 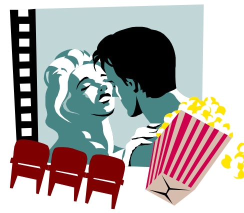 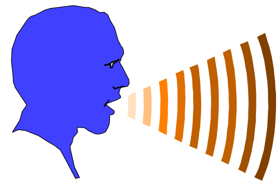 

Multimedia Communication Systems II

Digital TV Transmission: Channel Coding and Modulation

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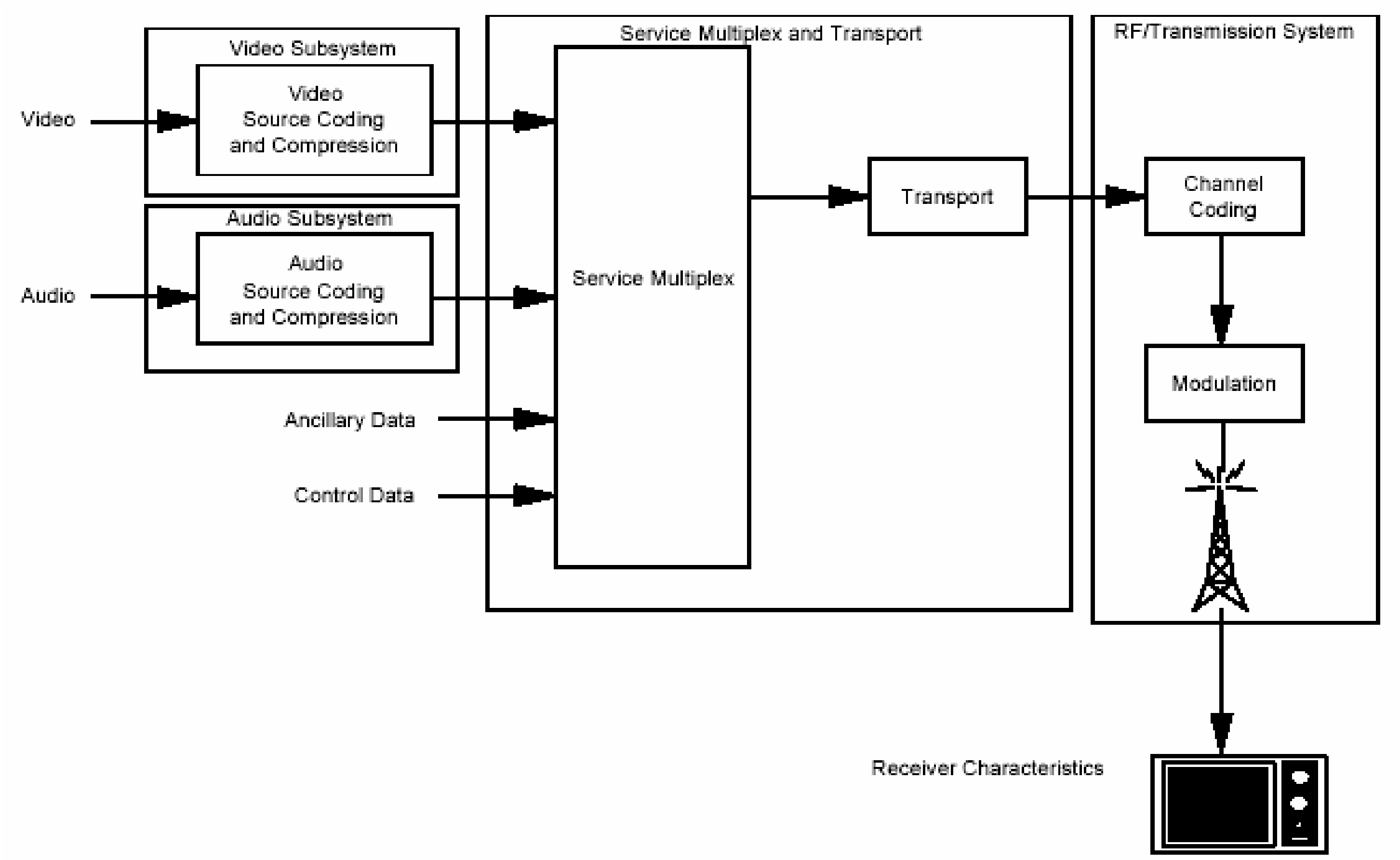
Outline

- Overview of ATSC DTV system
- Video formats and video coding
- Audio formats and audio coding
- Channel coding
- Modulation
- Difference with DVB system

ATSC DTV Standard: Summary

- Proved by ATSC (Advanced Television System Committee of FCC), initially in 1995, Revised Aug 2001
- Based on the Grand Alliance HDTV proposal
- Video encoding: MPEG2 video (mp@ml for SDTV, mp@hl for HDTV)
- Audio encoding: Dolby AC3 (5.1 channel)
- Multiplex and transport: MPEG2 transport stream syntax
- Channel coding and modulation: digital VSB
  - Terrestrial: 8-level VSB, enabling 19 mbps payload in 6 MHz channel
  - Cable: 16-level VSB, enabling 38 mbps payload in 6 MHz channel

ATSC DTV System Model

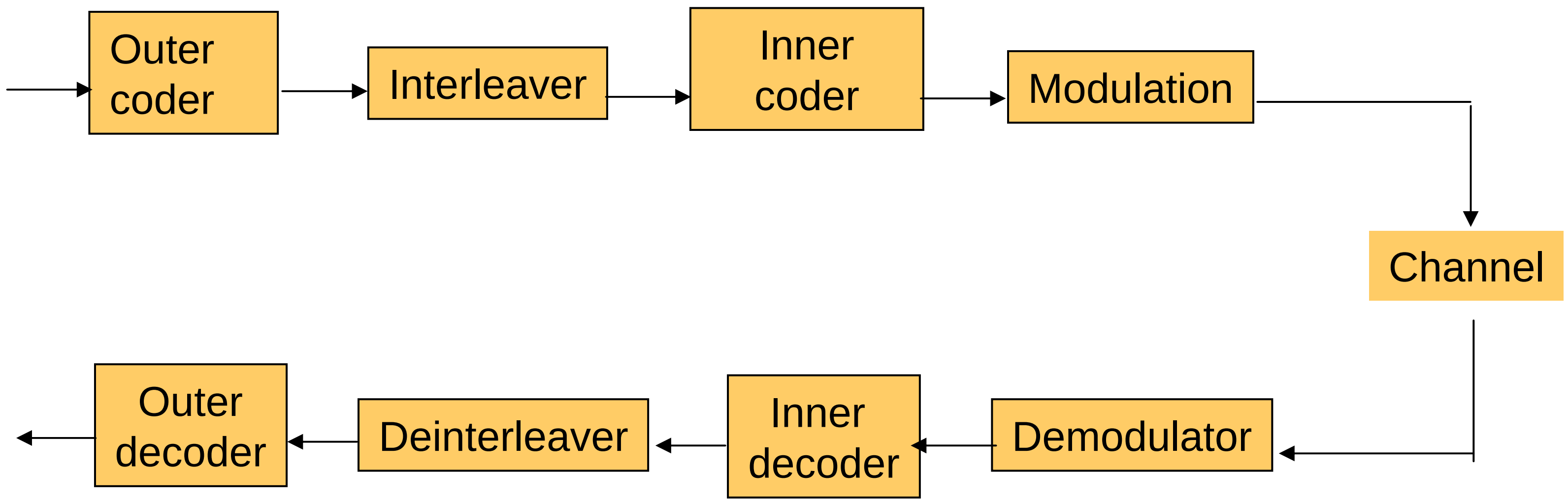


From Fig.5.1, ATSC DTV standard (A53/B)

Channel Coding: Overview

- To enable detection and correction of bit errors in the received bit stream
- CRC: allow error detection only
  - Ex: adding a parity bit to detect 1 bit error
- FEC: allow correction of up to a certain number of errors, depending on the code used and the redundancy introduced
  - Ex. Repetition code, repeat 3 times of each bit allow correction of 1 bit error (1->111,0->000)
  - Block codes vs. convolutional codes
  - Channel code rate r= k/n, k information bits, n coded bits
- Typical implementation for packetized transmission
  - Source bits + CRC bits -> FEC
  - If the number of errors exceeds FEC correction limit, CRC can detect the presence of residual erroneous bits, and the packet can be discarded or otherwise marked as containing wrong bits (w/o knowing which bits are wrong)

Concatenated Channel Coding



Deinterleaver randomize error bursts due to residual errors after inner decoder, so that the outer decoder only see randomly distributed errors

Why Interleaving?

- Original symbols:
  - A,B,C,D, E,F,G,H, I,J,K,L, M,N,O,P,….
- After interleaving (depth 4)
  - A,E,I,M, B,F,J,N, C,G,K,O, D,H,L,P,…
- Channel error (remaining after inner decoder) affects 4 consecutive symbols
  - A,E,I,M, X,X,X,X, C,G,K,O, D,H,L,P
- After deinterleaving
  - A,X,C,D, E,X,G,H, I,X,K,L, M,X,O,P
  - Only 1 symbol error in every 4 symbols, can be corrected by an appropriately designed FEC code

Channel Coding in ATSC DTV

- Using a concatenated channel coder
  - An RS outer coder, RS (207,187), symbol length=8. Can correct up to 10 symbol errors in 207 received symbols, r=187/207
  - An interleaver: spread the symbols in each RS block over many blocks
  - A trellis inner coder (incorporates an inner block interleaver), r=2/3
    - For every 2 bits, generates 3 bits, based on the past trace of 2 bits symbols as well as the current 2 bits
  - Total channel code rate = 187/207*2/3=0.60225

Modulation of Digital Signals: Overview

- For transmission of digital bits over analog channels
  - Convert group of digital bits into analog waveforms (symbols)
  - The analog waveforms are designed according to the desired carrier frequency
  - An analog channel of bandwidth B can carry at most 2B symbols/s. For reduced inter-symbol interference, lower than 2*B symbol rate is used typically
  - Equalizer is used at the receiver to reduce the inter-symbol interference (ISI), and multipath effect
  - Revisit the slides for lecture 8 in EE3414

Amplitude Shift Keying (ASK)

M-ary ASK: each group of $\log_2 M$ bits generates a symbol. The number corresponding to the symbol controls the amplitude of a sinusoid waveform. The number of cycles in the sinusoid waveform depends on the carrier frequency

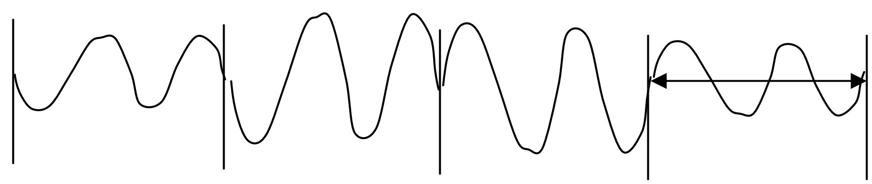
4-ASK: 2 bits/symbol (00=-3, 01=-1, 11=1, 10=3)

"00" "01" "11" "10"

Example: Given a sequence: 01001011…, what is the analog form resulting from 4-ASK?

Symbol representation: "-1","-3","3","1"

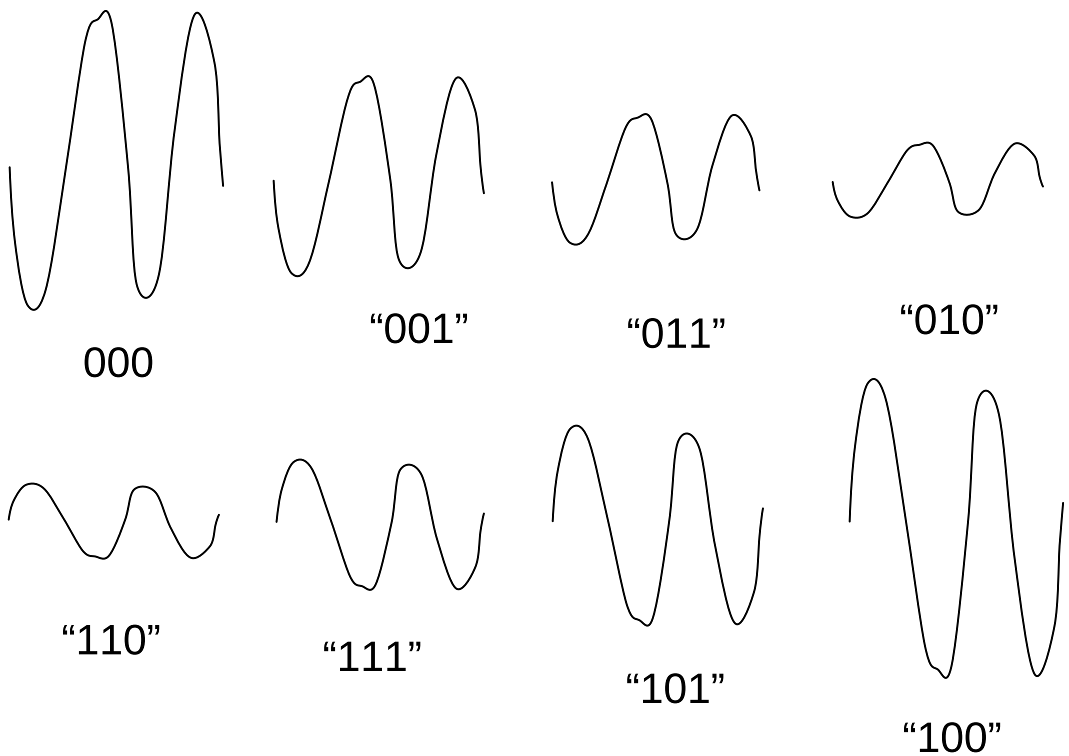
Waveform:



Symbol interval

8-ASK

8-ASK: 3 bits/symbol (000=-7, 001=-5, 011=--3, 010=-1, 110=1, 111=3, 101=5, 100=7)

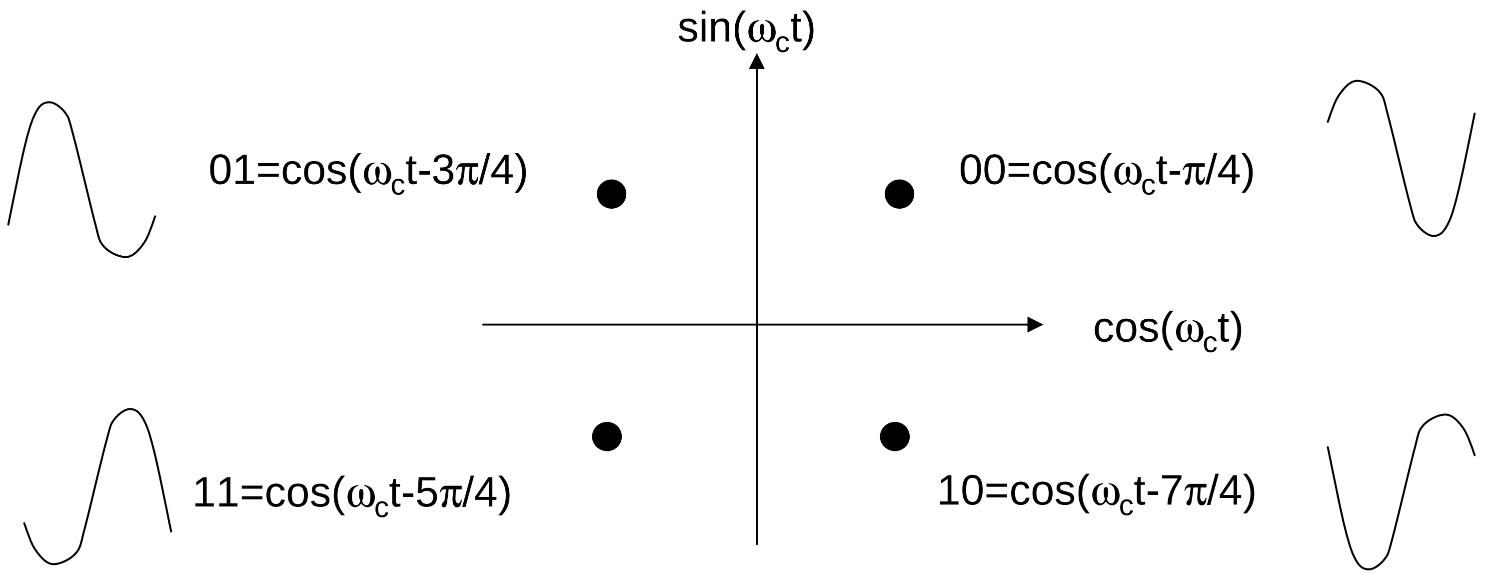


The mapping from bits to symbols are done so that adjacent symbols only vary by 1 bit, to minimize the impact of transmission error (aka “Gray coding”)

Quadrature Amplitude Modulation (QAM)

M-ary QAM uses symbols corresponding to sinusoids with different amplitude as well as phase, arranged in the two-dimensional plane.

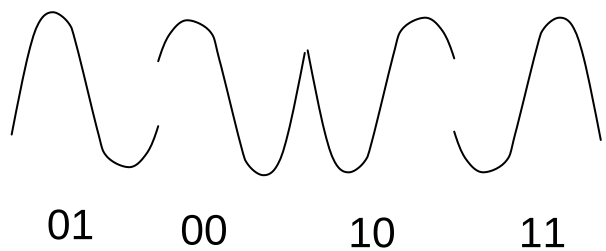
Ex. 4-QAM (only phase change):



Example of 4-QAM

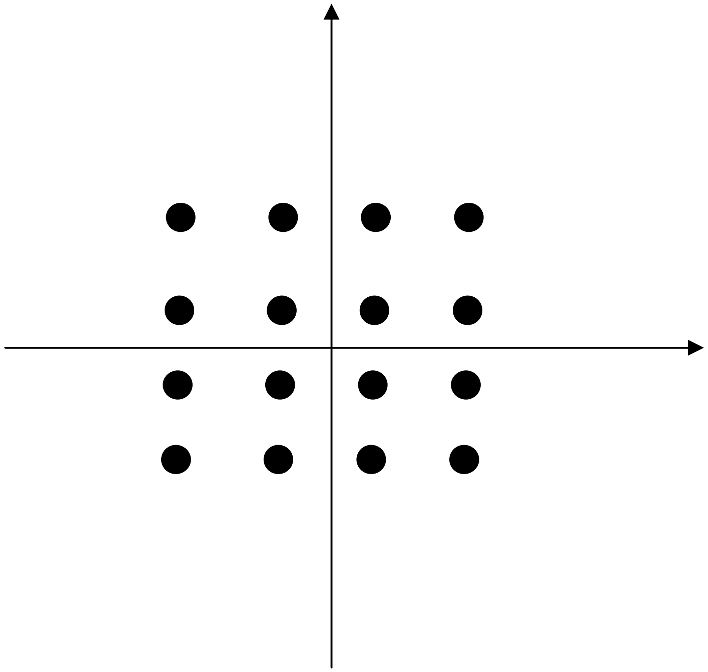
Example: Given a sequence: 01001011…, what is the analog form resulting from 4-ASK?

Using the previous mapping, the analog waveform for the above sequence is

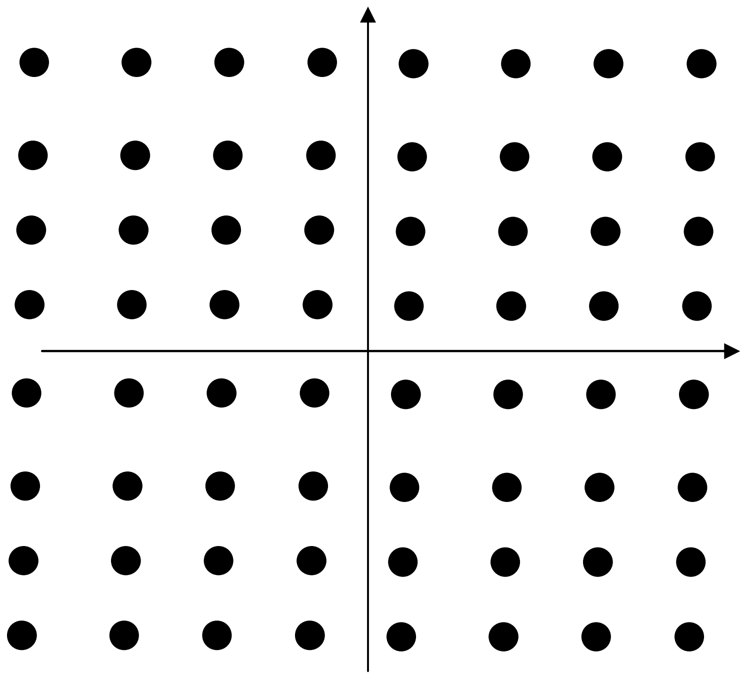


16-QAM, etc.

16 QAM (4 bits/symbol):



64-QAM (6 bits/symbol)

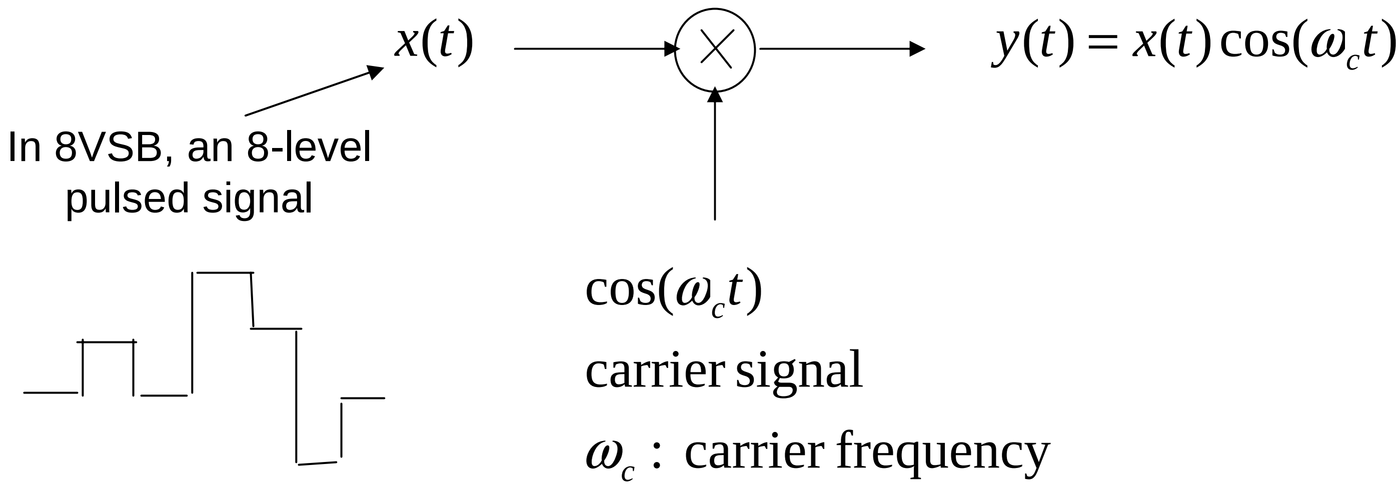


Modulation in ATSC System: 8-VSB

- 8-level amplitude shift keying
  - Each 3 bits generates a pulse, whose amplitude depends on the number corresponding to the 3 bits
- VSB: retaining only a small portion of the lower sideband, in addition to the upper band
  - The pulse train is multiplied with a sinusoidal wave at the carrier frequency
  - A shaping filter is applied to retain only a small portion of the LSB to save bandwidth
- Channel capacity and information rate
  - A 6MHz channel can deliver at most 12 Msymbols/s.
    - Recall a signal sampled at fs sample/s has a maximum bandwidth of fs/2
  - But ATSC system uses 10.762 Msymbols/s.
  - With 8-ASK, each symbol carries 3 bits. Thus the date rate is 10.762*3=32.286 Mbps (including channel coding redundancy)
  - Information bit rate = overall data rate * channel code rate =32.286*0.60225=19.44 Mbps

How do we shift the frequency of a signal? (Modulation Revisited!)

- By multiplying with a sinusoid signal !
- This is known as amplitude modulation (AM)



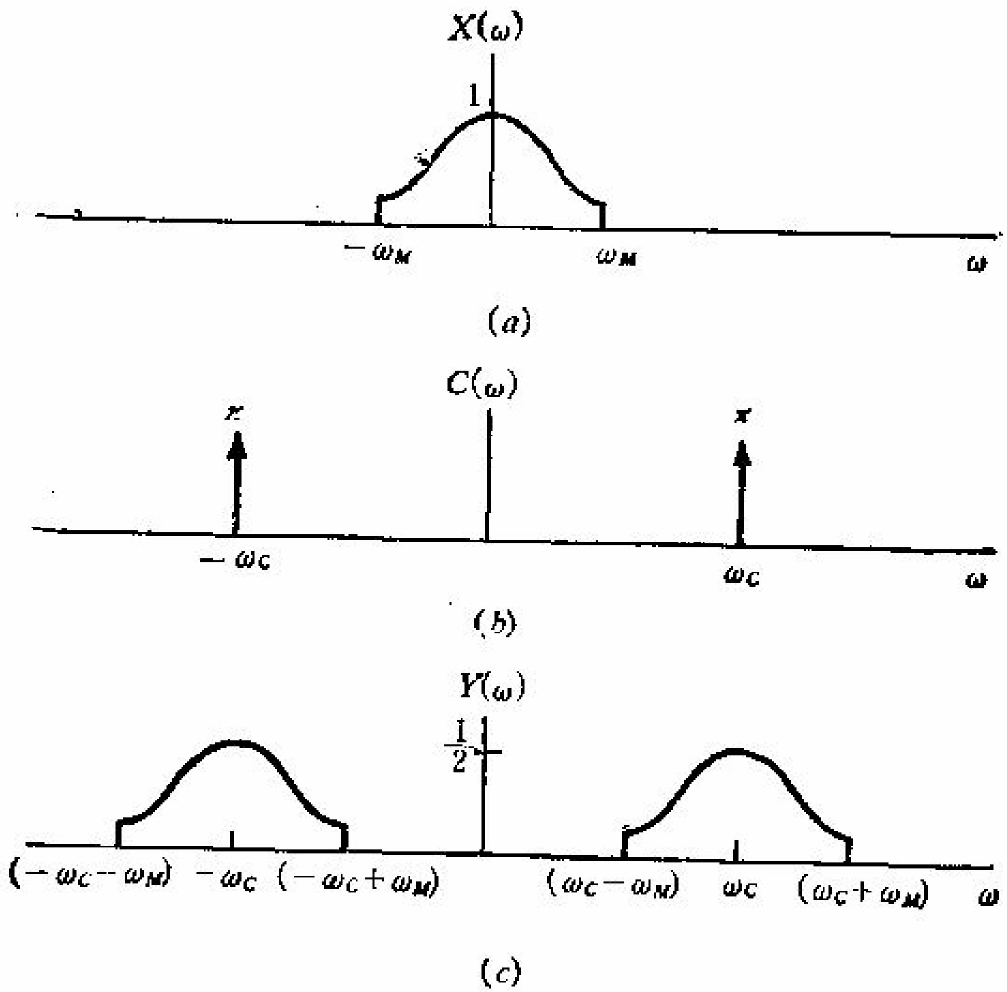
Frequency Domain Interpretation of Modulation

From Figure 7.5 in [Oppenheim]

$x(t)$

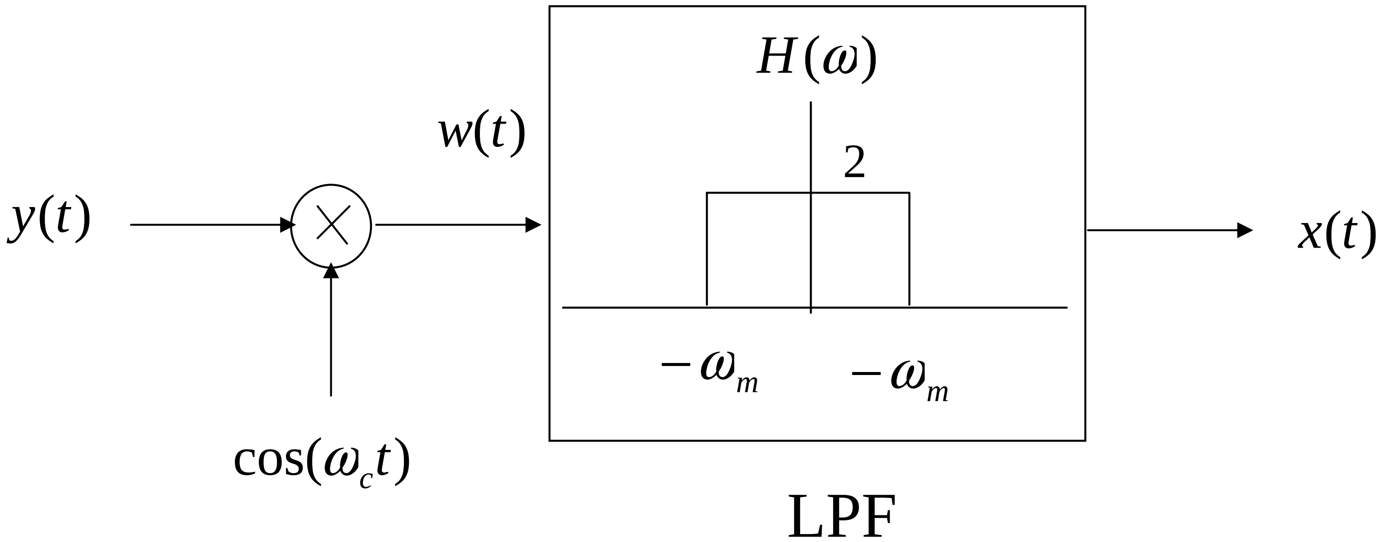
$\cos(\omega_c t)$

$y(t) = x(t)\cos(\omega_c t)$



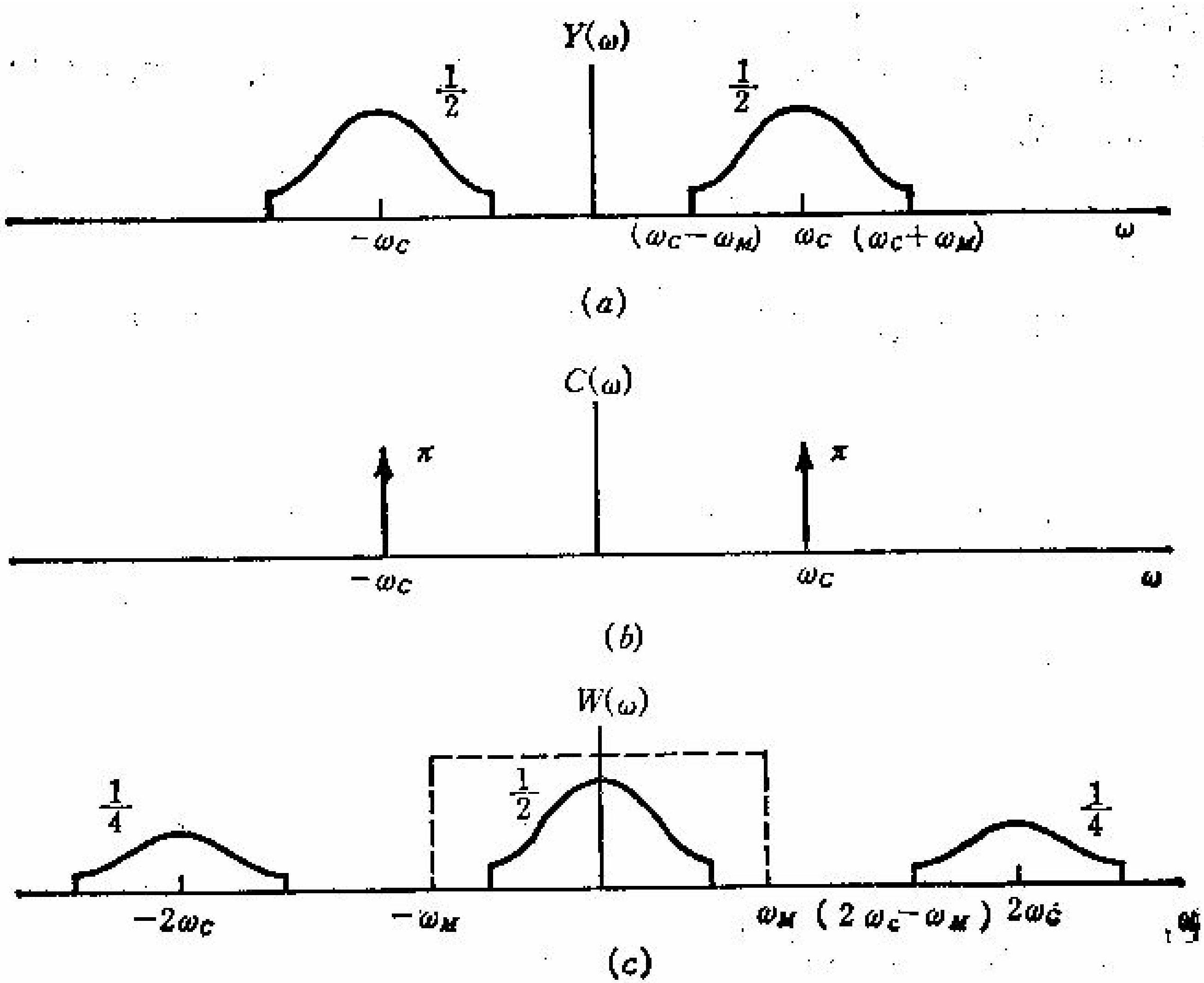
How to get back to the baseband? (Demodulation)

- By multiplying with the same sinusoid + low pass filtering!

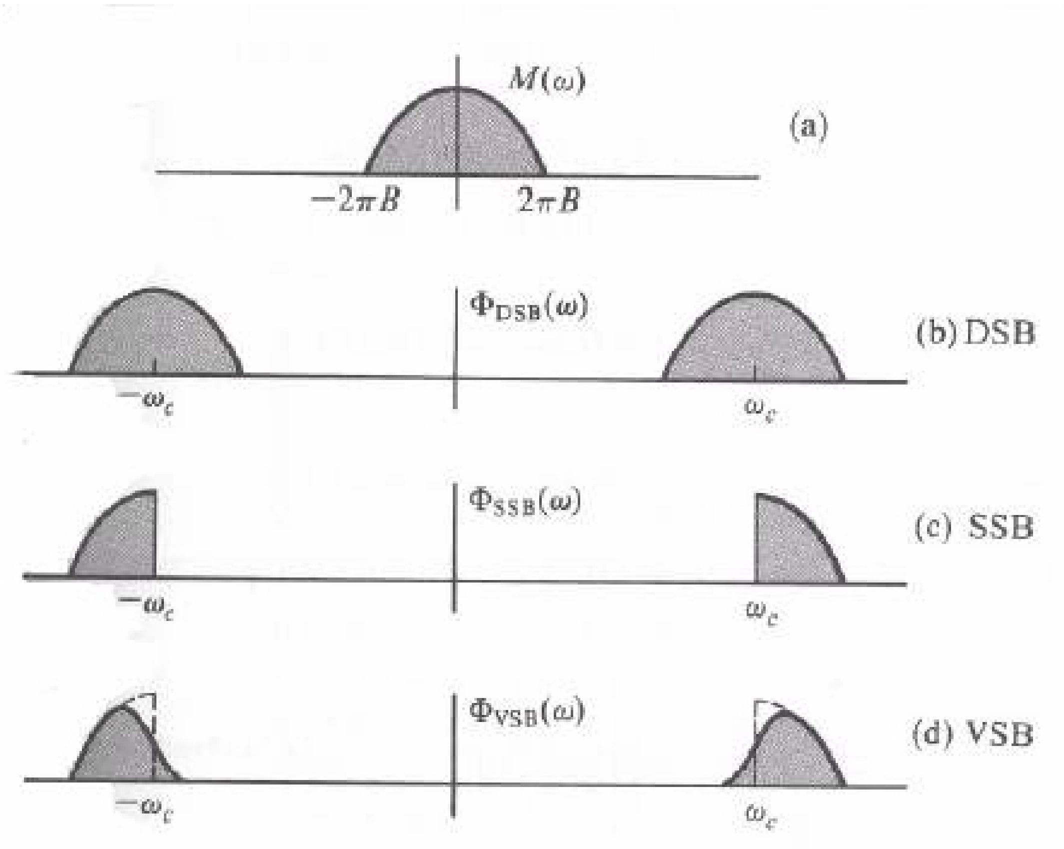


Frequency Domain Interpretation

Figure 7.7 in [Oppenheim]



DSB vs SSB vs VSB



VSB Implementation

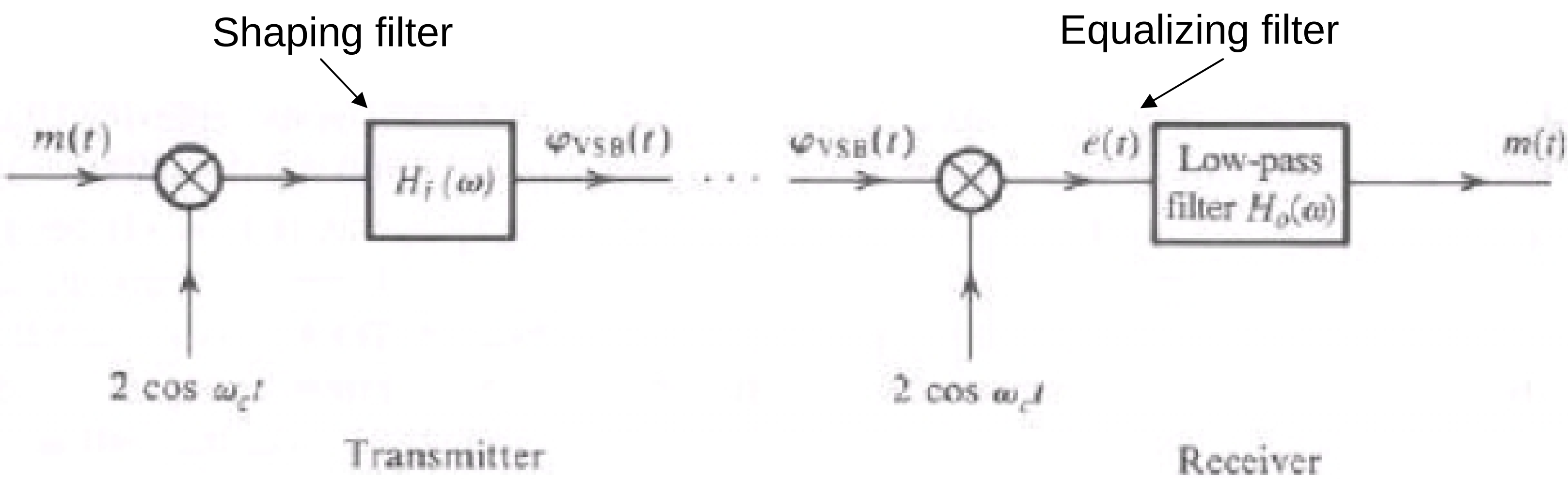


Figure 4.22 VSB modulator and demodulator.

$$\Phi_{VSB}(\omega) = [M(\omega+\omega_c) + M(\omega-\omega_c)]H_i(\omega)$$

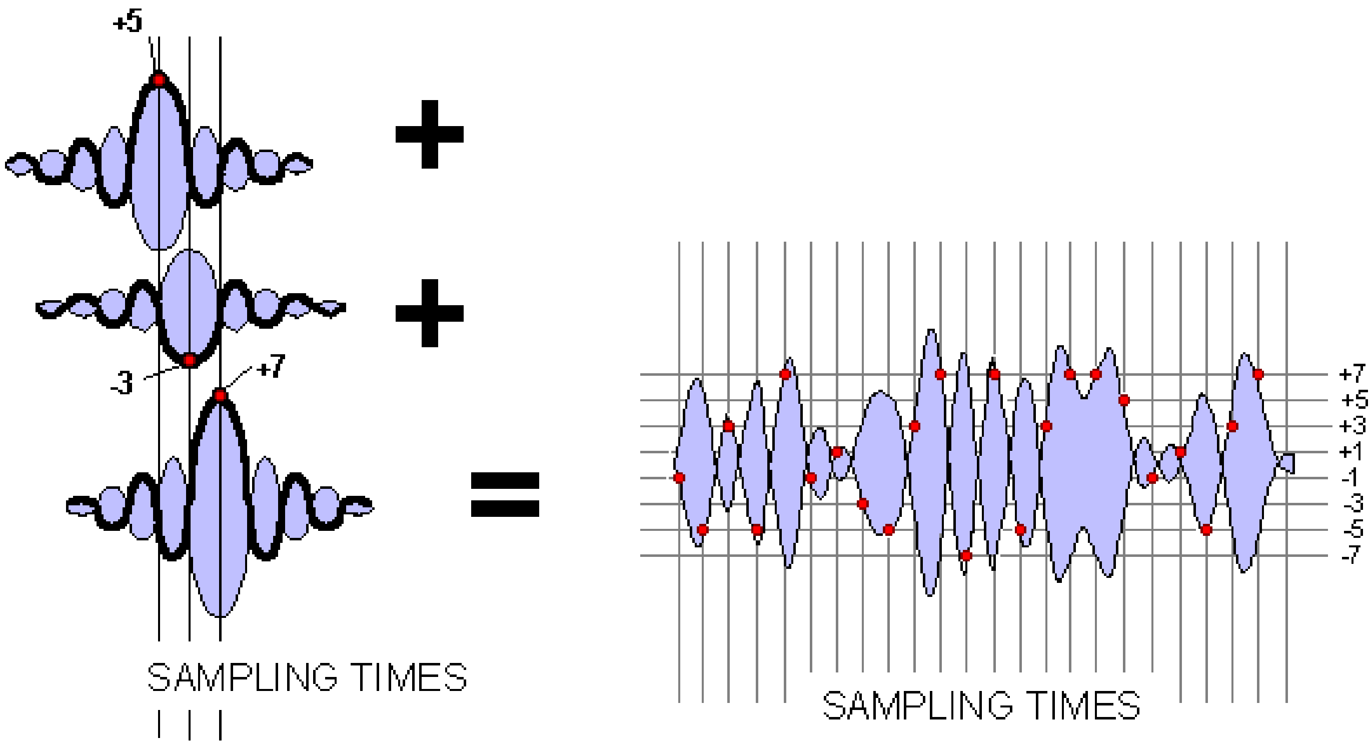
$$M(\omega) = M(\omega)[H_i(\omega+\omega_c) + H_i(\omega-\omega_c)]H_o(\omega)$$

$$H_o(\omega) = \frac{1}{H_i(\omega+\omega_c) + H_i(\omega-\omega_c)} \qquad |\omega| \le 2\pi B$$

8-VSB Shaping Filter

- The shaping filter generally modifies the signal levels.
- Each symbol (3 bits) last for a short time, only the value at the sampling time at the receiver needs to be correctly retained.
- A “Nyquist filter” is used as the shaping filter so that the signal values at the sampling instances are not modified.

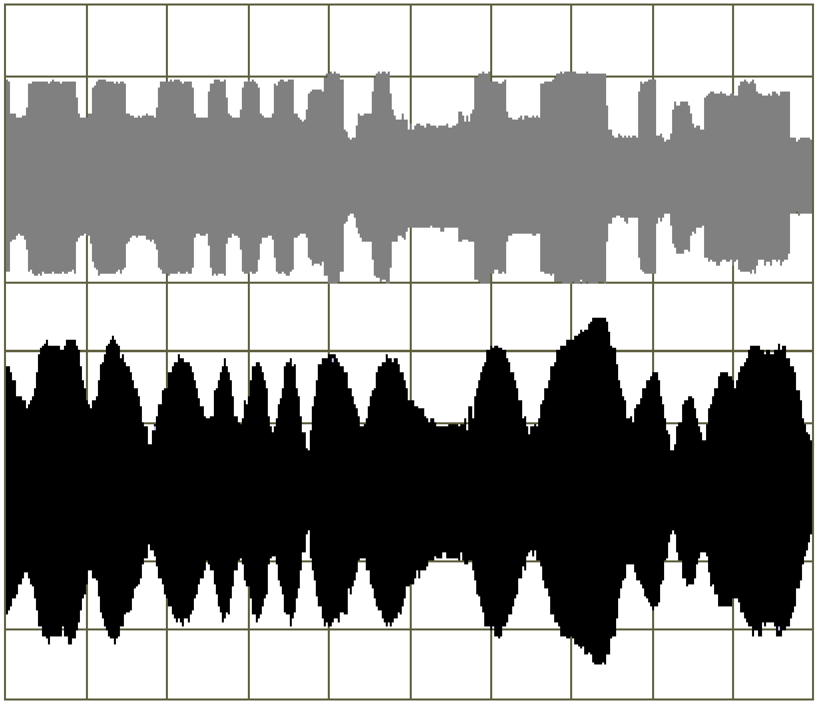
Nyquist Filter



At any given sampling time (vertical line), only one symbol pulse contributes to total signal amplitude, all other pulses experience a zero crossing. The resulting RF envelope corresponds to the eight digital levels only during the precise instant of sampling.

[From: D. Sparano, “What is exactly 8-VSB anyway”]

Effect of the VSB Shaping Filter



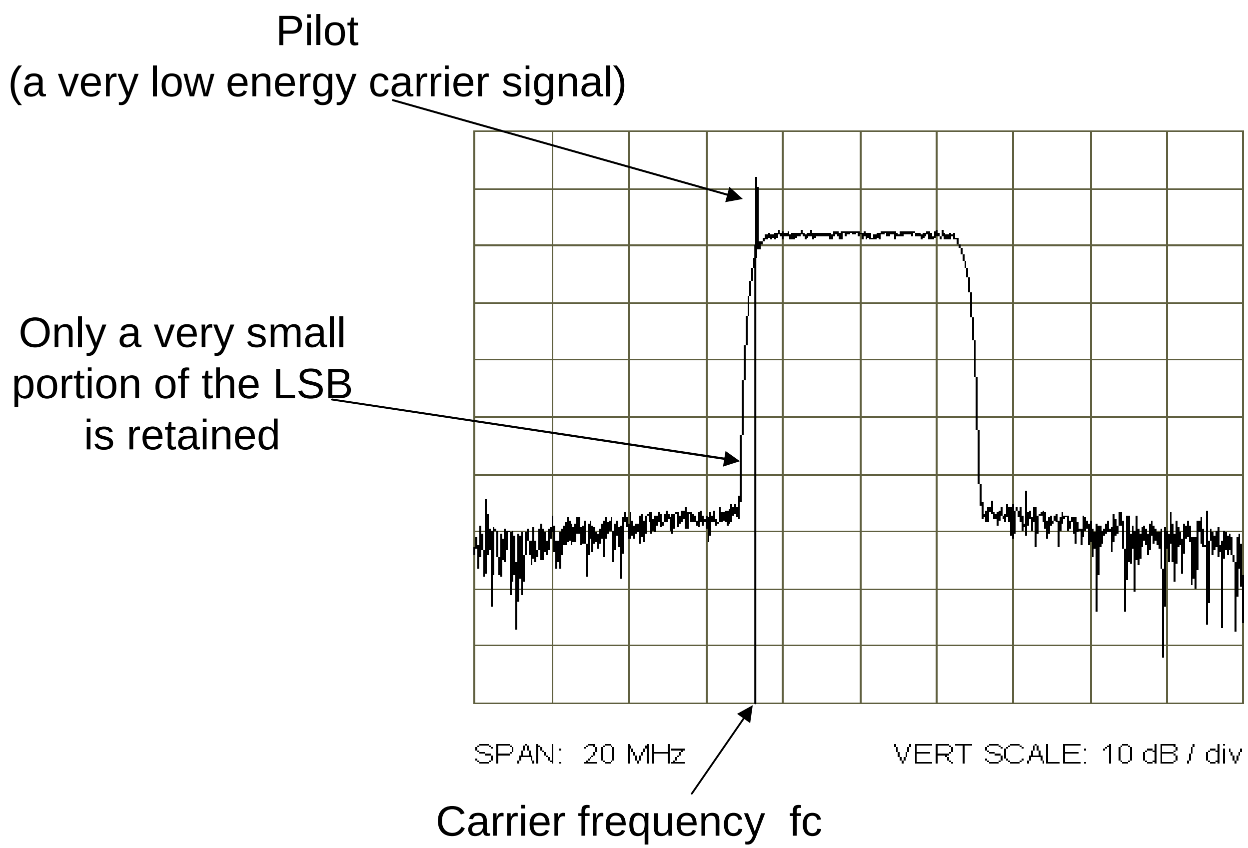
Top: Double sideband IF envelope before Nyquist filtering (shaping filter). Bottom: The same IF signal after Nyquist filtering. The squared-off transitions are lost and the envelope acquires a noise-like appearance.

[From: D. Sparano, "What is exactly 8-VSB anyway"]

ATSC “pilot” signal

- A non-zero DC value (“pilot”) is added to the baseband signal (the 8-level pulse signal) before modulation to enable carrier extraction at receiver
  - similar to VSB-C used in NTSC, but uses much lower energy, 7% of total

8-VSB RF Signal Spectrum



[From: D. Sparano, “What is exactly 8-VSB anyway”]

Receiver Equalizer

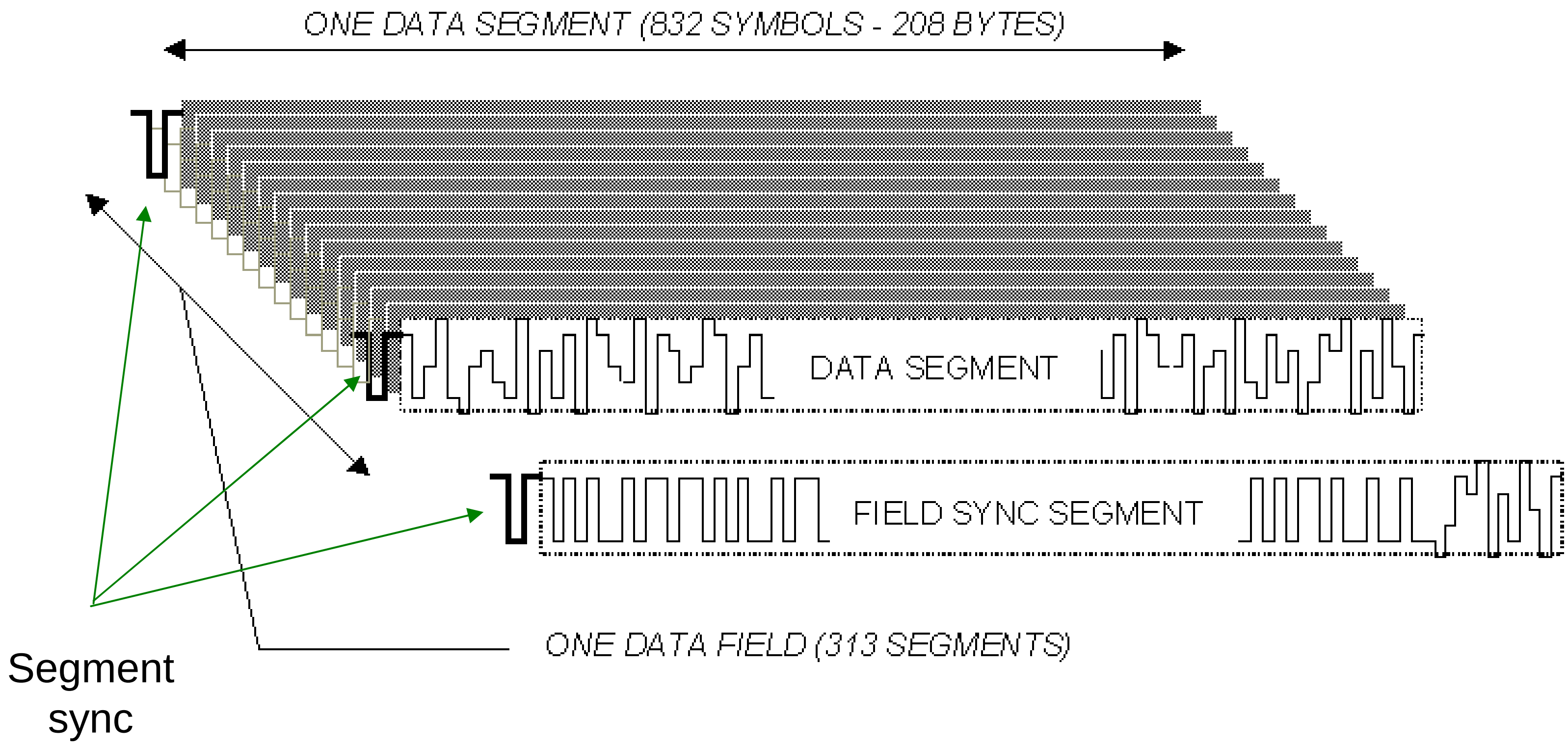
- Terrestrial broadcasting suffers from multipath effect
  - Received signal is sum of delayed and attenuated versions of the same signal with unknown delay variations
  - Create ghost of the original image
  - Equalizer = cancellation of inter-symbol interference (ISI) and ghost

- Equalizer design:
  - Think of the received signal as the original signal going through a filter
  - $g(n) = a_0 f(n+d_0) + a_1 f(n+d_1) + a_2 f(n+d_2) \ldots$
  - Can design an inverse filter to recover *f(n)* from *g(n).*
  - Need accurate estimation of a_i and d_i

Sync Signal

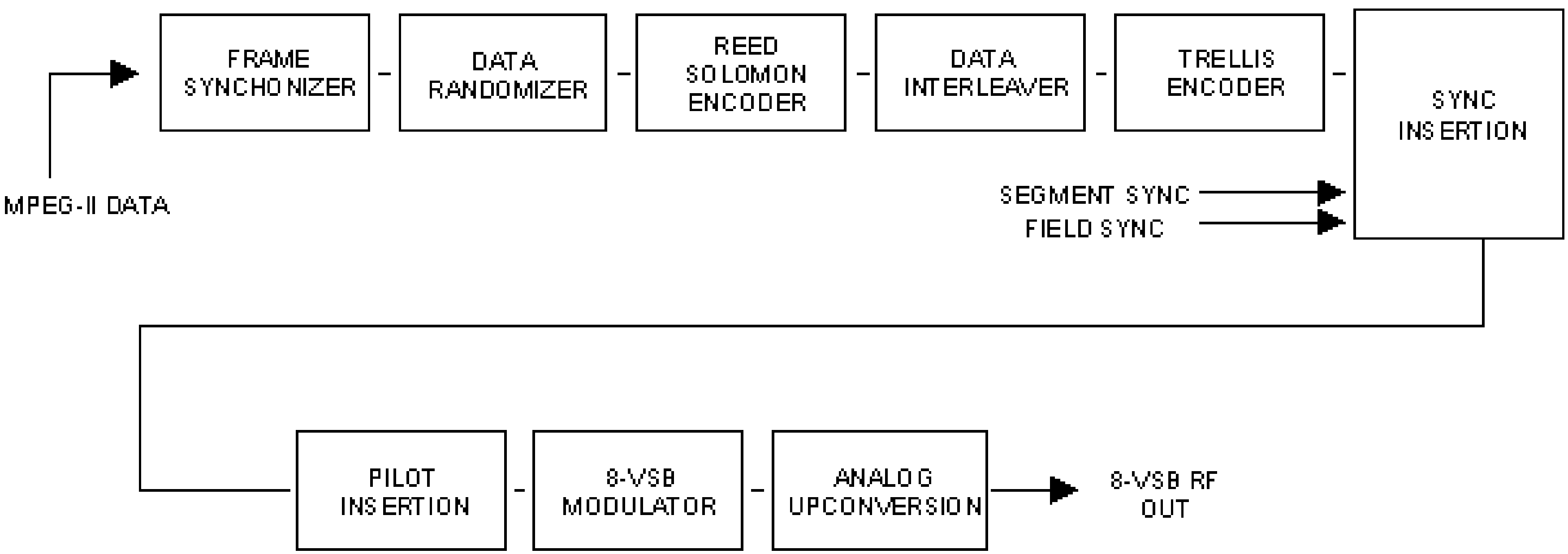
- Recall that NTSC video signal has horizontal retrace and vertical retrace to help the receiver recognize the beginning of a new line and a new field
- 8-VSB uses a similar design:
  – After every 828 symbols (resulting from 207 data bytes of 187 information bytes, or one MPEG transform packet, 77.3 us), a sync signal of length 4 symbols (0.37 us) is inserted
  – Each sync signal plus 828 data symbols form one data segment
  – After every 313 segments, a field sync of length equal to one data segment is added
  – Segment sync ~ horizontal sync
  – Field sync ~ vertical sync
  – The field sync is used to identify the multipath delay taps
  – The segment sync and field sync can be recovered at very high noise and interference levels (0 dB).

Data Structure



[From: D. Sparano, “What is exactly 8-VSB anyway”]

The Transmission Components of ATSC DTV (8-VSB Exciter)



[From: D. Sparano, “What is exactly 8-VSB anyway”]

Channel Coding and Modulation in DVB

- Also uses a concatenated code
  - Outer code: RS
  - Inner code: punctured convolutional code
- Use very different modulation technique
  - For conversion to complex symbols:
    - QPSK (=4-QAM, 2 bit/symbol)
    - 16 QAM (4 bit/symbol)
    - 64 QAM (6 bit/symbol)
  - Resulting complex symbols are split into multiple sub-channels, each using slightly shifted carrier frequency (OFDM)
  - Coded OFDM: refer to combination of the concatenated channel code and OFDM

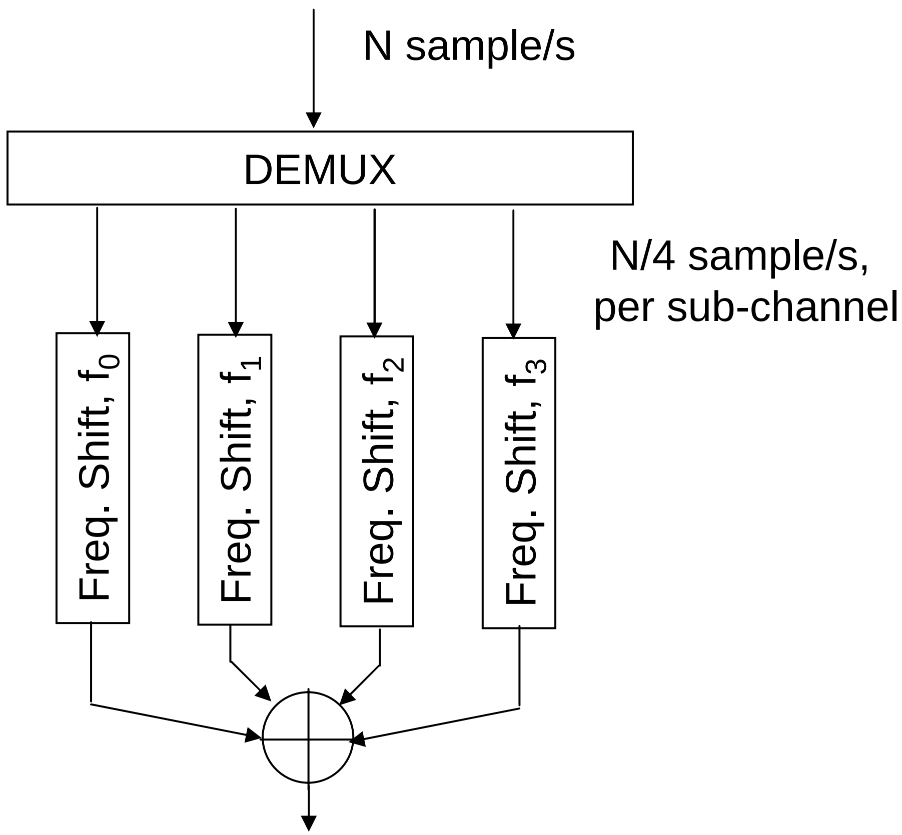
Orthogonal Frequency Division Multiplexing (OFDM)

- Basic ideas:
  - Split the original signal with N samples/s into M sub-channels, each with N/M samples/s and occupying a different frequency band (subband decomposition)
  - The sub-signals must be synchronized so that remultiplexing is possible at the demodulator
  - The modulation waveforms for the individual sub-channels should be orthogonal
    - When using sinusoidal waves with evenly spaced frequencies, can be realized by DFT

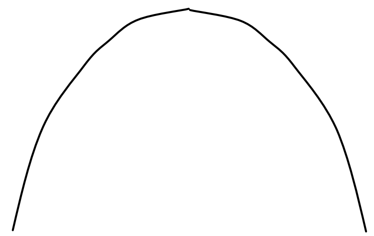
Fig.13.34 in Arnold

Example with 4 sub-channels

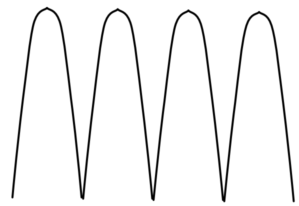
System Block Diagram:



Original Spectrum



Combined spectrum of the 4 sub-channels



From Fig.13.34 in [Arnold]

Advantage of OFDM

- Immunity to fading and interference
  - Fading and interference in one sub-carrier frequency (sub-signal) does not affect others
  - Use of interleaving/deinterleaving at multiplexer makes the burst error on one sub-channel spread randomly over the original signal, which can then be corrected by FEC decoding more effectively.
  - Also cause reduced interference to adjacent channels
  - Much better than 8-VSB to dynamic multipath fading (mobile receivers)
- But, compared to 8-VSB
  - More costly to implement
  - Require higher transmitter power to achieve the same coverage area, causing more interference to adjacent analog channels
  - Lower immunity to impulse noise

COFDM in DVB

- 2k mode
  - 2048 sub-carriers/channel, with 1705 of them at center used for carrying signals (including pilot signal)
- 8k mode
  - 8192 sub-carriers/channel, with 6817 used
- Each channel is 6, 7, or 8 MHz
- DVB-H uses a 4k mode

What you should know

- Channel coding
  - Principle of channel coding
  - Benefit of concatenated code and interleaver
  - Both DTV and DVB uses concatenated channel coding
- Modulation:
  - How to map digital signals to analog waveforms using M-ary ASK and M-ary QAM? (illustrate for the case of M=2 or 4)
  - Principles of VSB and OFDM
  - DTV uses 8 VSB (8-level ASK and VSB)
  - DVB uses QAM and COFDM (channel coding plus OFDM)
  - relative pros and cons of 8-VSB and COFDM

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