  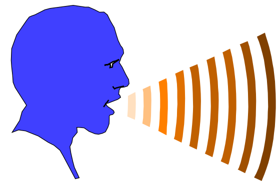 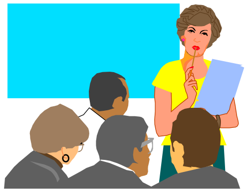

Multimedia Communication Systems II

Analog TV Systems: Monochrome TV

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Outline

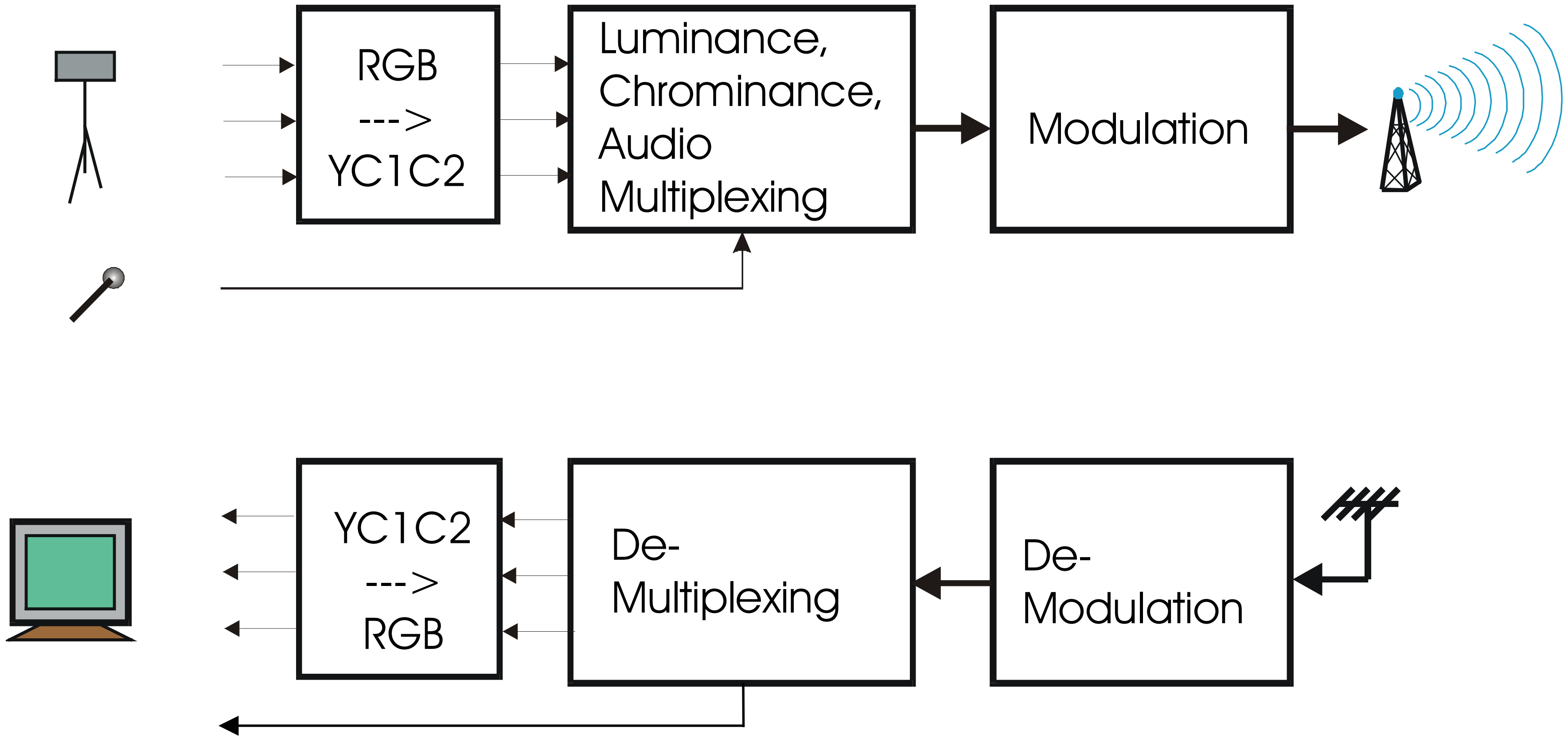
- Overview of TV systems development
- Video representation by raster scan:
  - Human vision system properties
  - progressive vs. interlaced scan
  - NTSC video
- Spectrum of a raster video
- Multiplexing of audio and video
- Multiplexing of Multiple TV Channel
- TV Receivers

Overview of TV System Development

- Analog Black and White TV:
  - 1941 NTSC standard settled, first commercial broadcast in US
- Analog Color TV
  - 1950 first commercial color TV broadcast (CBS), incompatible with B/W systems
  - 1953 FCC approves RCA color TV system (compatible with B/W systems) (NTSC color)
- Cable TV, Satellite TV, VCR
  - Cable TV becoming popular in 70's
- Digital TV through small dish satellite (MPEG2 encoded)
  - mid 90's
- DVD (MPEG-2 encoded)
  - mid 90's
- Digital TV broadcasting: SD and HD (MPEG-2 encoded)
  - Selected programs on air since late 90's
  - All stations must broadcast in digital by 2006 (FCC requirement)

See http://www.tvhistory.tv

Analog TV Broadcasting and Receiving



Questions to be Answered

- How is video captured and displayed?
  - How to represent a monochrome video
    - Video raster
  - How to represent color video, and multiplex different color components (next lecture)
- How to multiplex audio and video together
- How to allow multiple TV signals be broadcast over the air?
- How does a TV tune to a particular channel, and separate the audio and video and different color components in video?

Video Raster

- Real-world scene is a continuously varying 3-D signal (temporal, horizontal, vertical)
- Analog video is captured and stored in the raster format
  - Sampling in time: consecutive sets of frames
  - Sampling in vertical direction: successive scan lines in one frame
  - Video-raster = 1-D signal consisting of scan lines from successive frames
- Video is displayed in the raster format
  - Display successive frames
  - Display successive lines per frame
  - To enable the display to recognize the beginning of each frame and each line, special sync signals are inserted

What are the appropriate frame and line rates?

- Depending on
  - Human visual system properties
  - Viewing conditions
  - Capture/Transmission/Display technology
- Ideally we want the rate to be as high as possible to get best possible quality
- But higher rates mean the capture and display devices must work with very high data rate, and transmission of TV signals would take significant amount of bandwidth
- Human eye does not perceive separate lines/frames when the rate is sufficiently high
- Use just enough frame/line rate at which the eye perceives a continuous video

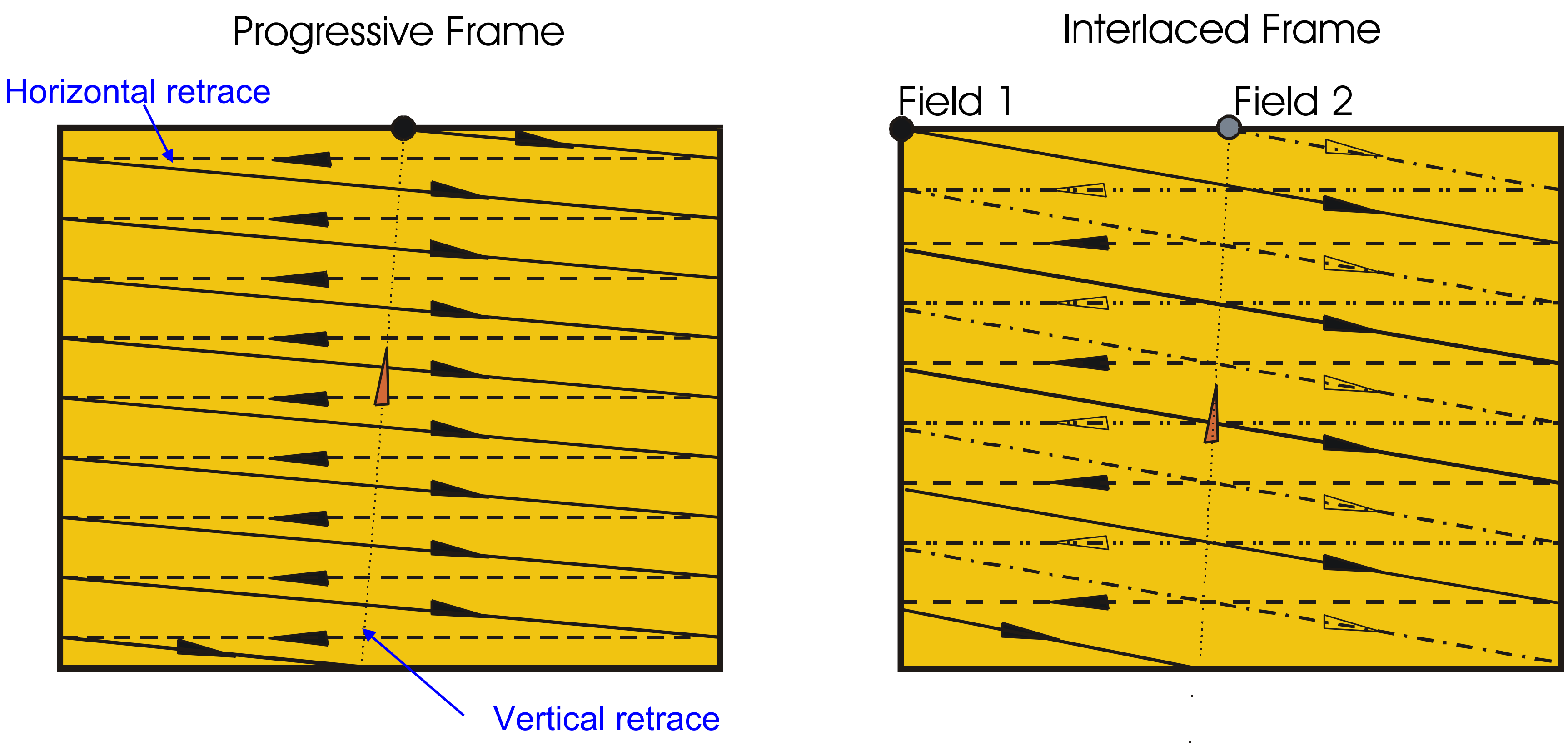
Properties of Human Visual System: Frame Merging

- Persistence of vision: the eye (or the brain rather) can retain the sensation of an image for a short time even after the actual image is removed
  – Allows the display of a video as successive frames
  – As long as the frame interval is shorter than the persistence period, the eye sees a continuously varying image in time
  – When the frame interval is too long, the eye observes frame flicker
  – The minimal frame rate (frames/second or fps or Hz) required to prevent frame flicker depends on display brightness, viewing distance.
    - Higher frame rate is required with closer viewing and brighter display
    - For TV viewing: 50-60 fps
    - For Movie viewing: 24 fps
    - For computer monitor: > 70 fps

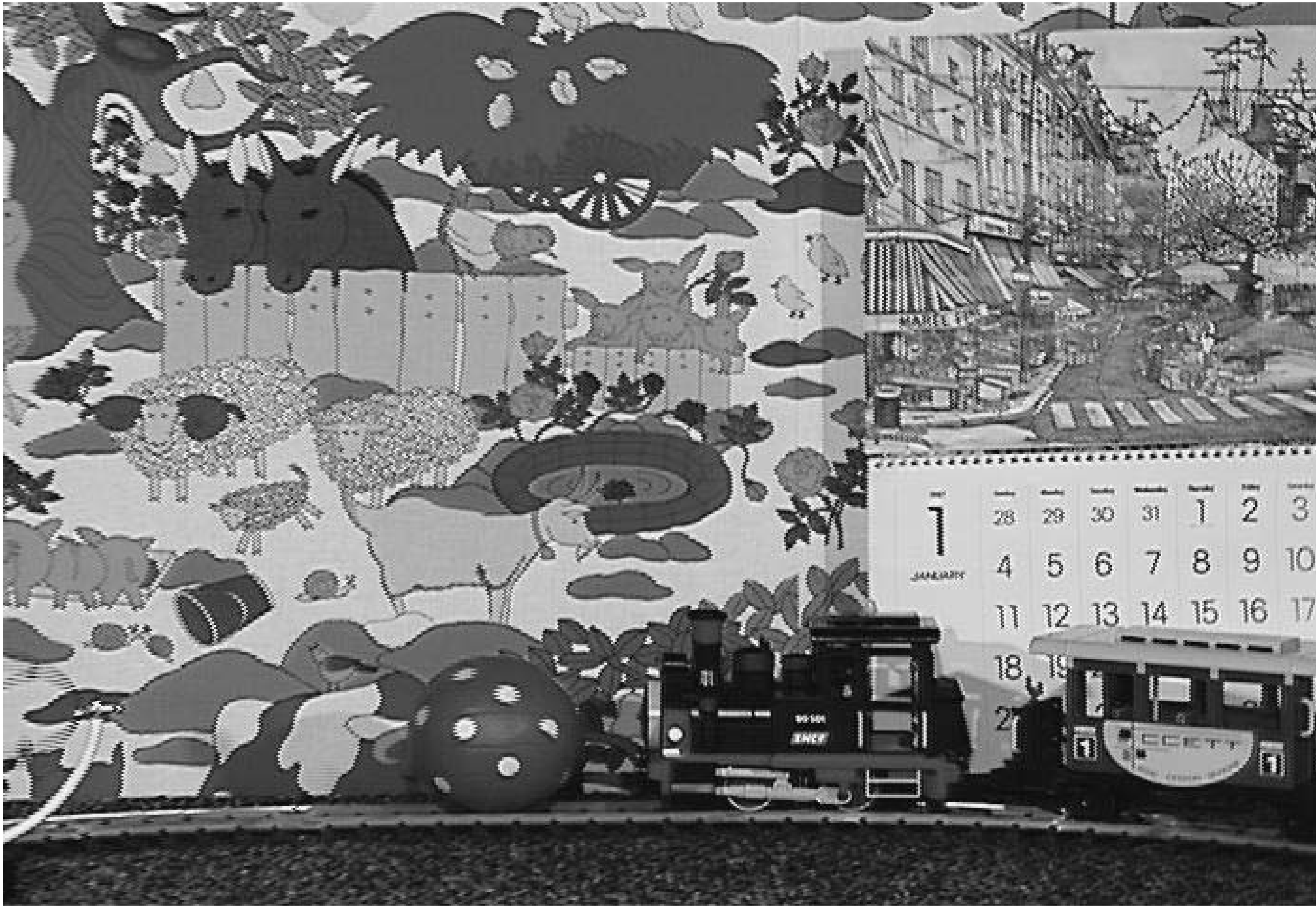
Properties of Human Visual System: Line Merging

- As with frame merging, the eye can fuse separate lines into one complete frame, as long as the spacing between lines is sufficiently small
  - The maximum vertical spacing between lines depends on the viewing distance, the screen size, and the display brightness
    - For common viewing distance and TV screen size, 500-600 lines per frame is acceptable
- Similarly, the eye can fuse separate pixels in a line into one continuously varying line, as long as the spacing between pixels is sufficiently small.
  - Principle behind fully digital video representation

Progressive and Interlaced Scans



Interlaced scan is developed to provide a trade-off between temporal and vertical resolution, for a given, fixed data rate (number of line/sec).



An Interlaced Frame (from mobilcal.mpeg420). Notice the “jaggedness” along vertical lines.

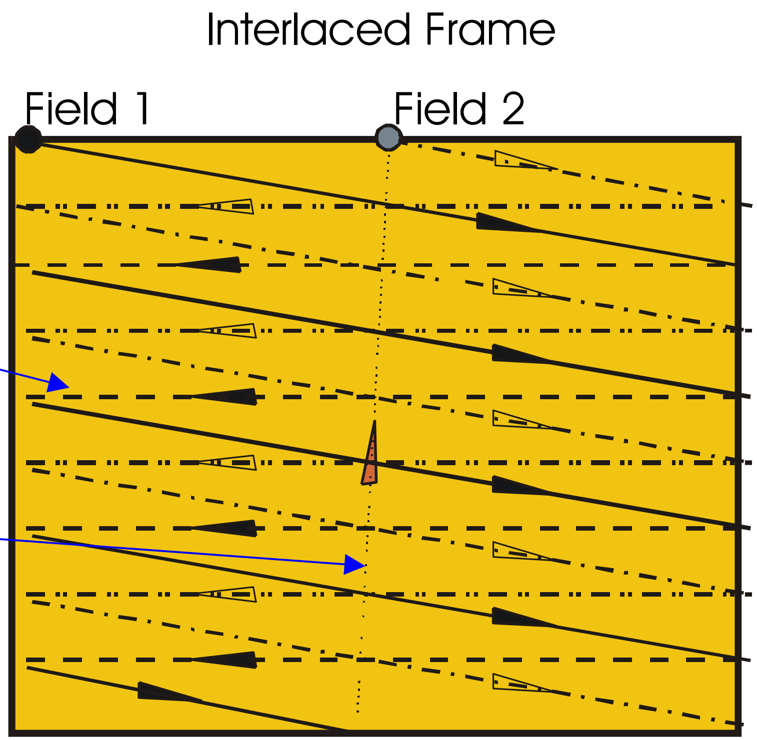
The top and bottom fields of the previous interlaced frame. Vertical lines are straight in each field

Why Interlacing?

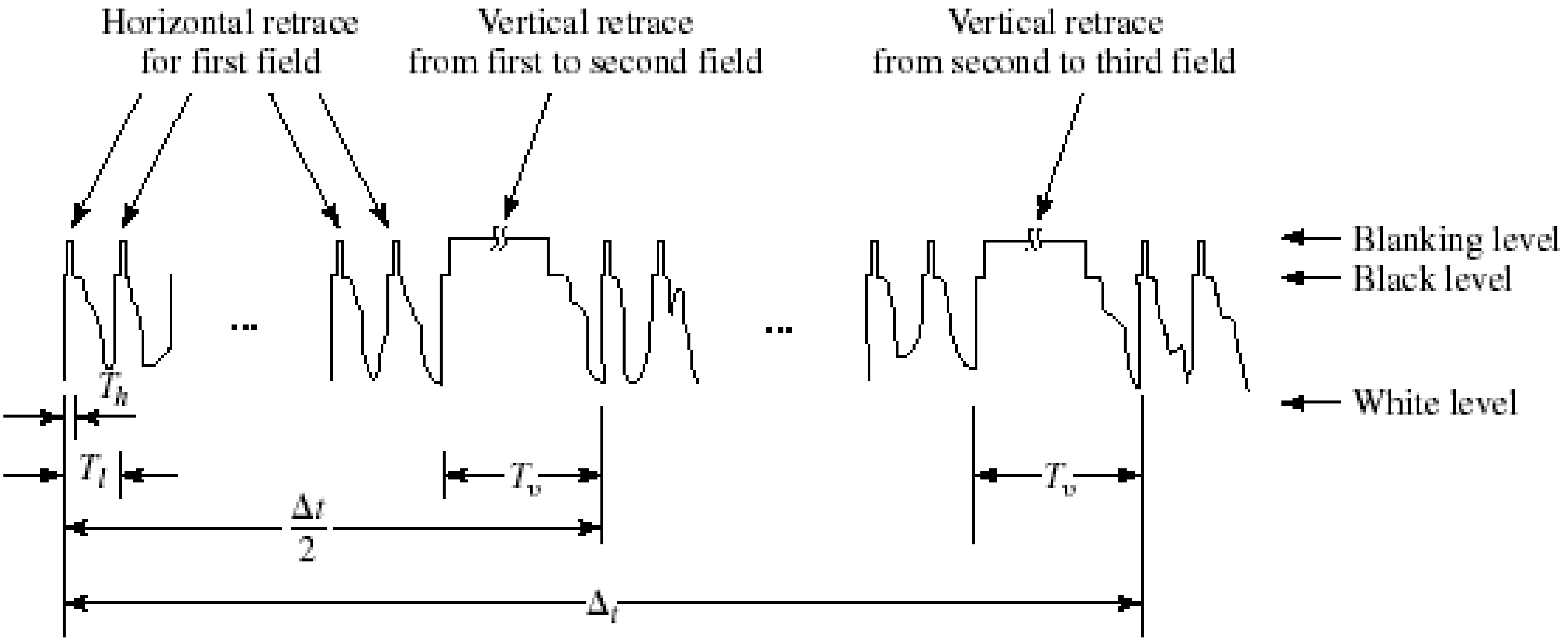
- Given a fixed line rate of 12000 lines/s
  - With progressive scan at 30 frames/s, one can have 400 lines/frame
  - With interlaced scan at 60 fields/s, one can have 200 lines/frame
- Interlacing allows higher temporal resolution, at the expense of vertical resolution, when the line rate is the same
  - Rendering fast moving objects better, but can not display vertical details as well
  - Human eye has reduced spatial resolution when the object is moving fast
  - When the scene is stationary, two fields merge into a frame with higher vertical resolution
  - But interlacing can also cause artifacts: interline flicker and line crawl
- At the time TV systems were first developed (1939-41), 60 frames/s, 525 lines/frame is technologically infeasible. Interlacing using 60 fields/s and 252.5 lines/field is a good compromise (an ingenious engineering solution!)

Adding Sync Signals

- For a display device to know when does a line/field end, special synchronization signal (with a constant voltage level) are used
  - Horizontal retrace
    - Reduce the actual time used to scan a line
  - Vertical retrace
    - Reduce the actual number of lines (active lines) that is used to describe the video



Waveform of an Interlaced Raster



From, Wang, et al. Video processing and communications, Fig.1.4(a)

NTSC Video Format

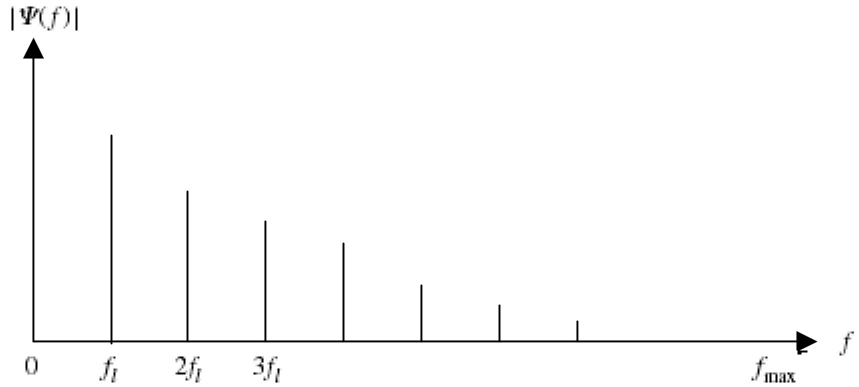
- NTSC is the monochrome TV system used in North America and Japan, drafted by the US National Television System Committee, which later migrated to the NTSC color TV system
- Standard approved 1941
- NTSC video format:
  - Field rate: 59.94 fields/s
  - Line rate: 525 lines/frame or 262.5 lines/field
  - Image aspect ratio (IAR=width:height)= 4:3
  - Line interval T_l=1/30*525=63.5 us
  - Horizontal retrace: T_h=10 us
  - Actual time to scan a line: T_l'=53.5 us
  - Vertical retrace between field: T_v=1333 us (21 scan lines per field)
  - Active lines: $N_{activeline}$=483 lines/frame

Spectrum of Typical Video Raster

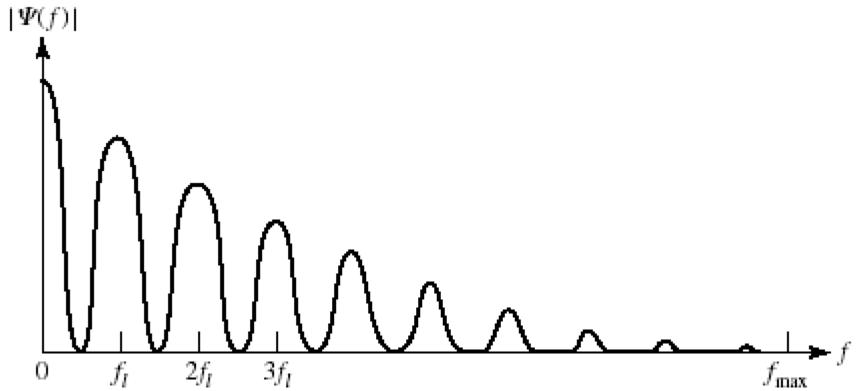
- A raster video has a pseudo periodic structure, with period equal to one line interval, because adjacent lines have similar waveform (intensity distribution)
- How should its spectrum (Fourier transform magnitude) look like?
- Recall that a true periodic signal with period T_0 will have a line spectrum (computed using Fourier series analysis) with spacing equal to fundamental frequency $f_0=1/T_0$, and the line magnitude depending on Fourier series coefficient, which depends on how the signal change within one period
- With a raster video, which is not truly periodic, each line is replaced by a bell-shaped function, and the peak magnitude gradually decreases to zero as the frequency increases, and the decay slope of the envelop of the spectrum depends on how fast the signal change within a line.

Spectrum of Raster Video

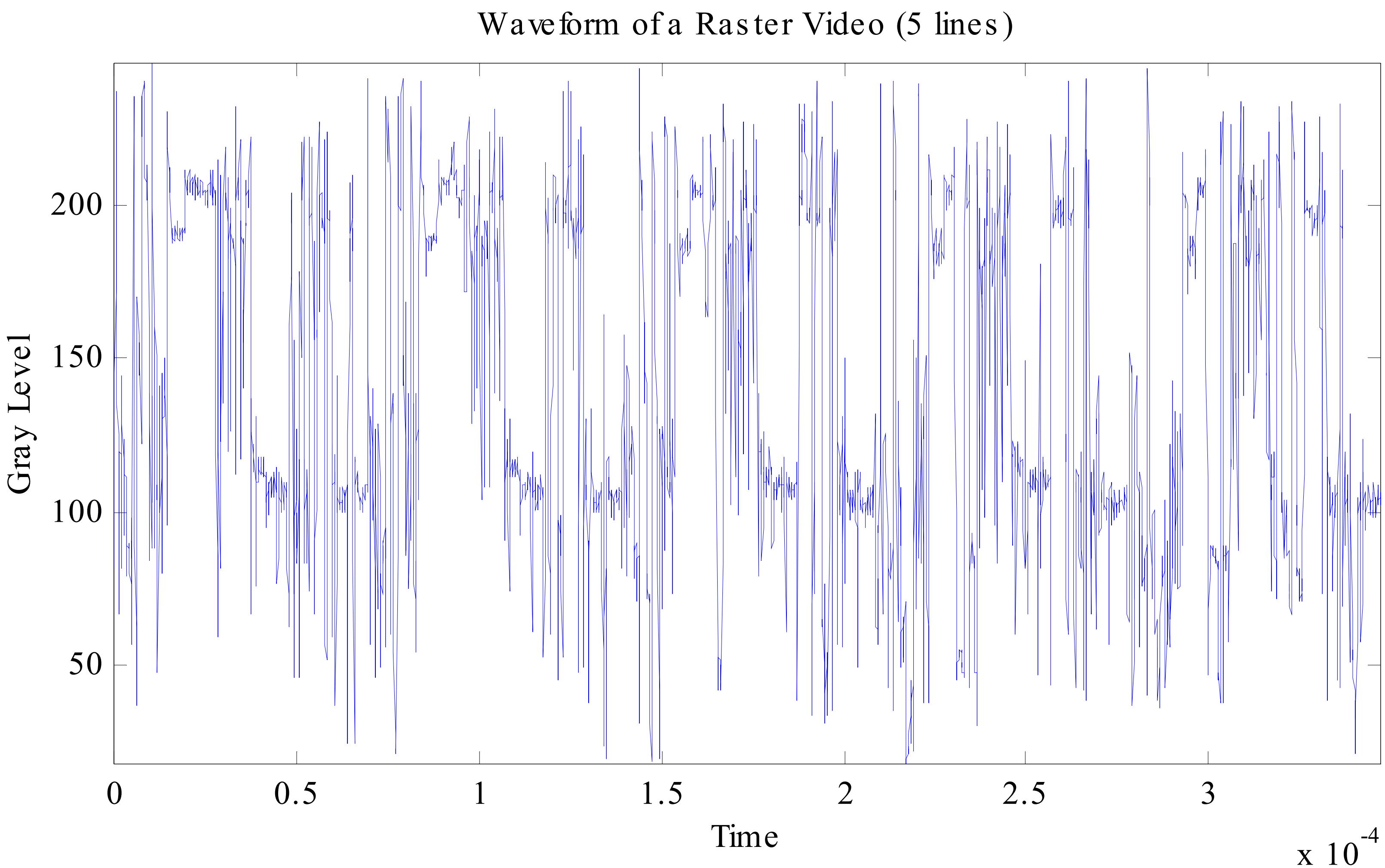
True Periodic Signal



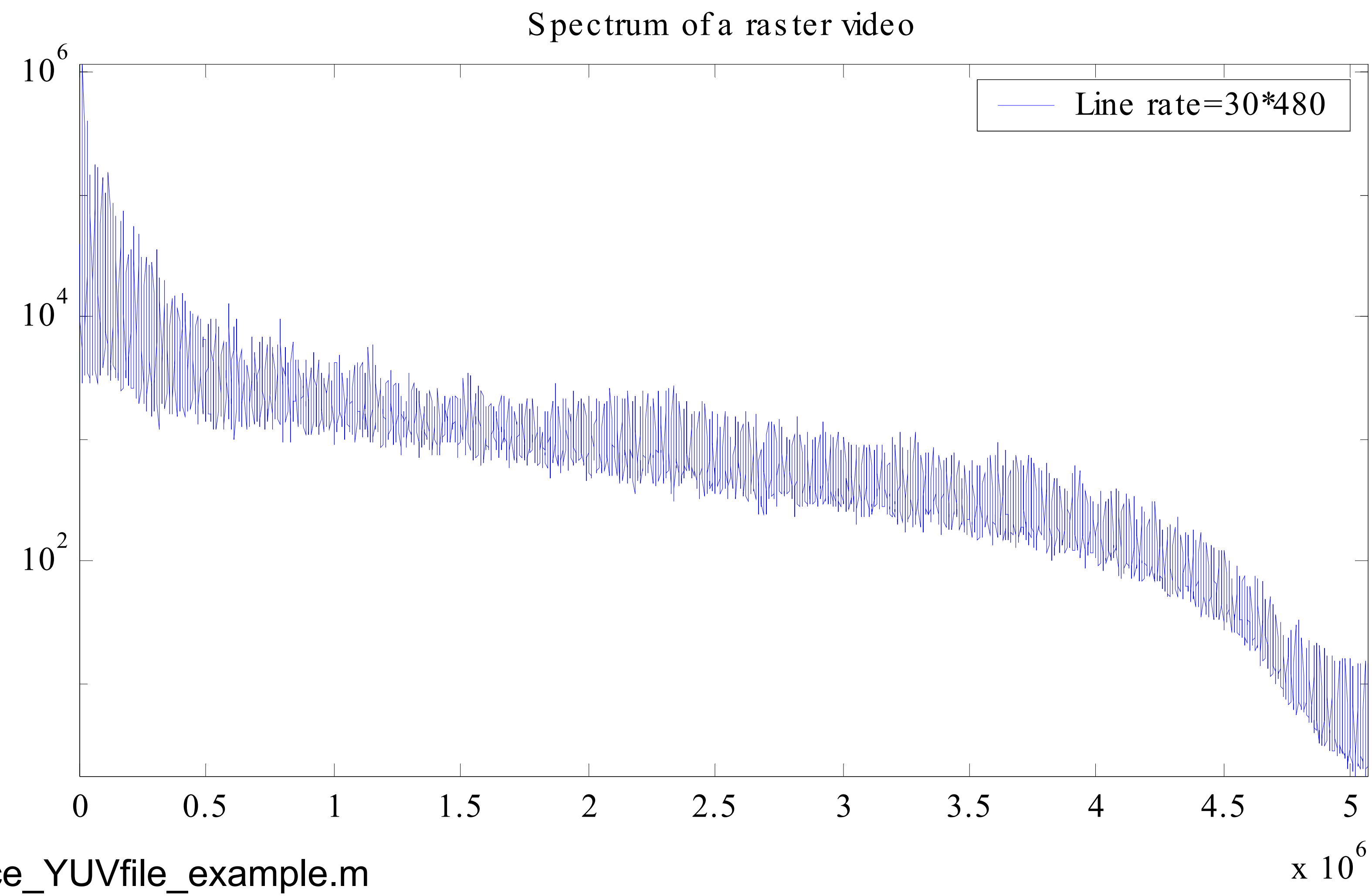
Typical video raster



Waveform from “Mobile Calendar”

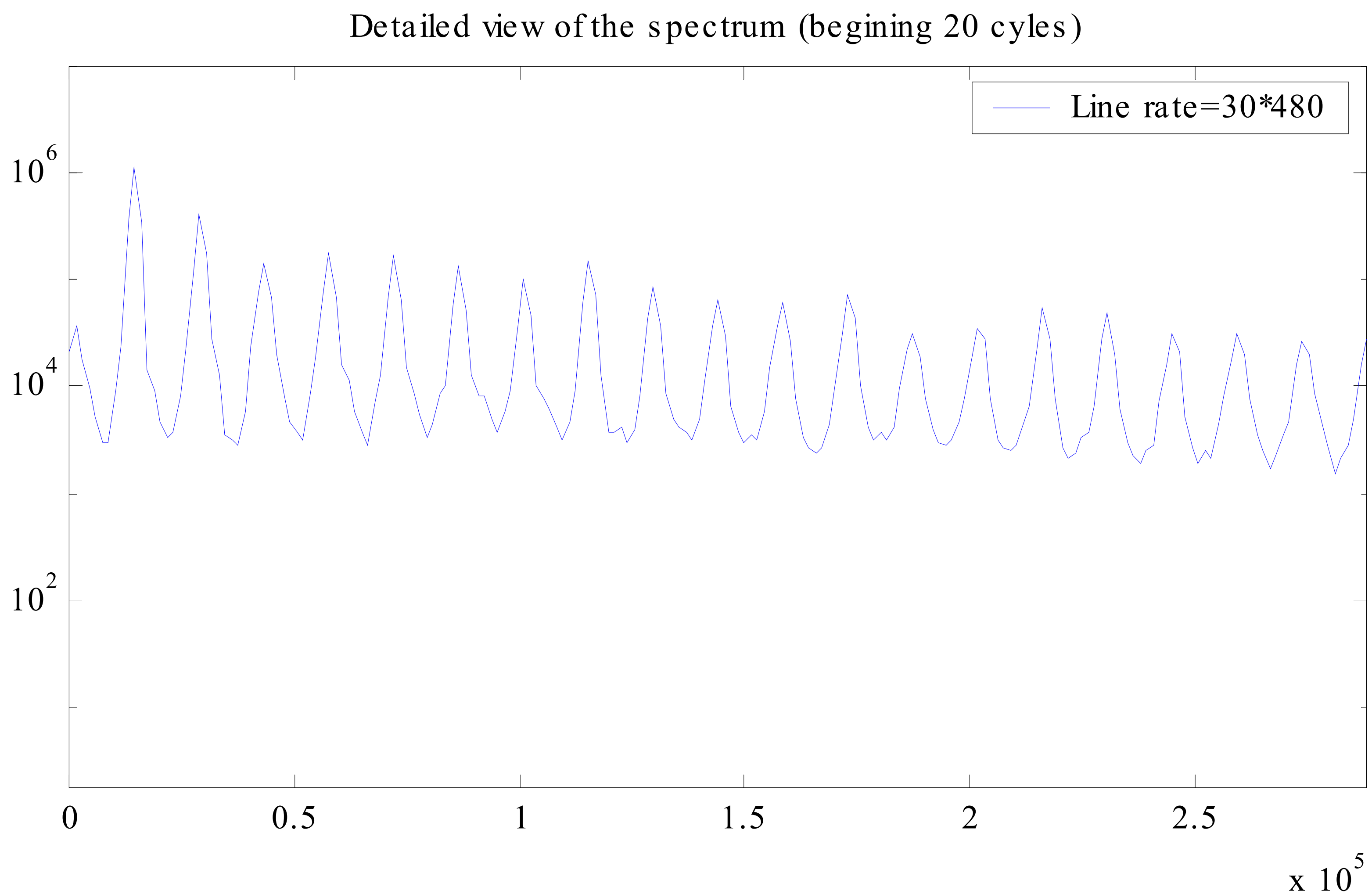


Spectrum computed from “Mobile Calendar”



Interlace_YUVfile_example.m

Detailed View of the Spectrum

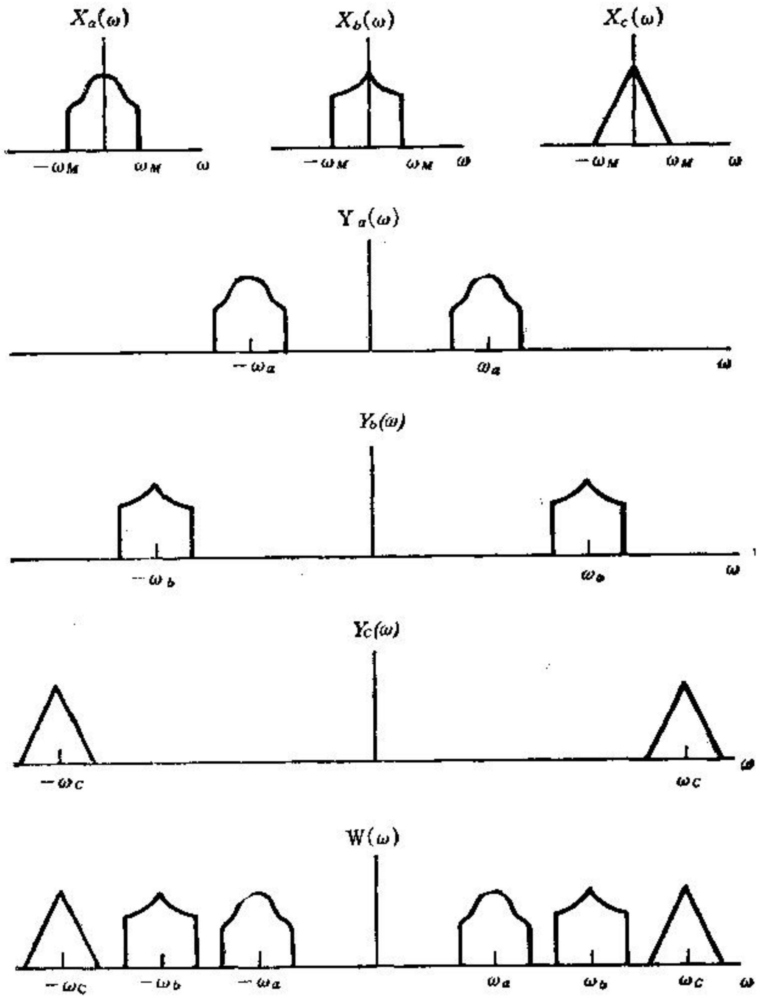


Video Bandwidth
(what is $f_{max?}$)

- For NTSC video
  - Maximum vertical frequency happens when black and white lines alternating on the screen, having
    - $N_{activeline}$ /2 =483/2 (cycles/picture-height)
  - The camera typically blurs the signal slightly (by the "Kell factor" or K)
    - $f_{v,max}=K*483/2$, K=0.7 for typical TV cameras
  - Maximum horizontal frequency (cycles/picture-width)
    - $f_{h,max}= f_{v,max}$ * picture-width/picture-height (cycles/picture-width)
  - Each line is scanned in T_l' =53.5 us
  - Corresponding temporal frequency is
    - $f_{max}= f_{h,max} / T_l'$ = 0.7*483/2*4/3/53.5 = 4.2 MHz (cycles/s)

How to allow multiple TV stations to transmit signals at the same time?

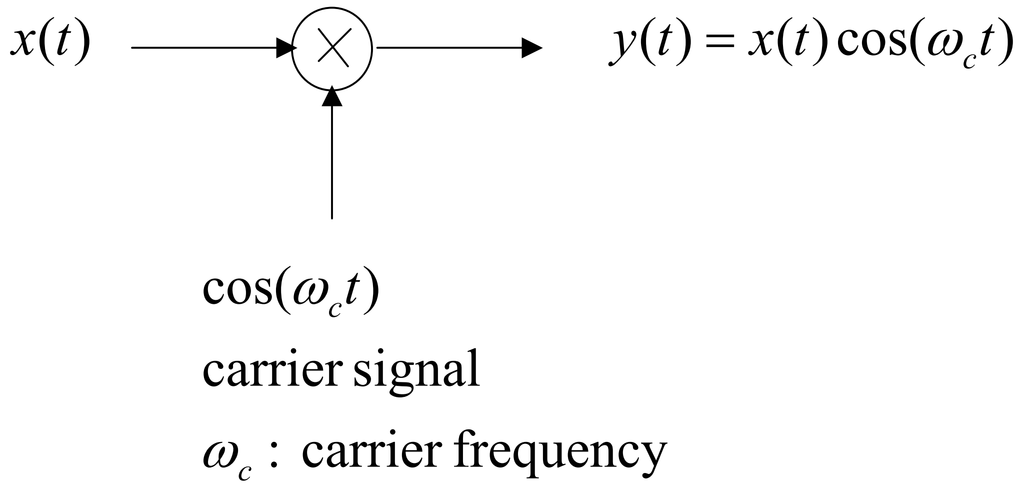
- Using frequency division multiplexing
  - Different TV channels occupy different frequency bands



From Figure 7.22 in [Oppenheim]

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

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



Basic Equalities

- Basic equality

$$x(t)e^{j2\pi f_c t} \leftrightarrow X(f - f_c)$$

$$x(t)e^{-j2\pi f_c t} \leftrightarrow X(f + f_c)$$

$$x(t)\cos(2\pi f_c t) \leftrightarrow \frac{1}{2}\left(X(f - f_c) + X(f + f_c)\right)$$

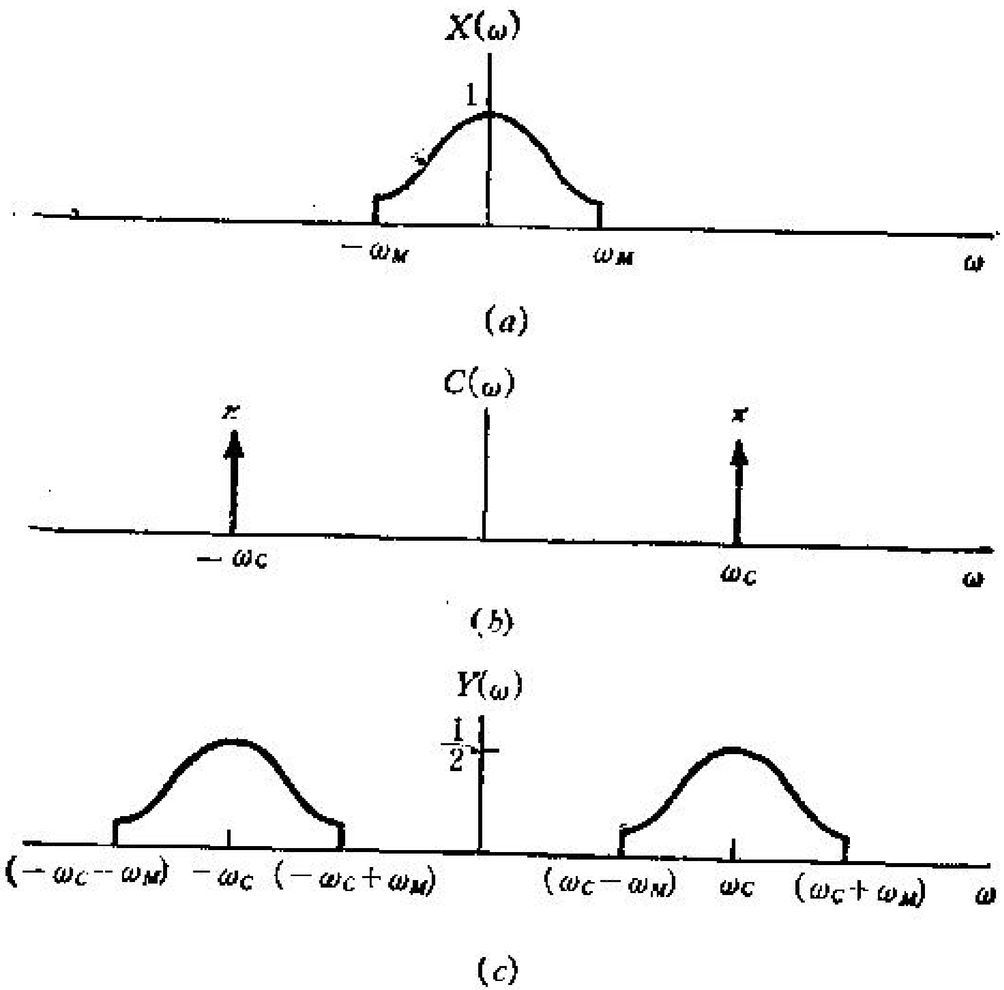
Frequency Domain Interpretation of Modulation

From Figure 7.5 in [Oppenheim]

$x(t)$

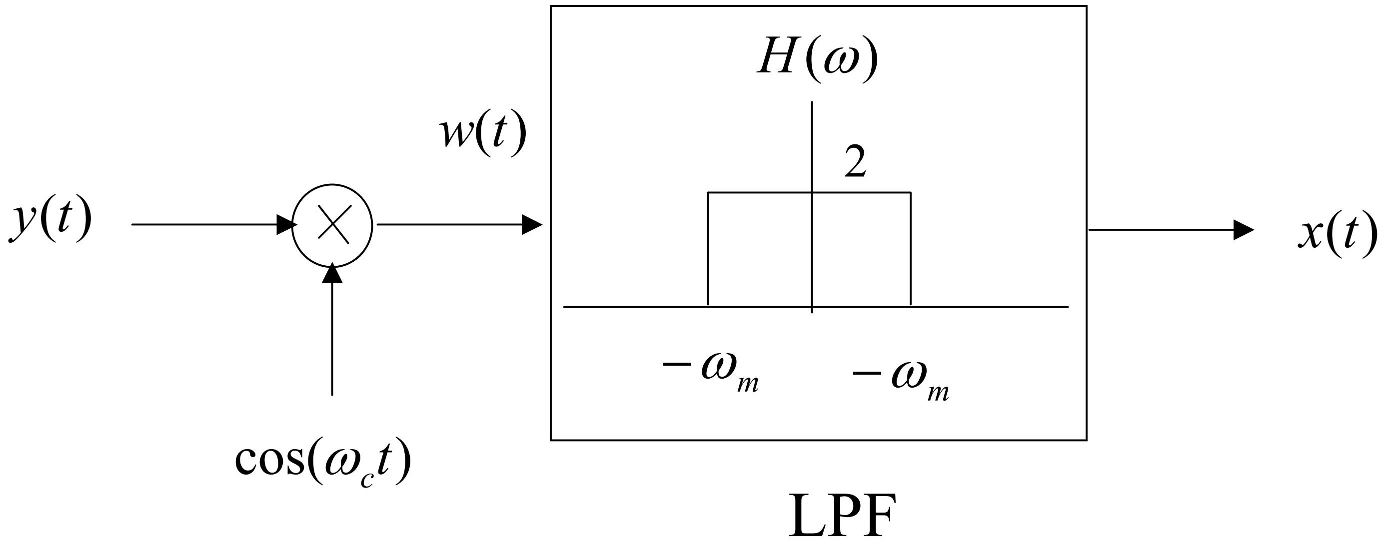
$\cos(\omega_c t)$

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



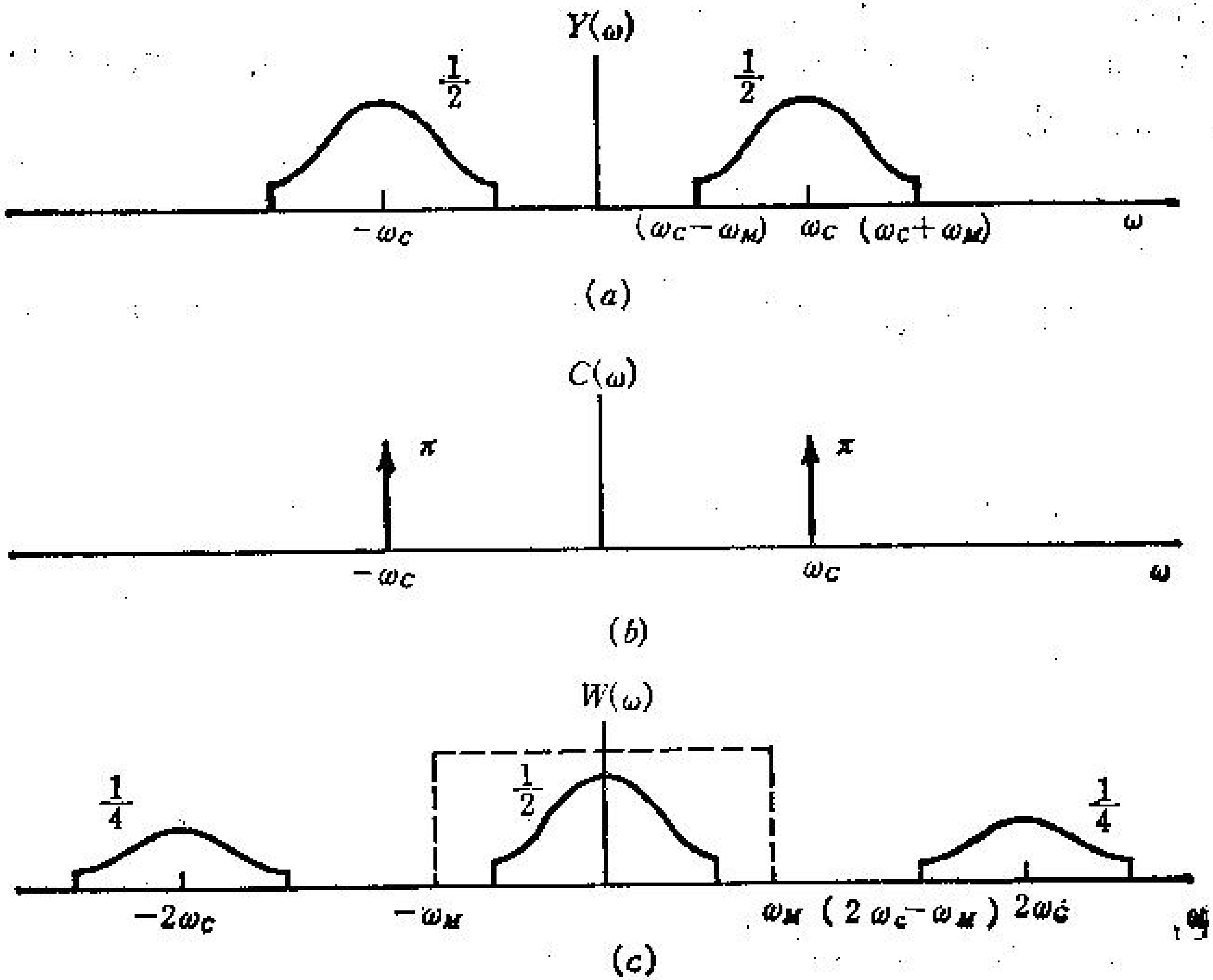
How to get back to the baseband? (Demodulation)

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



Frequency Domain Interpretation of Demodulation

Figure 7.7 in [Oppenheim]



Temporal Domain Interpretation

Modulation:

$$y(t) = x(t)\cos(2\pi f_c t)$$

Demodulation:

$$w(t) = y(t)\cos(2\pi f_c t) = x(t)\cos^2(2\pi f_c t)$$

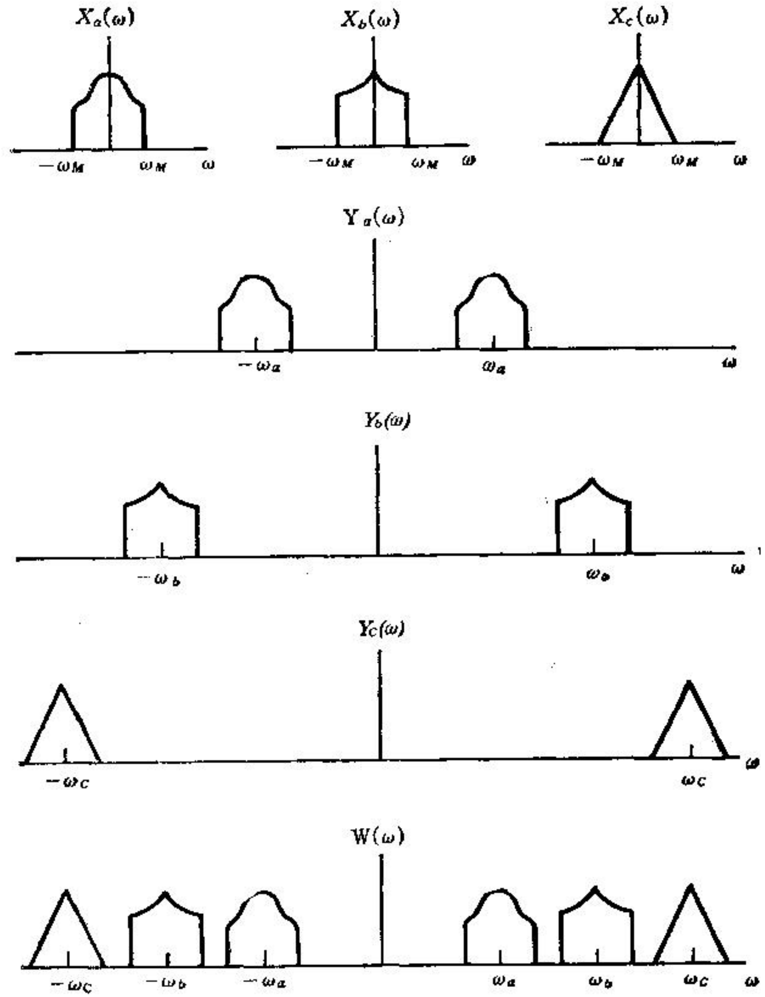
Using the equality $\cos^2(\theta) = \frac{1}{2}\left(1 + \cos(2\theta)\right)$

$$w(t) = \frac{1}{2}\left(1 + \cos(4\pi f_c t)\right)x(t) = \frac{1}{2}x(t) + \frac{1}{2}x(t)\cos(4\pi f_c t)$$

The LPF will retain the first term and remove the second term.

Frequency Division Multiplexing

- To transmit the three signals over the same channel, each signal is shifted to a different carrier frequency.
- From Figure 7.22 in [Oppenheim]



FDM Receiver

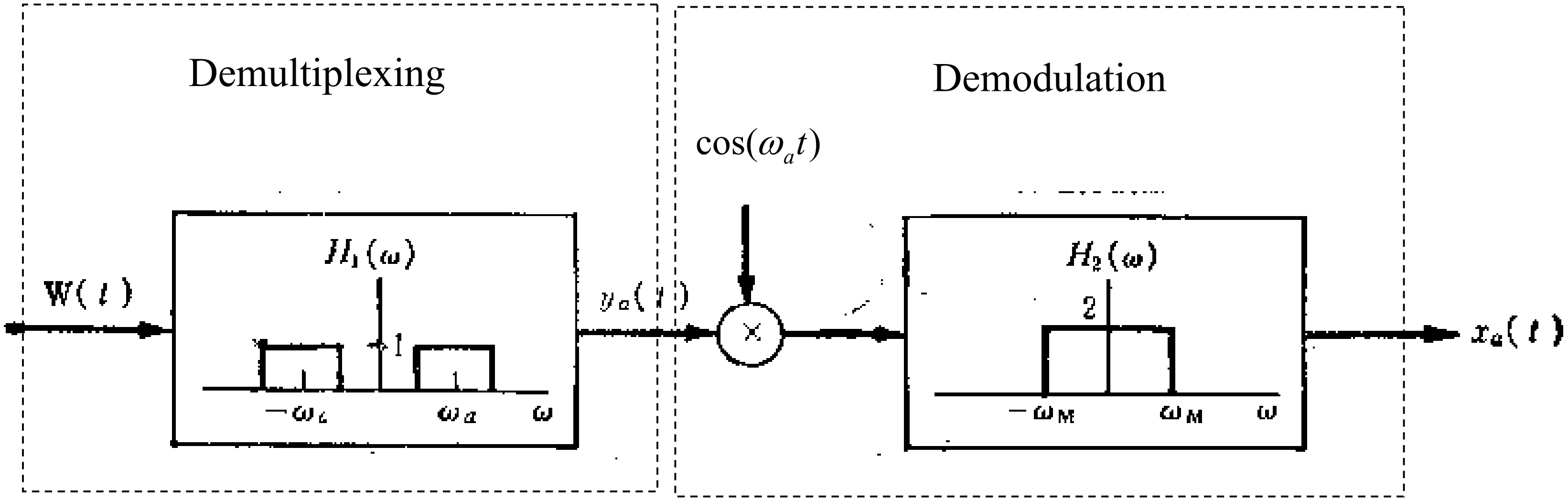
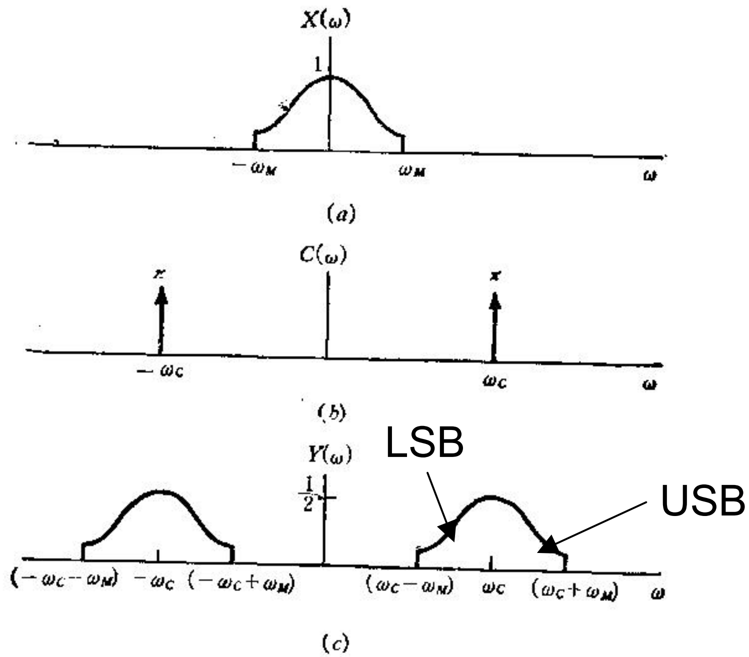


Figure 7.23 in [Oppenheim]

Variations of Amplitude Modulation

- What we have just discussed is called double sideband (DSB) amplitude modulation
  - Retains both the upper and lower side band (USB and LSB)
  - Transmit twice the bandwidth of the original signal

Also see Fig.4.1 in [Lathi]



Single Sideband (SSB) AM

- Send only USB or LSB
  - Use a lowpass or highpass filter to filter out the USB or LSB after shifting the frequency from baseband to the carrier
  - An alternate implementation using phase-shift circuit (Hilbert transform) *(not required for this class)*
- Demodulation of SSB
  - Can be done in the same way as DSB

Fig.4.15 in [Lathi]

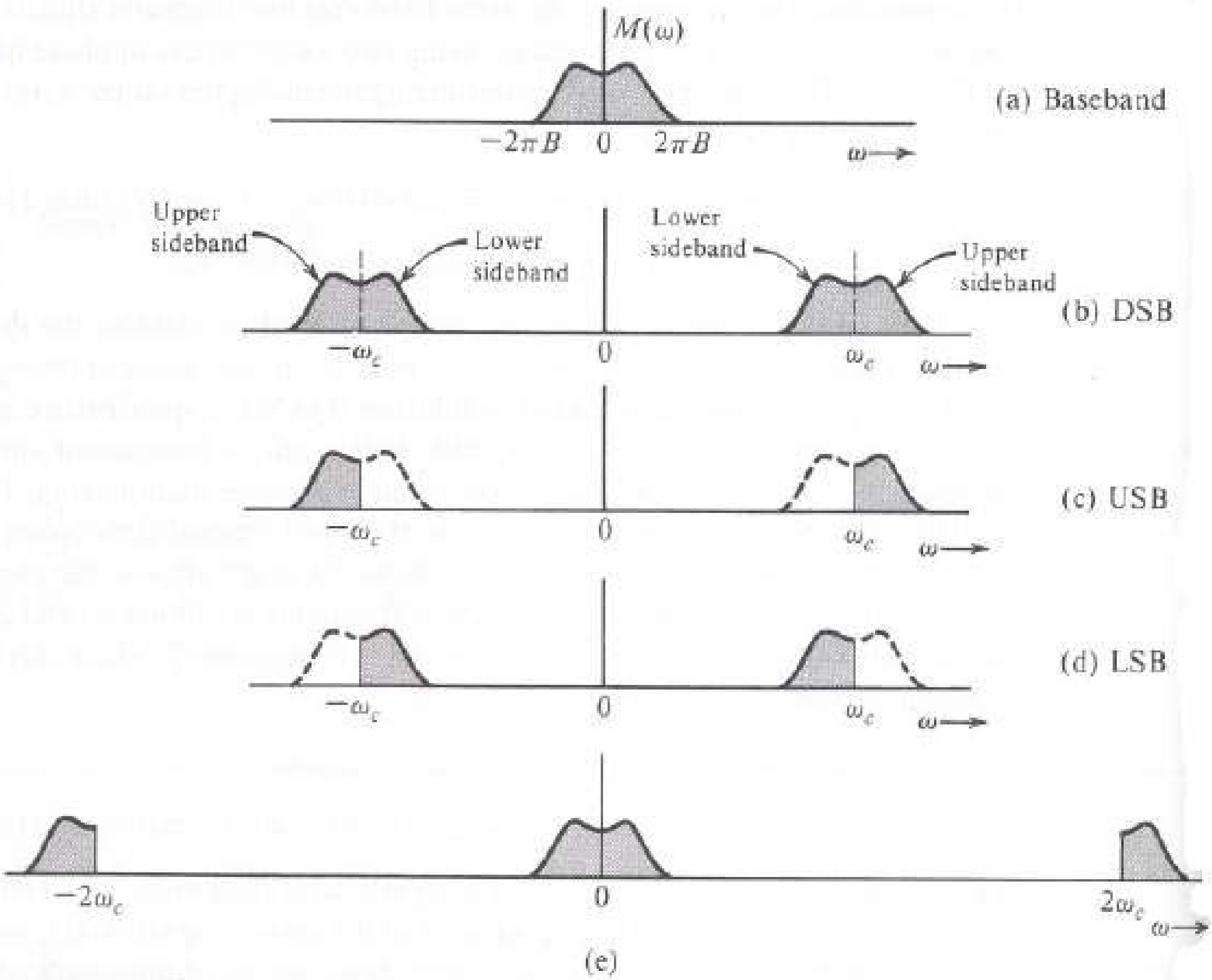


Figure 4.15 SSB spectra.

From [Lathi]

Vestigial Sideband (VSB) AM

- Realization of SSB requires filters with very sharp transition bands
  - Not easy to implement
- VSB retains a small portion of the unwanted sideband, and thus can be realized by a filter (called VSB shaping filter) that has a gradual transition band

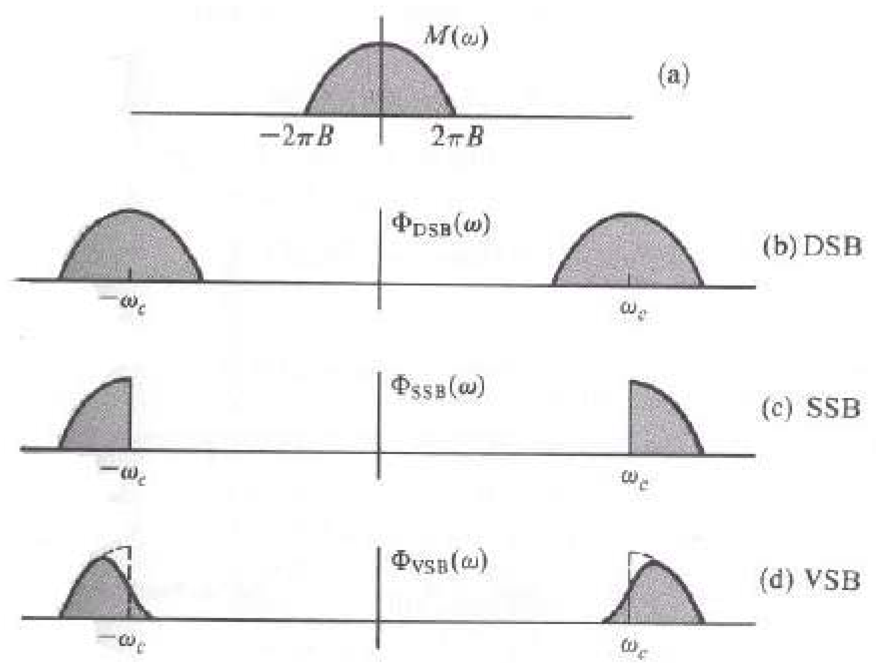


Fig.4.21 in [Lathi]

Demodulation of VSB

- Demodulation requires an appropriate equalizer filter
  - When the shaping filter is designed appropriately, the equalizer filter is a simple lowpass filter.

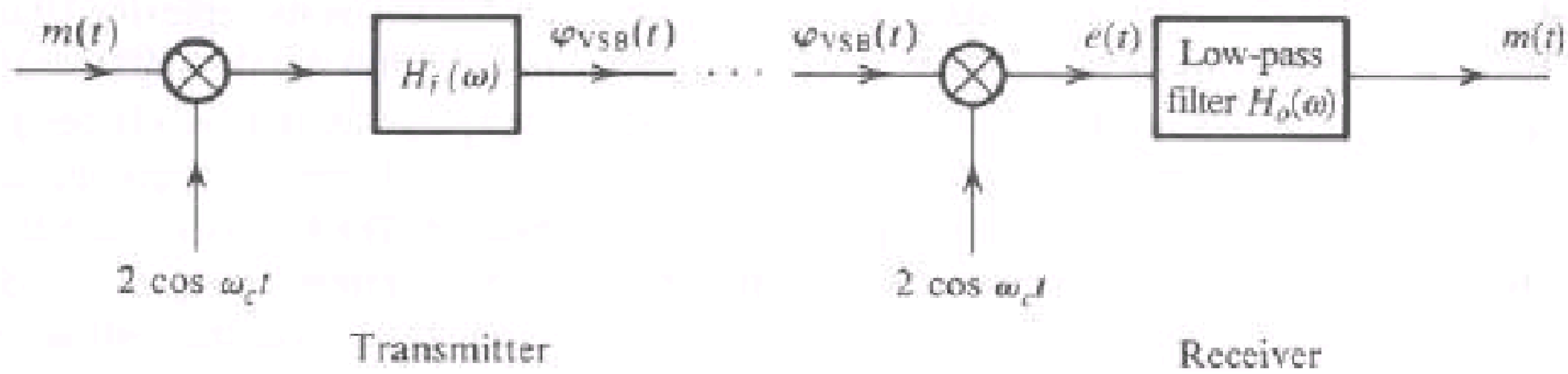


Figure 4.22 VSB modulator and demodulator.

Fig.4.22 in [Lathi]
Equations (4.18-4.20) and footnote (4.21)

Equalizing Filter in VSB

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

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

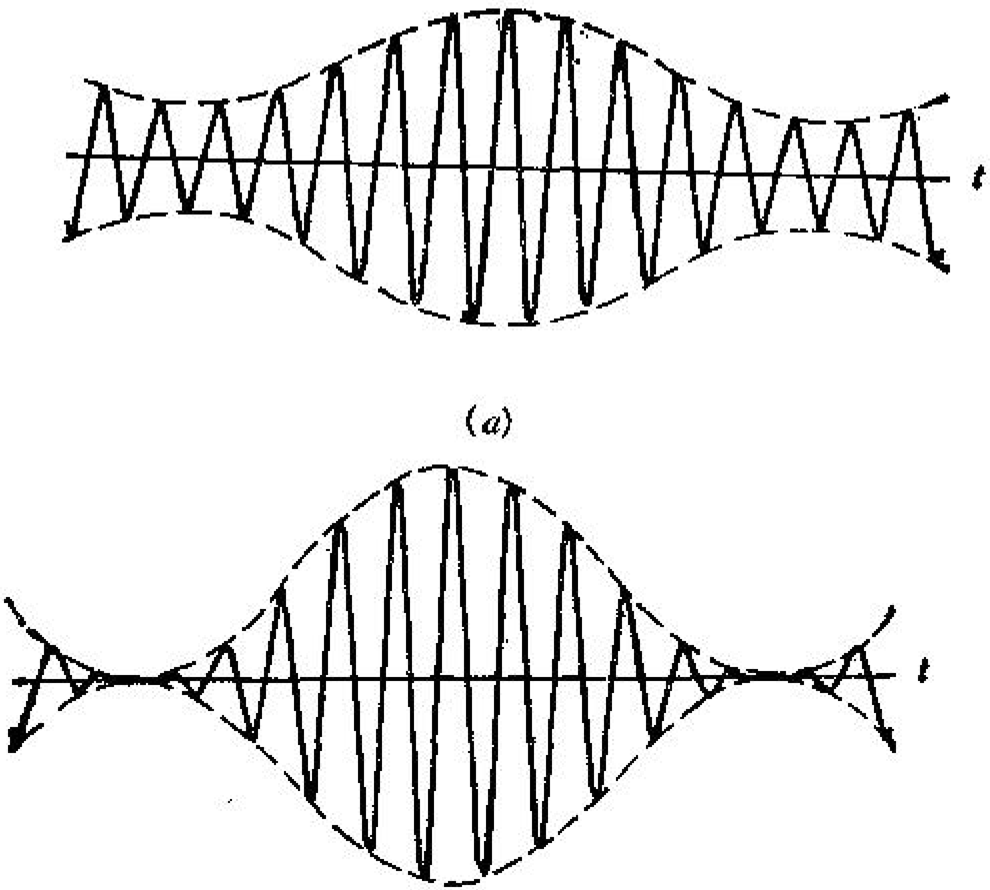
$$H_o(\omega) = \frac{1}{H_i(\omega + \omega_c) + H_i(\omega - \omega_c)} \qquad |\omega| \leq 2\pi B$$

Technical Challenge

- The demodulator must generate the carrier signal in exactly the same frequency and phase as the modulator
  - Synchronous modulation
  - The carrier signal is not transmitted (or suppressed), thus called DSB-SC, SSB-SC, VSB-SC
- When the carrier is transmitted together with the modulated signal, demodulation can be realized by envelop detection
  - Same principle can be applied to DSB, SSB, VSB, leading to DSB-C, SSB-C, VSB-C

Demodulation by Envelope Detection

Figure 7.14 in Signals and Systems

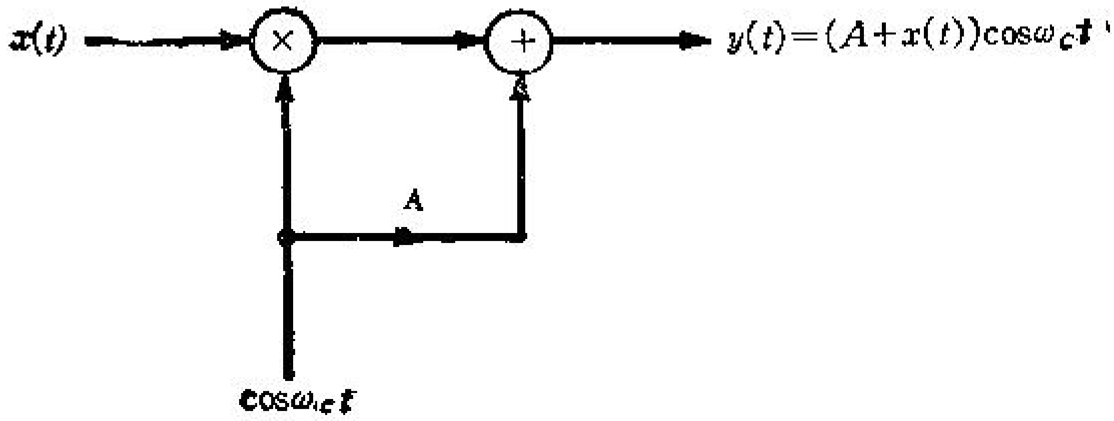


(a)

(b)

The modulating signal must be positive!

Asynchronous Amplitude Modulation



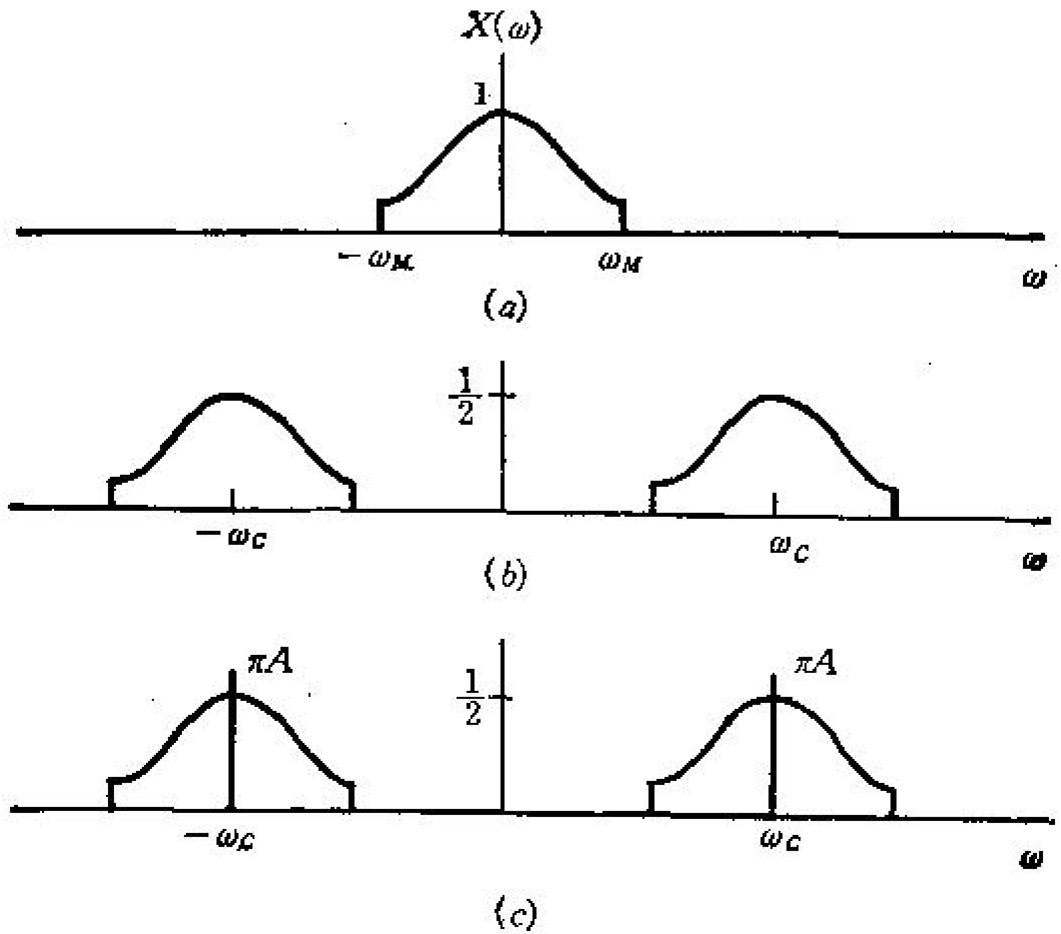
A: modulation index $A >= |x|_{max}$

Frequency Domain Interpretation

Figure 7.15 in Signals and Systems

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

$$y(t) = \left(x(t) + A\right)\cos(\omega_c t)$$



Trade-off between Power Efficiency and Complexity

- Synchronous modulation (suppressed carrier or SC)
  - Lower transmission power (don't need to transmit the carrier signal)
  - High demodulator complexity (must be synchronized with the modulator)
- Asynchronous modulation (with carrier or C)
  - Higher transmission power
  - Lower demodulator complexity
  - Used in AM radio broadcast and receiver
  - Also used in TV broadcast and receiver

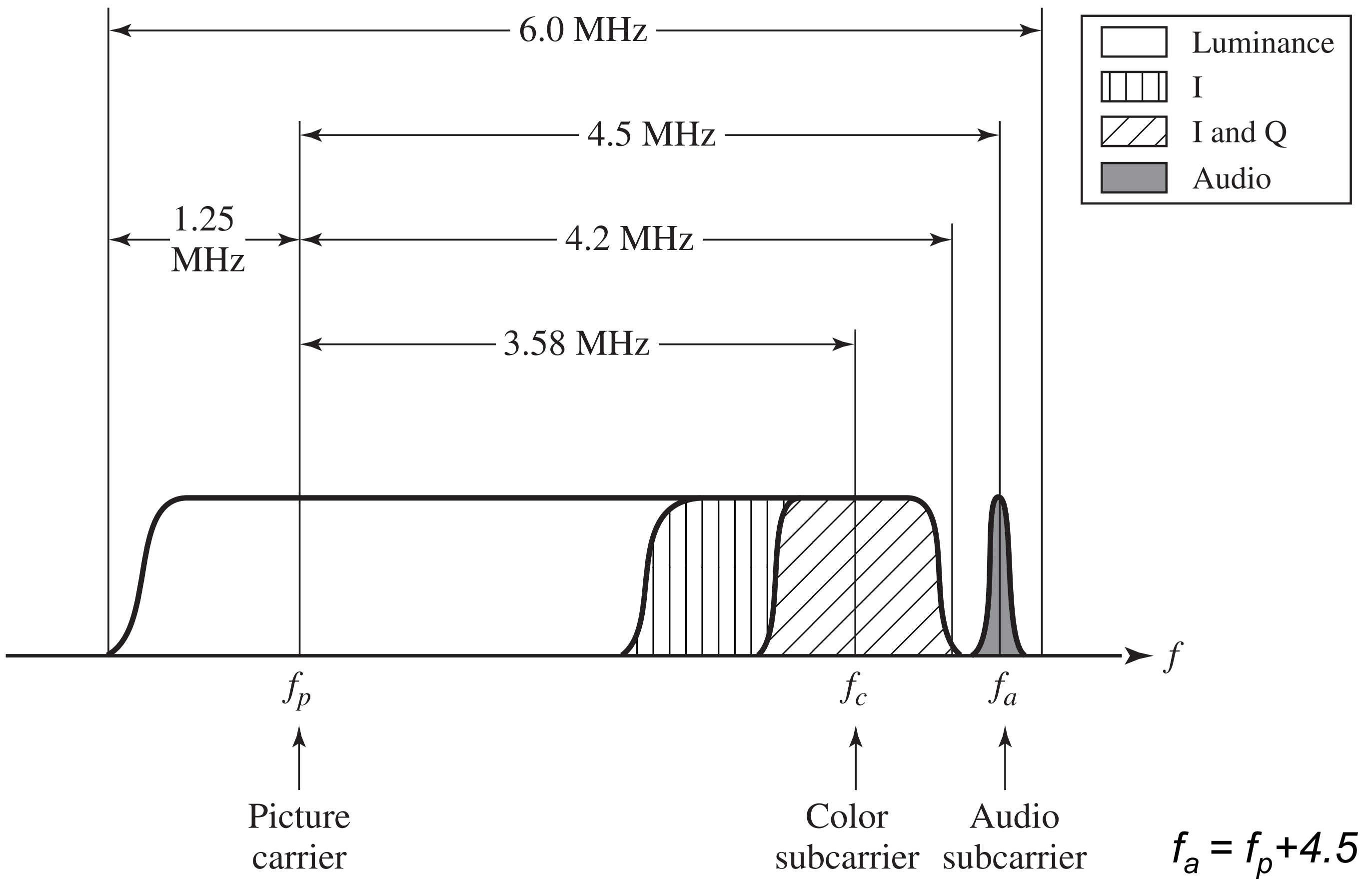
Other Modulation Methods

- Amplitude modulation $y(t) = x(t)\cos(2\pi f_c t + \theta_0)$
  - The amplitude of the carrier signal is controlled by the modulating signal
  - Pitfall of AM: channel noise can corrupt the amplitude easily.
- Frequency modulation $y(t) = \cos(\theta(t)), \dfrac{d\theta(t)}{dt} = 2\pi f_c t + k_f x(t)$
  - The frequency of the carrier signal is proportional to the modulating signal
- Phase modulation $y(t) = \cos(2\pi f_c t + \theta_0 + k_p x(t))$
  - The phase of the carrier signal is proportional to the modulating signal

Modulation Techniques Used in TV Broadcast

- Video signal is bandlimitted to 4.2 MHz
- Audio signal is bandlimitted to 100 KHz
- Audio and video are multiplexed into a single signal by modulating the audio signal to 4.5 MHz using frequency modulation, the combined signal has bandwidth 4.6 MHz
  - 200 KHz gap between video and audio to avoid interference
- The combined audio and video signal is then shifted to its carrier frequency f_c using VSB-C, retaining the upper side band up to 4.75 MHz, lower side band up to 1.25 MHz, totaling 6 MHz

Multiplexing of Multiple TV Channels



$f_a = f_p + 4.5$

For now, you can ignore the shaded parts corresponding to the chrominance components in color TV

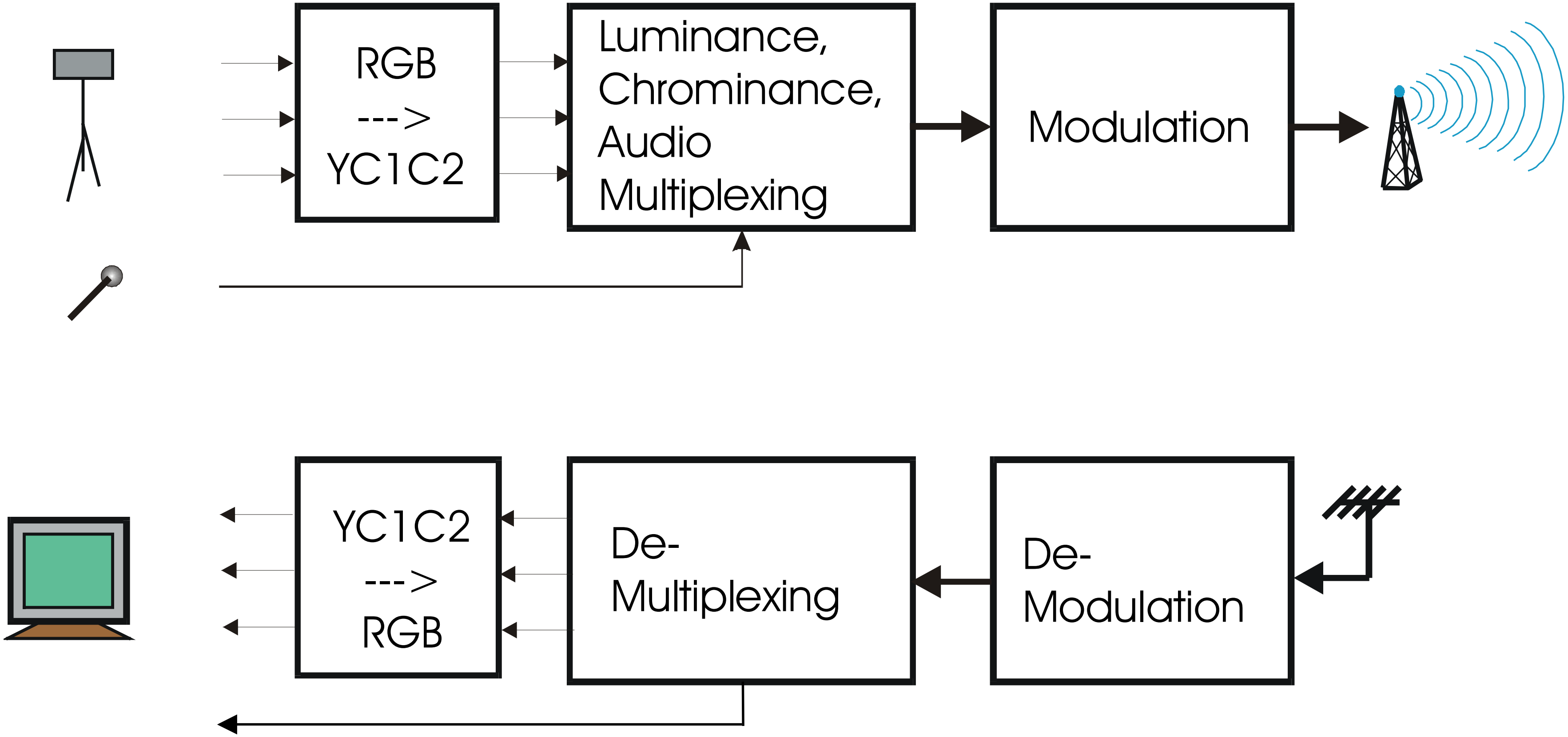
Terrestrial TV Channel Allocation in North America

- Each station is given 6 MHz
- VHF 2,3,4: 54-72
- VHF 5,6: 76-88
- VHF 7-13: 174 - 216 MHz
- UHF 14-83: 470 to 890 MHz
- In the same coverage area, only alternating channels can be used, leaving 6 MHz in between every two used channels, to avoid interference. These unused channels are called "taboo" channels

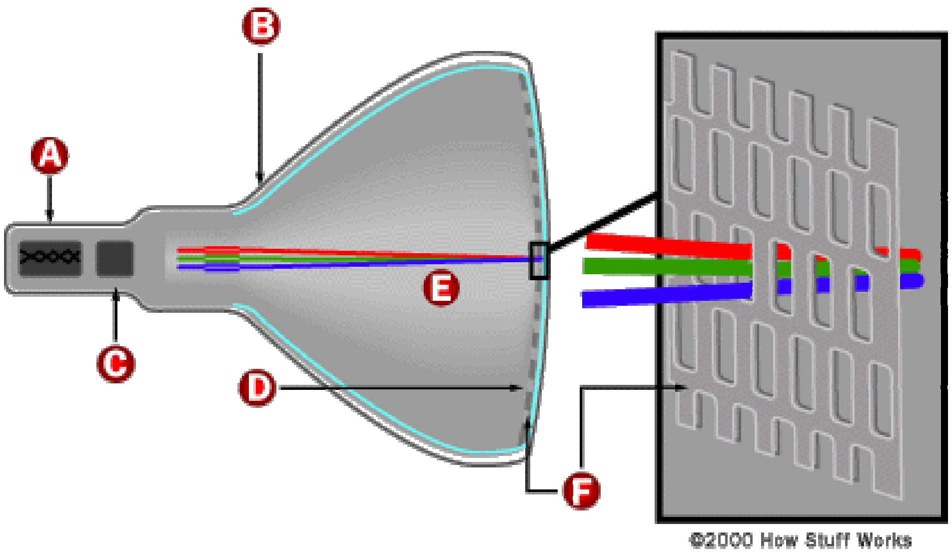
TV Receiver

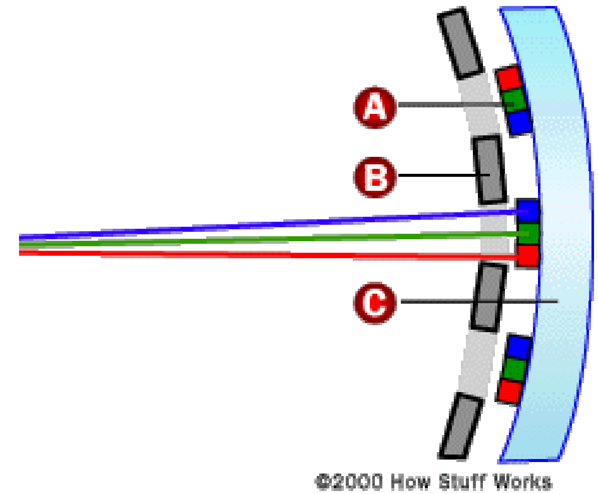
- How does your TV receives the broadcasted video over the air?
- Basic components in a TV receiver
  - Tuner to select the desired TV channel
    - VSB-C demodulation using superherodyne AM receiver
  - Separating audio and video
    - FM demodulation
  - Video display using CRT
  - Audio speaker

Basic Components in a TV Receiver



How Does the CRT Works?





A Cathode
B Conductive coating
C Anode
D Phosphor-coated screen
E Electron beams
F Shadow mask

http://www.howstuffworks.com/tv

What you should know

- How is a video represented? (What is a video raster)
- Why using interlacing?
- How to estimate the bandwidth of a raster video signal?
- What is the bandwidth of the NTSC video?
- How to multiplex audio and video into one signal?
- How to separate audio and video from the received signal
- What is the bandwidth of a NTSC TV channel?
- How to broadcast multiple TV signals over the air?
- What is the difference between DSB, SSB, and VSB?
- What is the difference modulation with suppressed carrier (SC) and with carrier (C)?
- How does your TV receiver tune to a particular station?
- What are the basic components in your TV

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