SUPERHETERODYNE RECEIVERS

→ Problems in TRF-Rx solved by converting every selected RF signal to a fixed lower frequency signal called Intermediate frequency (IF)

→ This frequency contains same amount of modulation.

→ IF signal is then amplified and demodulated to get back the modulating signal.

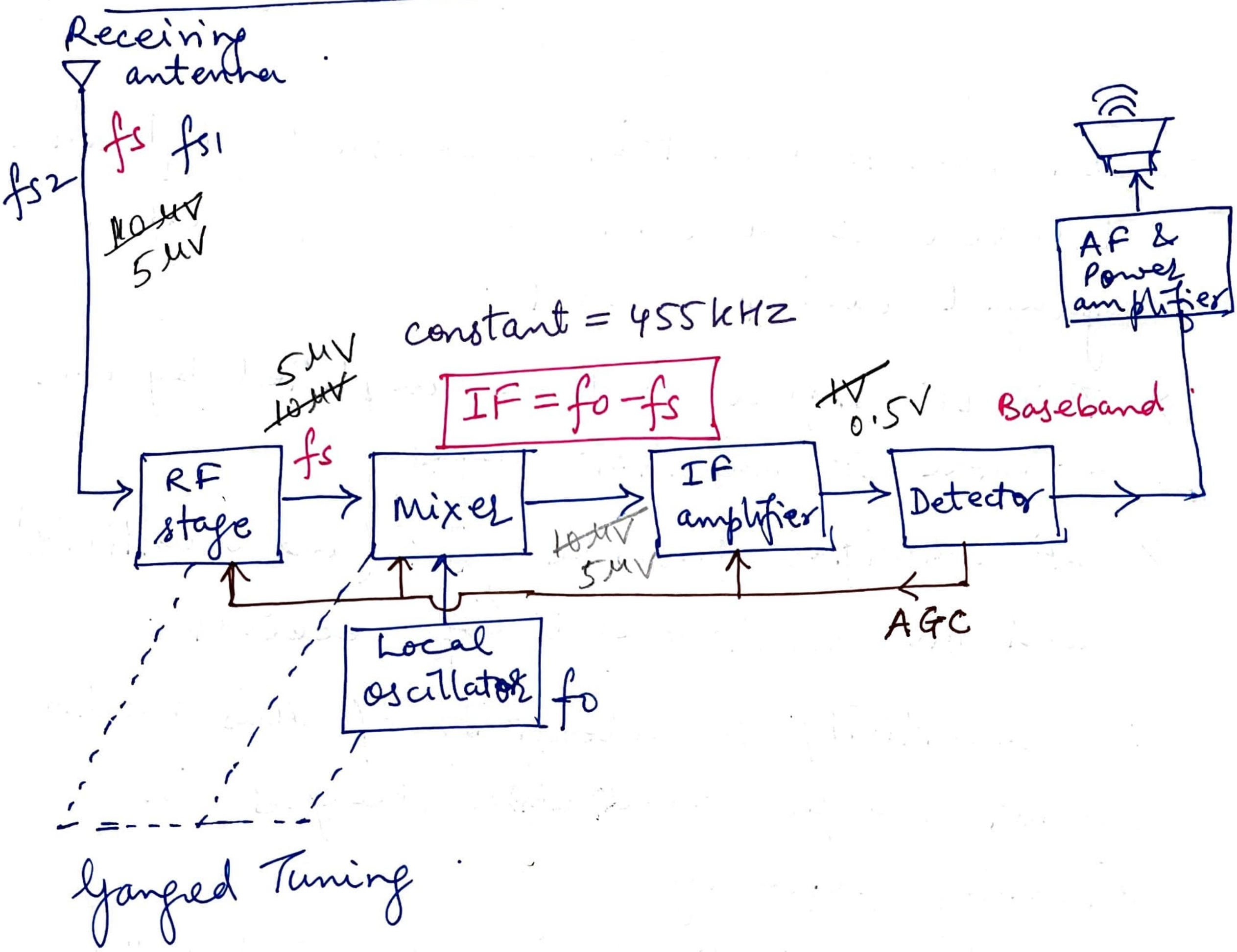
→ As IF < lowest RF frequency, possibility of oscillations and instability is minimized.

→ Also, the required value of Q for constant BW does not depend on frequency of desired signal because IF is constant and it is same for all incoming RF signal

⇒ Selectivity is not hampered.

∴ SH-Rx solves all problems associated with TRF-Rx.

BLOCK DIAGRAM OF SH-Rx



→ RF stage is used to select wanted / desired signal, reject all other signals and hence reduce the effect of noise.

→ We get a signal of frequency, fs at output of RF amplifier.

→ Mixer receives signal from RF stage (fs) and local oscillator (fo)

→ These two signals are mixed together to produce IF,

$$\text{ie. } IF = (f_o - f_s)$$

Typically, IF = 438 - 465 KHZ

IF = 455 KHZ

→ In order to maintain a constant difference between LO and incoming frequency, ganged tuning is used.

→ This IF signal is then amplified by one or more IF amplifier stages.

→ IF amplifier provide gain (and sensitivity) and BW requirement of receiver.

∴ Sensitivity & Selectivity of this receiver do not change much with changes in incoming frequency.

→ Amplified IF signal is detected by the detector to recover original modulating signal.

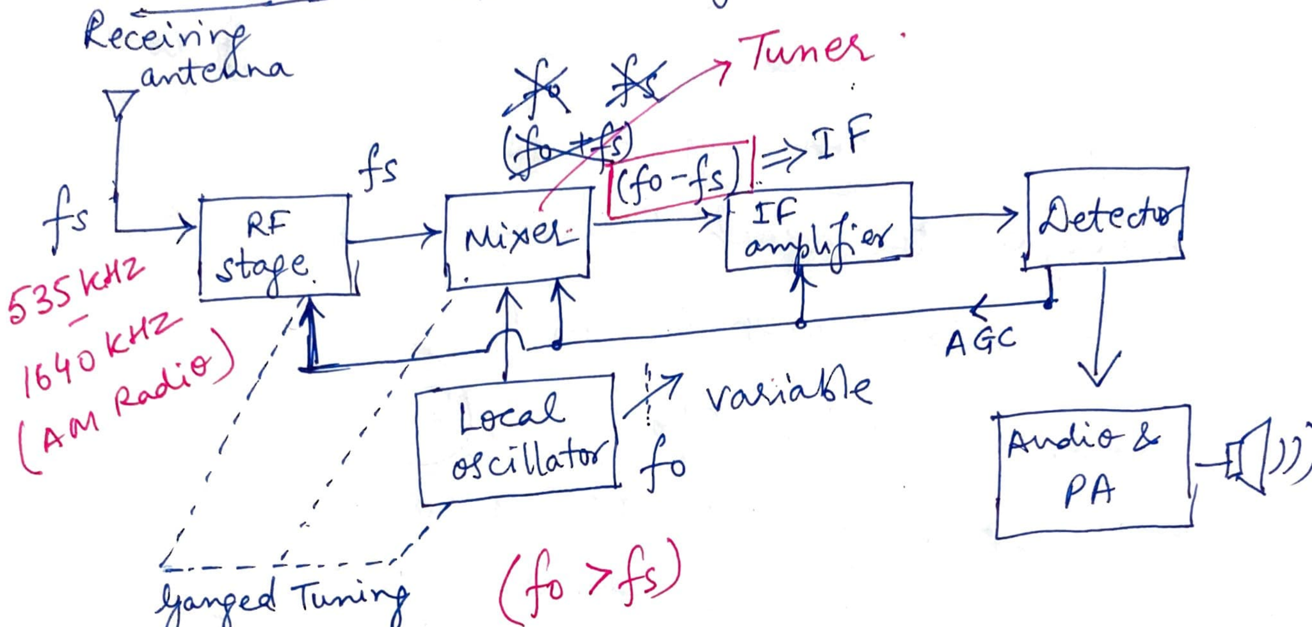
→ This is then amplified using audio and power amplifiers & given to loudspeaker.

→ AGC → Automatic Gain Control.

This circuit controls the gain of RF & IF stages to maintain constant output.

IMAGE FREQUENCY REJECTION —

→ SH-Rx — Superheterodyne Receiver.



$(f_o > f_s)$

→ IF → 455 KHZ

f_s → 535 KHZ ⇒ $f_o = 990$ KHZ

f_s → 1640 KHZ ⇒ $f_o = 2095$ KHZ

→ In broadcast AM-Rx,

$f_o > f_s$ by IF.

f_o → local oscillator frequency

f_s → incoming signal frequency

$$\Rightarrow f_o = f_s + IF$$

$$\Rightarrow \boxed{IF = (f_o - f_s)}$$

→ Output of mixer → f_o, f_s, (f_o+f_s), (f_o-f_s)

Out of these, (f_o-f_s) is only selected using a tuned circuit after the mixer.

→ Image frequency and its Rejection –

→ Let us assume LO frequency is set to f_o and unwanted signal, $f_{si} = (f_o + IF)$ manages to reach the input of mixer.

→ Then, mixer output will be –

$$f_o,\ (f_o + IF),\ 2f_o + IF,\ IF$$

This last component, IF is actually the difference between f_{si} & f_o.

This component will also be amplified by IF amplifier alongwith the desired signal, at frequency, f_s.

→ This will create interference because both the station corresponding to frequency f_s and f_{si} will be tuned at the same position.

→ This unwanted signal at frequency, f_{si} is known as <u>image frequency</u> and it is said to be the image of signal frequency, f_s.

→ Relation between f_s and f_{si} –

$$IF = (f_o - f_s)$$

$$\Rightarrow f_o = (f_s + IF) \quad \text{——— (1)}$$

We also know,

$$f_{si} = (f_o + IF)$$

from (1),

$$f_{si} = ((f_s + IF) + IF)$$

$$\boxed{f_{si} = f_s + 2IF}$$

→ Remedy –

→ Image frequency must be rejected by the receiver.

→ Image rejection depends on front end selectivity of receiver, ie. selectivity of the RF circuit.

→ Also, image rejection must be achieved before IF stage because once it reaches IF stage, it cannot be removed.

→ Use of RF amplifier improves image frequency rejection.

→ Double Spotting –

→ Let us understand this with an example –

→ Assume, We select IF of SH-Rx to be 470 KHz.

→ Assume a strong station at $f_s = 1640$ KHz

(a) Corresponding, $f_o = 2110$ KHz

($\because 2110 - 1640 = 470$) = IF.

Hence, strong station will be picked up.

(b) I want to tune to 700 KHz.

then, $f_o = 1170$ KHz ($\because 1170 - 700 = 470$) = IF

(IDEAL) → expected to pick 700 KHz

But ...

This signal, $f_s = 700$ KHz is very weak

1640 ↑ strong → Tries to mask

700 KHz ↓ weak ←

$f_o = 1170$

→ Now, when 1170 KHz of LO frequency is present, 1640 KHz signal will also beat with this f_o.

$(1640 - 1170) = 470$ KHz

Hence, this station will also get picked up at this point on the dial.

→ **Image rejection using a single tuned circuit** –

→ Rejection of image frequency by a single tuned circuit is given by –

$$\alpha = \frac{\text{gain at signal frequency}}{\text{gain at image frequency}}$$

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

where, $Q \rightarrow$ loaded Q of tuned circuit

$$\rho = \left[\frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} \right]$$

→ If the receiver has an RF stage, then there will be two tuned circuits both of them tuned to f_s.

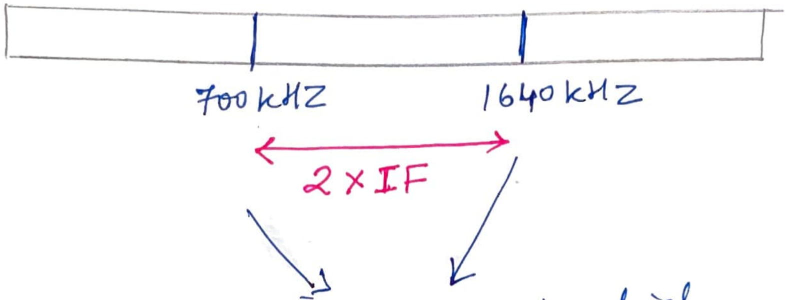
→ Rejection can then be calculated using same formula and total rejection will be the product of individual rejection introduced by individual tuned circuits.

Q1. In a SH-Rx having no RF amplifier, the loaded Q of antenna coupling circuit (at the input of mixer) is 90. If IF is 455 KHz, calculate –

(a) Image frequency and image frequency rejection ratio at 950 KHZ

→ 700 KHZ is weak and hence is masked by a strong signal at 1640 KHZ

Radio dial



Two points at which same station is tuned

→ Double spotting means the same station gets picked up at two different nearby points on the receiver dial.

→ It is due to poor front end selectivity. i.e. inadequate image frequency rejection.

→ It is harmful because a weak station may masked by reception of a strong station at the same point, on the dial.

→ It can be reduced by increasing front end selectivity of receiver.

→ Inclusion of RF amplifier stage will help in avoiding double spotting.

b) Image frequency and its rejection at 10 MHz.

Soln. (a) $Q = 90$ IF $= 455$ KHZ $f_s = 950$ KHZ

$$f_{si} = f_s + 2IF$$
$$= 950 + (2 \times 455)$$
$$= 1860 \text{ KHZ}$$

$$\Rightarrow \alpha = \sqrt{1 + Q^2 \rho^2}$$
$$= \sqrt{1 + (90^2 \times 1.45^2)} = \boxed{130.5}$$ good rejection

[We know,
$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{1860}{950} - \frac{950}{1860} = 1.45$$]

(b) $Q = 90$ IF $= 455$ KHZ $f_s = 10$ MHZ

$$f_{si} = f_s + 2IF = 10 + (2 \times 0.455)$$
$$= 10.91 \text{ MHZ}$$

$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{10.91}{10} - \frac{10}{10.91} = 0.174$$

$$\Rightarrow \alpha = \sqrt{1 + Q^2 \rho^2} = \sqrt{1 + (90^2 \times 0.174^2)}$$
$$= \boxed{15.72}$$ pretty less rejection.

→ Without RF amplifier, image rejection is adequate at low frequency. However, it is inadequate at higher frequency.

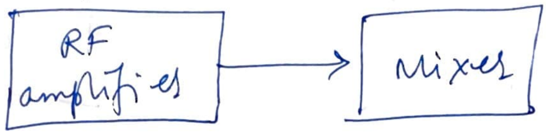
∴ RF amplifiers may be used at high freq.

Q2. In order to make image frequency rejection of receiver of previous example as good as 950 kHz for 10 MHz as well, calculate the loaded Q which an RF amplifier for this receiver would have to use.

$$f_s = 10\text{ MHz}$$

Soln:

α_1, Q_1 $\qquad\qquad$ $\alpha_2 = 15.72, Q_2$



$$\alpha = \alpha_1 \alpha_2 = 130.5$$

$$\alpha_1 = \frac{\alpha}{\alpha_2} = \frac{130.5}{15.72} = 8.3$$

$$\alpha_1 = \sqrt{1 + Q_1^2 \rho_1^2}$$

Substituting, $\rho = 0.174$

$\Rightarrow Q = 47.35$ → value of loaded Q of RF amplifier.

→ A well designed receiver would have same Q for tuned circuits of mixer and RF amplifier.

$\therefore Q_1 = Q_2$ = geometric mean of 90 and 47.35

$$= \sqrt{90 \times 47.35} = 65.28$$

3. With respect to previous example, calculate the new IF that would be needed if RF amplifier is not to be used.

Soln: At 950 kHz, $\rho = 1.45$ $\alpha = 130.5$

~~Let new f_{si}'~~

Let new value of image frequency be f_{si}''

We know,

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

$$\Rightarrow 1.45 = \frac{1860}{950} - \frac{950}{1860} = \frac{f_{si}'}{10\,MHz} - \frac{10\,MHz}{f_{si}'}$$

By equating,

$$\frac{f_{si}'}{10MHz} = \frac{1860}{950} = 1.9578$$

$$\Rightarrow f_{si}' = f_s + 2\,IF'$$

$$\Rightarrow IF' = \frac{19.578 - 10}{2} = 4.789\,MHz$$

$\Rightarrow$ Increase in image frequency will improve image rejection.