AM Demodulation I

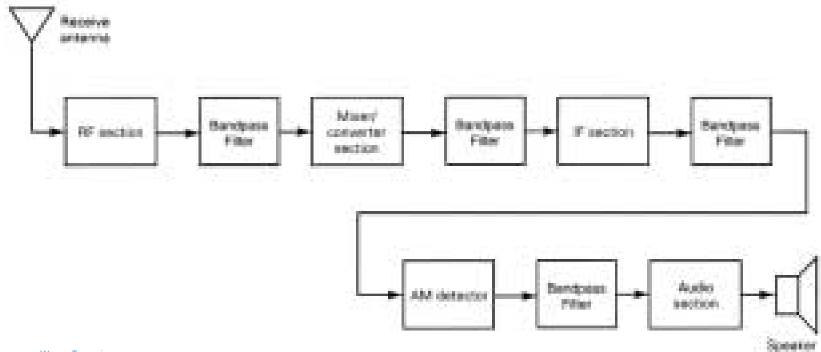
Tomasi Chapter 4

AM Demodulation

- **Need to receive, amplify and demodulate signal**
- **Need filters to bandlimit to handle only desired signal**
  - **Exclude other signals and noise**

AM Receiver Block Diagram

FIGURE 4-1 **Simplified block diagram of an AM receiver**



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Performance Measures

- **Selectivity**
  - **Ability to accept desire frequency band and reject others**
  - **Specify –3 dB and –60 dB bandwidths**
  - **Shape factor:**

$$SF = \frac{B_{-60\text{ dB}}}{B_{-3\text{ dB}}}$$

    - **Defines the steepness of the cutoff “skirts”** **(ideal SF = 1)**
  - **Standard channel spacings**
    - **AM broadcast radio: 10 kHz**
    - **FM broadcast radio: 200 kHz**
    - **TV broadcast: 6 MHz**

Performance Measures

- **Selectivity (cont.)**
  - **Noise proportional to *B***
  - **Bandwidth: Just enough for the signal (any more will increase noise but not signal)**
  - **Input (RF) bandwidth is wide; other bandwidths are narrower**
  - **Bandwidth improvement**

$$\mathrm{BI} = \frac{B_{\mathrm{RF}}}{B_{\mathrm{IF}}}$$

  - **Noise figure improvement:**

$$\mathrm{NF}_{\mathrm{improvement}} = 10\log(\mathrm{BI}) = 10\log\left(\frac{B_{\mathrm{RF}}}{B_{\mathrm{IF}}}\right)$$

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Performance Measures

- **Sensitivity**
  - **Smallest signal detected (in presence of noise) with "workable" output**
  - **Depends on required SNR**
    - **AM radio: requires >10 dB SNR**
    - **TV: requires >35 dB SNR**
    - **μwave receivers: >40 dB**
  - **Representative values of receiver threshold :**
    - **AM receiver: 50 μV at input**
    - **2-way mobile receiver: 0.1–10 μV**
  - **Improve sensitivity by reducing noise (not increasing transmitter power)**

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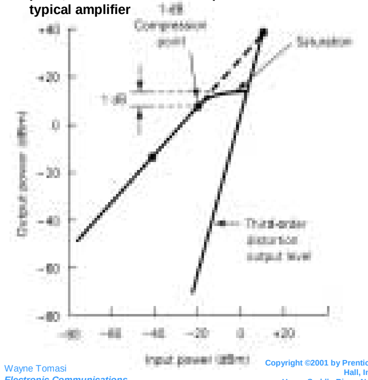
Performance Measures

- Dynamic Range
  - Sensitivity measures lowest power; can also have too much power at receiver
  - Single signal channel
    - Output linear with input until saturation occurs
    - **1-dB compression point**: input power where output is 1 dB below theory curve
    - Dynamic range:

$$\mathrm{DR}_{\mathrm{input}} = \frac{P_{\mathrm{in\,max}}}{P_{\mathrm{in\,min}}} \quad \text{or} \quad \mathrm{DR}_{\mathrm{input}}\,[\mathrm{dB}] = 10\log\left(\frac{P_{\mathrm{in\,max}}}{P_{\mathrm{in\,min}}}\right)$$

- 100 dB is good; intercept receiver ~160 dB desired

FIGURE 4-2 Linear gain, 1-dB compression point, and third-order intercept distortion for a typical amplifier



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Performance Measures

- Fidelity
  - Measure of ability to produce output that duplicates input
    - Deteriorations in amplitude, frequency, and phase
      - Amplitude distortion (e.g., nonuniform gain)
      - Frequency distortion: (e.g., new frequencies generated by nonlinearities; e.g., 3rd order distortion in two-signal system)
        - » Generates $2f_1 \pm f_2$, $2f_2 \pm f_1$, etc.; strength depends on signal strength (see prior graph)
        - » **Third-order intercept:** input power where third-order product has strength equal to signal (reduce by using perfect square-law detector)
  - Phase distortion
    - Due to nonuniform (or not linear) phase response of system elements (e.g., amplifiers, filters)
    - Not important for some signals (e.g., voice, music)

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Performance Measures

- **Insertion Loss**
  - **Adding a "black box" (e.g., bandpass filter) to the system incurs losses**

$$\text{IL}[\text{dB}] = 10\log\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right)$$

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Performance Measures

- **Thermal noise**
  - **Equivalent noise temperature:**

$$N = KTB \qquad \text{so,} \qquad T_e = \frac{N}{KB}$$

  - **T_e ~ 1,000K for noisy receivers and ~20K for low-noise receivers**
  - **Relation with noise factor (recall NF_{dB} = 10 log(F))**

$$T_e = T(F-1)$$

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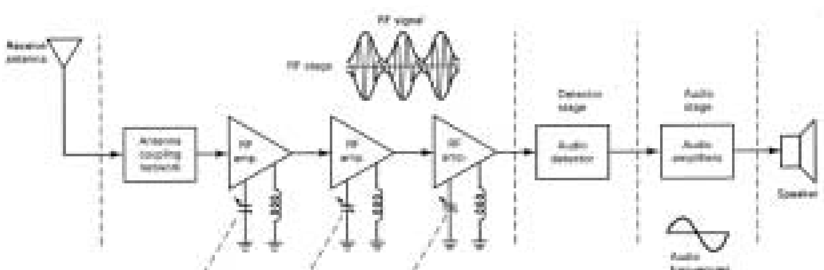
AM Receivers

- Coherent vs. incoherent receivers
  - **Coherent**: uses local oscillators synchronized to carrier frequency for demodulation
  - **Incoherent**: no local oscillators needed
    - Works with large SNR

Tuned Radio-Frequency (TRF) Receiver

FIGURE 4-3 Noncoherent tuned radio frequency receiver block diagram



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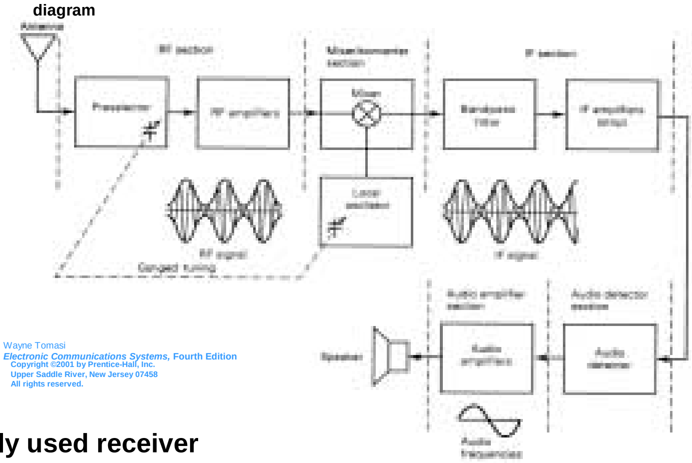
- **Simple design**
  - **RF bandpass amps (amplify and filter) in cascade, direct detector, audio amp to speaker**

- **Problems**
  - **Bandwidth varies with center frequency** (constant-Q filter; $Q = B/f_{center}$)
  - Tough to center all amplifier frequencies
  - Gains not uniform

Superheterodyne Receiver

FIGURE 4-4 AM superheterodyne receiver block diagram



- **Widely used receiver**
- **Superior gain, selectivity, and sensitivity**

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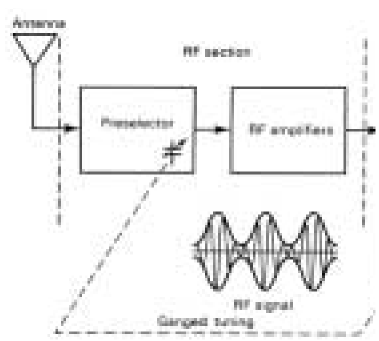
Superheterodyne Receiver

- RF section
  - Preselector
    - **Bandpass filter w broad passband and adjustable center frequency**
    - **Eliminates *image frequency region*** **(discussed later)**
    - **Reduces channel noise at input**
  - RF amplifier
    - **Amplifies signal**
    - **Bandpass filter (reduces noise)**
    - **Must be low-noise amplifier (LNA)**
    - **Predominantly determines sensitivity and noise figure of receiver**



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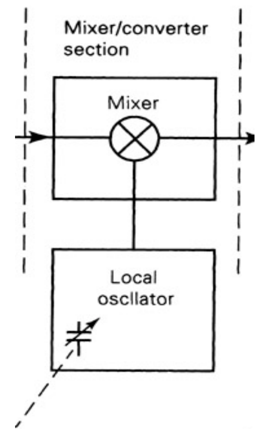
Superheterodyne Receiver

- Mixer/converter section
  - Local oscillator
    - Tunable source
    - Needs stability and accuracy
  - Mixer
    - 2 inputs; one output
    - Function multiplier ("heterodyning")

$$y(t) = Gx_1(t)\,x_2(t)$$

    - Downshifts message spectrum from RF region to IF region without changing content



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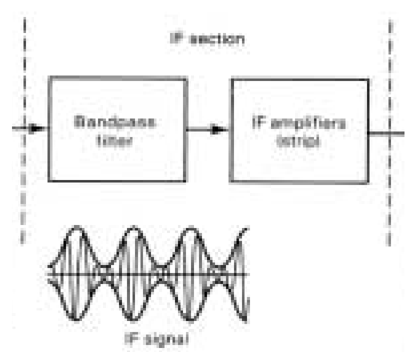
Superheterodyne Receiver

- IF section
  - Bandpass IF filter
    - Centered on IF center frequency (fixed-Q filter has fixed bandwidth w fixed center frequency)
    - Steep cutoff "skirts" (B ≈ 455 kHz in AM radio receivers)
  - Cascaded IF amplifiers (the *IF strip*)
    - Gain and selectivity determined here



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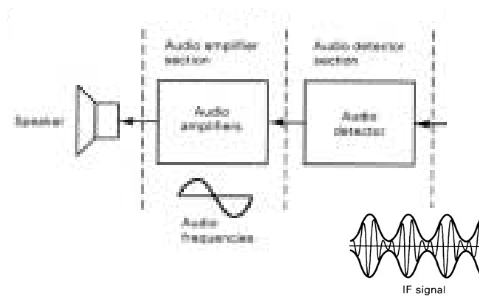
Superheterodyne Receiver

- Audio detector
  - Removes message from amplitude envelope of IF signal
  - Output is message signal (ideally, no remnants of IF)
- Audio amplifier
  - Filters any IF from message
  - Strengthens signal
  - Matches impedance levels to speakers



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Superheterodyne Receiver Operation

- Frequency translations
  - RF is received and filtered
  - Message spectrum at RF is translated to IF *("downconverted")*
    - Note: spectra are reversed in translation (i.e., USB at RF becomes LSB at IF and vice versa; no problem if DSB)
  - Amplified and filtered
  - Message removed from IF output by envelope detection
  - Result is message spectrum at audio *("baseband")*
- Example
  - RF AM signals from 535 to 1605 kHz (say, KGO 810 AM, 805-815 kHz on 810 kHz center frequency)
  - IF band: 450-460 kHz, centered on 455 kHz

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Choice of Frequencies

- IF (center) frequency: fixed by standardization
- Local oscillator frequency
  - Two choices
    - Above signal center frequency *("high side injection");* filter on difference frequency

$$f_{\text{lo}} = f_{\text{RF}} + f_{\text{IF}} \quad \text{(high side injection)}$$

    - Below signal center frequency *("low side injection");* filter on sum frequency

$$f_{\text{lo}} = f_{\text{RF}} - f_{\text{IF}} \quad \text{(low side injection)}$$

- Example

  f_{IF} = 455 kHz

  f_{RF} = 810 kHz

  - For high side injection,

    $f_{lo} = f_{RF} + f_{IF}$ = 810 + 455 kHz
    = 1265 kHz = 1.265 MHz

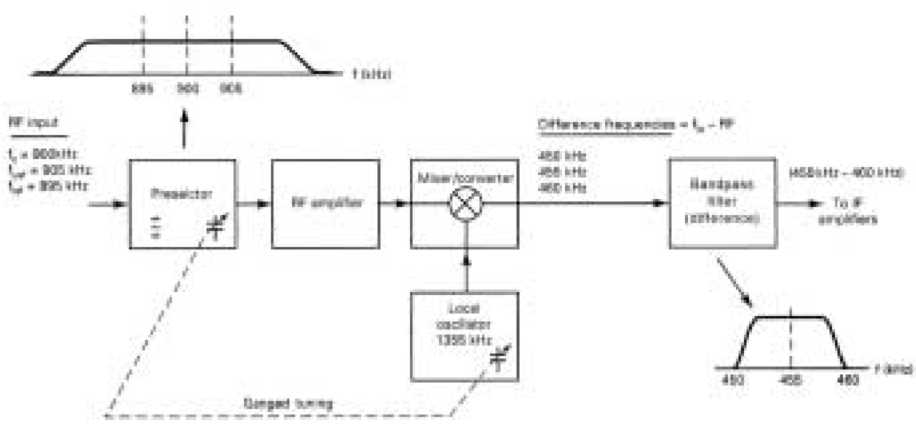
  - For low side injection,

    $f_{lo} = f_{RF} - f_{IF}$ = 810 - 455 kHz
    = 355 kHz

  - AM broadcast receivers use high side injection!!

Book Example 4-3 (pp. 150-151)

FIGURE 4-5 Figure for Example 4-3



LO "Tracking"

- LO needs to be at f_{IF} above f_{RF} for all f_{RF} (needs to "track" f_{RF})
- Preselector and LO are both tuned in unison ("gang" tuning)
  - Preselector: 540-1600 kHz (range of 2.96:1)
  - LO: 995-2055 kHz (range of 2.06:1)
  - C changes 2.96^2:1 for preselector and 2.06^2:1 for LO
  - Hard to design; LO frequency differs from desired freq by the ***tracking error*** (≤±3 kHz for commercial AM)
- Low side tracking has much larger variation and much larger tracking error
- Solution? Use digital tuning techniques

FIGURE 4-6 Receiver tracking: (a) preselector and local oscillator schematic; (b) tracking curve

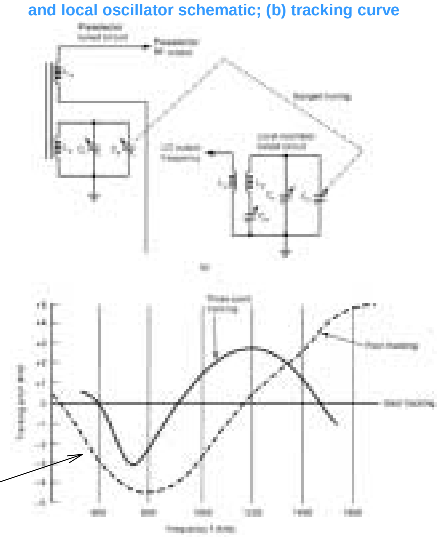
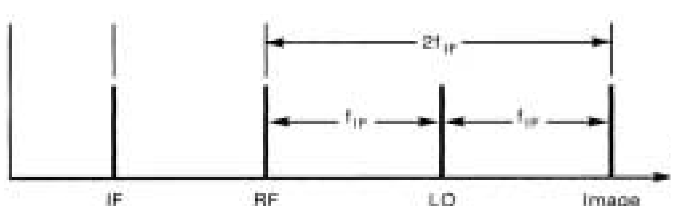


Image Frequency

- Image frequency
  - If allowed to enter receiver will mix w LO and produce an IF frequency
  - LO that is high-side injection for RF will also be low-side injector for image frequency
  - Solution: filter out image frequency w preselector filter
    - Larger f_{IF} makes this easier (tradeoff w IF amp gain)

FIGURE 4-9 Image frequency



$$f_{\text{im}} = f_{\text{lo}} + f_{\text{IF}} = f_{\text{RF}} + 2 f_{\text{IF}} \quad \text{(high side injection)}$$

Image Frequency

- Image frequency rejection ratio (IFRR)
  - Figure of merit for image-rejection filters (can be expressed in dB)

$$\text{IFRR} = \sqrt{1 + Q^2 \rho^2}$$

$$\text{where } \rho = \frac{f_{\text{im}}}{f_{\text{RF}}} - \frac{f_{\text{RF}}}{f_{\text{im}}}.$$

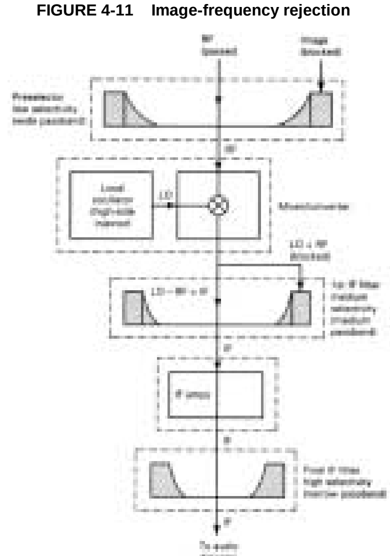
  - Multiple cascaded preselector filters

$$\text{IFRR}_{\text{Total}} = (\text{IFRR}_1)(\text{IFRR}_2)\ldots(\text{IFRR}_n)$$

Image Frequency Rejection

- Preselector passes broad RF region but blocks Image frequency
- Mixer downconverts RF region to IF
- First IF filters/amplifiers pass only IF region
- Final IF filter passes only IF region; sharp cutoff skirts

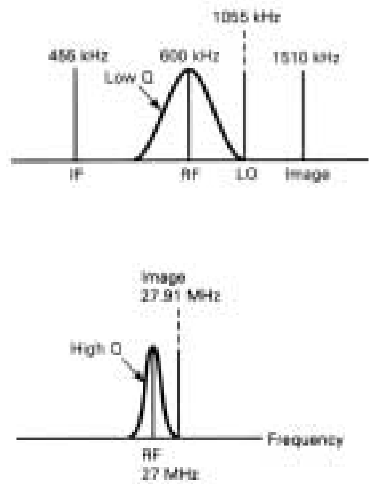
FIGURE 4-11 Image-frequency rejection



Filters

FIGURE 4-12 Frequency spectrum for Example 4-6

- Top: Easy filter design with low f_{RF} and fixed f_{IF}
- Bottom: Difficult filter design with high f_{RF} and fixed f_{IF}



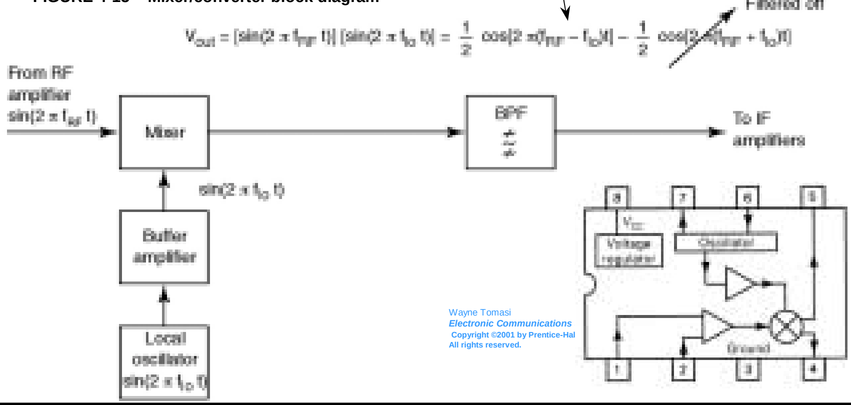
RF Amplifiers

- Need
  - High gain
  - Low noise (added to signal); low noise figure
  - Linear operation (no generation of harmonics or intermixed signals)
  - Moderate selectivity
  - High IFRR
- Electronic amplifiers with desirable properties exist

Mixer/Convertor

- Downconverts message spectrum from RF to IF (multiplication)
- Various implementations exist; available in IC form

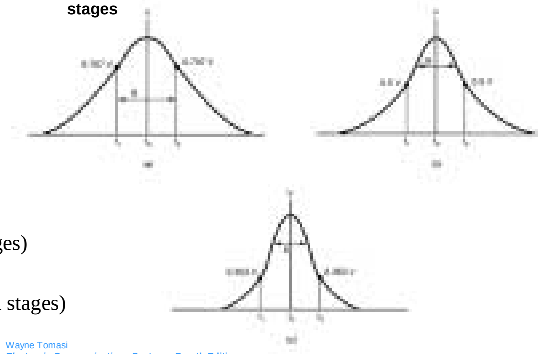
FIGURE 4-15   Mixer/converter block diagram



Cascaded Amplifiers and Filters

- Imperfect bandpass amplifiers and/or filters cause $B_{-3\ dB}$ to decrease
  - Cascaded devices narrow bandwidth of combination

FIGURE 4-22   Bandwidth reduction: (a) single-tuned stage; (b) two cascaded stages; (c) three cascaded stages



$$B_n = B_1\sqrt{2^{1/n} - 1} \quad \text{(single-tuned stages)}$$

$$B_{\text{ndt}} = B_{\text{1dt}}\sqrt[4]{2^{1/n} - 1} \quad \text{(double-tuned stages)}$$

AM Detector

- *Peak detector*: follows envelope of IF output (ignores IF fluctuations)
- Simple as diode followed by lowpass RC filter

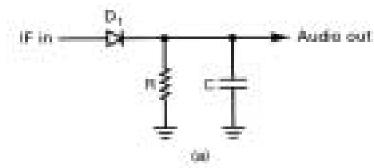
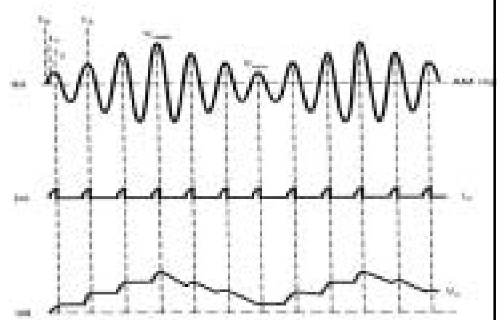


FIGURE 4-25 Peak detector: (a) schematic diagram; (b) AM input waveform; (c) diode current waveform; (d) output voltage waveform



Peak Detector

- Detected wave follows upper envelope of AM signal
- The diode is nonlinear mixing element; harmonics, sums and differences are generated; only the f_c-f_m signal is passed by RC lowpass filter

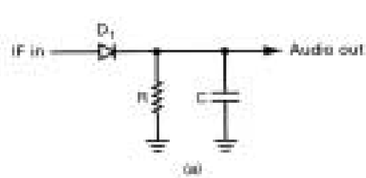
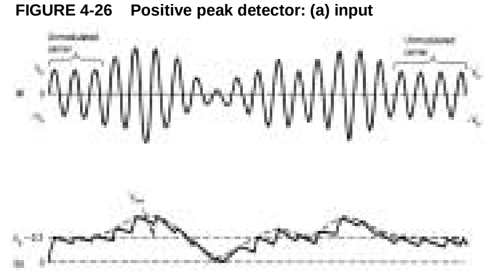


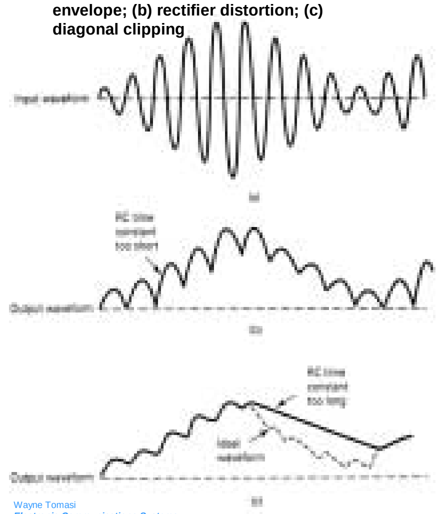
FIGURE 4-26 Positive peak detector: (a) input

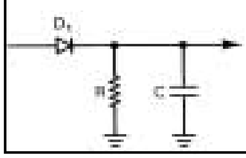


Peak Detector

- Trick is to get charge and discharge time constants right
- Charge: $1/R_{diode}C$
- Discharge: $1/RC$
- Too short: lots of f_C ripple on signal (removed by filtering)
- Too long: audio doesn't follow high frequencies in envelope (cannot recover)

FIGURE 4-27 Detector distortion: (a) input envelope; (b) rectifier distortion; (c) diagonal clipping





$$f_{m_{\max}} = \frac{\sqrt{\left(1/m^2\right)-1}}{2\pi RC}$$

(w/o attenuation)

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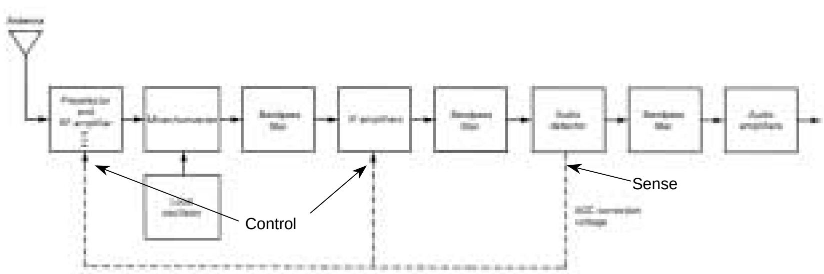
Bells and Whistles

- *Automatic gain control*
  - Raises gain for weak signal
  - Lowers gain for strong signal
  - Increases dynamic range of input signal

FIGURE 4-28 AM receiver with simple AGC



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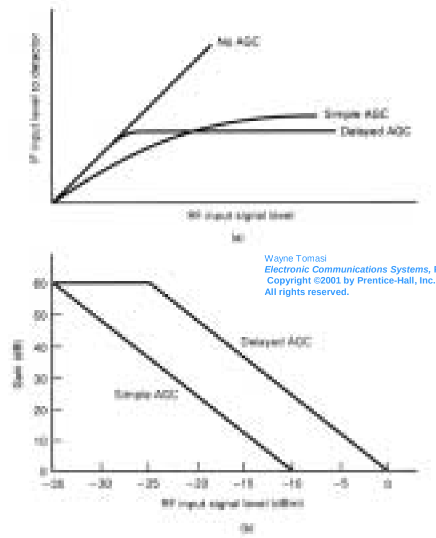
Automatic Gain Control

- **No AGC: limited dynamic range**
- **Simple AGC: increase input dynamic range**
- **Delayed AGC: Flat gain when input exceeds “threshold” value**

FIGURE 4-30 Automatic gain control (AGC): (a) response characteristics; (b) IF gain-versus-RF input signal level



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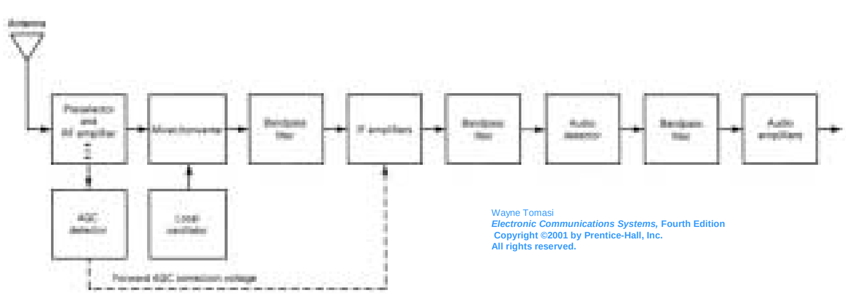
Automatic Gain Control

- ***Forward AGC*: Sense is done early in chain; control is applied later in chain**
  - **Advantage: no time delay in applying AFC**
  - **Feedforward process instead of feedback**
  - **Disadvantage: can be unstable**

FIGURE 4-31 Forward AGC



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Bells and Whistles

- *Squelch circuit*
  - Disables audio out when input falls below a threshold value
  - Eliminate channel noise when message is absent (or too weak)
- *Noise limiters (or clippers)*
  - Impulse noise: large noise "spikes" (short pulses)
  - Limits (or "clips") input to a maximum value
    - Same process as on PC surge suppressers
- *Noise blanking circuit*
  - Reduces effects of noise pulses
  - Detects pulse presence and mutes amplifiers

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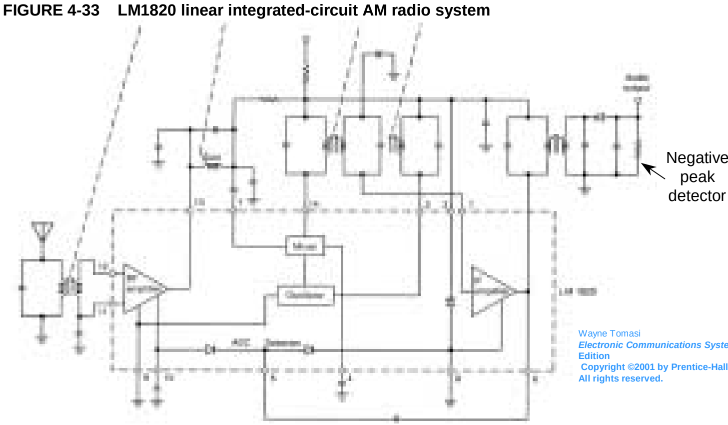
Demodulator Implementations

- Linear IC demodulator
- Lots of external inductors & capacitors (w tweaking)

FIGURE 4-33 LM1820 linear integrated-circuit AM radio system



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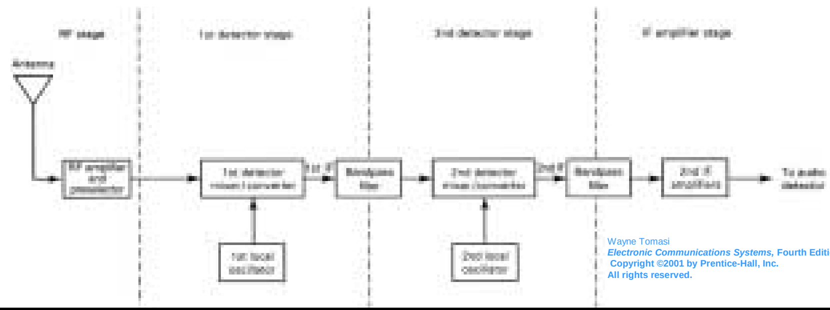
Demodulator Implementations

- Double-conversion demodulator
  - Two IF strips used instead of one
    - Higher: optimize for image frequency rejection
    - Lower: optimize for gain
    - Pro: Easier to design filters and amplifiers
    - Con: More components

FIGURE 4-34 Double-conversion AM receiver



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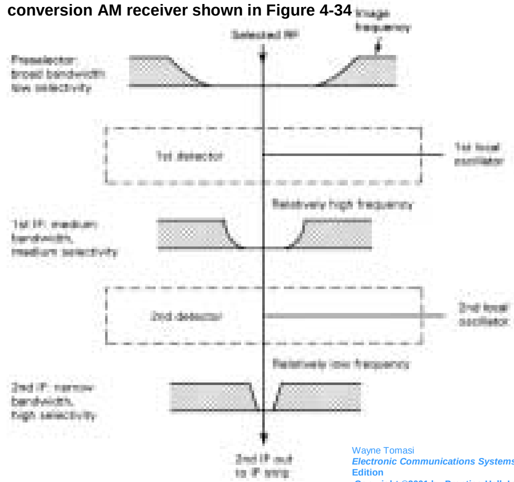
Double-Conversion Demodulator

- Frequency-domain view
- Filters become successively narrower as IF center frequency decreases
- Easier to build filters

FIGURE 4-35 Filtering requirements for the double-conversion AM receiver shown in Figure 4-34



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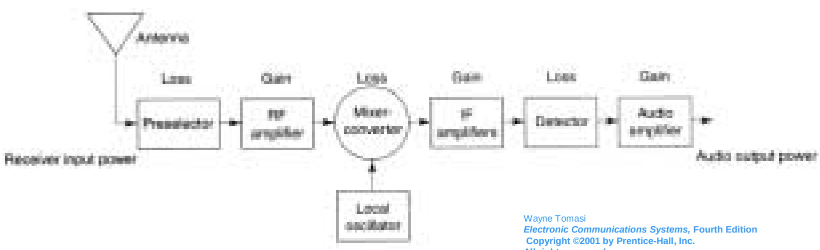
Receiver Gains and Losses

- **Various elements have gains** (e.g., amplifiers); **others** (e.g., filters)
- **Overall receiver gain is sum of dB gains and losses** (be careful if AGC is present!)

$$G[\mathrm{dB}] = \sum \mathrm{gains}[\mathrm{dB}] - \sum \mathrm{losses}[\mathrm{dB}]$$

$$P_{\mathrm{out}}[\mathrm{dBm}] = P_{\mathrm{in}}[\mathrm{dBm}] + G[\mathrm{dB}]$$

FIGURE 4-36 Receiver gains and losses



Summary

- **AM demodulation**
  - **Incoherent: amplify RF signal and use peak detector**
  - **Coherent: use LO**
- **Superheterodyne demodulation**
  - **Filter out image frequency w preselector**
  - **Frequency downconvert message sidebands to IF**
  - **Filter and amplify IF signal**
  - **Use peak detector to pull message off of IF carrier**
- **Reasons for IF**
  - **Use same center frequency for all channels to filter and amplifier design easier**
- **Bells and whistles**
  - **AGC**
  - **Noise clippers and blanking**
  - **Squelch circuit**
- **Various circuit implementations** (not covered in this course)