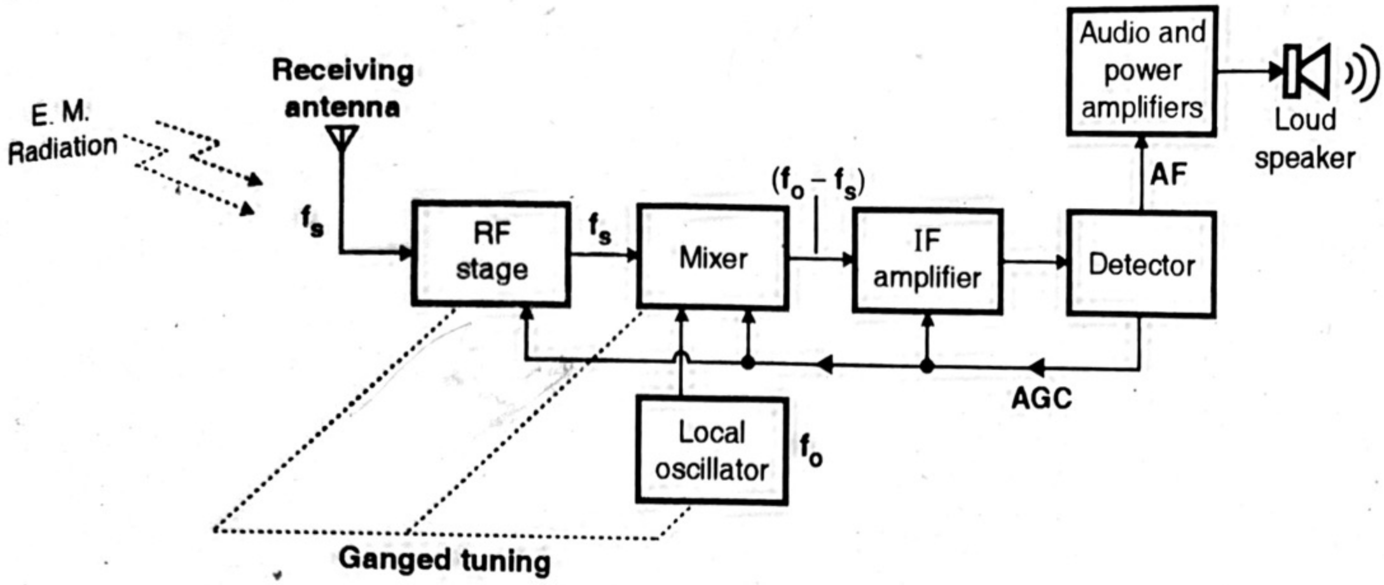

Fig. 5.2.2 : The superheterodyne receiver

Operation :

1. The DSBFC or AM signal transmitted by the transmitter travels through the air and reaches the receiving antenna. This signal is in the form of electromagnetic waves. It induces a very small voltage (few μV) into the receiving antenna.
2. **RF stage :** The RF stage is an amplifier which is used to select the wanted signal and reject other out of many, present at the antenna. It also reduces the effect of noise. At the output of the RF amplifier we get a signal at frequency "f_s".
3. **Mixer :** The mixer receives signals from the RF amplifier at frequency (f_s) and from the local oscillator at frequency (f_o) Such that $f_o > f_s$.
4. **Intermediate frequency (IF) :** The mixer will mix these signals to produce signals having frequencies f_s, f_o, $(f_o + f_s)$ and $(f_o - f_s)$ out of these the difference frequency component i.e. $(f_o - f_s)$ is selected and all others are rejected. This frequency is called as the intermediate frequency (IF).

$$\therefore \quad \textbf{I.F.} = (f_o - f_s) \qquad ...(5.2.5)$$

This frequency contains the same modulation as the original signal f_s.

5. In order to maintain a constant difference between the local oscillator frequency and the incoming frequency, ganged tuning is used. This is simultaneous tuning of RF amplifier, mixer and local oscillator and it is achieved by using ganged tuning capacitors (Tuning control in radio set).
6. This intermediate frequency signal is then amplified by one or more IF amplifier stages. IF amplifiers provide most of the gain (and hence sensitivity) and the bandwidth requirements of the receiver. Therefore the sensitivity and selectivity of this receiver do not change much with changes in the incoming frequency.
7. The amplified IF signal is detected by the detector to recover the original modulating signal. This is then amplified and applied to the loudspeaker.
8. AGC means automatic gain control. This circuit controls the gains of the RF and IF amplifiers to maintain a constant output voltage level even when the signal level at the receiver input is fluctuating. This is done by feeding a controlling dc voltage to the RF and IF amplifiers. The amplitude of this dc voltage is proportional to the detector output.

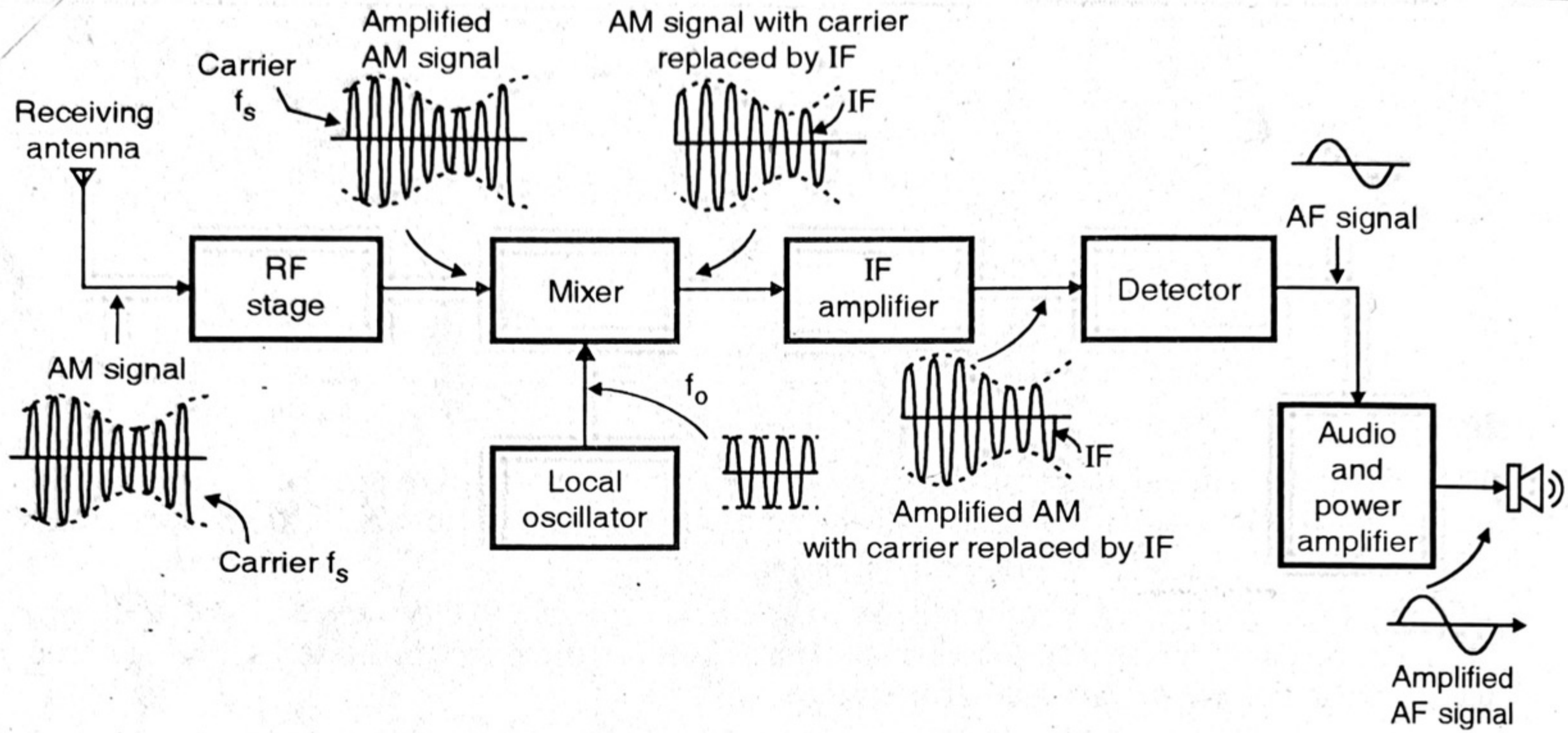

Fig. 5.2.3 : Superheterodyne receiver with waveforms shown at intermediate points

1. The selected signal is amplified by the RF amplifier. Hence the waveform at its output is an amplified AM signal.
2. Local oscillator produces a sinusoidal signal of frequency f_o. Where $f_o = f_s + IF$.
3. At the mixer output we get an AM signal with IF acting as a carrier. The same signal is then available in the amplified form at the output of the IF amplifier.
4. This waveform is applied to a detector, which removes the IF and produces an AF signal at the detector output.
5. This AF signal is amplified by the audio and power amplifier. Hence we get the amplified version of the AF signal.

Neeraj Shah

5.3.4 Image Frequency and its Rejection : [ASKED IN EXAM - DEC. 2000 !!!]

In the broadcast AM receivers the local oscillator frequency is higher than the incoming signal frequency by intermediate frequency i.e.

$$f_o = f_s + \text{I.F.} \qquad .....(5.3.1)$$

$$\text{or} \quad \text{I.F.} = (f_o - f_s) \qquad .....(5.3.2)$$

If two frequency components f_1 and f_2 are mixed in a mixer then mixer output consists of following components. If $(f_1 > f_2)$.

$$\text{Output of mixer} : f_1, f_2, (f_1 - f_2), \text{ and } (f_1 + f_2) \qquad .....(5.3.3)$$

Out of which the difference component i.e. $(f_1 - f_2)$ is selected using a tuned circuit after the mixer.

Now assume that the local oscillator frequency is set to "f_o" and an unwanted signal at frequency $f_{si} = (f_o + IF)$ manages to reach at the input of the mixer. Then the mixer output consists of the four frequency components of

$$f_o, (f_o + IF), (2f_o + IF) \text{ and } IF \quad .....(5.3.4)$$

Where the last component at IF is the difference between f_{si} and f_o. This component will also be amplified by the IF amplifier along with the desired signal at frequency f_s. This will create interference because both the stations corresponding to carrier frequencies f_s and f_{si} will be tuned at the same position.

This unwanted signal at frequency f_{si} is known as the "image frequency" and it is said to be the "image" of the signal frequency f_s. The relation between f_s and f_{si} is :

$$\boxed{\text{Image Frequency : } f_{si} = f_s + 2IF} \quad ....(5.3.5)$$

Remedy : The image frequency must be rejected by the receiver. The image rejection depends on the front end selectivity of the receiver i.e. the selectivity of the RF circuit. The image rejection must be achieved before the IF stage because once it reaches the IF stage it cannot be removed. The use of RF amplifier thus improves the image frequency rejection.

Image rejection using a single tuned circuit :

The rejection of an image frequency by a single tuned circuit is given by :

$$\alpha = \frac{\text{Gain at signal frequency}}{\text{Gain at image frequency}} = \sqrt{1 + Q^2 \rho^2} \quad .....(5.3.6)$$

Where Q = Loaded Q of the tuned circuit and

$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} \quad .....(5.3.7)$$

If the receiver has an RF stage then there will be two tuned circuits both tuned to f_s. The rejection of each circuit will be calculated by the formula in Equation (5.3.6). And the total rejection will be the product of individual rejection introduced by the individual tuned circuits.

5.3.5 Double Spotting :

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Fig. P. 5.3.3.

Ex. 5.3.1 : In a superheterodyne receiver having no RF amplifier the loaded Q of the antenna coupling circuit (at the input of the mixer) is 90. If the intermediate frequency is

Soun

455 kHz calculate the following :

(a) The image frequency and image frequency rejection ratio at 950 kHz and

(b) The image frequency and its rejection ratio at 10 MHz.

Soln. :

(a) Image frequency and its rejection ratio at 950 kHz. :

Given : $Q = 90$, IF = 455 kHz, $f_s = 950$ kHz

$$\therefore \text{ Image frequency } f_{si} = f_s + 2\text{IF} = [\,950 + 2 \times 455\,]$$

$$\therefore \quad f_{si} = 1860 \text{ kHz} \qquad \text{.....(1)}$$

$$\text{Image frequency rejection ratio } \alpha = \sqrt{1 + Q^2 \rho^2} \qquad \text{.....(2)}$$

$$\text{where} \quad \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{1860}{950} - \frac{950}{1860} = 1.45 \qquad \text{.....(3)}$$

$$\therefore \quad \alpha = \sqrt{1 + (90)^2 \times (1.45)^2}$$

$$\therefore \quad \alpha = 130.5 \qquad \text{.....(4)}$$

(b) Image frequency and its rejection at 10 MHz. :

Given : $Q = 90$, IF = 455 kHz, $f_s = 10$ MHz

$$\therefore \text{ Image frequency } f_{si} = 10 + (2 \times 0.455)$$

$$= 10.91 \text{ MHz} \qquad \text{.....(5)}$$

$$\rho = \frac{10.91}{10} - \frac{10}{10.91} = 0.174 \qquad \text{.....(6)}$$

$$\therefore \quad \alpha = \sqrt{1 + (90)^2 \times (0.174)^2} = 15.72 \qquad \text{.....(7)}$$

Comment :

So without RF amplifier the image rejection is adequate at low frequencies however it is inadequate at higher operating frequency. RF amplifier may therefore be used at high frequencies.

Ex. 5.3.2 : In order to make the image frequency rejection of the receiver of Ex. 5.3.2 as good at 10 MHz at it was at 950 kHz. Calculate : (a) the loaded Q which an RF amplifier for this receiver would have to have and (b) the new intermediate frequency that would be needed (if RF amplifier is not to be used).

Soln. :

(a) The loaded Q with RF amplifier included :

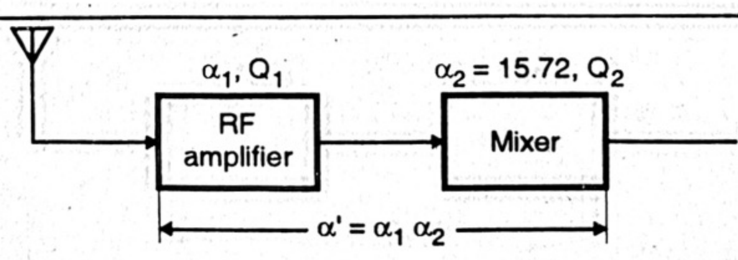


Fig. P. 5.3.2

Given : $\alpha' = 130.5$, $f_s = 10$ MHz

Looking at Fig. P. 5.3.2 we can write that,

$$\alpha' = \alpha_1 \alpha_2 = 130.5 \quad .....(1)$$

$$\text{But} \quad \alpha_2 = 15.72$$

$$\text{therefore} \quad \alpha_1 = \frac{130.5}{15.72} = 8.3 \quad .....(2)$$

$\therefore$ The loaded Q of RF amplifier i.e. Q_1 can be calculated as,

$$\alpha_1 = \sqrt{1 + Q_1^2 \rho^2} \quad .....(3)$$

From the Ex. 5.3.1, we can substitute $\rho = 0.174$

$$\therefore \quad Q_1 = 47.35 \quad .....(4)$$

Thus the value of loaded Q of the RF amplifier should be 47.35. A well designed receiver would have the same Q for the tuned circuits of the mixer and the RF amplifier. Here it is 65.28 which is the geometric mean of 90 and 47.35.

$$\therefore \quad Q_1 = Q_2 = 65.28 \quad .....(5)$$

(b) New IF if the RF amplifier is not used :

Now we want to calculate a new value of IF at which the rejection ratio α is same as that obtained at 950 kHz.

From Ex. 5.3.1 we get $\rho = 1.45$. Let the new value of image frequency be f'_{si}

$$\therefore \quad 1.45 = \frac{1860}{950} - \frac{950}{1860} = \frac{f'_{si}}{10\,\text{MHz}} - \frac{10\,\text{MHz}}{f'_{si}}$$

$$\therefore \quad \frac{f'_{si}}{10\,\text{MHz}} = \frac{1860}{950} = 1.9578$$

$$\therefore \quad f'_{si} = 1.9578 \times 10 = 19.578 \text{ MHz} \quad .....(6)$$

$$\text{However,} \quad f'_{si} = f_s + 2\,\text{IF}' \qquad \therefore \quad 19.578 = 10 + 2\,\text{IF}'$$

$$\therefore \quad \text{IF}' = 4.789 \text{ MHz} \quad .....(7)$$

Hence the new IF will be 4.789 MHz.

Remark : This shows that increase in the image frequency will improve the image rejection.

... explain the concept of double spotting in a superheterodyne

7.10 Formulae

(1) Image frequency
$$f_{Si} = f_s + 2f_i$$
$$f_i = \text{Intermediate frequency, normally } f_i = 455 \text{ kHz}$$
$$f_s = \text{Signal frequency.}$$

(2) Image frequency rejection ratio
$$\alpha = \sqrt{1 + Q^2\rho^2}$$
where Q = Quality factor
$$\rho = \frac{f_{Si}}{f_s} - \frac{f_s}{f_{Si}}$$

(3) Local oscillator frequency
$$f_o = f_s + f_i$$

7.11 Solved Problems

Problem 1 : When a superhetrodyne radio receiver is tuned to 555 kHz, its local oscillator frequency is 1010 kHz. What is image frequency.

Given :
$$f_s = 555 \text{ kHz}$$
$$f_o = 1010 \text{ kHz}$$

To find : f_{si}

Solution :

Image frequency, $f_{si} = f_s + 2f_i$

but $f_i = f_o - f_s$

$$\therefore \boxed{f_i = 455 \text{ kHz}}$$

$$\therefore f_{si} = 555 + 2(455)$$

$$\therefore \boxed{f_{si} = 1465 \text{ kHz}}$$

Problem 2 : *A receiver is tuned to 3 - 30 MHz and IF frequency is 40.525 MHz.*

(i) *Find range of local oscillator frequency and image frequency. Bandwidth = 10 kHz.*

(ii) *Draw frequency response of IF and AF amplifiers.*

Given :

$$f_{smin} = 3 \text{ MHz}, \quad f_{smax} = 30 \text{ MHz}$$

$$f_i = 40.525 \text{ MHz}, \quad BW = 10 \text{ kHz}$$

To find : f_{omax}, f_{omin}, f_{simax}, f_{simin}

Solution :

(i) We know that, $f_o = f_s + f_i$

$$\therefore \; f_{omax} = f_{smax} + f_i \qquad (\because f_i \text{ is always constant})$$

$$\therefore \; f_{omax} = 30 \text{ MHz} + 40.525 \text{ MHz}$$

$$\boxed{f_{omax} = 70.525 \text{ MHz}}$$

Similarly,

$$\boxed{f_{omin} = 43.525 \text{ MHz}}$$

Also,

$$f_{si} = f_s + 2f_i$$

$$\therefore \; f_{simax} = f_{smax} + 2f_i$$

$$\therefore \; f_{simax} = 30 \text{ MHz} + 2(40.525) \text{ MHz}$$

$$\boxed{f_{simax} = 111.050 \text{ MHz}}$$

Similarly,

$$\boxed{f_{simin} = 84.050 \text{ MHz}}$$

Problem 3 : In an AM receiver having no RF stage the loaded Q of the arial coupling circuit is 125. IF is 465 kHz find

(i) *Image frequency and its rejection at 1 MHz and 30 MHz.*

(ii) *The IF required to make the image rejection ratio as good as 30 MHz as it is at 1 MHz.*

Given :

$$f_i = 465 \text{ kHz}$$
$$Q = 125$$

To find : f_{si} and α in both cases.

Solution :

(i) **For f_s = 1 MHz**

$$f_{si} = f_s + 2f_i = 1 \text{ MHz} + 2(465) \text{ kHz}$$
$$= 1000 \text{ kHz} + 930 \text{ kHz}$$
$$\boxed{f_{si} = 1.93 \text{ MHz}}$$

Now, rejection ratio is given by

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

$$\text{and } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

$$\therefore \boxed{\rho = 1.4118}$$

$$\therefore \alpha = \sqrt{1 + Q^2\rho^2}$$

$$\boxed{\alpha = 176.486}$$

For f_s = 30 MHz

$$f_{si} = f_s + 2f_i = 30000 \text{ kHz} + 2(465) \text{ kHz}$$

$$\boxed{f_{si} = 30.93 \text{ MHz}}$$

Now, rejection ratio is given by

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

$$\text{and } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

$$\therefore \boxed{\rho = 0.061}$$

$$\therefore \boxed{\alpha = 7.69}$$

(ii) Required α = 176.486 and f_s = 30 MHz

We need to find f_i

Putting new value of α and Q in

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

$$\therefore \quad 125^2 \rho^2 + 1 = \alpha^2$$

$$\therefore \quad 125^2 \rho^2 + 1 = 31146.3$$

$$\therefore \rho^2 = 1.99336$$

$$\boxed{\rho = 1.41186}$$

$$\therefore \quad \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = 1.41186$$

$$\therefore \quad \frac{f_{si}^2 - f_s^2}{f_s f_{si}} = 1.41186$$

$$f_{si}^2 - f_s^2 = 1.41186 f_s f_{si}$$

$$\text{Put } f_s = 30 \text{ MHz}$$

$$\therefore f_{si}^2 - 42.355 f_{si} - 900 = 0$$

Solving this we get

$$\boxed{f_{si} = 57.898 \text{ MHz}}$$

$$\therefore \quad f_s + 2f_i = 57.898 \text{ MHz}$$

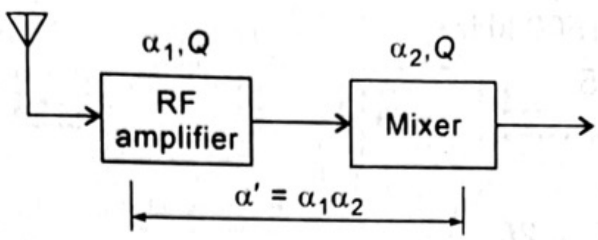
$$\therefore \quad 2f_i = 27.898 \text{ MHz}$$

$\therefore$ New IF frequency is

$$\therefore \quad \boxed{f_i = 13.949 \text{ MHz}}$$

Problem 4 : Consider the following block diagram of an SHR receiver.

Given that, overall rejection of image frequency is 100, find Q, both blocks have same Q. Also f_s = 1 MHz and f_i = 455 kHz.



Given :

$$\alpha' = 100$$

$$f_s = 1 \text{ MHz}$$

$$f_i = 455 \text{ kHz}$$

To find : Q

Solution : Image frequency is

$$f_{si} = f_s + 2f_i$$

$$\therefore \quad f_{si} = 1000 \text{ kHz} + 910 \text{ kHz}$$

$$\boxed{f_{si} = 1.91 \text{ MHz}}$$

Now, for RF amplifier

$$\alpha_1 = \sqrt{1 + Q^2\rho^2}$$

$$\text{and } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

$$\therefore \quad \boxed{\rho = 1.3864}$$

$$\therefore \quad \boxed{\alpha_1 = \sqrt{1 + 1.922\, Q^2}}$$

Similarly,
$$\therefore \boxed{\alpha_2 = \sqrt{1 + 1.922\,Q^2}}$$

Now,
$$\alpha' = \alpha_1 \alpha_2 = 100$$
$$\therefore (1 + 1.922\,Q^2) = 100$$
$$\therefore Q^2 = 51.508$$
$$\therefore \boxed{Q = 7.17}$$

Problem 5 : *The broadcast superhetrodyne receiver has intermediate frequency 455 kHz and it is tuned for 1500 kHz. Calculate the image frequency and the quality factor of the tuned circuit having image frequency rejection ratio equal to 75.*

Given :
$$f_i = 455 \text{ kHz}$$
$$f_s = 1500 \text{ kHz}$$
$$\alpha = 75$$

To find : f_{si}, Q

Solution :

We know,
$$f_{si} = f_s + 2f_i$$
$$\therefore f_{si} = 1500 \text{ kHz} + 2(455 \text{ kHz})$$
$$\therefore \boxed{f_{si} = 2410 \text{ kHz}}$$

Now, rejection ratio is given by
$$\alpha = \sqrt{1 + Q^2\rho^2} \qquad .....(1)$$
$$\text{and } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$
$$\therefore \boxed{\rho = 0.984}$$

Put in equation (1), we get
$$\therefore \alpha = \sqrt{1 + Q^2(0.984)^2}$$
$$\therefore 75 = \sqrt{1 + 0.968\,Q^2}$$
$$\therefore 1 + 0.968\,Q^2 = 5625$$
$$\therefore Q^2 = \frac{5624}{0.968}$$
$$\therefore \boxed{Q = 76.22}$$

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