Superheterodyne AM/ FM Receivers

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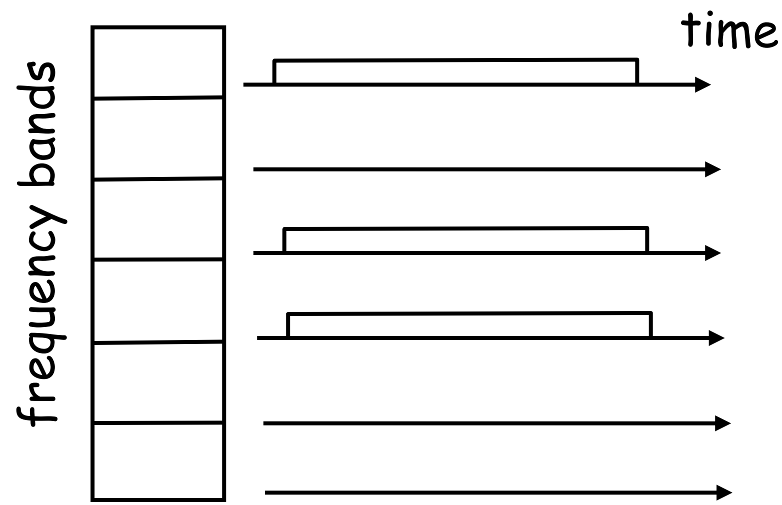
Frequency Division Multiple Access (FDMA)

- Frequency band (channel) divided into smaller bands
- Different transmitters transmit their signals on different bands
  - ❑e.g., different TV or radio stations
- Above is done to avoid interference between signals of different transmitters



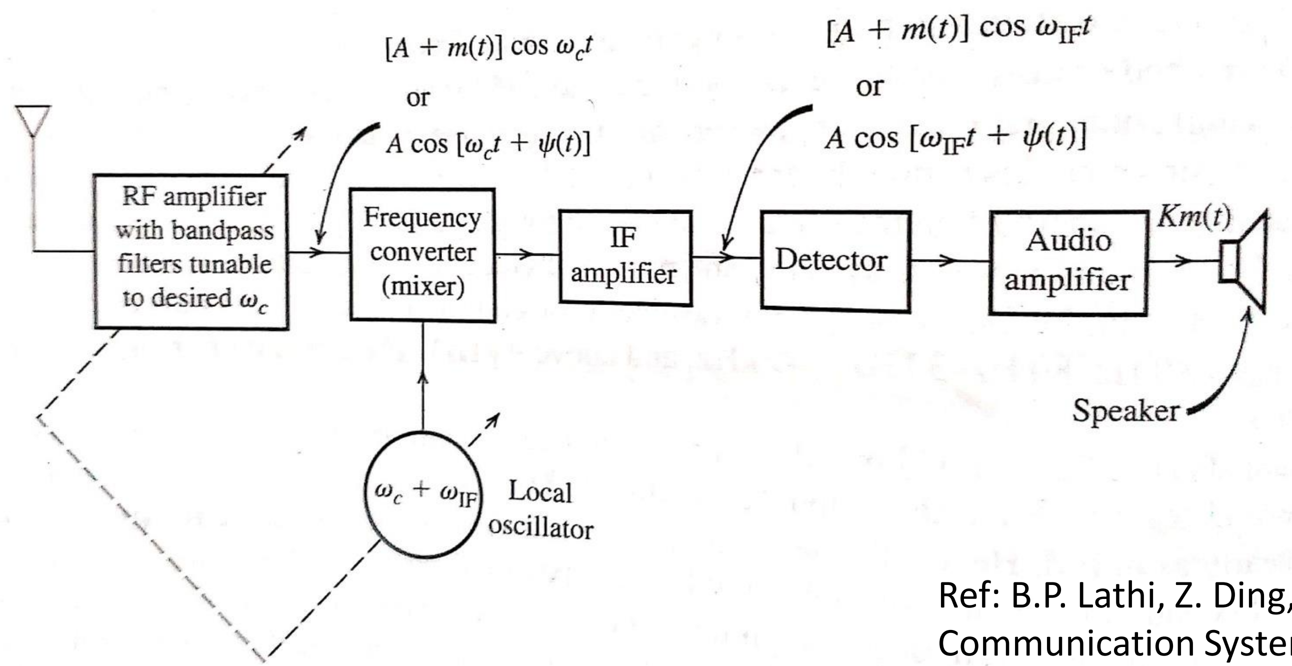
Ref: J. Kurose, K. Ross, “*Computer Networking: A Top Down Approach*”, Sixth Edition, Pearson Education, 2012.

Frequency Translation

- Frequency translator also known as "frequency converter" or "frequency mixer"
- Suppose we have a modulated signal $s_1(t)$, whose spectrum is centred on carrier frequency f_1:
  - ❑ $s_1(t) = a(t)\cos[2\pi f_1 t + \phi(t)]$
- Using $s_1(t)$, we want to generate a modulated signal $s_2(t)$, whose spectrum is centred on carrier frequency f_2:
  - ❑ $s_2(t) = a(t)\cos[2\pi f_2 t + \phi(t)]$
- How can we generate $s_2(t)$ from $s_1(t)$?
  - ❑ by multiplying $s_1(t)$ with $2\cos[2\pi f_l t]$ and band-pass filtering the product
  - ❑ where $f_l = f_2 - f_1$ if $f_2 > f_1$ and $f_l = f_1 - f_2$ if $f_1 > f_2$

Superheterodyne AM/ FM Receivers

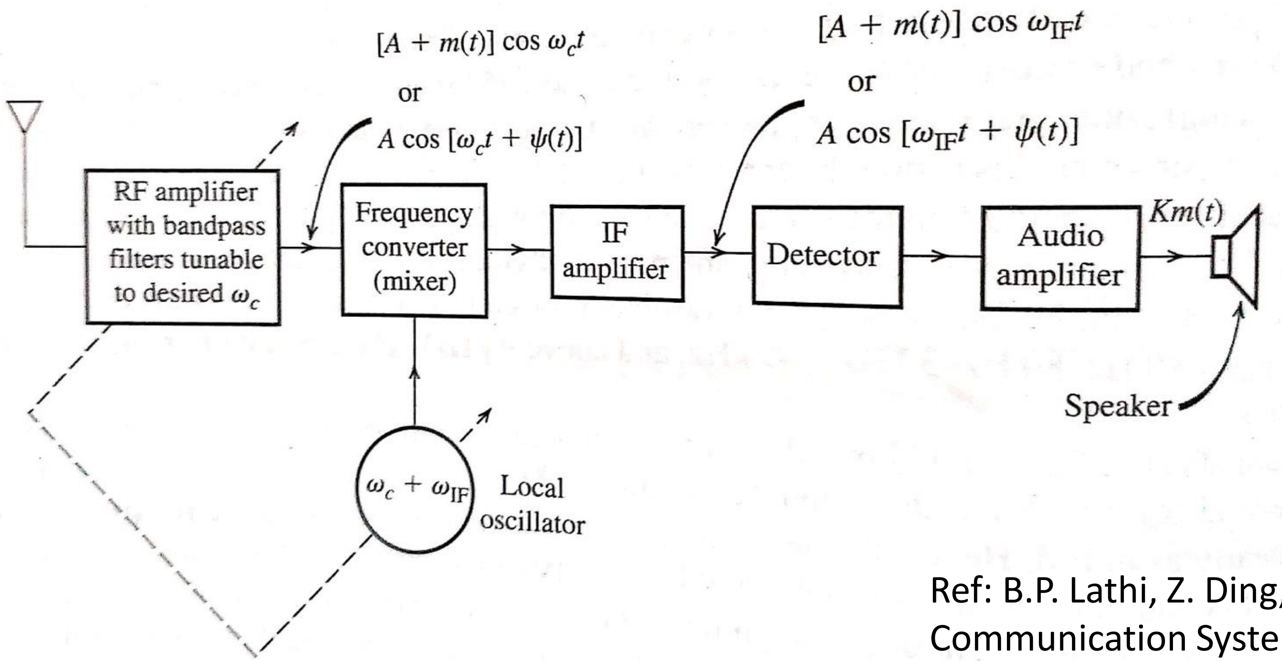
- Radio receiver used in broadcast AM and FM systems called *superheterodyne receiver*
- Consists of following components (see fig.):
  - ❑ RF (radio-frequency) section
  - ❑ Frequency converter (mixer)
  - ❑ IF (intermediate frequency) amplifier
  - ❑ AM or FM demodulator (detector)
  - ❑ Audio amplifier



Ref: B.P. Lathi, Z. Ding, "Modern Digital and Analog Communication Systems", 4th ed.

Superheterodyne AM/ FM Receivers (contd.)

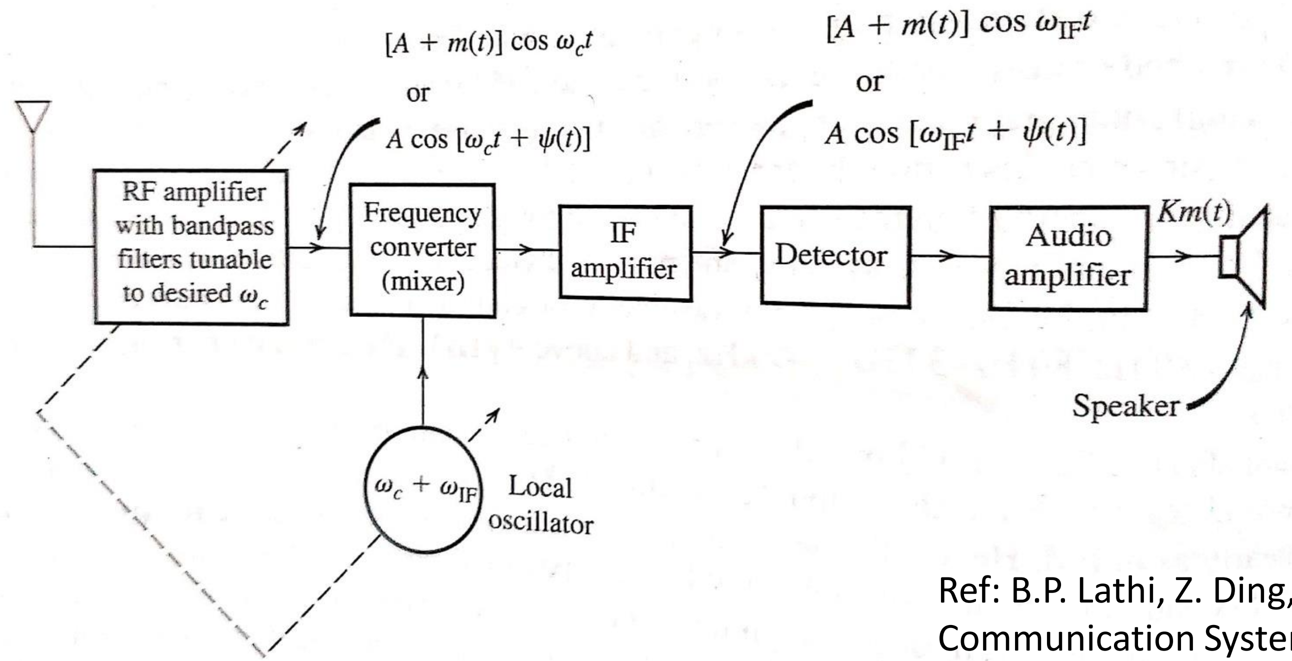
- RF section consists of a tunable band-pass filter and amplifier that:
  - ❑ picks up desired station by tuning the filter to the right frequency band
- Frequency converter translates carrier from frequency f_c to a *fixed* IF f_{IF}:
  - ❑ by using local oscillator with frequency $f_{LO} = f_c + f_{IF}$
- Simultaneous tuning of local oscillator and RF tunable filter is done by one joint knob:
  - ❑ tuning capacitors in both circuits are ganged together and designed such that frequency of LO is always f_{IF} above f_c
- Thus, every station that is tuned in is translated to fixed carrier frequency of f_{IF} for further processing



Ref: B.P. Lathi, Z. Ding, “Modern Digital and Analog Communication Systems”, 4th ed.

Superheterodyne AM/ FM Receivers (contd.)

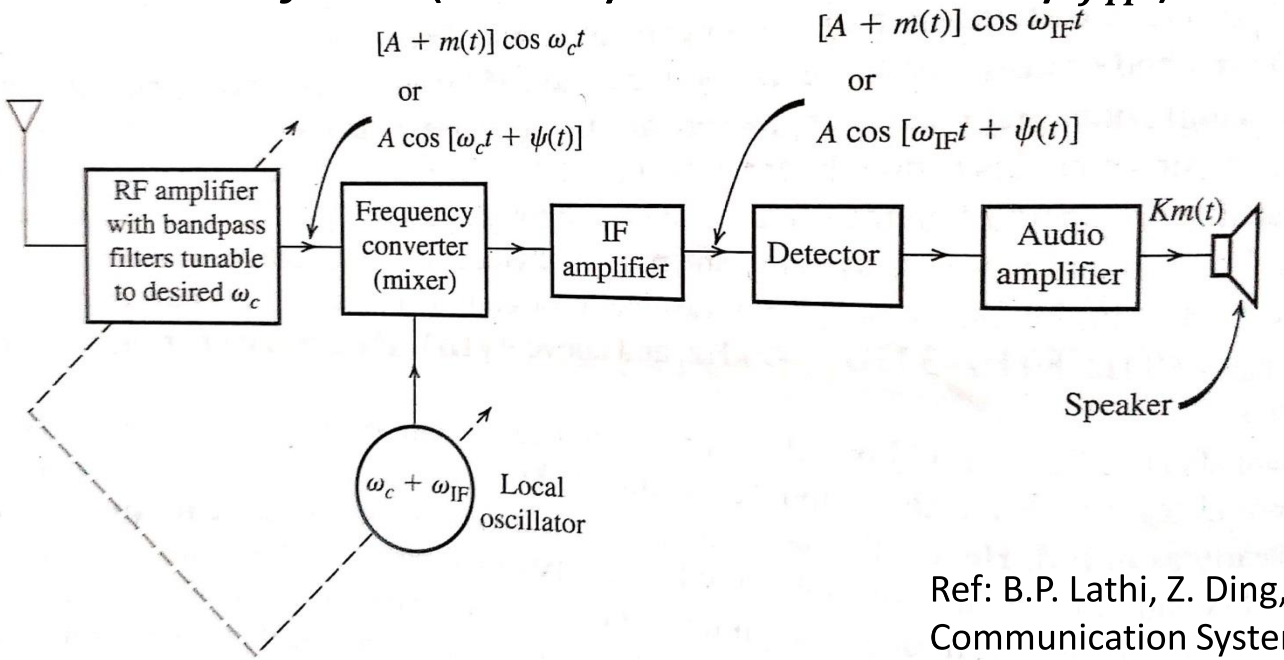
- Recall: every station that is tuned in is translated to fixed carrier frequency of f_{IF} for further processing
- E.g.:
  - ❑FM radio: $f_c \in [88 \text{ MHz}, 108 \text{ MHz}]$; $f_{IF} = 10.7$ MHz
  - ❑AM radio: $f_c \in [535 \text{ kHz}, 1605 \text{ kHz}]$; $f_{IF} = 455$ kHz
  - ❑TV: $f_c \in [54 \text{ MHz}, 88 \text{ MHz}], [174 \text{ MHz}, 216 \text{ MHz}], [470 \text{ MHz}, 806 \text{ MHz}]$; $f_{IF} = 38$ MHz



Ref: B.P. Lathi, Z. Ding, "Modern Digital and Analog Communication Systems", 4th ed.

Superheterodyne AM/ FM Receivers (contd.)

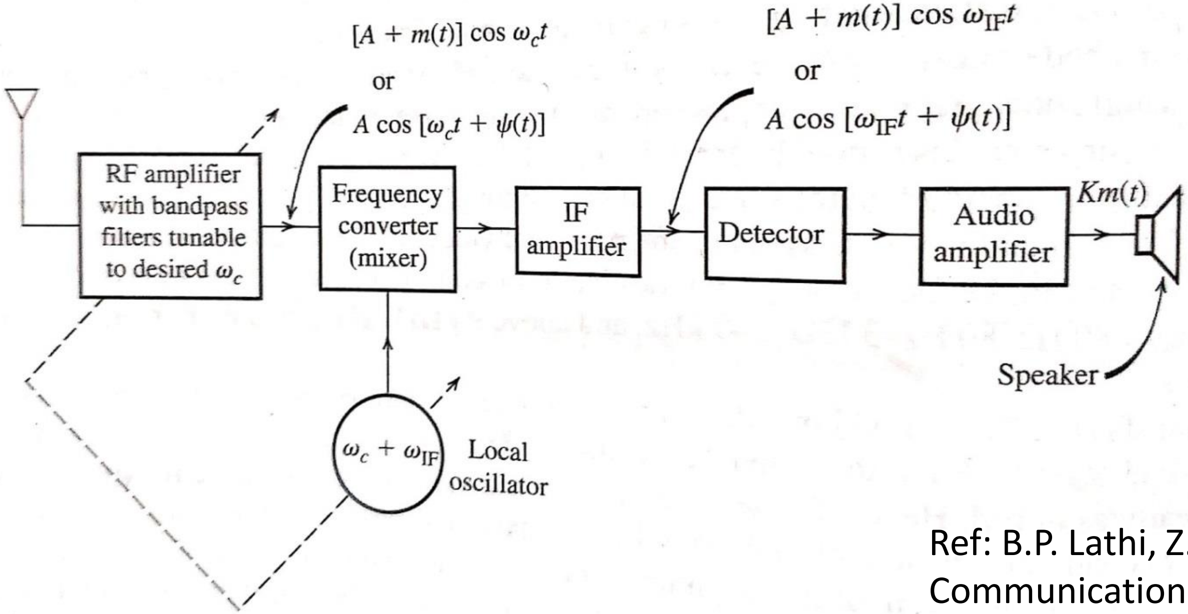
- Recall: every station that is tuned in is translated to fixed carrier frequency of f_{IF} for further processing
- Reason for above translation:
  - ❑ difficult to design selective bandpass filters that retain desired station and filter out adjacent stations *if center frequency is high* (f_c)
  - ❑ especially true in case of *tunable* filters
  - ❑ easier to design selective bandpass filters when center frequency is *low* and *fixed* (factory-tuned to exactly f_{IF})



Ref: B.P. Lathi, Z. Ding, “Modern Digital and Analog Communication Systems”, 4th ed.

Superheterodyne AM/ FM Receivers (contd.)

- Recall: IF section effectively suppresses adjacent-channel interference due to its high selectivity
- Why have band-pass filtering in RF section at all?
  - ❑ frequency converter also translates station at frequency $f_c' = f_c + 2f_{IF}$ to f_{IF}
  - ❑ $f_c' = f_c + 2f_{IF}$ called *image frequency* of f_c
  - ❑ band-pass filter suppresses image frequency
- E.g.: in case of AM, $f_{IF} = 455$ kHz; if $f_c = 1000$ kHz, then f_c':
  - ❑ 1910 kHz
- Note:
  - ❑ band-pass filter in RF section not very selective
  - ❑ although it cannot properly filter out adjacent channels, it can filter out image frequency well



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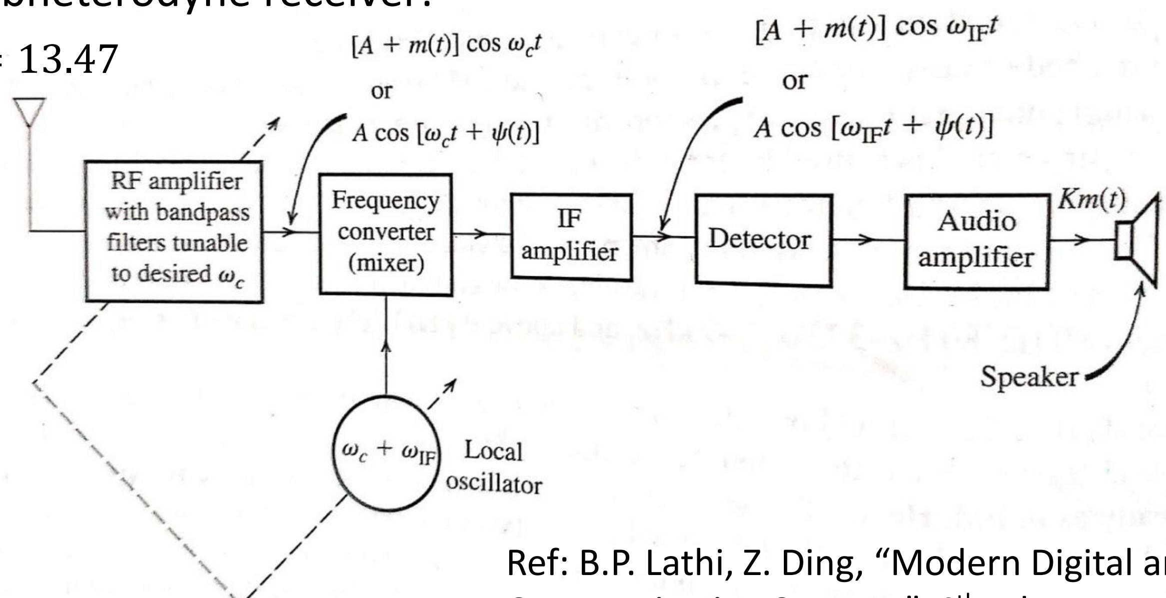
Superheterodyne AM/ FM Receivers (contd.)

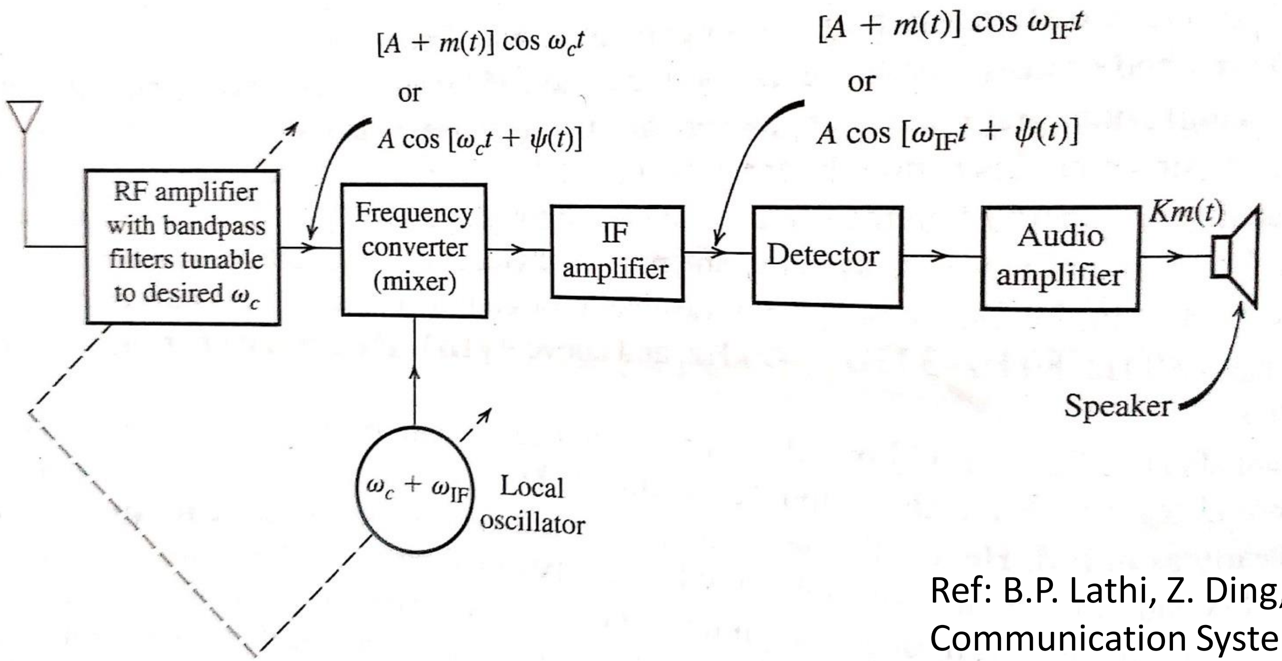
- *Super*heterodyne receiver: uses LO of frequency $f_{LO} = f_c + f_{IF}$ to translate from RF to IF
- *Sub*heterodyne receiver: uses LO of frequency $f_{LO} = f_c - f_{IF}$ to translate from RF to IF
- Reason for preferring superheterodyne receiver over subheterodyne receiver:
  - ❑ former requires smaller ratio of maximum to minimum frequency f_{LO} than latter
  - ❑ easier to design local oscillator that is to be tuned over smaller frequency ratio
- E.g.:
  - ❑ AM radio: min. and max. values of f_c are 540 kHz and 1600 kHz, resp.; $f_{IF} = 455$ kHz
  - ❑ Frequency ratio of superheterodyne receiver:
    - ○ $\frac{1600+455}{540+455} = \frac{2055}{995} = 2.065$
  - ❑ Frequency ratio of subheterodyne receiver:
    - ○ $\frac{1600-455}{540-455} = \frac{1145}{85} = 13.47$



Ref: B.P. Lathi, Z. Ding, "Modern Digital and Analog Communication Systems", 4th ed.

Automatic Gain Control (AGC)

- In general, signal strength of received AM signal varies dynamically due to time-varying nature of radio channels (fading)
- So by default, volume of sound emitted by AM radio receiver would fluctuate with time
- How can receiver compensate for this?
  - ❑ average voltage magnitude of detector output compared with reference level
  - ❑ signal amplified using a variable gain amplifier (VGA), whose gain is function of average voltage magnitude of detector output
- Thus, VGA output is relatively constant
- Above scheme called *AGC*



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Homodyne Receiver

- Also known as "*zero-IF receiver*" or "*direct conversion receiver*"
- Modulated signal directly translated from carrier frequency to baseband
- Band-pass filtering to remove adjacent channels and demodulation performed in baseband
- Advantages:
  - ❑ simpler design than superheterodyne receiver; no need for IF stage
  - ❑ no need for image frequency suppression
- Disadvantages:
  - ❑ envelope detection for AM or differentiation/ slope detection followed by envelope detection for FM cannot be performed
  - ❑ need to perform coherent demodulation, which is expensive