Lecture 6: Amplitude Modulation (QAM, SSB, VSB and Analog TV)

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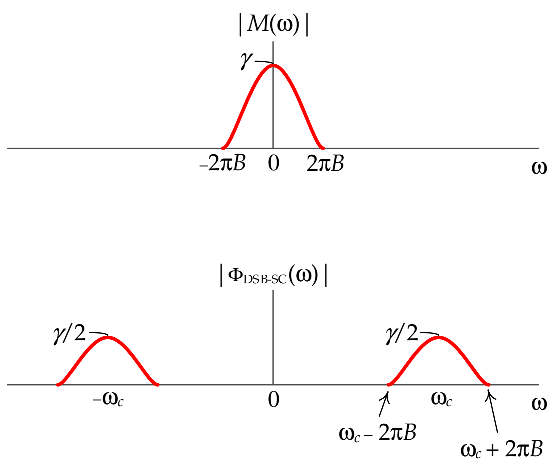
EE421: Communications I

Remember… DSB-SC



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Orthogonality

- Quadrature Amplitude Modulation (QAM) is similar to DSB-SC but uses two orthogonal carriers [$\sin(\omega_c t)$ & $\cos(\omega_c t)$].
- For the two signals to be orthogonal, we need:

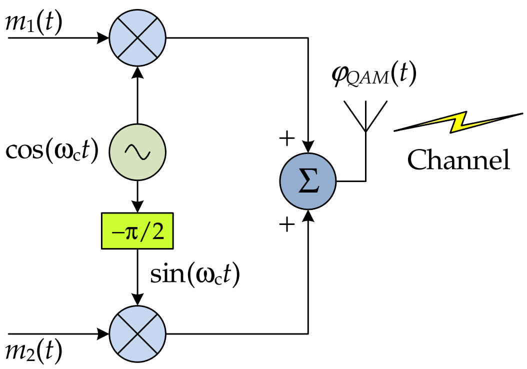
$$\overline{x(t) \cdot y(t)} = 0$$

- Do you know some examples of orthogonal signals?

Orthogonality is Popular

- In Modulation:
  - **QAM modulation** (sin/cos)
  - Used in DVB, Wi-Fi, WiMAX, 4G LTE, 5G
- In Multiplexing:
  - **OFDMA** (Multiple cosines)
  - Used in Wi-Fi, WiMAX, 4G LTE, 5G, etc
  - **CDMA** (Walsh codes, GOLD codes)
  - Used in 3G cellular telephony, etc

QAM (*Quadrature Amplitude Modulation*)



$$\phi_{QAM}(t) = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$$

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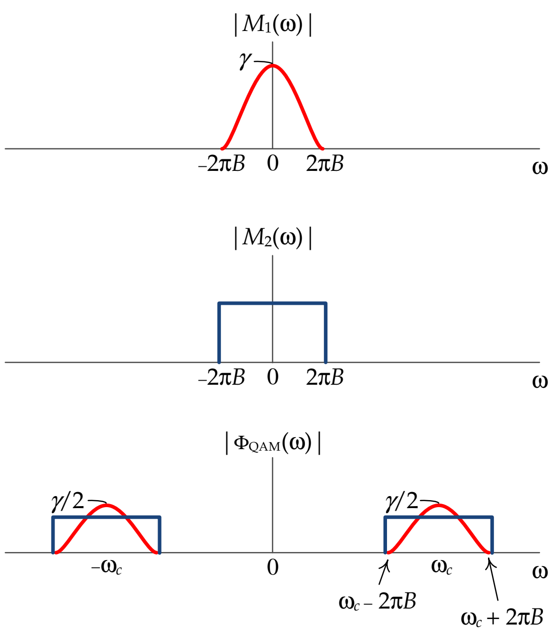

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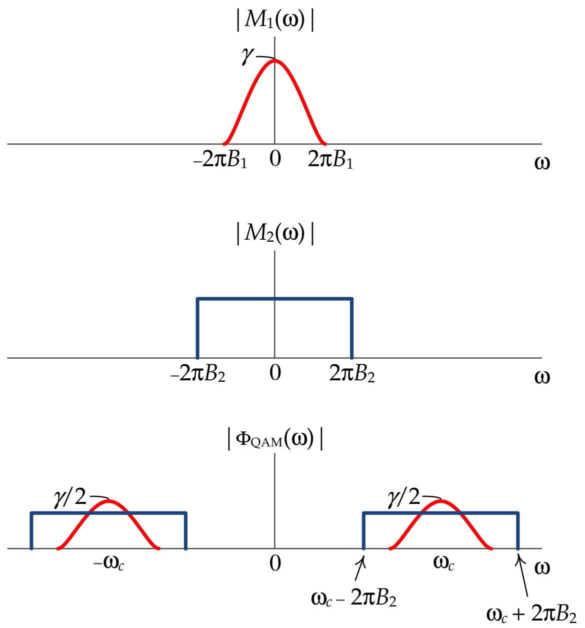
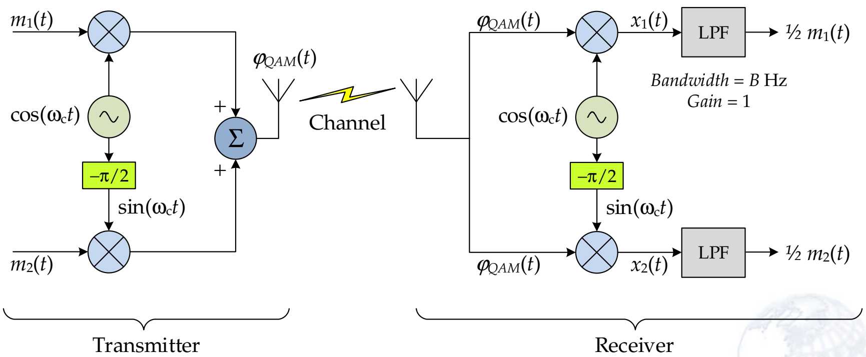


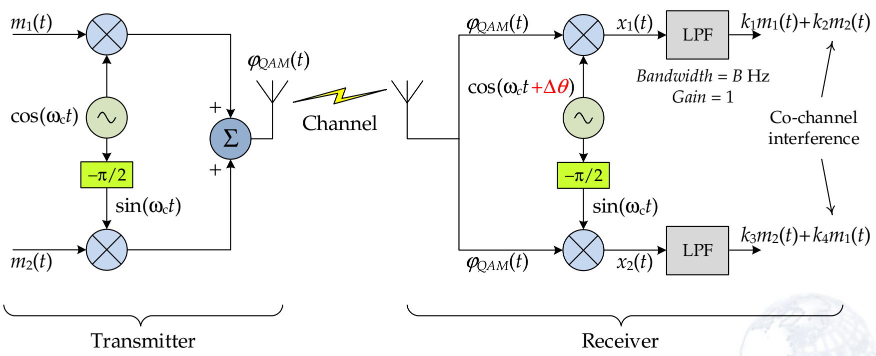
QAM Transmitter and Receiver



QAM vs. DSB-SC & DSB-LC

- **Advantages of QAM:**
  - QAM is more *bandwidth efficient* than DSB-SC, allowing us to send two signals on the same channel (of bandwidth 2*B*).
  - QAM has more *power efficient* TX than DSB-LC.
- **Disadvantages of QAM:**
  - Only synchronous demodulation is possible (cannot use the cheaper Asynchronous detector).
  - When synchronous detection is used for QAM with errors in synchronization, attenuation, distortion and **co-channel interference** show up.

Homework: P.4.4-1



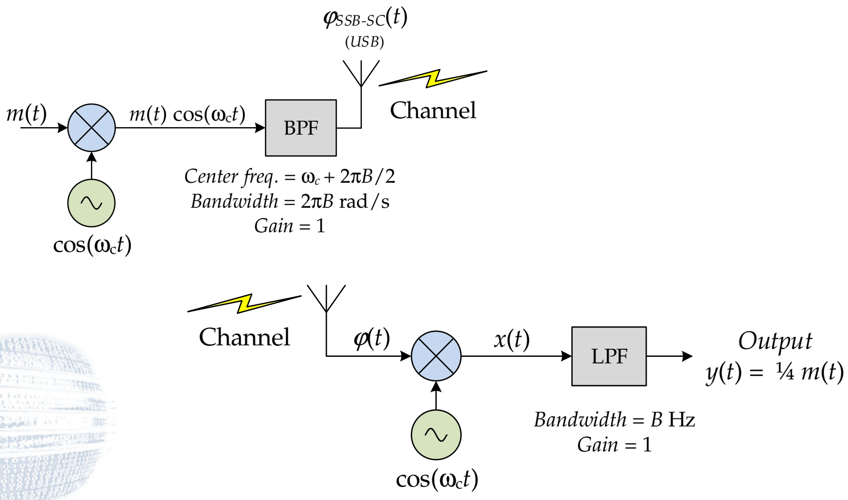
Applications

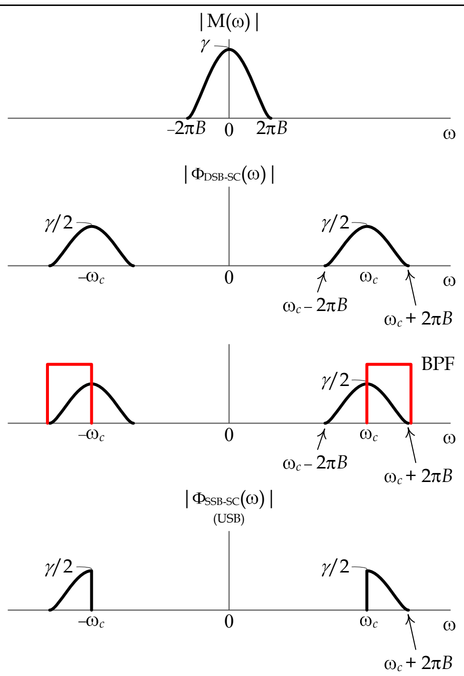
- Analog QAM is used to carry *chrominance* (color) information in Analog TV broadcasting.
- Digital QAM (to be discussed later) is very popular nowadays: DVB, DAB, Wi-Fi, WiMAX, 4G, 5G, ADSL, etc.
- DSB-SC is used in analog instrumentation, and as part of multiplexing in Stereo FM broadcasting.

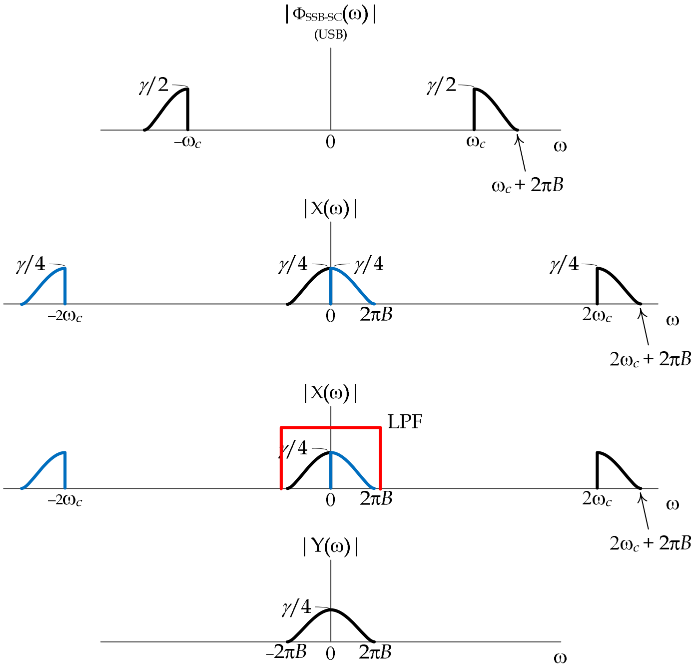
Single Sideband (SSB) Modulation

- Send one signal within bandwidth B.
- SSB Types:
  - **SSB-SC (USB)**: Single Sideband-Suppressed Carrier, Upper Sideband
  - **SSB-SC (LSB)**: Single Sideband-Suppressed Carrier, Lower Sideband
  - **SSB-LC (USB) or SSB+C (USB)** : Large Carrier *or* Plus Extra Carrier, Upper Sideband
  - **SSB-LC (LSB) or SSB+C (LSB)** : Large Carrier *or* Plus Extra Carrier, Lower Sideband

SSB-SC (USB) Modulation







SSB-SC vs. DSB-SC

- **Advantages of SSB-SC:**
  - SSB-SC has smaller *bandwidth* compared to DSB-SC, allowing us to send one signal on a channel of bandwidth B (instead of one signal over a bandwidth of $2B$ for DSB-SC).
- **Disadvantages of SSB-SC :**
  - The transmitter requires *very sharp* (almost ideal) BPF, which is expensive and difficult to build.

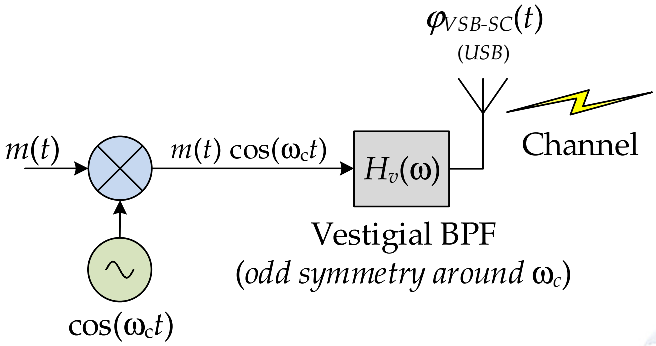
SSB-SC vs. QAM

- **Advantages of SSB-SC:**
  - SSB-SC has same *bandwidth efficiency* as QAM.
  - SSB-SC bandwidth is smaller than QAM. Smaller bandwidth means more immunity to frequency-selective fading.
  - In case of synchronization errors, SSB-SC suffers less attenuation and distortion compared to QAM.
- **Disadvantages of SSB-SC :**
  - The transmitter requires *very sharp* (almost ideal) BPF, which is expensive and difficult to build.

Summary

Bandwidth	Average Power
$B_{DSB-SC} = 2B$	$\overline{\varphi^2_{DSB-SC}(t)} = \frac{1}{2}\overline{m^2(t)}$
$B_{QAM} = 2B$	$\overline{\varphi^2_{QAM}(t)} =$ _____
$B_{SSB-SC} = B$	$\overline{\varphi^2_{SSB-SC}(t)} =$ _____
DSB-SC	$\overline{v_o^2(t)} =$ _____
SSB-SC	$\overline{v_o^2(t)} =$ _____

VSB-SC (USB) Transmitter



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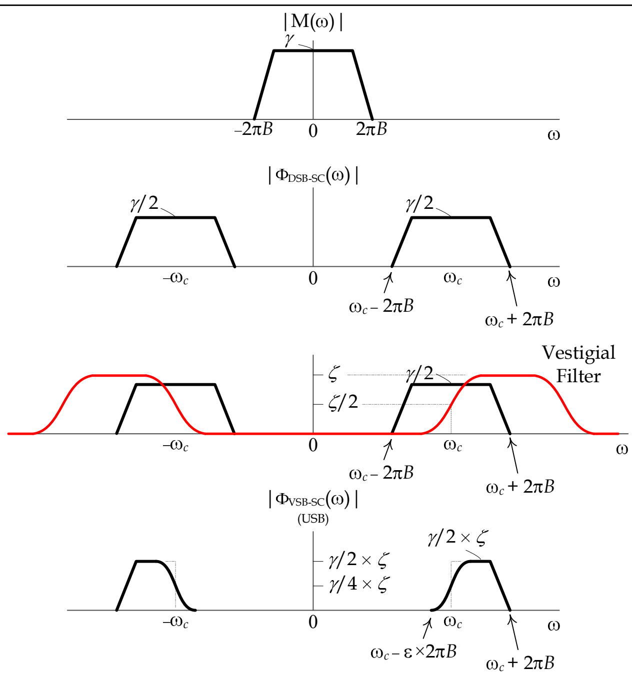

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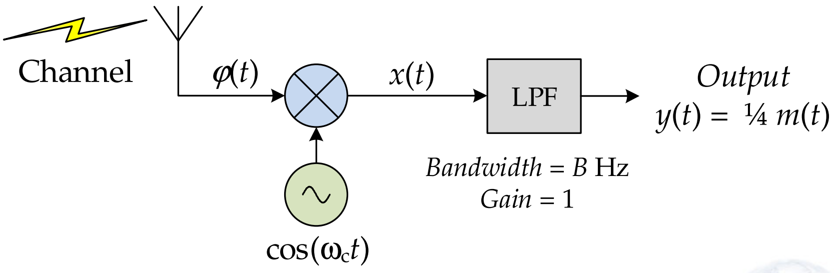
VSB-SC (USB) Receiver



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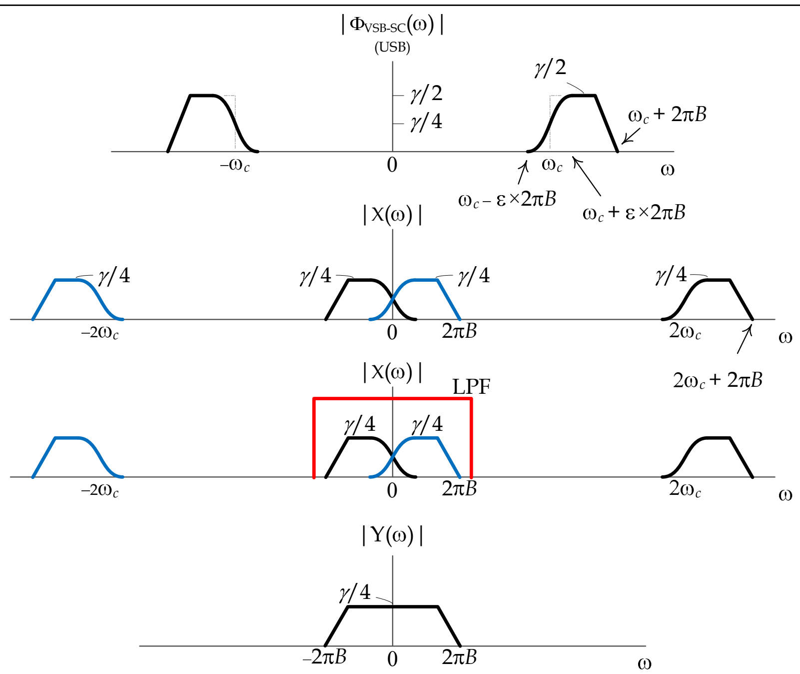

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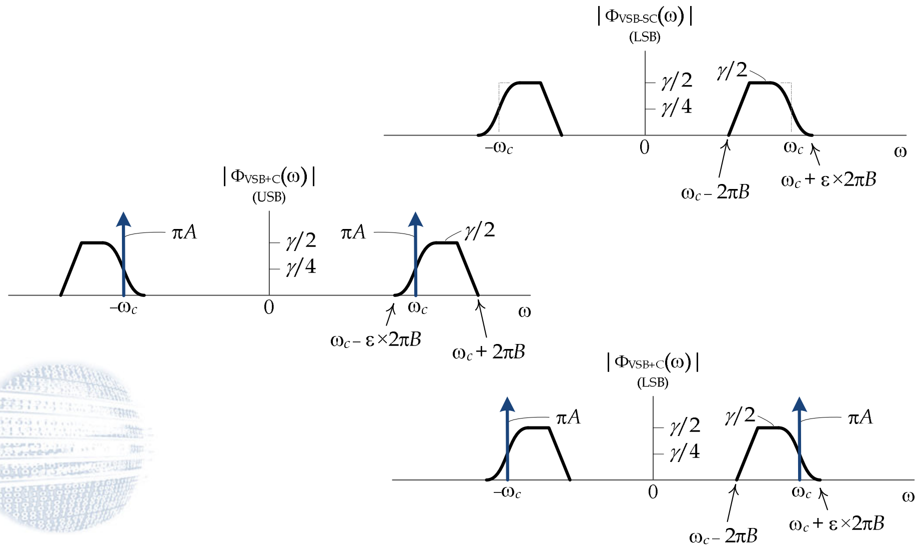
VSB-SC (LSB), VSB+C (USB), VSB+C (LSB)



VSB

- **Advantages of VSB:**
  - Simple to generate (no need for sharp filters).
  - Can vary the VSB filter bandwidth (flexibility).
  - VSB transmission bandwidth is smaller than DSB (i.e., which reduces channel cost).
  - Smaller bandwidth means more immunity to frequency-selective fading compared to DSB.
  - In case of synchronization errors, VSB-SC suffers less attenuation and distortion compared to DSB-SC.

VSB

- **Disadvantages of VSB:**
  - VSB bandwidth is slightly higher than SSB.
  - VSB-SC require synchronous detection.
  - VSB+C (which allows asynchronous detection) is less power efficient compared to DSB-LC (since we need $A \gg -m(t)_{\min}$).
- **Applications:**
  - VSB+C is used to send luminance (B & W) information in Analog TV broadcasting.
  - VSB-SC is used in facsimile (fax) machines.

Summary

- QAM
  - Bandwidth is $2B$ (but we send two signals)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{2}\overline{m_1^2(t)} + \frac{1}{2}\overline{m_2^2(t)}$
- SSB-SC (USB or LSB)
  - Bandwidth is B (one signal)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{4}\overline{m^2(t)}$
- VSB-SC (USB or LSB)
  - Bandwidth is $(1 + \epsilon)B$ (one signal)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{4}\overline{m^2(t)}$

Analog Television Standards

	U.S. Standard	European Standard
Analog TV	***NTSC:*** *National Television System Committee* *(VSB+C, QAM, FM; FDM)*	***PAL:*** *Phase Alternating Line* *(VSB+C, QAM, FM; FDM)*
Digital TV	***ATSC:*** *Advanced Television System Committee* *(MPEG-2; VSB-8 or QAM; TDM+FDM)*	***DVB-T, DVB-S, DVB-S2, ...:*** *Digital Video Broadcasting* *(MPEG-2; QPSK, QAM; TDM+FDM)*

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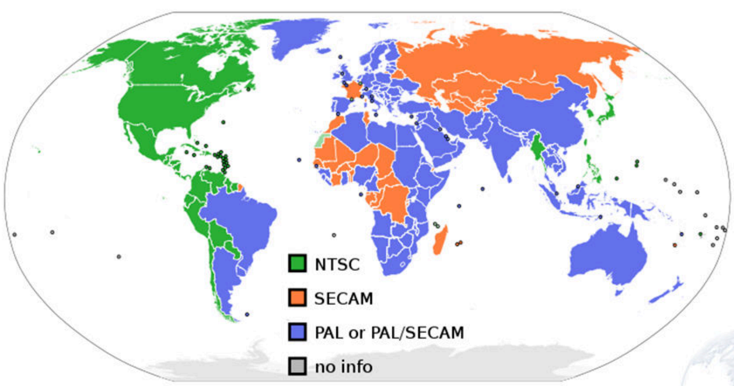
Analog Television (PAL/NTSC)



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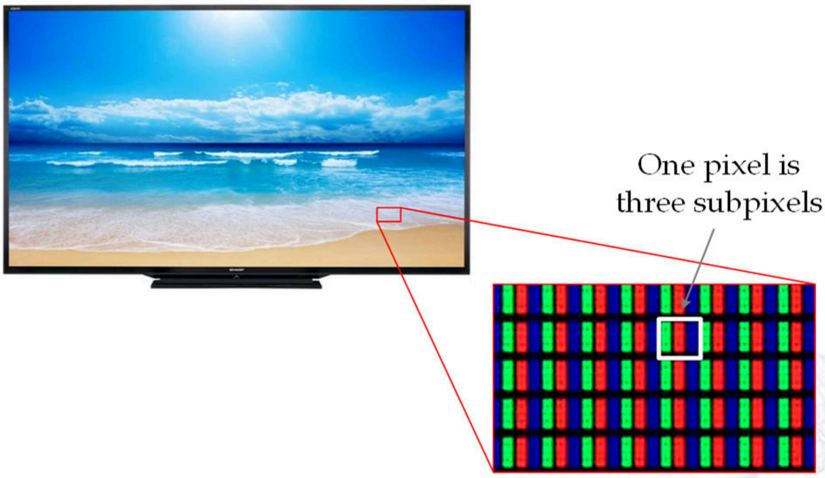
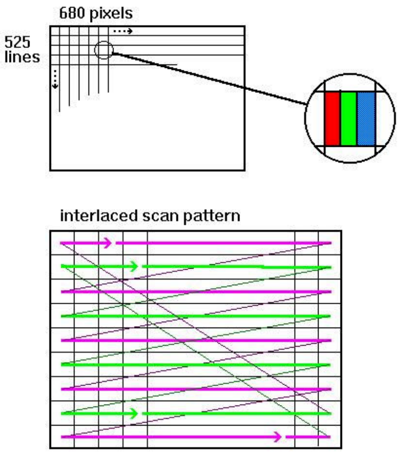
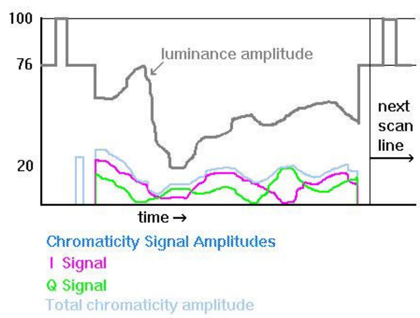
Television and Pixels

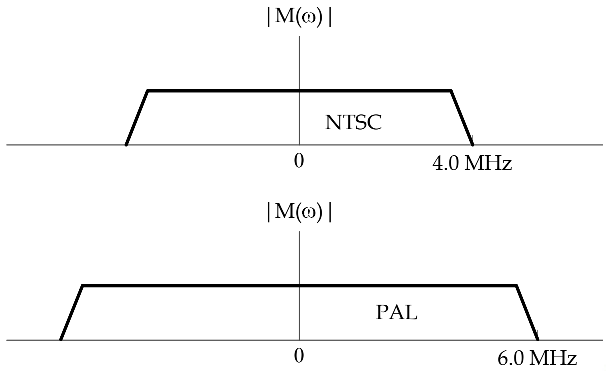


Scanning Lines and Resolution





Analog Television (PAL/NTSC)



Standard Definition (SDTV)

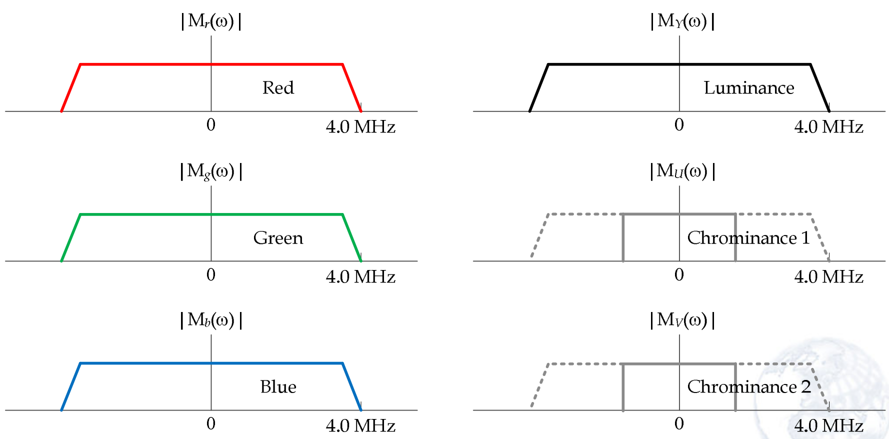
Resolution		Aspect ratio	Pixel shape	Form of scanning	Frame Rate (Hz)
Vertical	*Horizontal*				
480	640	4:3	square	interlaced	30 (60 fields/s)
				progressive	24 30 60
	704	4:3 or 16:9	non-square	interlaced	30 (60 fields/s)
				progressive	24 30 60

- Many other profiles and frame rates are supported by ATSC and DVB, but the above are the most popular and the most likely to be supported by a digital TV set (monitor). The monitor profile name is called 480i and 480p.

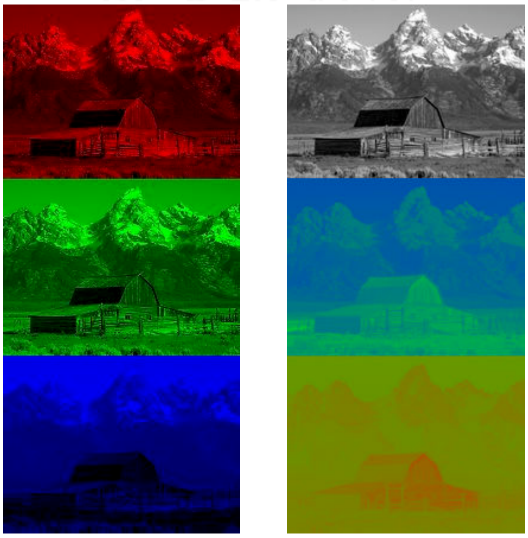
High Definition (HDTV)

Resolution		Aspect ratio	Pixel shape	Form of scanning	Frame Rate (Hz)
Vertical	*Horizontal*				
720	1280	16:9	square	progressive	24 30 60
1080	1920	16:9	square	interlaced	25 (50 fields/s) 30 (60 fields/s)
				progressive	24 25 30
2160	3840	16:9	square	progressive	30 60 120

Luminance & Chrominance



RGB to YUV



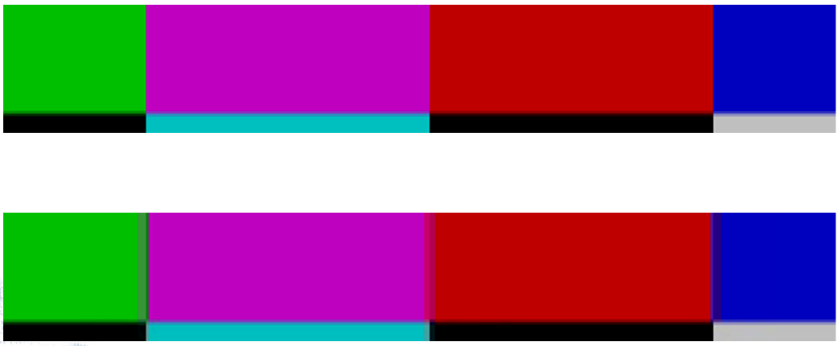
RGB to YUV Transformation

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

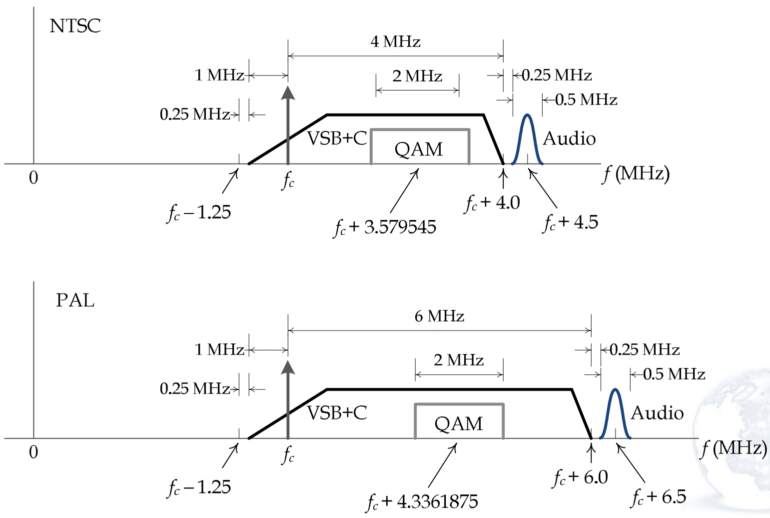
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}$$

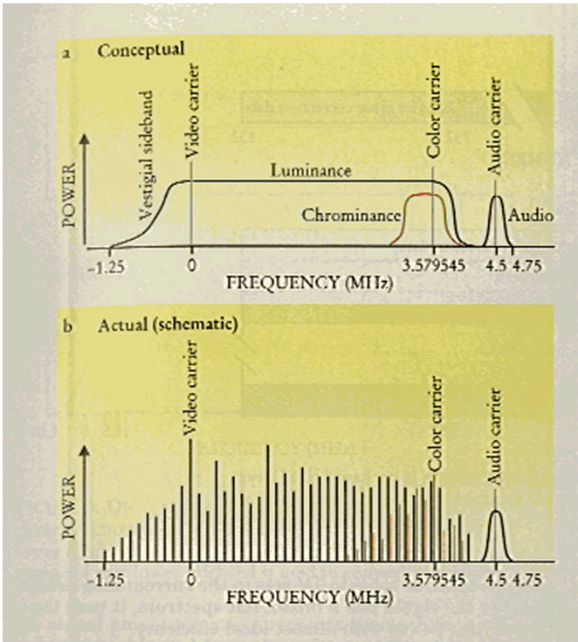
See *http://en.wikipedia.org/wiki/YUV* for mode details.

Noticeable only in sharp images



Analog TV(VSB+C & FM & QAM)





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