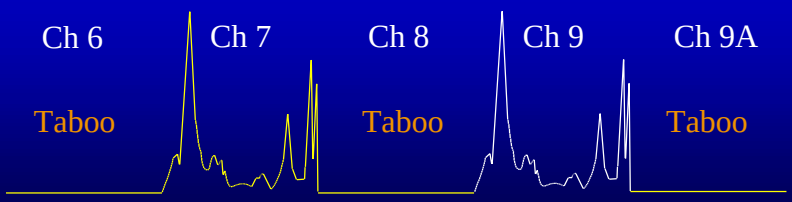
Channel Spacing

- 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

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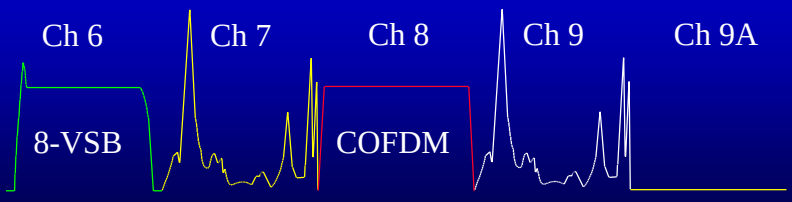
Digital Challenges

- 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

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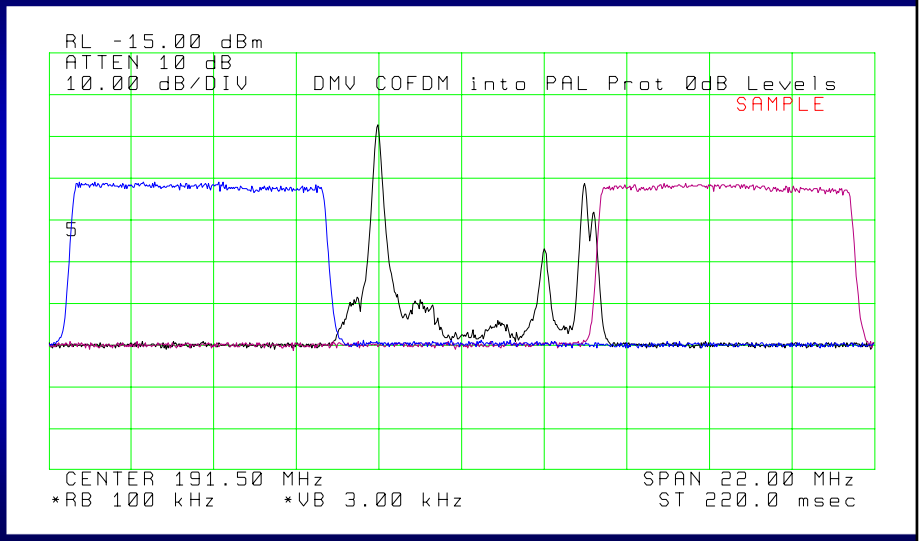
DTTB & PAL



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UHF Channels: London

Photograph by courtesy and © BBC R&D

Planning Issues

- **Channel Disturbances:**
  - *Noise, at edge of area with NO interference*
  - *Interference, Co Channel Interference and Adjacent Channel Interference*
  - *Multipath, Echoes:How Many, How Large, Moving?*
- **Antenna Pattern?**
  - *Static Roof Top? Directional? Wideband?*
  - *CCIR Antenna Rec BT-419-3*
  - *Portable Receivers? No Antenna?*
- **Frequency Re-Use Distances**
  - *Terrain Data*
  - *Propagation Models*
  - *Protection Ratios*

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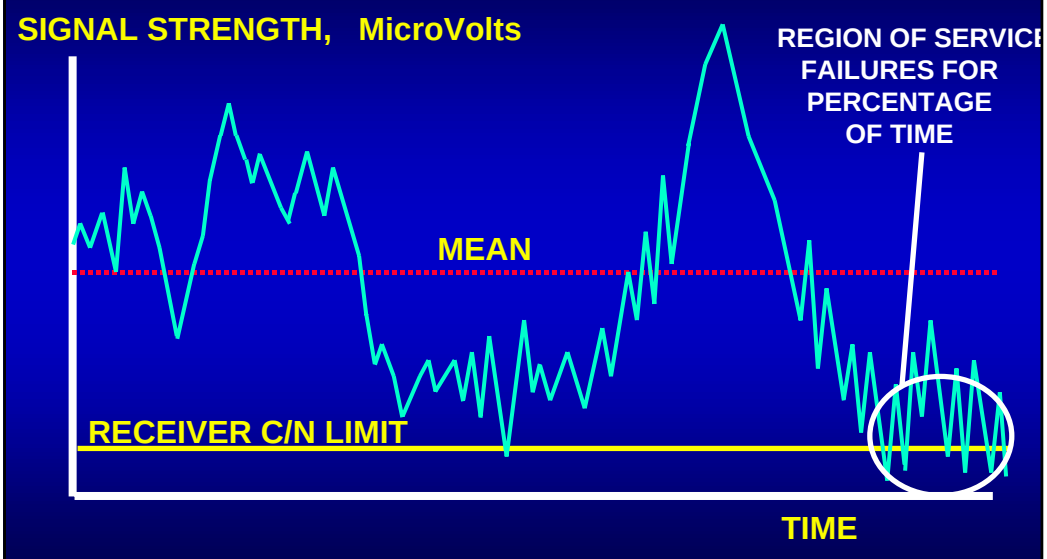
Signal Strength



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Digital Service Area Planning

- Analog TV has a slow gradual failure
  - Existing PAL service was planned for:
    50 % availability at
    50 % of locations
- Digital TV has a “cliff edge” failure
  - Digital TV needs planning for:
    90-99 % availability at
    90-99 % of locations

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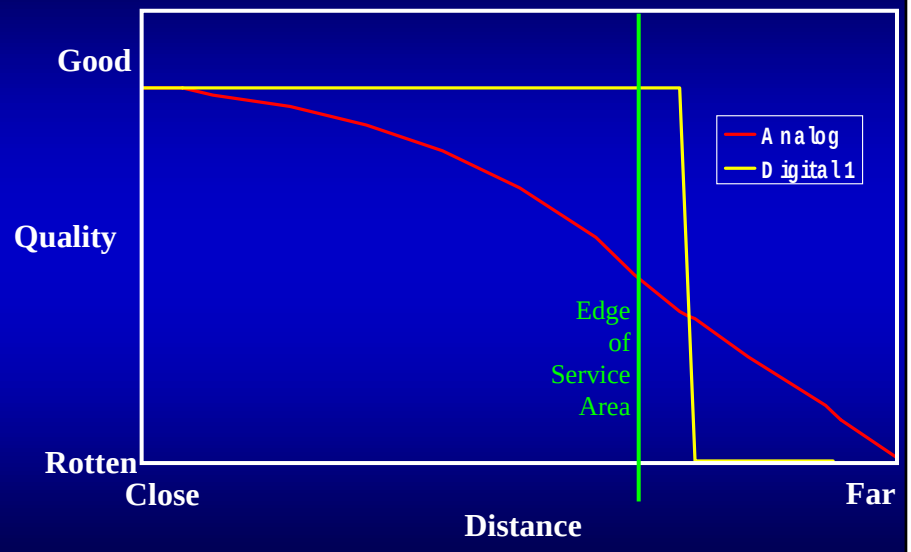
TV System Failure Characteristic



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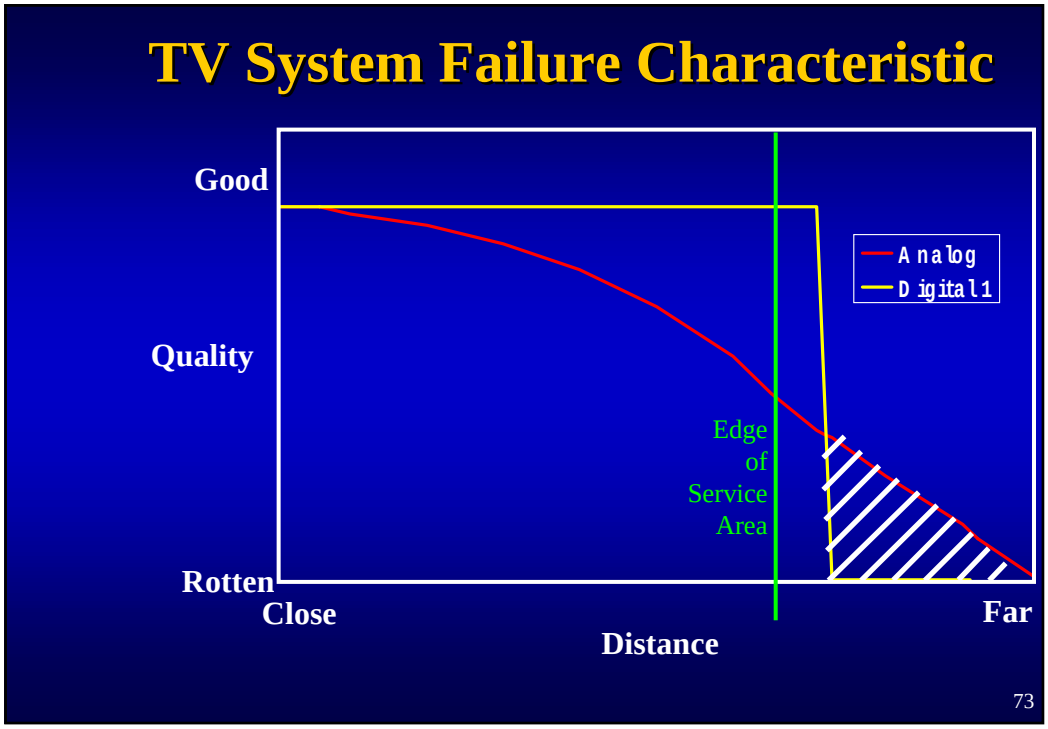
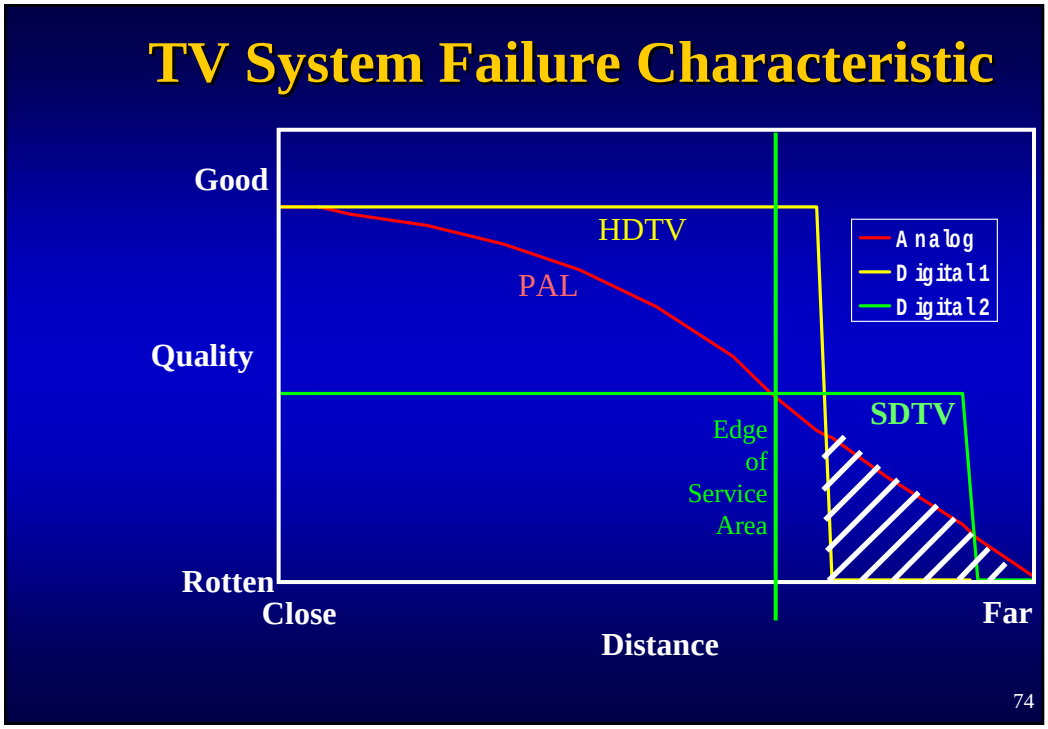
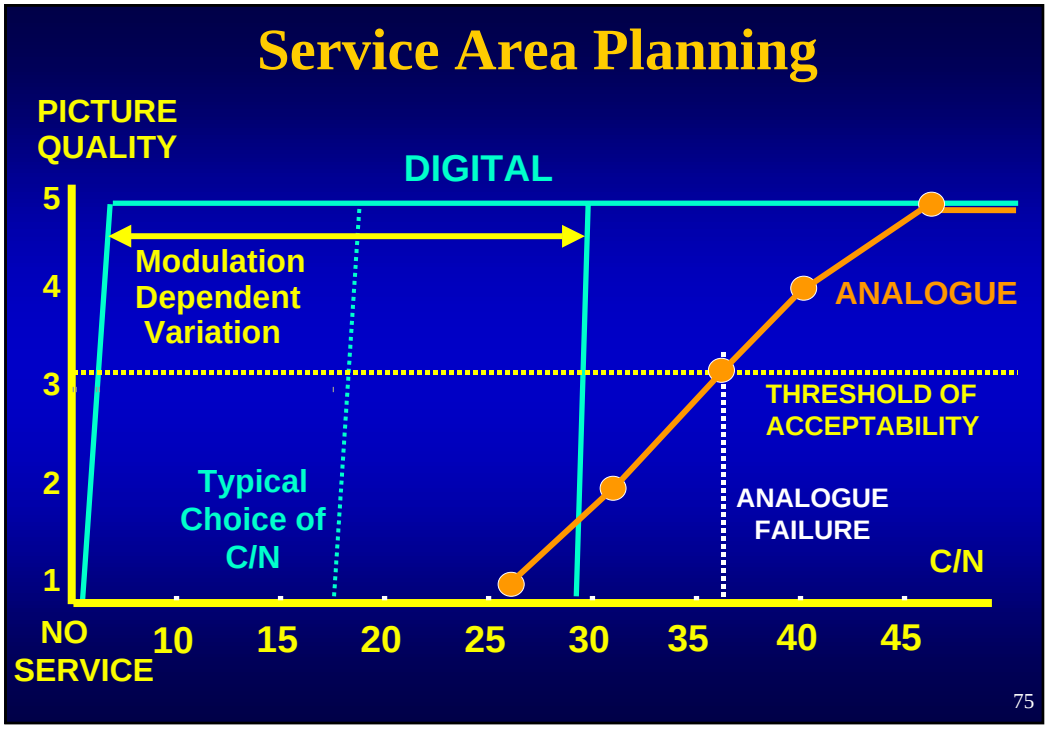
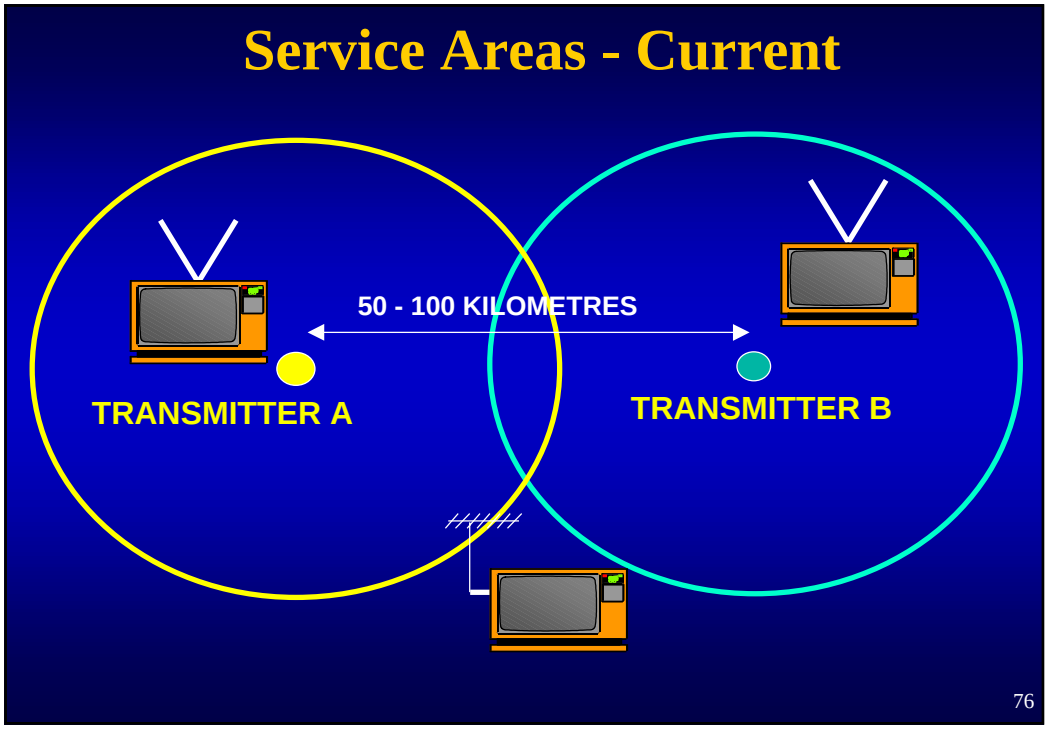
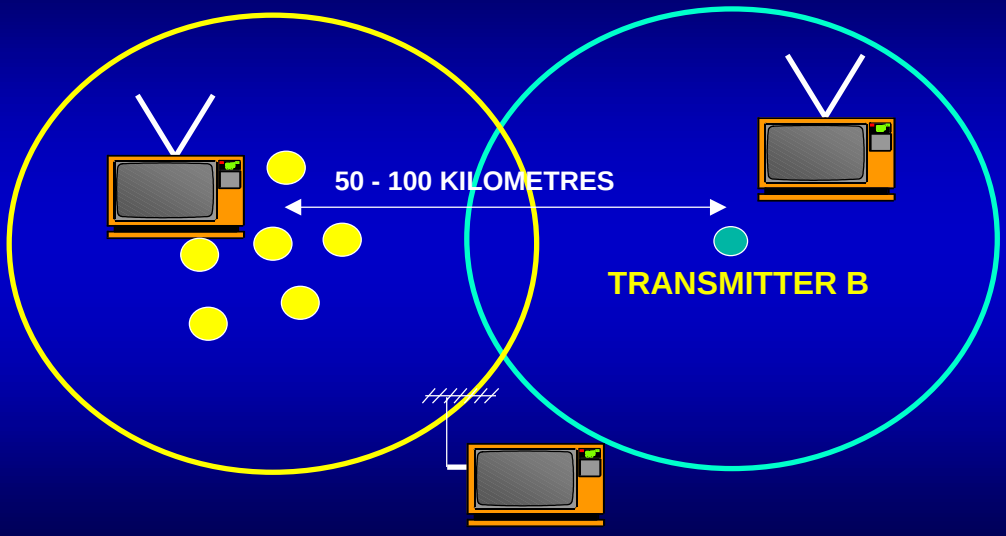

TV System Failure Characteristic
Good
Quality
Rotten
Close
Far
Distance
Edge
of
Service
Area
Analog
Digital1
73


TV System Failure Characteristic
Good
Quality
Rotten
Close
Far
Distance
HDTV
PAL
SDTV
Edge
of
Service
Area
Analog
Digital1
Digital2
74


Service Area Planning
PICTURE QUALITY
DIGITAL
5
4
3
2
1
Modulation Dependent Variation
ANALOGUE
THRESHOLD OF ACCEPTABILITY
Typical Choice of C/N
ANALOGUE FAILURE
C/N
NO SERVICE
10
15
20
25
30
35
40
45
75


Service Areas - Current
50 - 100 KILOMETRES
TRANSMITTER A
TRANSMITTER B
76

Service Areas - SFN



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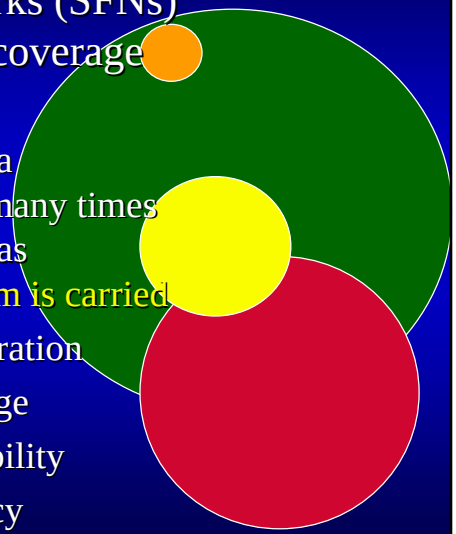
Digital Provides New Concepts

- Single frequency networks (SFNs) can help solve difficult coverage situations
  - SFNs allow the reuse of a transmission frequency many times in the same area so long as exactly the same program is carried
  - Allows lower power operation
  - Better shaping of coverage
  - Improved service availability
  - Better spectrum efficiency



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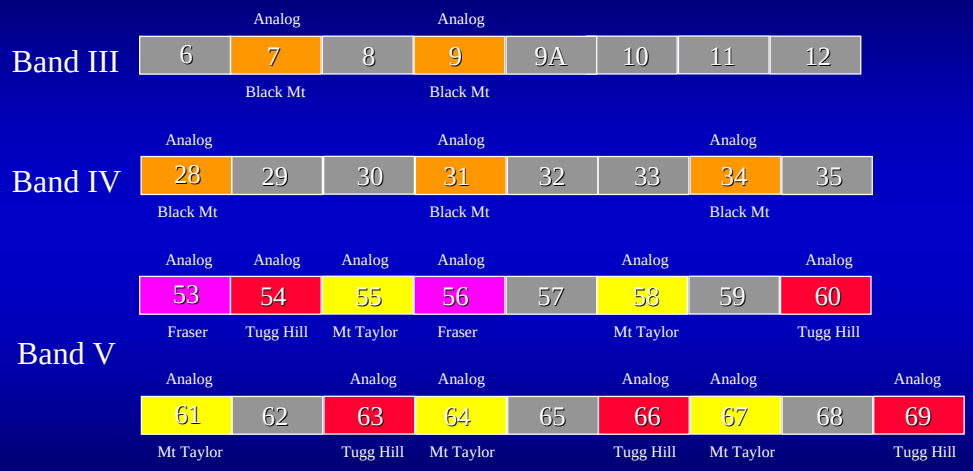
Analog Canberra Television



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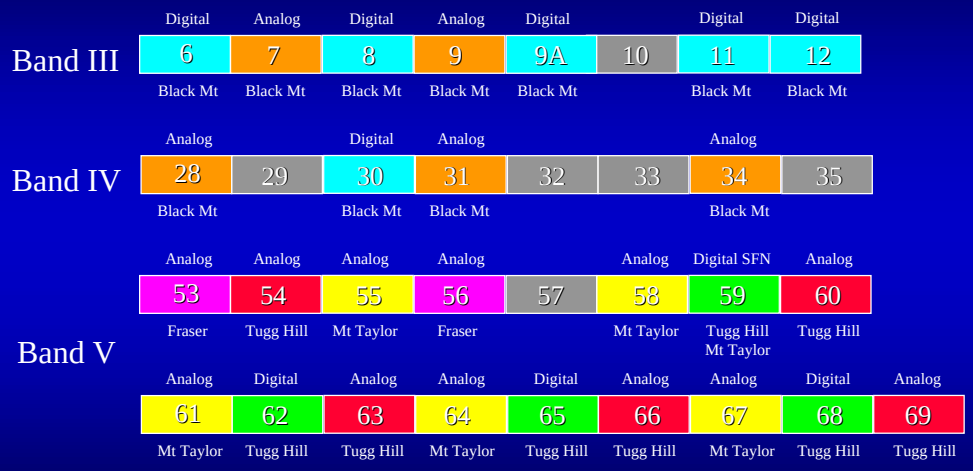
Digital Canberra Television



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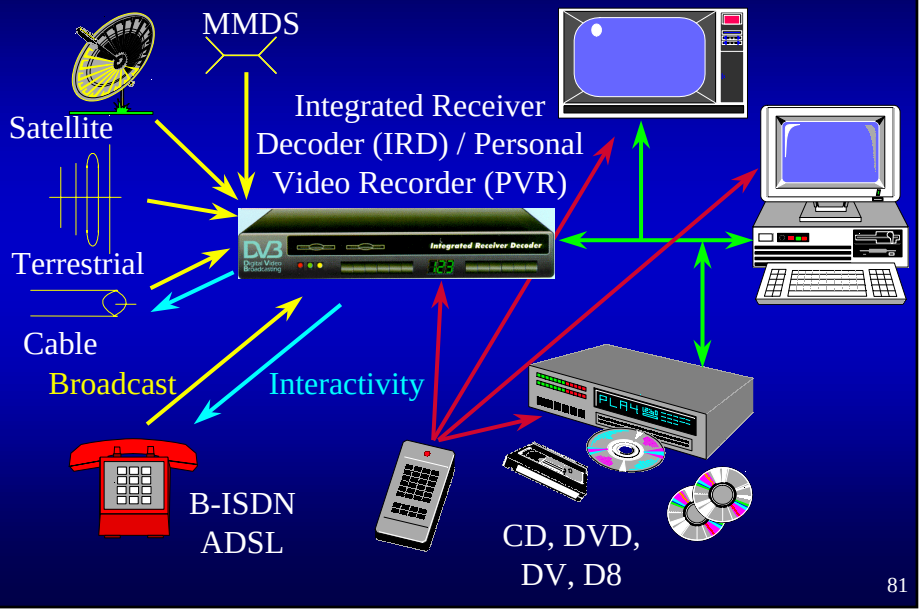
A Future Digital System Concept



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WebCT

- The Course presentations have been put in WEBCT:
  http://teaching.canberra.edu.au/SCRIPT/IS1512/scripts/serve_home
- You will see "MODULE4" when you login this page.
- Open "MODULE4", and you will find two pages called "MATERIAL1" and "MATERIAL2", which are the Acrobat handout versions of the power-point files "uocdtv43w.pdf" and "uocdtv46w.pdf", respectively.

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