CHAPTER 4
Superheterodyne Receiver

4.1 Selectivity and Tunability:

The assignment of different carrier frequencies for different broadcasting channels is a form of FDM. The receiver must, therefore, be able to select and detect one channel among many others present. The ability of the receiver to tune to a desired channel is called tunability, while the ability to select only that desired channel and discriminate against its neighbors is called selectivity. In early days of radio, a crystal radio was used which was tuned to a fixed carrier, through the use of a tuned tank circuit with a fixed center frequency. Since there are so many channels now, the need to vary the center frequency of this tank circuit must be a mandatory requirement in radio receivers.

The selectivity requirement must provide a pass band for the desired channel (carrier and two sidebands), yet attenuate the sidebands of the immediate neighbors. Since the spectrum is crammed, the tuned circuit must have very sharp edges, yet it must have a flat response throughout the bandwidth of the signal. A simple resonant circuit (Fig 4.1 a) cannot satisty these requirements. The bandwidth of such a circuit is f_0 / Q, which would allow for the desired channel, but would also pass at least one sideband of the neighboring channels on both sides. For example, if $f_o = 1MHz$ and $Q = 10$, then f_o / Q is 100kHz, which is 10 channels wide if the channel bandwidth is 10kHz. Thus, the required response function must look more like a band pass filter (BPF). Its center frequency is adjusted to the carrier frequency of the desired channel, and with a bandwidth equal to the bandwidth of the desired channel. The reponse edges must fall sharply short of the sidebands of the neighboring channels. The response must be flat in between (Fig 4.1b). Such a response can be obtained by an elaborate circuit design, including perhaps a crystal filter. But to make this circuit tunable is an added difficulty beyond practical considerations. Therefore, it is mandatory to separate the two issues, namely, tunability and selectivity.

4.2 Superheterodyning:

To be able to design a highly selective tank circuit with flat response, it must have a fixed center frequency. This contradicts the requirement of tunability. To solve this dilemma, the receiver must be able to convert the carrier frequency of each received channel to a fixed frequency called intermediate frequency (IF). In the case of AM medium wave broadcasting, it is 455kHz. For this fixed frequency, the BPF is well designed to give sharp selectivity. This process is called superheterodyning (meaning forcibly converting the frequency).

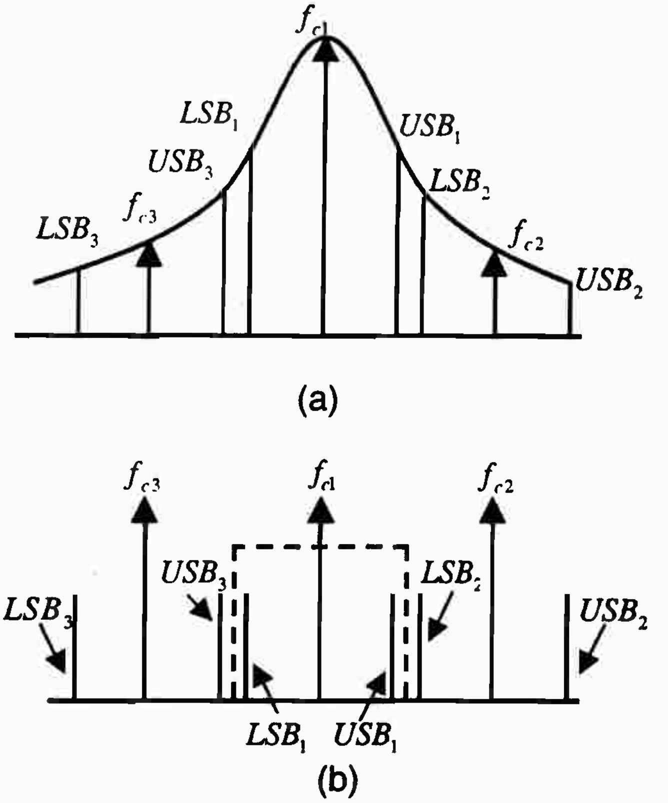

Fig. 4.1 Selectivity
a) frequency response of a parallel resonant circuit
b) required BPF with sharp selectivity

Fig. 4.2 shows a block diagram of a superheterodyne receiver. The key of the frequency conversion is a mixer and a local oscillator. The mixer is a nonlinear device whose function is to multiply the local oscillator and the RF input. The local oscillator is an RF oscillator located in the receiver. If the mixer characteristic is represented by

$$v_o = av_i + bv_i^2 + cv_i^3 + \ldots\ldots\ldots, \qquad (4-1)$$

$$v_i = A\cos\omega_c t + B\cos\omega_o t, \qquad (4-2)$$

where ω_c represents the carrier frequency of the channel to be selected and ω_o represents the frequency of the local oscillator. Then,

$$v_o = a(A\cos\omega_c t + B\cos\omega_o t) + b(A\cos\omega_c t + B\cos\omega_o t)^2 + c(A\cos\omega_c t + B\cos\omega_o t)^3 + \ldots\ldots \qquad (4-3)$$

The output frequencies, thus, are $\omega_c, \omega_o, (\omega_o - \omega_c), (\omega_c + \omega_o), 2\omega_c, 2\omega_o$, $(2\omega_c - \omega_o), (2\omega_o - \omega_c)$ etc. If we tune the IF amplifier such that

$$f_{IF} = f_o - f_c = 455\,kHz \qquad (4-4)$$

$$f_o = f_c + 455\,kHz \qquad (4-5)$$

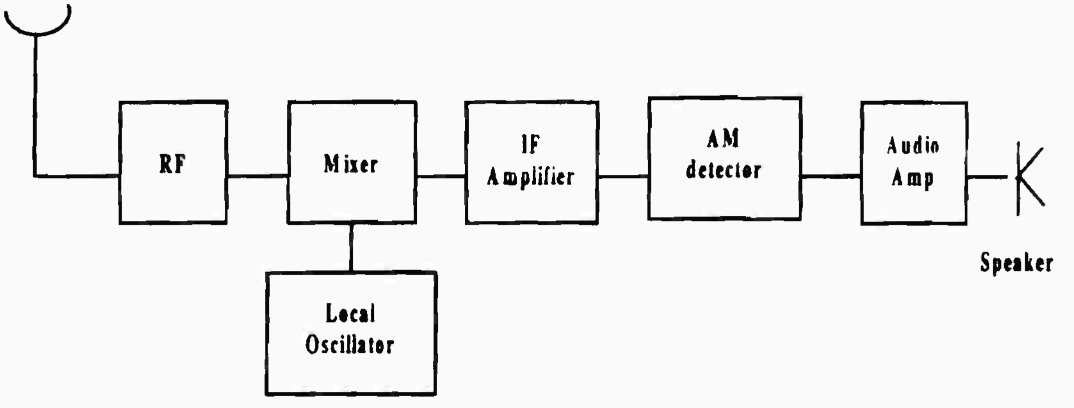

Fig. 4.2 Superheterodyne receiver

The BPF is designed to attenuate all frequency components, but $\omega_o - \omega_c$ is made to equate ω_{IF}. Since this is the center frequency of the BPF, the desired channel is selected. Since the bandwidth of the BPF is the bandwidth of the signal, both sidebands of the desired channel will pass, and the neighboring channels will be blocked. It should be noted that superheterodyning affects the carrier frequency as well as the sidebands (it inverts USB to LSB and LSB, to USB with no significant consequence). In all cases, the information content of the signal is not affected by superheterodyning.

EX. 4.1:

Consider 3 channels: A at 1000kHz with two sidebands at 1004kHz and 996kHz, B at 1010kHz with two sidebands at 1014kHz and 1006kHz, and C at 990kHz with two sidebands at 994kHz and 986kHz. It is required to select channel A. Show how these channels are located on the frequency spectrum after heterodyning. Show that the information content is not affected by superheterodyning.

Solution:

To select channel A, from eqn. (4-4) the frequency of the local oscillator is adjusted to 1455kHz. Channel A becomes after heterodyning:

Carrier	1455 -1000	= 455kHz
USB	1455 -1004	= 451kHz
LSB	1455 - 996	= 459kHz

For channel B:

Carrier	1455 -1010	= 445kHz
USB	1455 -1014	= 441kHz
LSB	1455 -1006	= 449kHz

For channel C:

Carrier	1455 - 990	= 465kHz
USB	1455 - 994	= 461kHz
LSB	1455 - 986	= 469kHz

We see from Fig. 4.3 that the three channels are transposed after heterodyning. This means that channel C - which was to the left of channel A before heterodyning - now comes to the right of channel A after heterodyning, and vice versa for channel B. Only channel A (carrier and two sidebands) fall within the passband window of the IF amplifier centered at 455kHz. Note that USB becomes LSB for every station. This transposition does not affect the frequency distribution, and hence, the information in each channel.

If we wish to tune to channel B, the local oscillator becomes 1465kHz

For channel A:

Carrier	1465 - 1000	= 465kHz
USB	1465 - 1004	= 461kHz
LSB	1465 - 996	= 469kHz

For channel B:

Carrier	1465 - 1010	= 455kHz
USB	1465 - 1014	= 451kHz
LSB	1465 - 1006	= 459kHz

For channel C:

Carrier	1465 - 990	= 475kHz
USB	1465 - 994	= 471kHz
LSB	1465 - 986	= 479kHz

We see that channel B is now centered within the IF amplifier passband, and channels A and C are shifted to its right. Superheterodyning is like projecting a film reel in front of a cinema projector. The film is passed across the window of projection, as we keep shifting from frame to frame. The channel selected is brought in - like a frame is brought into the projection window - as we keep changing the local oscillator frequency (tuning).

4.3 Tracking:

To maintain the relation eqn.(4-5) for all values of RF, the local oscillator must be ganged with the tuned circuit of the RF amplifier. This process is called tracking, meaning that the local oscillator tracks the RF.

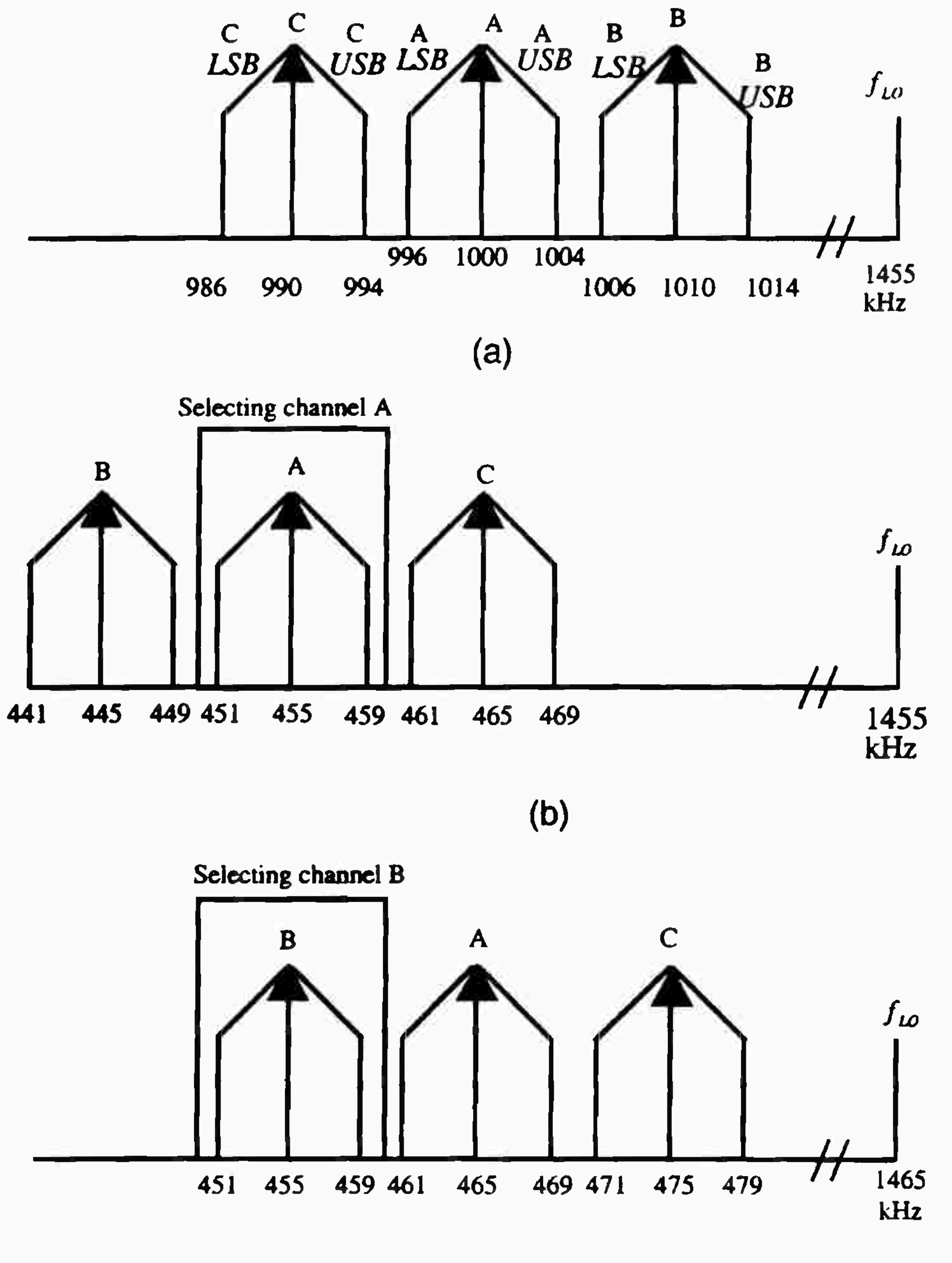

Fig. 4.3 Frequency spectrum for three stations
a) before heterodyning
b) after heterodyning for LO at 1455 kHz (selecting channel A)
c) after heterodyning for LO at 1465 kHz (selecting channel B)

This can be arranged by having an intimate relation between the capacitor of the local oscillator and the capacitor of the RF amplifier. This relation may be mechanical - as in old tuners - or electronic as in modern tuners, where a varactor is used as the capacitor of the tuned circuit. Here, the capacitance is varied by changing the bias voltage applied to the reverse biased pn junction.

It should be noted that great care must be exercised in the design of the local oscillator. If a drift in the frequency of the local oscillator occurs - due to temperature, humidity or aging - then tracking is lost, and the IF amplifier selects the wrong channel. Sophisticated circuits are used to maintain frequency stability of the local oscillator. Such circuits are called automatic frequency control (AFC).

4.4 Image Rejection:

It seems logical to question the need for the RF amplifier, noting that we could dispense with it and depend on the mixer and the local oscillator for the selection of the desired channel f_c. Actually, the RF amplifier is important in isolating the local oscillator from the antenna, thus, preventing the receiver from interfering with nearby receivers. Also, the mixer-being a passive nonlinear element - needs a strong signal at its input. This amplification is provided for by the RF amplifier. However, more importantly, the RF amplifier is necessary for another reason. Suppose we want to tune to an RF carrier f_{RF}. We set the local oscillator to a frequency $f_o = f_{RF} + f_{IF} = f_{RF} + 455kHz$

Suppose that there exists another channel whose frequency is $f'_{RF} = f_{RF} + 2f_{IF} = f_{RF} + 910kHz$. If the RF amplifier were not present, then all signals received by the antenna would go through straight to the mixer. The IF amplifier would be the only element which selects the desired channel f_{RF}. However, since the IF amplifier is adjusted to the difference frequency component $f_o - f_c$, then the desired channel will be selected by the IF amplifier. However, the channel f'_R - when heterodyned with f_o- will also produce 455kHz, because

$$\left|f_o - f'_{RF}\right| = \left|f_o - (f_{RF} + 2f_{IF})\right| = \left|f_{RF} + f_{IF} - f_{RF} - 2f_{IF}\right| = \left|-f_{IF}\right| = f_{IF}$$

Note that if $f'_{RF} > f_o$, then $f'_{RF} - f_o = f_{IF}$

We call f'_{RF} the image of f_{RF}. We see that this image f'_{RF} will also be caught by the IF amplifier together with f_{RF}. This image represents an interference to the desired channel f_{RF}. Actually, there is no line of defense against this image. The only way to combat the image is through the use of the RF amplifier. It may be true that the RF amplifier has poor adjacent channel discrimination, because its selectivity curve is not very sharp. However, because the image is well separated from the desired channel, the RF amplifier is capable of providing enough attenuation for the image. This is called image rejection. Thus, the main role for the RF amplifier is to block the image.

4.5 Double Conversion:

A more advanced system uses double conversion. This system is used in many communication receivers which use HF, VHF and UHF. In this case, two IF amplifiers are used, each operating at a different frequency. A local oscillator tracks the signal in each case. In Fig. 4.4, an input signal is at 20MHz, and the local oscillator is at 17.6MHz. The difference frequency of 2.4MHz is the high IF, which is then converted to 455kHz (low IF). Since for any incoming frequency, the high IF will always be 2.4MHz in the system shown, the oscillator for the second mixer does not need to be tunable. The oscillator input to the second mixer is 2.855MHz, thus, providing a difference frequency of 455kHz to the low IF amplifier.

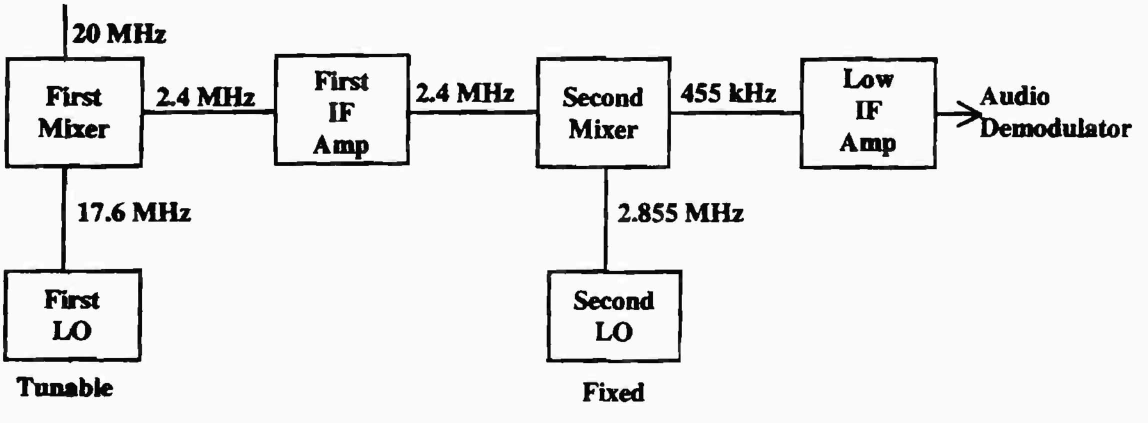

Fig. 4.4 Double conversion system

Problems:

1- When a superheterodyne receiver is tuned to 555kHz, its local oscillator provides the mixer with an input at 1010kHz. What is the image frequency?
2- The antenna of the receiver above is connected to a mixer via a tuned circuit whose Q_0 is 40. What is the rejection ratio?
3- Calculate the image rejection of a receiver for $Q_0 = 60$ at input frequencies 1MHz , 20 MHz.
4- If the image rejection ratio is to be 40 dB for an input frequency 10MHz. Calculate Q_0.
5- Sketch image rejection ratio versus input RF frequency.
6- Calculate the image rejection ratio of a double conversion system if $Q_0 = 100$. The first IF is 2MHz, the second IF is 200kHz, and the input signal is 30MHz.
7- Repeat for the double conversion system shown in Fig 4.4.
8- What is Q_0 in the double conversion system in the above problem if the image rejection ratio is 100.
9- Discuss the design criteria of an RF amplifier using an LC tank circuit.
10-Discuss the design criteria for an IF amplifier using a critically coupled tuned circuit.

References:

1- "Communication Electronics, Principles and Applications", L.E. Frenzel, 3rd ed., Glencoe - Mc Graw Hill, N.Y., 2000.

2- "Modern Digital and Analog Communication Systems", B.P. Lathi, 3rd ed., Oxford, 1998.

3- "Electronics, Circuits and Applications.", W.E Burke, D.G. Irvin, G.B. Mann, Bobbs-Merrill, Indianapolis, 1982.

4- "Electronic Communication Systems", G. Kennedy, Mc Graw Hill , N.Y., 1985.

5- "Electronics, Principles and Applications", C. Schuler, 2nd ed., Mc Graw Hill, N.Y., 1985.