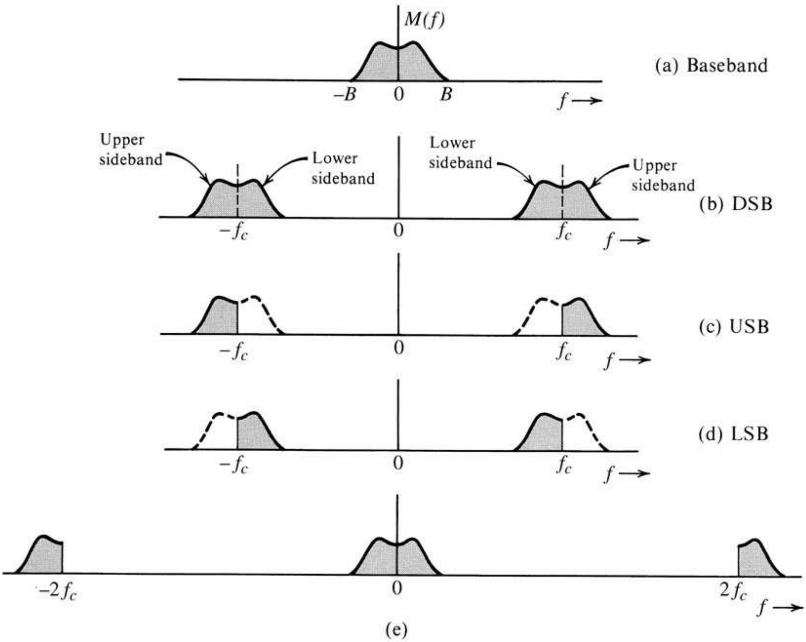
# Amplitude Modulation, II

- Single sideband modulation (SSB)
- Vestigial sideband modulation (VSB)
  - VSB spectrum
  - Modulator and demodulator
  - NTSC TV signsals
- Quadrature modulation
  - Spectral efficiency
  - Modulator and demodulator

# Single Sideband (SSB) in Frequency Domain



# SSB in Time Domain (review)

The upper sideband is the output of filtering signal $m(t)$ with an ideal single sideband filter:

$$H_{\mathrm{USB}}(f) = \begin{cases} 1 & 0 \le |f| \le B \\ 0 & \text{otherwise} \end{cases}$$

The modulated signal at carrier frequency of $f_c$ can be constructed by

$$m_{\mathrm{USB}}(t) = m(t)\cos\omega_c t \,\pm\, m_h(t)\sin\omega_c t\,,$$

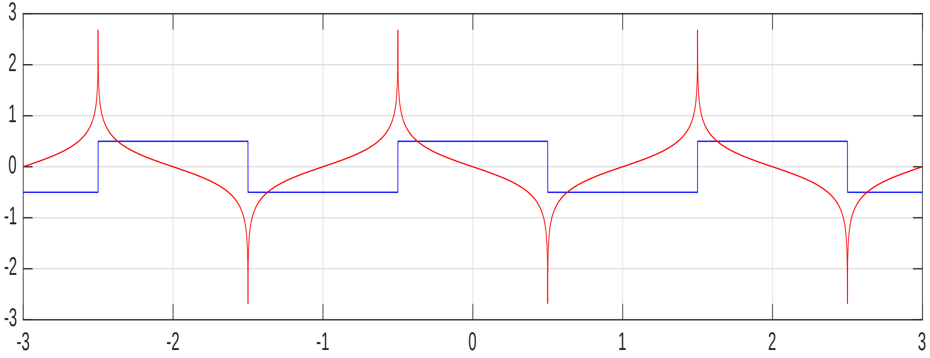
where $m(t)$ is the original real message signal, and

$$m_h(t) = m(t) * \frac{1}{\pi t}$$

is the Hilbert transform of $m(t)$.

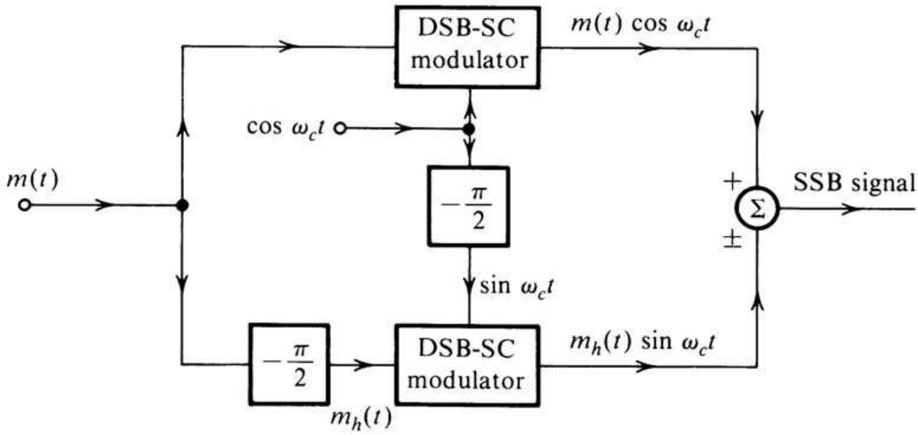
# Hilbert Transform of Square Wave

$$\mathcal{H}\left(\sum_{k=-\infty}^{\infty} \Pi(t-2k)\right) = \sum_{k=-\infty}^{\infty} \mathcal{H}\big(\Pi(t-2k)\big)$$
$$= \frac{1}{\pi}\sum_{k=-\infty}^{\infty} \ln\left|\frac{x-2k-\frac{1}{2}}{x-2k+\frac{1}{2}}\right|.$$



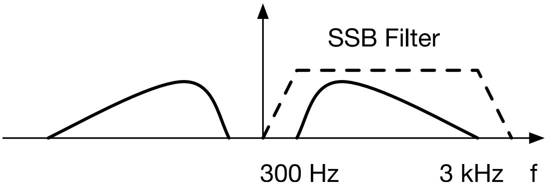
# SSB Modulation

The phase shifters perform the Hilbert transform. Note that all the signals are real valued.



# Vestigial Sideband Modulation (VSB)

- SSB relies on being able to filter out one sideband. For audio this is possible because the voice spectrum drops off below 300 Hz, allowing space for a transition band.




- This is not possible for other signals, like video, that have strong components at low frequencies.

- The solution is *Vestigial Sideband Modulation* (VSB): a small portion (a "vestige") of the unneeded sideband is used. This reduces DC distortion.

# Vestigial Sideband Modulation (cont.)

- VSB signals are generated using standard AM or DSB-SC modulation, then passing modulated signal through a sideband shaping filter.

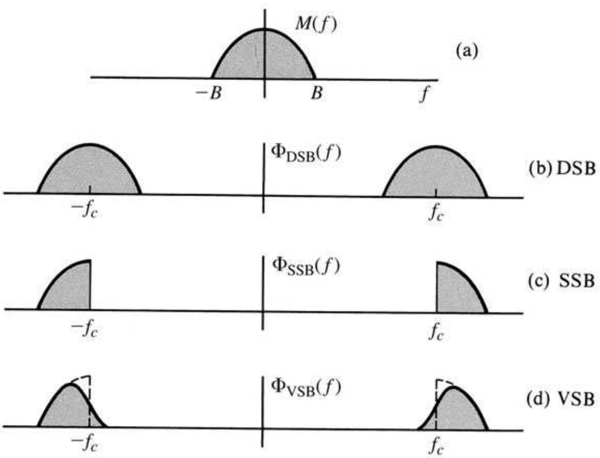
- Demodulation uses either standard AM or DSB-SC demodulation, depending on whether a carrier tone is transmitted.

- VSB modulation with envelope detection is used to modulate image in analog TV signals. (The audio signal is modulated using FM.)

# VSB Spectrum

In vestigial sideband, part of the lower sideband is retained.

A nonideal bandbass filter is used to cut off the lower sideband gradually.

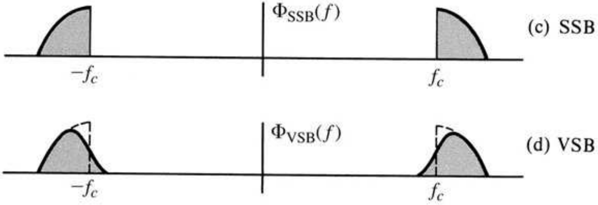


# VSB Modulator

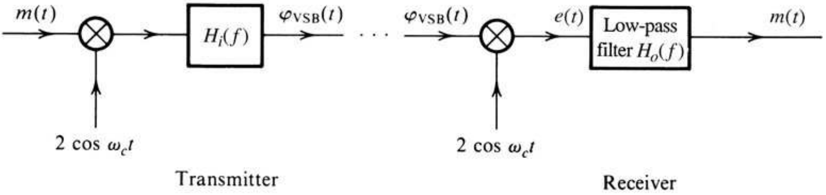
The transmitted signal has spectrum

$$\Phi_{\text{VSB}}(f) = \big(M(f+f_c) + M(f-f_c)\big)H_i(f)$$

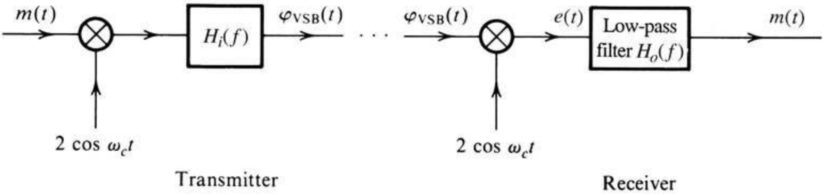
where $H_i(f)$ is the *shaping filter* for the VSB modulator.




Modulator and demodulator:



# VSB Demodulator




The intermediate demodulator signal

$$e(t) = \phi_{\mathrm{VSB}}(t) \cdot 2\cos\omega_c t$$

has spectrum

$$\Phi_{\mathrm{VSB}}(f+f_c) + \Phi_{\mathrm{VSB}}(f-f_c)$$

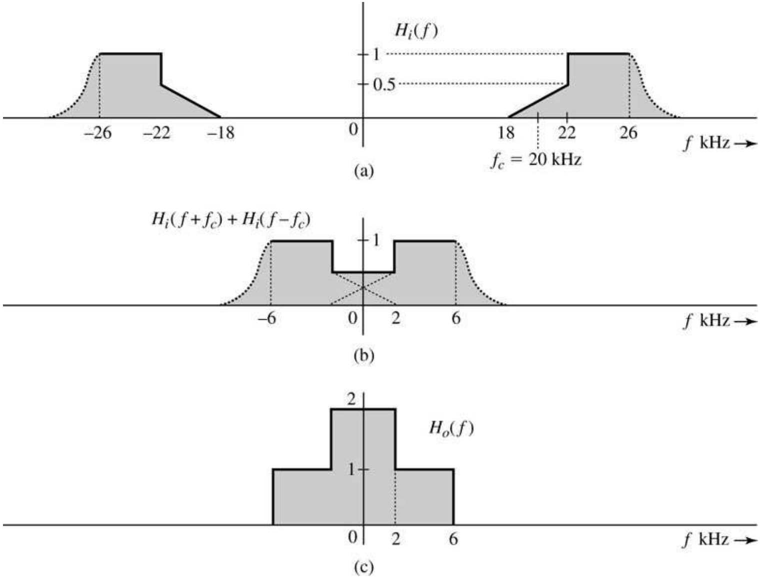
We can recover $m(t)$ by using a filter $H_o(f)$ defined by

$$H_o(f) = \frac{1}{H_i(f+f_c) + H_i(f-f_c)}, \quad |f| \le B$$

This is a low-pass filter that is the inverse of $H_i(f)$ when $|f| \le B$.

# VSB Demodulation Filter

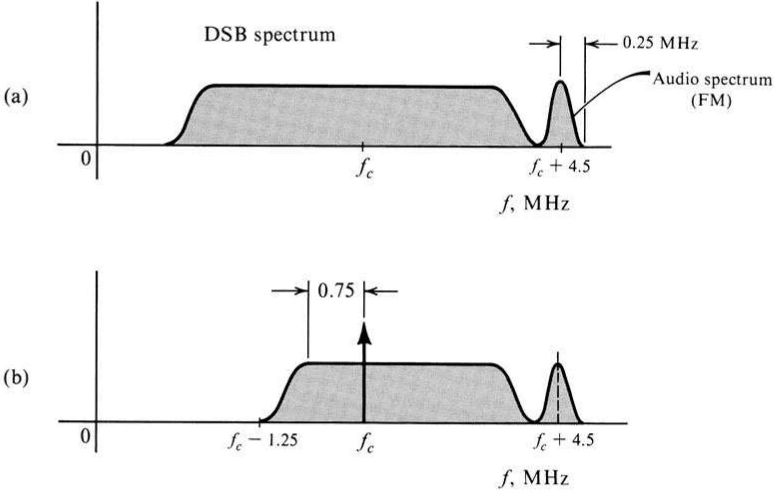
Surprisingly, $H_o(f)$ is *not* large for small values of $f$.



# VSB Example: US TV NTSC

Using VSB instead of DSB saves about 3 MHz and allows a carrier tone.

The shaping filter satisfies $H_i(f - f_c) + H_i(f + f_c) = c$, so $H_o(f) = 1/c$.



# Quadrature Amplitude Modulation (QAM)

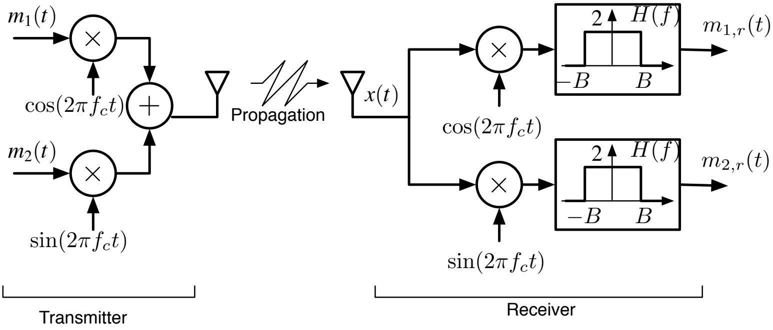
- DSB-SC modulates a signal with bandwidth $B$ to a transmitted signal with bandwidth $2B$
- SSB reduces the transmitted bandwidth to $B$, but
  - requires more complex modulator
  - reduces SNR (for a fixed carrier amplitude)
- Quadrature amplitude modulation uses the $2B$ transmitter bandwidth to send two independent signals:

$$m_{QAM,c}(t) = m_1(t)\cos(2\pi f_c t) + m_2(t)\sin(2\pi f_c t)$$

- QAM has the same *spectral efficiency* as SSB but does not need sharp bandpass filters
- QAM is used in almost all digital communication methods, including telephone modems, cable TV, satellite TV

# QAM Modulator and Demodulator

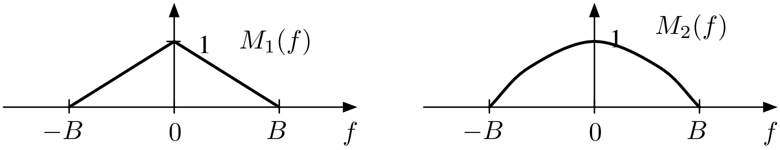
Two real messages, $m_1(t)$ and $m_2(t)$. $m_1$ is modulated on a cosine, and $m_2(t)$



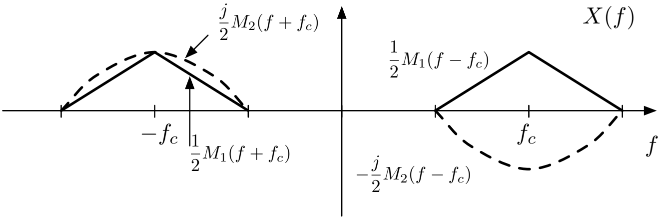

Note that we need a synchronous receiver, or the two channels will interfere. What happens with a $90^\circ$ phase shift?

# QAM Modulator and Demodulator (cont.)

If the input spectra look like




then the transmitted spectrum looks like




Demodulating with a cosine results in $M_1(t)$ at baseband, while demodulating with a sine yields $M_2(t)$.

# AM Modulation Summary

- Many different ways to encode information as amplitude
  - AM
  - DSB-SC AM
  - SSB
  - VSB
  - QAM
- Common issues
  - Synchronization
  - Bandwidth
- Next: encoding information in frequency (FM, PM)