Single-Sideband Modulation

Tomasi, Chapter

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Why SSB?

- DSBFC AM is wasteful
  - Inefficient spectrum utilization
    - Bandwidth is 2x what it needs to be
  - Inefficient power utilization
    - Message is only (at most) 1/3 of total power

- Solution?
  - Filter out one sideband and carrier
    - Solves bandwidth issue (but requires filters with high Q and high SF)
    - Power is still wasted
  - Generate only one sideband and low (or no) carrier signal

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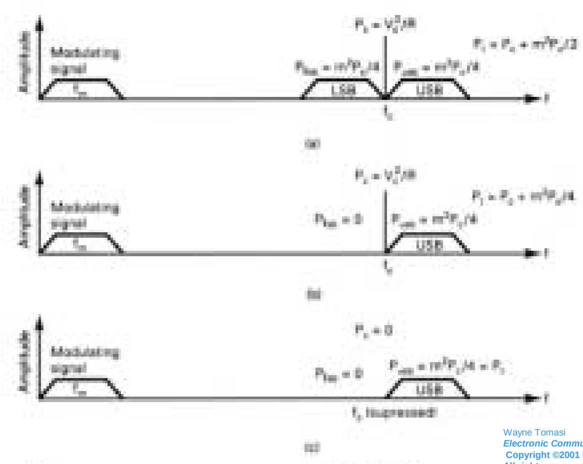
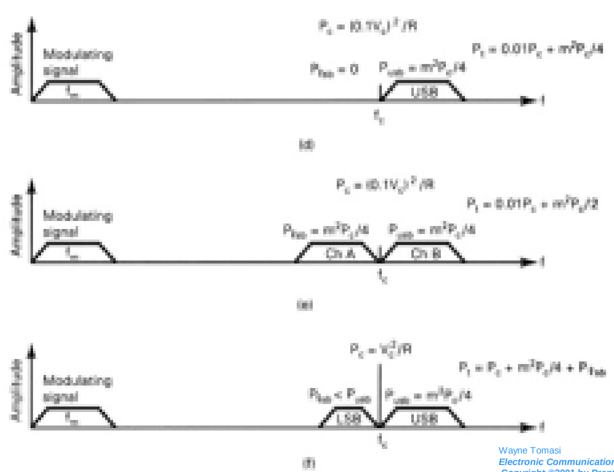
SSB Variations



- **FIGURE 5-1 Single-sideband systems:**
  - **(a) conventional DSBFC AM;**
  - **(b) full-carrier single sideband (SSBFC AM);**
  - **(c) suppressed-carrier single sideband (SSBSC AM);**

SSB Variations

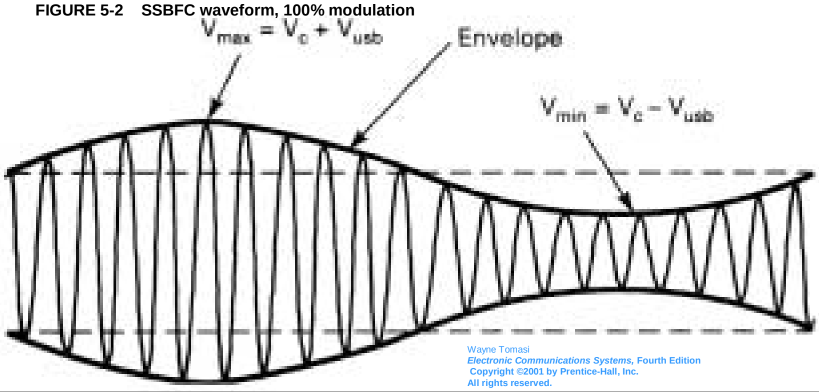


- **FIGURE 5-1 Single-sideband systems:**
  - **(d) reduced-carrier single sideband (SSBRC AM);**
  - **(e) independent sideband (ISB AM);**
  - **(f) vestigial sideband (VSB AM)**

SSBFC in Time-Domain

- m = 1 as shown
- Trough does not reach time axis
- Peak change is ½ that of DSBFC AM
- Same waveform as 50% DSBFC AM
- Info is in envelope

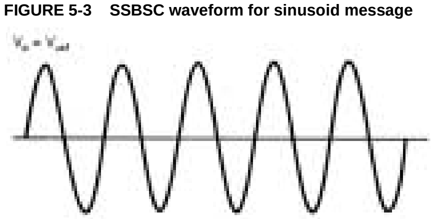
FIGURE 5-2 SSBFC waveform, 100% modulation



SSBSC

- Carrier totally suppressed; only one sideband generated
- Message is 100% of transmitted power
- Message is not in envelope
- Waveform = sinusoid @ $fc+f_m$ (for USB); actually is an FM signal

FIGURE 5-3 SSBSC waveform for sinusoid message



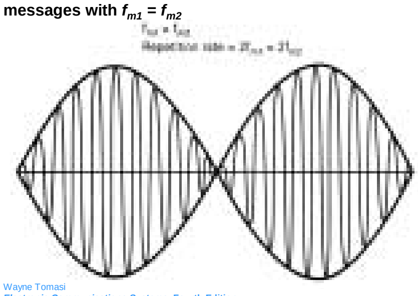
SSBRC AM

- **Single sideband with reduced carrier**
- **Carrier is ~10% is unmodulated amplitude** **(up to 96% of power is sideband message)**
- **Often called *SSB with reinserted carrier***
- **Reinserted carrier may be called *pilot tone* (used for demodulation)**
  - **Carrier separated amplified (to make $V_C \geq V_m$) and reinserted to make DSBFC AM at receiver**

ISB AM

- **Single carrier modulated by two independent messages**
- **Equivalent to two SSBSC signals that are combined and (suppressed) carrier reinserted**
- **Used in US for stereo AM**
- **Time-domain: waveform with f_{m1} and f_{m2} sinusoids**

FIGURE 5-4 ISB waveform when sinusoid messages with $f_{m1} = f_{m2}$



To plot waveform:
1) Sketch spectrum
2) Use Excel to add sinusoids

VSB AM

- Vestigial sideband AM
- Like DSBFC but only part of second sideband is transmitted
- Lower f_m's transmitted DSB (can have *m* up to 100%); higher f_m's transmitted SSB (can have *m* up to 50% max)
- Emphasizes low frequencies of message
- Used in US broadcast TV picture transmission

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Comparison of Three Common AM Time-Domain Waveforms

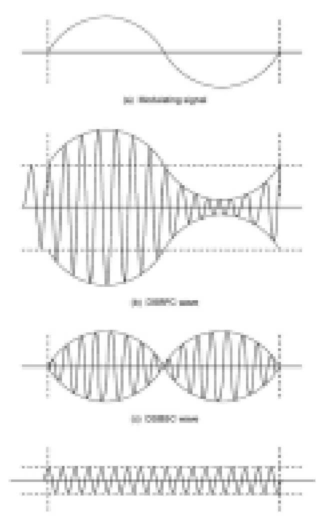
- FIGURE 5-5 Comparison of three AM transmission systems

  a) Modulating signal (single-frequency sinusoid)

  b) DSBFC wave: info in envelope, envelope *f* follows f_m

  c) DSBSC wave: information in envelope, envelope *f* is 2x f_m

  d) SSBSC wave: No info in envelope, signal is at f_c+f_m



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DSBFC AM vs. SSBSC AM

- DSBFC AM
  - *@ m = 1*: $P_t = 1.5P_c$, P_m = 1/3 P_t
- SSBSC AM
  - *@ m=1*: $P_m = P_t$
  - **Produces same message power at receiver with 1/3 the power and half the bandwidth**

Not used in EO3502:

PEP (peak envelope power) is the RMS signal power developed when message signal is at its maximum amplitudes

PEV (peak envelope voltage) is the RMS signal voltage developed when message signal is at its maximum amplitudes

Phasor representation of voltages

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Summary of SSB Pros and Cons

- **Pros:**
  - **Power conservation: more transmitter power in message** (up to 100%)
    - **For fixed transmitter power, can have up to 3x more power in message** (4.8 dB improvement in message power)
  - **Spectrum conservation: half the spectral width**
    - **Less noise in receiver since "*B*" will be –3 dB smaller in noise calculation**

    SNR now improved by 4.8 + 3 = 7.8 dB
  - **Less susceptible to "selective fading": multipath has different attenuations for different frequencies. less bandwidth lowers susceptibility**
- **Cons**
  - **More complex receiver needed**
    - **Better filters**
    - **Cannot use envelope detectors**
    - **Need to generate a carrier frequency signal locally** (local oscillator) **the is frequency locked to transmitter** (crystal controlled oscillator; phase-locked loop)
    - **Complicated tuners** (lots of tweaking; less of an issue with digital tuners)

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The Equations of SSB

- **Modulating sinusoid message**

$$v_m(t) = E_m \sin(2\pi f_m t) = mE_c \sin(2\pi f_m t)$$

- **Carrier**

$$v_c(t) = E_c \sin(2\pi f_c t)$$

- **DSBFC AM**

$$v_{am}(t) = \left[1 + \underbrace{m\sin(2\pi f_m t)}_{\text{message}} \right] \underbrace{E_c \sin(2\pi f_c t)}_{\text{carrier}}$$

DSBFC: Add dc to message & multiply

DSBSC: Just multiply

- **DSBSC AM**

$$v_{\text{DSBAM}}(t) = \left[\underbrace{m\sin(2\pi f_m t)}_{\text{message}} \right] \underbrace{E_c \sin(2\pi f_c t)}_{\text{carrier}}$$

$$= \underbrace{-\frac{mE_c}{2}\cos[2\pi(f_c + f_m)t]}_{\text{Upper sideband}} + \underbrace{\frac{mE_c}{2}\cos[2\pi(f_c - f_m)t]}_{\text{Lower sideband}}$$

Note: No carrier!

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SSB Modulation Techniques

- **Need…**
  - **Multiplier** **("balanced modulators")**
    - **EO3502: assume availability** **(pp. 197-204)**
  - **Filters** **(to remove spurious frequencies and remove sidebands)**

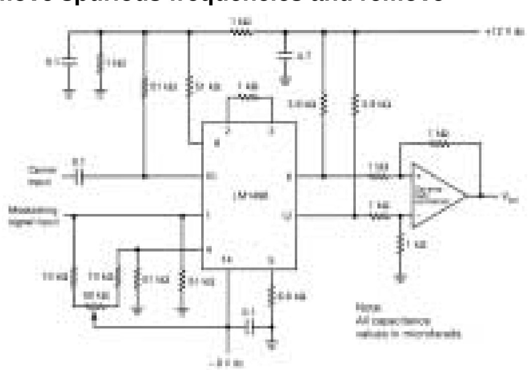

FIGURE 5-12 **AM DSBSC modulator using the LM1496/1596 linear integrated circuit (From Tomasi, 2001, © all rights reserved.)**

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SSB Transmitter w Filters

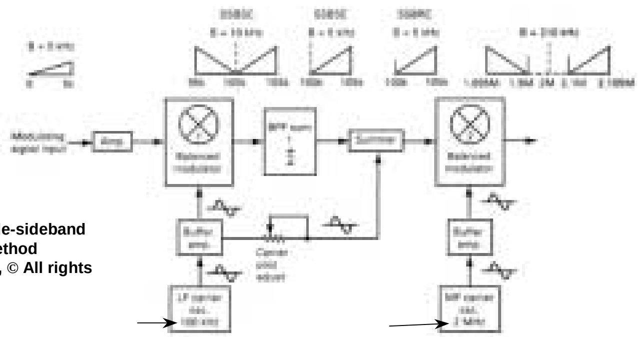

FIGURE 5-13 Single-sideband transmitter: filter method (From Tomasi, 2001, © All rights reserved.)

- **3 stages of frequency conversion** (2 “intermediate frequencies”)
- **Balanced modulator multiplier #1** (upshift to 100 kHz; the 1st intermediate frequency, “*1st IF*”)
- **Bandpass filter #1 to pass USB**
- **Reinsert suppressed carrier at 100 kHz** (if desired, optional)
- **Balanced modulator multiplier #2** (upshift to 2 MHz, the *2nd IF*)

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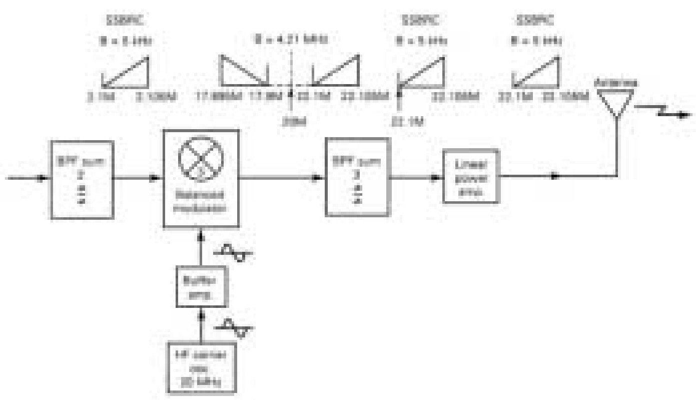
SSB Transmitter w Filters (cont.)



- **Bandpass filter #2 to pass USB**
- **Balanced modulator multiplier #3** (upshift to 20 MHz, the “*transmission frequency*”)
- **Bandpass filter #3 to pass USB** (w reinserted carrier)
- **Power amp and antenna; broadcast at 22.1025 MHz (±2.5 kHz)**

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Filter Requirements

- BPF #1: f_c = 102.5 kHz, B_{filter} = 5 kHz ⇒ Q = 20.5, band separation = 0 Hz
- BPF #2: f_c = 2.1025 MHz, B_{filter} = 5 kHz ⇒ Q = 420.5,, band separation = 200 kHz
- BPF #3: f_c = 22.1025 MHz, B_{filter} = 5 kHz ⇒ Q = 4,420, band separation = 2.2 MHz

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Single Upshift Transmitter

- One multiplier, one filter
- BPF requirements:
  - f_c = 22.1025 MHz
  - B_{filter} = 5 kHz ⇒ Q = 20.5
  - Band separation = 0 Hz
    - Need a high-SF filter combined with a high-Q!
- Multiple channels = multiple broadcast frequencies
  - B_{filter} of fixed-Q filter changes with f_{center}
  - Need to compromise design

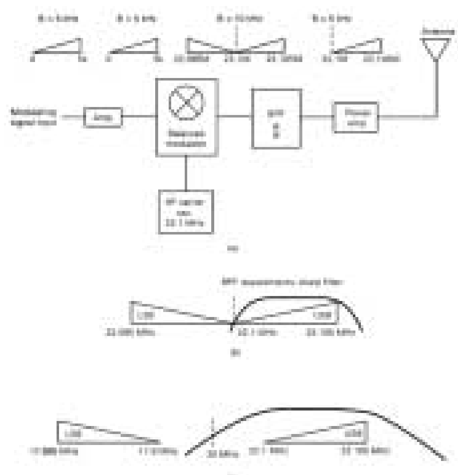

FIGURE 5-14 Single conversion SSBSC transmitter, filter method: (a) block diagram; (b) output spectrum and filtering requirements for a single-conversion transmitter; (c) output spectrum and filtering requirements for a three-conversion transmitter (From Tomasi, 2001, © all rights reserved.)

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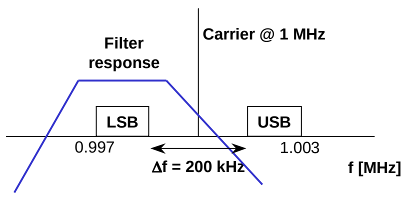
More on Filters

- Q required to separate one sideband from other sideband, separated by *Δf.* Carrier frequency is f_c . The desired suppression is *S* [in dB].

$$Q = \frac{f_c \sqrt{10^{S/20}}}{4\Delta f}$$

- Text example: Two sidebands separated by *Δf* of 200 kHz, 80 dB suppression, carrier at 1 MHz



$$Q = \frac{f_c \sqrt{10^{S/20}}}{4\Delta f}$$

$$= \frac{\left(1\times10^6\right)\left(\sqrt{10^{80/20}}\right)}{4\left(200\times10^3\right)}$$

$$= 125{,}000$$

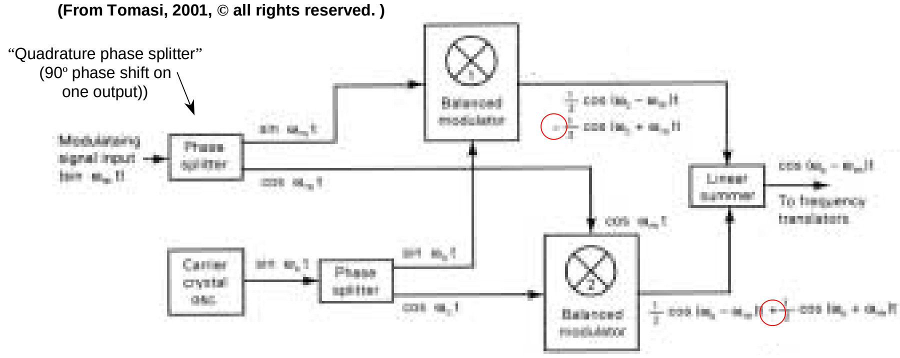
Filter Technologies

Technology	Q_{max}	Insertion Loss
Electronic LC filters	~100	--
Crystal filters	~100,000	1.5 – 3.0 dB
Ceramic filters	~2,000	2 – 4 dB
Surface acoustic wave (SAW)	~5,000	25 – 35 dB (µwave freqs)

Destructive Interference
(Phase Shift Method)

- **Cancel a sideband by adding a 180º-shifted version of itself** **(EO3502: ignore phasor argument in Tomasi)**

FIGURE 5-18 SSB transmitter: phase shift method
(From Tomasi, 2001, © all rights reserved.)



Note: sin(x-90°) = cos x ; cos x cos y = ½[cos(x+y) + cos(x-y)]; sin x sin y = ½[cos(x+y) – cos(x-y)]

Another Phase Shift Configuration

- **Eliminates need for bandpass phase shifters**
  (only single-freq phase shifters used)

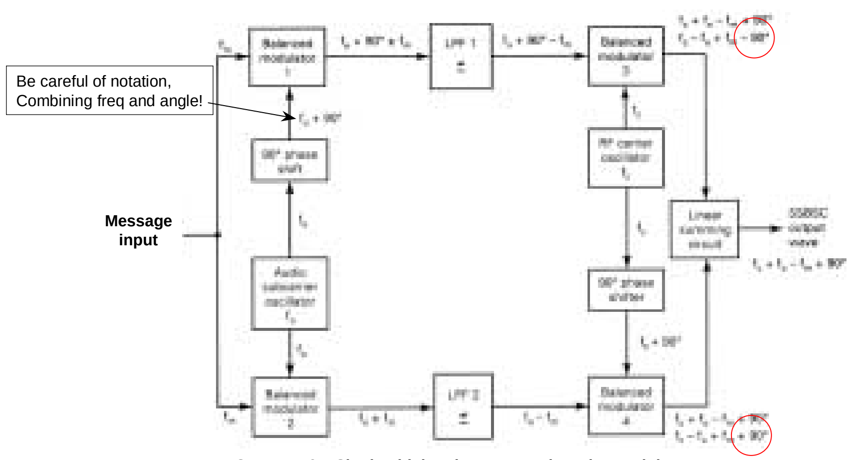
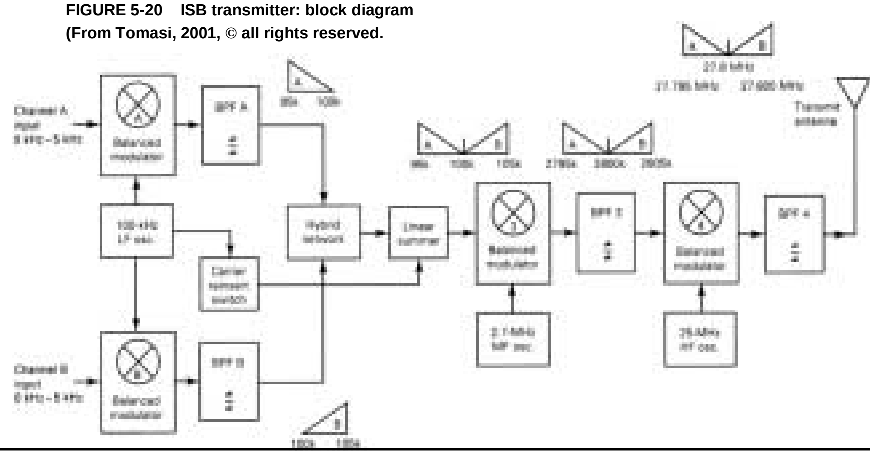


FIGURE 5-19 Single-sideband suppressed-carrier modulator; the "third method" (From Tomasi, 2001, © all rights reserved.)

ISB AM Transmitter

- Goal: independent message on each sideband
- BPF A and B filter different sidebands; "hybrid network" adds them
- Reduced carrier reinserted; followed by 2-stage frequency upshifting

FIGURE 5-20 ISB transmitter: block diagram



SSB Receivers

- ***BFO receiver***: uses "***beat frequency oscillator***"
  - 1st mixer downshifts to IF
  - IF strip amplifies and filters
  - 2nd mixer downshifts to baseband since $f_{BFO} = f_{IF}$ *(also called "homodyning")*
  - Oscillators are *not* synchronized ("noncoherent"); vulnerable to carrier-frequency drift

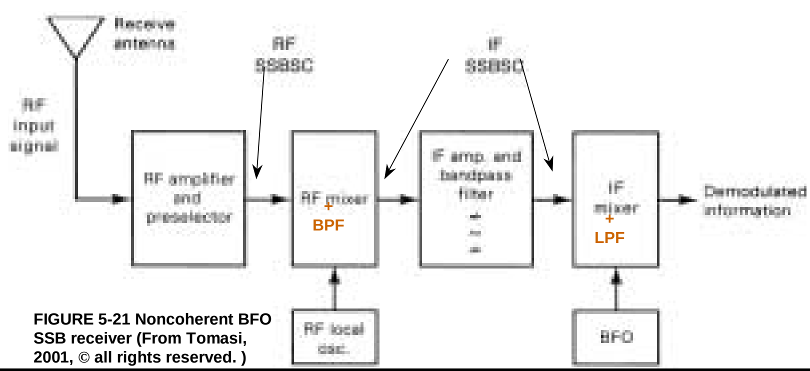


FIGURE 5-21 Noncoherent BFO SSB receiver (From Tomasi,

Mixer (Multiplier) Vocabulary

- ***Modulator mixer*** **("product modulator")**
  - **Multiplies signals and filters out low frequencies (difference frequencies)**
  - **Performs upshift or upconversion function**
- ***Demodulator mixer*** **("product detector")**
  - **Multiplies signals and filters out high frequencies (sum frequencies)**
  - **Performs downshift or downconversion function**

Coherent SSB BFO Receiver

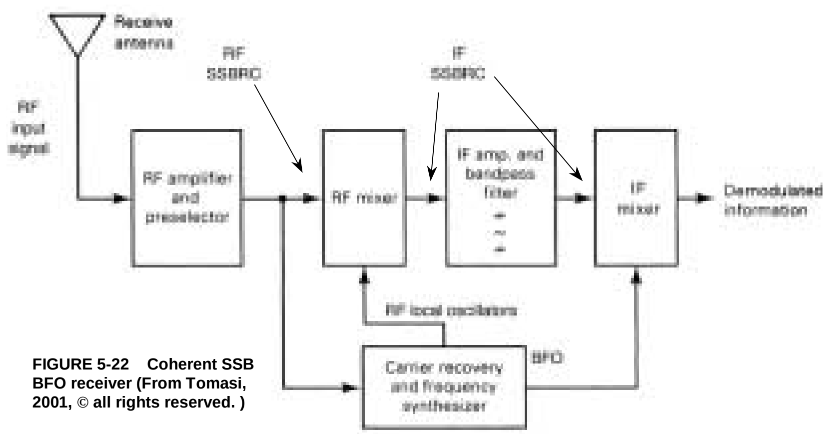


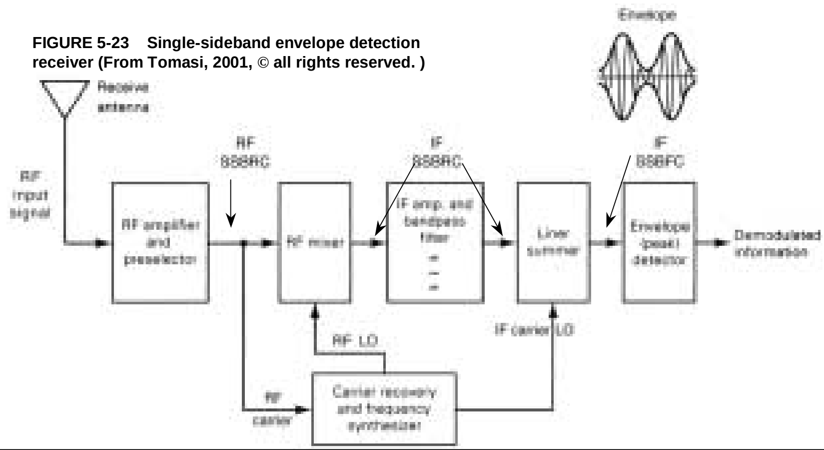
FIGURE 5-22 Coherent SSB BFO receiver (From Tomasi, 2001, © all rights reserved.)

- **Carrier recovered; LO and BFO locked to carrier (phase lock loop)**
  - **If carrier drifts, LO and BFO follow it; differences are constant**

SSB Envelope Detection Receiver

- LO is synched to carrier
- RF mixer down shits to IF
- IF strip amplifies and filters
- IF LO generated from carrier & added to IF output signal (added, not multiplied!)
- Produces SSB FC signal at IF
- SSB FC envelope detected to recover message

FIGURE 5-23 Single-sideband envelope detection receiver (From Tomasi, 2001, © all rights reserved.)



Multichannel Pilot SSB Receiver

- Phase lock loop (PLL) recovers IF and generates synchronized LO and BFO signals
- 2 IFs: 1st mixer downconverts to 1st IF; 1st IF strip amplifies and filters
- 2nd mixer downconverts to 2nd IF; 2nd IF strip amplifies and filters
- 3rd mixer mixes with BFO to homodyne down to baseband
- Amplified and passed to output
- Squelch and AGC also shown in figure

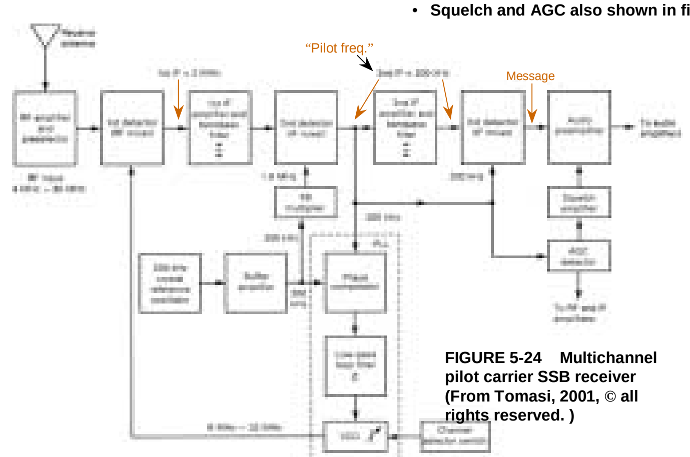
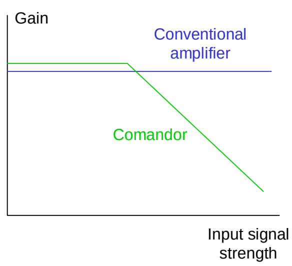


FIGURE 5-24 Multichannel pilot carrier SSB receiver (From Tomasi, 2001, © all rights reserved.)

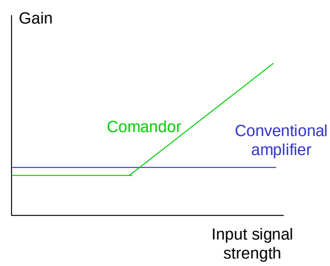
Bells and Whistles: Companding

- Amplifier gain is *not* independent of input signal strength
  - High-strength signals are amplified less than low strength signals
- Allows high dynamic-range signals to use limited dynamic-range channels

TRANSMITTER



RECEIVER



Frequency Division Multiplexing

- ***Multiplexing:*** multiple channels separated in a feature space (e.g., frequency span)
- FDM: stacking channels of information into region of spectrum (e.g., radio stations)
- Use function multipliers to upconvert baseband messages into assigned frequency slots
- Receivers use tunable LO to select channel and mixers to downconvert selected channel to baseband

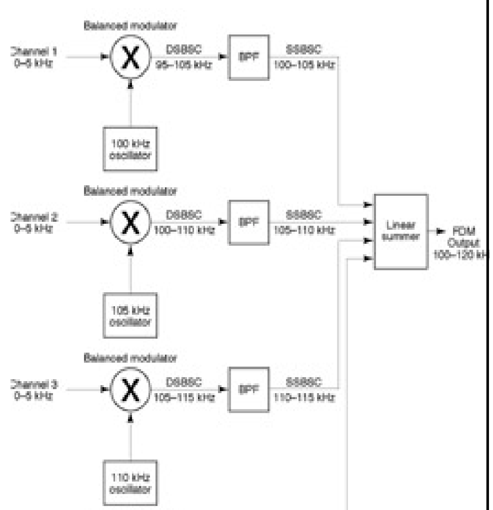


FIGURE 5-26 SSBSC FDM system: (a) Block diagram; (b) Output frequency spectrum (From Tomasi, 2001, © all rights reserved.)

Quadrature Multiplexing

- Allows two indepen-dent message to share region of spectrum simultaneously
- Messages separated by 90° phase shift of carrier
- ***I channel***: **In-phase channel**
- ***Q channel***: ***quadrature channel*** **(90° phase-shifted channel)**
- **Shown: DSBSC QM**

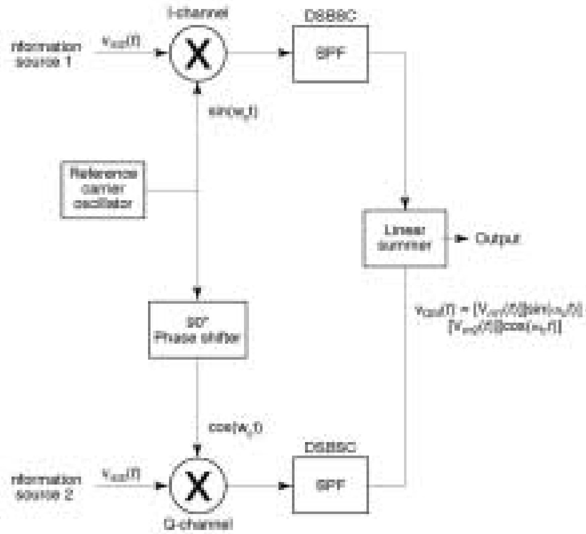


FIGURE 5-27 DSBSC QM System block diagram (From Tomasi, 2001, © all rights reserved.)

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SSB Measurements

- **PEP: Peak envelope power**
  - **Measured with two single-frequency sinusoids with equal power applied as messages**

$$\text{PEP} = \frac{\sqrt{E_1^2 + E_2^2}}{R} = \frac{2E^2}{R}$$

$$P_{\text{average}} = \frac{\text{PEP}}{2}$$

where E_1 and E_2 are RMS voltages.

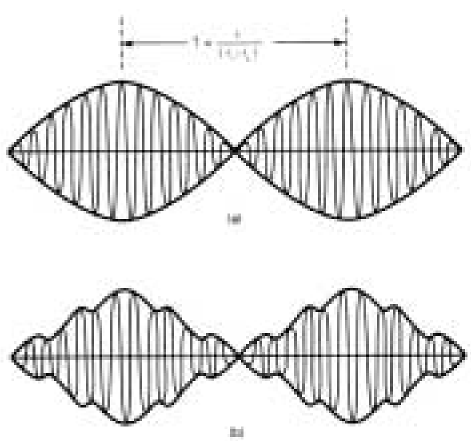

FIGURE 5-28 Two-tone SSB test signal: (a) without reinserted carrier; (b) with reinserted carrier (From Tomasi, 2001, © all rights reserved.)

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Summary

- SSB conserves power and spectrum
- Several variations possible
  - SSB FC
  - SSB SC
  - SSB reduced carrier
  - ISB
  - Vestigial SB
- Waveforms
  - Frequency domain
  - Time domain
- Transmitters
  - Block diagrams
  - Filter requirements
  - Phase shift cancellation
- Receivers
  - BFO receivers
  - Coherent receivers
  - Carrier recovery
  - Downshifting via heterodyning and homodyning

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